MINISTRY OF FOREIGN AFFAIRS OF DENMARK

Mykolaiv
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Assistance to the Development of the Mykolaiv Masterplan

Potential Alternative Energy Sources in District Heating and Power Sectors, Note

Final

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Contents

List of Appendices

List of Figures

List of Abbreviations

4GDH	4th Generation District Heating
4GDH&C	4th Generation District Heating and Cooling
CHP	Combined Heat and Power
COP	Coefficient of Performance
DC	District Cooling
DH	District Heating
GHG	Greenhouse gas Emissions
IEA	International Energy Agency
PV	Photovoltaic
PVT	Photovoltaic/thermal
SDH	Solar District Heating
SMR	Small Modular Reactor
WtE	Waste to Energy

1 Introduction

This note has been developed within the framework of the project "Mykolaiv - Denmark partnership – Technical support unit" financed by the Danish Ministry of Foreign Affairs (MFA). The project, which has been entrusted COWI, is a framework contract, which, among others, includes assistance to the Mykolaiv City Administration (MCA) in developing the Mykolaiv Masterplan in close cooperation with an Italian company, One Works.

Box 1-1 COWI's contribution to Mykolaiv Masterplan

Mykolaiv Masterplan, which has been requested by the Mayor of Mykolaiv City, has a time horizon till 2050. It provides a compass for actions to be taken by the Mykolaiv City to ensure that it will develop into a thriving city attractive to its citizens and business community.

COWI and One Works assist Mykolaiv City Administration in developing the masterplan. In this work, COWI focuses on three sectors:

Water and wastewater

Energy, including power, district heating and renewable energy sources

Solid waste management.

Mykolaiv City Administration meets every week with COWI and One Works to ensure proper coordination.

COWI has established a project organization consisting of a project management team and three sector teams of professionals, each headed by a Discipline Leader. Three sectoral Focal Points are responsible for monitoring cross-cutting activities, ensuring coordination between the parties and maintaining consistency in the deliverables.

To enhance transparency in the development of the Mykolaiv Masterplan, given its significant public interest and exposure, COWI has established three sector-specific Sounding Boards inviting all potentially interested parties to take part in these.

This document serves as an introductory overview of alternative and readily accessible energy sources within the global market. It encompasses the description of energy sources used in urban heating and cooling systems, as well as technologies for electricity generation. The technologies outlined in this document have the potential to become fundamental components of forthcoming energy systems for contemporary, environmentally conscious cities, characterized by sustainable management and development practices.

The technologies discussed in this report serve as a foundation for selecting optimal solutions for Mykolaiv, a Ukrainian city that has suffered due to the war. The reconstruction and expansion of the energy system, as well as district heating, require the use of technologies that will rapidly restore the full functionality of urban systems, allowing for dynamic yet sustainable development. On the other hand, they will provide a source of green, environmentally friendly energy for the future as well.

It is important to note that the document presents a wide range of technologies available on the market. However, the selection of optimal solutions for Mykolaiv should take into account local conditions, constraints, and legal regulations. Another important aspect concerns limitations in the case of large-scale, professional sources of electrical energy. While some of them are described here, it should be remembered that these are solutions primarily dependent on national authorities, and their implementation at the municipal level may be unfeasible.

Nevertheless, this report aims to identify technologies that could play a significant role in the development of a modern electrical energy system. Although as of today, some of the discussed technologies are unlikely to be applicable to Mykolaiv's case, their future utilization cannot be ruled out.

2 Sustainable Energy Sources

Sustainable energy sources will play a pivotal role in shaping the future of energy systems, district heating and cooling. They present a pathway to address critical global challenges while unlocking a multitude of benefits for society, the environment, and the economy.

- Reducing Environmental Impact:

Sustainable energy sources like wind, solar, and biomass are inherently cleaner and emit fewer greenhouse gases compared to fossil fuels. By integrating these sources into district heating and energy systems, we can significantly reduce air pollution, combat climate change, and preserve our natural ecosystems.

- Energy Independence and Security:

Dependence on locally sourced renewable energy diminishes reliance on volatile global energy markets and foreign energy supplies. This bolsters energy security, ensuring stable and resilient energy access for communities, even in the face of global energy crises.

- Economic Opportunities:

The transition to sustainable energy sources generates jobs and stimulates economic growth. The renewable energy sector has become a source of employment and investment, driving innovation and fostering economic development in regions embracing these technologies.

- Cost Savings:

Over time, sustainable energy sources can lead to cost savings for consumers and municipalities. Solar and wind energy, in particular, have seen substantial cost reductions, making them increasingly competitive compared to traditional fossil fuels.

- Community and Social Benefits:

Sustainable energy projects often involve community engagement and ownership, offering local residents opportunities to participate in and benefit from these initiatives. This not only strengthens community bonds but also promotes social equity and inclusivity.

- Technological Advancements:

Investing in sustainable energy sources spurs research and development, leading to technological innovations that can benefit sectors beyond energy, including transportation and agriculture.

- Environmental Stewardship:

Incorporating sustainable energy sources aligns with a broader commitment to environmental stewardship. It reflects responsible resource management and a dedication to leaving a cleaner, healthier planet for future generations.

- Scalability and Flexibility:

Sustainable energy systems based on biomass, WtE, solar, wind energy, geothermal and other sustainable sources are highly adaptable to varying energy demands and can be integrated with energy storage solutions, allowing for flexibility in energy generation and distribution to meet changing needs.

The integration of sustainable energy sources into future district heating and energy systems is imperative for a sustainable, resilient, and environmentally responsible energy future. By embracing these sources, we can reduce our carbon footprint, enhance energy security, stimulate economic growth, and create a more equitable and prosperous society. It represents a critical step toward building a sustainable and thriving future for all.

A city like Mykolaiv, scarred by the tumult of war, should fully seize the opportunity for reconstruction and strive to attain the highest standards. It can become a dream city for those seeking a modern, secure place to live.

The vision should be based on the utilization of renewable energy sources such as solar, wind, geothermal, and biomass to minimize greenhouse gas emissions.

2.1 Biomass

While decentralized heat supply is a recommended approach for future district heating sectors, larger systems can benefit from a core heat source that operates independently of natural conditions such as sunlight, wind, and outdoor temperatures. This core source can cover deficits during cold winters or periods with limited wind or solar availability. Utilizing biomass in modern CHP ensures highly efficient heat and power production. The technology is mature and well-known, making it a safe and viable option for implementation.

Sustainable biomass is the preferred energy carrier for such large-scale, reliable production units. Utilizing biomass in modern combined heat and power CHP systems ensures highly efficient heat and power production. The technology is mature and well-known, making it a safe and viable option for implementation.
The positive effects from relying on biomass can be seen in aspects like:

- Replacement of fossil fuels and reduction of greenhouse gas (GHG) emissions

According to the Bioenergy Policy Roadmap for Ukraine until 2050, bioenergy plays a significant role in replacing fossil fuels and reducing GHG emissions representing the largest share among all renewable energy sources in both heat and power production.[1]

- Progressing toward energy independence

Based on 2020 data, Ukraine heavily imported energy carriers such as natural gas, petrol, diesel, coal, oil, and oil products. Bioenergy derived from domestic biomass has the potential to replace a significant portion of these imported resources, contributing to energy independence. This could keep financial resources within the country and support national investments.

