Waste-to-Energy and Social Acceptance: Copenhill WtE plant in Copenhagen

IEA Bioenergy: Task 36

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Index

Preface

This is the first of a case study compilation to explore lessons on material and energy valorisation of waste within the framework of IEA Bioenergy Task 36. The set of case studies will be published during 2021 covering social and public acceptance aspects, barriers in Waste-to-Energy (WtE) implementation, success stories for decentralized solutions, and integration of WtE within material and/or nutrient recovery. The purpose of these case studies is to showcase examples from which countries can get inspiration and support in implementing suitable policies and solutions in the waste/resource management and WtE sector that would facilitate their transition towards circularity.

IEA Bioenergy Task 36, working on the topic 'Material and Energy Valorisation of Waste in a Circular Economy', seeks to raise public awareness of sustainable energy generation from biomass residues and waste fractions including MSW as well as to increase technical information dissemination. As outlined in the 3-year work programme, Task 36 seeks to understand what role energy from waste and material recycling can have in a circular economy and identify technical and non-technical barriers and opportunities needed to achieve this vision.

See http://task36.ieabioenergy.com/ for links to the work performed by IEA Bioenergy Task 36.

Summary

The construction of the Copenhill Waste-to-Energy (WtE) plant in a residential suburb in Copenhagen redefines the concept of a WtE plant. This is not just because of its location in a residential area and its special architecture, since that had already been achieved by Spittelau WtE plant in Wien (Austria); but rather for providing a multi-functional building with room for social and industrial activities in a sustainable manner and with good utilization of urban space. Copenhill represents an example of integration of WtE plants in an urban area and collaboration with the residents to achieve social acceptance in the activities developed by the waste and energy sector. In other words, Copenhill is the first WtE-plant of a new reinvented concept; there may be lessons in this for planned projects around the world, as a lack of community acceptance is often cited as a factor in unsuccessful proposals.

Located only 2 km away from the Royal Palace, Copenhill is integrated into urban life with its innovative architectonic design offering a recreational area on the facility rooftop that includes an all year skiing slope, and a champagne bar for those who would like to visit, as well as a climbing wall on the facade.

From a technical point of view, Copenhill was conceived from the idea of being a WtE plant showcase that Denmark could export to the world. Therefore, it was built using the best available technology to ensure the highest environmental performance and energy efficiency all in all in the safest environment. In addition, the construction site was used for training apprentices in works associated with the construction of WtE plants, providing economic benefit for the community.

This case study describes technical and economic aspects of the Copenhill plant, and how Amager Resource Center (ARC), owners of Copenhill, and the residents in the city of Copenhagen found the way to share a common area in which everyone could feel safe and contribute to a more sustainable city while being a profitable business.

Background

Amager Resource Center (ARC) is a non-profit public company owned by five municipalities (Dragør, Frederiksberg, Hvidovre, Copenhagen and Tårnby) in the area of Copenhagen that provides waste management services for 645,000 citizens and 68,000 businesses while providing electricity to 80,000 households and district heating to 90,000 apartments. Its business area includes collection of household waste and recyclables, recycling, a Waste-to-Energy (WtE) facility (named as Amager Bakke in Danish and Copenhill in English), sorting plants and a landfill.

The first ARC WtE plant began operations in 1970s and had a capacity of c.a. 430,000 tonnes of municipal and industrial waste per year. In 2010, ARC realized that in order to meet the future waste challenges, the ARC WtE plant needed to be replaced or updated since it could not be in operation for too long due to its age and condition (1). At that time, ARC decided to set a strategy for constructing a new WtE plant that would have the capacity to treat the expected increased amount of residual waste in the most efficient and environmentally friendly way.

The first challenge was to find the right location for the plant. Financial and technical calculations showed that the location of the old ARC WtE plant in the island of Amager was indeed the most suitable from an energy efficiency and waste handling point of view (1) since part of the already existing infrastructure to connect to/access the district heating network and waste weighting facility could be used.

When the old ARC plant was built, the island of Amager was the outskirts of Copenhagen. However, the city has grown over the years towards that area and nowadays the plant is not surrounded by residential areas, but it is part of it. Therefore, the new plant had to have an architecture that would fit with the surroundings and, in some way, would merge with the urban lifestyle in the area.

