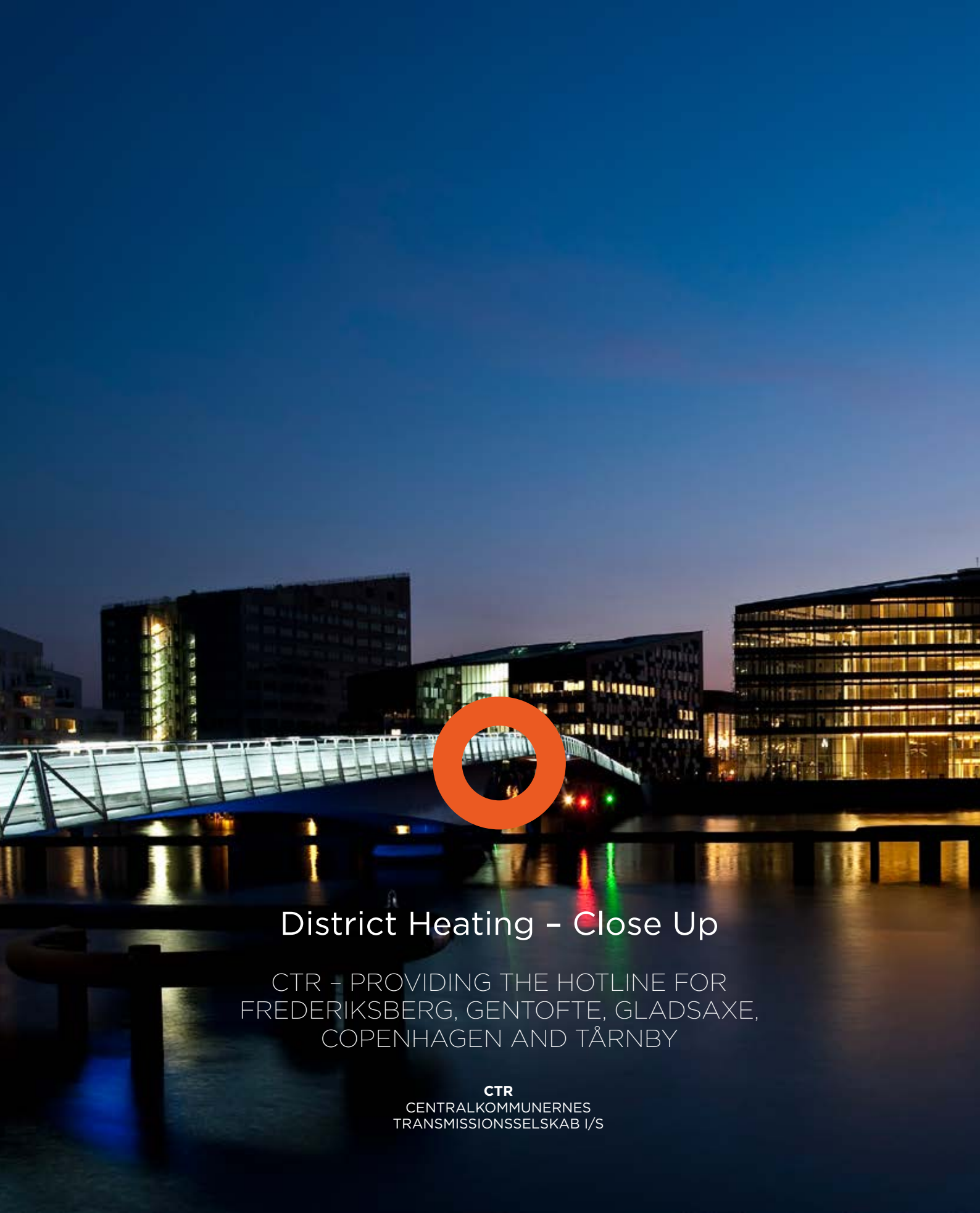


District Heating – Close Up

CTR – PROVIDING THE HOTLINE FOR FREDERIKSBERG, GENTOFTE, GLADSAXE, COPENHAGEN AND TÅRNBY

CTR
CENTRALKOMMUNERNES
TRANSMISSIONSSELSKAB I/S

CONTENTS

From oil crisis to climate-friendly heat supply

CTR: BORN OUT OF THE OIL CRISES OF THE 1970S

DISTRICT HEATING IN COPENHAGEN

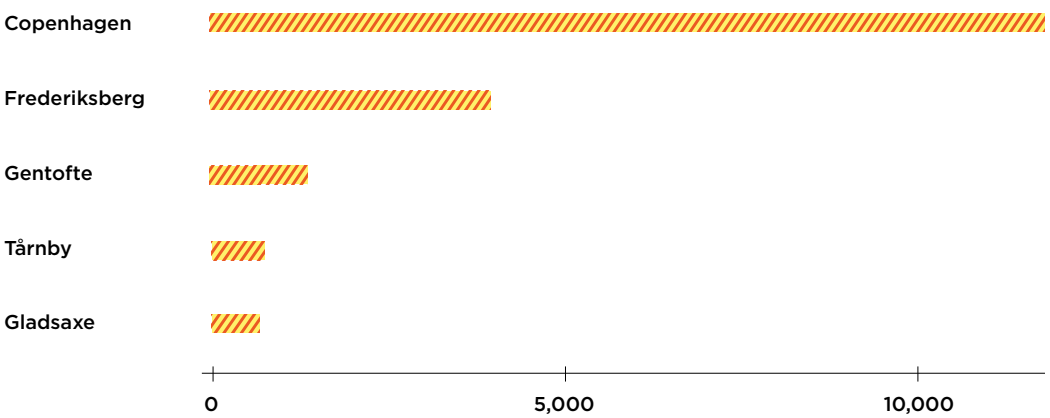
The history of district heating in Copenhagen goes back long before CTR: It began already in 1869, when steam was used for the first time to heat a building in Copenhagen, and in 1903, Denmark's first plant to produce both district heat and electricity was ready for use in Frederiksberg a waste to heat plant. In 1926, power station also started to supply district heat, for recipients such as hospitals.

The history of one of the biggest heat transmission companies in the world began with the international oil crisis of 1973: the crisis transformed energy consumption and energy sources into critical issues, and the question of how a nation could reduce its dependence on oil suddenly topped the political agenda in Denmark.