- Creating new job opportunities through the use of domestic fuels

[1] ROADMAP FOR BIOENERGY DEVELOPMENT IN UKRAINE UNTIL 2050, UABIO, https://uabio.org/wp-content/uploads/2020/11/uabio-position-paper-26-en.pdf

One of the challenges Ukraine may face after the war is the number of people who have migrated out of the country. Encouraging people to return to their homeland requires the creation of job opportunities. Building the economy around indigenous resources provides ample opportunities to generate new employment opportunities. Ukraine, being a large-scale agricultural nation, produces significant quantities of organic biomass waste. Processing this waste for energy purposes can create extensive job opportunities for its people.

Basing the economy on indigenous resources provides ample opportunities for creating new job opportunities. Ukraine, as a large-scale agricultural nation, is a significant producer of organic biomass waste. The processing of this waste for energy purposes creates extensive employment opportunities for the people.

The biomass considered for energy production includes wood, sunflower husks, straw, by-products of grain and maize production, stalks, agricultural residues, and energy crops like willow, poplar, and miscanthus.

Technologies already available on the market allow the burning of highly inhomogeneous biomass, which can be mixed with different fuels. This opens up possibilities for new types of biomass that could not be used previously.

The most common way of utilizing organic biomass is its direct combustion in a furnace. However, new technologies are emerging that enable the conversion of biomass into biogas or syngas through anaerobic digestion or gasification processes This approach offers several benefits, including the potential for simpler and possibly more cost-effective plant designs, fuel flexibility for the reactor, reduced primary emissions, and the ability to achieve higher modulation of furnace output.

Typical large-scale biomass-based CHP's have capacities of more than 100 MW of thermal input and 25 MWe. Possible are even larger plants, exceeding 1000 MW of thermal input. This make technology suitable for being a core heat and electricity production unit to the new DH system.

Examples of Danish and British biomass CHP plants that could serve as good models to follow [2]:

• Fyn Power Plant (DK), Unit 8: commissioned in 2009, with 120 MWth input, 35 MWe, and 84 MW of district heat. It utilizes 170,000 tonnes of straw per year and is equipped with a flue gas condenser. It has been retrofitted with SCR at the tail end.

• Sleaford (UK): commissioned in 2014, with 115 MWth input (straw/wood chips), 38.5 MWe, and a net electrical efficiency of 33%. It processes 240,000 tonnes of straw annually.

• Lisbjerg (DK): commissioned in 2016, with 110 MWth input and an energy efficiency of 103% in CHP mode. It is equipped with a tail-end SCR, combustion air humidification, and a flue gas condenser.

• Snetterton (UK): commissioned in 2017, with 130 MWth input (straw/wood chips), 44 MWe, and a net electrical efficiency of 34%. It utilizes 270,000 tonnes of straw per year.

2 DEA, Energy technology catalogue chapters for the biomass and waste plant types, https://ens.dk/sites/ens.dk/files/Analyser/biomass_and_waste_plant_july_2017.pdf

• Avedøre Power Plant (DK), Unit 2: This is a multi-fuel CHP extraction power plant that can operate on wood pellets, straw, oil (HFO), and natural gas. It was commissioned in 2002. It has a separate biomass-fired boiler with 100 MWth input (ultra-super critical steam data – 290 bar, 540°C) supplying steam in parallel with the main boiler. It processes 170,000 tonnes of straw annually. When the plant is running on 100% wood pellets in the main boiler and 100% straw, it produces 425 MWe in condensing mode and 355 MWe and 485 MWth heat output in backpressure CHP mode.

• Sindal: commissioned in 2018, this plant combines updraft biomass gasification and a combustion chamber with ORC. It has a heat output of 5 MWth and generates 800 kWe of electricity.

2.2 Waste to Energy

Waste-to-energy encompasses various processes for converting waste materials into useful forms of energy. That technology can stand as a cornerstone within future, modern urban energy systems and the domain of district heating and cooling, presenting an array of compelling merits. It assumes a fundamental role in:

- Innovative Waste Management: WtE, through the conversion of non-recyclable waste into valuable energy, serves as a bulwark against undue dependence on landfills.

- Renewable Energy Sourcing: With nearly half of its energy output classified as renewable, drawn from the wellspring of biogenic waste, WtE contributes meaningfully to sustainable energy portfolios.

- Reliability in Energy Provision: Unlike some renewable counterparts, WtE offers a predictable and unwavering energy supply, amenable to diverse applications.

- Resource Retrieval: WtE facilities are adept at salvaging secondary raw materials, channeled toward construction, metal recycling, and a host of other industries.

- Mitigation of Carbon Emissions: By diverting waste away from landfills, WtE plays a significant role in curbing carbon dioxide emissions.

- Versatile Energy Applications: WtE-derived energy finds utility across a spectrum encompassing electricity generation, heating, cooling, and even the production of hydrogen.

- Advocating Circularity and Sustainability: WtE aligns seamlessly with circular economic models, capitalizing on the reuse of discarded materials.

- Anticipated Growth: The scope of WtE applications is poised for amplification, encompassing households, industrial establishments, thereby diminishing the demand for primary resources.

- Multifaceted Facilities: WtE plants are metamorphosing into multifunctional centres, augmenting their primary roles with recreational amenities and educational facilities.

- Global Promise: WtE harbors prospects for worldwide adoption, buoyed by innovative waste transportation fuelled by hydrogen and integrated waste-to-water processes.

- EU Pioneership: The European Union strides ahead as a trailblazer in the advancement of WtE technology and the orchestration of sustainable waste management paradigms.

- Policy Advocacy: Critical to the sustained success of WtE are policies that underpin the waste hierarchy, acknowledge its sustainability, and foster the export of relevant technologies.

WtE stands as an emblem of cleanliness, innovation, and indispensability, seamlessly interwoven with circular and sustainable ideals. Its intrinsic role within urban energy systems is not only pivotal but an indispensable harbinger of a sustainable future. [3]

In the coming years, Mykolaiv can implement waste utilization to produce heat. Organic waste can be converted into biogas or syngas through anaerobic digestion or gasification processes. Such biofuels can be then burnt to generate heat. It is also possible to directly recover energy through the combustion process of pre-sorted municipal waste, which will be separated from the waste that can undergo recycling processes. This renewable energy source can reduce dependence on traditional fossil fuels and lower greenhouse gas emissions. The implementation of WtE technology in the urban energy, heating, and cooling system of Mykolaiv will have a positive impact on both improving the city's overall energy balance and reducing the economic and environmental costs of waste management.

The image below presents an ideal scheme of utilizing energy from waste in the urban energy system. The concept was presented by the ESWET association.

