MARTIN plants and technologies

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Denmark has a long tradition for Waste to Energy (WtE). Totally in Denmark, 25 WtE plants generate power and district heating from waste. Around 30% of total Danish waste arisings are used for energy generation.

Almost ten years ago, the board of ARC (Amager Ressourcecenter, a publicly owned waste management company in Copenhagen, Denmark) started discussing how to meet the future waste challenges in the five owner municipalities.

ARC inaugurated its first WtE plant back in 1970, and during the first decade of this millennium it became clear that the old plant, due to its age and condition, would have to stop production in a not too distant future. Waste quantities treated at the old plant amounted to some 430,000 tonnes per year of municipal and industrial waste.

The board and owners of the intermunicipal company – five municipalities with Copenhagen holding the largest share of ownership – were facing some key strategic decisions about the construction of a new plant.

First and foremost, the location of a new plant needed to be chosen, and it was decided to locate it next to the old plant. This decision was primarily based on the district
heating network, which is actually directly connected to the old plant. All calculations showed that energy efficiency and waste handling would be optimal with the existing infrastructure. The old plant was to cease production after the opening of the new one, and minor improvements were to be made to extend the life of the plant until the new one was in operation.

However, not only the energy system played a role in the location of the new plant. When the old plant opened in 1970 it was located on the outskirts of Copenhagen, but over the years the Danish capital had seen rapid growth in population and a shift from a blue-collar to a white-collar city. So now ARC was actually located in not an industrial, but in a residential area. Consequently, the new plant needed to be integrated in urban life.

Having realized this, it was clear that the architecture of the plant could not be a standard solution. The board decided that there was to be public access to the plant in some manner and that the plant was to contribute to the city landscape with something out of the ordinary. In fact, one of the major tourist attractions in Copenhagen is the Little Mermaid: when you stand looking at her you can see the plant in the not so far distance. To meet these ambitions, an architectural completion was held in 2011 and the winner was BIG, Bjarke Ingels Group, with the proposal for Copenhill. The idea behind this Copenhill was to use the roof of the plant for recreational purposes in form of a ski slope and a café. Under the heading of Hedonistic sustainability the idea was to show that eco-friendly behaviour is not about abstaining from fun – by contrast making a point to the opposite.

Denmark is the home of quite a few large companies with knowledge and experience in WtE. The world still needs WtE capacity and Danish industry has a substantial export of technical and consultancy expertise. Therefore, it was decided as a second strategic issue that the plant was to have the highest standards for environmental protection and energy efficiency: in this way it could be a modern showcase for WtE, attracting international interest in Danish and international companies working on the new plant. The ambition was clear:

*Copenhill was to be equipped with the best available technology with the highest environmental standards and energy efficiency.*

So as the planning was about to begin two strategic decisions stood clear:

The New Plant was going to be part of the city and had to have public access and a friendly and inviting architecture. The name Amager Bakke was coined for the plant. The name Amager Bakke is bound to the local area but international attention led to the use of the english name Copenhill to help the geographical understanding

Amager Bakke should be a showcase for Waste to Energy and therefore the plant should be state of the art regarding environment and energy efficiency.

The plant was designed with two parallel lines with a total capacity of 560,000 tonnes per year and each line having a separate flue gas cleaning system.
1. Financing of Copenhill

With these high ambitions for the plant, heavy investments for the company and its owners were called for. Total costs of the project were estimated at around 530 million EUR. In the Danish system it is not an option to finance such a project with taxes; instead, Copenhill has been financed with a loan from the Danish bank for municipalities and regions, KommuneKredit. KommuneKredit's business model is essentially about creating financial latitude for Danish municipalities and regions by offering funding and financial advice at the lowest possible cost.

The business model of Copenhill rests on two sources of incomes: a gate fee for all incoming waste and sale of energy to the Nordic Market Pool for electricity and supply of heat to the district heating system where the prices depends on a complicated model involving three different prices. The gate fee is around 60 EUR/tonne, but at least two thirds of that fee go back to the State as a tax. The Budget works on a cost-coverage non-profit principle under which revenues and expenses have to balance on a five year basis.

2. Construction of Copenhill

During 2011 and 2012 the technical requirements were put up for tender following detailed investigations of capacity, energy efficiency and environmental standards.

Based on assessments of total waste arisings it was decided to expand the capacity of the plant to 560,000 tonnes a year: in doing so the plant would be able to meet the expected continuous growth of the population in the coming 30 years’ period.

The construction of Copenhill began in March 2013. With more than 6,000 men and women from all over Europe involved in the building process, it was important to be crystal clear about priorities.

Throughout the building process, there were three top priorities: (1) safety, (2) orderly conditions and (3) the education of apprentices. The ambition was to ensure that all work was done under orderly and secure conditions for everyone involved according to the standards that apply to the Danish labour market. At the same time, it was a goal to use the construction project as an opportunity to train new apprentices.

