HIGH LEVEL ANALYSIS OF CO_2 CAPTURE IN THE WASTE-TO-ENERGY SECTOR

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Abstract

There is currently a large amount of interest from the Waste-to-Energy (WtE) sector in Europe towards implementation of post-combustion carbon capture technology. This study gives a high level analysis of the implementation of a CO_2 capture plant (no post-treatment of the captured CO_2 is considered) for three generic WtE plants that process 60, 200 and 500 kton of waste per year respectively. The heat and electricity demand of the plants are analysed and compared to the energy generation of the reference WtE plant. It is shown that regardless of the size of the plant, approximately 53% of the steam for district heating and 5% of the electricity generation of the reference WtE plant is needed to run the CO_2 capture plant. Additionally, a techno-economic analysis has been conducted that shows that the expected costs for a CO_2 capture plant are 30 to 55 €/ton CO_2 captured, depending on the considered scale. Additionally, it is shown that for smaller WtE plants, CAPEX is the dominant factor, while for larger WtE plants, the variable OPEX is dominating.

Keywords: *CO_2 capture, Waste-to-Energy, process modelling, TEA*

1. CO_2 capture in the Waste-to-energy sector

Waste incineration is used as a means to reduce the volume of non-recyclable waste and capturing or destroying of hazardous substances, as compared to landfilling of waste. Additionally, incineration enables the recovery of the energy released by the oxidation of the organic waste and high pressure steam is generated, which is often used in a combined heat and power (CHP) system. Often, the generated electricity is transferred to the grid, and the heat is used for district heating. The gross efficiency (useable energy versus total energy input) of the CHP system is much higher than systems with electricity generation only.

Waste-to-Energy (WtE) plants are generally one or two orders of magnitude smaller than full-scale power plants. The average WtE plant in Europe has an incineration capacity of ca. 200 kton/year [1]. In 2019, AVR (Duiven, The Netherlands) has commissioned the first commercial full-scale CO_2 capture plant in the WtE sector. The captured CO_2 is liquefied and transported for direct use in the horticulture sector. The capture plant of AVR is shown in Figure 1.

The main advantages of implementing CO_2 capture in the WtE sector is that a large part of the waste (ca. 50%) is biogenic of nature, and thereby, the same percentage of CO_2 has a biogenic origin. Negative emissions can be achieved when capturing and storing the majority of the CO_2 in the flue gas. Additionally, the business model for the WtE plant is generally based on incineration of the waste, and therefore, energy (in the form of low pressure steam) is often available at relatively low prices. This is especially relevant in the summer, when the need for district heating is low or null.

Figure 1, the commercial AVR CO_2 capture plant in Duiven, The Netherlands [2].

To illustrate the implications of CO_2 capture in the WtE sector, this chapter discusses three case studies. The three case studies are based on different scales, representative for the WtE sector: 60 kton/year (Norwegian average), 200 kton/year (European average), and 500 kton/year (Dutch average). The case study of the 200 kton/year WtE plant was developed and reported in the ALIGN-CCUS project (https://www.alignccus.eu/). In that project, both the first generation MEA solvent and the second generation CESAR1 solvent (a mix of AMP and Piperazine) have been evaluated, and it was found that

MEA is the preferred solvent when energy/heat is relatively cheap. Therefore, the cases in this study use MEA (30 wt%) as the solvent of choice. A detailed description of the capture plant modelling can be found in the ALIGN-CCUS work [3].

2. Reference WtE and CO_2 capture plant description

The simplified reference WtE plant used in this study can be found in Figure 2. The energy content of the waste is estimated at 11.2 MJ/kg (wet basis, 20 wt% moisture). Simple mass and energy balance calculations are used to calculate the flue gas composition and temperature, before entering the waste heat recovery unit (WHRU), where high pressure steam is produced at 40 bar and 400 °C. After the WHRU, the flue gas continues to the flue gas pre-treatment and finally to the CO_2 capture plant. The produced steam is used for electricity generation, and the low pressure steam (at 3 bar) is used for district heating and/or CO_2 capture. The main results of the WtE plant modelling without CO_2 capture can be found in Table 1.

