Chapter 7.

Biowaste biorefining

Vast tonnages of organic waste materials are available worldwide, which seems to circumvent concerns about using food crops as feedstocks for biorefining. The idea of using organic waste is consistent with other major policy goals, especially a circular economy, which minimises waste generation and promotes a greater level of recycling in society. Biorefining of such "biowastes" goes further: it takes materials that are effectively worthless and turns them into value-added products. But are these materials really waste? What of municipal waste as a feedstock? Is the completely rural setting the optimum location, or does a coastal-rural location make more sense when agriculture is out-of-season? This chapter explores such questions, as well as the potential for public policy clashes.

Introduction

The term "waste" (Box 7.1) as related to use as feedstock in biorefineries refers to a wide range of materials. They include: agricultural residues, such as straw and animal manure and sludges; by-products of animal rendering, especially animal fat; forestry residues; waste industrial gases, especially carbon monoxide (CO) and carbon dioxide (CO_2); and the organic fraction of municipal solid waste (MSW), such as food wastes and plastic waste if not sorted for recycling. Nevertheless, waste biorefining will need, on a case-by-case basis, to be investigated regarding its true sustainability. For example, the collection of waste materials and their delivery to a biorefinery site has both economic and environmental costs. These involve the use of fossil fuels and concomitant greenhouse gas (GHG) emissions for their transportation. Careful supply chain design and security will be essential.

It is important to distinguish between different levels of waste when designing supply chains for biorefineries. Materials like straw, for example, may not be waste materials at all. They could have other uses such as wheat and barley straw for animal bedding. Indeed, calculating the volumes of such materials could be part of a biorefinery roadmap (national or regional). Ideally, since agricultural wastes are seasonal, a waste biorefinery should be able to process multiple waste streams; forestry residues may not be readily available in winter months, and municipal waste should be available year-round.

Box 7.1. **Waste or resource?**

It is fashionable to use the word "resource" to describe waste since, in theory, all waste should be a resource to achieve the circular economy. "Resource" might be used in the context of a feedstock such as sugar, or sugar cane. On the other hand, bagasse is a fibrous "waste" material of sugar cane processing that can also be used in biorefining; it too is arguably a resource. Further, materials that end up in landfill sites, or are burned or similarly discarded, will be termed "waste". Wood chips are manufactured products used for bioenergy purposes. However, forestry residues, for example, are "waste" materials of forestry that can eventually become a resource. Wastes could alternatively be considered "renewable resources" that can be used and reused to generate valuable and marketable products (Velis, 2015). A description that would avoid conflict would be "secondary raw material feedstock".

The EU Waste Framework Directive defines waste as any substance or object that the holder discards or intends to discard or is required to discard.[1] It also sets out the requirement to manage waste in accordance with a "waste hierarchy". The hierarchy affords top priority to waste prevention, followed by preparing for reuse, then recycling, other types of recovery (including energy recovery) and last of all disposal (e.g. landfill). This definition of waste can lead to problems in using such biowastes as feedstocks for biorefining.

1. www.gov.uk/waste-legislation-and-regulations#eu-waste-framework-directive.

The earliest biorefineries in the modern era of industrial biotechnology date effectively from the beginning of the 21st century. They were often ethanol biorefineries, already common in Brazil, that used food crops as the source of biomass to produce fermentable sugars. For the vast majority of countries, the luxury of home-grown, highly efficient, highly sustainable sugar cane as the source of carbon is not possible. The 21st century boom arrived with corn starch biorefining to ethanol for two purposes: as a replacement for methyl tertiary butyl ether (MTBE) as a fuel oxygenate; and as a gasoline supplement (typically a 10% blend of ethanol with 90% gasoline), with a view to further high percentage ethanol fuels (typically E85, with 85% ethanol).

It was not long, however, until controversy arose over use of a food crop for energy purposes. From the early years of this century, many have seen food crops as a biomass source for liquid biofuels production. The bioethanol industry based on corn (maize) as a feedstock (first-generation biofuels) expanded rapidly. This stoked concern over the role of biofuels in food price increases around 2008, the so-called food vs. fuel debate (e.g. Mueller et al., 2011). Evidence links first-generation biofuels to the price spike, some of it showing a marginal effect among a host of factors. However, the actual extent of the linkage will probably never be known. Many studies (e.g. Abbott et al., 2008: Timmer, 2008, IFPRI, 2010; De Gorter et al., 2013) have identified a complex interaction of causes, of which biofuels were only a part. However, the quest was already underway to use organic waste sources as carbon sources in future biorefineries.

Using waste materials in biorefining has several advantages. It relieves pressure on land, thereby enhancing sustainability. It avoids issues both around indirect land-use change (ILUC) (Van Stappen et al., 2011) and the food vs. fuel debate. Through these three actions, it improves public opinion. Further, in the case of waste industrial gases, especially CO and CO_2, it also uses GHGs that would otherwise become emissions. In other words, it contributes to science and policy goals around reducing emissions in climate policy. In the case of MSW, all of the above apply (as MSW is converted to methane in landfill sites, and methane is a much more potent GHG than CO_2). MSW also addresses an additional policy challenge – the diminishing supply of suitable sites for new landfills, a problem for many countries.

Flexible waste management regulation

Overly stringent waste management regulations can disable the exchange of waste materials in industrial symbiosis. For example, some countries would not have approved the piping of flue gas from Statoil to Gyproc at Kalundborg and the sale of liquid sulphur by Statoil to Kemira because both substances would be classified as hazardous waste. Waste regulation has become increasingly stringent in most OECD countries. The Danish waste regulation system, however, is quite flexible; the Danish Ministry of the Environment also encourages industry to find uses for all waste streams on a case-by-case basis. This allows companies to focus on finding creative ways to become more environmentally benign instead of “fighting the regulator” (Desrochers, 2002). In Europe, the legal qualification of some residues or co-products as waste hinders a broad range of potential biorefinery initiatives. Furthermore, local environmental and spatial permits for managing biowastes are limiting possibilities (Fava et al., 2015).