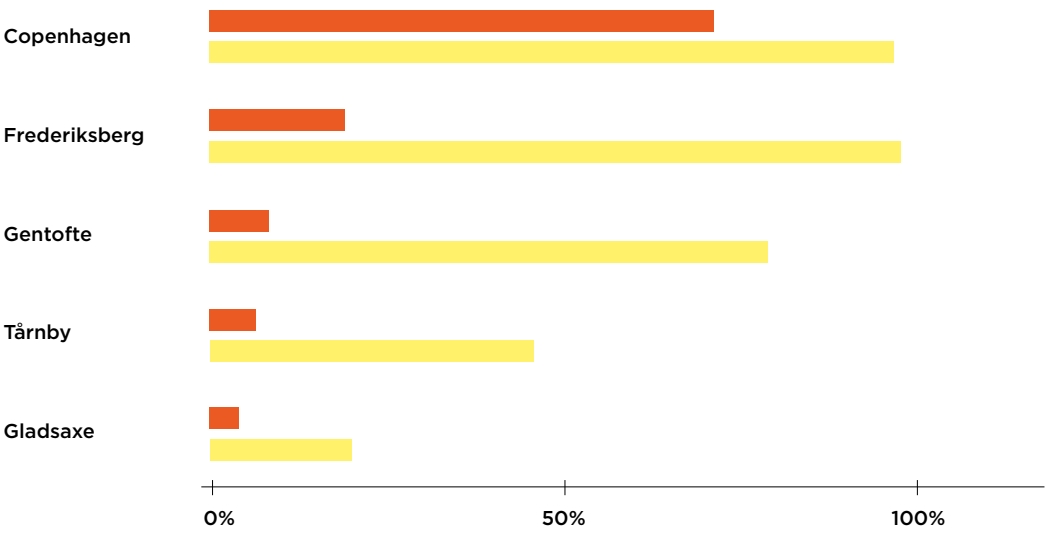
The first energy plan for all of Denmark came in 1976. It stipulated that all new power plants had to generate heat along with electricity, and in 1978 the report "Power and heat transmission in Greater Copenhagen" concluded that it was financially feasible to create a transmission grid for district heating in Copenhagen. The next global oil crisis occurred the following year, prompting a Danish statutory requirement that all municipalities must implement a heat-planning process. Centralkommunernes Transmissionsselskab I/S – formed by the municipalities of Frederiksberg, Gentofte, Gladsaxe, Copenhagen and Tårnby – came into being when the first CTR board took up its duties on 29 February 1984. In 1986, Tårnby became the first municipality to receive heat from CTR's transmission grid, and additional district-heating areas were developed in the municipalities and connected to the transmission grid during the following years.

