Kemin Digipolis

The potential of useful heat from electricity-intensive industries in Sea Lapland

Rev. 4
16.5.2025

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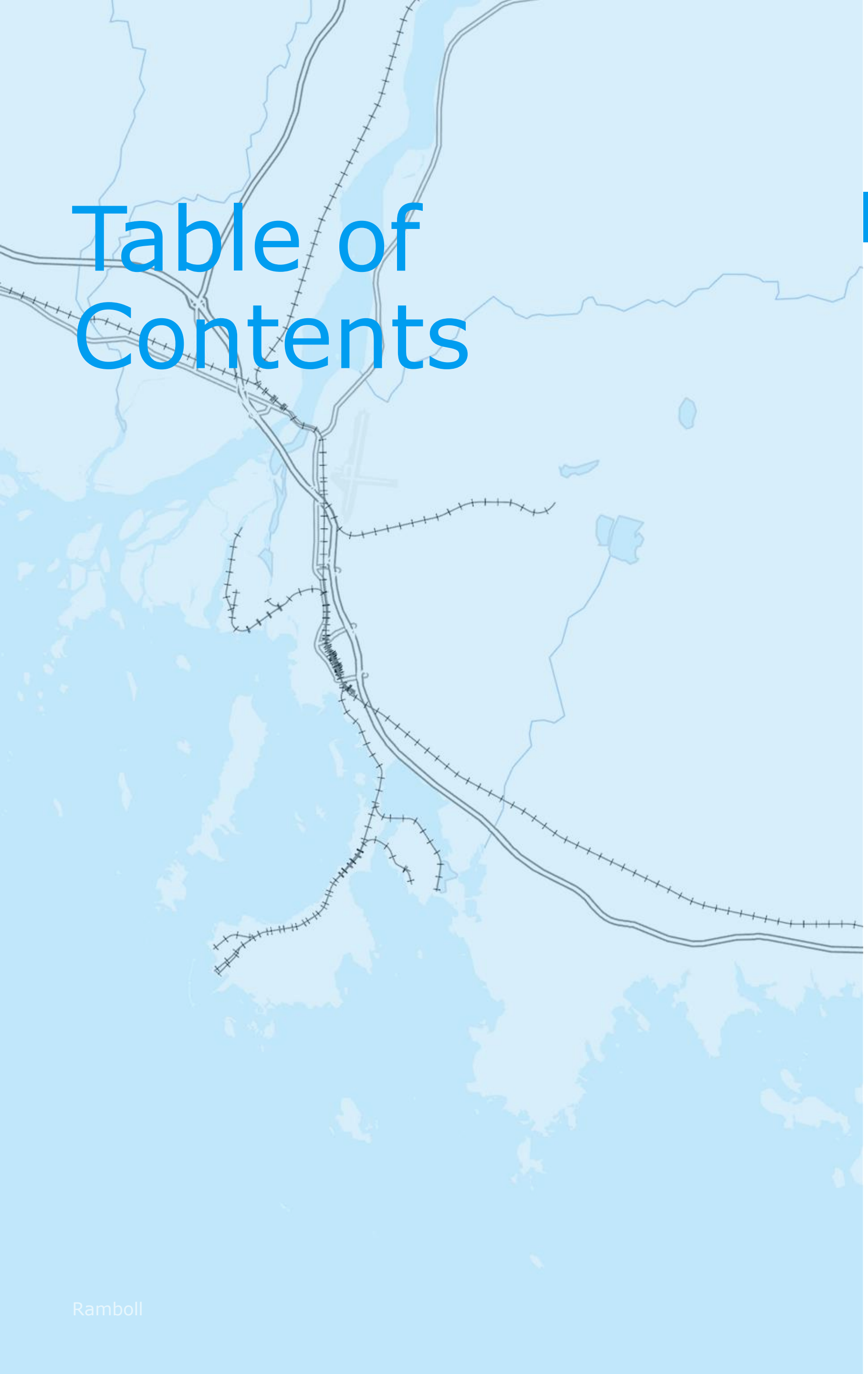
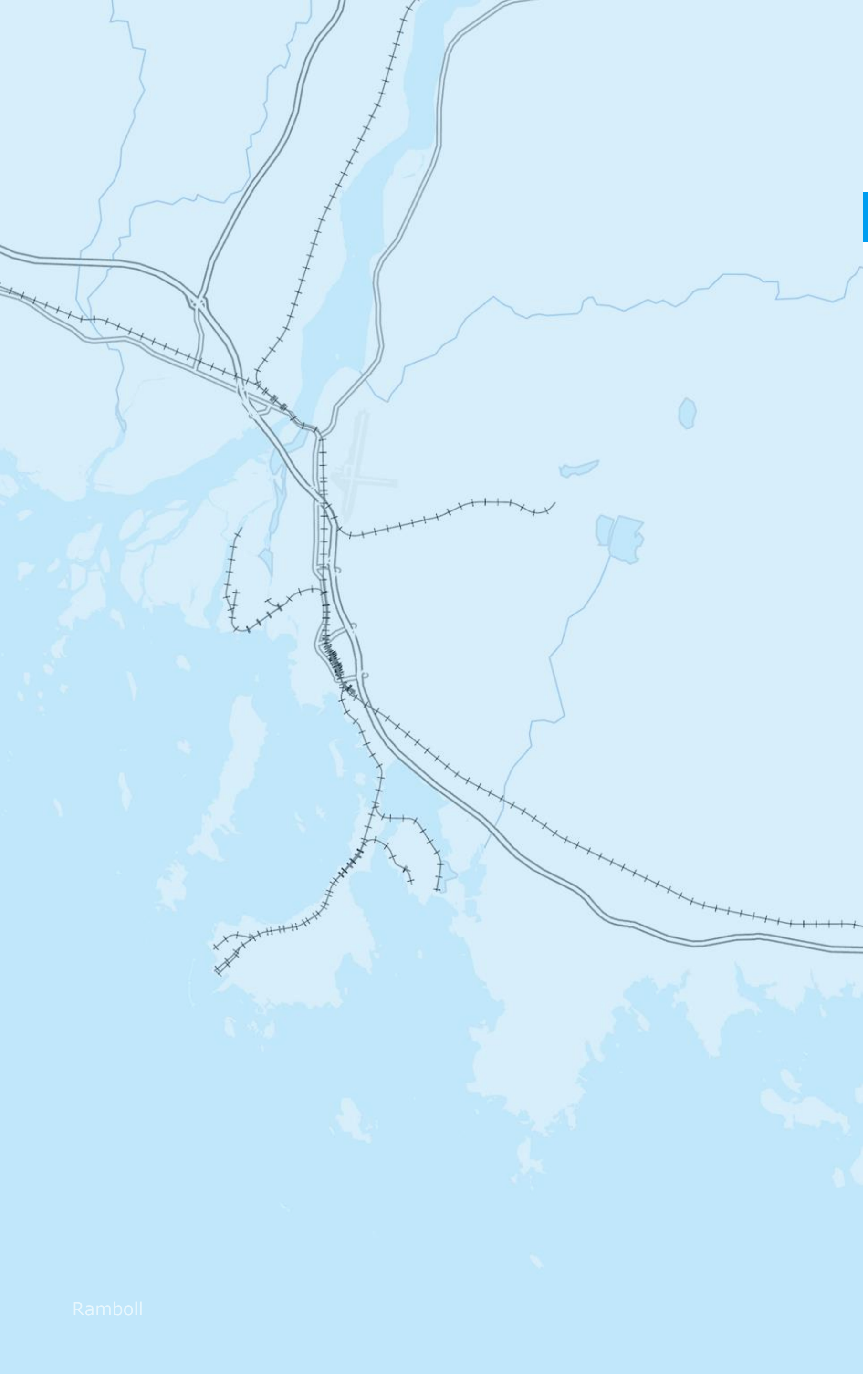


Table of Contents



1. Introduction

Background and Objectives

The Sea Lapland region hosts significant electricity-intensive industry that produces considerable amounts of waste heat. This heat can be effectively utilized in district heating networks, industrial processes, and solutions that improve energy efficiency. The area's renewable energy production, hydrogen electrolysis, and data centers are growing in importance, which increases the significance of circular economy and energy use optimization.

The Kemi East area offers a potential location for electricity-intensive industry and energy production. It is located near Fingrid's electrical substation, main power lines, and a possible hydrogen pipeline route, but initiating industrial activities requires infrastructure development and zoning changes.

The objective of this work is to analyse the possibilities of utilizing waste heat in Sea Lapland, particularly its effects on energy efficiency, economy, and climate targets. Additionally, the suitability of the Kemi East area for industrial and energy investments is examined, and infrastructure development needs are mapped. This work provides an overview of how waste heat, electrical grids, and energy infrastructure can promote sustainable development and industrial growth in the region.