In this context, policy that encourages an institutional framework that forces companies to internalise their externalities should be given high priority. Such a policy should leave companies the necessary freedom to develop new and profitable uses for by-products.

Geography and its importance for public policy

In recent years, much has been said of rural biorefining, an approach that has pros and cons. One policy goal of a bioeconomy, for example, is rural regeneration. This is needed in many OECD countries as agriculture has become more efficient, drastically reducing the proportion of people working in the sector. As the landfill dilemma is principally an issue of large conurbations, however, the rural model for MSW biorefining is less likely to be attractive: there is often public resistance to building landfills in rural locations to take urban waste. It is equally likely this will apply to rural MSW biorefining unless there are significant incentives, such as local jobs.

The landfill dilemma and lessons for waste biorefining

It is becoming more difficult to find suitable sites for properly engineered landfilling in most countries. Even in Australia, with its large land mass and low population, the available supply of landfill is arguably a scarce resource to be used conservatively (Pickin, 2009). In Japan, with its limited space and high population density, it is becoming increasingly difficult to obtain public acceptance for waste disposal facilities, such as landfill sites; there is rising pressure on land use and growing public concern over environmental and health protection (Ishizaka and Tanaka, 2003). Some regions of the United Kingdom are facing the prospect of no easily accessible landfill sites within the next five years (CIWM Journal, 2017).

Since the 1980s, more than three-quarters of all landfills in the United States have closed (Biomass Magazine, 2011), while waste quantities have ballooned. Across the country, waste output has gone up about 65%, with over half still being landfilled (US EPA, 2014). The waste output of Chicago, Illinois, is now more than 300% what it was in the early 1980s, with remaining landfills getting farther from the city. Figures for 2013 show an Illinois-wide landfill life expectancy of 21 years (Illinois Environmental Protection Agency, 2014). For Chicago itself, landfills could last less than ten years. Since 1997, four New York City boroughs have sent MSW by road or rail to landfills as far away as Ohio, Pennsylvania, South Carolina and Virginia. Meanwhile, New York State has imported MSW from New England and Canada to its up-state landfill sites.

In the European Union, the waste management and recycling sector has a high growth rate. In addition, it is labour-intensive, providing between 1.2 million and 1.5 million jobs (Fava et al., 2015). Waste volumes, however, continue to grow. Variation is maximal: some countries landfill 100%, others nil (OECD, 2017a). On the whole, European data show that preferences for treating waste have shifted in the past decade. More waste is being pushed up the waste hierarchy to be recovered for energy or recycled.

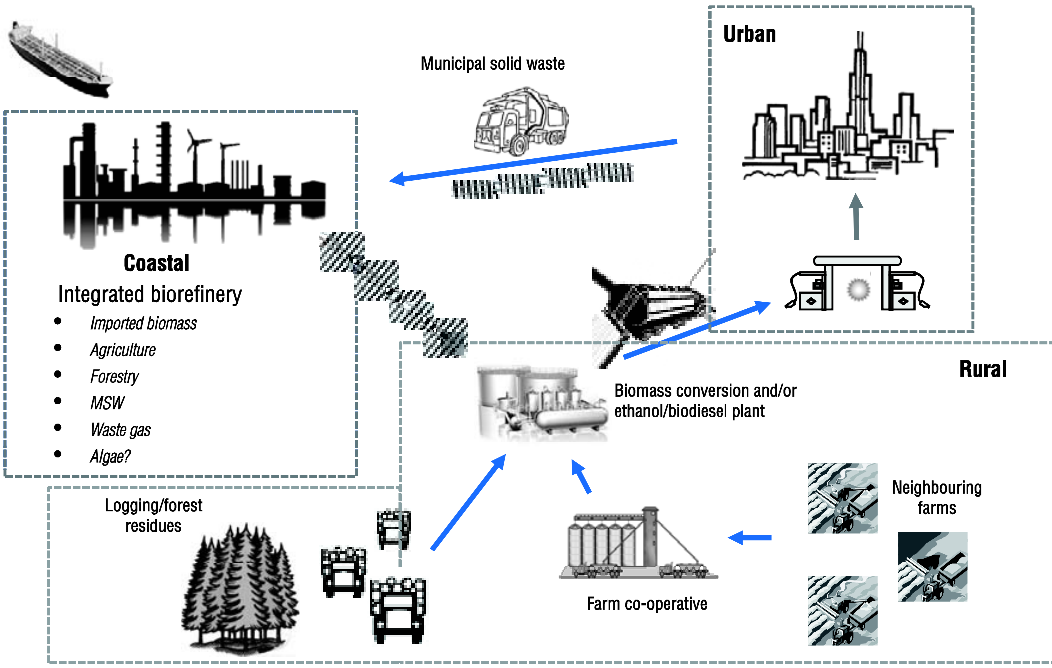
Meanwhile, new landfills might be the single least-popular kind of construction for a municipality, with an array of complex regulatory issues. These include siting restrictions in floodplains, wetlands and faults, as well as the need to protect endangered species, surface water and groundwater. Other considerations include disease and vector (rodents, birds, insects) control; open burning prohibitions; explosive methane gas control; fire prevention through use of cover materials; prevention of bird hazards to aircraft; and closure and post-closure requirements. Thus, from several directions, there is continuous pressure to reduce the amount of material being landfilled. Some MSW, if it can be sorted, can be directed towards biorefining.