In many ways, ARC has been a pioneer – enrolling new clauses in the contracts, finding and hiring apprentices, and developing new work procedures to live up to the new clauses.
This has not only been a priority for ARC; it was also ensured that suppliers’ compliance with the contracts was actively followed up. Hence, whether directly or indirectly involved in the building process, everyone involved had to adhere to the same safety rules.

Under the headline *one accident is one too many*, an occupational safety coordination team was established from the start to monitor health and safety issues at the building site. Similarly, from day one it was mandatory for all people with access to the construction site to attend a safety course and carry ID cards. Every single morning, the health and safety coordinators met to review the activities of the coming days in relation to safety. And they made daily rounds to follow up on issues, answer questions and have a hands-on feel on what was going on around the building site. This clear focus was a huge success – even in the most hectic periods there were 75% fewer work injuries compared to similar construction sites in the country.

Next, it was important for ARC to ensure that all work was done under orderly conditions and according to the standards that apply to the Danish labour market. And the company succeeded. By entering into close dialogue with trade unions and contractors, and by conducting follow-ups and checks, Danish pay and working conditions at the construction site were secured.

One last area of prioritisation was the establishment of new apprenticeships. ARC wanted to use the construction process as an opportunity for suppliers to educate new apprentices for the future labour market. At the outset of the construction, a goal was therefore set of 62 apprenticeships a year throughout the construction period. Towards the end of the project in April 2017, this had grown to 68 apprenticeships a year.

3. Copenhill and environmental performance

The plant is built to fulfil the highest level of environmental performance, even at European level. The plant certainly manages to comply with these stringent emission levels. There have been several reasons to request such stringent requirements, the major one being the desire to secure that future levels can be complied with. Furthermore, the plant is located close to the centre of Copenhagen, and within a few kilometres from the Queen’s castle. The ski slope on the roof has also played an important role in the process of setting the emission levels.

Companies polluting must, according to the Danish Environmental Protection Act, limit pollution to match best available techniques, BAT.

The EU decides the environmental requirements for European companies based on what can be achieved with the *best available techniques*. The environmental requirements are formulated as BAT conclusions and form part of the so-called BREF documents: *BAT reference documents*.

BREF documents are reviewed every eight years so that new techniques can be reflected in the legislation. BREF documents – and BAT – have been prepared for about 30 industrial sectors.
The environmental requirements of the BREF documents include the companies’ emissions and use of resources. In accordance with the EU Industrial Emissions Directive (IED), which was implemented in Denmark on January 7, 2013, the BREF documents are binding on the companies in the sense that they are incorporated into their environmental approvals. Companies have a duty to comply with the new requirements no later than four years after publication of BAT conclusions.

Compared to the emissions from the old plant it is seen that the emissions of SO$_2$ have been reduced by approximately 97 %, and NO$_x$ has been reduced by about 85 %.

During the first year of operation the actual environmental performance of the plant has now been demonstrated. Table 1 compares the different limit values with actual measured emissions.

Table 1: Overview of different limit values for emissions into the air for WtE plants compared with typical measured emission values based on the first year of operation; the values are based on daily averages

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Unit</th>
<th>EU Directive</th>
<th>Environmental approval</th>
<th>BREF-document (new plants)</th>
<th>Typical measured value (average)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Particulate</td>
<td>mg/m$^3$ (s,d) 11% O$_2$</td>
<td>10</td>
<td>5</td>
<td>2-5</td>
<td>0.82</td>
</tr>
<tr>
<td>HCl</td>
<td>mg/m$^3$ (s,d) 11% O$_2$</td>
<td>10</td>
<td>5</td>
<td>2-8 (2-6)</td>
<td>0.58</td>
</tr>
<tr>
<td>SO$_2$</td>
<td>mg/m$^3$ (s,d) 11% O$_2$</td>
<td>50</td>
<td>30</td>
<td>5-40 (5-30)</td>
<td>1.16</td>
</tr>
<tr>
<td>NO$_x$</td>
<td>mg/m$^3$ (s,d) 11% O$_2$</td>
<td>400</td>
<td>100</td>
<td>50-150 (50-120)</td>
<td>14.65</td>
</tr>
<tr>
<td>Hg</td>
<td>mg/m$^3$ (s,d) 11% O$_2$</td>
<td>0.05</td>
<td>0.025</td>
<td>0.005-0.020 (0.005-0.020)</td>
<td>0.0004</td>
</tr>
<tr>
<td>Sum of 9 metals</td>
<td>mg/m$^3$ (s,d) 11% O$_2$</td>
<td>0.5</td>
<td>0.25</td>
<td>0.01-0.3</td>
<td>0.009</td>
</tr>
<tr>
<td>Dioxins (TEQ)</td>
<td>ng/m$^3$ (s,d) 11% O$_2$</td>
<td>0.1</td>
<td>0.08</td>
<td>0.01-0.08 (0.01-0.06)</td>
<td>0.0015</td>
</tr>
</tbody>
</table>

Such a significant reduction of the emissions will normally produce higher amounts of residues from the flue gas cleaning process. This is not the case, however, as Copenhill is equipped with state of the art flue gas cleaning equipment utilising the reaction/absorption agents in a much more efficient way than hitherto.

