Sector Research: Energy from Waste

by 350 PPM Research Department

350PPM
Capitalist Solutions to Climate Change

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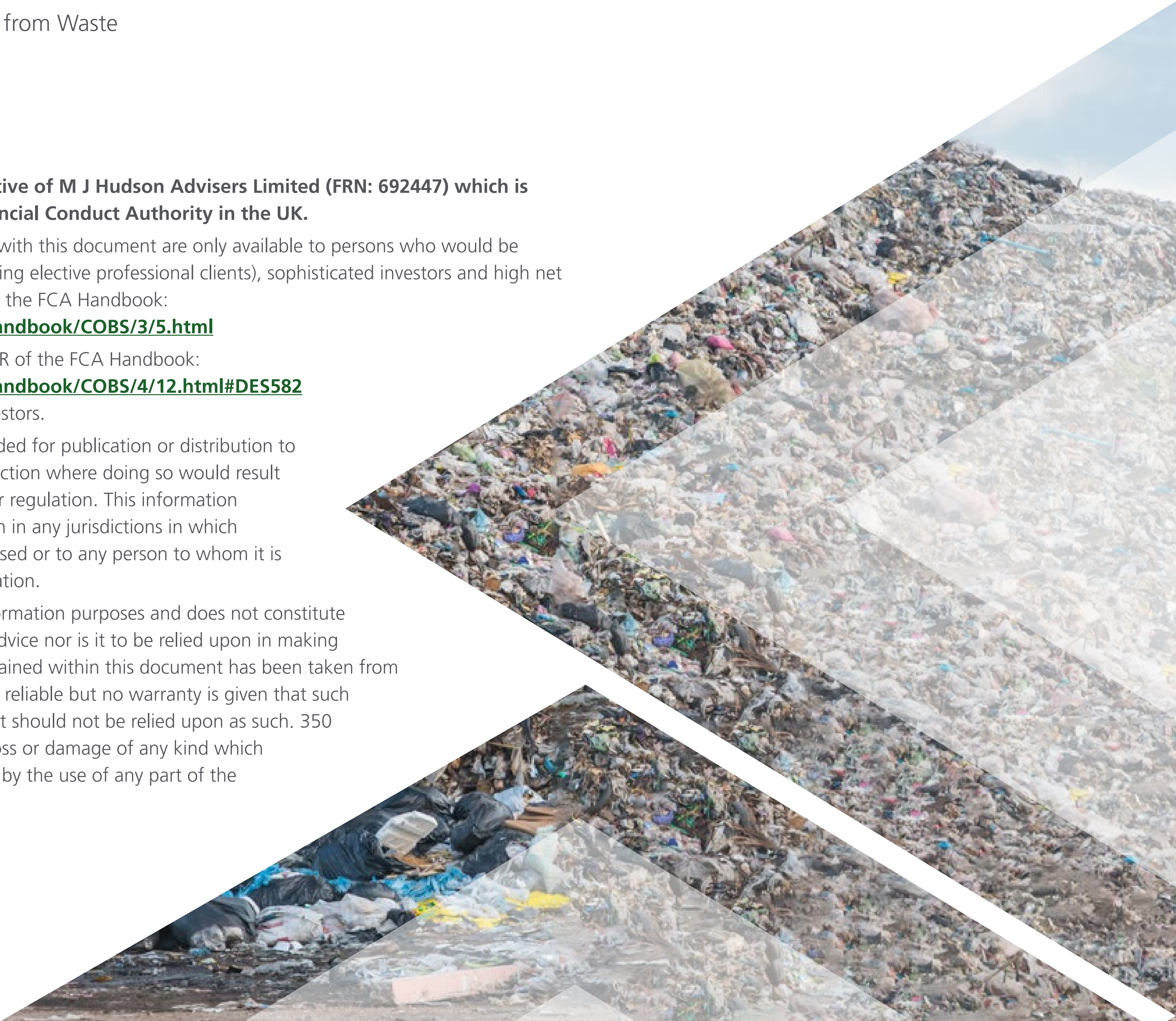


Introduction

Worldwide government policy is increasingly influenced by the linked premises that our planet is undergoing potentially catastrophic warming and that its resources are finite and should therefore be used as efficiently as possible. As a result, many countries are transitioning from linear take-make-dispose resource models to more sustainable cycles in which resources are recycled at end-of-life or, if this is not feasible, converted to energy. Creating Energy from Waste (EfW) addresses these two premises simultaneously: dealing with non-reusable and non-recyclable waste sustainably; generating reliable, decentralised and low carbon energy.

In this report, we introduce EfW and briefly assess its market potential in the UK and worldwide. Our main findings are:

- The UK has a well-established and rapidly growing EfW market. Government policy is supportive, with high landfill tax and various subsidies available.
- The UK still sends 12 million tonnes of waste to landfill per annum and exports 3.5 million tonnes, waste that could instead be dealt with by new EfW capacity.
- It is forecast the UK needs additional EfW capacity of up to 11 million tonnes per annum by 2030, with 6 million tonnes a more conservative estimate. This is a multi-billion-pound opportunity either way.
- Worldwide, the EfW market is highly fragmented, with Europe well established, Asia fast-growing and developing countries largely not involved.
- The World Bank estimates that global waste generation will nearly double from 2014 to 2025, to over 6 million tonnes of waste per day. Currently, over 70% of global waste ends up in landfill.
- 60 new EfW plants are forecast to be built worldwide every year until 2026, with an average capacity of 17 million tonnes per annum.
- We have barely scratched the surface of worldwide EfW potential, particularly in developing countries.

The Waste Hierarchy

To minimise the total environmental impact when using and disposing of finite resources, an ordered series of steps known as the 'waste hierarchy' has been enshrined in UK and EU law, see **Figure 1**, below.

Figure 1 – Depiction of the 'waste hierarchy' – how waste should ideally be dealt with to minimise environmental impact.

The idea is that each step should be completed as fully as is technically and economically possible before passing the smallest possible amount of waste onto the next step.

