## TECHNOLOGY FACTSHEET

# MUNICIPAL SOLID WASTE INCINERATOR - ELECTRICITY PRODUCTION AND DISTRICT HEATING

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| Date of factsheet | 4-12-2018 |
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| Sector | Built environment<br>Other sectors |
| ETS / Non-ETS | Non-ETS |
| Type of Technology | CHP |

**Description**

Waste streams can be avoided in a number of ways. These include waste prevention, the re-usage of materials and the recycling of materials. When waste streams are no longer avoidable, it is possible to utilize them to generate energy (ECN, 2006), both heat and electricity. Waste incinerators (in Dutch 'afvalverbrandingsinstallatie/AVI' or 'afval energiecentrale'), can be utilised to this purpose (Vereniging van afvalbedrijven, 2017).

Working of the Technology
A waste incinerator or waste-to-energy plant can be a combined-heat and power-plant (CHP). Water is evaporated in a boiler to produce high pressure steam which is expanded in a turbine to generate electricity using a generator. Cooling water cools down the water that has passed through the turbine. From the drain of the steam turbine heat can be fed into a heat network. Heat can be supplied to different sectors such as the built environment, industry or horticulture. This factsheet focuses on a waste CHP plants connected to a heat network. A waste incinerator without CO2 capture and storage (CCS) is considered in this factsheet.

In most cases, waste-to-energy plants are utilised to burn a mixture of municipal solid waste (MSW) and company waste.
The waste incinerator technology generally employs moving grate furnaces (ETRI, 2014).

Main Components
The main technological components of a waste incinerator consist of a waste bunker, cranes, furnace, ash storage bunkers, boiler, fly ash handling equipment, slag handling equipment and wet gas washing equipment. Waste incinerators are also equipped with advanced flue gas cleaners to prevent or limit the emission of various possibly harmful substances, amongst others: PM, VOC, NOx, NH3, SO2. Flue gas cleaners are included in the costs presented in this factsheet.

Energy production related aspects
The waste mixture is partly biogenic which results in a lower CO2 emission factor (kgCO2/GJ heat supplied) compared to heat produced by fossil fuel-fired CHP plants (ECN, 2017c; CE, 2016; Ecofys, 2014).

The downside of utilizing heat for district heating is that it lowers the electrical efficiency of CHP plants (loss of electricity production). Typical losses are given in this factsheet.

It is also important to note that the energy produced by waste incinerators is a by-product of waste treatment (Ecofys, 2014). This means that the amount of energy produced can be higher or lower depending on waste availability and that the level of energy produced will not necessarily follow energy demand.  Last but not least, heat and electricity output can be controlled and can vary depending on the season.

**TRL level 2020**

TRL 9

The technology is already being applied on a large-scale and can therefore be considered to be mature (ECN, 2006). Currently, there are 12 waste incinerators in the Netherland (CBS, 2018). Examples of waste incinerators used for district heating are AEB Amsterdam, AVR Rijnmond, HVC Alkmaar and AVI Duiven (ECN, 2017).

## TECHNICAL DIMENSIONS

| | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Capacity | Functional Unit | | Value and Range | | | | | | | | |
| | MWe | | | | | | | | | | 87 |
| | | | 31 | | | - | | | | | 154 |
| Potential | MWe | NL | Current | | | 2030 | | | 2050 | | |
| | | | - | | | - | | | - | | |
| | | | Min | - | Max | Min | - | Max | Min | - | Max |
| Market share | % | Share of final heat demand built environment | 1.1 | | | - | | | - | | |
| | | | 1.1 | - | 1.1 | Min | - | Max | Min | - | Max |
| Capacity utlization factor | 0.60 | | | | | | | | | | |
| Full-load running hours per year | 5,262 | | | | | | | | | | |
| Unit of Activity | PJe/year | 1.65 | | | | | | | | | |
| Technical lifetime (years) | 30 | | | | | | | | | | |
| Progress ratio | - | | | | | | | | | | |
| Hourly profile | Yes | | | | | | | | | | |

**Explanation**

Rijkswaterstaat published a report with data on a number of waste incinerators in the Netherlands, including: AEB Amsterdam, AVR Rijnmond, HVC Alkmaar, SITA ReEnergy Roosendaal and AVI Duiven (Vereniging van afvalbedrijven, 2017). The report provides information on the annual gross electricity production (GWhe) of each incinerator and on the heat they supplied (TJ) to heat networks in 2016. The thermal (MWth) and electrical capacities (MWe) of CHP plants are also provided.