Furthermore, there are powerful policy motivators against new landfills. For example, in the European Union, the "landfill directive" – Directive 99/31/EC – limits the quantities of biodegradable wastes (kitchen and similar wastes, including paper) that can be landfilled. Sending organic material to landfill can then be discouraged via taxes on landfill tipping (Scharff, 2014). Several US states, including Connecticut, Vermont, California and Massachusetts, are passing legislation to drive organic waste diversion. This policy (slowly) creates regulatory pressure to adopt other conversion technologies. Over the last decade, Japan has shifted from a waste management policy to an integrated waste and material management approach that promotes dematerialisation and resource efficiency. Landfill shortage and dependency on natural resources imports have been key drivers of these changes (OECD, 2010).

Alternative models to consider

Figure 7.1 examines some of the local geographical, infrastructure and social conditions that must be considered to develop alternatives to rural locations for biorefineries.

Figure 7.1. **Alternatives to the entirely rural model for biorefinery locations**



Note: MSW = municipal solid waste.

Source: OECD (2017b), *The Next Production Revolution*, http://dx.doi.org/10.1787/9789264271036-en.

Why the coastal/rural or coastal/suburban biorefinery makes sense

Importing biomass, specifically wood chips, for electricity generation may be necessary or desirable. For this purpose, a coastal location with port facilities makes sense. However, it may not make sense to transport wood chips into the rural setting to generate electricity and then send it back to a city. Many cities struggle to regenerate former industrial sites on coasts such as docklands.

To compensate for the loss of a large biorefinery in the countryside, it may make economic sense to build small industrial facilities in rural locations for several reasons:

- This would bring some jobs to the countryside (rural regeneration).
- Transporting agricultural and forestry residue biomass, low in energy density, does not make economic sense. Converting this biomass into ethanol and/or concentrated sugar solutions or biocoal at rural cellulosic plants may make better sense. (Storing a concentrated sugar solution also provides a biorefinery feedstock outside of the crop growing seasons). Ethanol can then be sent either to the large integrated biorefinery or a petrol blending plant, or both. This creates at least two markets for ethanol – for fuel and for chemicals.
- Many cities struggle to regenerate former coastal industrial sites e.g. docklands.
- Transport distances would be smaller.

- Environmental footprint of the small plant would be less than a full integrated biorefinery, and there would be less conflict with brownfield policies.[1]
- It is still possible in a small facility to generate electricity.
- There could be significant numbers of indirect and induced rural jobs e.g. warehousing, farmers' co-operatives to collect agricultural residues, haulage jobs.
- Small facilities require lower quantities of water – the Crescentino biorefinery, for example, supplies all its water needs from biomass and requires no river water.

It likely takes less time to transport MSW by road, rail or barge over relatively short distances to a coastal location than to a rural facility. Hauling MSW into a rural location could be unpopular with country people (smells, wear-and-tear on roads, safety issues around schools).

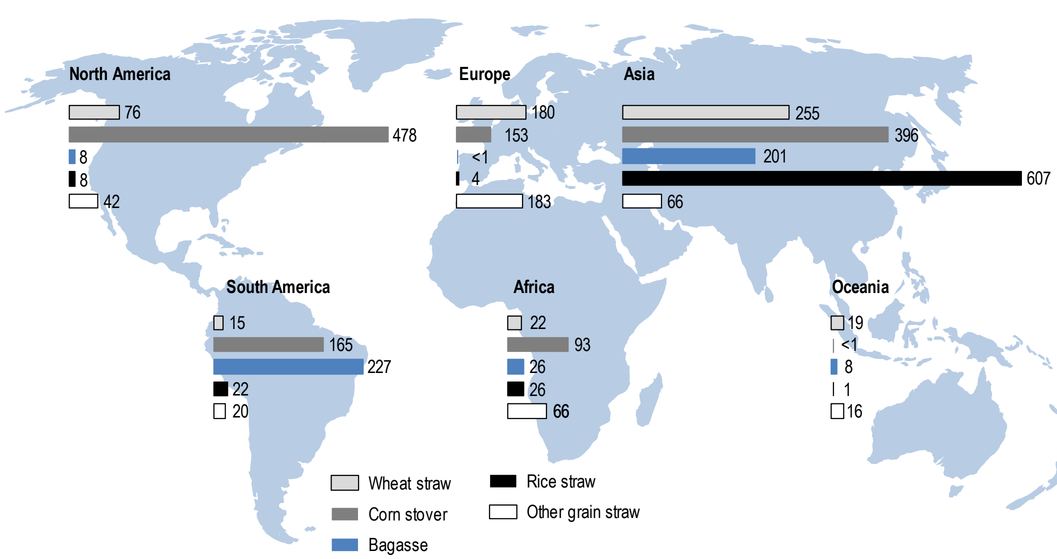
Another factor for consideration is the future commercial deployment of marine biorefineries, to date still struggling behind other biorefinery types. Abundant seawater and access to waste CO_2 from, say coastal petro-refineries and petrochemicals plants, may play a major role in determining the location of marine biorefineries. It might be prudent to build integrated biorefineries at coastal locations so that future marine biorefineries could be co-located when ready for deployment.

Waste materials available for bio-based production

Theoretically, a vast treasure trove of solid, liquid and gaseous wastes is available (Figure 7.2), but limited in practice for various reasons. Collecting straw or forestry residues, for example, may not be worthwhile for farmers or forest owners, who thus may need incentives. Municipal solid waste contains a lot of fermentable materials, but they are mixed up with non-fermentable materials. Industrial waste gases exist in profusion and are often in a relatively pure form. However, microbial processes for their fermentation are immature, giving companies little incentive to capture waste gases.

Figure 7.2. **Estimates of lignocellulosic waste materials available globally for bio-production**

Million tonnes



Source: Redrawn from KTN (2016), *From Shale Gas to Biomass: The Future of Chemical Feedstocks*.