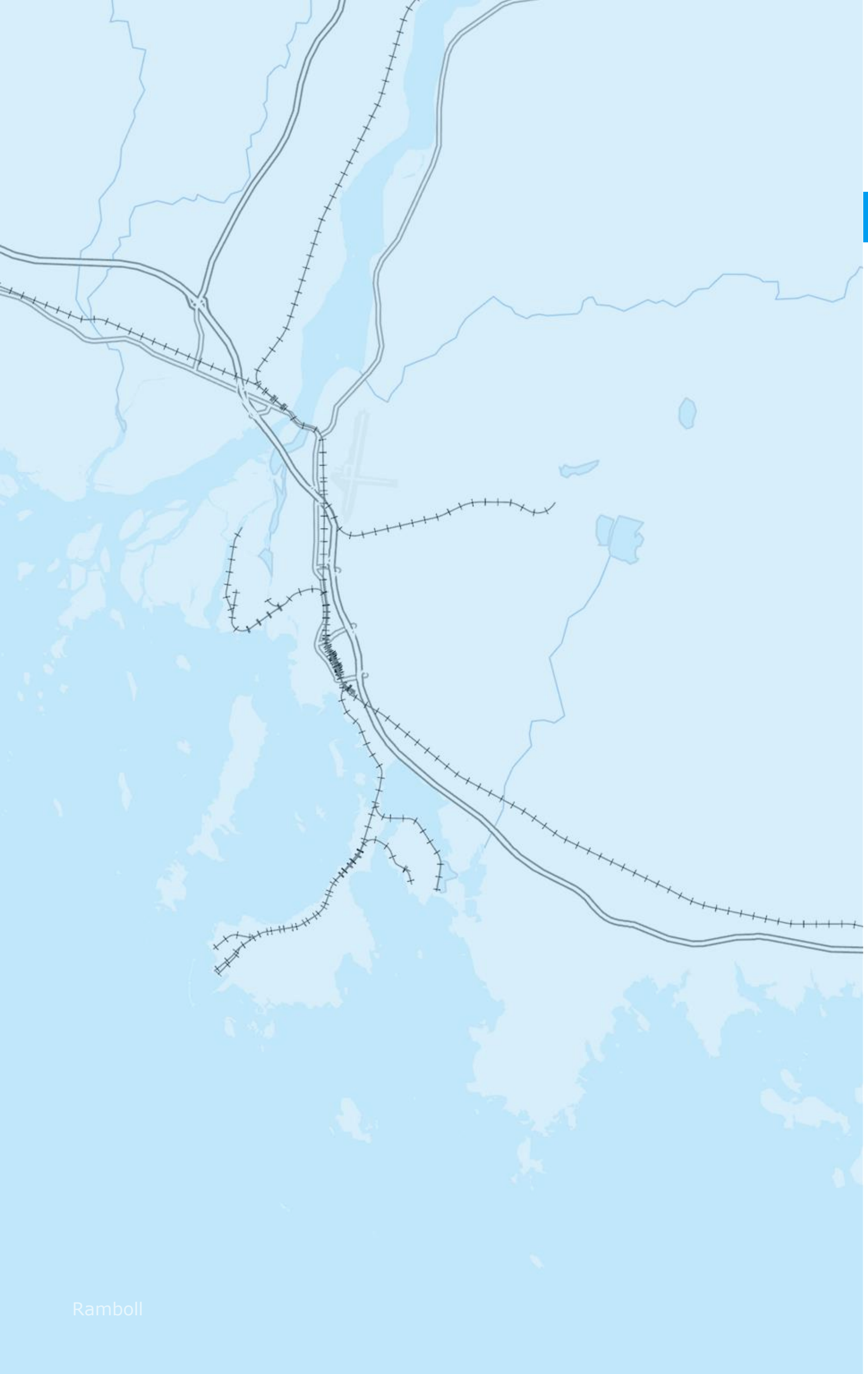
Starting Points and Scope

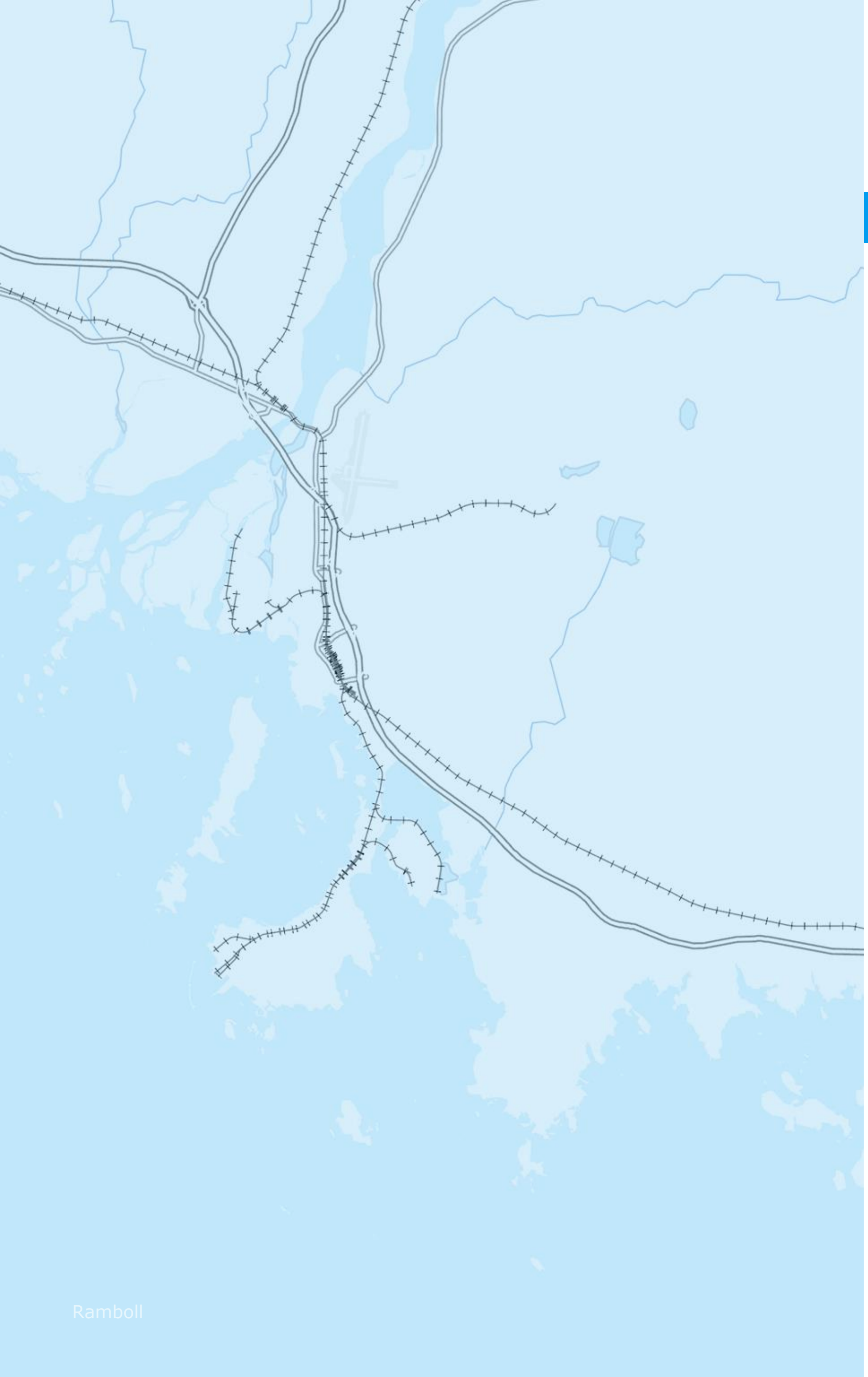
This work examines the possibilities for electricity-intensive industry, energy infrastructure, and waste heat utilization in the Sea Lapland region, focusing on the needs of urban development, energy production, and industry. The focal point of the examination is the Kemi East area, whose infrastructure, such as Fingrid's electrical substation, main power lines, and the planned hydrogen pipeline route, creates a potential location for industry and energy production.

The study focuses on high-power energy use, hydrogen production, and waste heat utilization, and does not consider small-scale renewable energy projects or the business strategies of individual companies.

Geographically, the work concentrates on the industrial and energy infrastructure of Sea Lapland. Environmental and societal impacts, such as nearby residential areas, groundwater regions, and protected sites, are taken into account, but their detailed impact assessment is part of further studies.

The goal is to provide an overview of how waste heat, energy networks, and infrastructure can promote industrial and urban development in the Sea Lapland region, maintaining the examination at a strategic and regional development level.





Energy infrastructure projects in Sea Lapland and surrounding areas

Veitsiluoto datacenter

A new data center is opening in early 2025 in the former premises of the Stora Enso paper mill in Veitsiluoto, Kemi. The center's electricity intake will be 70 MW, enabling a high capacity for computing power.

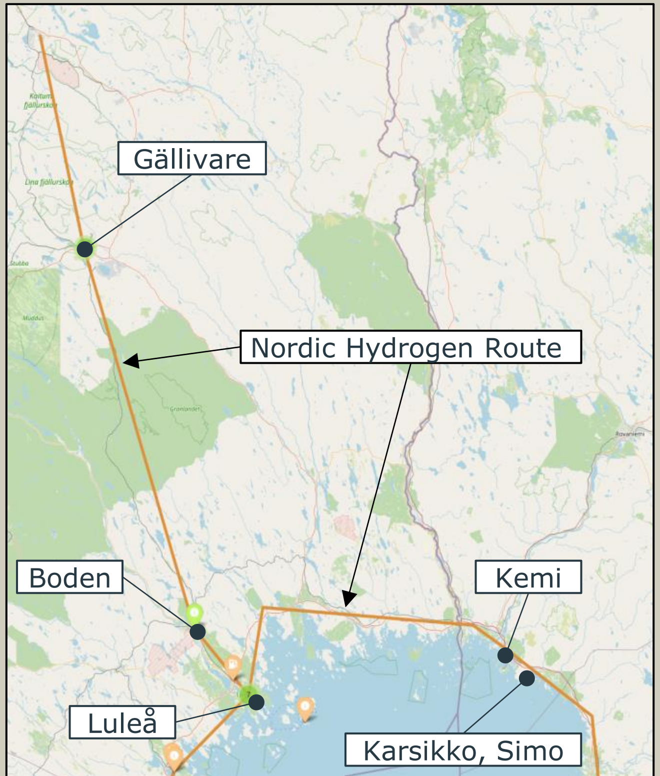
Hydrogen Projects in Tornio's Arctio North Area

- **Norwegian Hydrogen:** A 20-hectare land reservation for a hydrogen production plant. Initially, the plant's production capacity is 50-100 MW, with potential expansion to a 600 MW to 1 GW facility. Planned to be completed in 2026.
- **Verso Energy:** Land reservation for the production of hydrogen and synthetic aviation fuel.

Hydrogen Economy projects in Northern Sweden

Several significant hydrogen projects are underway in Northern Sweden, aiming to develop low-carbon industry and strengthen the hydrogen economy. The most notable projects are:

- **Nordic Hydrogen Route**: A 1000 km cross-border hydrogen infrastructure, aiming to create an open hydrogen market in the Bay of Bothnia area. The project has received EU funding.
- **H2 Green Steel (Boden)**: 700 MW electrolyser capacity designed fro fossil-free steel production.
- **Hybrit Green Steel (Boden, Luleå)**: Uses hydrogen for carbon dioxide-free steel production
- **Green Wolverine (Luleå)**: An ammonia production plant using hydrogen, 600 Mwe electrolyser capacity, planned to be completed by 2026.
- **BothniaLinkH2 (Luleå)**: A hydrogen production plant, planned to be completed by 2027, but exact capacity details are not available.
- **Hybrit Demo (Gällivare)**: A plant desigend fro hydrogen production to meet the needs of the iron ore industry, with a 500 Mwe electrolyser capacity, to be completed by 2025.



© https://ltu.instante.se/V%C3%A4tgas/HydrogenProjects_20240205.html

Energy infrastructure projects in Sea Lapland and surrounding areas

Hydrogen projects in Norway

Bodø Clean Hydrogen Project

In Bodø, Northern Norway, a project focused on clean hydrogen production is being developed. The goal of the project is to build a hydrogen production plant powered by renewable energy, with an electrolyser capacity of 30 MW. The first phase is planned to be completed by 2026. The plant supports regional industry and transportation, while also advancing Norway's green transition.

Yara's Renewable Hydrogen plant

In Porsgrunn, Norway, there is a pilot plant for renewable hydrogen and ammonia. The aim is to replace hydrogen derived from natural gas with electrolytically produced hydrogen. This enables the production of low-carbon fertilizers, significantly reducing the carbon footprint of food production.