During the more than thirty years since then, CTR has continually focused on ensuring the supply of

HEATING PURCHASES (TJ, 2013)



OWNERSHIP
DISTRICT-HEATING COVERAGE RATIO, INCLUDING NEW AREAS



heat to the residents of the five stakeholder municipalities at the lowest price possible. The general heightening of environmental awareness in society prompted wishes to make the heat supply more climate-friendly. Today, CTR has a specific strategic objective to make the district heating carbon neutral by 2025.

Day-to-day operation

CTR provides district heating for use by apartment buildings, public institutions, schools, sport centres, manufacturing companies and single-family houses. According to the law, all newly constructed buildings with a total heating requirement of more than 250 kW (equivalent to around 30 normal households) must be connected to the collective energy supply.

In addition, the City of Copenhagen has decided to exercise its legal option of requiring mandatory connection for all households.

CTR is led by an executive management of two individuals and, in 2013, the day-to-day management of the transmission company was provided by around 30 employees, including eight engineers, who ensure that the central control room for the whole heat-supply system is staffed round the clock. In addition, the five municipalities' heat-distribution companies – together with a number of external suppliers – inspect and maintain the 54-km-long district-heating grid with affiliated stations and peak-load and reserve-load plants.

CTR also uses external consultants for planning and other tasks, and for construction projects, technical analyses, legal questions, etc.

Low-cost heat for Greater Copenhagen

STABLE SUPPLY AND LOW PRICES

As the name says in Danish, CTR is responsible for transmitting district heating. CTR is tasked with purchasing heat from producers and reselling it to municipal heat-distribution companies – without making a profit. In other words, CTR is not responsible for generating heat or supplying it directly to end-users: **CTR provides the link between heat production and heat distribution.**

A district-heating company of this size tasked solely with heat transmission is rare. And it is notably the transmission system which helps to ensure optimal heat supply for the residents of the five municipalities of Copenhagen.

Purchase and sale of heat

The heat supply in CTR's transmission system is primarily based on heat from CHP plants and waste-incineration plants. Accordingly, CTR is in constant, close dialogue with CHP plants and waste-incineration plants to ensure the purchase of the right volume of heat from the right plant at the right time. CTR buys heat from a total of six large plants in Greater Copenhagen and resells it to the municipal heat-distribution companies. The price of the delivered heat is agreed with each individual plant in advance. CTR resells the heat at a pool price which is the same for all five stakeholder municipalities. The heating price is fixed according to the principle that CTR's earnings must balance with its costs year by year, as stipulated in the provisions of the Danish Heat Supply Act. If operations generate a financial surplus or deficit in one year, this will be carried forward and included in the calculation of the heat price for the following year.

Collaboration with VEKS and HOFOR

The heat transmission grids of CTR and Vestegnens Kraftvarmeselskab (VEKS) are interconnected, but the two companies are independent of each other. Like CTR, VEKS's grid transmits heat generated at CHP and waste-treatment plants. The two companies collaborate extensively on heat purchases, to stabilise supplies and ensure the lowest heat prices possible. Their collaboration is based on the unhindered pumping of hot water between the companies – through reciprocal purchase and sale – which is possible for the very reason that their transmission grids are interconnected. This maximises their potential to optimally exploit the heat produced throughout the area. CTR and VEKS can jointly buy heat from plants throughout the area offering the lowest prices at the time in question and exploit each other's reserve capacities to stabilise supply: If there is a shortage of district heat in

CTR has a turnover of approx. DKK 2 billion a year

FIVE HEAT PRODUCERS

CTR buys most of its district heating from three CHP plants and three waste-treatment plants.

H.C. Ørsted Power Station
(owned by DONG Energy)

Avedøre Power Station
(owned by DONG Energy)

Amager Power Station
(owned by HOFOR EnergiProduktion)

Amagerforbrænding incineration plant
(ARC)
(owned by 5 municipalities)

Lynetten waste-water treatment plant
(Biofos Lynettefællesskabet)
(owned by 15 municipalities)

Vestforbrænding incineration plant
(owned by 19 municipalities)

VEKS's grid, CTR can start up its own peak-load and reserve-load plants – and vice versa.

CTR also collaborates with HOFOR Varme on buying heat. HOFOR receives heat from CTR to meet the demand of two-thirds of its customers, but buys heat directly from the producer for customers whose heat is supplied as steam.

The three companies – CTR, HOFOR Varme and VEKS – have also set up a partnership aimed at optimising heat procurement, called Varmelast.dk.