In 2010, an architectural tender was held in which it was demanded that the plant should be accessible for the public. The winner was announced in January 2011. The Danish Bjarke Ingels Group (BIG) with the project for Copenhill that proposed to add a recreational area that included a ski slope on the rooftop of the WtE plant and could show that both worlds, living a sustainable life and having fun, could go together.

In addition, Denmark plays an important role in the WtE sector, exporting technology and knowledge all over the world. Therefore, it was decided that Copenhill should be an example of the best available technologies, highest environmental performance and greater efficiency that could raise interest internationally and bring business back to Denmark.

Waste sources and logistics

Copenhill treats the residual waste of 645,000 inhabitants and 68,000 companies. In 2020, Copenhill converted 599,000 tonnes of waste into heat and electricity. Approximately 23 % of the waste fuels incinerated at Copenhill is residual waste generated by households from the 5 owner municipalities, while the rest is commercial and industrial waste. The plant was mainly built to serve the five municipality owners but, as the capacity is higher than the demand, Copenhill also receives waste from other countries during winter and other municipalities if they experience difficulties with their own WtE plants (Figure 1).

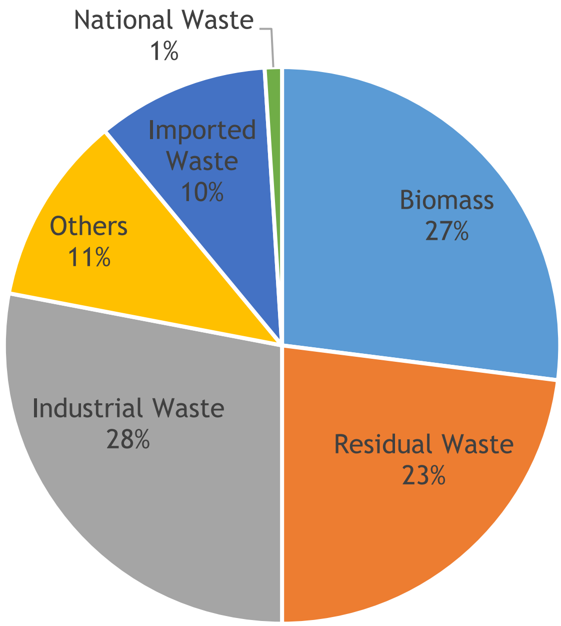

Figure 1. Distribution (%) of the waste treated in Copenhill during 2020. The total amount of waste treated at the plant that year was 599,000 tonnes.

The waste is source sorted prior to collection but each municipality does it in a different way. However, from July 20201 all 98 Danish municipalities are obliged to sort and collect the different waste fractions: food waste, glass, paper, residual waste, metal, plastics, food and drinking packaging, cardboard, textiles and hazardous waste.

Copenhill receives 250—300 trucks with residual waste per day (2). At the reception, the trucks are weighted and approximately 5 % of them undergo random inspection to guarantee that the waste received is suitable for incineration, which means that any waste that is not in line with the environmental permit or that might cause damage to the facilities is rejected.

The proximity of the WtE plant to the households and commercial and business activities where the residual waste is generated, minimizes the transport distance leading to lower emissions, reduction of problems of smell of dust, and save costs.

Technical Implementation

The new Copenhill WtE plant was meant to replace the old one built back in the 1970s and was expected to have a better environmental performance and energy efficiency. Nowadays, Copenhill WtE is considered as one of the best plants in the world regarding:

- environmental performance,
- energy efficiency,
- and safety

which guarantees a safe and sound environment which is crucial to operate in the area.