A large amount of waste can be used as feedstock, but political will is needed to provide incentives for its collection. In the case of rice straw, for example (OECD, 2015), well over half a billion tonnes is available in Asia, and this material is routinely burned.

Bio-production bottlenecks in the United States have occurred due to multiple factors. These include high costs of both biomass resources, and enzymes or chemicals to break down biomass. Other factors include the recalcitrant nature of lignocellulosic feedstocks and the need for optimised bioprocesses for a wider array of varying feedstocks. The US Department of Agriculture (USDA) has been addressing the need for new feedstocks (Box 7.2), while helping maintain and develop the first-generation ethanol and biodiesel industry.

Box 7.2. **The need for new feedstocks in the United States: Initiatives of the USDA**

To address bio-production bottleneck factors, the US Department of Agriculture (USDA) introduced five Regional Biomass Research Centers. As one advantage, this programme provided incentives for field researchers (those optimising crops as feedstocks for biofuels) to work closely with researchers developing biorefinery technologies. As the industry evolved, focus has gone from creating corn- and grain-derived ethanol to creating cellulosic ethanol. It is moving towards integrated processes that produce drop-in replacement to petroleum products. Technologies to produce advanced biofuels such as *n*-butanol, pyrolysis bio-oil, hydroxymethylfurfural, liquefied biogas and even (bio)hydrogen have been developed and are arguably commercially viable.

Still, the corn ethanol industry is a multi-million dollar enterprise that merits research towards making it as efficient as possible. One strategy to reach the Renewable Fuels Standard (RFS) targets is to make stepwise improvements in the existing biorefinery concepts. These stepwise improvements must include a regional strategy that builds in enough flexibility to use the "cheapest sources of renewable carbon" within a given region. Such flexibility implies, for example, using grain sorghum, switchgrass or miscanthus in the US Midwest; sweet sorghum or cane sugar in the US South; guayule bagasse in the US Southwest; almond hull sugars in California; and even citrus peel waste in Florida. Another key element is the ability to integrate existing ethanol plants into other operations. Specifically, this enables thermochemical conversion of all biomass sources or integrated digesters to produce biogas and biogas-derived products. Biorefinery strategies are best optimised when field feedstock research on yield, crop quality and biomass cost are co-ordinated with biorefinery strategies (Orts and McMahan, 2016).

Source: Courtesy of Harry Baumes, USDA.

Waste gases

Adani (2015) has attempted to quantify how much waste from different categories is available and to put those numbers into the context of industrial production. Fermentable gases are produced in large quantities from different sectors. However, their collection from some of these sectors is not feasible. Two that are feasible for collection also contribute significantly to emissions: energy supply and industry.

Clearly, in the sectors where collection is feasible, CO_2 is by far the most important gas, although methane (CH_4) is far more potent as a GHG. Four critical figures given by Adani (2015) regarding the potential of gas use in waste biorefining are:

- consumption of renewable raw material for chemical industry and others: 857 million tonnes per year
- total mass used producing chemicals: 271 million tonnes per year

- total mass from CO_2 industry and energy production: 7 596 million tonnes per year
- total mass from biowaste and food loss: ~ 354 million tonnes per year.

The figures suggest, at least on a superficial level, that the amount of CO_2 available far exceeds requirements. Totals, however, can mask many feasibility issues. These include the efficiency of gas use in biorefinery operations, as well as other technical aspects relating to purity of gases, ease and cost of collection. Some preliminary estimates from LanzaTech, a leading company in gas fermentations, suggest that more than 30 billion gallons per year of high-value products can be produced from steel mill waste gases alone; this is a considerable contribution to the worldwide energy and chemical pool (AIChE, 2011).

Residual biomass

Bentsen et al. (2014) suggested more than 3.5 billion tonnes of residual biomass are generated every year in the world, representing about 66% of world energy consumption in transport. In Europe, another study identified 900 million tonnes per year of waste and residues (IEEP et al., 2014). Considering existing competing use and soil quality conservation, 223-225 million tonnes per year of residual biomass are available for advanced biofuel production. This is equivalent to 12% of current road fuel consumption or 16% of projected consumption in 2030.

The UK Department for Environment, Food and Rural Affairs (Defra) estimates that 100 million tonnes of biowaste are available for biogas production in the United Kingdom. This includes agricultural residues, food and drink waste and sewage sludge (House of Lords, 2014). The serious caveat is about purity. Every stage in a bio-based process that requires purification of material represents an additional cost.

