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Capacity, Efficiency and Emissions: Pushing the Limits of Energy-from-Waste Plants

Reto Strobel and Maurice Waldner

The technology used in energy-from-waste (EfW) plants has been continuously improved in recent years – not in revolutionary fashion, but steadily. The new plants being planned and built, especially in China and the Middle East, are getting larger and larger, with anticipated throughputs of more than 5,000 metric tons of municipal solid waste per day. These numbers were hardly imaginable just a few years ago. Designing such large plants creates new challenges for plant designers and engineers, but also renders new possibilities in terms of the efficiency of plant operation and electricity generation.

It's not only newly-built plants that can profit from the latest advances in grate incineration technology, but also existing ones already in operation. Today, many EfW plant operators are looking for opportunities to increase their revenue. A power upgrade increasing the plant's waste throughput capacity is probably the most attractive route to higher profits. This article will discuss the challenges and options for power upgrades, including some examples recently executed by Hitachi Zosen Inova (HZI).

Last but not least, more stringent emission limits require state-of-the-art flue gas treatment systems coupled with optimized combustion processes. The amount of uncontrolled NO_x in particular is heavily influenced by the combustion process itself. Operation with low excess air (low oxygen concentrations and less flue gas) suppresses the oxidation of nitrogen oxide precursors into NO_x, and thus makes it easier to achieve lower emission levels without upgrading the NO_x abatement system. Especially in combination with a power upgrade, a reduction in the O_2 content used for combustion makes sense, as it also allows for higher loads without increasing flue gas throughput.

1. New energy-from-waste plants

In recent years there has been a clear trend towards larger energy-from-waste facilities. The last round of increase in plant size started at the beginning of this century, mainly driven by the UK market. Current demand for even larger plants is primarily arising from megacities outside Europe. Figure 1 illustrates this trend, depicting the new records for waste thermal power capacity set by plants built by HZI over the years. The commencement of EfW development in the UK around the year 2000 with significantly larger plants compared to continental Europe pushed the incineration capacity to about 80 MW per line. Today we are seeing calls for the thermal capacity of single incineration lines to be increased even further, with another disruptive jump to about 120 MW thermal power per line.