Electrical Capacity Of Waste Incinerators In The Netherlands
In 2016, the electrical capacity of waste incinerators (i.e the ones used for district heating) in the Netherlands varied between 31 and 154 MWe (Rijkswaterstaat, 2017). The main electrical capacity given above is an average of the capacity of the five waste incinerators mentioned above (Vereniging van afvalbedrijven, 2017). On average, these five waste CHP plants are run on full-load around 5.262 hours per year. This translates to a capacity utilisation factor of 60%. A CHP plant with a capacity of 87MWe produces 1,65 PJe per year (at a capacity factor of 60%).

Heat Capacity Of Waste Incinerators In The Netherlands
Full load hours for district heating are not the same as for electricity generation. This is because there is a different load duration curve for heat. Indeed, the demand for heat peaks in the winter, but remains considerably lower in the other seasons. Heat is continuously available at waste incineration plants. However, due to limited overlap with the heat demand, only 30 to 45% of the available heat can be supplied per year (ECN, 2011). A heat loss of 25% in the heat networks can be assumed (ECN, 2017a). If there are 4.500 full-load hours (Energy Matters, 2012) and the heat source produces 0,8 PJth per year, then the thermal output capacity for district heating needs to be around 50MWth. The minimum heat disconnection capacity for district heating is 3MWth (PBL, 2017).

Heat Production and Supply of Waste Incinerators In The Netherlands
In 2017, waste incinerators in the Netherlands produced about 23 PJth of heat (CBS, 2018). This heat is partly supplied to the built-environment, and partly to other sectors. The un-utilised heat is lost. The Centraal Bureau voor de Statistiek (CBS) does not provide specific figures about the heat supplied by waste incinerators to the built-environment. However, based on the statistics from ECN (2015 data) and Rijkswaterstaat (2016 data), it can be estimated that waste incinerators supplied 4 to 6PJ of the final heat demand of the built-environment (ECN, 2017a; Vereniging van afvalbedrijven, 2017). In 2016, the final heat demand in the built-environment amounted to 452PJ (ECN, 2017b). Based on the above estimates, this would mean that in that year waste incinerators provided 1% of the total heat demanded by the sector.

Waste Availability In The Netherlands
While the capacity (efficiency) of waste incinerators in the Netherlands increased in the last few years, the inland availability of waste decreased (CBS, 2018). Since the Netherlands is located close to the sea, it is however relatively cheap to import waste from other European countries with low waste-treatment capacities (CBS, 2018).

Potential In The Netherlands
ECN (2011) indicates that, in the Netherlands, the amount of heat supplied by waste incinerators can increase by 11 PJth (ECN, 2011). Some of this potential has already been utilised since total installed capacity has already increased over the last years.

Technical Lifetime Waste Incinerators
ECN (2011) indicates that a waste incinerator has a technical lifetime of 30 years (ECN, 2011). ETRI (2014) indicates a technical lifetime of 25 years (ETRI, 2014).