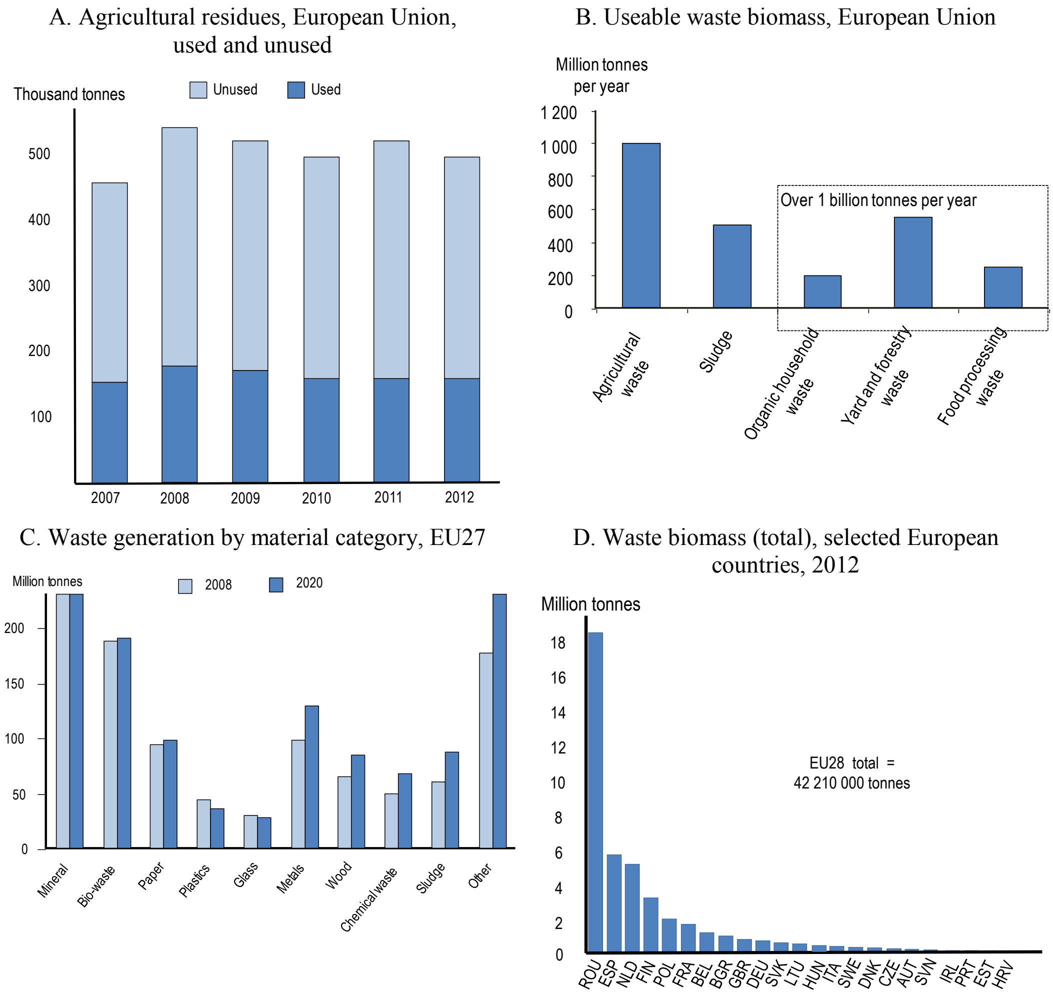
The problem of terminology and definitions, and how these influence potential estimates

Figure 7.3 shows several estimates of the quantities of waste materials generated annually in the European Union. There is a problem of definition, which leads to huge variation in figures across different sources.

The figures in (a) and (b), for example, are quite different, which may relate to the difference between "agricultural residues" and "agricultural waste". Comparing (c) with (b), the numbers for "sludge" are also very different. The use of the term "biowaste" in (c) could incorporate all of the categories in (b). The numbers in (d) refer to "waste biomass" in the European Union, 2012.

Therefore, the mixture of terms and a lack of standardised definitions make it difficult to truly assess the volumes of different (waste) materials that can be used in biorefining. Conversely, volumes from crop feedstocks (e.g. sugar cane or sugar beet) are collected internationally and readily comparable. Therefore, an important message for both the public and private sectors is the need for standard terms and definitions. For the public sector, standards are important when attempting to make strategic documents like biorefinery roadmaps. For example, how would it be possible to create a timeline for a national or regional biorefining industry in the absence of certainty around feedstock volumes? For the private sector, building a biorefinery to a certain tonnage capacity also needs certainty on available feedstocks.

Figure 7.3. **Data from different sources highlight the discrepancies in waste potential**



Sources: (a) https://biobs.jrc.ec.europa.eu/market/agricultural-biomass (accessed in 2016); (b) Fava et al. (2015), "Biowaste biorefinery in Europe: Opportunities and research & development needs"; (c) OECD (2014), "Present and future policy for bio-based production"; (d) https://biobs.jrc.ec.europa.eu/market/waste-biomass-total (accessed in 2016).

The development of common definitions will enable better data collection by both private and public entities. This would help resolve the issue of comparison between different data sources mentioned above.

- "Bioeconomy": lack of an agreed definition is a hindrance (denies the science input, no international databases, possible trade barriers).
- "Biowaste": most statistics do not distinguish between wet and dry weight, so no comparisons can be performed. It is extremely important to clarify the definition of biowaste. According to the European Commission:

> Biowaste is defined as biodegradable garden and park waste, food and kitchen waste from households, restaurants, caterers and retail premises, and comparable waste from food processing plants. It does not include forestry or agricultural residues, manure, sewage sludge, or other biodegradable waste such as natural textiles, paper or processed wood. It also excludes those by-products of food production that never become waste. (EC, 2018).

By leaving out forestry and agricultural residues, the tonnages generated will be very different.

- The definition of "waste disposal" could be changed to allow collection, transportation and sorting in view of its conversion in biorefineries. If a material is to be converted in a biorefinery then it should effectively no longer be regarded as a waste, but as a resource. If this is done officially, it will nullify many problems around collection and transport.
- A definition of "bio-based product" and a harmonised framework for bio-based products are needed as a standard for public procurement and business development. The European Committee for Standardisation (CEN) has made progress in development of such a framework, but there is still a need to spread use of the developed standards to capitalise on their market pull potential. This international co-operation can be done by, for example, exchange of best practices and experiences to reach a more coherent approach to bio-based products globally. Without it, trade barriers are certain to develop.
- "Competitive potential", which generally requires an economic model of competing technologies, needs to be assessed. For example, the future of zero-carbon transportation depends on whether cellulosic ethanol becomes economical at large scale and can compete with electric vehicles.

Ultimately, integration of actors across sectors and hence the creation of new value chains is limited by disparity, as well as lack of both control of terminology and standards. In short, a commonly agreed vocabulary throughout value chains is needed – from feedstock suppliers to biorefining to downstream actors in the application sectors.