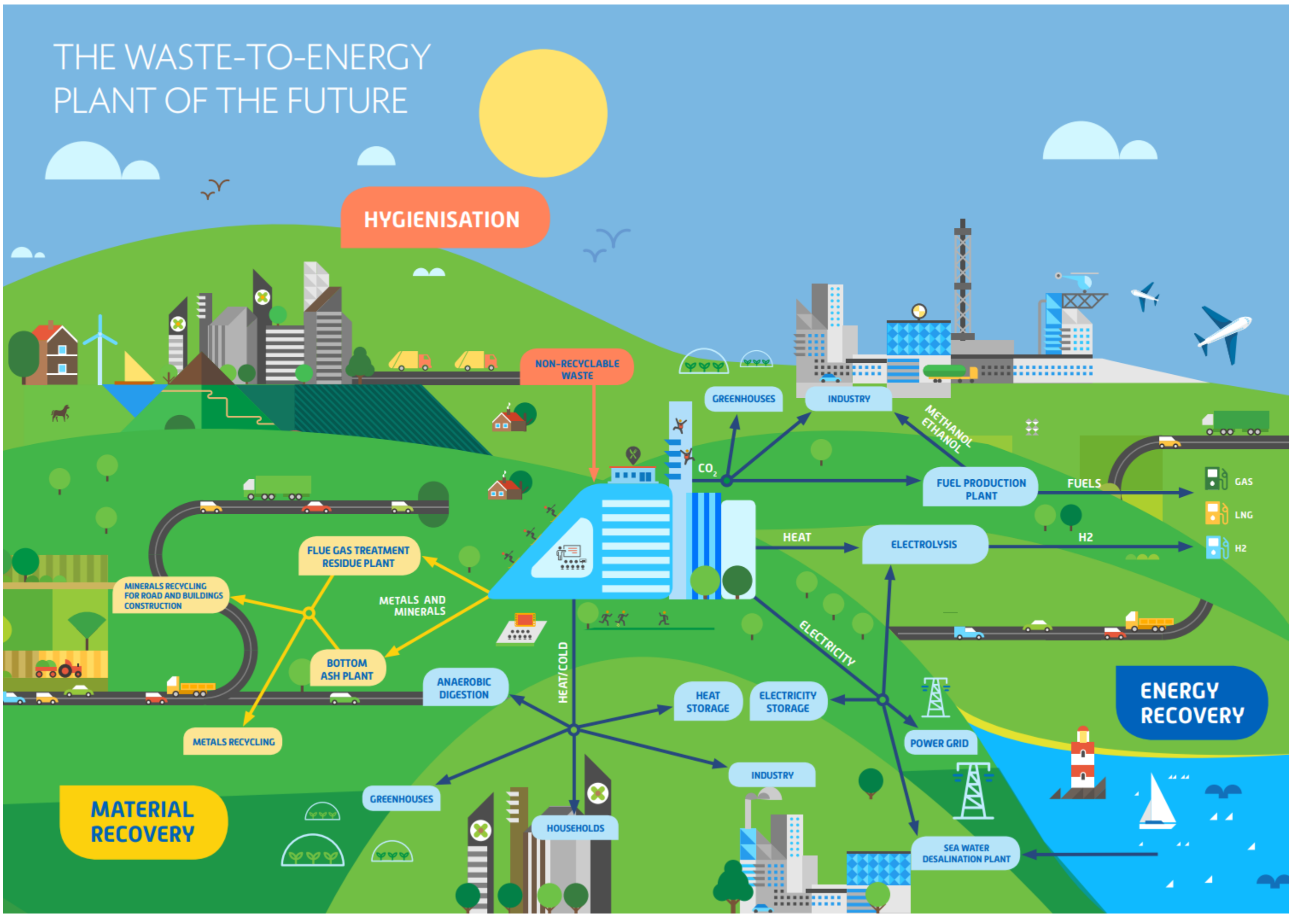

Figure 2-1 The WtE plant of the future[4]

Examples of modern European WtE plants that could serve as a good model to follow:

[3] ESWET, Waste-to-Energy: a reality for affordable heating in local districts, https://eswet.eu/waste-to-energy-a-reality-for-affordable-heating-in-local-districts/
[4] ESWET 2050 Waste to Energy Vision, Clerens, https://clerens.eu/our-stories-eswet-2050-vision/

a) Sysav, Malmö, Sweden

b) Rea Dalmine, Bergamo, Italy

c) Giubiasco, Ticino, Switzerland,

d) Amager Bakke, Copenhagen, Denmark.

2.3 Heat Pumps

To further enhance the sustainability of the district heating system, Mykolaiv should transition towards incorporating a low-temperature district heating network, supported by high-capacity heat pumps, for example. This renewable energy technology can significantly reduce carbon emissions and provide a reliable and consistent source of heat for the city's residents. Large-scale heat pumps are typically designed for maximum utilization of the accessible heat source.

Below are several key points that emphasize the significance of heat pumps in district heating:

- **Efficient Base Load Unit**

Heat pumps are known for their high energy efficiency. They can efficiently extract heat from various sources, such as the environment or industrial processes, making them a sustainable choice for district heat production. When considering Mykolaiv's location, potential heat sources for heat pumps can include ambient air, water bodies (from the Southern Bug River), the ground (from geothermal sources), or excess heat (from industrial processes or data centres that will appear with the city's industrialization). The initial investment in heat pumps is relatively high, and they are best suited for applications as base load units with a substantial volume of operational hours at high load. Designed lifetime of heat pumps ranging from 15 to 25 years. It's worth noting that the life of the heat pump installation can be extended by replacing or renovating the compressor part.

- **Suitable Low-Temperature Heat Source for a Modern Low-Temperature 4GDH System**

Depending on the available heat source, heat pumps can deliver heat up to approximately 85°C. However, the efficiency of the heat pump (COP factor) decreases with increasing output temperature. Heat pumps are often designed to boost the return pipe temperature.

Since the future district heating system of Mykolaiv is intended for low-temperature operation (meaning 70-80°C supplied to end customers), heat pumps can be directly connected to the system. Operating the network at lower temperature levels leads to significant savings due to lower heat losses.

- **Renewable Energy Integration**

Heat pumps can effectively integrate renewable energy sources like solar or geothermal energy into district heating systems, reducing reliance on fossil fuels and lowering carbon emissions.

- **Decentralized Solutions**

Heat pumps allow for decentralized heating and cooling solutions, reducing the need for extensive distribution networks. This makes district heating more adaptable to different locations and scales. Typical applications include using local waste heat sources, such as freezers in supermarkets or data centres.

- **Seasonal Flexibility by Combined Heat and Cold Production**

A critical aspect of heat pumps is their ability to provide both heating and cooling, making them suitable for year-round use in District Heating and District Cooling Networks. A heat pump with combined heating and cooling can utilize different heat sources in combination, such as cooling demand and wastewater. This combined solution is often efficient because it can increase the number of full load hours for the heat pump. An example of such a system producing combined heat and cold is presented in Figure 2-2 Simultaneous production of heat and cold with heat .