The capacity of the plant was increased from 430,000 to 560,000 tonnes/year to meet the expected increased on residual waste to be treated in the area in during the coming 30 years. The plant is equipped with two furnace lines operating at 25—35 tonnes of waste per hour each (2-3) (Figure 2). Note that the capacity of the plant in tonnage is dependent on the calorific value of the waste fuel. According to the environmental permit, Copenhill can treat maximum 560,000 tonnes/year at a net calorific value of 11.5 GJ/ton. If the average net calorific value of the waste fuel is lower than 11.5GJ/ton, then more waste fuel can be treated. Each line is equipped with a Babcock & Wilcox Vølund's grate-fired boiler (112 MW fired per boiler) called DynaGrate® with water-cooled wear zone, a flue gas condensation system and a joint Siemens steam turbine and generator system. The turbine and generator is supplied with 440 °C steam at 70 bar (Table 1) (4,7). The net thermal efficiency of the plant is 107%[1]. Copenhill operates 24 hours a day, 365 days a year[2].

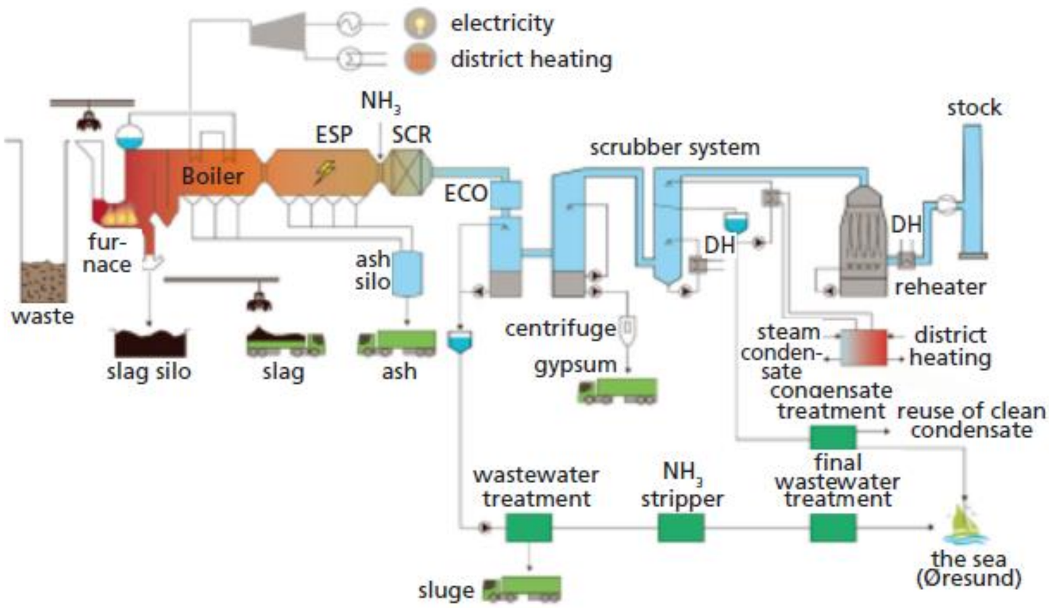

Figure 2. Diagram of Copenhill WtE plants including flue gas cleaning system (1)

Each line has a separate flue gas cleaning system which also differs from the equipment in the old plant. While the old plant used dry and semi-dry process, the new one uses wet cleaning equipment leading to a 45 % decrease in solid residues. In addition, the wet flue gas

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1 Based on the net calorific value. When the net calorific value is calculated, the energy needed for evaporation of the moisture in the fuel is deducted. In a plant with flue gas condensation, part of that evaporation energy is recovered which then from the definitions can result in an efficiency >100%.
2 The plant is normally in operation all year around; however each line will be closed for maintenance during certain periods. so the plant will not operate at full capacity all year around.

system cleaning generates 3 waste fractions: fly ash, filter cakes from wastewater cleaning and gypsum from the SO_2 removal system (1). The wastewater needs to be treated before being discharged to the sea.

The R1 efficiency (11) of the plant (calculated based on designed parameters) is 143 % which is way above the 65 % required by the EU Incineration Directive 2008/98/EC for facilities for recovery of energy, meaning that the Copenhill plant recovers the energy from the waste combusted in a very efficient way.

The location of the plant was in some way related to technical and economic aspects. Building the new incineration plant at the same site as the old one allowed to use the already existing infrastructure for putting the electricity and heat into the network of the city of Copenhagen, which saved costs. In addition, the location of the plant in an urban area considerably reduces the transport of the waste, reducing both costs and emissions.

