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Waste-to-Energy with CCS: A pathway to carbon-negative power generation

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Introduction

A growing global population and rising living standards are producing ever greater quantities of municipal solid waste (MSW).

It is projected that globally by 2050, 3.40 billion tonnes of waste will be generated each year (The World Bank, 2018); a staggering 70 per cent increase from 2016 levels. Today, most of the world's waste is landfilled (37 per cent), dumped (33 per cent), recycled or reused (19 per cent), or incinerated (11 per cent) (The World Bank, 2018).

Both landfilling and dumping are highly unsustainable solutions; they use large areas of land and result in the release of significant environmental pollutants, including the greenhouse gases carbon dioxide (CO_2) and methane (CH_4) as the waste decomposes and often pose a health and safety hazard in developing countries (The World Bank, 2019). Landfill storages near cities are coming under increased capacity pressure, resulting in rising landfill charges by local governments.

This same growth in population and living standards is also driving ever-larger demand for energy, especially electricity.

A key solution to these challenges of MSW disposal, rising energy demand and methane emissions from MSW is Waste-to-Energy (WtE); the generation of energy – in the form of electricity and heat – from the processing of waste. The addition of carbon capture and storage (CCS) to WtE has the potential to make waste a zero or even negative emissions energy source, depending on the ratio between biogenic and non-biogenic waste fraction.

What is Municipal Solid Waste?

Municipal Solid Waste is the solid waste material produced by households and commercial businesses. The average global composition (by mass) of MSW is shown in Figure 1.

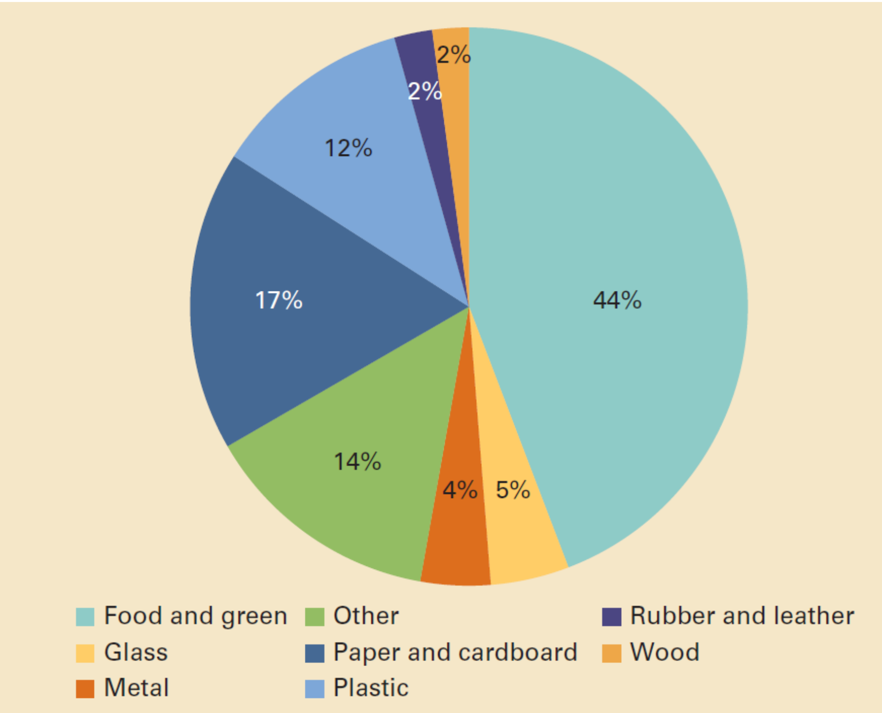

Figure 1: MSW global average composition by mass (Kaza, et al., 2018)

In lower-income countries, there tends to be a higher proportion of food and green waste, while higher-income countries tend to have more recyclables (glass, metals, paper and cardboard) and much more plastic. Per capita volumes of MSW also rise strongly with income (Figure 2), so economic growth in the developing world will result in much higher production of MSW.