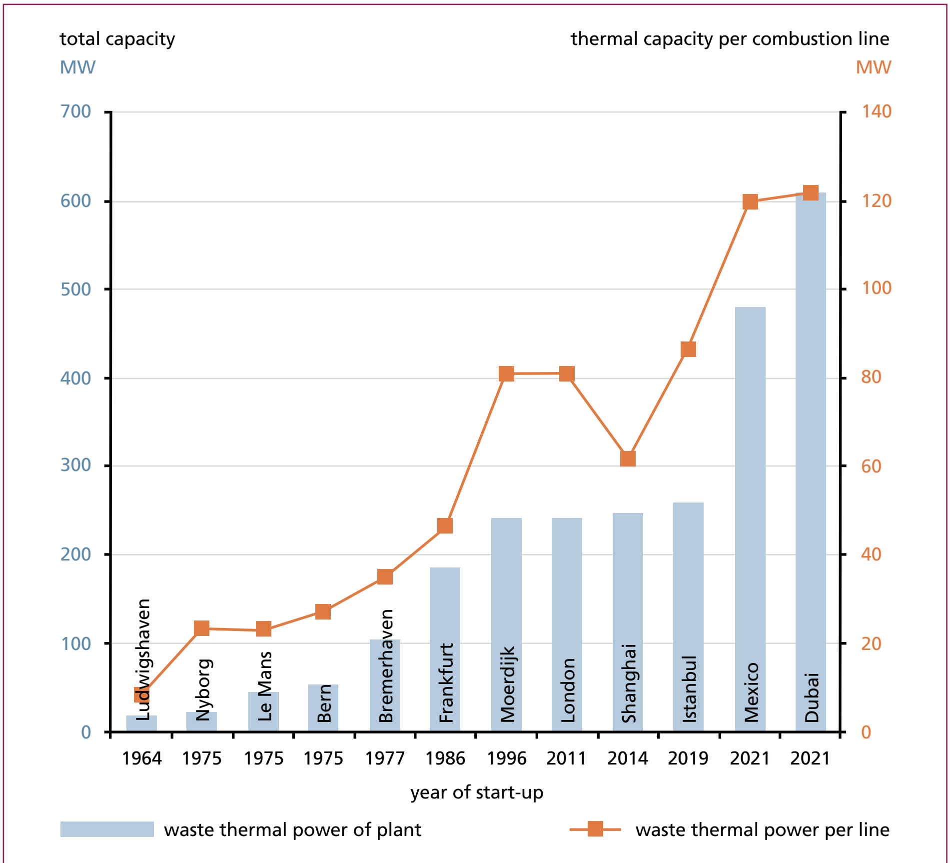


Figure 1: Thermal capacity of the largest EfW plants built by HZI over the years; US plants have been omitted

EfW plants currently being built in China in particular are setting new records in terms of waste treatment capacity and thermal power. For instance, the waste-to-energy plant in Shenzhen that is currently under construction will be able to process up to 5,600 metric tons of waste per day. By way of illustration, this corresponds to about half the capacity of all 30 waste-to-energy plants currently in operation in Switzerland. The trend towards larger EfW plants is fuelled by two main factors: firstly, by the abundant availability of municipal solid waste in megacities such as Shenzhen, Mexico and Dubai, and secondly by cost and efficiency considerations. Scaling effects reduce the investment costs per weight of processed waste. The operating costs related to the amount of waste throughput are also significantly lower for larger plants. Additionally, higher electrical efficiencies can be reached with larger installations, significantly reducing the required gate fee for profitable operation of such large facilities.

In the following sections a short technical résumé of the currently planned EfW plants for the megacities of Dubai and Mexico is given. It addresses the challenges related to the large size of such plants.

1.1. Mexico

Mexico City is one of the largest metropolitan areas of the world, with more than 20 million inhabitants generating about 13,000 metric tons of waste every day [1], of which the majority is currently disposed of in landfill. The planned waste-to-energy plant will have the capacity to treat about 5,000 metric tons of waste per day. The plant is expected to generate about 170 MW of electrical power output, to be used for the Mexico City metro system. The key parameters are summarized in Table 1.

Total waste capacity	> 5,000 t/h
Total thermal power	480 MW
Net calorific value range	7,000 – 11,720 kJ/kg
Number of incineration lines	4 lines
Steam parameters	421 °C, 61 bara
Flue gas treatment	dry system

Table 1:

Key parameters for the EfW plant planned for Mexico City

The plant's waste incineration technology is based on a reciprocating grate with a width of more than 15 meters consisting of 30 individual grate elements. Special care must be taken to ensure the even distribution of waste across the whole grate width. The large boiler – large by the standards of energy-from-waste plants – required special attention, given its location in an earthquake zone.

Figure 2:

Illustration of the EfW plant designed for the treatment of the municipal solid waste generated by Mexico City; it consists of four incineration lines each with a thermal capacity of 120 MW

1.2. Dubai

To achieve the target of a sharp reduction in waste landfill sites, the municipality of Dubai is planning to build the world's largest waste-to-energy plant [2]. Its municipal solid waste generation is estimated at around 8,000 metric tons per day, of which 75 % can be treated in the planned EfW plant. The sheer size of the plant is more reminiscent of a coal power station than of the traditional EfW plants we know from Europe. The whole business model is based on the high cost-effectiveness of such a large plant, including the costs of capital and operation. The scaling effects are further reflected in the high efficiency of such a large plant, which will achieve a gross electrical output of up to 34 %. This renders the plant competitive with landfills in terms of waste disposal costs.

The key parameters of the Dubai EfW plant are summarized in Table 2. A visualization of the plant with five parallel combustion lines is shown in Figure 3.