## COSTS

| | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| Year of Euro | 2015 | | | | | | | | | |
| | **Euro per Functional Unit** | **Current** | | | **2030** | | | **2050** | | |
| Investment costs | mln. € / MWe | 5.66 | | | 5.27 | | | 4.56 | | |
| | | 2.78 | - | 8.06 | 4.03 | - | 7.30 | 3.30 | - | 5.97 |
| Other costs per year | mln. € / MWe | - | | | - | | | - | | |
| | | *Min* | - | *Max* | *Min* | - | *Max* | *Min* | - | *Max* |
| Fixed operational costs per year (excl. fuel costs) | mln. € / MWe | 0.25 | | | 0.24 | | | 0.21 | | |
| | | - | - | 0.37 | 0.18 | - | 0.33 | 0.15 | - | 0.27 |
| Variable costs per year | mln. € / MWe | 0.04 | | | 0.04 | | | 0.04 | | |
| | | 0.04 | - | 0.14 | 0.04 | - | 0.04 | 0.04 | - | 0.04 |

Costs explanation

Overview:
Waste incinerators have relatively higher costs compared to other power plant technologies. This is mainly because of the advanced flue-gas cleansing systems they require (ETRI, 2014). The implementation of such systems accounts for 15 % to 35% of total capital investments, and possibly additional operational costs, but it can reduce treatment costs (European Commission, 2018). In addition to this, high fuel-handling costs should also be considered (ETRI, 2014). Different approaches and regulations on the treatment, recovery and disposal of ash residues fly ash and bottom ash) may also influence implementation accosts and minimize landfilling costs.

The ETRI (2014), Energy Matters (2012), ECN (2006), PBL (2017) and ECN (2011) reports provide information on waste incinerators': investment costs, capital expense (CAPEX), fixed operational costs (FOM), and variable operational costs (VOM). Costs are described for incinerators of different capacity levels.

**Costs explanation per source**

- ETRI (2014) lists a range of CAPEX per MWe for a municipal solid waste incinerator with a net electrical capacity of 50MWe (ETRI, 2014). The following cost components are included in the CAPEX (ETRI, 2014): civil and structural costs, major equipment costs, balance of plant costs, electrical and I&C supply and installation, indirect project costs and development costs. The costs not included are: interconnection costs and insurance costs. ETRI indicates a CAPEX of 4.430 to 8.020 €/kWe in 2020, a CAPEX of 4.010 to 7.260 €/kWe in 2030 and a CAPEX of 3280-5940 €/kWe in 2050. The fixed operational costs (FOM) per year amount to 4,5% of the CAPEX (same in 2020, 2030 and 2050). This is namely 3,0% for FOM and 1,5% for FOM refurbishment. The VOM per year amount to 6,9 €/MWh (same in 2020, 2030 and 2050) and is converted to €/MW by assuming 5.262 full load hours per year. Labour cost for construction/installation amounts to 1,5% of the CAPEX (same in 2020, 2030 and 2050).

- Energy Matters (2012) suggests that investment costs for a waste incinerator reach 2.700 € per kWe for a plant with capacity of 60MWe. Here the CAPEX include: civil and structural costs, and major equipment costs including heat disconnection costs. Fixed operational costs are zero (Energy Matters, 2012). Variable costs per year reach 4.8 million € per year (Energy Matters, 2012). This plant is used for electricity production and district heating.

- ECN (2006) suggests that the investment costs of a waste incinerator reach 1.940 €/kWth (ECN, 2006). Here the CAPEX includes: civil and structural costs, major equipment costs including heat disconnection costs. This plant is used for electricity production and district heating. The thermal capacity is 186 MWth and the electrical capacity 56 MWe. The fixed operational costs per year amount to 5% of the investment costs (ECN, 2006). The variable operational costs per year are 22 €/MWhe (ECN, 2006) and is converted to €/MW by assuming 5.262 full load hours per year.

When a CHP plant supplies heat to a heat network for the first time, there are additional investment costs for heat disconnection:
- PBL (2017) indicates an investment of 150-175 euros 2017/kWth, output (PBL, 2017). The costs consist of the investment/CAPEX for heat disconnection (in Dutch 'kosten warmte uitkoppeling'). The fixed operational costs per year amount to 5% of the investment cost (PBL, 2017).
- ECN (2011) indicates investment costs of 300 euros2011/kWth,output (CE, 2011). The costs indicated by ECN (2011) consist of the investment/CAPEX for heat disconnection (Dutch: 'kosten warmte uitkoppeling').