Table 1. Plant design parameters for each of the line at Copenhill WtE plant (4-7)

Parameters	Values
Waste fuel Capacity	35 ton/h
Lower heating value	11.5 MJ/kg
Steam output	141.1 tonne/h
Steam temperature	440 °C
Steam pressure	70 bar
Boiler outlet flue gas temperature	160 °C
Boiler outlet flue gas temperature	160 °C
Net electricity efficiency	17%
Net thermal efficiency	83%

TECHNICAL CHALLENGES

The construction process itself had one-year delay and the budget had to be increased by c.a. 10%.

The initial project included a chimney that instead of emitting its exhaust continuously, it would do it in the form of “smoke rings”, made from steam. The idea behind this was that one water vapour ring would be emitted for every tonne of CO_2 that would be saved in comparison to the old plant. The idea was that this should be seen as a reminder to the locals about consumption and sustainability. The idea of the smoke rings had to be abandoned since the installation would require a part of the steam that could otherwise be used for generating energy, thus decreasing the energy efficiency of the plant. Energy efficiency and production cost of energy had to be prioritised in order to supply the city with cheap heat prices and low waste fees.

Economical aspects

FUNDING THE PROJECT

Waste-to-Energy plant

The total investment for the construction of the plant c.a. 500 M€. This high investment was possible because of a long-term financial plan that will guarantee that the plant will be up and running and keeping the business for around 30 years. The construction of the plant was financed with a loan form the Danish Bank for municipalities and regions, KommuneKredit, that provided funding at a very low cost (1) and the loan was guaranteed by the 5 municipality owners.

Figure 3. View of the Copenhill plant

Recreational Area

The cost for the recreational area was close to 11M€. According to the Danish legislation, as in most of the countries, no public money from the energy/heat production or waste taxes can be used for such a project. Therefore, the recreational part of the building was set up as a total independent private foundation (The Amager Bakke Foundation) that was responsible for raising funds for its construction. Private foundations and donations contributed to 49 % of the total budget, while the remaining 51 % was loaned from the owner municipalities. ARC stated that the only disadvantage of having a private operator running the recreational facilities on the rooftop was the need of signing contracts that, in most of the cases, were quite complicated. Apart from that, the cooperation between the public entity and the private operator has worked well (3).

INCOMES/REVENUES

Copenhill has two types of incomes: the gate fee for the incoming waste and revenue from selling heat and electricity to the market.

The gate fee for handling waste is c.a. 60 €/tonne and c.a. 60 % of it is goes to the government as tax. In 2020, Copenhill supplied heat to 90,000 apartments (1.363 GWh) and electricity to 80,000 households (244 GWh) (7).

The connection to the plant to the district heating network allows selling heat all year-around at almost full load (7). The fact that Copenhill is close to the areas where the district heating is needed, makes it easy to transfer the energy generated by the facility to the local network making possible a sounder business case. The price for the heat depends on a set model that considered three different prices. The electricity is traded on the Nord Pool market.

Environmental Aspects

Copenhill was built with the aim of complying not only todays' strictest national and European emission standards, but also those that might be set during the coming 30 years that the plant is expected to be operative. In addition, the facility is in a residential area in Copenhagen and has a recreative area in its rooftop which requires an extra effort to guarantee that the environmental performance is met.

Aspects like no odours or dust from waste transportation and as low emissions as possible from the plant were crucial for ensuring a sound environment for those living in the surroundings and enjoying the recreational areas, resulting in very few complaints about these matters from those living in the area – according to ARC (5).

FLUE GAS CLEANING

One of the biggest achievements of Copenhill has been to use the available technology in a new setting. That is the case of the selective catalytic reduction (SCR) system. The NOx reduction could be achieved thanks to a front-end (hot) (SCR) of NOx by ammonia. By placing the SCR in the front and not in the tail-end, the process allows to save energy (7). Each furnace line has a separate flue gas-scrubbing system composed by an electronic filter that removes most of the fly ash in the smoke, and 3 scrubbers that remove hydrochloric acid, mercury, and other undesirable substances. The sulphur dioxide is removed using lime, a dust filter eliminates the last remnant of dust in the smoke and the moisture is condensed into water. This disposition was chosen because of (7):