Total waste capacity	> 6,000 t/h
Total thermal power	610 MW
Net calorific value range	7,000 – 14,000 kJ/kg
Number of incineration lines	5 lines
Steam parameters	432 °C, 77 bara
Flue gas treatment	dry system

Table 2:

Key parameters for the EfW plant planned for Dubai

Figure 3:

Illustration of the project for an EfW plant in Dubai; it consists of five incineration lines each with a thermal capacity of 122 MW, giving a total thermal capacity of 610 MW

2. Power upgrades

As many energy-from-waste operators in Europe seek ways of increasing the profitability of their plants, increasing the plant's capacity has become a very attractive option. When it comes to the waste incineration process, there are basically two alternatives for generating higher revenues:

- increasing plant efficiency to generate more electrical output
- increasing plant capacity to increase electrical output and waste throughput

Market prices for electricity in Europe have steadily decreased in recent years. For European EfW operators, contrary to the situation in Dubai for instance, this means that the gate fee has become more and more important, as it is the main source of income. So it is not surprising that a power upgrade boosting waste throughput capacity is much more attractive than merely increasing the plant's electrical efficiency – especially when there is enough waste available to be thermally converted into energy.

Most plants have rather high margins on the basis of their original design. For instance, boilers and fans were designed to cope with overload conditions, and usually include certain margins to account for uncertainties during the design phase of the plant. However, once a plant has been in operation for a while, the waste characteristics are better known than they were in the design stage. Also, operators are more experienced, and generally the plant runs more smoothly. This means that many of the design margins incorporated to account for the contractor's initial uncertainties are no longer required, and a power upgrade is typically possible without exchanging major equipment. Figure 4 summarizes the potential limitations for power upgrades.

Figure 4:

Typical limitations for a power upgrade

Some of the limitations shown in Figure 4 can be partly overcome by means of relatively cheap adjustments to the combustion control system or with the aid of additional sensors for improved plant performance. Table 3 lists some solutions for surmounting the plant's limitations. None of these measures require the replacement of major equipment such as fans or pumps. Instead, logics and sensors are used to make use of the plant's full potential. This is a cost-efficient approach to power upgrades avoiding expensive investments in larger plant equipment.

Table 3: Limitations for power upgrades and ways to overcome them without changing plant equipment.

Limitation	Solutions (only logics and some sensors)
Solid burn-out	• Improved feed-rate control • Automated fire position control
Induced draft (ID) fan, flue gas treatment	• Constant flue gas flow • Low excess air operation • Higher adiabatic temperatures
Air fans	• Optimized damper control • Low excess air operation • Sub-stoichiometric primary air
Pumps and boiler	• Limitation control (prevent overshoot) • Small live steam control deviations
Turbine, generator	• Partial by-pass operation • Small live steam control deviations

Most boilers are usually designed large and do not pose any limitation when it comes to power upgrades. Fans (such as the primary air or induced draft fan) and the flue gas treatment system are more critical. If the volume flow of primary air or flue gas were to be scaled linearly with the thermal power of the plant, the pressure drop in the systems would increase by the power of two according to:

$$\Delta p \propto \Delta V^2 \text{ and } P_{Motor} \propto \Delta V^3 \quad (1)$$

This relation implies that a linear increase in the primary air flow and flue gas flows with the power upgrade is not feasible, as the fans will be a limiting factor. An increase in 10 % flue gas flow for instance will lead to an increase in ID fan motor power of 33 %. However, most plants exhibit great potential in terms of increasing the thermal power without significantly increasing the volume flows of primary or secondary air required for combustion. By reducing the amount of air used for combustion while increasing the thermal load, the flue gas flow does not have to be increased proportionally to the thermal power of the plant.

EfW plants designed with an O_2 concentration of around 6 vol % (wet) or higher at the boiler exit have great potential for a power upgrade without increasing the flue gas flow. Several EfW plants have already demonstrated the ability to operate continuously at an average O_2 concentration between 2.5 and 4 vol % without significant adverse effects in terms of boiler corrosion or boiler fouling [6, 8].

Figure 5 shows the potential for increased thermal power without increasing the flue gas flow for three different reference scenarios. Depending on the amount of excess air before the upgrade, an increase in power output between 10 and 25 % is achievable for most existing plants without altering the amount of flue gas to be treated by the flue gas treatment system.