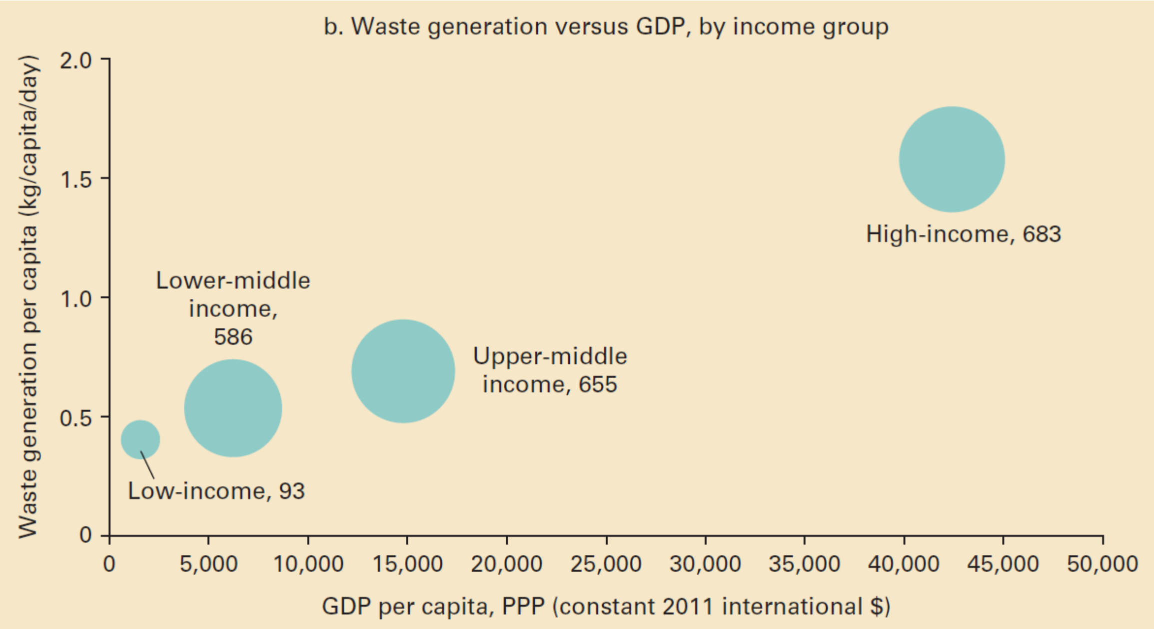

Figure 2: Waste generation per capita by Income Group (Kaza, et al., 2018, p. 23)

The proportion of plastic in MSW is rising (Energy Information Administration (USA), 2007) as kerbside recycling has reduced the recyclables content of MSW in many countries – especially paper and cardboard.

The heterogeneous nature of MSW means that sorting is required before use in WtE plants. Non-combustible materials and valuable substances (e.g. metals) are typically removed using bulk sorting equipment.

The remaining materials, mostly plastics, food and green waste, as well as contaminated paper and cardboard, are typically sent to landfill. It is these materials which are prime candidates for WtE.

Waste-to-Energy plants

Over 2,430 WtE plants are operating globally. More than 2,700 plants with an MSW capacity of 530 million tonnes are forecast to be operational by 2027 (Ecoprog, 2018).

Waste to Energy facilities incinerate combustible materials in MSW. Depending on the combustibles content, incineration can reduce MSW volumes by up to 90 per cent (Perrot & Subiantoro, 2018). This reduces pressure on landfills while providing a reliable energy source for heat and electricity for growing cities around the world.

The energy they provide can also displace energy from conventional fossil fuel facilities, helping abate greenhouse gas emissions.

Waste-to-Energy operation

A typical WtE plant consists of the following parts (Azapagic & Perdan, 2011):

- Waste handling, including waste reception and pre-treatment
- Incinerator and boiler
- Energy recovery and energy generation plant
- Air pollution control plant
- Ash treatment and removal.

A technology overview diagram is provided in Figure 3:

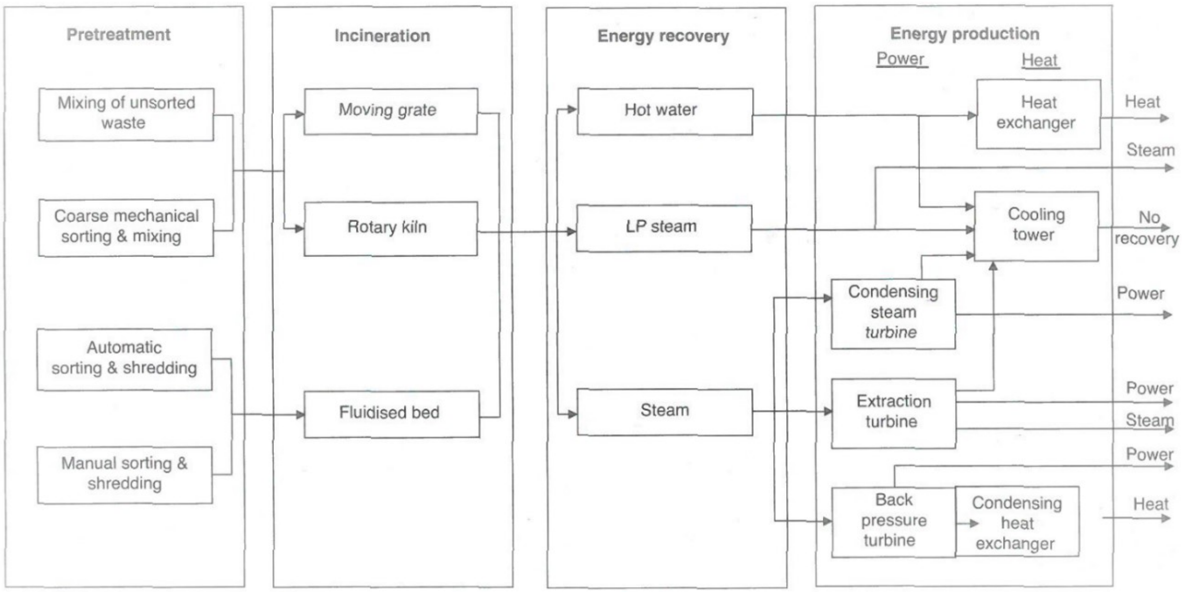

Figure 3: Waste to Energy – a technology overview (Azapagic & Perdan, 2011, p. 275)

A typical representation of a WtE plant producing electricity and heat for homes is provided in Figure 4:

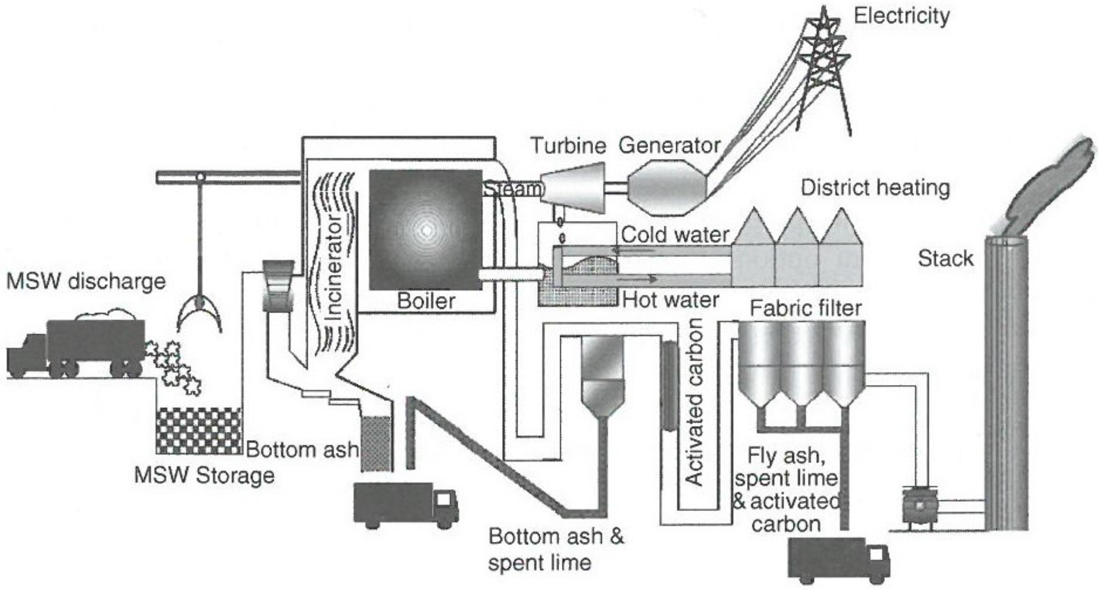

Figure 4: Typical Waste-to-Energy representation for heat and power production (Azapagic & Perdan, 2011)

Waste handling and pre-treatment

A combination of manual and automated processes are used to separate MSW into components, including pneumatic, magnetic and sieving operations. Large objects are removed, and the separation equipment produces a range of streams for composting, recycling and fuel.

Generally, waste is suitable for combustion without additional fuel when it contains <50 per cent moisture, >25 per cent carbon and has <60 per cent ash yield. Plastics, paper, cardboard, leather, wood and food materials are all suitable fuel components.

The fuel stream is typically shredded to reduce particle size for improved combustion.

Waste-to-Energy and climate change

MSW contains materials of biogenic (plant-derived) and non-biogenic (fossil fuel) origin. When incinerated, the biogenic component produces CO_2, which does not lead to increasing atmospheric CO_2 levels.