After minimising the amount of waste that is produced in the first place through waste prevention and reuse, the next priority is to recycle as much useful material as possible from the waste that is unavoidably generated. In the UK, the household recycling rate is currently ~45% (2016)[1]. In an ideal world, we would recycle 100% of end-of-life materials, however there are reasons why this is not, and likely never will be, possible[2]:

- Some materials are not recyclable for technical or economic reasons.
- Many materials cannot be infinitely recycled.
- Some waste is too heavily contaminated.
- Even after recycling there are residues that need to be disposed of.

The waste remaining after recycling is termed 'residual waste'. Historically, this residual waste has been disposed of in landfill, but as the waste hierarchy suggests, this is the option of last resort – for reasons explained below – and there is another option that must be considered first: Energy from Waste (denoted 'Other Recovery' in **Figure 1**).

1 https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/746642/UK_Statistics_on_Waste_statistical_notice_October_2018_FINAL.pdf
2 http://www.esauk.org/application/files/7715/3589/6450/20180606_Energy_for_the_circular_economy_an_overview_of_EfW_in_the_UK.pdf

What is Energy from Waste (EfW)?

The term EfW covers a group of processes and technologies by which waste can be converted into energy – in the form of electricity or heat – or energy carriers (fuels) such as biomethane. It is not possible to convert 100% of the waste to a single product, but by-products of EfW often have their own uses, with only a small fraction of waste ultimately having no use and ending up in landfill.

EfW processes can be subdivided into three main categories: thermochemical, biochemical and chemical.

As the name suggests, thermochemical processes recover energy from waste using chemical processes that occur at high temperatures. Combustion is the most common thermochemical process; this involves simply burning the waste, then using the resulting heat to generate electricity (or directly as heat). Other thermochemical processes include gasification and pyrolysis. See the later section 'Thermochemical Processes' for more details.

Biochemical processes utilise microbes to break down organic wastes (e.g. sewage sludge, food waste) into useful products at low temperature. The most common example is anaerobic digestion – the breakdown of organic waste in the absence of oxygen. The main output of anaerobic digestion is biomethane, a natural gas substitute that can be injected directly into the existing gas grid, a process known as gas-to-grid.

Chemical processes use (non-microbial, low temperature) chemical reactions to create useful products from waste. For example, the process of esterification can be used to create biodiesel from waste cooking oil.

How does an EfW plant work?

Combustion-based EfW is the most common type of EfW – 95% of worldwide EfW plants are of this type[3]. A typical combustion-based EfW plant is depicted in **Figure 2**, on the next page.

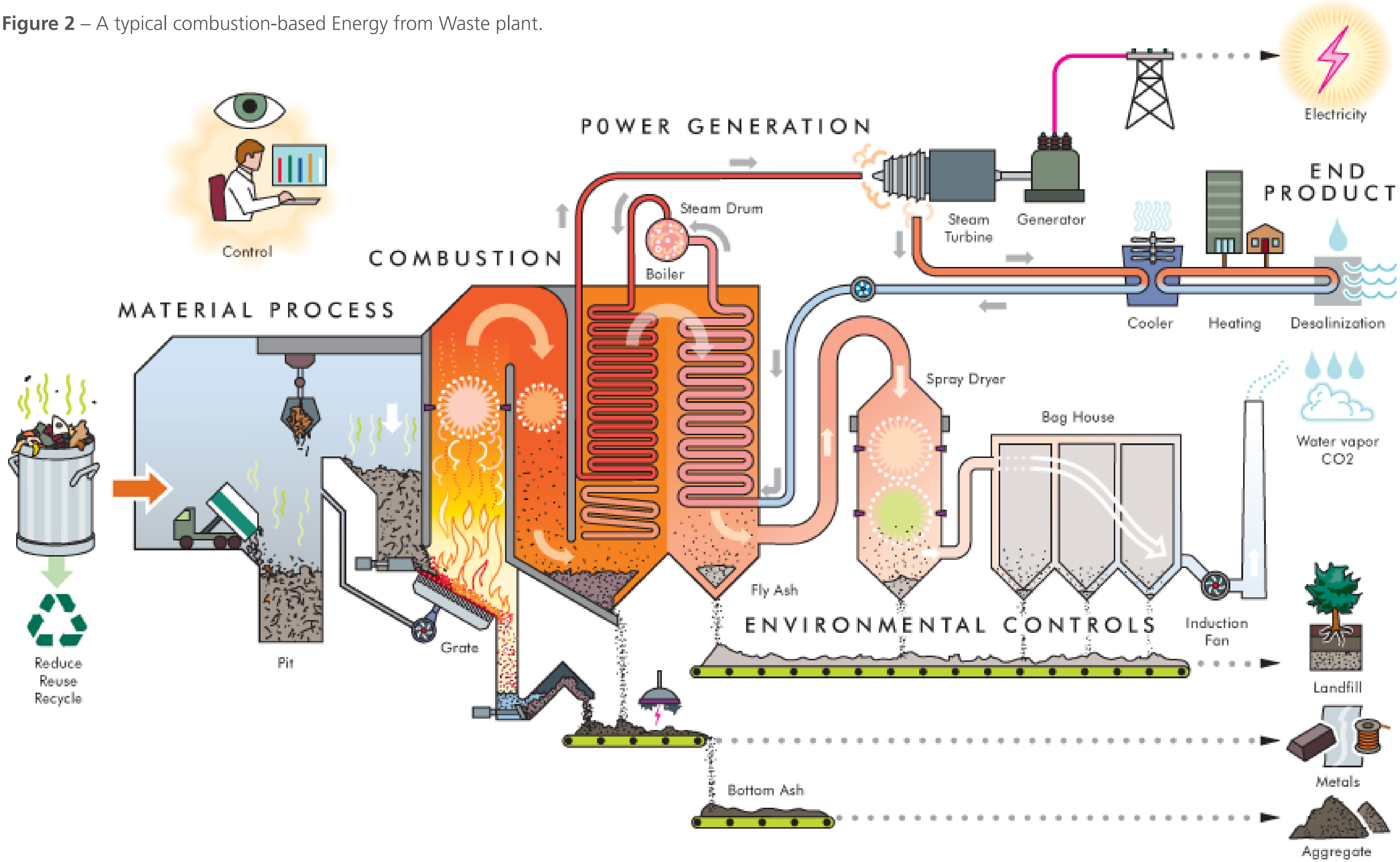
Breaking down **Figure 2** into separate steps, the plant works as follows:

- Waste is collected at homes and businesses and then processed or delivered directly to the plant's storage bunker. Pre-processed waste is most often in the form of Refuse Derived Fuel (RDF) – dried, shredded and baled residual waste with most non-combustible components removed.
- A crane grabs the waste then places it into a feed hopper. The waste drops down a feed chute onto a moving grate where it is burnt.
- The action of the moving grate turns the waste to allow it to burn fully.
- The burnt-out ash passes through the ash discharger onto an ash handling system which extracts metal for recycling.
- The remaining ash – known as bottom ash – is largely recycled as an aggregate or road bed material, for example.
- Hot gases pass over the boiler tubes where they are cooled, while water in the tubes becomes high pressure steam.
- The steam turns a turbine and generates electricity for export to the grid. The electricity generated from the organic component of waste is classified as renewable energy. In typical household residual waste, the organic component is more than half of the total.
- In some plants, waste heat is exported to local businesses or residences via a district heating system.
- The gases from the boiler go through an extensive clean-up process. This consists of a gas scrubber and a bag filter where particulates are filtered out. The resulting material, known as Air Pollution Control Residue (APCR) can be partially recycled, with the rest sent for disposal at a licensed site.
- The cleaned gases are finally released to the atmosphere through a chimney. These gases consist mainly of CO_2 and water vapour.

Instead of burning the waste on a moving grate, a common variation is to burn it on a 'fluidised bed' – a continually stirred bin of heated sand-like material. This method allows for more efficient combustion and the creation of lower levels of certain pollutants, but the input waste requires additional pre-processing.

3 https://www.ecoprog.com/fileadmin/user_upload/pressemitteilungen/ecoprog_press_release_Waste_to_Energy_2017-2018.pdf

Figure 2 – A typical combustion-based Energy from Waste plant.



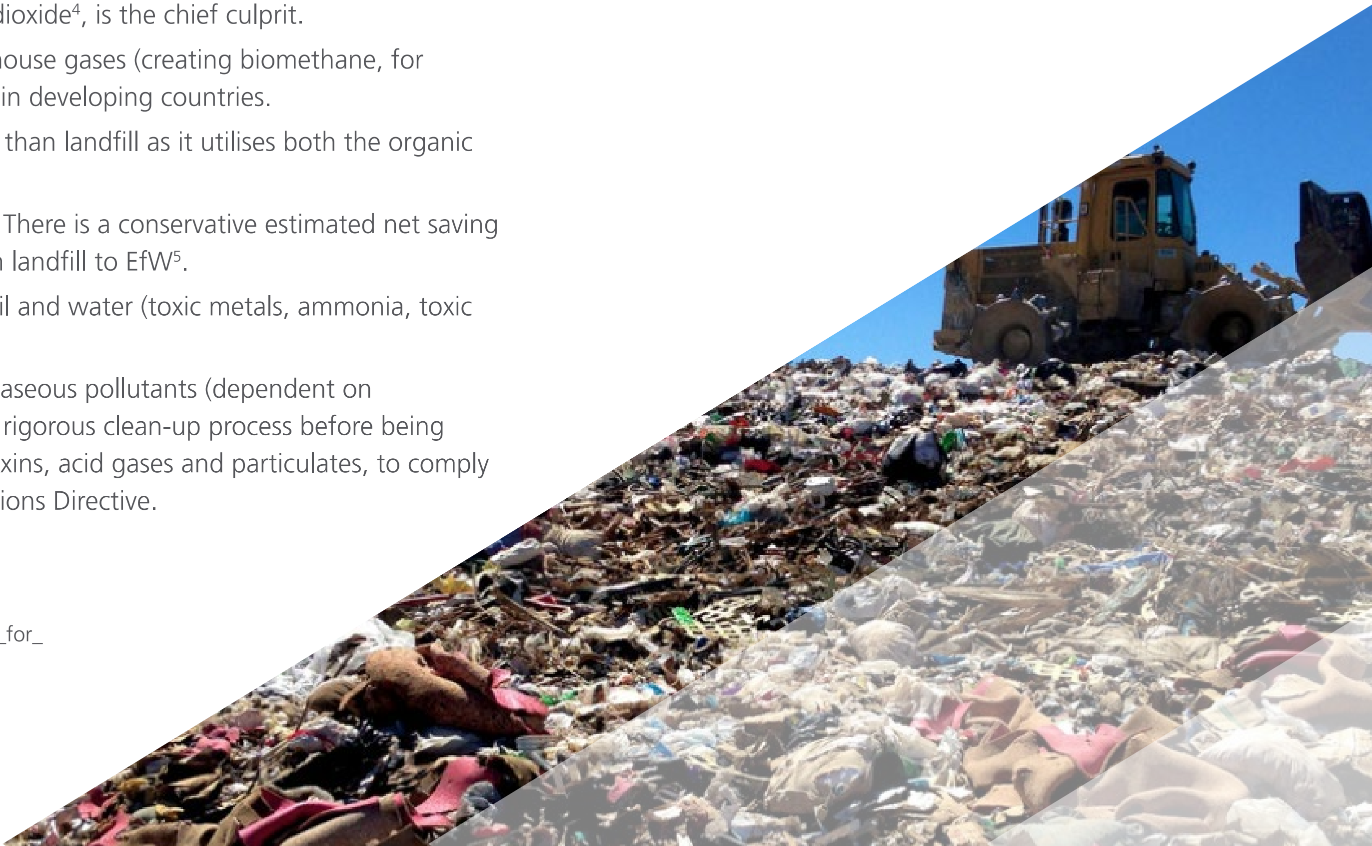
Landfill or Energy from Waste?