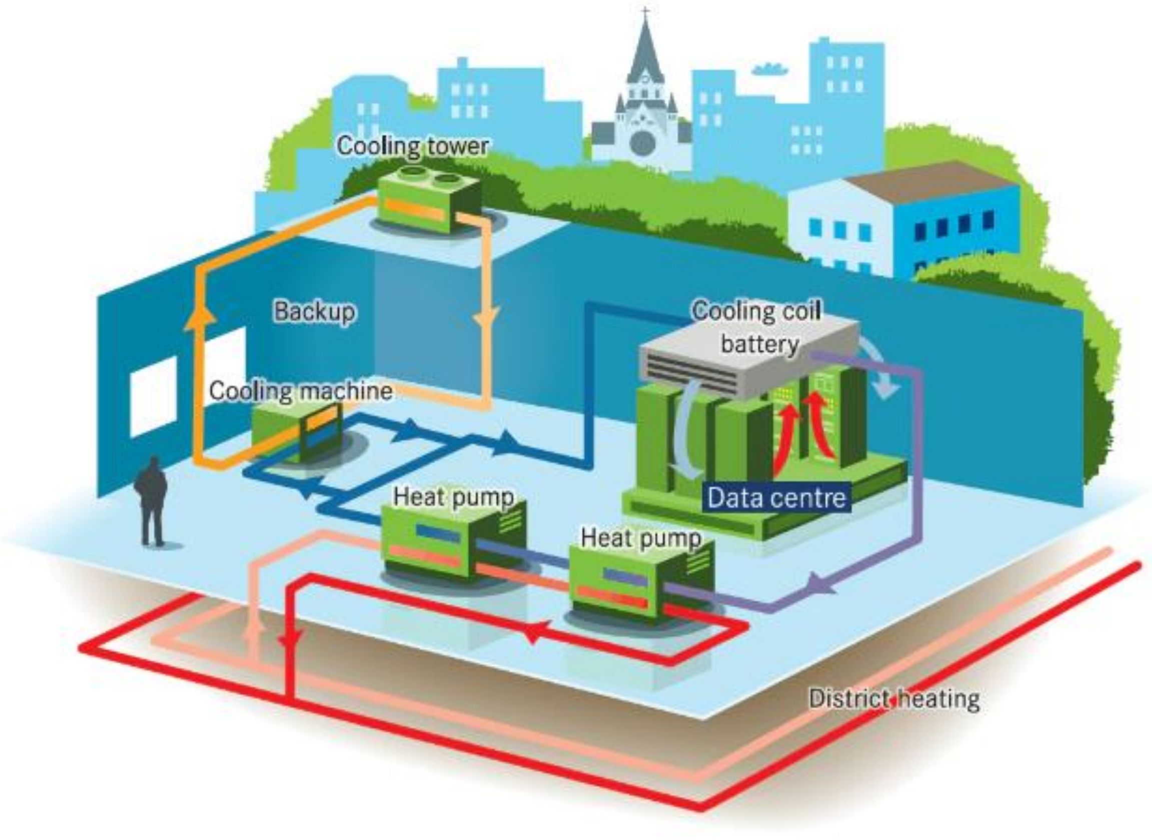

Figure 2-2 Simultaneous production of heat and cold with heat pump[5]

Potential heat pump applications in Mykolaiv city are:

Compression Water Source Heat Pumps utilizing river water

A water source heat pump employs submerged piping to extract thermal energy from various water sources. In Mykolaiv's case, the Southern Bug River would be an obvious heat source.

5 Heat pumps in district heating and cooling systems – Analysis - IEA

Flowing through Mykolaiv, the Southern Bug River can serve as an excellent heat source for a high-capacity heat pump.

The temperature of the Southern Bug River in Mykolaiv varies between 4°C in winter and 25°C in summer. Although the temperature in winter is relatively low, it can still be utilized with a reasonable COP (Coefficient of Performance) factor.

The share of cooling water returned to the river is minimal, and the cooled water will not harm aquatic life.

Compression Heat Pumps utilizing excess heat

Excess heat-based heat pumps offer an ingenious solution to harness wasted heat from industrial processes and data centers that require cooling. This captured heat, otherwise lost, becomes a valuable heat source for the heat pump, resulting in significant energy savings.

One of the key advantages of excess heat utilization is its versatility. It can provide both heating and cooling when needed.

However, the primary challenge lies in bridging the gap between the excess heat source and the district heating network.

Compression Sewage Water Heat Pump

One more promising heat source for heat pumps is sewage water, which is abundant and provides heat with temperatures typically above freezing. To harness this potential, a heat pump system can be strategically installed at the sewage treatment plant or sewage collectors.

While the main hurdle may involve connecting the plant to the city centre with a lengthy pipeline for wider district heating use, the heat generated by this heat pump can serve dual purposes. It can be used internally at the plant for essential processes like sludge drying, while also being available for local consumers in the vicinity.

Compression Air to Water Heat Pump

The air-to-water heat pump stands out for its adaptability, tapping into the surrounding air's heat reservoir, making it a versatile choice for various locations. This solution is a proven and widely adopted technology in Danish DH systems.

It works by drawing heat from the nearby air to raise the district heating water temperature. This means it can efficiently produce the heat needed for homes and businesses, taking the water from a lower to a higher temperature range.

Absorption Heat Pumps

Absorption heat pumps shine in scenarios where electricity costs are exceptionally high or when there's an excess of heat available at the right temperatures. These situations are most beneficial when the cooling or heating produced is of higher value than the energy input required, which comes in the form of heat consumption.

Possible size of heat pump

Large-scale compression heat pumps are readily accessible with capacities of up to approximately 5 MW. Nevertheless, by connecting them in parallel, there's potential for even greater heat production. In Denmark, the most extensive heat pump facility utilizing this technology can generate approximately 40 MW of heat.

Absorption heat pumps, on the other hand, can reach capacities of around 20 MW.[6]

2.4 Geothermal heat

Geothermal energy has potential to play a pivotal role in modern district heating systems, offering numerous advantages that contribute to sustainability, energy efficiency, and reduced environmental impact. Here are some key points highlighting the importance of geothermal energy in district heating:

1. Sustainability: Geothermal energy is a renewable and environmentally friendly heat source. It produces minimal greenhouse gas emissions, making it a crucial component of efforts to reduce carbon footprints and combat climate change.

2. Energy Independence: Geothermal resources are typically localized, reducing dependence on imported fuels and enhancing energy security. Communities can tap into their own geothermal reservoirs, reducing exposure to energy price fluctuations.

3. Reliability: Geothermal energy provides a consistent and stable source of heat. It can serve as a reliable base load for district heating systems, ensuring a continuous supply of warmth to homes and businesses regardless of external weather conditions.

4. Efficiency: Geothermal district heating systems are highly efficient, with low heat losses during transmission. This efficiency translates into cost savings and reduced energy waste.

5. Local Economic Benefits: Developing geothermal resources can create jobs and stimulate the local economy. It promotes investments in infrastructure and technology while supporting the growth of the renewable energy sector.

6. Reduction of Air Pollution: By replacing fossil fuel-based heating systems with geothermal energy, district heating contributes to improved air quality by eliminating emissions from burning fossil fuels.

7. Versatility: Geothermal energy is adaptable to various district heating scales, from small residential communities to large urban areas, making it a versatile solution for different regions and population sizes.

[6] DEA, https://ens.dk/sites/ens.dk/files/Analyser/biomass_and_waste_plant_july_2017.pdf

8. Longevity: Well-designed geothermal district heating systems, if properly maintained, can have a lifespan of several decades, providing a long-term and sustainable heat supply solution.

9. Integration with Renewable Mix: Geothermal energy can be integrated into a mix of renewable energy sources, enhancing the overall sustainability of a region's energy supply.

In summary, geothermal energy can be a vital component of modern district heating systems due to its sustainability, reliability, and efficiency. Its utilization aligns with the global push towards reducing carbon emissions, making it an essential part of the transition to greener and more sustainable urban heating solutions.

