11 Reasons why Carbon Capture Should be Prioritized in the Waste to Energy Sector

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The concentration of CO_2 and other greenhouse gasses in the atmosphere have been rising steadily over the last decades. These rising gas concentrations are leading to climate change. With the rising Greenhouse Gas (GHG) emissions, the urgency to act has only increased. In the past, the Intergovernmental Panel on Climate Change (IPCC) believed that climate targets could be met through a various set of mitigating measures like efficiency gains and increasing the share of renewable energy. Implementing these measures were urgent and carbon removal from the atmosphere was regarded as optional. However, IPCC's sixth assessment report changed its tone to one of urgency; carbon removal from the atmosphere is not regarded as optional anymore but as a requirement if we are to meet climate targets (Figure 1) [21]. Within the headline statements of the report, the following is stated with regards to Carbon Dioxide Removal (CDR):

The deployment of CDR to counterbalance hard-to-abate residual emissions is unavoidable if net zero CO_2 or GHG emissions are to be achieved.

CDR processes remove CO_2 from the air and sequestrate it permanently, resulting in a net reduction in the atmospheric CO_2 concentration. CDR solutions can be classified in two types: (1) Nature-based solutions (2) Man-made solutions. The most obvious nature-based solutions are trees. Limited man-made solutions exist, among others these include Direct Air Capture (DAC) and Bio-Energy Carbon Capture & Storage (BECCS). In DAC, CO_2 is captured from the ambient air and sequestered permanently. In BECCS, biomass is burned for energy recovery and the CO_2 emissions are captured and thereafter sequestered permanently.

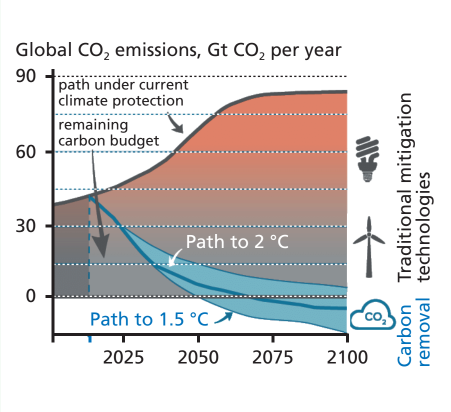

Figure 1: Showing the crucial role of carbon removal to keep global warming below 1.5 °C [21]

Due to the biomass present in Municipal Solid Waste (MSW), Waste to Energy (WtE) combined with Carbon Capture and Storage (CCS) falls under the category of BECCS and can generate negative emissions, as explained further [20]. Consequently WtE + CCS is uniquely positioned to contribute to limiting climate change [20].

Carbon capture, the next step for Europe's sustainable waste management

Europe's waste management GHG emissions have been reduced with 42 % between 1997 and 2017 [14]. This reduction is mainly realized by redirecting waste from landfills to other treatment options higher in the waste hierarchy – Including waste incineration which has doubled in this period [14]. This reduction is generated even with rising amounts of waste generated in Europe [15]. This is a major accomplishment showing that sustainable waste management makes a difference. In terms of environmental legislation and policy, Europe is a leading example for the world. And, in fact, many non-European countries are basing their environmental legislation on Europe's. (European) Industrial players who have made this transition to sustainable waste management possible are also benefitting from exporting Europe's legislative environmental framework.

A next step for Europe's legislators is to support the removal of CO_2 from the air. This is also reflected in the European Commission's communication on Sustainable Carbon Cycles. The communication highlights the need to remove carbon from the atmosphere and the ambition of Europe to become carbon neutral by 2050 and to achieve negative emissions thereafter [13]. The European direction is set and aims to put Europe and its industrial players at the front of this development.

Waste to energy combined with Carbon Capture Utilization and Storage (CCUS) can play a crucial role to meet Europe's ambitious climate goals. The continuation of this manuscript dives deeper into 11 reasons why carbon capture should be prioritized in the waste to energy sector.

1. The low hanging fruit – methane

It is estimated that about 3 % of global greenhouse gas emissions are linked to post-consumer waste and wastewater [3]. Methane emissions from landfill and wastewater are collectively responsible for 90 % of the waste sector's GHG emissions. In fact, 18 % of global anthropogenic methane emissions originate from the waste sector [3]. Methane is produced in landfills due to decomposition of the organic waste fraction. Methane's impact is so significant due to its high Global Warming Potential (GWP), being between 84 and 28 times higher than CO_2 over a 20 and 100 years period, respectively [6].

