1. Introduction

A linear economic model generates mountains of waste. It involves the extraction and processing of virgin raw materials, while products are used and then thrown away. In the past, Europe sent millions of tonnes of paper, cardboard, plastics and textiles
overseas for processing with different variations of quality. At the beginning of 2018, China imposed strict limits on recycling impurities, leaving Europe to clean up its act and improve its capacity to sort and recycle waste, as well as to keep recycling streams clean.

In a shift away from a linear economic model, Europe adopted the Circular Economy Package in 2018. The package introduces new waste management targets. For municipal waste, it sets a 10 % cap for landfilling and a recycling target of 65 % for 2035 (European Union [8]).

While there are some moves towards a more circular model, product design will not be reinvented overnight. To successfully close the loop, we must focus on quality as well as quantity. As Europe seeks to address its waste challenges, Waste-to-Energy (WtE) will continue to provide essential waste treatment where recycling is not appropriate, and offer a source of secondary raw materials and energy for the circular economy.

Waste-to-Energy also contributes to the EU 2030 targets for greenhouse gas emissions reduction (at least 40 % cuts from 1990 levels) and for renewable energy (at least 32 % share) adopted in 2018 (European Union [7]).

This article demonstrates the Waste-to-Energy industry's commitment to waste recovery, clean energy production, as well as its role in reducing environmental pollution.

1.1. Vision on the Waste-to-Energy sector in 2035

As a society, we envisage a well-functioning circular economy in 2035 where quality recycling is steadily increasing and landfilling is limited to a minimum. WtE (incineration with energy recovery) has an essential function in it and is well recognised as an enabler of the circular economy.

The WtE sector has a pivotal role to play in moving towards a resource-efficient, low-carbon, circular economy. WtE is an established and important renewable energy provider for both electricity and heat from residual (not recycled) materials all over Europe.

An integrated waste management system, with WtE, is a cornerstone of the circular economy. We must keep valuable resources out of landfill and treat the waste that cannot be reused or recycled without impacting human health and the environment.

WtE technology and processes will become increasingly resource-efficient. Clean minerals and metals will be recycled from bottom ash. Operators are exploring capturing and using CO₂ from the flue gas where appropriate and sustainable. The industry is pursuing best practices, continuously implementing best available techniques (BAT) and developing innovative technologies to improve efficiency and reduce emissions.

The WtE sector is committed to engaging with neighbouring communities, businesses and industries to help them become less dependent on fossil fuels. Dialogue will be essential in order to learn more about people's needs and to discuss the social and economic benefits WtE can bring to local communities, including skilled and secure jobs.
1.2. Waste-to-Energy today

Many of the products used in our society are not designed to be robust, easily-repaired or upgraded and are often made from mixed materials which cannot be easily recycled. While we should do everything we can to adopt new technologies and policies which minimise waste creation, current production methods and consumption patterns will continue to generate residual waste which is contaminated or too low-quality to recycle.

The success of recycling relies significantly on efficient collection. Even if all waste streams were separately collected 100% cannot be recycled due to the use of some poor-quality materials.

In line with the waste hierarchy, WtE is the most environmentally-sound treatment for recovering value from residual waste. The circular economy needs an outlet for its residual (not recycled) waste. Such low-quality waste is rejected by recycling facilities because it cannot be recycled in a technically, economically or environmentally feasible way (for example, degraded material that has already been recycled several times). By cooperating with partners across the whole value chain, the sector works to prevent this waste from going to landfill.

The environmentally safe and sound thermal treatment of waste (residual waste, sorting residues, rejects etc.), and the implementation of a sustainable waste hierarchy that applies life cycle thinking as set in Article 4 of the EU Waste Framework Directive are essential. The general environmental protection principles should apply, including:

- precaution and sustainability,
- technical feasibility and economic viability,
- protection of resources,
- overall environmental, human health, economic and social impacts.

When prevention, reuse and recycling are not possible, the remaining residual waste (including the rejects from sorting and recycling) should be safely treated.

WtE is designed to thermally treat residues from households, industry or commerce by incinerating it under strictly controlled conditions to generate energy. It helps to ensure the recycling/remanufacturing cycle is not contaminated. WtE acts as a sink for pollutants that must be safely destroyed, such as sanitary waste or infectious waste from hospitals. It guarantees reliable waste treatment, 24 hours per day, all year round, and delivery of base-load energy.