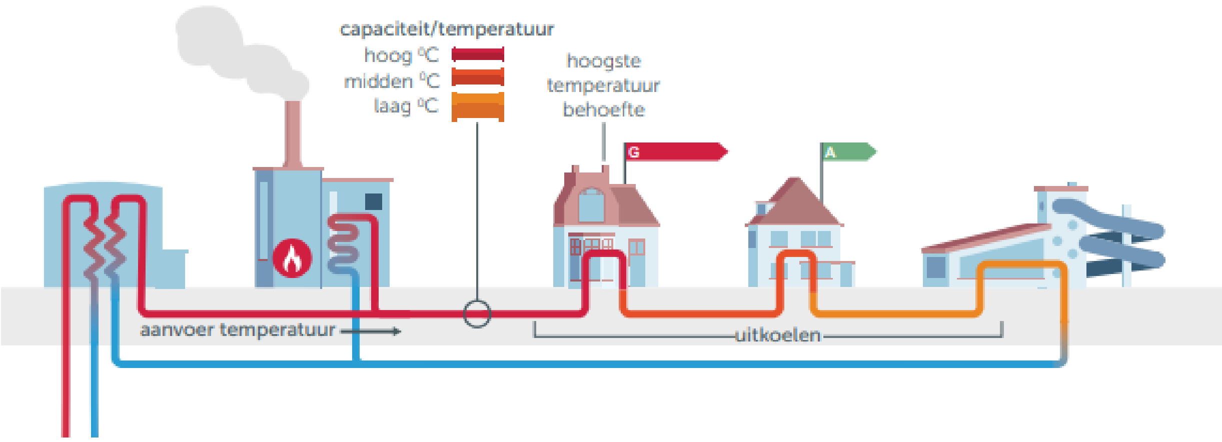

Figure 2-3 Example of geothermal energy application[7]

Geothermal energy has a well-established presence in district heating systems, with examples from various regions showcasing its effectiveness. For example, in the Netherlands, it has been harnessed for greenhouse heating, demonstrating its practicality. However, Munich's experience truly stands out. Munich has taken ambitious steps toward sustainability by incorporating geothermal energy as a cornerstone of its heat supply transition. The city's geographically advantageous underground conditions have allowed for the successful execution of over seven geothermal projects. This journey began over a decade ago, and since then, Munich has made remarkable strides in the field.

In 2014, Munich embarked on a large-scale initiative to optimize the region's geothermal potential. This involved extensive seismic research conducted beneath significant urban areas. The outcomes of this research paved the way for various geothermal projects, collectively holding the promise of providing heat to more than 80,000 households in the foreseeable future.

Munich's case demonstrates that geothermal energy can be a reliable and sustainable heat source for district heating networks. Its decade-long integration into the city's district heating system showcases the feasibility and effectiveness of geothermal energy in modern urban heating solutions.

[7] Geothermal energy in heating networks, brochure-aardwarmte-in-warmtenetten-web.pdf (warmtenetwerk.nl)

According to the 2020 review of the Direct Utilization of Geothermal Energy, Ukraine emerged as the leader in terms of the largest increase (%) in worldwide direct use of geothermal energy. Therefore, the potential for incorporating geothermal energy into the energy mix for Mykolaiv should be thoroughly analyzed.

Geothermal resources are important and promising in Ukraine's national energy production, and there is potential for geothermal energy to become one of the leading sources of the country's heat and power generation. According to investigations of the potential for utilisation of deep geothermal heat sources, Mykolaiv's' location in the Black Sea coastal area offers favourable conditions for the extraction of geothermal heat at temperatures suitable for district heating. We refer to a study on geothermal potential in Ukraine.[8]

2.5 Excess heat

Excess heat, also known as waste heat, is a valuable resource that can be repurposed for various applications, contributing to energy efficiency and sustainability. The future of excess heat utilization in DH/DC systems is aligned with the broader goals of energy efficiency, sustainability, reduced carbon emissions and primary energy. Advancements in technology, coupled with a growing awareness of environmental concerns, will drive the transformation of these systems, making them more resilient, adaptable, and environmentally friendly.

Advanced waste heat recovery systems can capture and convert this excess heat into usable energy for district heating and cooling networks. These systems are expected to improve in efficiency and scalability.

There are different sources of excess heat such as:

1. Industrial Processes – e.g., heavy industry, food processing industry

   District heating networks can be integrated with nearby industrial facilities, allowing them to exchange excess heat. This concept, known as industrial symbiosis, promotes energy efficiency and reduces waste in industrial processes.

2. Power and Heat Generation – thermal power plants or nuclear plants

   Power and heat generation units often produce huge amounts of excess heat that is irreversibly lost and released to the atmosphere in the form of flue gases or steam generated in the cooling processes. Reduction of energy lost in such processes may significantly improve energy balance of the installation.

3. Wastewater Treatment Plants

   Heat might be recovered directly from wastewater and later from treatment processes. By application of heat pumps heat might be recovered on the wastewater network as well as on wastewater treatment plant.

4. Data Centres

[8] Studies show large, untapped geothermal potential in Ukraine (thinkgeoenergy.com)

As data centres continue to grow in number and size, excess heat generated by their servers can be harnessed for heating nearby buildings. This practice not only reduces energy waste but also minimizes the need for alternative cooling systems.

5. Buildings

Architectural and building design solutions, such as incorporating solar energy into passive design, well-insulated building walls, efficient windows, as well as heat recovery from ventilation systems, have the potential to capture and retain excess heat from sunlight, building equipment, office utilities as well as users of residential and commercial spaces. Besides, the building corpus may serve as heat storage by intelligent control and adjustment of temperatures aimed at reducing peak loads in the District heating system, while respecting the requirements for thermal comfort.

Good example of excess heat recovery and utilization is Open District Heating in Stockholm, driven by Stockholm Exergi, that is at the forefront of sustainable heat recovery innovation. This pioneering system offers a unique opportunity for data centres, supermarkets, and various businesses that produce surplus heat to contribute to a more sustainable and economically viable energy ecosystem.

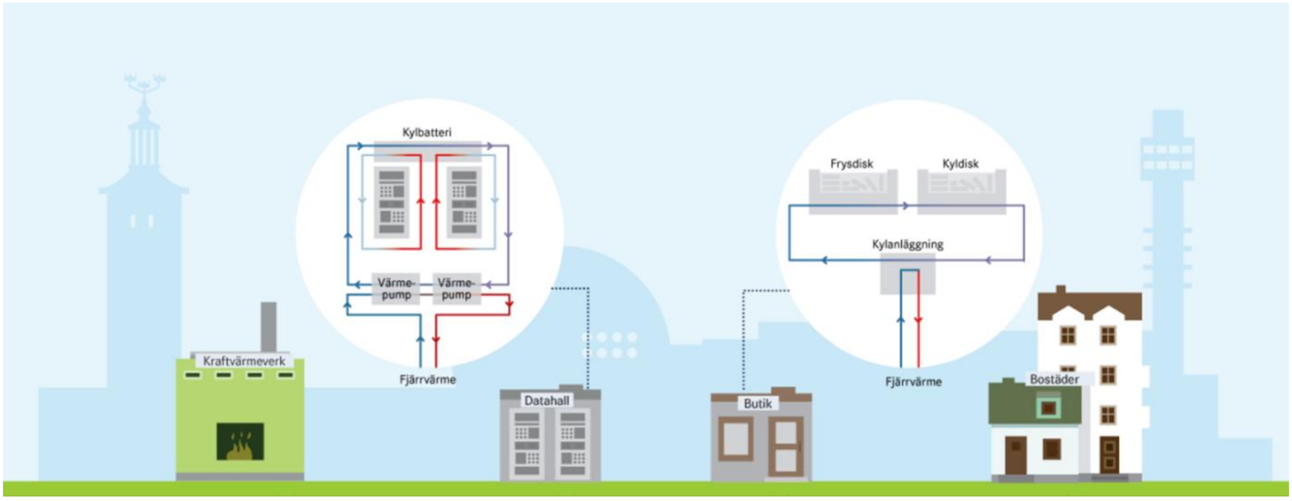

Figure 2-4 Example of excess heat recovery and utilization[9]

Stockholm Exergi (SE) boasts an extensive district heating network comprising approximately 3,000 kilometers of pipes running beneath the streets of Stockholm. Additionally, they operate a world-unique district cooling network spanning around 300 kilometers of pipes. These intricate distribution systems facilitate the transfer of energy from locations with excess energy to areas where energy demand is prevalent.

Open District Heating opens up avenues for companies and businesses located near their network to sell their excess heat, actively promoting the efficient utilization of surplus thermal energy. This initiative aligns with SE's overarching mission of fostering sustainability, reducing waste, and minimizing environmental impact.