The Confederation of European Waste to Energy Plants (CEWEP) reported that an emission factor of 600 kg CO_{2Eq} per ton waste treated can be considered for landfills as a European average [5]. Here the GWP of methane on a 100 year timeframe is considered and that European landfills have on average a 53 % methane recovery [5]. While for WtE the emission factor is calculated to be -20 kg $CO2_{Eq}$ per ton waste treated, taking into account energy substitution and bottom ash material recovery [5]. It is important to note this is the case for Europe. And that typically in less developed countries the percentage of organics in the waste will be higher in comparison to Europe, resulting in more methane emissions per ton of waste [18].

A study done by Wang et al. on different types of landfills showed that for venting landfills the emission factors can go up to 5,000 kg CO_{2Eq} per ton waste treated in a 20 year time period[1] [26]. It must be noted that landfill simulations are complex and that the outcome varies depending on the considered assumptions and type of landfill considered.

Although it is very hard to pinpoint an exact number on landfill emission factors, based on the above the emission factor per ton waste treated in a WtE.

With two billion tons of waste generated each year, 70 % of that waste is still landfilled and only a fraction of the global landfilling is currently done through sanitary or controlled landfilling (Figure 2), it goes without doubt that the current climate impact of landfilling is enormous [18]. Due to its short atmospheric lifetime and its high GWP, a methane emission reduction can lead to quick results in slowing down climate change. Here lies a gigantic opportunity and urgency for the waste sector to reduce its climate impact by diverting waste from landfills to WtE and recycling.

[1] Nearly all methane gas is released in the first 20 years after the waste is dumped.

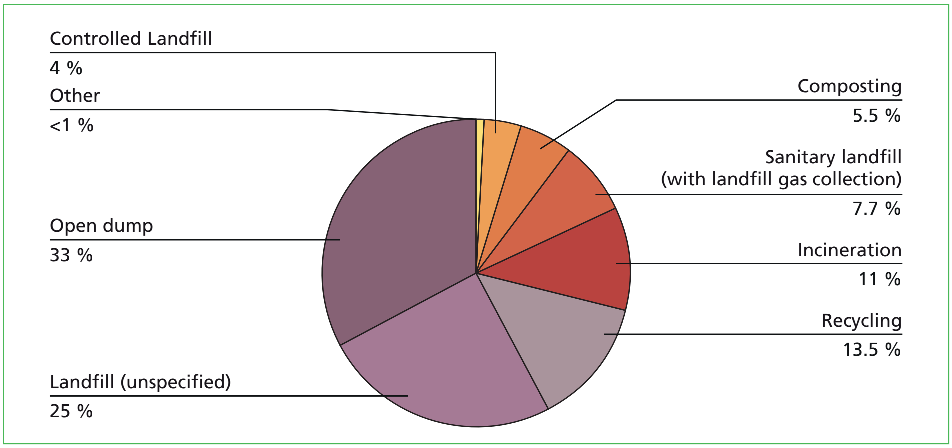

Figure 2: Distribution of global waste treatment and disposal, figure modified from [18]

Treating non-recyclable waste through WtE can drastically bring down the emission factor in comparison to landfill but for WtE the story does not stop there. The emission factor of WtE can even become negative by implementing CCS which is discussed in the next section.

2. Negative emissions

Although WtE is preferable to landfill considering the CO_2 equivalent impact, the WtE process produces considerable volumes of CO_2. Typically, as a rule of thumb one ton of MSW incinerated in a WtE facility will result in the formation of one ton of CO_2 emissions[2].

These CO_2 emissions can be divided in two types: (1) Non-biogenic CO_2 emissions (typically 40 %) and (2) Biogenic CO_2 emissions (typically 60 %) as shown in Figure 3 [16]. Non-biogenic CO_2 emissions come from fossil-related waste such as non-recyclable plastics. As this CO_2 is derived from fossil fuels, its release will result in a net positive emission of CO_2 in the atmosphere when incinerated. In contrast, biogenic CO_2 is CO_2 that was originally present in the atmosphere and is for example taken up by trees and enters the WtE installation through waste such as non-recyclable- or post recycling paper. When this paper is incinerated, biogenic CO_2 is emitted to the air. This CO_2 is considered carbon neutral and will consequently have a net zero contribution.

In case a WtE facility is combined with a CCS facility, this biogenic CO_2 can be captured and stored permanently within secure geological formations under the ground. This means that the captured and stored biogenic CO_2 becomes carbon negative instead of carbon neutral, resulting in net negative emissions. If the fossil CO_2 is sequestered, then the fossil CO_2 component is returned to where fossil fuels were previously extracted, effectively closing the loop and resulting in a net zero emission.