Varmelast.dk: Closely regulated procurement system

The two companies which operate the CHP plants in Greater Copenhagen – HOFOR Energi-Produktion and DONG Energy – are competitors insofar as the electricity co-generated with the heat sold to CTR and VEKS is concerned.

This makes for a complex situation where, on the one hand, it must be ensured that the suppliers are not given a competitive advantage by being able to access knowledge of one another's business areas. On the other hand, it must also be ensured that the lowest-cost plants are used to produce district heating at any time of the day or night. For this purpose, a meticulously agreed and closely regulated partnership has been set up between buyer and seller under the auspices of Varmelast.dk.

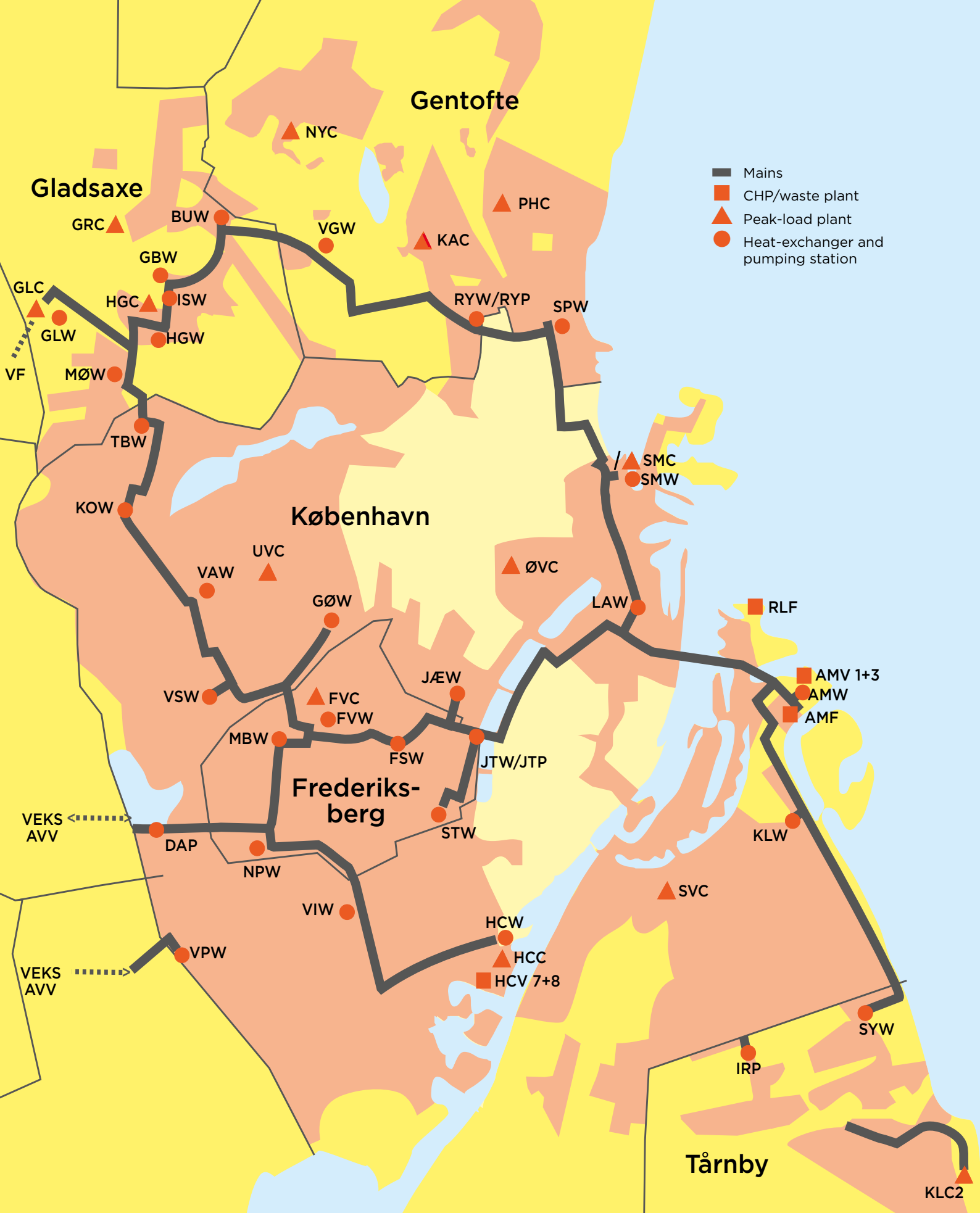
CTR, VEKS and HOFOR prepare heat forecasts for Varmelast.dk every day, showing the heating demand over the next 24 hours, based on meteorological data. After this, the heat producers issue cost graphs. These graphs show the ongoing hourly cost of producing heat over the next 24 hours. The graphs take account of a wide variety of factors such as charges and fuel prices at the individual plants and prices expected on the electricity market; the graphs also take into account that some of the heating demand will be met with steam and the rest with hot water.