- its high flexibility: it can cope with more restrictive environmental requirements
- being able to treat flue gas with a potential high concentration of pollutants
- using environmentally friendly consumables such as limestone
- the wastewater generated could easily be treated
- the amount of solid waste generated was low, and
- high energy recovery

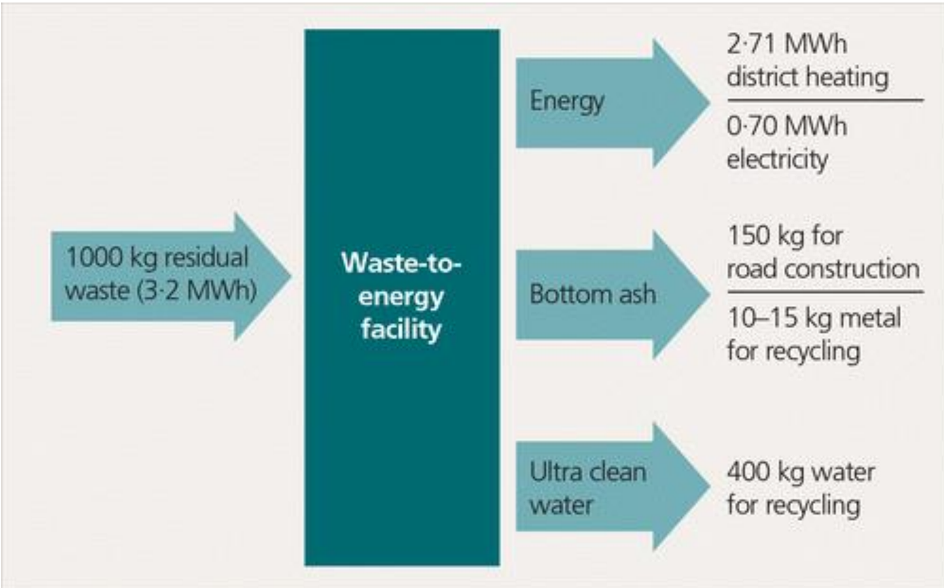

Figure 4. Outputs from Copenhill (7)

The emissions levels for the first year of operation of the plant are compared to emission limits set by the legislation in Table 2 and demonstrates that the is operating below those limits and that the way waste is treated in the plant in a sound way.

QUICK FACTS ABOUT EMISSIONS

The flue gas cleaning systems achieve:

- 99% reduction of hydrochloric acid
- Dioxins are removed
- 99.5% reduction of sulphuric acid
- NO_x removed by 96%

*Table 2. Comparison of different limit values for emissions into the air from WtE plants typical measured emissions emission values based on the first year of operation. The values area based on daily averages (1). Unit: mg/m3 (s,d.) 11 %O2. *Sum of 9 metals: Hg, Cd, Tl, As, Pb Cr, Cu, Ni and Zn. BREF: best available techniques (BAT) reference (9). TEQ: toxic equivalence.*

Parameter (mg/m³ (s,d) 11 %O_2)	EU Directive	Environmental approval	BREF	Copenhill facility
Particulate	10	5	2-5	0.82
HCl	10	5	2-8	0.58
SO_2	50	30	5-40	1.16
NO_x	400	1000	50-150	14.65
Hg	0.05	0.025	0.005-0.002	0.0004
Sum of 9 metals*	0.5	0.25	0.01-0.3	0.009
Dioxins (TEQ)	0.1	0.08	0.01-0.08	0.0015

WASTEWATER

The process generates condensate and wastewater that after treatment is discharged to the Øresund sea. The discharged water needs to meet the metal content standards established for drinking water as a way proving that is not polluting the sea.

ASHES

Approximately 17-20% wt. of the waste burnt at the plant remains as slag (bottom ash). The slag is treated with the aim of recovering metals for recycling. For every 200 kg of slag, 10-15 kg of metal can be recovered and be reused or recycled (6). The remaining slag is used as filler in road construction activities. It is estimated that 15-20 kg of fly ash are generated per ton of incoming waste.