An additional benefit of operation at lower oxygen levels is a marked reduction in uncontrolled NO_x emissions, which will be discussed in Chapter 3.

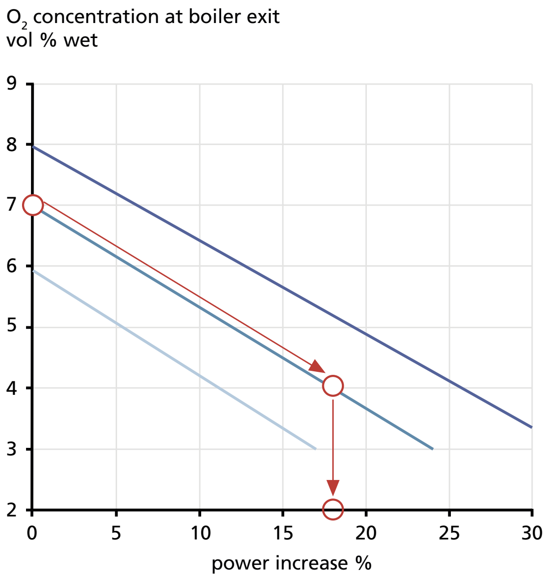


Figure 5:

Potential for a power increase without altering the flue gas flow for three different reference O_2 concentrations at the boiler exit; reading example: Decreasing the excess air from 7 to 4 vol %, the thermal power can be increased by about 18 % without altering the flue gas flow

2.1. Combustion control system

The boiler with its associated pumps and valves, as well as the whole heat utilization system, is designed to cope with fluctuations in thermal power release. The margins are typically rather high, as during the design phase little information is available about waste characteristics, and the achievable live steam control quality can only be estimated.

These days, advances in combustion control algorithms, combined with additional sensors, enable energy-from-waste plants to operate with more stable live steam production. As a result, installed margins from the past can be used to accomplish overload situations. Figure 6 shows an example for live steam flow fluctuations before and after optimization of the combustion control system (CCS) in an EfW plant. Prior to the optimization, very high fluctuations with large overshoots were observed. The 98 % percentile was about 7 % above live steam set point, while after optimization of the CCS setup live steam flow was much closer to the set point (the 98 % percentile down to 2.1 % above set point).

This shows that greater potential for a power upgrade lies in optimal combustion control, as fewer margins are required. In the example shown in Figure 6, the live steam set point could be increased by 5 % without reducing the effective margin.

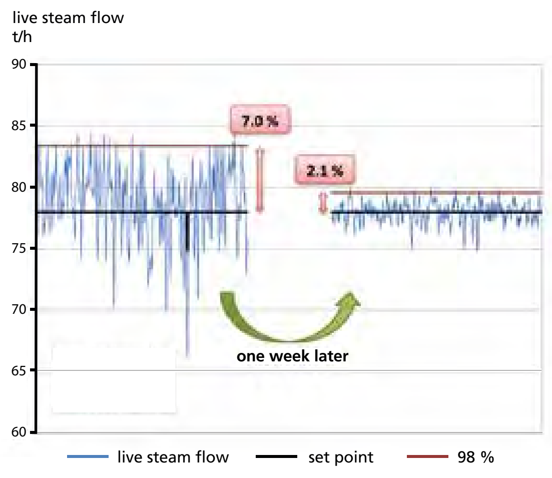
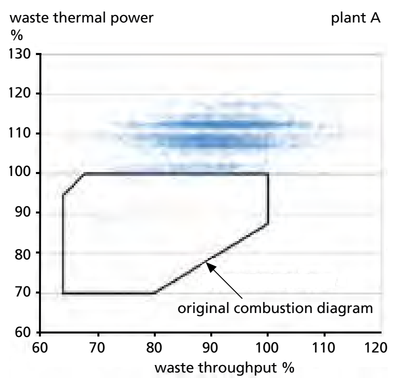


Figure 6:

Live steam fluctuation in the same EfW plant before (left) and after (right) optimization of the combustion control system; one minute average values over one day are shown; the upper 98 % percentile was reduced from 7 to 2 % deviation from the live steam flow set point; this gives greater flexibility to increase the live steam set point

2.2. Examples

Two examples of the potential of low excess air operation in combination with optimal combustion control are shown in Figure 7. Operation data over an extended period is shown for both plants. As a reference, the combustion diagram used for the design of the original equipment of the plant is indicated. For both plants, the limitation with regard to thermal power could be increased by more than 15 %. The power upgrades were executed without replacing any major plant equipment.