Varmelast.dk then calculates the cheapest way to meet the combined heating demand hour by hour and ultimately orders the requisite supplies from the producers. The plans are adjusted three times every 24 hours to take account of any deviations in the heating demand and electricity prices, as well as of any changes at the various production plants.

CTR'S ASSET VALUES	EXPENDITURE, DKK 1,000	PCT OF TOTAL ASSET VALUES
Land and buildings	20,637	1 %
Peak-load plants	464,888	16 %
Heat-exchanger and pumping stations	638,805	22 %
Transmission mains	1,724,648	58 %
Control and monitoring	87,422	3 %
Total	**2,936,400**	

500,000

CTR supplies district heating to 500,000 Danes


Gentofte
Gladsaxe
København
Frederiks-
berg
Tårnby
NYC
GRC
BUW
VGW
KAC
PHC
GBW
GLC
HGC
ISW
RYW/RYP
SPW
GLW
HGW
VF
MØW
TBW
SMC
SMW
KOW
UVC
VAW
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FVW
MBW
FSW
JTW/JTP
VEKS
AVV
DAP
STW
KLW
NPW
SVC
VIW
HCW
VPW
HCC
HCV 7+8
SYW
IRP
KLC2
Mains
CHP/waste plant
Peak-load plant
Heat-exchanger and
pumping station

45 m

Conduits are laid in a utility tunnel bored 45 metres below the water surface.

From CHP plant to radiator

CLOSELY MONITORING THE WHOLE PROCESS – FROM PRODUCTION TO END-USER

CTR's transmission grid extends for roughly 54 kilometres beneath the roads and streets of the five stakeholder municipalities. Hot water flows through this grid in large dual-string pipes: one string for the supply flow and the other for the return flow. CTR's grid ends at the heat-exchanger stations where the municipal heat-distribution companies take over and distribute the heat to the consumers.

Much of the conduit grid is laid out as a ring connection, both to stabilise the supply and out of consideration for the operating economy: this very set-up makes it possible to always get heat from the cheapest source and enables the re-routing of heat in the event of repairs, operational interruptions or similar.

Except for a few sites, the transmission mains are underground, which can be a complicated matter in a large urban area such as Copenhagen. This made it crucial to lay a high-quality conduit grid to minimise costly and difficult maintenance, and is also why different technologies have been used depending on local pipe-laying conditions and the dimensions of the district-heating pipes. The conduits on the section underneath Copenhagen Harbour, for instance, were laid through a utility tunnel bored 45 metres below the water surface.

Seawater in the pipes

CTR's transmission grid is a closed system in which three large pumping stations circulate the same water to the heat-producing plants, which heat up the water, and to the heat-exchanger stations where the heat is transferred to local district-heating grids.

Small amounts of water are naturally lost in the operation of a district-heating system: during re-laying, repair and maintenance work or as a result of gasket leaks from the system's many components. As water is a scarce resource, CTR continually seeks to meet the need for supplementary feed water using sources other than ordinary tap water, eg. processed seawater. The water is kept under very high pressure in the transmission grid. The supply-flow water temperature can be as high as 120 °C, so if the water is not pressurised, it would convert to steam in the pipes. At maximum operation and pressure, the 20,000 m^3 of water contained in the system can flow throughout the system's 54 km in just two hours.

Heat-exchanger and pumping stations

Besides the transmission mains, which distributes heat throughout the supply area, a number of technical plants, or stations, have been built. A total of 27 heat-exchanger stations transfer the heat to the heat-

PRESSURE ON THE SYSTEM

CTR's transmission system contains a total of 20,000 m^3 of water, equivalent to the contents of 500 large tanker trucks. The conveyed water is pressurised at up to 25 bar and flows through the pipes at a speed of up to 4.5 metres/second.

supply mains of the local district-heating companies. The heat exchangers installed at these stations transfer the heat, while keeping the water in the transmission grid separate from the water in the local district-heating grids. This is necessary due to the various systems' vast differences in pressure, temperature and water quality.

In addition, the heat-exchanger stations help to stabilise the operation of the transmission system. This separation ensures that local operational disruptions will not affect the operation of the transmission system – and, thus, the supply in the rest of CTR's service territory.