CO_2

Copenhill is running a pilot project for coupling CO_2-capture technology to its plant. From 2022, the demonstration plant will be able to capture 12 tonnes CO_2 per day and it has recently been decided that this pilot plant will be upscaled in the coming year. That decision means that c.a. 500,000 tons of CO_2 annually emitted by Copenhill might be captured the direct CO_2 emissions to the atmosphere reduced to the minimum. In other words, with this addition, the facility will be able to burn residual waste with very little or no impact on the environment in terms of CO_2 emissions. The CO_2-capture facility will contribute to reach the national goal that Denmark has set on reducing greenhouse emission by 70 % in 2030 and that the municipality of Copenhagen will become the first carbon neutral city by 2025.

Policy Aspects

ENVIRONMENTAL POLICY

The technology was chosen based on a series of criteria that included economic, environmental aspects and legislation. Copenhill was designed to fulfil the requirements set by the in the Danish environmental permit (7) which is based on the EU Directive 2010/75/EU (8) on industrial emissions, and the BAT-reference (BREF) (9). Therefore, Copenhill should be able to cope not only with today's environmental requirements, but also with those to come.

SECURITY

More than 6,000 people were involved in the construction of the plant and the aim was that all the work done was according to the Danish Labour Market to ensure safety. New clauses were included in the contracts with the suppliers to make sure that anyone who participated in some way in the building process, no matter the person was involved directly or not, had to follow the same safety rules.

ORDERLY

ARC had as aim that all the work related to the construction of the new plant were done "*under orderly conditions*" (1) according to the Danish Labour Market. This was achieved thanks to the close discussions with contractors, suppliers, and trade unions and by carrying out follow-up activities. The "*pay and working conditions at the construction site were secured*" (1).

Social aspects

As in other Scandinavian countries where district heating systems is part of the urban infrastructure, WtE is generally well-accepted in Denmark since it provides heat at a relatively cheap price. This approach does not mean that Denmark supports a linear economy over emerging circular economy concepts but that WtE is seen as a necessary part of an effective integrated waste management solution. In its transition to a more circular society, Denmark aims to reduce the total WtE capacity from 3.95 Mton to 2.6 Mton by 2030. However, not everyone has the same opinion, and some have expressed concern regarding the construction of the plant since they consider that the plant was over-sized and that the environmental and economic consequences could be opposite to the expected ones (13).

A common comment is that the WtE competes with recycling and might hamper the recycling since the plants needs so much feedstock. There is also comments about that municipalities that have a WtE plant would have less material recycling because they prioritise providing their plant with combustible waste. In a statistical analysis made by the Danish Waste Association (Dansk Affaldsforening), no such tendencies could be shown. The recycling rate on both MSW and C&IW were on the same level for municipalities that owned (or had part-ownership) of a WtE plant. One explanation to this might be that the WtE plants in Denmark is owned by the municipalities and have political as well as economic targets to achieve.

THE IMPORTANCE OF COMMUNICATION

As the plant was meant to be built in a residential area, it was crucial to have the support from the residents to avoid a "not in my back yard" situation. Therefore, before the construction activities started in March 2013, the construction plan was included in the Municipal Plan which means that for a period of time all the information related the project is open for anyone would like to revise it (i.e., citizens, experts in WtE, NGOs…) and provide feedback.

Figure 5. View of the closest residential area from Copenhill offices

The closest neighbour to the plant is a residential building at c.a. 200 m *Figure 5*. Copenhill and the residents' association have always had a good dialogue while the plant was under construction and after it went into operations. Copenhill communicates with the residents' association whenever something that will take place at the plant could affect them. A good communication with those living in the surroundings is crucial for making this project work.

One success factor in this case might also have been that it was the municipality themselves that were to own and operate the plant and not a private company that might be perceived to put the economic profitability over the safety for the surroundings.

RECREATIONAL AREA

As the plant was built in what will become a residential area, the architecture of the building became extremely important as well as to make sure that the urban space was used in a good way. The idea behind Copenhill was that no fence would separate the facility from the local community, but rather that common areas for sharing would be built to facilitate the integration of the plant in the city.