The waste hierarchy, outlined in **Figure 1** on page 4, has been designed to minimise the waste that ends up in landfill, but beyond the issue of not dumping things that could have instead been reused or recycled, why is using landfill for waste problematic and why is EfW preferable? Some of the key points include:

- Dumping all the waste generated by the increasingly large number of people in the world is not sustainable – you will end up having to dedicate an inordinately large and growing amount of land for this locally unpopular purpose (visual impact, odour, vermin…).
- EfW requires a much smaller footprint than landfill.
- The organic portion of landfill waste is a significant source of potent greenhouse gases. Methane, whose global warming potential is 28 times that of carbon dioxide[4], is the chief culprit.
- Modern landfills do capture and utilise most of these greenhouse gases (creating biomethane, for example), however this is not a universal practice, especially in developing countries.
- EfW is typically more efficient at converting waste to energy than landfill as it utilises both the organic and non-organic constituents of the waste.
- EfW avoids most greenhouse gas emissions other than CO_2. There is a conservative estimated net saving of 200 kg of CO_2e per tonne of residual waste diverted from landfill to EfW[5].
- Landfills are sources of pollutants that end up in the local soil and water (toxic metals, ammonia, toxic organic compounds)[6].
- EfW plants also typically create small amounts of solid and gaseous pollutants (dependent on technology). As shown in **Figure 2**, flue gases go through a rigorous clean-up process before being released into the atmosphere, removing nitrogen oxides, dioxins, acid gases and particulates, to comply with strict legal requirements; in the UK, the Industrial Emissions Directive.

Recycling or Energy from Waste?

Countries with high levels of EfW also tend to have high levels of recycling – the idea of competition between the two is not borne out by the evidence; resource efficient countries tend to be good at both. Examples include Austria, Holland, Switzerland and Belgium.[5]



4 https://www.ghgprotocol.org/sites/default/files/ghgp/Global-Warming-Potential-Values%20%28Feb%2016%202016%29_1.pdf
5 http://www.esauk.org/application/files/7715/3589/6450/20180606_Energy_for_the_circular_economy_an_overview_of_EfW_in_the_UK.pdf
6 https://sciencing.com/effects-landfills-environment-8662463.html

Thermochemical Processes (based on [3])

There are three main types of processes that are used to convert waste into energy (and other products) in a thermochemical-based EfW plant. In any one plant, all these processes will occur to some extent, but we label the EfW plant by the dominant process involved. The main differences between combustion, gasification and pyrolysis are the amount of air introduced in the process, the temperature of the process and the end products you get as a result.

Combustion

Combustion is the complete oxidation of (dry, combustible) materials contained in waste. This process is highly exothermic – it creates heat – and, as described earlier, this heat is then used directly or to create electricity. The main by-product is bottom ash (~20% of input).

Combustion is by far the most widely used form of thermochemical EfW. The other types of thermochemical EfW are less established and are grouped together under the term 'Advanced Thermal Treatment' (ATT). These plants usually require more processed input waste than standard combustion systems and operate on a smaller scale. Rather than generating heat directly through combustion, ATT converts waste into products that can then be used to create heat (or have some other use).

Advanced Thermal Treatment: Gasification

Gasification is the thermal decomposition of waste in the presence of an oxidant of lower amount than that required for combustion. The main product (~85%) is a gaseous mixture composed primarily of carbon monoxide and hydrogen, syngas. Syngas can be burnt directly or used as a starting point to manufacture fertilizers, pure hydrogen, methane or liquid transportation fuels. The solid by-product, char, can be burnt or used, for example, as a soil amendment to sequester (lock away) carbon in soil, one method of fighting climate change.

Though more complicated and expensive than combustion, gasification has several advantages. If done correctly, it is possible to ultimately extract more energy out of suitable waste via gasification versus direct combustion. In addition, due to the lower temperature of gasification versus combustion, certain pollutants are generated at lower levels (nitrogen and sulphur oxides).

Advanced Thermal Treatment: Pyrolysis

Pyrolysis is the thermal decomposition of organic materials (and some inorganic materials such as tyres and plastic waste) in the absence of oxygen. Pyrolysis is the fundamental chemical reaction that is the precursor of both combustion and gasification. Pyrolysis can occur at lower temperatures than gasification and, like gasification, has reduced emissions versus combustion.

Pyrolysis produces solid, liquid and gaseous products in relative proportions determined by the temperature involved and the speed of the process. Slow pyrolysis results in solid char as the main product. The more common fast pyrolysis typically yields ~60% bio-oil, ~20% char and ~20% syngas. Bio-oil can be burnt directly, refined into transportation fuels or used as a chemical feedstock.

Economics of EfW

Simply put, for an EfW plant to be viable it needs:

- A regular and ongoing supply of waste of the right quantity and type for which it is paid sufficiently to process.
- The ability to sell its output products (electricity etc.) at sufficiently high prices on an ongoing basis.

Key metrics such as efficiency (how much saleable output is extracted from the input waste), availability (the percentage of time a plant is operational) and operational capacity (how much waste is processed when operational) all impinge on viability.