Municipal solid waste volumes

> CEO [of Enerkem] Vincent Chornet looked at the big picture of potential, and it is big. Although there are 1.3 billion metric tonnes of MSW, about 420 million of them are suitable for Enerkem. That's as much as 160 billion liters (42 billion gallons) of renewable fuels (or chemicals) from one sector alone – more than doubling the addressable market for biofuels with just the one feedstock – and vastly outstripping the current [dollars] being brought in via waste to energy (incineration) technologies, which is around $7.6B, or a fraction of the $70B+ market available with the new technology. (Lane, 2015b.)

The figures for tonnages of MSW (Box 7.3) mentioned above are global tonnages. The figures merit further investigation from the public policy perspective. Although this appears to be an unprecedented opportunity to really make a difference to the landfill dilemma, the potential interaction between the private sector and public policy must be examined. For example, would this activity interfere with other markets, especially recycling, energy recovery and electricity generation, and industrial composting?

Addressing the latter part of the quotation, combusting mixed waste also comes with issues. These include cost, sorting, scrubbing the gas stream to remove toxins, GHG emissions, and, in some locations, negative public reaction. Moreover, as the quotation hints, the product – electric power – is low value and effectively zero value added.

Different figures give a perspective on what MSW tonnages translate to in bio-based production (Table 7.1).

Table 7.1. **Conversion of tonnages of MSW into crude oil and bio-based equivalents**

Quantity of MSW = 260 million tonnes/year

Biomass feedstock (10% water)	140 400 000 tonnes per year
Crude oil equivalent	322 436 000 barrels per year
Diesel fuel equivalent	14 490 billion gallons per year
Ethanol equivalent	24 500 billion gallons per year
Electricity equivalent	164 300 000 megawatts per year

Source: Hennessey (2011), "Biomass feedstock from MSW: Backbone for the biorefining industry".

Box 7.3. **What is municipal solid waste?**

Generally, in European countries and OECD countries, municipal solid waste (MSW) covers waste from households (82% of total MSW), including bulky waste. The remainder of MSW comes from commerce and trade, office buildings, institutions and small businesses, yard and garden waste, street sweepings, the contents of litter containers and market cleansing waste (Eurostat, 2003). The definition of MSW excludes waste from municipal sewage networks and treatment, as well as municipal construction and demolition waste. However, national definitions of MSW may differ (OECD, 2007). In a developing economy, MSW is generally defined as the waste produced in a municipality. Most MSW generated in developing countries is non-segregated and, therefore, either hazardous or non-hazardous (Karak et al., 2012). Many countries likely contain a significant amount of food waste, which is extremely useful for gasification or fermentation.

About 65% of municipal waste is biodegradable. The EU Directive on the landfill of waste aims to reduce environmental pressures from landfill, particularly methane emissions and leachates (Official Journal of the European Communities, 1999). It requires member states to reduce landfill of biodegradable municipal waste to 75% of the amounts generated in 1995 by 2006, to 50% by 2009 and to 35% by 2016.

In the United States, the number of landfill sites has dropped by 75% in the past 25 years. However, this number is deceptive. Much of the decrease is due to consolidation of multiple landfills into a single, more efficient facility. Also, technology has allowed for each acre of landfill to take 30% more waste. So, during this time, the available landfill per person has actually increased by almost 30%. As of 2010, total US MSW generation was 250 million tonnes. Paper and paperboard account for 29%, and yard trimmings and food scraps account for another 27%. The rest breaks down as follows: plastics 12%; metals 9%, rubber, leather and textiles 8%; wood approximately 6.4% and glass 5% (Hennessey, 2011).

The earliest MSW biorefineries are open for business

At least two high-profile biorefineries have been established through public-private partnerships to convert MSW into bioethanol and methanol. The facility in Ineos Vero Beach, Florida, which received a USD 75 million loan in 2011 (USDA, 2014), is relatively small. In 2013, it began producing 8 million gallons of cellulosic ethanol per year from vegetative and yard waste, as well as MSW. The other is the Enerkem plant in Edmonton, Canada. Both are gasification and fermentation plants i.e. gasification is needed to get MSW ready for use as a feedstock.

Is MSW biorefining a truly sustainable and economic business model?

In the face of growing waste management and disposal costs, the demand for petro-based products – fuel, plastics or chemicals – also continues to rise. Although governments have been notoriously slow to adopt sustainability policies, sustainability goals and mission statements are increasingly common among many large corporations. Indeed, in the absence of public policy, industry may go it alone. However, this may not result in the most sustainable solutions or the most desired public policy goals.

The policy pros and cons

This section is largely a summary and extrapolation of some considerations in RWI (2014).

There are two potential revenue streams for a biorefinery facility, which are both uncertain: the gate or tipping fees[2] from taking the waste; and revenues from selling biofuels. Gate fees vary enormously by country and region, and landfill tax tends to make gate fees higher. Where gate fees are low, the production of biofuels from waste is not cost-competitive with landfill. Therefore, public stimulus is needed for countries, regions or cities to break out of the landfill dilemma.

For waste treatment facilities such as incinerators or composting plants, the fee offsets the operation, maintenance, labour costs and capital costs of the facility along with any profits and final disposal costs of any unusable residues.

For some years, many have argued for a policy shift to offer more support for bio-based chemicals. In this particular case, chemicals usually have higher margins than liquid fuels, have more value added and create more jobs than biofuels. Therefore, diversifying MSW biorefineries so they can also make bio-based chemicals would seem to improve the economics irrespective of gate fees.

This is a competitive market. Anaerobic digestion (AD) is a tried-and-tested technology that has been brought up-to-date in the last decade; it now involves the anaerobic fermentation of waste to biogas, which is over 50% methane. AD facilities are generally cheaper to design and build than waste-to-biofuels biorefineries, plus they are significantly better proven. The flexibility of AD as a process allows for biogas to be used to generate electricity. It can be piped as gas and create fertiliser, and be adapted to provide combined heat and power.