Norway's Hydrogen Strategy

The Norwegian government released a national hydrogen strategy in June 2020, aiming to promote the safe use and production of hydrogen and to develop Norway's hydrogen economy. The strategy emphasizes both blue and green hydrogen production, leveraging the country's abundant renewable energy resources and strong expertise in energy and maritime industries.

Carbon Storage Opportunities in Norway

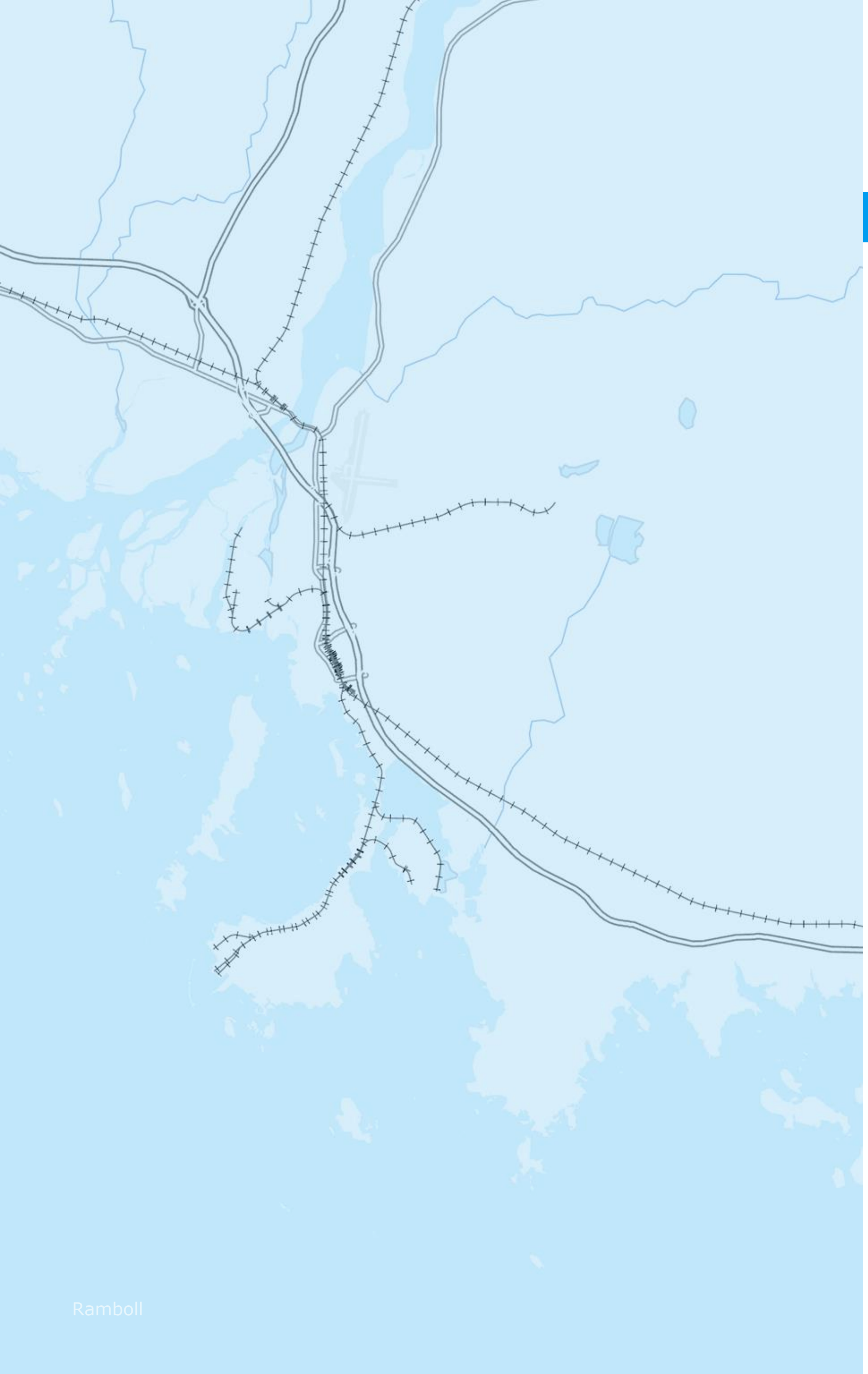
Norway has over 27 years of experience in safely storing carbon dioxide in geological formations beneath the seabed. This makes the country a leading player in carbon capture and storage (CCS) technologies.

Northern Lights Project

Supported by the Norwegian government, the Northern Lights project is developing infrastructure for carbon dioxide capture and storage. The goal of the project is to enable the safe storage of carbon dioxide in the Norwegian continental shelf, which helps reduce emissions both in Norway and other European countries.

Cooperation with Finland

Finland and Norway have agreed to start cooperation regarding the transportation and storage of carbon dioxide. Since Finland's soil does not allow for permanent carbon dioxide storage, cooperation with Norway offers Finnish companies the opportunity to utilize Norway's storage capabilities..

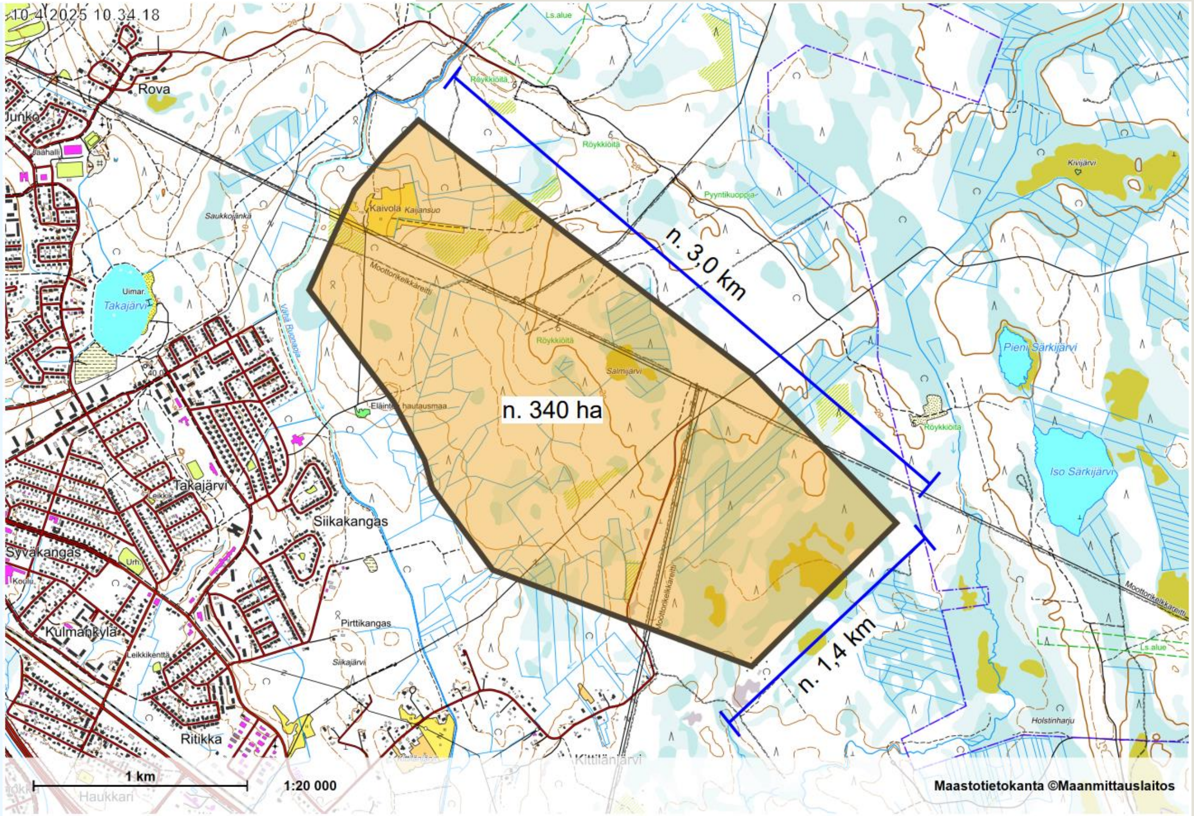


Potential of the Kemi East Area

The Kemi East area covers 351 hectares, and its current land use consists of forest and swamp, with no existing buildings. Accessibility is currently moderate, but it would improve significantly if the planned road reservation indicated in the master plan were realized.

The area is advantageous in terms of the electricity grid, as Fingrid's Kittilänjärvi electrical substation is located in the northern part of the area, and the Isohaara-Simojoki 110 kV main power line runs along the northern edge. Additionally, three 110 kV power lines branch off from the Kittilänjärvi substation, which enables efficient electricity supply and transmission.

The nearest district heating network is located approximately 1 km to the west in the Takajärvi area, and there is also a possible route for a gas pipeline nearby. The data network runs parallel to Highway 4 and the railway slightly further to the west of the area. The western alternative route of Gasgrid's preliminary hydrogen pipeline crosses the eastern part of the area, providing opportunities for hydrogen industry placement within the area.



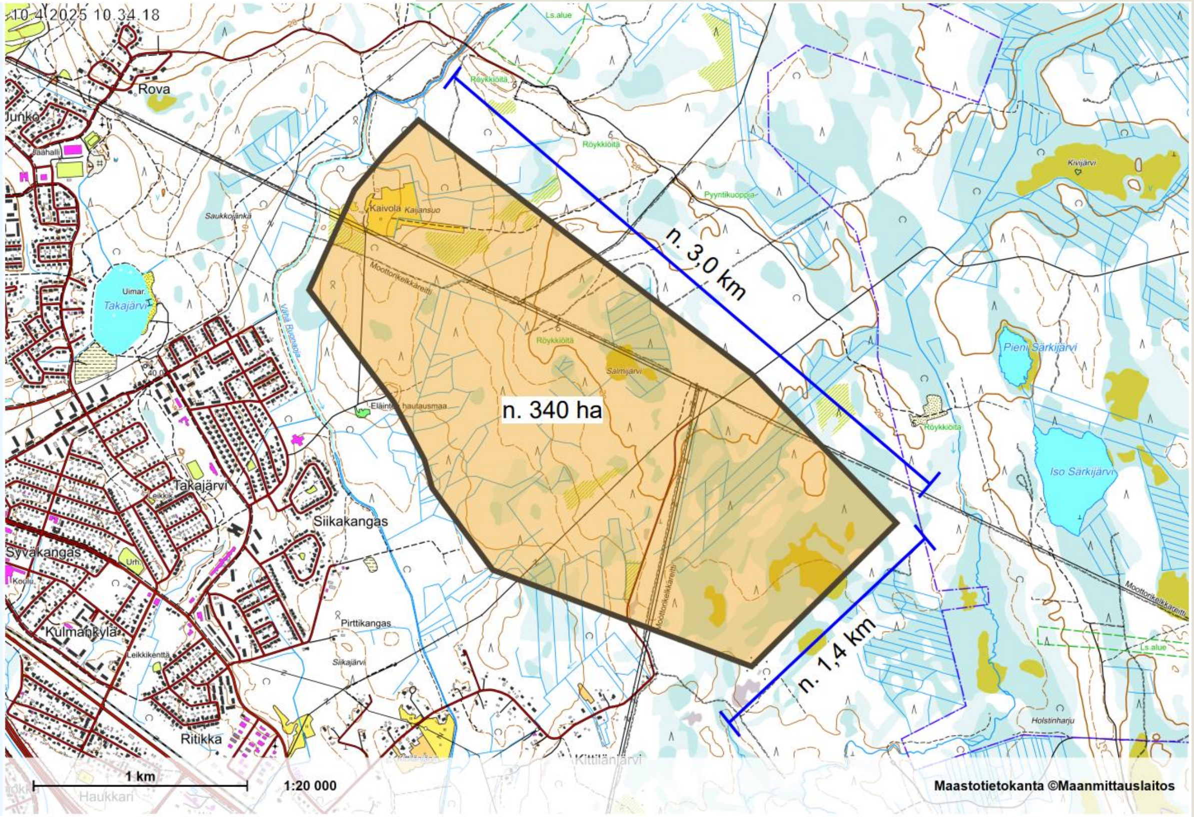
Potential of the Kemi East Area

Possible Uses:

The area can accommodate activities that require high energy consumption, and there is also potential for electricity production either for the grid or for facilities located within the area. Additionally, the area is suitable for activities whose production processes require sources of fresh water.

The current master plan does not support industrial activities in the area, so its implementation for industrial use would require updating the master plan. Planning must also consider nearby residential areas, groundwater regions, and the archaeological site located within the area. Given its location, accessibility, and infrastructure, the area is suitable for the following types of facilities:

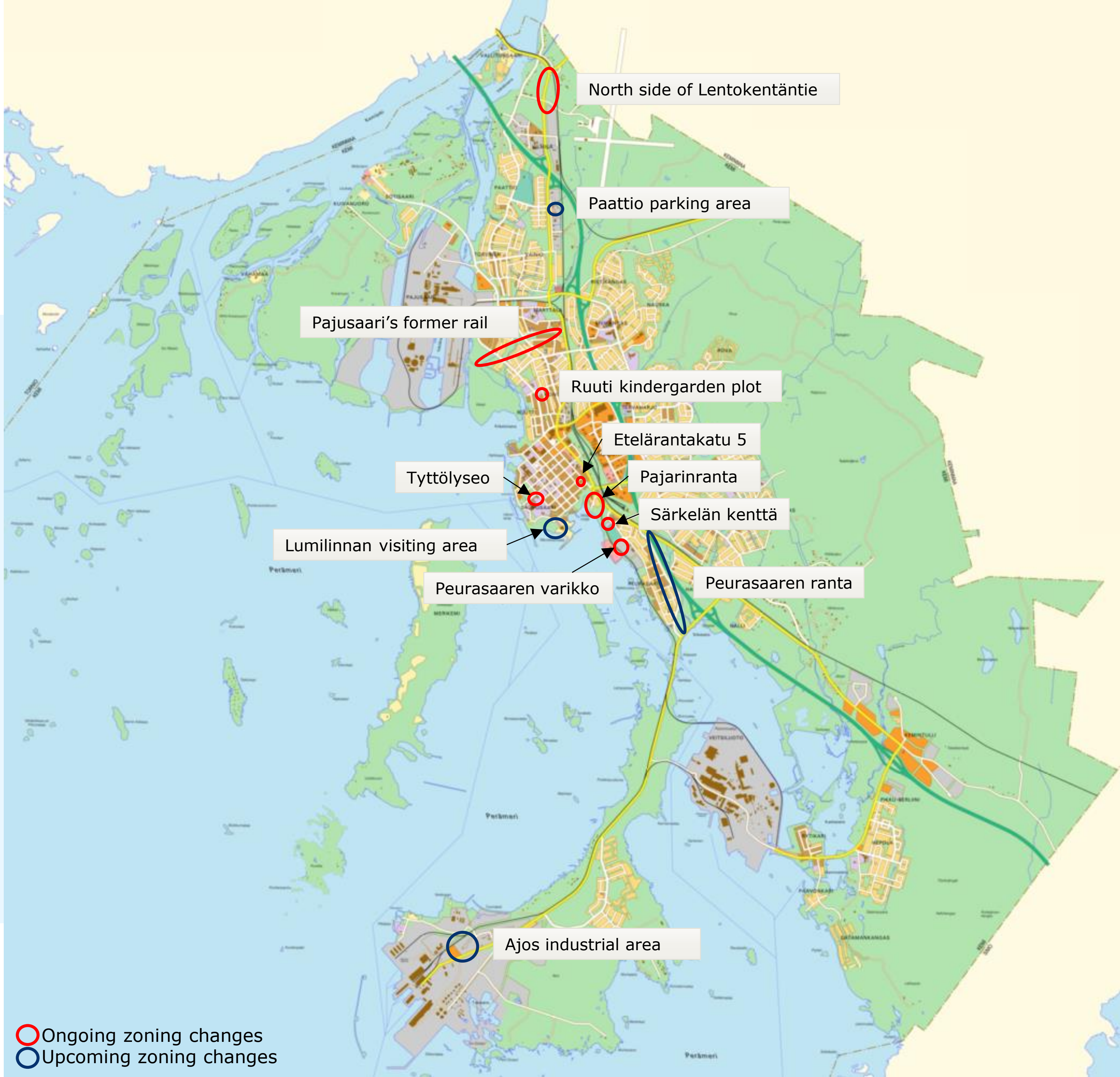
- **Solar power and related energy production**
- **Solar panel and battery manufacturing**
- **Other industrial activities**
- **Hydrogen electrolysis and derivatives**
- **Small nuclear power**



Regional Plans
Zoning Changes

Kemi Zoning Review 2025

- Potentially zoned logistics centers, industry, or services in the area can create opportunities for waste heat utilization.
- The T-Kem area could attract entities that utilize the energy resources of the area
- Next to the airport, there could be opportunities for energy-efficient logistics or production solutions where waste heat can be utilized.
- Zoning changes of interest for waste heat utilization:
  - **New hotel**
  - **New upper secondary school**
  - **New wastewater treatment plant**
  - **Changing the service construction block area and industrial area to T-Kem area**
  - **Expanding the area used by a circular economy company**
  - **New swimming hall**



Regional Plans
Hotel

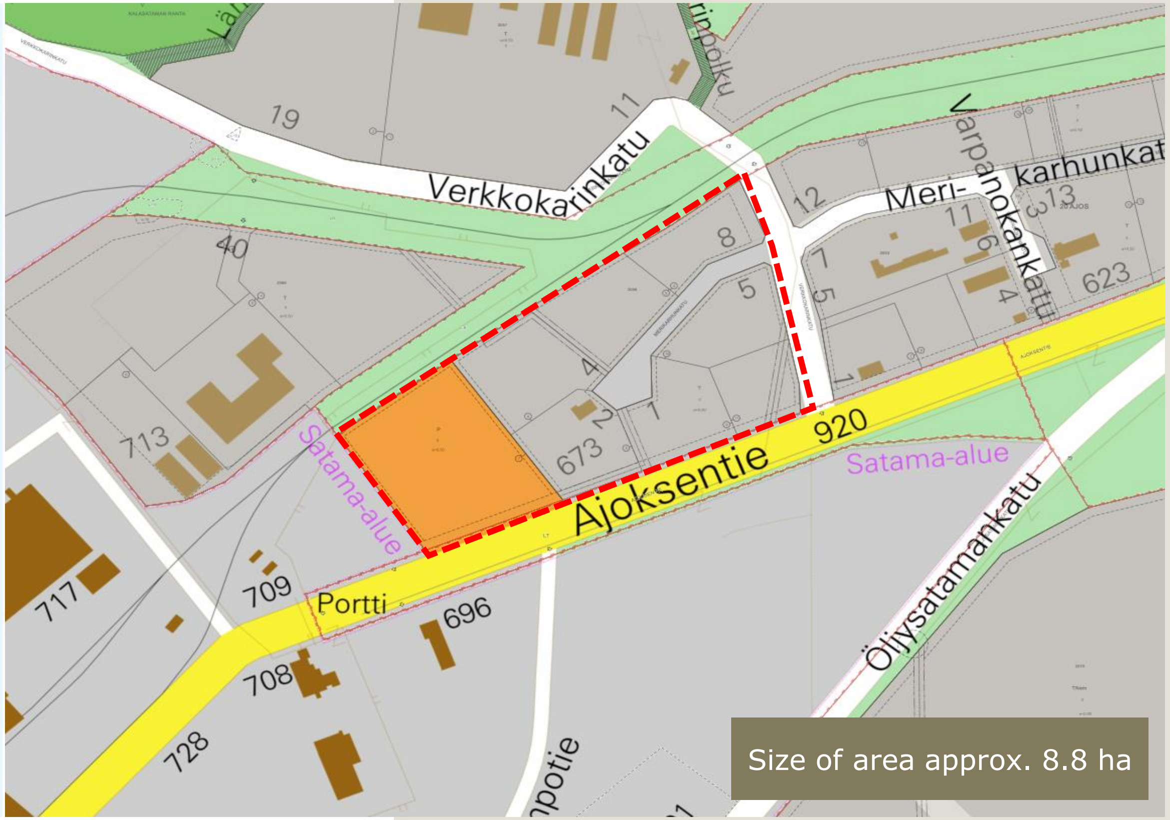
- The zoning change was initiated in conjuction with the zoning review approved by the Kemi City Council on February 10th, 2025, § 38.
- The objective of the zoning change is to enable Kemin Matkailu Oy's hotel project adjacent to LumiLinna.
- The zoning change drafting focuses on the tourism area located to the east of Mansikkanokanpuisto, which currently hosts LumiLinna and related tourism activities.
- Plans visible, in progress, and approved | Kemi

RM	Block area for buildings serving tourism
W	Water area
VL	Local recreation area
	Street square

Regional Plans
Ajos Industrial Area

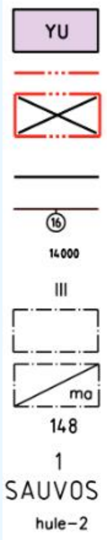
- The block area for service construction at the end of Ajoksentie and the surrounding industrial area aim to be more broadly adapted to the needs suitable for the T-Kem block area.
- T-Kem: “Block area for industrial and storage buildings, on which/where a significant facility manufacturing or storing hazardous chemicals may be located.”