[2] The UK environment agency mentions a range between 0.7 and 1.7 kg CO_2 per kg of MSW combusted [28[.

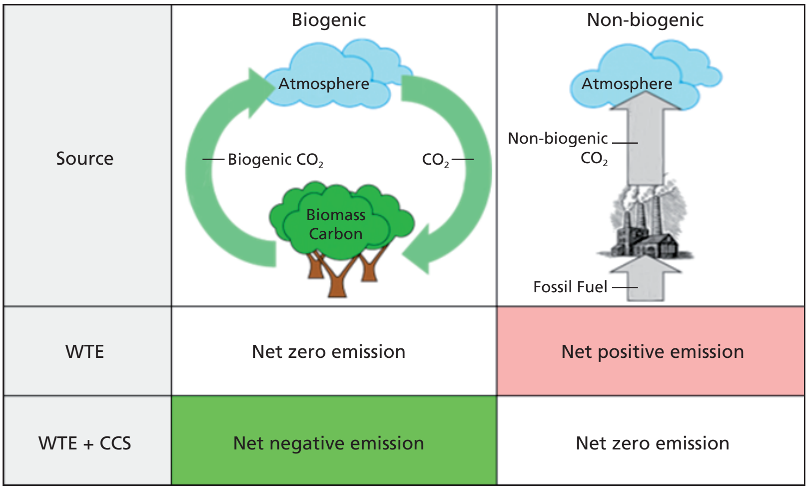

Figure 3: Overview of types of CO_2 present in a WtE's fuel and their net contribution to atmospheric CO_2 concentrations in case of a WtE and a WtE + CCS scenario.

A study done by Cabinet Merlin and ENVEA on 11 French WtE installations showed that the distribution of biogenic-fossil CO_2 emissions is typically 60 to 40 % [16]. Considering this distribution and a 90 % capture efficiency the CCS institute calculated that for a 1,000 tpd WtE installation 500 tpd net negative emissions could be generated as shown in Figure 4 [19].

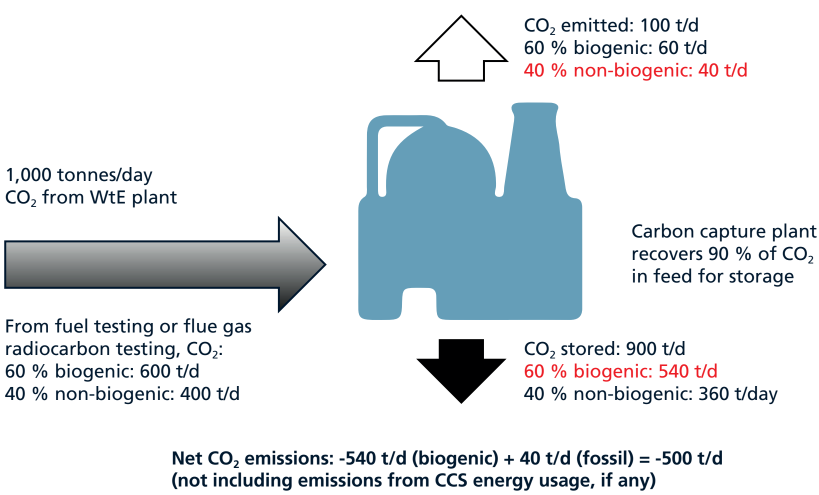

Figure 4: Calculation of negative emissions from a WtE plant combined with a CC plant, figure from [19]

Capturing and sequestering biogenic CO_2 therefore decreases the concentration of CO_2 in the atmosphere. These negative emissions enable WtE processes to offset the emissions of other more challenging CO_2 emitters. A way to offset these emissions is to buy negative emissions, which have a value up to 200 EUR per ton negative CO_2 emission on the voluntary market [10].

3. Proven technical viability

Another important reason to implement CC in WtE is that it is proven to work. Some first of a kind examples are:

- AVR in Duiven (The Netherlands), who have proved since Q3 2019 that capturing a 100,000 tons per year CO_2 from a WtE plant works [4];
- Twence in Hengelo (The Netherlands), that had a CC demonstration unit running smoothly since 2014 with flue gases from their WtE plant and is now building a new 100,000 tons per year plant scheduled to be operational in Q4 2023 [2];
- Fortum Oslo Varme (Norway), that after a long feasibility study and extended pilot tests, is building a 400,000 tons per year plant in their WtE plant, which should be operational in 2026 [23].

Today, there are also multitude feasibility studies ongoing all around the world to implement CC in the WtE sector.