Incineration is also both proven and effective at disposal and energy generation. Early incinerators had a bad reputation, but the challenges have been overcome. In Japan, incineration with energy capture has been increasingly popular as it can be used to tackle the vast waste plastics problem (Yamashita and Matsumoto, 2014).[3] Burning the other organic fraction of MSW with plastics reduces the sorting difficulties. In effect, MSW biorefineries are in competition with other buyers such as incineration utilities (Knight et al., 2015).

There are counter-arguments that favour waste-to-biofuels (and/or chemicals). First, the technology creates fuel from non-recyclable and non-compostable MSW i.e. it can work in partnership with other sustainable waste technologies, not against them. Second, more experience is being gained with gasification technology, which will help with the economics and the confidence in using a process such as Enerkem. There is also an embryonic technology to turn waste gases (and natural gas) into animal feed and value-added chemicals through fermentation. Calysta of Norway uses natural gas-fed fermentation to produce feed-quality protein with high nutritional value for use in aquaculture (Calysta, n.d.).

Eventually, the diversity of chemicals that can be produced after gasification will be higher. Environmental regulations are constantly becoming more stringent. Therefore, any technology that can improve both economic and environmental outcomes while creating jobs must be taken seriously, even if alternatives such as landfill are more competitive. Landfill is no solution for the 21st century.

Scale-up is now the critical issue

MSW biorefineries are thus far unproven at commercial scale. Second-generation biofuels are too recent for a long-term success story that could provide evidence of a scalable, repeatable business model. The successes of first-generation ethanol in Brazil are not transferrable to other countries. Thus, there is even less experience with waste-to-biofuels projects and facilities. Without high quality, robust data from functioning operations, the justification for large capital injections will remain a barrier. However, the number of such projects is gradually growing. They can be regarded as flagship projects; if successful, they should help de-risk future projects. Nevertheless, policy makers will be obliged to study the business case carefully on an individual basis. This will require close communication between municipalities and their waste management operators, the private sector and the potential investors along with public agencies offering investment.

Notes

1. In town planning, brownfield land is an area of land previously used or built upon, as opposed to greenfield land, which has never been built upon. Brownfield status is a legal designation that places restrictions, conditions or incentives on redevelopment.
2. A gate fee and tipping fee mean the same thing. It is the charge levied upon a given quantity of waste received at a waste processing facility. In the case of a landfill, the fee is generally levied to offset the cost of opening, maintaining and eventually closing the site. It may also include any landfill tax that is applicable locally. See http://en.wikipedia.org/wiki/Gate_fee.
3. The ultimate destination for about 3% of plastic waste is the oceans. It has been estimated that the plastic waste entering the world's oceans could double in the next ten years (Jambeck et al., 2015).

References

Abbott, P. et al. (2008), "What's driving food prices?", *Farm Foundation Issue Report*, Farm Foundation, Oak Brook, United States.

Adani, F. (2015), "Availability of bio-waste types (including gases)", presentation at Biorefining: bio-waste and organic by-products exploitation in multi-purpose biorefinery schemes workshop, Ecomondo 2015, 4 November, Rimini Fiera, Italy.

AIChE (2011), "Gas Fermentation of Industrial Waste Gases to Fuels and Chemicals", webpage, https://www.aiche.org/academy/videos/conference-presentations/gas-fermentation-industrial-waste-gases-fuel-and-chemicals (accessed 7 December 2017).

Bentsen, N.S. et al. (2014), "Agricultural residue production and potentials for energy and materials services", *Progress in Energy and Combustion Science*, Vol. 40, Elsevier, Amsterdam, pp. 59-73.

Biomass Magazine (2011), "The role of MSW for future biorefineries", *Biomass Magazine*, 18 January, http://biomassmagazine.com/articles/6746/the-role-of-msw-for-future-biorefineries/?ref=brm.

Calysta (n.d.), "Nutrition", webpage, http://calysta.com/nutrition (accessed 7 December 2017).

CIWM Journal (2017), "UK Faces "Serious" Waste Infrastructure Capacity Gap – SUEZ", *CIWM Journal*, 16 August, https://ciwm-journal.co.uk/uk-faces-serious-waste-infrastructure-capacity-gap-suez.

De Gorter, H. et al. (2013), "How biofuels policies affect the level of grains and oilseed prices: Theory, models and evidence", *Global Food Security*, Vol. 2/2, Elsevier, Amsterdam, pp. 82-88.

Desrochers, P. (2002), "Cities and industrial symbiosis. Some historical perspectives and policy implications", *Journal of Industrial Ecology*, Vol. 4, pp. 29-44.

EC (European Commission) (2018), "Biodegradable waste", web page, http://ec.europa.eu/environment/waste/compost/ (accessed 2 March 2018).

Eurostat, (2003), *Waste Generated and Treated in Europe*, Office for Official Publications of the European Communities, Luxembourg.

Fava, F. et al. (2015), "Biowaste biorefinery in Europe: Opportunities and research & development needs", *New Biotechnology*, Vol. 32/1, Elsevier, Amsterdam, pp. 100-108.

Hennessey, E. (2011), "Biomass feedstock from MSW: Backbone for the biorefining industry", presentation at the municipal solid waste to biofuels 2011 summit, Chicago, 10-11 February.

House of Lords (2014), "Waste or resource? Stimulating a bioeconomy", *Report of the Science and Technology Select Committee*, HL Paper No. 141, The Stationery Office Limited, London.

IEEP et al. (2014), *Wasted: Europe's Untapped Resource: An Assessment of Advanced Biofuels from Wastes & Residues*, Institute for Environmental Policy et al., Brussels, http://europeanclimate.org/wp-content/uploads/2014/02/WASTED-final.pdf.