P	Services area
T	Industrial and storage area



Regional Plans
Swimming hall

- The Kemi swimming hall is not part of a nationally significant area complex but is located centrally along Meripuistokatu on the outskirts of valuable areas.
- The zoning plan has provisions for expanding the swimming hall building to the southeast and southwest sides of existing buildings.
- Kemi City Facilities Service applied for a demolition permit for the old part of the swimming hall from Building Control on June 21, 2022. The demolition permit could not be granted without a zoning change, as the swimming hall was protected in the zoning plan with the designation sr-1.
- The protection designation was successfully removed, and the demolition permit for the swimming hall has been granted. [Legal force as of September 25, 2024](#).
- Construction of the new swimming hall on the current swimming hall plot is scheduled to begin in 2027, and the new hall is expected to be completed by 2029.
- The energy consumption of the new swimming hall is not expected to exceed the energy needs of the current swimming hall.



Block area for buildings serving sports activities

Line located 3 meters outside the zoning boundary.

Line located 3 meters outside the city plan area boundary, from within which zoning markings and regulations are removed.

Boundary of the block, section of the block, and area.
Boundary and number of the plot according to the binding plot division.

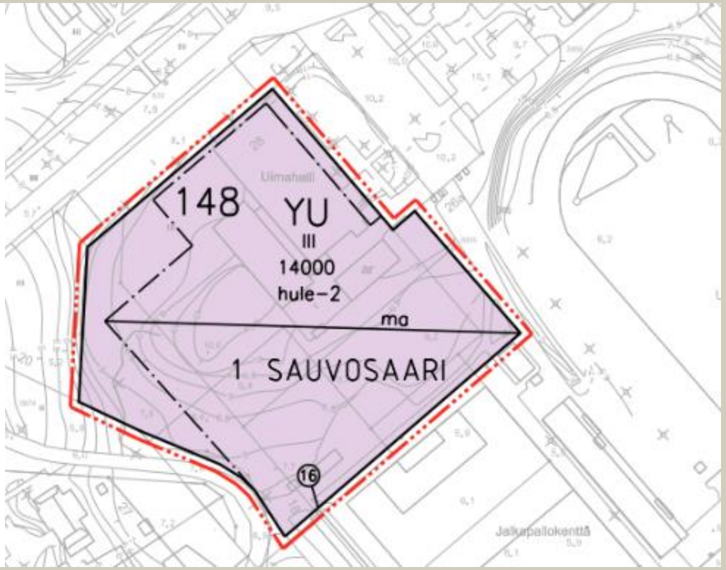
Building rights in square meters of floor area.

The Roman numeral indicates the maximum allowable number of floors for buildings, a building, or a part of it.
Building area.

Underground space.

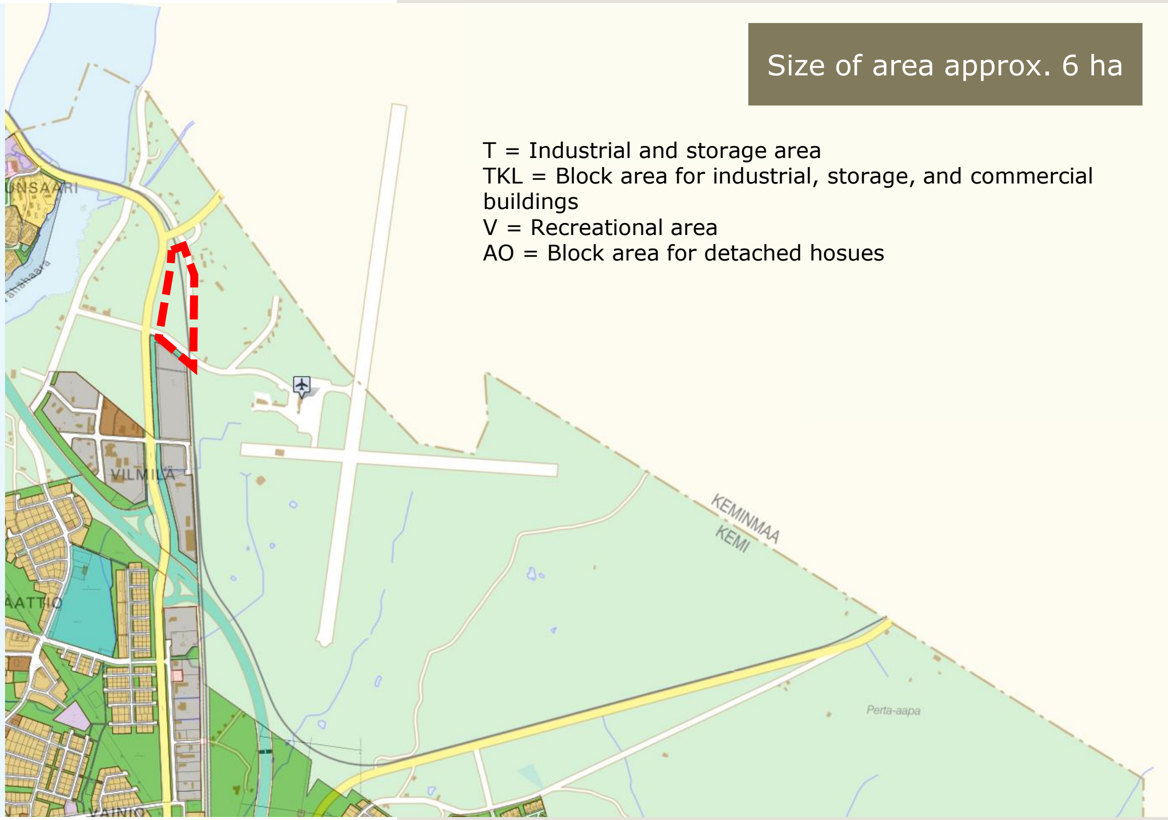
Block number.

District number.
District name.
Building permit documents must include stormwater (including roof water) management plans.



Regional plans
Airport

- Yle: Small airports in Lapland have a significant impact on the operations of major companies. (in Finnish)
- Currently, the operation of the airport is secured with goverment support until 2026.
- "In Sea Lapland, there are significant export industry actors. The area hosts, for example, Tornio steel plant, Kemi bioproduct plant, Outokumpu's Kemi mine, and Veitsiluoto sawmill. It is of primary importance that company and project management can move around and have a good airport nearby.“
- HS: Finavia: The goverment should stop purchasing regional flights (in Finnish)
- At the beginning of 2025, the airport company Finavia proposed that Finland's air traffic should return to a market-based model. This would mean the end of goverment-subsidized regional flight services. Finavia also stated that the airport network could be optimized to match actual demand.
- Lapinkansa: Finavia wants to reduce the regional airport network (in Finnish)
- The maintenance of Kemi-Tornio results in relatively high costs → Finavia’s proposal is alarming.
- Kemi zoning review 2025
- **Zoning of the area north of Lentokentäntie =** The unzoned area will be reviewed with the aim of designating it for services, industry, and business activities in accordance with the master plan. The zoning plan is in the preparation phase..

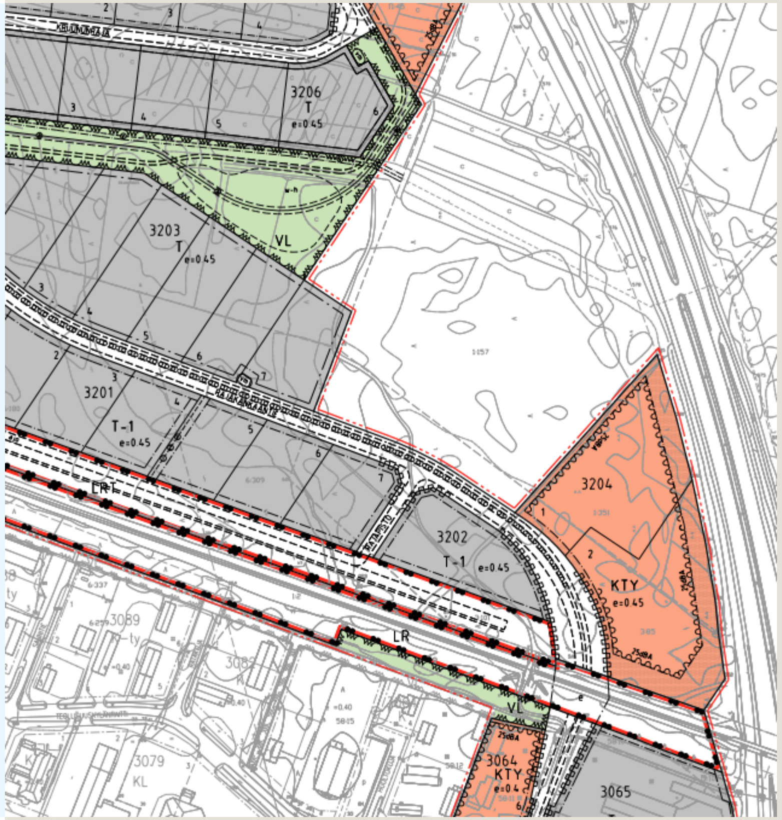


Size of area approx. 6 ha

T = Industrial and storage area
TKL = Block area for industrial, storage, and commercial buildings
V = Recreational area
AO = Block area for detached hosues

Regional Plans
Rajakangas Business Park

- Located in Keminmaa
- No zoning changes are currently pending for Keminmaa
- Rajakangas Business Park is at the heart of Sea Lapland, and space is allocated for business activities
- Space reserved for industrial rail, for example
- [Plots and business areas – Keminmaa](#) (in Finnish)



Utilization of Waste Heat

In industry, excess waste heat can be generated during production processes. This heat is not directly utilized as part of the process and is released into the environment without being captured

Industrial waste heat
Waste heat formation includes combustion processes, operation of machinery and equipment, cooling systems, and chemical processes.

By capturing waste heat, it can be utilized in other industrial processes, business, or residential needs. Particularly, large industrial plants can generate a significant amount of waste heat regionally, from which other operators/facilities can synergistically benefit.

Below are examples of waste heat utilization opportunities across different sectors. Waste heat is generated in industrial plants from combustion processes, the operation of machinery and equipment, cooling systems, and chemical processes. This excess heat can be captured and reused in various fields, such as industry, energy production, tourism, and housing.

Industrial waste heat can serve many different sectors, and its utilization can reduce the need for primary energy, lower the carbon footprint, and improve energy efficiency across society.