The non-biogenic component of MSW has been rising over time as more paper is being recycled (diverted away from MSW) and increased amounts of plastics are being disposed of to MSW streams (Energy Information Administration (USA), 2007). This is increasing the heat content of MSW but is also increasing the net CO_2 emissions from MSW incineration. MSW composition is variable, as is its biogenic carbon fraction. However, for a typical MSW composition,

Figure 5 on the following page shows typical carbon and carbon dioxide amounts for MSW incineration.

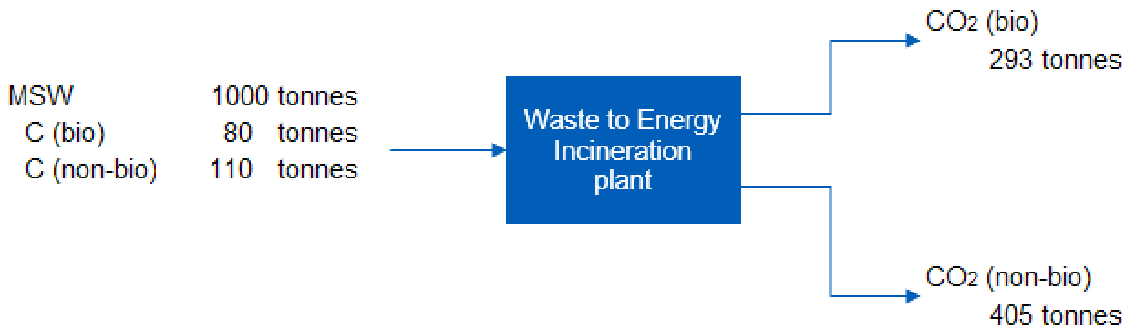

Figure 5: Carbon balance for 1000 tonnes of MSW

If a capture project captures more than the non-biogenic fraction of its CO_2 emissions, it can allow a facility to become a net-negative CO_2 emitter.

MSW landfilling is also a major source of methane emissions in the form of landfill gas. Methane is 25 times as potent a greenhouse gas as CO_2. WtE plants avoid the formation of landfill gas by incinerating the organic methane-producing compounds in MSW and can, therefore, improve the net emissions savings available.

There is increasing urgency to reduce and eliminate emissions of greenhouse gases (including CO_2) from human activities. Local and National policies, as well as the global Paris Agreement, will ensure there is increasing pressure to reduce emissions, including from WtE plants.

The only way to eliminate net CO_2 emissions from the waste-to-energy industry is carbon capture and storage (CCS). For WtE plants operating on MSW with a significant biogenic component, CCS provides a pathway to negative CO_2 emissions while producing the power and handling the waste produced by our growing populations and economies.

Waste-to-Energy + CCS

Flue gases produced by WtE plants are similar to those produced by coal-fired power plants (refer to Table 1).

Gas species	Waste incineration flue gas	Pulverised coal flue gas
O_2 (vol %)	7 - 14	~ 6
N_2 (vol %)	Balance	~ 76
CO_2 (vol %)	6 - 12	~ 11
H_2O (vol %)	10 - 18	~ 6
NO_x (ppmw)	200 - 500	500 - 800

Table 1: Typical flue gas compositions for Waste to Energy and Pulverised coal flue gases (Zevenhoven & Kilpinen, 2002)

CO_2 capture for a waste to energy plant is simpler than for a coal-fired power station. MSW contains much less sulphur and produces less particulates than coal, which means less capital investment is required for gas cleaning.

CO_2 concentrations are variable for WtE, depending on the specific materials present in the MSW being combusted. Concentrations are in the range best suited for capture with amine-based absorption plants.

Current developments in solvent innovation, process integration and intensification could potentially lower the CO_2 capture cost to USD 35-50 per tonne CO_2 in power generation applications.

Waste to Energy plants operate at a smaller scale than conventional coal or gas-fired power stations, so their CO_2 capture volumes are also smaller. Successful CCS installations will need to be able to deliver low-cost abatement without the economies of scale available at larger power plants.

Twence Waste to Energy plant – Netherlands

The Twence WtE plant is a facility which has operated since 1986 in Hengelo, The Netherlands. Every year the facility processes over 830,000 tonnes of waste, generating 405000 MWh of electricity and 1.5 million GJ of thermal energy for district heating.