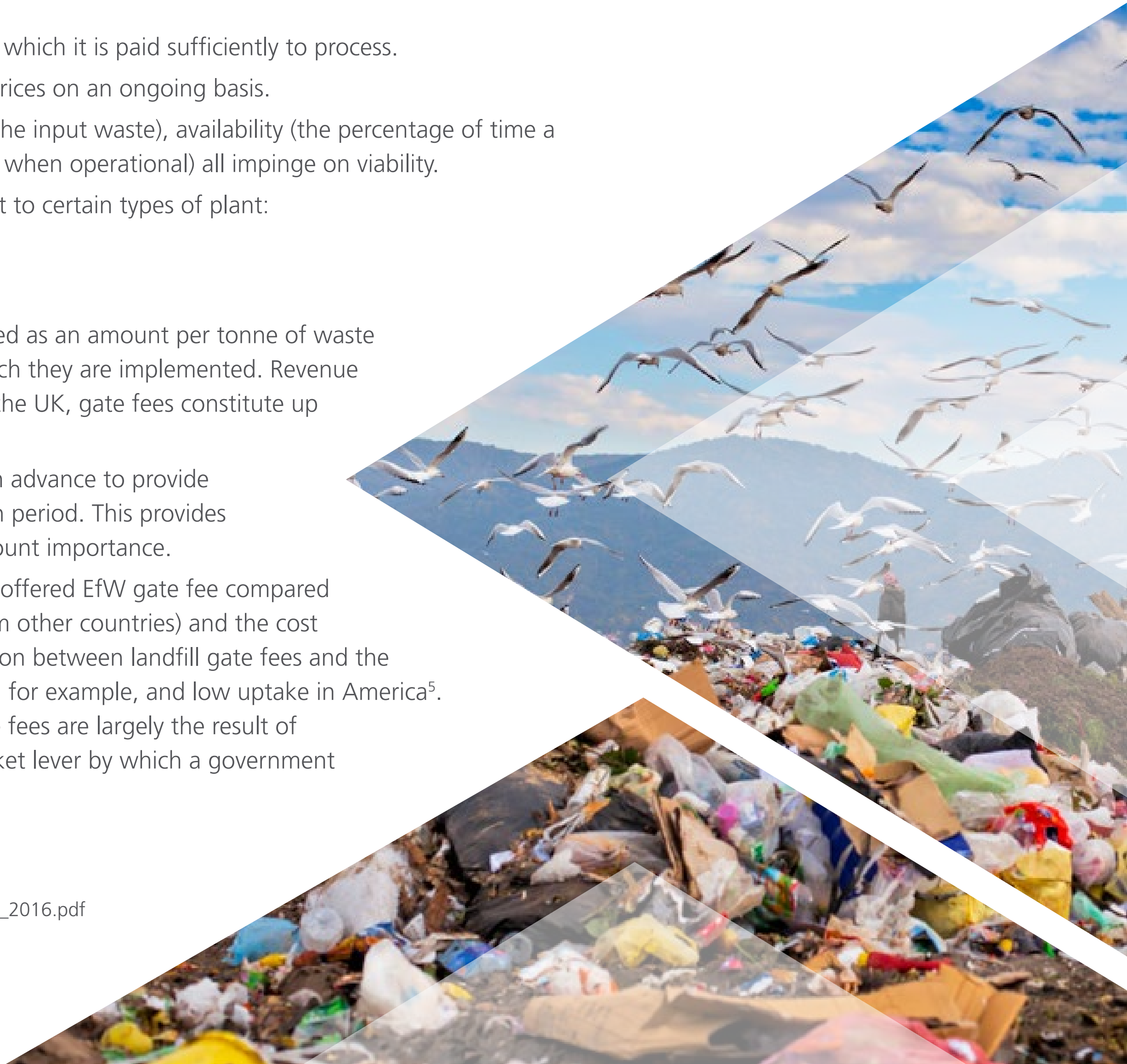
EfW plants earn the following revenues, some of which will be more relevant to certain types of plant:

Gate Fees

EfW plants charge a 'gate fee' to receive and dispose of waste, usually quoted as an amount per tonne of waste processed. Gate fees vary greatly depending on the country or region in which they are implemented. Revenue from gate fees is usually the largest stream of income for an EfW facility; in the UK, gate fees constitute up to 70% of income[7].

Gate fees are usually based on a contract – with a waste supplier agreeing in advance to provide a certain amount of waste of a certain type at a certain gate fee for a certain period. This provides revenue certainty for the plant; the availability of such contracts is of paramount importance.

Securing such contracts in the first place depends on the relative cost of the offered EfW gate fee compared to competitor EfWs (both local and international plants accepting waste from other countries) and the cost of sending waste to landfill. As you might expect, there is a positive correlation between landfill gate fees and the uptake of EfW, as demonstrated by high EfW uptake in the UK and Sweden, for example, and low uptake in America[5]. As landfilling is fundamentally a cheaper process than EfW, high landfill gate fees are largely the result of governments adding landfill tax to this gate fee. Landfill tax is the main market lever by which a government can divert waste from landfill.



7 https://www.worldenergy.org/wp-content/uploads/2017/03/WEResources_Waste_to_Energy_2016.pdf

Selling Electricity

EfW plants also earn revenues by selling the electricity they generate. The electricity price is usually fixed in advance of its generation by contract between the plant and party who agrees to purchase the electricity (Power Purchase Agreement, PPA). This provides revenue certainty for the plant.

The type and energy content of the waste, as well as the efficiency of the plant at converting this energy content to electricity, determine how much electricity can be generated from a given quantity of input. The energy content of the waste can vary greatly depending on its constituents with, for example, organic materials yielding little energy (4 MJ/Kg) and plastics considerably more (35 MJ/Kg)[7].

In some countries, the price the plant receives for electricity is bolstered or stabilised by various government mechanisms. In the UK, for example, Advanced Thermal Treatment plants are eligible for the CfD (Contracts for Difference) scheme. This is a competitive process, with the winning bidders benefiting from a guaranteed and fixed price for the electricity they sell, backed by the UK government. As a well-established technology, standard combustion plants are not eligible for this scheme. Also in the UK, EfW plants can participate in the Capacity Market, a subsidy aiming to ensure the security of the UK's electricity supply, while anaerobic digestion plants can get paid for the electricity they produce via the Feed-in Tarrifs (FiT) scheme.

Another potential source of electricity-related income is the provision of balancing and ancillary services to the grid operator, National Grid in the UK.

Finally, it is worth noting that a small proportion of the electricity generated is used to run the plant itself. This 'parasitic load' varies considerably, with a 2017 UK average value of 13.4%[8].

Selling Heat

For those plants able to export heat to local industry or residences, this provides an additional revenue stream. Supplying both heat and electricity, rather than just electricity, increases the overall efficiency of the plant. However, extracting heat will typically increase costs and reduce the amount of electricity generated. This may only be worth it if there is a guaranteed customer for the heat, contracted in advance.

Government mechanisms exist that subsidise the sale of heat from EfW plants. In the UK, for example, heat generated by certain EfW plants is eligible for the non-domestic Renewable Heat Incentive (RHI). This pays out based on the amount of heat generated.

Depending on the type of EfW, end products other than heat and electricity may generate significant revenues. This area will not be covered in detail in this report.