Forestry Industry
Uses: Drying materials, heating spaces, preheating production processes, other production processes

Food Industry
Uses: heating greenhouses, heating growing spaces and tanks (insects, mushrooms, fish, algae), bioreactor cultivation, drying materials

Other Manufacturing Industries
Uses: heating spaces, preheating production processes, other production processes

Energy Industry
Uses: renewable energy production, energy storage, preheating production processes

Tourism
Uses: heating spaces and hot water, spas and swimming pools

Housing
Uses: heating spaces

Electrolyser

An electrolyzer is a device where electrolysis occurs, the splitting of water into hydrogen and oxygen using electrical energy.

The most common electrolyzer technologies planned in Finland are

Alkaline Electrolysis (AEL)

- The most mature and widely adopted technology.
- Process temperature: 60-80 °C
- Operating pressure: 30 bar

Proton Exchange Membrane Electrolysis (PEM)

- Rapidly gaining market share.
- Development stage nearing completion
- Process temperature: 50-80 °C
- Operating pressure: 30-40 bar

Solid Oxide Electrolysis (SOEC)

- Still in early commercialization and pilot phases.
- Promising but still developing technology.
- Process temperature: 600-850 °C
- Operating pressure: 1-5 bar

Case Luulaja1

Research on the waste heat of the electrolyzer to be placed in Luleå:

100 MW AEL → 310 630 MWh waste heat in a year

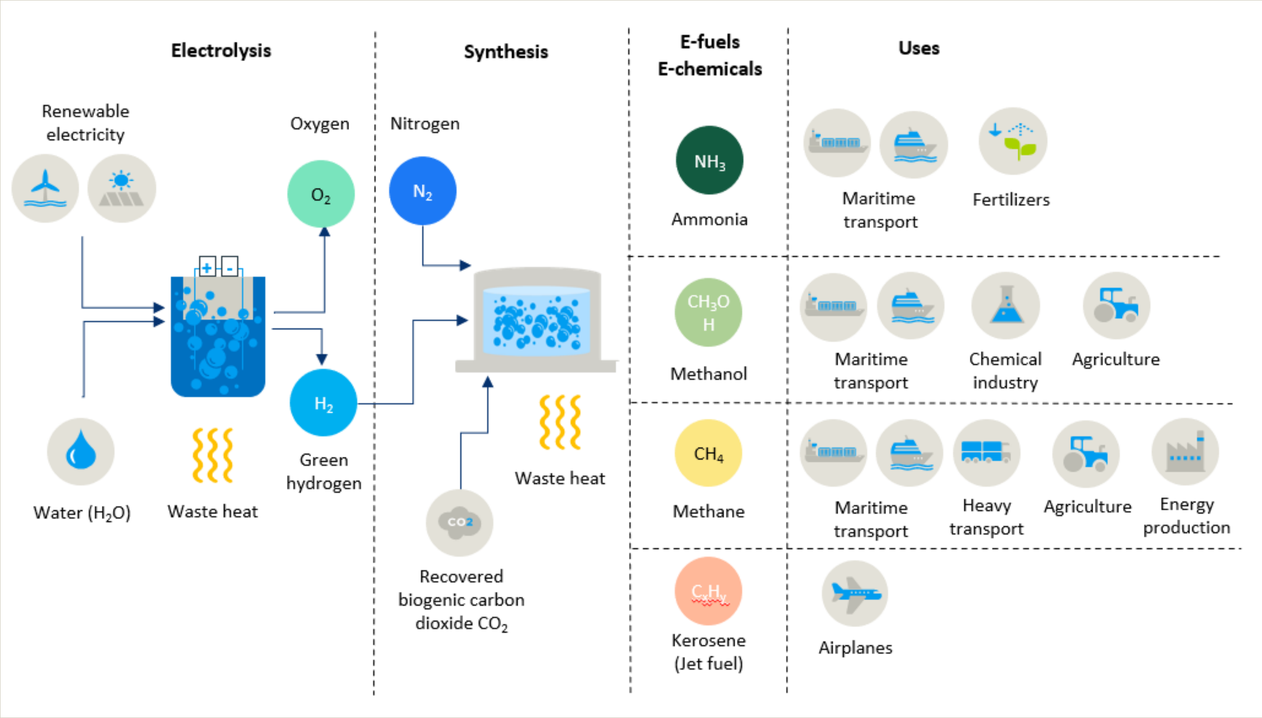
100 MW PEM → 203 060 MWh waste heat in a year

PEM consumes about 21% less water compared to AEL, because PEM converts electricity more efficiently into hydrogen, thus generating less waste heat.

Lähteet: 1https://www.diva-portal.org/smash/get/diva2:1670187/FULLTEXT01.pdf
2Elektrolyysiteknologioiden edit ja haitat, Juuso Klemi opinnäytetyö

Electrolysis – Hydrogen Refinement

- Hydrogen produced by electrolysis can be used as-is or further refined.
- Different feedstocks are required in the refinement process depending on the product – for example, ammonia production requires nitrogen gas, while methanol and methane production require carbon dioxide.
- By refining hydrogen, the number of potential uses increases. Hydrogen and its derivatives are useful, among other things, as transportation fuels, in the chemical and process industries, in fertilizer production, and as a component in electricity production for balancing power.
  - The balancing power concept is based on the fluctuations in renewable electricity production: hydrogen is produced using surplus renewable electricity, and electricity is generated from hydrogen when renewable electricity production is insufficient.
- Waste heat is generated at various stages of the process, which can be utilized for industrial or district heating needs. Another significant by-product of electrolysis is oxygen, which can be used in process industries and the food industry.



When are hydrogen and synthetic fuels defined as renewable energy?

RFNBO criteria

RFNBO fuels must meet three criteria:

1. The usage should achieve at least a 70% reduction in greenhouse gas emissions.
2. The carbon dioxide (CO_2) used must come from an approved source.
3. The electricity used must meet the criteria for renewable electricity.

- All green hydrogen and RFNBO fuels produced by a facility are considered renewable if:
  1. Renewable electricity production is directly connected to the production facility and:
     - The renewable energy production facility starts operation simultaneously or after the fuel production facility (at the earliest 36 months before).
     - The renewable energy production facility is not connected to the grid.
  2. Alternatively, grid electricity is used, but it can be demonstrated that the grid electricity is renewable and it meets the criteria of the delegated regulation. Key criteria include:
     - Complementarity/additionality principle: the introduction of renewable energy production < 36 months before RFNBO production and PPA (Power Purchase Agreement).
     - Grid electricity emission intensity < 65 gCO_2eq/kWh + PPA + geographical & temporal correlation + balance adjustments.
     - Over 90% of the grid electricity is renewable.
- If the grid electricity does not meet the criteria of the regulation, only part of the hydrogen and fuel produced by the facility will be considered renewable.
- The production of grid electricity in Finland is expected to stay below the emission limit in the future.

EU guidance

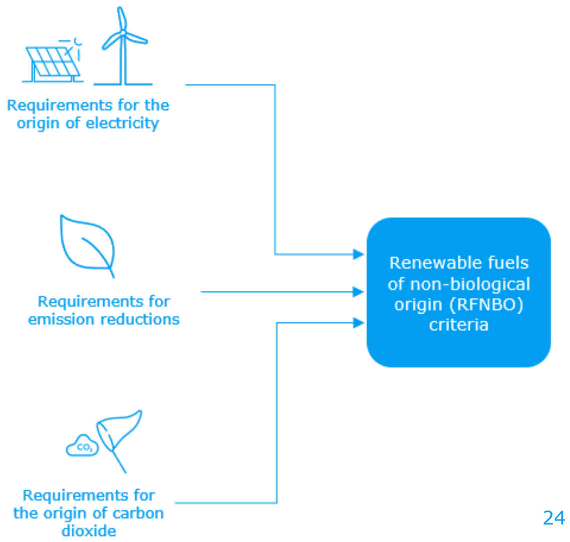
Hydrogen produced by electrolysis does not always meet the definition of renewable hydrogen. The classification of hydrogen is based on the Renewable Energy Directive (RED III) and its complementary delegated regulations.

The delegated regulation approved by the EU in June 2023:

- Defines the conditions under which hydrogen, hydrogen-based fuels, or other energy carriers can be considered renewable fuels of non-biological origin (RFNBOs).
- What is defined as renewable energy.

Regulation preparation is still ongoing at the EU level, so the following criteria may change.

The criteria for RFNBO fuels can be roughly divided into three parts.



Electrolysers

Impact of Temperature

To PEM Electrolysers

PEM electrolyzers operate more efficiently at higher temperatures, as the change in entropy is minimal, improving their stability and performance. However, excessively high temperatures can dry out the electrolyzer's membrane, hindering the proton flow from the anode to the cathode and thus reducing the cell's efficiency. A wet proton exchange membrane is crucial for effective proton transfer.

Temperature increases accelerate the electrochemical reaction and improve efficiency, but they also increase leakage currents and can cause hydrogen to migrate to the cathode side, damaging bipolar plates, catalysts, and seals. Continuous operation at high temperatures shortens the lifespan of the cell. Performance depends on various factors, including structure, component design, chemical composition, and operating conditions

To AEL Electrolysers

Pressure does not significantly affect the hydrogen flow rate, cell voltage, cell stack power, or system efficiency. Instead, higher temperatures enhance electrochemical efficiency, visible as lower voltages and reduced power requirements, which decreases energy costs and improves energy efficiency.

However, raising the temperature has limitations. Electrode oxidation and passivation degrade performance, and excessively high temperatures can reduce water activity in the electrolyte solution, excessively drying it. Managing these limitations is crucial for optimal electrolyzer operation.

Optimization

Optimizing the temperature of an electrolyzer is important for plant efficiency and profitability. The right temperature boosts hydrogen production but is influenced by many factors.

Effects on Production Process:
Higher temperatures can improve electrochemical efficiency, lower cell voltage, and reduce energy consumption. Conversely, excessively high temperatures can damage electrodes and impair electrolyte properties, diminishing performance..

Profitability:
While higher temperatures can enhance efficiency and lower energy costs, they can also increase material wear and maintenance costs. Optimization requires balancing technical and economic factors.

Influencing Factors:

- The type of electrolyzer (e.g., AEL, PEM) reacts differently to temperature.
- Operating conditions, such as pressure, flow rate, and electrolyte composition, impact optimization.
- Economic factors, including energy, material, and maintenance costs, guide decision-making.