Key features of Open District Heating include:

[9] Right now, we're heating more than 31,000 modern apartments with excess heat, Stockholm Exergy, https://www.stockholmexergi.se/en/heat-recovery/

1. Energy Recycling: Businesses with excess heat can become suppliers to Open District Heating, effectively recycling their surplus heat into the district heating network. This not only serves as an environmentally responsible means of disposing of excess heat but also contributes to heating households across Stockholm.

2. Targeted Beneficiaries: Open District Heating is ideally suited for data centres, supermarkets, and industrial businesses that regularly generate surplus heat. It addresses the dual objectives of efficient heat management and economic gain while advancing more sustainable urban energy solutions.

3. Marketplace for Heat Trade: By integrating excess heat into the district heating network, Stockholm Exergi has created a unique marketplace for the trade of surplus heat. This fosters economic opportunities for businesses while helping Stockholm transition toward a sustainable future.

4. Sustainability Commitment: SE's investment in heat recovery is a pivotal component of its mission to build a sustainable city. By 2030, the ambitious goal is to have 100 percent of Stockholm's district heating generated from renewable and recovered energy sources.

5. Effective, Profitable, and Sustainable: Open District Heating promises a more effective, profitable, and sustainable energy system for Stockholm, aligning with the city's long-term sustainability objectives.

2.6 Hydropower

Hydropower is a renewable and sustainable energy source that generates electricity using the energy of flowing water. Key points highlighting its importance in electricity production include:

1. Sustainability: Hydropower relies on the natural water cycle, making it an inexhaustible energy source. As long as water flows in rivers and streams, hydropower can generate electricity.

2. Low Environmental Impact: It has a relatively low environmental footprint compared to other large-scale energy sources like coal or nuclear power.

3. Reliability and Stability: Hydropower plants are highly reliable and provide a stable source of electricity since river water flow rates are typically predictable and manageable.

4. Long-term Durability: Hydropower offers long-term energy generation with relatively low maintenance costs.

5. Grid Stabilization: Hydropower can play a crucial role in stabilizing the grid by rapidly adjusting its power output to match changing demand, providing valuable support for grid stability and the integration of intermittent renewable sources such as wind and solar.

6. Additional Benefits: Specially designed hydropower projects can provide additional benefits such as flood control, water supply, irrigation, and recreational opportunities.

Hydropower provides clean, reliable, and sustainable energy. However, because investments in run-of-river hydropower plants, including building dams, are typically at the national level and primarily fall under the national power system, rather than local governments, hydropower is not subjected to further analysis.

3 Diversified Heat Sources

Development of hybrid systems that combine different heat sources, such as geothermal, mentioned earlier, solar, and cogeneration, to ensure reliable supply.

To achieve carbon-neutrality, integration of various renewable energy sources into district heating system is necessary. Apart from heat pumps, solar thermal collectors, photovoltaics, wind power, and hydroelectricity can contribute to the energy mix.

3.1 Renewables

Solar thermal collectors

Solar District Heating (SDH) facilities represent a significant implementation of solar thermal technology on a large scale. These installations are seamlessly integrated into local district heating networks, serving both residential and industrial purposes. During warmer seasons, SDH plants have the capacity to entirely substitute other heat sources, typically fossil fuels, that are traditionally used for heating purposes. Furthermore, advancements in large-scale thermal storage technology have made it feasible to accumulate surplus heat in summer for subsequent use during the winter months. Even in the winter, solar heat can contribute to fulfilling a portion of the heating demand.

The economic and environmental advantages resulting from the well-established reliability of this solar heating method, coupled with decades of technical experience, have fuelled a growing interest in its commercial deployment. Presently, numerous SDH plants are operational in countries such as Sweden, Denmark, Germany, and Austria.[10]

Photovoltaics, wind energy and hydroelectricity

For district heating companies, the adoption of PV cells for electricity production aligns with goal of transitioning to greener heat sources and lowering heating prices. It showcases the potential for district heating companies to embrace renewable energy solutions, reduce environmental impact, and gain financial stability through careful planning and investment. However, each district heating company should carefully evaluate its specific circumstances, including sun exposure, budget, and legislative requirements.

Some of the advantages of using PV (Photovoltaic) systems by companies producing heat for city heating purposes include:

1. Renewable Energy Source: PV cells harness solar energy, a renewable and abundant resource, making it an environmentally friendly choice.

2. Reduced Environmental Impact: Solar PV significantly reduces greenhouse gas emissions and reliance on fossil fuels, contributing to a cleaner environment.

3. Budget Security: By generating their own electricity, district heating companies can secure fixed-price agreements, ensuring stability in electricity expenses.

[10] Solar Heat Europe, https://solarheateurope.eu/about-solar-heat/solar-district-heating/

4. Cost-Efficient: The calculation shows that the heating price can be remarkably low, reducing costs compared to conventional heating sources like natural gas.

5. Potential for Electricity Sales: Excess electricity can be sold back to the grid, potentially generating additional revenue.

PVT

Conventional solar photovoltaic (PV) and solar thermal systems are often deployed independently, resulting in an inefficient utilization of solar radiation. These systems typically achieve a mere conversion rate of less than 20% of incoming sunlight into electricity, while the remaining 80% of solar energy is dissipated as unused heat.

In contrast, the emergence of solar photovoltaic/thermal (PVT) technology presents a groundbreaking approach. PVT systems represent a hybrid solution that seamlessly integrates PV and thermal components. This innovative approach has the potential to markedly enhance overall efficiency by harnessing both electricity generation and heat production in unison. Beyond its efficiency gains, PVT technology serves a dual purpose by effectively cooling the solar cells, thus optimizing their performance, while simultaneously generating valuable heat energy for various applications, including integration into district heating systems.

Notably, the development of hybrid photovoltaic and thermal panels, which have the capacity to concurrently generate electricity and heat, marks a highly promising advancement within this field. As PVT technology continues its evolution, it is poised to assume a pivotal role in meeting the energy demands of certain segments of urban district heating networks.

The ongoing research into solar PVT technology is progressing at an accelerated pace, with a clear emphasis on enhancing technical aspects and raising awareness of its multifaceted potential. Esteemed organizations such as the International Energy Agency (IEA) are actively engaged in research endeavors dedicated to evaluating the current status of PVT collectors and systems. The overarching objective is to spur technological advancements in this dynamic and promising domain.

In summary, the seamless integration of PVT technology into district heating systems represents a promising leap forward in terms of energy efficiency. This integration not only reduces dependence on fossil fuels but also has potential to contribute substantially to the development of sustainable solutions for urban heating needs.[11]

Wind power and Hydroelectricity

Wind power and hydroelectricity offer versatile solutions for urban energy needs. These renewable energy sources can be harnessed directly to supply electricity to urban grids, and their applications can extend to heating and cooling through innovative methods.

Utilizing wind farms and hydro-energy plants, cities can directly tap into clean power generation. This electricity can be seamlessly integrated into urban grids, reducing reliance on conventional fossil fuels and lowering carbon emissions.

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[11] Solar Hybrid Photovoltaic / Thermal (PVT) Technology, Cool Down To Heat, https://solaredition.com/solar-hybrid-photovoltaic-thermal-pvt-technology-cool-down-to-heat/

Moreover, the versatility of wind and hydroelectric power extends to indirect applications for heating and cooling within urban environments. Advanced technologies such as heat pumps and electrode boilers can efficiently convert renewable electrical energy into heat or cooling, making it suitable for a wide range of city purposes. This dual functionality not only enhances energy efficiency but also contributes to sustainable urban development.