Figure 6: Twence WtE Plant, Netherlands (image: twence.nl)

Aker Solutions recently signed an agreement to deliver a carbon capture and liquefaction plant at the Twence facility (Doyle, 2019). The capture plant is centred on Aker's "Just Catch" modular carbon capture system, designed around simplicity, ease of installation, rapid deployment and low capture costs. The use of standardised plant drawings, plant layout, containers and foundations greatly simplifies the engineering complexity and cost compared to a conventional capture project.

The use of modular designs enables flexible applications and offers the cost savings of larger-scale manufacturing of carbon capture system components. Some capture system components are provided in standard shipping containers; a low-cost method of system delivery and packaging.

The capture system will have a CO_2 capture capacity of 100,000 tonnes per year by 2021 (Aker Solutions, 2019). Liquefied CO_2 will be sold to customers by tanker for use in greenhouses and industrial applications.

Klemetsrud, Norway

The Klemetsrud Waste-to-Energy facility in Oslo, Norway is a three-train facility processing over 400,000 tonnes of non-recyclable MSW. It can generate 55 MW of heat for 40,000 homes and 10.5 MW of electricity.

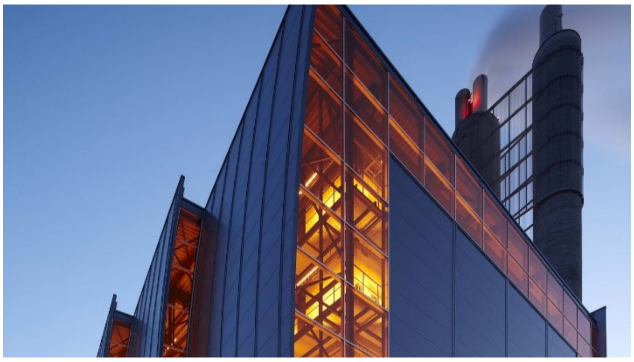

Figure 7: Klemetsrud Waste-to-Energy plant in Oslo, Norway (image: thechemicalengineer.com)

Following a successful 2011 pilot project to capture 90 per cent of the CO_2 from a small flue gas stream, a full-scale carbon capture project is now under development.

The project will capture 400,000 tonnes of CO_2 every year with an amine-based absorption capture plant. Although this is an early example of large-scale capture from Waste-to-Energy, the capture process is well understood and tested in other capture applications. As Waste-to-Energy flue gas is comparable to that from power station, captured emissions will be transported by ship for storage. Fifty per cent of the captured CO_2 is biogenic, making this a partial bio-energy with carbon capture and storage (BECCS) facility; a CO_2-negative project.

Saga City, Japan

Saga City in Saga Prefecture, Japan, is the home of an MSW waste-to-energy plant. Since 2016, a Toshiba-designed CO_2 capture plant has operated at this site (Figure 8) capturing 10 tonnes/day for use in the local agricultural sector. This is producing economic value from CO_2 which would otherwise have been vented to the atmosphere.

Figure 8: Carbon capture plant at Saga City WtE plant, Japan (image supplied)

Towards zero waste and negative carbon emissions

One key advantage of waste-to-energy plants is not just in providing “low-carbon” energy and zero waste, but its potential “negative carbon” contribution towards climate change mitigation targets.

Using CCS in the waste-to-energy industry presents a particular opportunity for bioenergy with carbon capture and storage (BECCS); one of the few abatement technologies that can be carbon negative. BECCS involves the utilisation of biomass as an energy source and the capture and permanent storage of the CO_2 produced.

The Intergovernmental Panel on Climate Change (IPCC) SR15 report (2018, p. 34) acknowledges that Carbon Dioxide Removal (CDR), including BECCS, is necessary to limit warming to 1.5°C:

> *“All analysed pathways limiting warming to 1.5°C with no or limited overshoot use CDR to some extent to neutralize emissions from sources for which no mitigation measures have been identified and, in most cases, also to achieve net negative emissions to return global warming to 1.5°C”.*

Conclusion

The rapid growth of municipal solid waste production and living standards will continue to increase the quantities of MSW production around the world. The conventional option of landfilling is environmentally unsustainable and becoming uneconomic. Demand for more energy and reduced landfilling volumes is encouraging continued growth in WtE plants.

If the world is to keep on track with its emissions reduction targets under the Paris agreement, it is vital that the WtE sector manages its CO_2 emissions.

The continued growth of MSW generation and the need for scalable negative-emissions energy options will only increase the opportunities for CCS in the WtE sector.

Further information:

For more details of next-generation capture technology and process modification paths, please contact the Global CCS Institute.

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