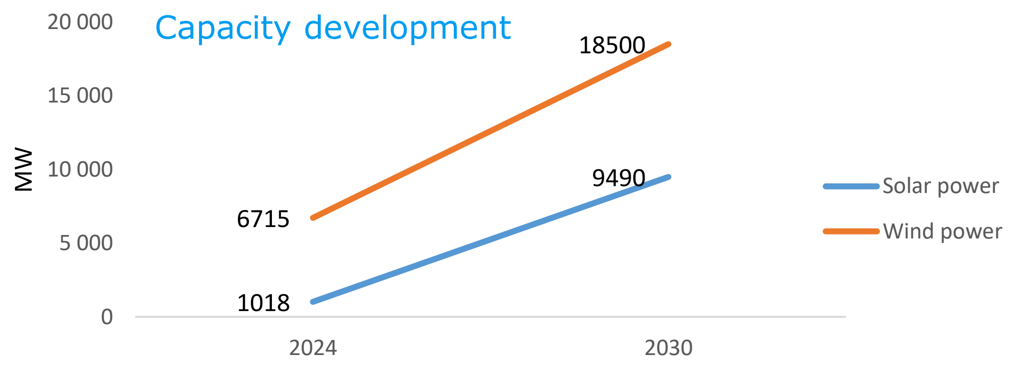
Sources:
Ganley, J.C. (2009). High temperature and pressure alkaline electrolysis. https://doi.org/10.1016/j.ijhydene.2009.02.083
Azuan, M., Yahaya, N.Z., Melinda, A. & Umar, M.W. (2019). Effect of temperature on performance of advanced alkaline electrolyzer. https://www.sci-int.com/pdf/637054513794717651.pdf
Vuorinen, L. (2019). Kannattavuusmalli datakeskuksen hukkalämmön hyödyntämiseen kaukolämpöverkossa. https://urn.fi/URN:NBN:fi-fe201902043985

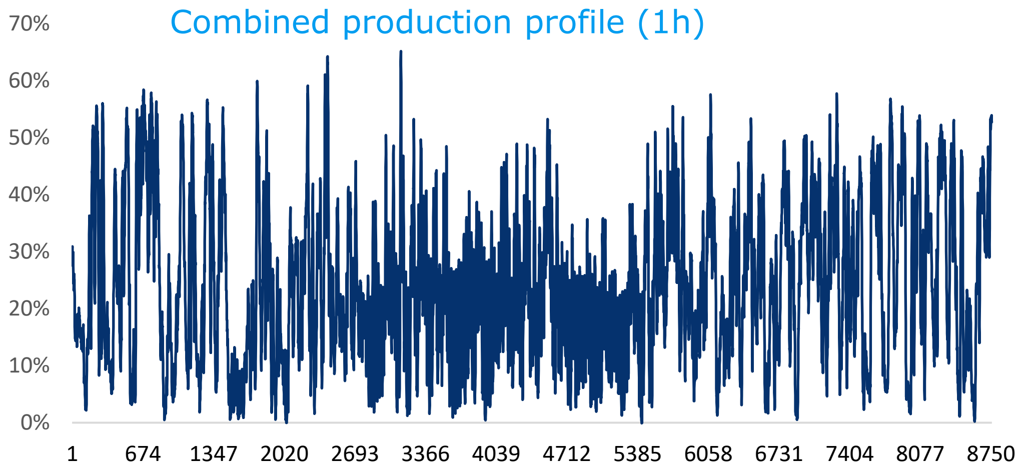
Electrolysers - Temperature

Impact of Temperature

- **Waste Heat from Electrolyzers**
  The amount of waste heat depends on the operating mode and method. Green hydrogen production varies with the availability of renewable energy sources such as wind and solar power. Continuous operation at nominal power produces steady heat, whereas optimizing usage according to electricity prices results in more variable heat production. In Finland, the low emission factor of electricity production reduces the need for strict monitoring of renewable energy.
- **Factors Affecting Waste Heat:**
  - Annual operating hours and production power.
  - Maintenance shutdowns.
  - Variations in wind power.
  - Operating Modes:
    - **ON:** Normal operation (5–100%).
    - **STANDBY:** No production, but heat and pressure are maintained.
    - **OFF:** Shutdown, temperature drops to ambient levels
- The load tolerance, startup times, and standby losses of the electrolyzer affect flexibility and energy efficiency.
- A well-maintained plant can operate continuously, but cell stack wear requires regular maintenance breaks. The need for maintenance depends on the size and technology of the system, and shutdowns can be related to cell stack replacement or cleaning processes.

Solar and wind power capacity & combined production profile.





Date Center

A high-power data processing facility that stores, processes, and distributes large amounts of digital data and services.

- The number of data centers has grown significantly with increased digitalization, adoption of cloud services, AI, and streaming services, as they require substantial computing power and storage capacity.
- The characteristics of the waste heat generated are influenced by how IT equipment in the data center is cooled and from where within the center the heat is captured. The optimal heat recovery point depends on both the cooling method of the equipment and the production mode of the cooling.
- Traditional air cooling is no longer sufficient for more efficient data centers, making liquid cooling the preferred choice. The waste heat produced by liquid cooling can also be stored for other uses.

Table: Characteristics of Waste Heat in Data Centers

Cooling Method	Cooling Medium for servers	Waste heat recovery point	Waste Heat Temperature
Air Cooling	air	Return air after servers	35 – 45 °C
		Return air from air conditioning unit	25 – 40 °C
		Cooling fluid from air conditioning unit	10 – 20 °C
Liquid Cooling (single-phase)	water	Cooling water after servers	22 – 65 °C
Liquid Cooling (two-phase)	cooling fluid	Cooling fluid/gas after servers	62 – 80 °C
		Cooling water for primary cooling loop	45 – 90 °C

Restrictions on the use of waste heat are imposed by the power demand of the district heating network, which can be lower than the power of the waste heat at times or continuously. Thus, the data center must have a fully-sized cooling system that manages cooling when heat cannot be transferred to the district heating network.

Power requirements range from tens of kilowatts to hundreds of megawatts. The amount of waste heat can vary or remain steady depending on the purpose of the data center.

A 70-MW data center is opening in the Veitsiluoto area at the beginning of 2025.
Image: Yle, Antti Ullakko, November 7, 2024.

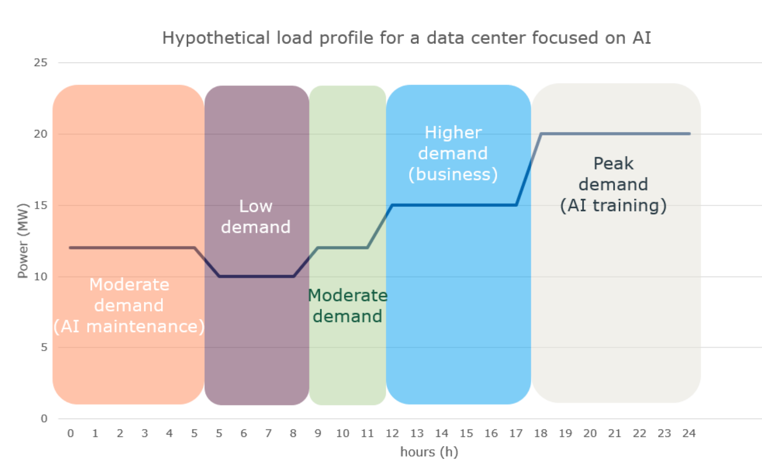
Sources: https://lutpub.lut.fi/bitstream/handle/10024/159119/Diplomity%c3%b6_Vuorinen_Laura.pdf?sequence=1&isAllowed=y
https://www.cejn.com/fi-fi/articles/shaping-the-future-of-liquid-cooling-technology-in-data-centers-cejn-and-the-open-compute-project/

Data Center types

Type of Data center	Purpose	Usage rate	Power class (MW)	Exmples in Finland / Possible future projects
Cryptocurrency Mining Center	Mining Bitcoin and other cryptocurrencies	Steady	10-100	BitTEK (Kemi), Northern Data (Kajaani)
Corporate Data Center	Company's own IT services	Varies	0,1-5	Companies' own centers (banks, insurance companies, telecom operators...)
Cloud Data Center	Providing public cloud services (e.g., Google Cloud)	Varies	20-100+	Google (Hamina), Microsoft coming (Espoo/Kirkkonummi)
Colocation	Companies rent server capacity and space	Varies	2-50	Equinix (Helsinki), Ficolo (Helsinki, Pori, Tampere)
Hyperscale	Giant data centers of large tech companies (search engine, streaming, social media)	Steady	20-100+	Google (Hamina), Microsoft (rakenteilla)
High Performance Computing (HPC) Center	Artificial intelligence, scientific computing, simulation, machine learning	Varies		CSC LUMI (Kajaani)
Edge	Fast communication, 5G, IoT, real-time data analytics	Varies	0,1-1	Not yet in Finland, but potential as 5G network expands.

When the usage rate is variable, the data center operates according to customer demand or data traffic load.

Example of AI data center's load profile during the day. A data center can schedule AI training tasks during nighttime when electricity is cheaper. The local power grid might experience a sudden increase in demand during these hours.[2]



[1]Crypto mining and data center fast facts: https://scienceforgeorgia.org/wp-content/uploads/2024/02/Crypto-and-Data-One-Pager.pdf
[2] https://theconversation.com/how-utilities-are-working-to-meet-ai-data-centers-voracious-appetite-for-electricity-240196
Production profile: https://nzero.com/article/how-data-centers-can-scale-sustainably-to-meet-demand/

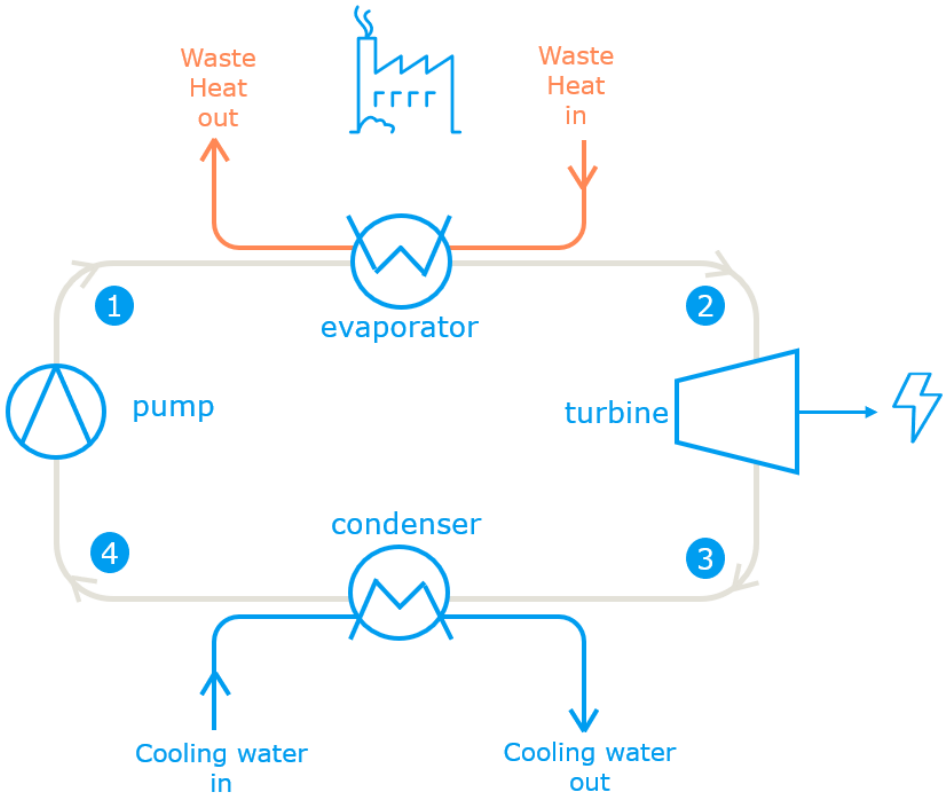
Organic Rankine Cycle - Technique

The Organic Rankine Cycle (ORC) technology enables the utilization of low-temperature waste heat in electricity production.