This article sets out how WtE operators support the security of residual waste treatment, development of high-quality, cost-effective recycling routes and how the WtE sector contributes to climate protection and the transition to a circular economy. It also outlines opportunities for the WtE sector to adopt innovative technologies, and offers propositions to help policymakers design more sustainable environment, energy and related policies and oversee their successful implementation.
2. Waste-to-Energy in Europe

2.1. Waste in the EU: where are we heading? Projections for 2035

Currently there are around 500 Waste-to-Energy plants operating across Europe, treating more than 90 million tonnes of waste annually.

The transition towards a circular economy is only just beginning. In 2017, less than half of Europe’s municipal waste was recycled or composted while a quarter of its municipal waste was landfilled – the equivalent of landfilling the volume of Wembley Stadium every week.

In the future, better and more widespread source-separated collection of waste is expected to help reduce mixed waste streams. The new European waste legislation supports this trend. However, taking into account the demographic and economic changes which will impact the amount of waste produced, it is unclear to which extent reduction in waste generation is truly feasible [16]. When we achieve the municipal waste recycling targets set by the 2018 Circular Economy Package, there will still be a need to treat the residual (not recycled) waste in an environmentally sound way.

Furthermore, municipal waste is only a small part of the whole waste volume (around 10 %). In industrialised countries around 50 % of the waste treated by WtE comes from commercial and industrial waste, for which there are currently no targets set.

The Confederation of European Waste-to-Energy plants (CEWEP) assessed the capacity needs in Europe, in 2035, assuming that the 65 % recycling target of municipal waste would be achieved and even more ambitiously 68 % of non-hazardous commercial and industrial (C&I) waste would be recycled. With this in mind, it was calculated that around 142 million tonnes of residual waste treatment capacity would be needed by 2035 (the calculations were peer-reviewed by Prognos, 2019) [2].

Current WtE capacity is about 90 million tonnes and the capacity for co-incineration (e.g. in cement kilns) is around 11 million tonnes. This leaves a gap of approximately 40 million tonnes which must be closed if ambitious recycling and landfill reduction targets are to be achieved. A debate is needed on how to bridge this gap in Europe in order to avoid unsustainable routes for these waste streams, such as dumping or open fires.

WtE capacity will be needed to help fill this gap, which will be the most obvious in Southern and Eastern Europe, and maintain high-quality recycling streams. Should the gap be filled with WtE by 2035, it is estimated that WtE plants could contribute to the sustainable energy market by supplying heat to 22 million people and electricity to almost 28 million people. 115 million tonnes of CO₂ eq emissions could be saved by treating this waste in WtE plants. This is more than the total annual CO₂ eq emissions from fossil fuels in Belgium.
2.2. Sustainability and Waste-to-Energy

2.2.1. Reducing landfilling and supporting quality recycling

Almost half of EU Member States are still heavily reliant on landfilling (Figure 1). Valuable resources are being buried with the risk of contaminating soil and groundwater. Decomposing waste in landfills also generates methane – a greenhouse gas 28 times more potent than CO₂ [13].

During 2001 to 2017 (Figure 2), landfill rates in the EU-28 fell sharply while recycling rates rose considerably. WtE treatment rates also increased, but less than recycling. This demonstrates that WtE and recycling work well together to reduce landfilling.

Furthermore, with increasing recycling rates, WtE will be needed to treat the rejects from recycling and sorting facilities as well as the residual waste remaining after source separation. This is the case for municipal waste as well as commercial and industrial waste. According to Eurostat there are, based on all waste volumes, more than 91 million tonnes of sorting residues generated every year in EU-28 [10].

Residual (not recycled) waste should be treated near to where it arises. In cases where the local treatment capacity is not sufficient to divert it from landfills, it is more environmentally sound to temporarily send it to efficient WtE plants that have spare capacity elsewhere. Life cycle criteria are important and should be considered.
2.2.2. Producing renewable energy locally and paving the way to decarbonisation

Currently, EU28 WtE plants produce enough electricity to supply almost 18 million people per year. WtE can provide a local source of baseload power that complements intermittent renewable energy sources such as wind or solar while at the same time makes Europe less dependent on fossil fuel imports.

Most WtE plants are combined heat and power (CHP) plants which provide heat to urban district heating networks, as well as electricity. Today, WtE in EU28 is able to provide around 15 million people with heat annually. Future developments will further replace traditional fossil fuels which are used for heating or cooling.