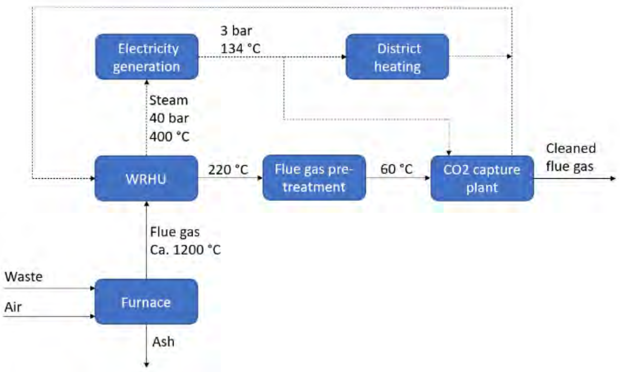

Figure 2, schematic overview of the simplified WtE plant. Flue gas streams are represented by a continuous line, while the steam cycle is represented by a dotted line.

Table 1, Main results from the WtE plant modelling

Parameter	Units	60 kton/year	200 kton/year	500 kton/year
Electricity generation	MW_e	3.01	10.24	25.74
District heating generation	MW_{th}	13.89	47.22	118.65
Flue gas flow rate	kg/hr	57000	190000	475000
CO_2 concentration in flue gas	vol% (wet)	8.94	8.94	8.94

Figure 3 shows a schematic representation of the CO_2 capture plant simulated in this study. The simulation tool used in this work is ProTreat. The MEA model in ProTreat has been validated against VLE data [4], and pilot plant operation [3].

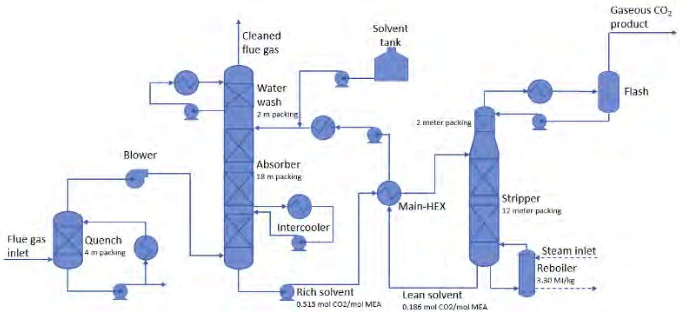

Figure 3, schematic representation of the CO_2 capture plant used in this study, including modelling parameters that are constant for all three cases.

The CO_2 capture plant is modelled assuming a 70% flooding parameter in all columns, and is further optimized by varying the solvent flow rate to minimize the reboiler duty. The main results can be found in Table 2. 47.9% of the steam for district heating and 4.4% of the electricity generated by the reference plant are used in the CO_2 capture plant (regardless of scale). Note that CO_2 conditioning (e.g. liquefaction) is not included in this study, which would have a significant impact on the electricity demand. Also note that there is a possibility for generating additional heat for the district heating system with the returned cooling water of the capture plant. This is especially relevant for the stripper condenser heat exchanger, which has a cooling duty of 31% of the reboiler duty in the simulations. This option has not been taken into account in our analysis, but should be explored in future research.

Table 2, main operational results of the CO_2 capture plant

Parameter	Units	60 kton/year	200 kton/year	500 kton/year
CO_2 capture percentage	%	90	90	90
Reboiler duty	MW_{th}	6.66	22.2	55.5
Electricity demand	kW_e	133	443	1109
Solvent flow rate	kg/hr	100500	335000	837500

3. Techno-economic analysis

The techno-economic analysis has been performed using the Aspen Capital Cost Estimator V10 (ACCE). The total direct cost of material is taken from ACCE for all equipment, together with the engineering, procurement and construction costs, and the cost methodology shown in Table 3 is followed.

Table 3, main assumptions for the techno-economic analysis. TPC = Total process costs

Parameter	Units	Value
Cost year (Europe)	-	2019
Discount factor	%	8
Depreciation of plant	Years	15
Plant availability	%	90
Maintenance costs	% of TPC	2.5
Labour percentage of maintenance	% of maintenance	40
Operators costs (6 operators)	k€/year	360
Technologist costs	k€/year	100
Insurance costs	% of TPC	2
Administrative and overhead labour costs	% of total labour costs	30
Heat costs	€/GJ	4

Electricity costs	€/kWh	0.1
Cooling water costs*	€/m^3	0.3

*** Cooling water make-up is estimated at 1 m3/GJ cooling**

The total process costs of installing the CO_2 capture plant at the existing reference WtE plants is estimated at 9.3, 16.5 and 31.4 M€ for the 60, 200 and 500 kton WtE plants respectively. The corresponding total cost of CO_2 capture for the three cases is evaluated between 30 and 55 €/ton CO_2 captured, and is shown in Figure 4. The higher cost for the small scale can be fully accounted to the higher specific CAPEX (economy of scale) and fixed OPEX (as the same amount of operators and technologist costs are expected for the different scales). At the larger scales, the variable OPEX becomes the cost-dominating factor.