Other Considerations

As well as having input and output contracts in place as discussed above, before a plant becomes operational, it is necessary to secure planning permission, any other necessary permitting (e.g. environmental), grid (and potentially heat) connection(s) and, of course, design, build and staff the plant. In the UK, most plants are of a size where planning decisions are taken at a local, not national level. The construction of an EfW plant is a lengthy – typically 4-6 years[8] – and costly process. Capital and operational costs vary significantly depending on technology, scale, contract type, business model and input waste type. Availability of funding is most dependent on the revenue certainty that can be provided.

8 http://www.tolvik.com/wp-content/uploads/Tolvik-UK-EfW-Statistics-2017.pdf

Forecasting the EfW Market

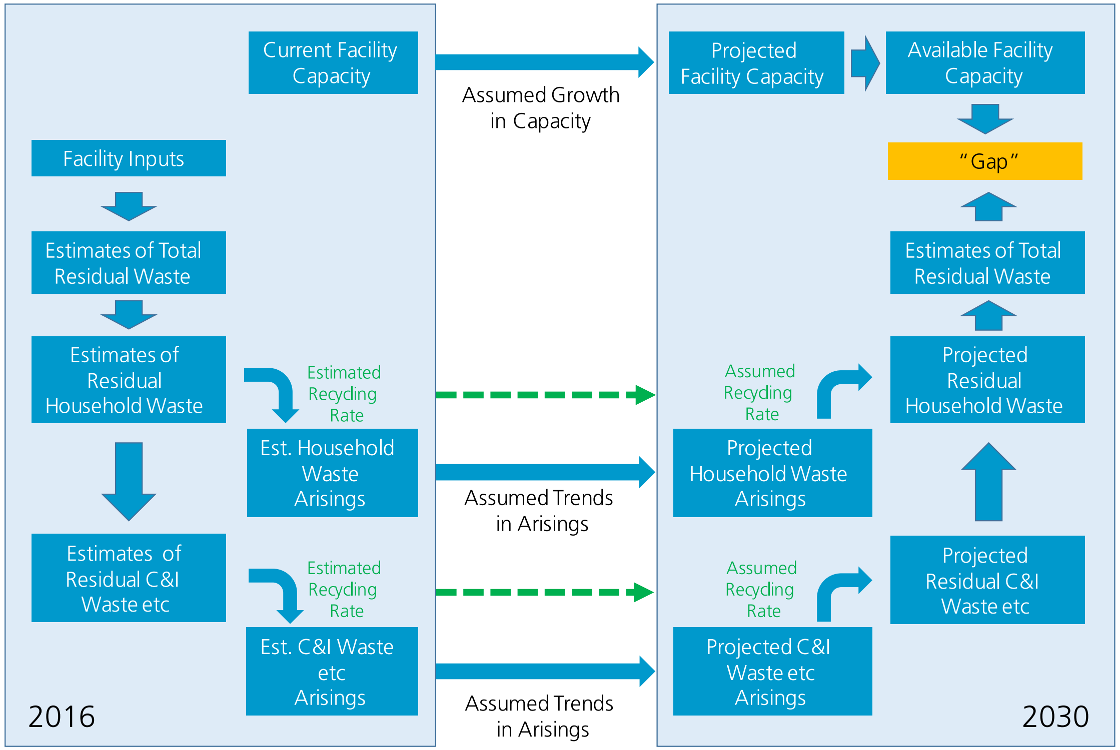
A useful concept when forecasting the EfW market on a national level is the 'capacity gap'. This is the difference between the amount of residual waste generated and the EfW capacity available to process this waste. The assumption is that the capacity should be as big as the waste generated, and that any shortfall represents an opportunity to build more EfW plants. **Figure 3**, below, shows one simplified model used in a review paper by Tolvik Consulting to forecast the capacity gap (in the UK) in 2030, given what we know about it in 2016. Tolvik Consulting are independent waste and bioenergy experts.

In this model, five variables largely determine the capacity gap forecast: how much waste will be generated in the household and C&I (Commercial and Industrial) sectors, how much waste will be recycled in those sectors, and the future EfW capacity, all in 2030.

Each of those variables is determined by a host of other factors. For example, speaking broadly, trends in waste generation rates are influenced by population growth, rate of urbanisation, GDP and public habits, to name a few. Trends in recycling rates are likewise influenced by factors such as government policy, use of materials, public habits, recycling technology and the markets for recycled materials.

Although the notion of a national capacity gap is a useful measure when looking at the entire industry, the prospects for any given EfW plant will be more directly influenced by local factors outlined in the previous section – local competition and pricing, local planning policy etc.

Figure 3 – Tolvik Consulting model for predicting the UK EfW capacity gap in 2030[9]. C&I = Commercial and Industrial.



9 http://www.esauk.org/application/files/6015/3589/6453/UK_Residual_Waste_Capacity_Gap_Analysis.pdf

EfW in the UK

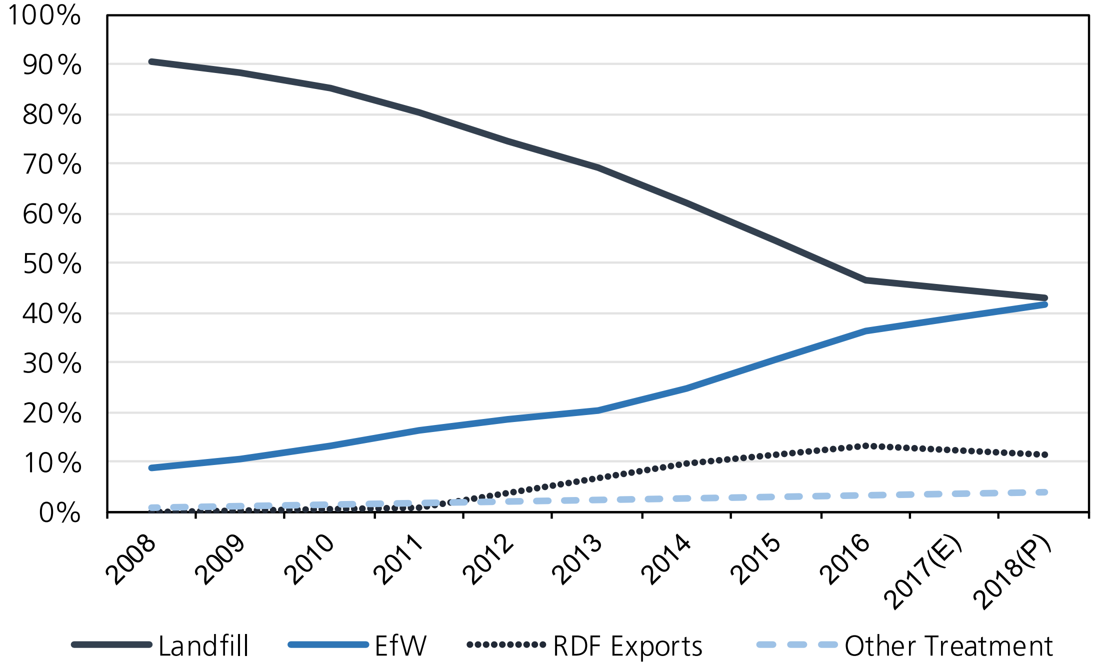
Current Market (based on [8] unless otherwise indicated)