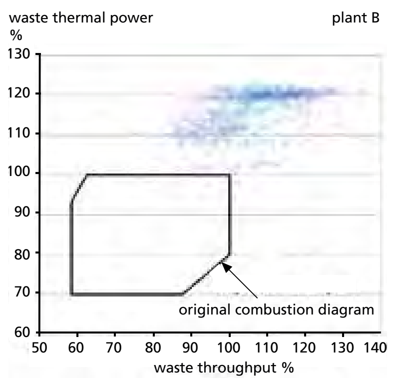


Figure 7: Operation data of two plants after power upgrade; every blue dot represents a 2-hour averaged operation value over the course of one year (left plot, plant A) and half a year (right plot, plant B); for comparison the original range of the combustion diagram is shown

3. Emissions

Besides the beneficial effect of power upgrades without higher flue gas flow rates, the reduction in oxygen in the combustion process also significantly reduces the formation of uncontrolled NO_x [7]. Besides other measures such as staged injection of secondary air [4,5] or the use of recirculated flue gas [3], combustion with low excess air effectively reduces NO_x in the flue gas.

With a combination of all three measures, uncontrolled NO_x levels could be reduced to below 150 mg/Nm^3 (at 11 % O_2), while the average O_2 concentration at the boiler exit was around 3 vol % [6]. With such low NO_x levels to be treated by the NO_x abatement system (SCR or SNCR), the consumption of ammonia can be markedly reduced. It also enables SNCR systems to achieve lower emission limits.

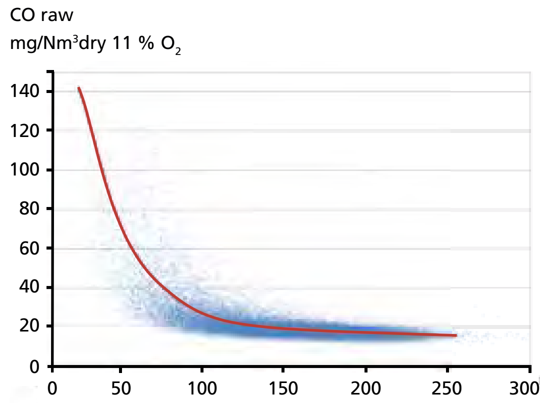


Figure 8:

Relation of carbon monoxide and NO_x concentration in the raw gas for an EfW plant equipped with recirculated flue gas. The one-minute averaged values were recorded over one month while running the plant at an O_2 set point of 3 vol % wet.

Source: Strobel, R.; Waldner, M. H.; Gablinger, H.: Highly efficient combustion with low excess air in a modern energy-from-waste (EfW) plant. In: Waste Management, 73, 2018, pp. 301-306

Similar to the considerations regarding power upgrades, a stable combustion process is crucial for successful operation at low O_2 levels. With less oxygen present in the combustion process, the formation of carbon monoxide (CO) becomes more critical and needs to be under control. The relation of CO and NO_x in the raw exhaust gas is shown in Figure 8. The data shown was recorded during a one month period of operation with O_2 set point of 3 vol % wet. It can be clearly seen that the optimal point of operation yields NO_x concentrations between 100 and 150 mg/Nm^3. Below 100 mg/Nm^3, the amount of CO increased significantly. A well-tuned combustion control system will thus find the optimal point of operation in terms of CO and NO_x formation and adjust the excess air accordingly [6].

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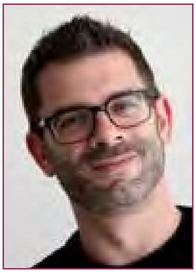

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