As the transmission system covers a large geographical area, it is necessary to boost the water along the way, to ensure that it also reaches the remotest grid sections. Three large pumping stations provide this boost by increasing the pressure locally in the system. The vast majority of all CTR stations are underground, which means that, together with the heat-supply mains, they are part of an unseen transmission system which continuously ensures that consumers are supplied with climate-friendly, low-cost heat.

Seven reserve-load and peak-load plants

CTR owns seven reserve-load and peak-load plants distributed at various points of the transmission grid. They are brought on line to meet peak demand in the system or to respond to operational disruptions. These are situations where the large CHP plants cannot supply sufficient output, e.g. due to a very high demand for heat or because one of the plants or CTR stations is being repaired. The reserve-load and peak-load plants can also be brought on line if system bottlenecks arise that impede the supply of sufficient heat for brief periods of time.

Bringing these plants on line is a costly, environmentally-harmful way to generate heat, however, which is why they are only used during a limited period each year. CTR is gradually converting its plants to natural gas, because natural gas costs less and emits less CO_2 than oil. In the long term, the plants will be converted to run on renewable energy to the greatest extent possible.

CKR: the heart and brain of the transmission grid

The heart of the whole transmission grid beats at Frederiksberg, because this is where CTR's control room, called CKR, is located. Even though most days are calm and uneventful, the command centre is dominated by many computer screens staffed round the clock by two engineers on duty during daytime hours and one engineer during evening and night shifts.

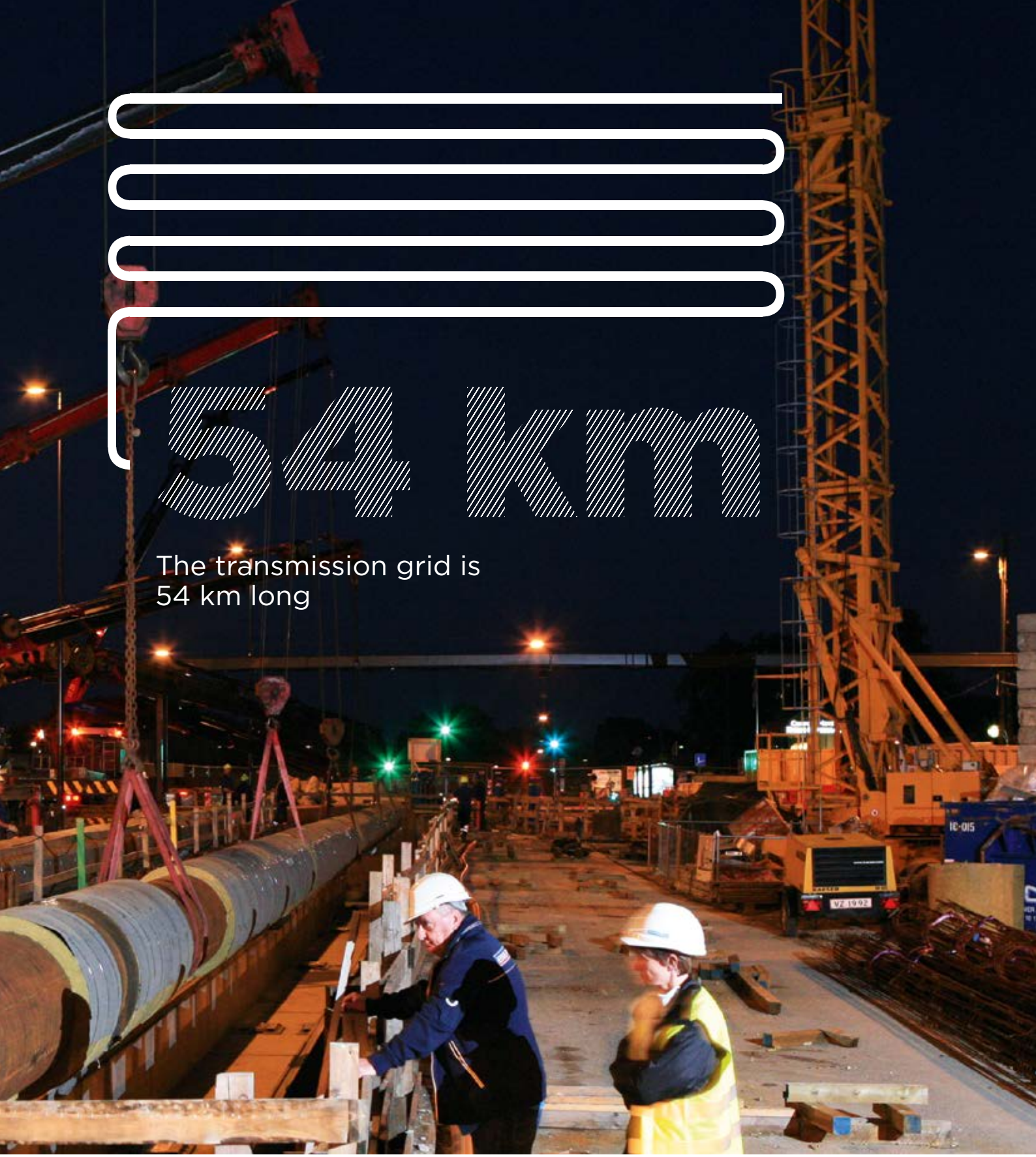
CKR staff manage an enormous control, regulation and monitoring system which constantly keeps track of 10,000 measurements throughout the supply grid. On-duty staff monitor production at the various plants and are automatically warned by the system of any abnormalities in both the production and distribution system.