## ENERGY IN- AND OUTPUTS

| | **Energy carrier** | **Unit** | **Current** | | | **2030** | | | **2050** | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Energy carriers (per unit of main output) | *Main output:* Electricity | PJ | -1.00 | | | -1.00 | | | -1.00 | | |
| | | | -1.00 | - | -1.00 | -1.00 | - | -1.00 | -1.00 | - | -1.00 |
| | Waste (biogenic) | PJ | 4.14 | | | 4.14 | | | 4.14 | | |
| | | | 1.77 | - | 4.14 | 1.72 | - | 4.14 | 1.31 | - | 4.14 |
| | Waste (non-biogenic) | PJ | 3.53 | | | 3.53 | | | 3.53 | | |
| | | | 1.45 | - | 3.53 | 1.41 | - | 3.53 | 1.07 | - | 3.53 |
| | Heat | PJ | -2.30 | | | -2.30 | | | -2.30 | | |
| | | | -2.30 | - | -1.33 | -2.30 | - | -1.20 | -2.30 | - | -1.05 |

Energy in- and Outputs explanation

Overview
Due to limited steam temperature, the electrical efficiency of waste incinerators is relatively low compared to that of (gas or coal-fired) power plants (ECN, 2011). Indeed, Brunner and Rechberger (2015) suggest that the steam parameters in typical waste to energy facilities can only reach 400 degree Celsius (and 40 bars) whilst fossil fuels fired thermal power plants can reach up to 550 degree Celsius (and 40 bar) (Brunner and Rechberger,2015).

Ratios
- According to CBS 'Hernieuwbare Energie in Nederland 2017' the ratio of net electricity production (i.e. elec. production minus self-consumption) to energy input from waste is 13%, namely 10.130 TJ of net electricity production divided by 77.631 TJ waste input (CBS, 2018). The average thermal efficiency for the conversion of waste input to heat is 30%, namely 23.522 TJ of heat production divided by 77.631 TJ waste input (CBS, 2018). In 2017, 54% of the energy content of waste was renewable (i.e. biogenic) (CBS, 2018).

- The National Energy Outlook (2016) projects that waste incinerators will have an electrical efficiency of 16% and a thermal efficiency of 27% by 2020 (ECN, 2016b). In 2030, the electrical efficiency is expected to reach 19% and the thermal efficiency 23%. In 2050, the electrical efficiency is expected to reach 20% and the thermal efficiency 20%. The biogenic waste fraction is assumed 55 % in all years.

- A study by CE (2010) gives on overview of efficiencies of waste incinerators in the Netherlands. The waste incinerators have a net electrical efficiency of 10-27% and a 0-21% thermal efficiency (for district heating). In the table above a 15% conversion efficiency from energy input to heat for district heating is taken and a 20% efficiency for electricity production is taken. Furthermore 55% biogenic waste is assumed.

- ETRI (2014) discusses the net electrical efficiency of a municipal solid waste incinerator. In 2020, 2030 and 2050 the suggested net efficiency are 31%, 32% and 42% (ETRI, 2014). Furthermore 55% biogenic waste is assumed in all years. This plant is used for electricity production.

In future years, the ratio of biogenic waste : non-biogenic waste could change, for instance because of more reuse and recycling. This effect however is difficult to quantify and for this

## MATERIAL FLOWS (OPTIONAL)

| | **Material** | **Unit** | **Current** | | | **2030** | | | **2050** | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Material flows | | | - | | | - | | | - | | |
| | | | *Min* | - | *Max* | *Min* | - | *Max* | *Min* | - | *Max* |
| | | | - | | | - | | | - | | |
| | | | *Min* | - | *Max* | *Min* | - | *Max* | *Min* | - | *Max* |
| Material flows explanation | | | | | | | | | | | |