Figure 4a, shown adjacent, shows the historical development of the UK residual waste market. As little as 10 years ago, virtually all waste ended up in landfill. In 2017, however, it is estimated that 39.1% of residual waste was sent to EFWs. In 2018, it is expected that for the first time the tonnage of residual waste sent to EfWs in the UK will exceed the tonnage sent to landfill. A rapid escalation of the landfill tax between 2007 and 2014 was the main driver for this shift.

Currently, there are 42 thermochemical EfW plants in the UK (end of 2017), 8 of which export heat, with 16 under construction. In addition, there are over 640 recorded active small-scale anaerobic digestion plants, processing organic waste (October 2018)[10].

Despite this progress, the UK still sends approximately 12 Mtpa (million tonnes per annum) of residual waste to landfill. Due to landfills closing and a lack of domestic EfWs, we are also exporting large quantities of waste to other EU countries. Current RDF (Refuse Derived Fuel) exports from the UK are estimated at 3.5 Mtpa[11]. This is at a cost to the UK; we are spending approximately £280m a year to export waste for other countries to generate energy for their own benefit[12].

Figure 4a – Development of UK residual waste treatment[8].



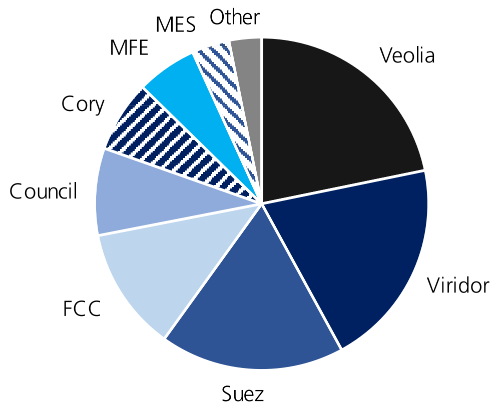
10 https://anaerobic-digestion.com/anaerobic-digestion-plants/anaerobic-digestion-plants-uk/
11 Based on Environment Agency, Reasons for trends in English refuse derived fuel exports since 2010 (2015)
12 Policy Exchange, Going round in circles: Developing a new approach to waste policy following Brexit (2017), p29

Most of the thermochemical EfW plants now operational in the UK were developed with government investment under the Public Private Partnership (PPP) / Public Finance Initiative (PFI) regime. These benefited from long term contracts accepting municipal waste from local councils. The UK waste market is now focussed on 'merchant' projects. These are privately funded projects which utilise private specialist fuel supply such as RDF, C&I waste and waste wood.

Local councils operate a minor fraction of the EfW market, see **Figure 4b**, below, which shows the 2017 market share by input tonnage. The market is dominated by 3 private operators who have a combined market share of ~60%.

Figure 4b – 2017 UK EfW market share of input tonnage[8].

Operator	Input (kt)	Share
Veolia	2,343	21.5%
Viridor	2,180	20.0%
Suez	1,924	17.7%
FCC	1,292	11.9%
Council	911	8.4%
Cory	746	6.9%
MFE	632	5.8%
MES	391	3.6%
Other	465	4.3%
Total	10,883	100%

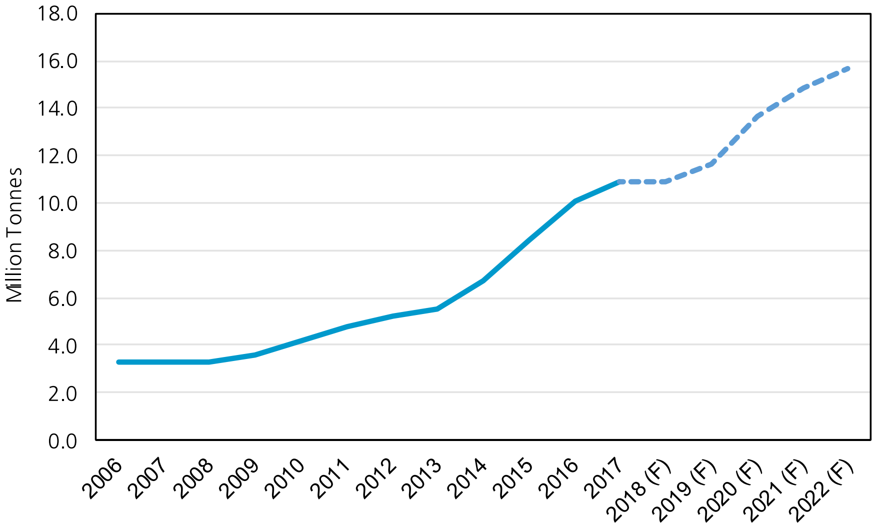


In 2017, median EfW gate fees ranged from £56 to £91/tonne. Generally, EfW gate fees in 2017 were higher than in 2016. This rise reflects the impact of indexation provisions in longer term contracts and the increasing cost of alternatives – both in RDF export (primarily driven by strengthening European EfW markets) and landfill (where in some areas the reduced number of landfills has led to a decline in competition and higher gate fees).