4. Stable and reliable operation

A good reason to choose WtE to implement CC is that it is a continuous process: running twenty-four hours a day, seven days a week, with a high availability. A PREWIN survey (PREWIN stands for Performance, Reliability and Emissions Reduction in Waste Incinerators) of 2019 with data from 237 European WtE lines showed that the average WtE availability is 90 % [26]. For new plants the availability is typically more than 8,000 hours per year (considering both planned and unplanned shutdowns). This is very useful and far easier to manage for the CO_2 offtake whether the CO_2 is to be sequestered or utilised. A continuous process is always easier to manage than a batch process.

In addition, WtE facilities can consist out of multiple incineration lines which are shutdown consecutively for maintenance. This means that the CC facility can still capture CO_2 of the operating lines, resulting in an even higher availability of the CC facility. The typical availability of a CC facility is in the order of 8,400 hours per year.

5. Long-term assets

Keppel Seghers considers that WtE plants are essential in the medium to long term for the treatment of non-recyclable, residual MSW. These facilities are typically backed up by long term Waste Supply Agreements and Power Purchase Agreements and are local per definition. They are normally close to the waste source, and close to the energy offtake. In comparison to other energy intensive sectors such as glass. Such sectors can face risks such as *off-shoring* where the industry is relocated to other geographies with much lower energy- or labour costs for example.

WtE plants are long-term assets so the risk of stranded assets is mitigated when considering investing in CC combined with WtE. In France for example, there are 127 WtE plants with an average age of 27 years [9]. Some examples Keppel Seghers have built include the ISVAG WtE plant in Antwerp Belgium (1989) which is still running smoothly with an availability of more than 92 %.

6. Ready to be deployed

One of the conclusions of the National Academies of Sciences, Engineering and Medicine's publication on negative emissions technologies and reliable sequestrations was that there are four CDR technologies ready for large scale deployment [22]. One of these four is BECCS. Looking at WtE + CCS in particular, 2,500 WtE installations are in operation with a total treatment capacity of 420 millions tpy [9]. Considering a capture efficiency of 90 % this results in 378 millions tons of CO_2 captured per year instead of being released[3] and in 210 million tons of negative CO_2 emissions. Off course not every WtE will be able to be equipped with CC – and this will not happen overnight – but it shows that the potential for WtE is significant.

7. Scale range

The scale of WtE facilities can vary between a few ten thousands ton to more than a million tons of yearly CO_2 emissions. Different CC technologies are still being developed and tested at different scales. Due to its scale range, the WtE sector can be a very interesting sector to scale up and test new technologies.

8. Integration and synergies

An eighth reason to implement CC in WtE first is the number of synergies between the two processes.

A carbon capture process requires a significant amount of steam and cooling and it also requires other utilities like power, water, air, ... A WtE produces steam and has cooling capacity available. The steam of the WtE plant can be used for the reboiler and reclaimer of the CC plant. As the steam is not send to the condenser, spare cooling capacity becomes available. Synergies between the two processes save CAPEX, OPEX and space, and ultimately decrease the total cost of capturing CO_2 (vs a standalone plant). Other potential synergies include combining the flue gas cleaning systems.

[3] Assuming that 1 ton of waste incinerated leads to 1 ton of CO_2 emissions. 378 million tons of CO_2 is both fossil and biogenic CO_2.

The extent of integration will influence the total cost of carbon capture. The better and more optimized the integration, the lower the overall cost.

A part of the captured CO_2 can be used to make carbonated bricks or building aggregates from incineration ashes or the CO_2 can be used for the production of bicarbonate applied in flue gas cleaning [8, 23].

9. Cost competitiveness

Another reason to integrate CC in WtE first is the cost competitiveness. Compared to the implementation of carbon capture in other industrial sectors, the cost in the WtE sector is competitive according to a recent Eunomia report [7] (Table 1).

It must be noted that the cost are depending on among others the synergy between the CC process with the WtE process, the choice of the CC technology, the choice of solvent, the distance from the CO_2 source to the storage or utilisation site and the cost of storing or utilising CO_2.

As pointed out earlier WtE combined with CCS is uniquely positioned to do CDR and generate negative CO_2 emissions. In comparison to DAC, WtE combined with CCS is expected to be a much cheaper solution and currently deployable at a larger scale. In case of DAC, the current cost per captured ton of CO_2 is estimated to be between 250 and 600 EUR per ton, a multitude of the cost for capturing CO_2 from WtE [28[.