In essence, wind turbines and hydroelectricity represent integral components of modern urban energy systems, providing both direct and indirect benefits to meet the diverse energy needs of cities while promoting environmental sustainability.

3.2 Electrode boilers

The application of electric boilers in a district heating system offers several advantages, such as:

- **Improved Flexibility**: Electric boilers with efficiency levels above 99% provide a high degree of flexibility in the district heating system. They can easily be brought into operation whenever the price of electricity is low, ensuring that the system operates in a cost-efficient manner. This flexibility allows the district heating system to adapt to changing energy market conditions.

- **Cost Efficiency**: The operation of electric boilers becomes cost-efficient when electricity prices are low. This cost-effectiveness can be leveraged to optimize energy consumption and minimize expenses for the district heating provider and consumers.

- **Sustainability**: The sustainability of electric boilers in a district heating system depends on the source of electricity. If the electricity used in the boilers comes from renewable sources such as wind or solar power, the system can significantly reduce its carbon footprint and contribute to environmental sustainability.

- **Integration with Renewables**: To ensure sustainability, integrating electric boilers with renewable energy sources is crucial. By using green energy to power the electric boilers, the district heating system can minimize its reliance on fossil fuels and reduce greenhouse gas emissions.

- **Energy Storage**: Electric boilers can be connected to heat storage systems. This integration allows excess electricity to be converted into heat and stored efficiently. During times of low electricity demand or when renewable energy generation is high, the excess energy can be stored in the form of heat. Later, when demand is high or renewable energy generation is low, this stored heat can be released into the district heating system. This method of energy storage enhances system reliability and efficiency.

In summary, the application of electric boilers in a district heating system offers increased flexibility, cost efficiency, and sustainability when powered by surplus green energy sources. By integrating these boilers with heat storage systems, energy can be stored and utilized efficiently, further improving the overall performance and reliability of the district heating system.

3.3 Small Modular Reactors (SMRs)

In the relentless pursuit of sustainable, clean energy solutions, a compelling innovation is emerging - the application of SMRs to revolutionize district heating. While the concept of nuclear district heating is not entirely novel, the maturation of SMR technologies has sparked renewed interest and promises to address urgent climate goals.

A Proven Concept: Nuclear Power for District Heating

Historically, nuclear power has been used for providing district heat. Finland and Sweden, for instance, designed reactor models for district heating as far back as the late 1970s. Today, a number of nuclear plants worldwide are efficiently supplying heat to their local communities, underscoring the feasibility of this approach.

The Promise of SMRs for District Heating

SMRs offer a range of compelling advantages for district heating:

Optimal Sizing: Unlike large-scale nuclear power plants primarily designed for multi-gigawatt electricity generation, SMRs re tailored for heat supply. They seamlessly fit within the heat requirements of even the largest heating networks, with capacities ranging from Combined Heat and Power (CHP) plants producing up to 500 MW of heat to pure heating plants in the 200-400 MW range.

Smaller, pool-type heating reactors with outputs as low as 50 MW are also viable options. They are typically designed for production of warm water below 100ºC which does not require a pressurized enclosure of the reactor core, and therefore much cheaper and safer than conventional pressurized reactors.

Economic Efficiency: The modularized construction and serialized production of SMRs promise rapid deployment, creating significant cost advantages. Preliminary studies have yielded encouraging results, highlighting the economic viability of nuclear district heating.

New Siting Opportunities: SMRs' reduced size opens up innovative safety and siting considerations. These reactors can potentially be located closer to urban areas and heating networks while maintaining the highest safety standards, thereby increasing accessibility to densely populated areas.

Diverse SMR Designs for Varied Applications

Initial investigations by research organizations have demonstrated the promise of SMRs for district heating. Notably, even SMR designs initially optimized for electricity generation, like the NuScale SMR, exhibit competitive potential when managed judiciously. These designs could also play a valuable role in combined heat and power (CHP) configurations, especially when coupled with heat storage solutions.

A Global Endeavor with Far-Reaching Implications

The application of SMRs for district heating extends well beyond national borders. As nations grapple with the pressing need to decarbonize heating systems, this innovative approach holds global appeal. Finland, in particular, is poised to lead the way, potentially inspiring Eastern European nations searching for alternatives to fossil fuel-based heating.

Challenges and the Road Ahead

While the potential of SMR-based district heating is undeniably exciting, several challenges must be addressed. Regulatory frameworks must adapt to accommodate SMRs, ensuring streamlined licensing and construction processes. Timely legislative action is paramount to meet ambitious decarbonization targets. Additionally, newcomers to the nuclear industry will require support and guidance to ensure responsible operations.

A Vision for a Sustainable Future

In conclusion, the integration of SMRs into district heating represents a pioneering, unconventional approach to clean and sustainable heat production. Nuclear power, harnessed through SMRs, holds the promise of significantly reducing carbon emissions in district heating. As the world races to meet climate goals, this innovative solution could reshape the future of clean energy and environmental stewardship.

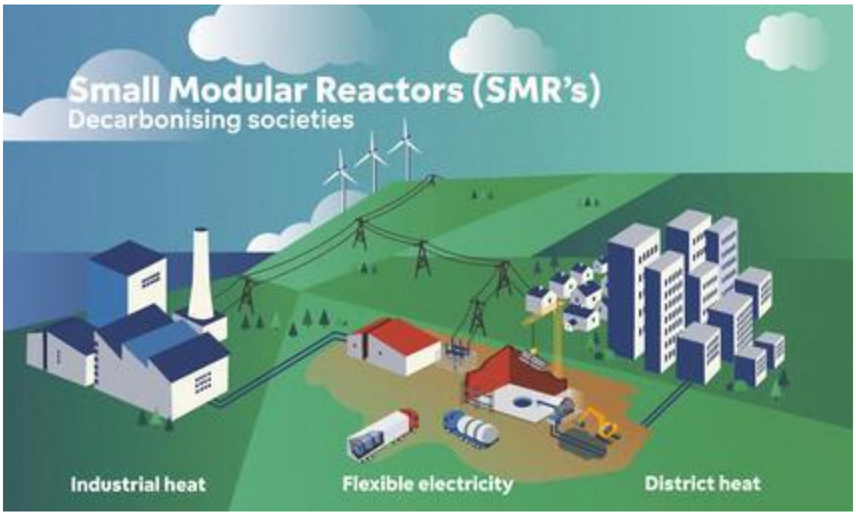

Figure 3-1 Idea of SMRs integration with DH[12]

3.4 Fuel Cells

Fuel cells might have a significant application in modern energy systems, particularly in the context of renewable energy integration, district heating, and urban energy systems. Below is a breakdown of their application and importance:

Application in Modern Energy Systems:

Decentralized Energy Generation: Fuel cells can be installed wherever decentralized energy is required, including buildings and urban quarters. This decentralized approach allows for energy generation close to the point of consumption, reducing transmission losses.

[12] Clean district heating with SMRs, Fortum, https://www.fortum.com/about-us/blog-podcast/forthedoers-blog/clean-district-heating-smrs

Integration with Renewable Hydrogen: Fuel cell technology is designed to work efficiently with hydrogen, making it a pioneering solution in the hydrogen economy. When powered by green hydrogen, which is produced using renewable sources, the fuel cells become entirely carbon-neutral.

Reduced Emissions: Fuel cell systems generate significantly lower emissions compared to conventional energy converters, especially when operated with hydrogen or biomethane. This contributes to carbon reduction and improved air quality.