If a fault occurs in the transmission grid, CKR contacts the municipal heat-distribution companies, which respond by sending staff to rectify the fault. This keeps the response management a step ahead at all times. CKR staff discover the fault and, in most instances, the municipal companies manage to fix it before consumers ever lack heat.

Similarly, the CKR also functions as the brain of the grid: because this is where staff optimise grid operations – thus stabilising supply at the consumers. CKR staff are responsible for deciding when to bring peak-load plants on line, if this is required. They also adjust the supply-flow temperature throughout the system, which is crucial, seeing that just a one-degree rise can increase consumption by millions of DKK annually and correspondingly worsen the environmental impact.

20,000m³

CTR's transmission system contains a total of 20,000 m³ of water



54 km

The transmission grid is
54 km long

District heating is visionary heat

ECO-FRIENDLY HEAT SUPPLY

In densely populated urban areas – such as Greater Copenhagen – district heating is a very climate-friendly source of heat: The district-heating system exploits the surplus heat from the electricity-generation process at CHP plants and, similarly, from the incineration of collected municipal waste at waste-incineration plants. This explains why district heating uses less energy overall than individual heating.

In addition, the production of heat is gathered at a few large units, which makes it easier to efficiently filter and clean gases from the incineration process. Even though the heating demand represents society's biggest need for energy compared to electricity and transportation, the environmental impact of heating in Copenhagen is very low because of district heating.

Focus on carbon emissions

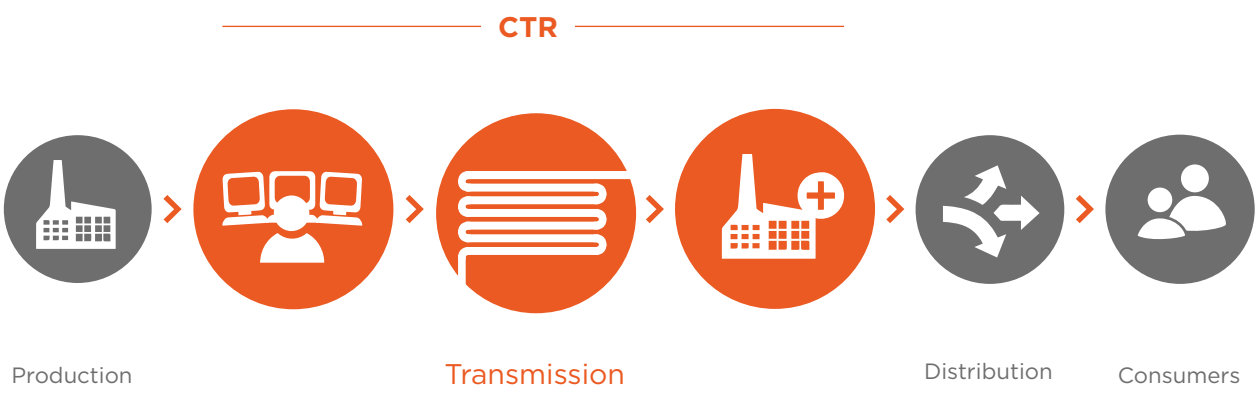
The focus on environmental impact and carbon emissions has been intensifying ever since CTR came into being. One way to achieve a more environmentally-friendly supply of energy is to enlarge the district-