There are two major differences from the old to the new flue gas cleaning system; firstly, Copenhill is equipped with a wet flue gas cleaning system while the old plant used dry and semi-dry processes. This change has resulted in a decrease in residues of some 45 %.

Secondly, wet flue gas cleaning has the advantage that the residues split into three fractions; fly ash, sludge from cleaning of wastewater, and gypsum from SO$_2$-removal. This fractionation gives Copenhill the possibility to utilise each residue individually by adjustment in the cleaning processes.
The only disadvantage of the flue gas cleaning process at Copenhill is that it produces wastewater that has to be treated before discharge to the sea. The environmental requirements for treatment are very strict and under constant surveillance.

Figure 3: Diagram of Copenhill WtE plant including flue gas cleaning process

4. Copenhill energy performance

A high-energy performance begins with a clean and effective combustion process. Actually, the combustion process also has an influence on the environmental performance, as the combustion minimises unburned items, including organic micro pollutants such as dioxins/furans and PCBs, thereby reducing the need for subsequent cleaning. At Copenhill measurements demonstrate a very low level of dioxins/furans in the flue gas outlet of the electrostatic precipitator.

An effective combustion is primarily assured by high temperature and sufficient time to burn the gases. Given a physical design of the incinerator and the boiler, the main parameter influencing the combustion temperature and the retention time of the gases at high temperature is the volume of combustion air blown into the furnace; this parameter is measured as oxygen content in the flue gas after the boiler.

An oxygen content in the flue gas very close to zero will give the highest effectiveness. However, a high combustion temperature causes the flue gas to start smelting and becoming adhesive. The fouling will then grow rapidly which may result in much lower heat transfer from flue gas to water/steam and even to blockage of the boiler. Consequently, the optimal excess amount of air has to be found.

The above description is valid for the direct boiler efficiency, but as indicated in Figure 1 Copenhill also generates district heating by utilising the condensation energy of the
water vapour in the flue gas. This takes place in two steps, both of which are integrated in the flue gas treatment as a third scrubber step.

The first condensation step is direct condensation by means of a slurry with activated carbon which is chilled with cold water returning from the district heating system. The second condensation step uses steam-driven heat pumps to chill condensed water from the flue gas. The bleed of condensed water is either reused as feed for the production of boiler water, or purified before it is emitted into the sea.

Due to the condensation steps, the overall design efficiency is 106 %, based on lower heat value in the waste. The first year of operation demonstrates an overall efficiency of 103 %, of which the condensation step gives 12 to 13 %-points.

This leaves the direct boiler efficiency at 90 %. This value is comparable to the old plant, which demonstrated an efficiency of approximately 82 %. Amager Bakke is indeed quite superior to the old plant.

R1 efficiency

The EU Waste Incineration Directive 2008/98/EC sets up a calculation method for a defined R1 efficiency. This R1 efficiency is not comparable with the efficiencies calculated above, but only used to benchmark WtE plants across Europe and classify the plants into different categories. The highest ranking category is facility for recovery of energy, which requires an R1 efficiency of at least 65 %.

The calculation for Copenhill, based on design parameters, gives a R1 efficiency of 143 % – it can be concluded that the energy contained in the waste fed into the plant is recovered in a very efficient way.

5. First waste fire and production

The plant had its first waste fire in June 2017 and was in commissioning in the years 2017, 2018 and early 2019. During its first entire year of production the plant received 443,000 tonnes of waste and supplied 135 GWh of electricity and 1,090 GWh of district heating. This corresponds to the annual electricity consumption of 30,000 families and the district heating consumption of 60,000 families.

In the years to come the generation of Energy will increase as Copenhill will reach its full capacity.

6. Facts about Copenhill

The construction of Copenhill has consumed about 5,000 tonnes of steel and approximately 35,000 m³ of concrete.

The building is 200 meters long, 60 meters wide and 85 meters high. The smoke stack is 125 meters high.

The capacity of the pit is 37,000 m³.
The main consultants were:
Bascon A/S
BIG CPH
Moe & Brødsgaard A/S
Rambøll Energi

The contractors are:
NCC
GEO Copenhagen
Tvilum Landinspektørftirma A/S

The suppliers of equipment were:
Furnaces: Babcock & Wilcox Vølund
Turbine & CMS (control and monitoring system): Siemens Denmark A/S
Flue gas cleaning system: LAB France

The total costs of the Copenhill WtE plant amounted to 533 million EUR.

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