Importance for District Heating and Cooling:

Resilient Energy Supply: Fuel cell systems can supply entire building complexes or urban quarters with electricity and heat. This enhances the resilience of district heating systems and reduces the risk of unscheduled outages, ensuring a stable energy supply.

High Efficiency Combined Heat and Power (CHP): The high-temperature exhaust gas produced by the electrochemical process can be used for heating or cooling, increasing the cost-effectiveness of fuel cell systems. This makes them competitive with other CHP units and district heating solutions in terms of efficiency and operating costs.

Flexibility in Energy Supply: Fuel cell systems are modular and scalable, allowing them to match varying energy demands in district heating networks. They can be easily combined with other renewable energy sources, such as solar or wind, for a more diverse and resilient energy supply.

Advantages in Urban Energy Systems:

Lower Costs: Fuel cell technology reduces the total cost of ownership compared to traditional power generation methods. The high efficiency of fuel cell systems results in cost-effective electricity and heat production, leading to a rapid return on investment for urban energy systems.

Greater Independence: Decentralized on-site power generation with fuel cells eliminates the need to rely solely on the power grid. This independence is crucial in urban areas where grid stability can be a concern, ensuring a reliable energy supply.

Simple Installation: Prefabricated and modular fuel cell systems with plug-and-play capabilities simplify planning and installation. They can be easily integrated with other urban energy solutions like heat pumps, photovoltaics, or battery storage, enhancing overall energy system flexibility.

High Efficiency: Fuel cells achieve high electrical efficiency levels, making them more efficient than fossil fuel-based power generation. This efficiency is especially valuable in densely populated urban areas with high energy demands.

Sustainability: Fuel cell systems are designed to operate with green hydrogen or other clean fuels, significantly reducing carbon emissions. Waste heat utilization further increases their sustainability by maximizing energy reuse.

In conclusion, fuel cells might have a crucial role to play in contemporary energy systems by providing decentralized, effective, and eco-friendly energy production. Their utilization in district heating and urban energy systems enhances resilience, cost-efficiency, and sustainability, in line with the shift towards cleaner and more sustainable energy sources. To incorporate fuel cell technology, the development of a hydrogen-based economy including the roll out of a dedicated hydrogen network is imperative. The efficient operation of fuel cells hinges on the availability and application of green hydrogen as a fuel source.[13]

[13] Our SOFC system for buildings and urban quarters – highly efficient, reliable, and environmentally friendly, BOSCH, https://www.bosch-hydrogen-energy.com/sofc/applications/buildings/

4 Energy Storage

In today's energy systems, energy storage represents one of the most critical challenges, particularly in meeting the demands of accumulating surplus energy when it's abundantly available and swiftly responding to surges in demand. The importance of energy storage technologies, encompassing electric batteries, thermal storage systems, and various innovative solutions, cannot be overstated. These technologies offer a plethora of advantages, including the ability to capture and retain excess energy efficiently, subsequently releasing it when demand peaks. This not only enhances the reliability and resilience of the energy grid but also promotes the efficient utilization of renewable resources, making them an indispensable component of modern energy infrastructure.

4.1 Grid Scale Energy Storage Devices

Energy storage can be categorized into three timescales[14]:

1. Level 1 (Seconds-minutes): Involves load balancing for short-term fluctuations in demand and supply, often achievable with various battery types.

2. Level 2 (Hours-days): Enables the storage of surplus energy from sources like solar or wind for later use, reducing the strain on the grid during peak demand. This form of storage may involve technologies like flow batteries or thermal storage.

3. Level 3 (Weeks-months): Geared towards seasonal energy storage, allowing excess energy generated in the summer to be stored for use in the winter. This is critical for regions with significant differences in sunlight between seasons.

Each level of storage demands specific attributes:

- Level 1: High scalability, low cost, and short charge-holding duration.

- Level 2: High capacity, power independence, and longer lifespan.

- Level 3: Storage depends on geographical location and solar energy potential.

Several technologies are being explored for energy storage, including:

- **Pumped Hydro**: Utilizes elevation differences to store energy by pumping water uphill and then releasing it to generate electricity.

- **Flow Batteries**: Store energy in liquid tanks, offering independent scalability of capacity and power.

- **Thermal Storage**: Uses temperature differences to convert heat into electricity and store it for later use.

- **Liquid Air**: Stores energy as compressed air and releases it to generate power by allowing it to expand.

[14] 100% Renewables: Is Massive-Scale Energy Storage for Renewable Energy Possible? | ClimateScience

- **Compressed Air**: Stores compressed air underground for energy storage, but scaling for long-term storage is challenging.

- **Flywheels**: Store energy as kinetic energy by spinning a rotor at high speeds in a vacuum, providing rapid response.

Storage costs and efficiency vary by region, provider, and technology, making it essential to consider not only the initial cost but also energy losses during storage and conversion. Balancing the cost of energy generation and storage is a crucial factor in designing effective energy systems.

4.2 Virtual Battery

In district heating systems that use electricity for heating, there is a sophisticated approach which considers price fluctuations. Big size electric boilers efficiently utilize large electricity capacities during periods of low prices, thereby preventing the curtailment of wind and solar power generation. Large electric heat pumps can be paused when electricity prices are high. Combined heat and power (CHP) plants can step in during these high-price periods to generate electricity. Heat storage tanks are employed to store the most cost-effective heat for later use. From the perspective of the power system, this setup resembles the installation of a massive electric battery (virtual battery) within the district heating system.[15]

4.3 Electro-Thermal Energy Storage (ETES) - combined heat, cool and electricity production

This alternative enables efficient and reversible exchange of forms of energy and supply either heat, cool or electricity, depending on actual needs. This is the perfect solution for sector coupling, where the energy requirements of commercial, industrial, and residential sectors have been integrated. The core of the technology is a CO_2 based turbo compressor which operates as a heat pump. System uses compression or expansion of CO_2 to store or release energy from water tanks. It can be easily powered by renewable sources.
In case of high-power demand, it switches to convert stored heat into electricity and vice versa, when higher heat production is required. It can also be applied to cover cooling demands.
Having the advantage of being a storage, it increases the flexibility of heat delivery to the district heating network.
An example of real implementation of this solution is Esbjerg city in Denmark, where a 50 MW thermal CO_2 heat pump is to be accomplished[16].

4.4 Green fuels – Hydrogen Energy Storage

Hydrogen is emerging as a promising new alternative fuel that holds immense potential for decarbonizing various sectors, including transportation and industry. The production of hydrogen, particularly through green methods like electrolysis using renewable energy sources, generates a substantial amount of waste heat. To maximize the efficiency and sustainability of our energy systems, this waste heat must not go unused. By integrating this surplus heat into district heating systems, cities like Mykolaiv can enhance their thermal energy supply, reducing the reliance on fossil fuels and further contributing to their goal of becoming carbon neutral. Harnessing the waste heat from hydrogen and other green fuels' production presents a significant opportunity to create a more

[15] The virtual battery, HOT&COOL MAGAZINE, No 2, 2023
[16] The virtual battery, HOT&COOL MAGAZINE, No 2, 2023

circular and eco-friendly approach to energy utilization, fostering a greener future for the city and its residents. As a fuel in the district heating and energy sector, hydrogen enables the use of co-firing gas engines, gradually transitioning from natural gas to hydrogen. Additionally, it can serve as a seasonal energy storage medium. Excess renewable energy can be used to produce hydrogen, which is then stored and used for generation of electricity and heat during colder months when energy demand is higher.

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