DISTRICT-HEATING PLAN FOR COPENHAGEN

CTR, VEKS and HOFOR Varme collaborated on the District-Heating Plan for Copenhagen. This strategic collaboration involves the ongoing development of the area's future heat supply. The initial analysis phases of the collaboration assessed that there would be a significant climate-related benefit from using biomass to generate power and heat. Subsequently, some of the biggest CHP plants have been converted to use exactly that. The third phase of collaboration involving the district-heating plan will analyse and coordinate the major investments required to develop the grid and production processes over the next 10–15 years. This includes assessing the role of biomass in the long term, heat-market trends, and the future role of waste-incineration plants in the district-heating system.
In addition, a number of other potential heat-generation technologies are available for developing/replacing the existing capacity. These include the following:

- geothermal energy
- solar heating
- heat pumps
- heat storage
- temperature reduction

Electric boilers and peak-load boilers are also options, but would probably provide only a small share of the heat.



heating grid. The district-heating cover in the City of Copenhagen and Frederiksberg Municipality is almost 100 %, but it is still possible to replace individual heating with district heating in the municipalities of Tårnby, Gentofte and Gladsaxe.

Carbon emissions from CTR's heat supply fell by around 50 % from 1990 to 2013 and, as mentioned above, CTR intends for the district heating to be completely carbon neutral by 2025. For this reason, among others, CTR – together with the CHP plants – focuses on the environmental impact and increasingly uses carbon-neutral fuels to replace coal.

In 2013, 46 % of all district heating in Copenhagen (supplied by CTR, VEKS and HOFOR Varme) was based on carbon-neutral fuels.

Underground heat

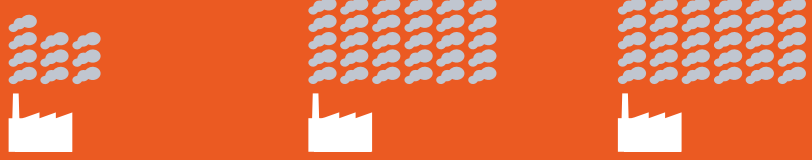
Combined with the use of carbon-neutral biofuels at CHP plants, geothermal energy is one of the other options for achieving a carbon-neutral heat supply in the future.

CTR collaborates with VEKS, HOFOR Varme and DONG Energy to operate a pilot plant involving geothermal energy in Amager. Water at a temperature of 70 °C is pumped up to the surface through a well extending 2,700 metres down into the ground. The hot underground water is used to heat district-heating water by means of a heat exchanger combined with a heat pump. Heat pumps increase the temperature of the district-heating water obtained by the exchanger to correspond with the operating temperature of the transmission grid. The heat pumps are powered by steam, i.e. heat-sourced power, in an absorption heat pump. After the water cools, it is returned underground through a different well.

Emissions

Emissions per thermal unit delivered from the transmission system
The declaration is based on the total heat purchases of
CTR, HOFOR and VEKS

1990



CO_2 SO_2 NO_x

2013

CO_2 SO_2 NO_x

GEOTHERMAL ENERGY

The water – which is pumped up from some 2,700 metres underground – is around 70 °C and also millions of years old. It contains a wide variety of salts and minerals, so it is important to keep the water from the geothermal well separate from the district-heating water by means of heat exchangers.

In 2013, the plant was one of three geothermal facilities in Denmark and has been operating since 2005. It meets almost 1 % of the total heating demand in CTR's service territory. A geothermal plant requires a large-scale investment involving many costly feasibility studies and analyses. As a result, the heat cost predominantly comprises plant depreciation and operating costs (staff, maintenance, electricity for pumps and purchases of heat-sourced power for the heat pumps). However, the fuel has no other costs, and the plant is expected to supply climate-friendly underground heat for up to 30 years. If a carbon-free fuel is used to power the heat pump, e.g. a bio-based propellant or wind-based electricity, the heat from the geothermal plant can be completely free of carbon emissions.

After 30 to 50 years of operation, the temperature in the well will have fallen to such an extent that it maybe is no longer profitable to pump up the water.

Heat for 6,000 households

Operating a geothermal system requires energy: pumping up the water, extracting the heat using a heat pump and distributing the heat out through the grid. But ten units of heat are produced for each unit of energy (the electricity used to operate the geothermal plant in Amager). This does not include surplus heat produced by the absorption heat pump, which is also converted into district heating in the process.

The pilot plant currently generates heat to meet the heating demands of around 6,000 households a year.

Therefore, the possibility of establishing star-shaped systems in CTR's service territory are currently being looked into: In this type of system, several wells are positioned in a star shape around a common centre, to maximise the amount of heat extracted from the biggest underground area possible at a single site.

A single star-shaped system could probably meet 7–10 % of the total heating demand in CTR's service territory.

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