## EMISSIONS (Non-fuel/energy-related emissions or emissions reductions (e.g. CCS)

| | **Substance** | **Unit** | **Current** | | | **2030** | | | **2050** | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Emissions | | | - | | | - | | | - | | |
| | | | *Min* | - | *Max* | *Min* | - | *Max* | *Min* | - | *Max* |
| | | | - | | | - | | | - | | |
| | | | *Min* | - | *Max* | *Min* | - | *Max* | *Min* | - | *Max* |
| | | | - | | | - | | | - | | |
| | | | *Min* | - | *Max* | *Min* | - | *Max* | *Min* | - | *Max* |
| | | | - | | | - | | | - | | |
| | | | *Min* | - | *Max* | *Min* | - | *Max* | *Min* | - | *Max* |

Emissions explanation

Waste incineration generates harmful emissions, including dust, dioxins, furans, heavy metals, SOx, NOx, HCI and HF (Poggio A. and Grieco E. 2010). There are three by-product emissions of solid waste incinerators commonly discussed in literature, namely: fly ash (from flue gas), bottom ash and air pollution control residues (APC). New technologies have considerably decreased the emission or release of these components in the environment. Some emission remain but it is minimum, and varies as a result of local regulation.

Fly Ash
The fly ash content of flue gas is minimised (from >150 mg/Nm3 to <5mg/Nm3) thanks to wet and dry multi-stage flue gas cleanser systems (Brunner P.H., Rechberger H., 2015). Poggio A. and Grieco E. (2010) list the 4 most common acid-gas removal systems: dry systems with Ca(OH)2, dry treatment with NaHCO3, semi-dry process with Ca(OH)2 and wet scrubbing. It is also worth notting that these systems also serve to remove fine particulates carriers of heavy metals and POPs (Brunner P.H., Rechberger H., 2015). As mentioned in teh cost section, the implementation of flue glas cleansers accounts for a large part of total capital investment (European Comussion, 2018).

Bottom Ash
Bottom ash emissions are most commonly landfilled and treated to before being used in construction material (Brunner P.H., Rechberger H., 2015).

APC Residues
APC residues can stored in under ground storage, but they are also seen as a potential source of recyclible metals such as aluminum, copper and other (Brunner P.H., Rechberger H., 2015). The recovery of such metals is a potential source of revenue.

| OTHER | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| **Parameter** | **Unit** | **Current** | | | **2030** | | | **2050** | | |
| Loss of electricity production per unit of heat produced | GJe/GJth | 0.20 | | | 0.20 | | | 0.20 | | |
| | | 0.09 | - | 0.20 | 0.09 | - | 0.20 | 0.09 | - | 0.20 |
| Water withdrawal | liters/kWh | 3.3 | | | 3.3 | | | 3.3 | | |
| | | 3.3 | - | 3.3 | 3.3 | - | 3.3 | 3.3 | - | 3.3 |
| Water consumption | liters/kWh | 2.1 | | | 2.1 | | | 2.1 | | |
| | | 2.1 | - | 2.1 | 2.1 | - | 2.1 | 2.1 | - | 2.1 |
| | | - | | | - | | | - | | |
| | | *Min* | - | *Max* | *Min* | - | *Max* | *Min* | - | *Max* |
| Explanation | • A downside of utilising heat for district heating is that it lowers the electrical conversion efficiency of the CHP plant. For each GJth of drain-heat supplied to district heating, there is a 0,2 GJe loss of electricity production (ECN, 2016a). Thus, the higher the heat temperature, the higher the losses. ECN (2011) indicates a loss of 0,18 GJe/GJth for drain-heat at 120 °C and a loss of 0,09 GJe/GJth at 80 °C (ECN, 2011).<br>• According to ETRI the water withdrawal is equal to 3,3 liters per kWhe and the water consumption to 2,1 liters per kWhe in case of usage of cooling towers (ETRI, 2014). Water consumption refers to the water that is not returned to the water system. | | | | | | | | | |

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