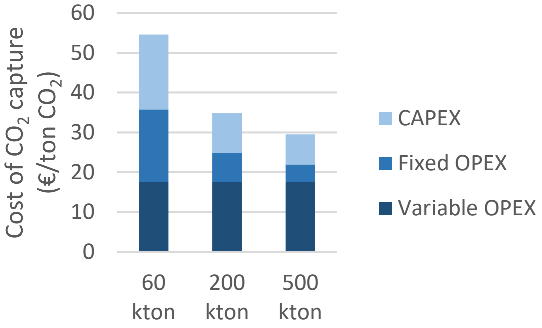

Figure 4, cost of CO_2 capture for the three WtE plant sizes considered in this study.

A breakdown of the variable OPEX costs are shown in Figure 5 (specific costs per ton of CO_2 are identical for all three cases). The heat/steam costs dominate the variable OPEX, as is common for post-combustion CO_2 capture. In this study, the assumption is made that heat is available at 4 €/GJ. In reality, this value is variable, and could be much lower for WtE plants with a CHP system, especially when the demand for district heating is low. This could decrease the total cost of CO_2 capture further below 30 €/ton for large scale plants.

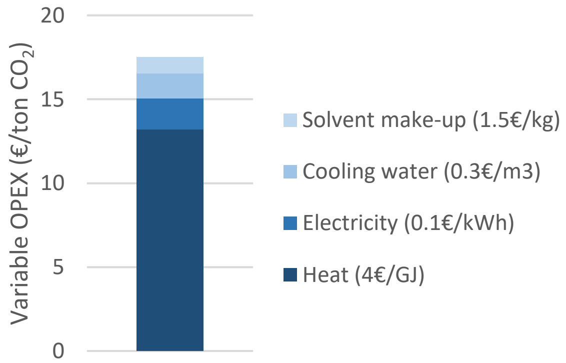

Figure 5, Variable OPEX costs

In all three cases, the columns (absorber, stripper and quench) dominate the equipment costs (60 to 65%), followed by the heat exchangers including the reboiler (15 to 20%), as shown in Figure 6. The other equipment combined accounts to approximately 20 to 25 % of the costs. It is also shown that the columns experience a lower economy of scale effect than the other units, as the percentage of column costs increases with scale.

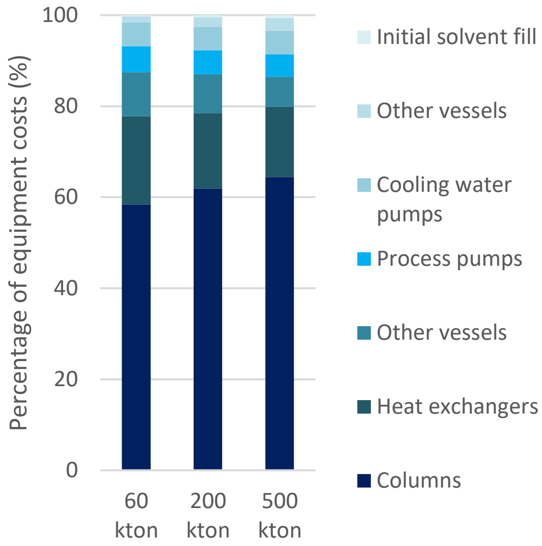

Figure 6, impact of different equipment on the total cost

4. Conclusions

This paper evaluates the cost of CO_2 capture in the WtE sector, focusing on the effect of the plant scale. The results indicate that the cost of CO_2 capture for a 60 kton/year scale plants (Norwegian average) is 55 €/ton CO_2 captured, which is significantly higher than for a 500 kton/year scale plant (Dutch average), evaluated at 30 €/ton CO_2 captured. Additionally, for smaller WtE plants where energy is relatively cheap, cost optimization could be achieved by optimizing the design of the plant and reducing the CAPEX, rather than minimizing the energy demand of the plant. Considering that most of the CO_2 in the flue gas of WtE plants is biogenic, CCS in this sector offers a very cost competitive negative emissions option.

References

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