Table 1: Cost of CCUS per industry, data from [7]

Sector	Estimated GBP/t CO_2
Waste to energy	66 – 110
Iron production and other metal processing	80
Cement and lime	80 – 140
Other non-metallic minerals	140
Glass	140
Refining and chemicals	140 – 200

10. Renewable energy

Reducing the CO_2 concentration in the atmosphere is crucial for limiting climate change. As the carbon capture process is very energy intensive it is best to avoid as much as possible the utilization of fossil energy for the capturing process. This is also the reason why DAC typically only make sense when (an abundance of) renewable energy is used.

A WtE produces - partly renewable- energy which can be used in the capture process. Making it more sustainable than compared to other industrial sectors. A study of Cabinet Merlin showed that 58 % of the energy of WtE is considered as renewable energy [16].

11. New business model for Waste to Energy

Finally, new financial incentives for developing CC in WtE are present or are being developed.

In the actual economic model for a WtE project. The plant is financed by the gate fee charged to the municipality, by the sale of energy, and the sale of recyclables from the process.

When CC is integrated in the WtE sector, even if there is a reduction of the revenue from energy sale (because of the consumption of a part of the energy from the WtE by the CC plant) there are new sources of revenue possible (Figure 5):

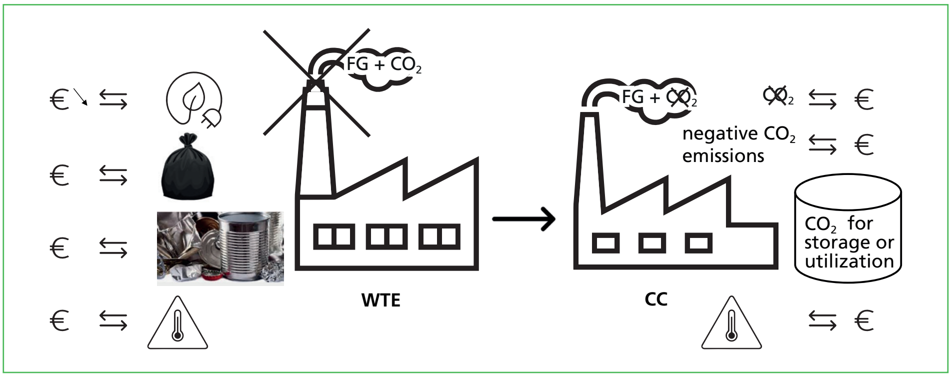

Figure 5: New economic model of a WtE plant combined with CC

- From the capture of fossil CO_2 through a tax levy [1], and/or emission allowances. Fossil CO_2 emissions of WtE fall under a tax scheme in the Netherlands. In Sweden and Denmark, waste incineration is already part of the European Trade System (ETS). In the future waste incineration might be fall under the ETS on a EU level [12]. The value of CO_2 under the ETS currently sits around 85 EUR/ton at the time of writing while the cost of capturing CO_2 is continuously decreasing.
- The negative emissions of a WtE + CCS allow to offset the emissions of other more challenging CO_2 emitters. Today such negative emissions have a value on the voluntary market. This price can range up to 200 EUR per ton negative CO_2 emission [10].
- From the sale of residual heat in a district heating or district cooling network. This is a good way to recover heat from the CC plant.

12. Conclusions

Methane gas emissions are responsible for the majority of the GHG footprint of the waste sector. Treating non-recyclable waste through WtE can drastically bring down the emission factor in comparison to landfill. Despite emissions reduction, the removal of carbon from the atmosphere becomes unavoidable to limit climate change. WtE + CCS is uniquely positioned to contribute to fighting climate change due to its production of negative emissions.

This article aims to provide an overview of different reasons why it makes sense to deploy CC in the waste to energy sector. Nevertheless, the authors would like to highlight that carbon capture in the waste to energy sector can only fully contribute to decarbonisation efforts when a supportive legislative framework is present which covers the complete waste management sector [11].

What do we do at Keppel Seghers with Carbon Capture.

- At the origin, Keppel Seghers is a world class technology provider in the Waste to Energy sector. For 45 years, we have built more than 100 Waste to Energy plants in more than 25 countries. We see Carbon Capture as the new normal in Waste to Energy, we are actively working on it for 3 years now.
- We have achieved the Feasibility Study for the integration of a Carbon Capture plant in the Runcorn Waste to Energy for the capture of around 1 million ton CO_2 per year with four different technologies compared. We are engaged in a feasibility study in Singapore to decarbonise multiple WtE installations. We are in confidential dialogue with Carbon Capture suppliers with different technologies to find the best match between Carbon Capture and Waste to Energy. We are also discussing the implementation of different pilot plant projects. And we are chairing the *Carbon Capture, Utilisation and Storage* working group in our Industry Association ESWET (European Suppliers of Waste to Energy technology).

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