Energy produced from waste is partially renewable. This is due to the biodegradable (organic) content in the waste (the exact amount depends on the waste input which is determined by consumer behaviour, local waste management systems, etc.). Despite growing source separation of biowaste there is still a biodegradable fraction in the residual waste that is too contaminated for composting or other recycling, such as greasy paper (e.g. from fries) or sanitary materials.

2.2.3. Providing recycled materials

Bottom ash is collected from the bottom of the furnace of WtE plants after waste has been thermally treated in the plant. This ash is a source of ferrous and non-ferrous metals which can only be recovered and recycled after incineration due to the nature of the waste. As an example, the amount of iron recovered from European bottom ash each year could be used to build 6,000 wind turbines.

More than 3 million tonnes of CO₂ equivalent emissions are saved by recovering metals from bottom ash each year (2,000 kg of CO₂-equivalent are saved for each tonne of metal recycled from bottom ash [5]).
After the metals are removed, the remaining mineral share of the bottom ash can be used as secondary raw materials in road construction or as a covering layer on landfill sites. This could help to address concerns raised by the United Nations Environment Programme [14] about the high volume of virgin sand and gravel being extracted from the natural environment [15].

Recycled metals from WtE bottom ash are included in the EU recycling targets (European Union [8], Article 11a (6)) yet recovered minerals are not, despite offering an alternative to virgin resources. The WtE sector is working with policymakers in order to have recovered minerals treated in the same way as metals.

2.2.4. Emissions are low, strictly regulated and transparent

The environmental standards for WtE plants have evolved significantly over the decades. State-of-the-art pollution control technologies and procedures ensure that emissions from WtE plants meet very strict requirements, set within the EU law. The industry uses flue gas cleaning systems to remove particulate matter (PM), acids and other gases, organic compounds, heavy metals and numerous other substances which come from treated waste.

WtE is one of the most strictly regulated industrial sectors. Multiple studies [4,11,12] undertaken have found no evidence of WtE’s impact on health or environment. Only a very small fraction of air emissions in Europe comes from it. Data collected by the European Pollutant Release and Transfer Register for example shows that dioxin emissions from WtE (considered as a marker for incineration of waste in the past) account for less than 0.2 % of the total industrial dioxin emissions, not considering road transport. WtE’s contribution would be even more negligible if transport was taken into account.

The technical basis for WtE permits in Europe is set by the Best Available Techniques (BAT) included in the Waste Incineration BAT Reference document (BREF), which was most recently revised in 2019. The continuous review of this technical document (every 8 years) ensures that WtE plants achieve the lowest emission levels using the latest pollution abatement techniques and procedures.

3. Innovation showcase

These examples demonstrate how WtE plant operators are contributing to the United Nations Sustainable Development Goals (SDGs) through innovation and leadership.

Figure 3: Sustainable Development Goals to which WtE plants contribute

Source: Eurostat; Municipal waste by waste operations (env_wasmun), 2017 data, 2019
3.1. Government and industry partnership on bottom ash recovery

European WtE plants produce approximately 20 million tonnes of bottom ash annually, which is the incombustible part of treated waste.

In 2012, the Dutch Ministry of Infrastructure and Environment signed a Green Deal on bottom ash with the industry, represented by the Dutch Waste Management Association. The agreement aims to have 100% of the raw materials, recovered from bottom ash, put to high-grade use by 2020.

The Dutch Green Deal has attracted interest from around Europe as a good example of cooperation between the government and the WtE industry in achieving circular economy goals. It has provided impetus for the Dutch WtE sector to invest in innovative technologies to improve bottom ash quality so that it can be used without additional precautionary and aftercare measures. By classifying processed bottom ash as having the same quality as primary construction materials, the ash can now substitute virgin raw materials like sand or gravel.

In 2017, the first batch of paving stones made using clean bottom ash from the Twence WtE plant were produced, destined for use in a sustainable building complex in Hengelo.

3.2. Industrial symbiosis delivers renewable heat

In the Port of Antwerp, WtE facilities process one million tonnes of waste yearly, converting the waste into energy and materials. They supply electricity to 170,000 households, but until recently only some of the excess heat was used.