IFPRI (2010), *Reflections on the Global Food Crisis: How did it Happen? How has it Hurt? And How can We Prevent the Next One?*, International Food Policy Research Institute, Washington, DC.

Illinois Environmental Protection Agency (2014), *Illinois Landfill Projections of Disposal Capacity as of January 1, 2014*, Illinois Environmental Protection Agency, Springfield, United States, www.epa.state.il.us/land/landfill-capacity/2013/landfill-capacity-report-2014.pdf.

Ishizaka, K. and M. Tanaka (2003), "Resolving public conflict in site selection process – a risk communication approach", *Waste Management*, Vol. 23/5, Elsevier, Amsterdam, pp. 385-396.

Jambeck, J.R. et al. (2015), "Plastic waste inputs from land into the ocean", *Science*, Vol. 347/6223, American Association for the Advancement of Science, Washington, DC, pp. 768-771.

Karak, T. et al. (2012), "Municipal solid waste generation, composition, and management: The world scenario", *Critical Reviews in Environmental Science and Technology*, Vol. 42/15, Taylor & France Online, pp. 1509-1630.

Knight, L. et al. (2015), "Supply market uncertainty: Exploring consequences and responses within sustainability transitions", *Journal of Purchasing & Supply Management*, Vol. 21/3, Elsevier, Amsterdam, pp. 167-177.

KTN (2016), *From Shale Gas to Biomass: The Future of Chemical Feedstocks*, Knowledge Transfer Network, Horsham, United Kingdom.

Lane, J. (2015), "Who said what: The hottest slides from ABLC 2015", *Biofuels Digest*, 15 March 2015.

Mueller, S.A. et al. (2011), "Impact of biofuel production and other supply and demand factors on food price increases in 2008", *Biomass and Bioenergy*, Vol. 35/5, Elsevier, Amsterdam, pp. 1623-1632.

OECD (2017a), "Municipal waste generation and treatment", *OECD.Stat*, OECD, Paris, https://stats.oecd.org/Index.aspx?DataSetCode=MUNW (accessed 1 October 2017).

OECD (2017b), *The Next Production Revolution*, OECD Publishing, Paris, http://dx.doi.org/10.1787/9789264271036-en.

OECD (2015), "Genomics for sustainable development in emerging economies: Food, environment and industry", *Report of the Joint HUGO-OECD Workshop*, 14 March, Kuala Lumpur, OECD, Paris.

OECD (2014), "Present and future policy for bio-based production", *Report of an OECD Workshop*, Turin, 9 October 2014, OECD, Paris.

OECD (2010), *Environmental Performance Reviews: Japan 2010*, OECD Publishing, Paris, http://dx.doi.org/10.1787/9789264087873-en.

OECD (2007), *Environmental Data, Compendium 2006-2008*, OECD Publishing, Paris, www.oecd.org/env/indicators-modelling-outlooks/oecdenvironmentaldatacompendium.htm.

Official Journal of the European Communities (1999), "Council Directive 1999/31/EC of 26 April 1999 on the landfill of waste", http://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:31999L0031&from=EN (accessed 7 December 2017).

Orts, W.J. and C.M. McMahan (2016), "Biorefinery developments for advanced biofuels from a sustainable array of biomass feedstocks: Survey of recent biomass conversion research from Agricultural Research Service", *BioEnergy Research*, Vol. 9/2, Springer, pp. 430-446.

Pickin, J. (2009), "Australian landfill capacities into the future", report commissioned by the Department of the Environment, Water, Heritage and the Arts, Hyder Consulting Pty Ltd., Melbourne, Australia.

RWI (2014), "Is the conversion of municipal solid waste to biofuels and bio-products a truly sustainable and economic business model in the USA*?", An Analysis of the USA Market and the State of Play for MSW to Biofuels and Bio-products Projects*, Renewable Waste Intelligence, London.

Scharff, H. (2014), "Landfill reduction experience in The Netherlands", *Waste Management*, Vol. 34, Elsevier, Amsterdam, pp. 2218-2224.

Timmer, P.C. (2008), "Causes of High Food Price plus Technical Annexes", *Economics Working Paper Series*, No. 128 (October), Asian Development Bank, Manila.

USDA (2014), "USDA announces loan guarantee to help innovative company turn waste into renewable jet fuel", News Release, USDA Office of Communications Release No. 0195.14, US Department of Agriculture, Washington, DC.

US EPA (2014), "Municipal solid waste generation, recycling, and disposal in the United States: Facts and figures for 2012", EPA-530-F-14-001, February 2014, US Environmental Protection Agency, Washington, DC.

Van Stappen, F. et al. (2011), "Direct and indirect land use changes issues in European sustainability initiatives: State-of-the-art, open issues and future developments", *Biomass and Bioenergy,* Vol. 35, Elsevier, Amsterdam, pp. 4824-4834.

Velis, C.A. (2015), "Circular economy and global secondary material supply chains", *Waste Management Research*, Vol. 33/5, Sage Publications, Thousand Oaks, United States, pp. 389-391.

Yamashita, M. and S.-I. Matsumoto (2014), "Status of recycling plastic bottles in Japan and a comparison of the energy costs of different recycling methods", *International Journal of Environmental Protection and Policy*, Vol. 2/4, Science Publishing Group, New York, pp. 132-137.

Part III.

Towards bio-production of materials: Replacing the oil barrel

From:

Meeting Policy Challenges for a Sustainable Bioeconomy

Access the complete publication at:

https://doi.org/10.1787/9789264292345-en

Please cite this chapter as:

OECD (2018), “Biowaste biorefining”, in *Meeting Policy Challenges for a Sustainable Bioeconomy*, OECD Publishing, Paris.

DOI: https://doi.org/10.1787/9789264292345-10-en

OECD