Six projects participated in the tender, and the one from the Danish architect firm Bjarke Ingels Group A/S (BIG) was selected. The project proposed the construction of a recreational area at energy plant. The recreational area on the rooftop includes a 490 m artificial ski slope (made of plastic and not artificial snow) and hiking/running area and a champagne bar run by a private operator and offers an excellent view of Øresund and the city of Copenhagen. The façade is an 80 m vertical climbing wall. Around 30 local sport organizations were invited to collaborate in the development of the recreational area (7). A new metro line with a stop close to the plant is planned, which means that Copenhill will be fully integrated in the city and will be easy to access.

Figure 6. Copenhill recreational area in the roof top. Source: ARC website, Ehrhorn/Hummerston

INTEREST FROM PUBLIC & PRIVATE PERSONALTIES

From the beginning, the Copenhill attracted interest from the local politicians since it could be a good way to promote Copenhagen as an example of "future green city" (12). Once the project was approved, it also rose interest form politician in high level (i.e. prime minister of Denmark; UN climate delegate), Danish and Swedish monarchy and the climate activist Greta Thunberg who have shown their interest in the project (3).

Copenhill has not invested public money on advertising their facilities since that is not considered as a good use of the public money. However, Copenhill has not objected to private companies financing some advertisement of ARC if that is in some way connected with their interests. That was the case of Audi that sponsored an advertising campaign about Copenhill with ads in Danish newspapers and billboards in some central buildings of the city of Copenhagen. The plant has also got a lot of attention from the running (i.e. Garmin), climbing/bouldering, and skiing community, and welcomes any type of advertisement that could come from their side (3). Copenhill receives also lot of visits from companies and organizations around the world previous booking.

OPPORTUNITY TO TRAIN NEW APPRENTICES

From the beginning, it was a goal that the construction of the plant would become a showcase that could promote the Danish WtE expertise (5). As part of this idea, it was decided to give the opportunity to the suppliers to train new apprentices for the future labour market in all the areas during the construction of the plant. Therefore, when setting contracts with sub-contractors, suppliers, etc. new clauses in this regard were included. In addition, new work procedures/protocols were included to make sure that all the work would take place according to the standards of the Danish labour market and everyone followed the same safety rules. In total, there were 62-68 apprenticeship/year until the end of the construction of the plant in April 2017 (1).

Lessons learned / recommendations

Copenhill WtE plant provides a solution for handling residual waste that cannot be reused or recycled in the municipality of Copenhagen while finding the way to contribute to reach the carbon neutral national targets and serving as an example of how this kind of plants will operate and be part of the urban life in the future.

The lesson learned from this project are:

- *Integration of a WtE plant in an urban area*
  Copenhill is an example of how the WtE plant concept can be redefined. The right use of technology can provide a safe and sound environment where recreational activities and waste management activities can go together. Better use of the urban area, reduction in waste transportation, proximity to the district heating network and high efficiency and environmental performance are among the main features of the plant.

- *Communication with locals is crucial for integrating WtE plants in urban areas*
  Despite of the fact that WtE is well-accepted in Denmark, having such a plant in a residential area might be controversial. Therefore, continuous exchange of information between the WtE plant, residents' representative and business and commercial activities sharing a common urban area is crucial. Being open and involving residents and local association in an early stage of the project and keeping an open communication will make the be part of it. Communication through groups in social media or regular meetings with residents' associations could be a good communication tools in this case.

- *Known pieces of technology can lead to higher environmental performance*
  By using well-known technology in a different way, it is possible to achieve great environmental improvements. The change in position of the SCR from the tail-end to the front in the process allowed to reduce considerable the NOx emissions while saving energy in the process.

- *The construction site can be used as an opportunity for training employees in the sector*
  When a project is conceived as showcase for the world, as it was the case for Copenhill, it is possible to convert the construction site in a place for training employees. In this way, the seed for well-prepared professionals ready to export the

technology developed in the country is plant. Such initiatives provide economic benefits for the community.

Reservation

The sources from the technical data presented in this publication were facilitated by ARC and subcontractors and extra information was gathered through personal communication with ARC with the aim of providing correct and reliable technical data.
It is also important to mention that in regard to social acceptance, there might be more opinions that the ones expressed in this case study, but due to the length of this case study, it was not possible to be included.

Acknowledgments

The author thanks ARC for sharing their insight and experiences as well as technical data.

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