Until 2019 the chemical industries in the Port of Antwerp were using fossil fuels, particularly gas, in their processes. The individual gas-fired boilers were responsible for thousands of tonnes of CO₂ emissions. ECLUSE is a collaborative project to deliver steam from local WtE plants to six industrial companies through a high-pressure pipeline. The project which came online in 2019 replaces fossil-based energy by supplying steam, improving the efficiency of the WtE plants and ensuring a cost-effective and long-term energy supply for neighbouring industries.

ECLUSE supplies at least 5% of the renewable heat produced in the Flanders region, ensuring CO₂ savings of at least 100,000 tonnes each year, similar to the CO₂ savings from 50 standard 2.3 MW wind turbines.

3.3. Cleaner air for Wuppertal in Germany

Wuppertal Stadtwerke put ten new fuel cell-powered buses on the road in 2019. The vehicles use emission-free hydrogen gas produced locally, using electrolyzers powered by the AWG Waste-to-Energy plant in Wuppertal. The hydrogen filling station is located near the plant.

This is an important first step towards diesel-free public transportation and electromobility.
This is not the first time AWG has strived for better air quality and greater energy efficiency. In 2018, the district heating network in Wuppertal was connected to the WtE plant. At the same time, a coal-fired power plant in the Wuppertal valley was shut down. The combined effect was a considerable reduction in CO₂ emissions and other pollutants.

4. Conclusions and policy recommendations

In order to achieve the ambitions outlined in this article, changes will be required in policy.

4.1. Recognise Waste-to-Energy as an essential part of a circular economy and apply the waste hierarchy based on life cycle thinking

Waste management systems must take life cycle thinking into consideration and aim for the best overall environmental outcome when applying the waste hierarchy. Diverting waste from landfills is an essential step in moving waste treatment up the waste hierarchy. In 2017, about 58 million tonnes of municipal waste were still landfilled in Europe, rising to almost 200 million tonnes if other waste streams are considered.

Future EU waste legislation also needs to set targets for landfill diversion and recycling for commercial and industrial waste. Quality recycling is key. The European Commission’s Communication on the Interface Between Chemical, Product and Waste Legislation [6] emphasises the importance of recycled material quality.

Further policy developments must recognise WtE’s key role for treating waste that is contaminated with substances which are not fit for recycling. At the same time, metals and minerals from WtE bottom ash can be recycled to substitute primary resources.

4.2. Count minerals recycled from the bottom ash in recycling targets, as well as metals

The new Waste Framework Directive allows Member States to count metals recycled from bottom ash towards achieving their recycling targets, which encourages the WtE sector to further improve its metal recycling efforts.

However, the mineral fraction of the bottom ash is not yet explicitly recognised in the Waste Framework Directive. While public-private-partnerships like the Dutch Green Deal on bottom ash are a stepping stone towards the use of the processed mineral fraction of bottom ash, there is a lack of EU-level incentives to allow the materials from bottom ash to re-enter the material loop.
4.3. Recognise Waste-to-Energy’s contribution to climate protection as a holistic approach which avoids landfills and replaces fossil fuels

In addition to avoiding greenhouse gas emissions from landfills, WtE helps achieve policy objectives by replacing fossil fuels in conventional power plants with renewable energy generated from partially biodegradable residual waste. This enables WtE plants to contribute to the EU’s renewable energy target of 32 % under the EU 2030 Climate and Energy Framework.

WtE plants could produce 190 TWh of energy by 2035, enough to supply more than 50 million people with heat and electricity and to replace 10 % of the energy supplied by the coal sector today.

In many European cities WtE contributes significantly to district heating networks (about 90 TWh per year). There is a major opportunity for further improvement by linking more heat (or process steam) customers to WtE plants. The Heat Road Map Europe 2050 suggests that the potential is 200 TWh per year by 2050 for heat alone [1].

While the Efficiency Criterion (the R1 formula) introduced in the 2008 EU Waste Framework Directive has incentivised WtE investments in efficiency, further policy changes are needed to improve infrastructure for district heating and cooling as well as promote the efficient integration of WtE plants into local heat and power grids.

5. Literature

[10] Eurostat; Generation of waste by waste category, hazardousness and NACE Rev. 2 activity (env_wasgen), 2016 data, 2019


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Several plants in Germany have been provided with this technology. Figure 8 shows a plant, realised with a dry hydrator for a Ca(OH)₂ production capacity of approximately 3 t/h.

As alternative there is the possibility to install the dry hydrator close to the additive can now be injected directly into the reactor without temporary storage in a silo. Figure 9 shows such a dry hydrator as well as the corresponding WtE plant.