Market Forecast

Figure 5, below, shows a near-term forecast for the size of the UK EfW market in terms of operational capacity, based on known projects under development. This is clearly a growth market.

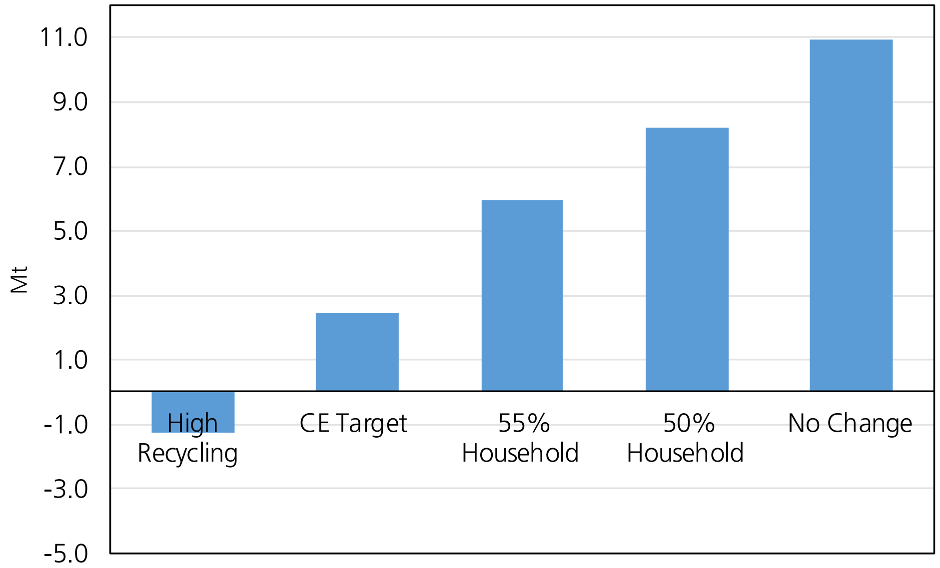
Figure 5 – Projected EfW operational capacity (in Mtpa)[8].



Recent trends suggest that the EfWs most likely to be developed will either be smaller Advanced Thermal Treatment facilities, benefitting either from subsidy support (CfD) or enhanced energy revenues via private electricity/ heat arrangements, or larger scale EfWs based on conventional moving grate technologies, benefiting from economies of scale.[8]

To generate forecasts further out, Tolvik Consulting used the model of **Figure 3** to forecast the capacity gap in 2030, giving the results shown in **Figure 6**. They found that the 2030 capacity gap is highly sensitive to the household recycling rate, but that there is a potential need for additional EfW capacity of up to ~11 Mtpa. These results assume that waste is treated locally, with no RDF exports.[8]

Figure 6 – Projected UK 2030 residual waste capacity gap with different percentage levels of household recycling (excludes RDF exports)[9]



Based on the EU Circular Economy Package, the UK government is targeting 50% municipal recycling by 2020, 60% for 2030 (marked as 'CE Target' on **Figure 6**), and 65% for 2035. The UK has indicated that it will adopt the EU Circular Economy Package in its entirety post Brexit, including these targets. Given that we are unlikely to meet the 2020 target, it seems reasonable to assume that this might also be the case for the later targets. Let's assume that 55% recycling is a realistic estimate. This gives a capacity gap of ~6 Mtpa (equivalent to 24 medium-sized plants of 0.25 Mtpa) and a multi-billion-pound opportunity.

EfW Worldwide

Current Market (based on [2])

Europe may be the largest and most sophisticated market for EfW technologies, but the market is expanding rapidly worldwide. Since the beginning of 2015, over 200 new plants with a treatment capacity of more than 50 Mtpa were commissioned throughout the world. About 70% of these capacities were installed in new construction projects in China; another 10% were implemented in the rest of Asia. Around 20% of the capacities were realised in Europe, mostly in new construction projects in the UK as well as modernisation and expansion projects in other parts of Europe.

There were ~2450 operational thermochemical EfW plants worldwide in late 2017, with a treatment capacity of 330 Mtpa. Most of these facilities are equipped with grate firing technology; only about 20% use fluidised bed combustion. The use of Advanced Thermal Treatment is a minor, but growing, component of the overall market.

Market Forecast (based on [7] unless indicated)

Considering projections for population growth and the increase in urbanisation, the World Bank estimates that global waste generation will nearly double from 2014 to 2025, to over 6 million tonnes of waste per day. In addition, global waste generation rates are not expected to peak by the end of this century. While OECD countries may reach 'peak waste' by 2050, and East Asia and Pacific countries by 2075, waste may continue to grow in Sub-Saharan Africa. By 2100, global waste generation may hit 11 million tonnes per day.

These waste generation statistics, combined with the fact that ~70% of global waste currently ends up in landfill – higher in developing countries, who cannot currently afford EfW – mean that we have barely scratched the surface of the potential EfW market. The growth of the market and future technological advancements will most likely drive the costs down for EfW technologies, potentially making them affordable in developing countries as well. Further research into increasing the energy efficiency of the plants, along with treating outputs for pollutants is expected to benefit market growth.

Set against this background, Ecoprog, a consultancy specialising in the fields of environmental and energy technology, forecast that 60 new EfW plants will be built worldwide every year until 2026, with an average capacity of 17 Mtpa[2].

Meanwhile, the World Energy Council, the UN-accredited global energy body, forecasts that the global EfW market is expected to maintain its steady growth to 2023, growing at a CAGR (Compound Annual Growth Rate) of over 5.5%, when it is estimated it would be worth US$ 40 billion. They predict that biological EfW technologies will experience faster growth at an average of 9.7% per annum. From a regional perspective, the Asia-Pacific region is predicted to continue growing the fastest, driven by increasing waste generation and government initiatives in China and India; and higher technology penetration in Japan.

Closing Quote

To close this report, here is a summarising quote from the World Energy Council (slightly edited for readability):

"The EfW market will continue to develop globally as governments will impose supportive regulation with subsidies and tax benefits. The need to increase the share of renewable energy and reduce greenhouse gas emissions, along with raising environmental consciousness to protect the environment from polluting and unsustainable practices such as landfilling will have a positive impact on market development."[7]

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