Description

- The Organic Rankine Cycle (ORC) is similar to the conventional Rankine process but uses an organic substance as the working fluid instead of water, which evaporates at lower temperatures. This allows the use of waste heat for electricity production through a turbine at lower temperatures.
- Operational Recommendations:
  - The temperature should be above 100 °C (generally 150-350 °C). Higher temperature improves efficiency.
  - Cold thermal sink
  - At temperatures below 100 °C, more waste heat and larger equipment are required, which reduces efficiency and increases costs.
- Main Components and Functions of the ORC Process:
  - Pump: Pressure increase
  - Evaporator: Evaporation of the working fluid
  - Turbine: Electricity production
  - Condenser: Conversion of the working fluid back to liquid
  - A regenerator can be added to the process to improve efficiency.
- Advantages of Organic Working Fluid:
  - Simplifies plant structure
  - Enables smaller unit sizes and decentralized electricity production
  - Avoids problems caused by wet steam in the turbine
  - Improves operational reliability

Process diagram



Organic Rankine Cycle – Efficiency & Profitability Factors

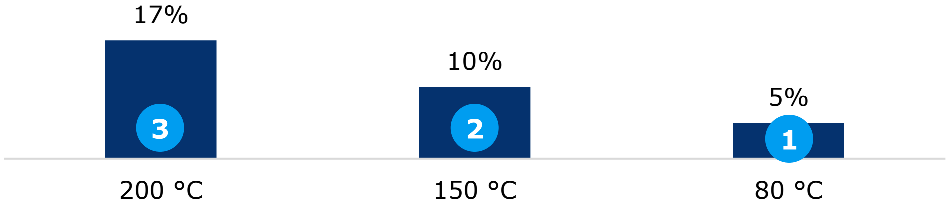
The efficiency of ORC technology is heavily tied to the temperature of the waste heat.

Factors affecting profitability and efficiency

- **Profitability:** For the ORC process to function effectively, a cold thermal sink is also required. High transferable power, low temperature, and small temperature differences in the cooling flow result in high flows and, consequently, relatively high pumping costs.
- **Profitability:** To make the utilization of low-temperature waste heat in an ORC process profitable for electricity production, the following conditions are needed:
  - Waste heat should be practically free.
  - Waste heat must be available continuously and have a sufficiently large capacity to achieve high peak usage time for the ORC plant.
  - A cold thermal sink is needed, such as seawater or air cooling, which should be readily available.
  - Pumping distances should not be excessively long.
  - Electricity prices must be sufficiently high.
- **Efficiency:** When waste heat is a low-temperature heat source, the achievable electrical efficiency rates are typically low, often below 10%. Efficiency is strongly dependent on the temperature of the heat source and the temperature difference between the heat source and the thermal sink.
- **Efficiency:** The maximum theoretical efficiency (Carnot efficiency) of the process is determined by the temperatures of the hot and cold sides of the process. In practice, efficiencies of ORC processes are at best about 45% of the theoretical maximum efficiency.
- .

Efficiency for example temperature levels by waste heat source

1. 80 °C: Typical waste heat temperature of **PEM Electrolyzers**
2. 150 °C: Waste heat temperature from **E-SAF Production**
3. 200 °C: Possible waste heat temperature of **SOEC Electrolyzers**



Example Comparison of PEM and SOEC Electrolyzers, assumed size 10 MW:

Technology	Operating temperature	Total amount of waste heat	Waste heat temperature
SOEC	700-800°C	~0,5-1,5 MW	100-300°C
PEM	50-80°C	~3,5-4,5 MW	50-80°C

A significant difference between electrolyzers is their operating temperature. Although the operating temperature of SOEC is very high, this does not directly mean that the waste heat temperature is equally high. SOEC equipment recycles a large portion of the heat internally for steam preheating and cell stack maintenance, resulting in less "excess" waste heat with a lower temperature than the operating temperature.

Organic Rankine Cycle – Costs

Waste heat temperature affects the costs.

Investments – CAPEX

- ORC system investment costs consist of the following parts:
  - Equipment: turbine, generator, heat exchangers, control systems
  - EPC: Engineering, procurement, and construction, including design, installation, and commissioning
  - Other construction works (placement, foundations, pipelines)
- Investment costs can achieve economies of scale based on the power class
  - For smaller systems (under 1 MWe), the investment is estimated at approximately €2000–5000 per kW
  - For larger systems (over 1 MWe), the price is estimated at approximately €1000–2000 per kW
  - EPC costs are usually 20–30% of the total investment.
  - Other construction works can account for 10–20% of the total investment.
- The temperature of the waste heat being utilized affects the investment. At lower temperatures, physically larger components such as larger heat exchangers and pumps are required.
  - Lower temperatures typically also have a lower pressure difference, which means a larger or more complex turbine.

Operating costs – OPEX

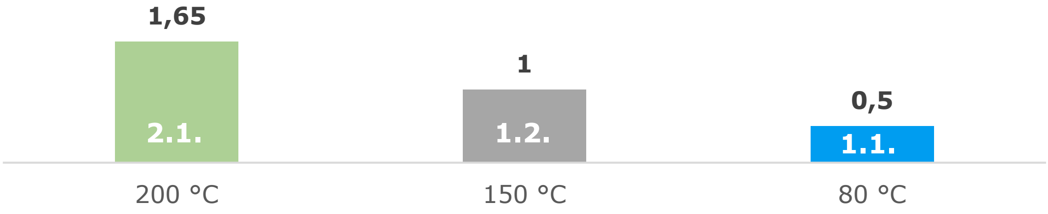
- ORC system operating costs consist of the following parts:
  - Maintenance and operational costs (e.g., parts replacements and labor)
  - Replacement and additions of working fluid.
  - Auxiliary electricity used by the system (pumps, cooling and ventilation systems).
- ORC technology is simple and easy to use, and it does not require a local operator. The process is controlled by automation, allowing the equipment to be located in remote locations.
- Additionally, the equipment requires minimal maintenance, and there are no major equipment replacements involved (the turbine does not experience erosion or corrosion).
- Moreover, the equipment is quick to start up or shut down, the use of the working fluid does not require various chemicals like conventional power plants, and only small amounts of the working fluid need to be added.
- Typically, OPEX costs in the ORC process are around 2-5% of the investment costs.

Organic Rankine Cycle – Electricity production

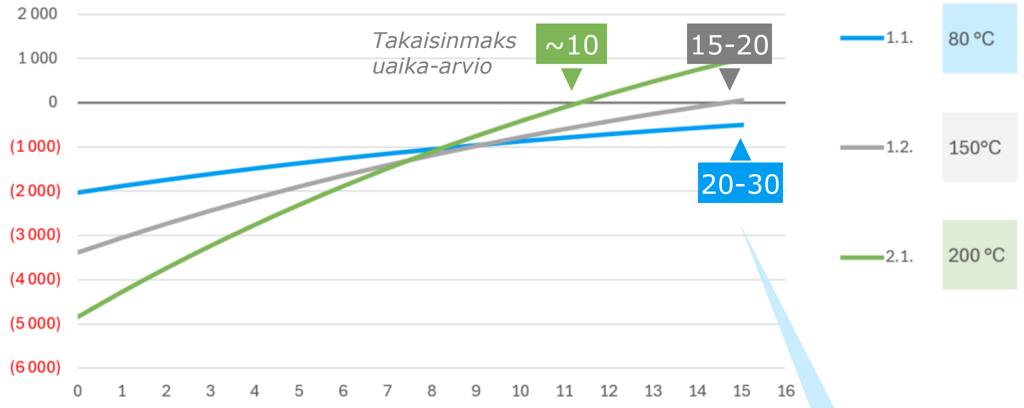
The higher the temperature, the more profitable it is to generate electricity with ORC technology

Electricity production and payback period

Electricity production (MWe) at different operating temperatures



Net present value (EUR) and payback period at different operating temperatures



Low temperature (80 °C) ORC system has lower efficiency, lower electricity output and larger equipment than other options

Calculation assumptions and estimated annual savings

Table Assumptions in cost calculations

Temperature	CAPEX, equipment	CAPEX, EPC	CAPEX, other	OPEX
80°C	4 000 €/kW	25 % equipments on top of CAPEX	15 % of previous	2 % of CAPEX
150°C	2 500 €/kW	25 % equipments on top of CAPEX	15 % of previous	2 % of CAPEX
200°C	2 000 €/kW	35 % equipments on top of CAPEX	15 % of previous	2 % of CAPEX

Table Achieved savings and returns

Temperature	Transfer fees, €	Electricity cost, €	Total income and savings, €
80°C	22 500	201 500	224 000
150°C	45 000	403 000	448 100
200°C	74 300	665 000	739 000

Other heat-to-electricity technologies

Technology	Principle	Applications	Exploitable temperature range	Readiness level	In use in Finland
Steam turbines	Heat evaporates water, turbine rotates	Power plants, nuclear power plants, geothermal energy	> 150 °C	High	Yes
Thermoelectric Generator (TEG)	Temperature difference generates electric current	Spacecraft, industrial waste heat	> 150 °C	Medium	No
ORC (Organic Rankine Cycle)	Utilization of low-grade heat	Waste heat recovery, geothermal energy	50-150 °C	High	Yes
Kalina cycle	Use of ammonia mixture improves efficiency	Low-temperature power plants	100-350 °C [1]	Medium	No
Thermionic Conversion	Electron movement due to heat	In research stage	> 1000 °C	Low	No
Pyroelectric Conversion	Electrical polarization of materials	Future applications	Varies by material	Low	No
Sand battery	Storing heat in sand	Heat storage connected to electric and district heating networks	Core 500 °C Edges 150-200 °C	Medium	Yes

[1]Crypto Kalina cycle power systems in waste heat recovery applications, https://www.globalcement.com/magazine/articles/721-kalina-cycle-power-systems-in-waste-heat-recovery-applications

2.1 Connecting waste heat to the district heating network

Requirements and Benefits

Utilizing waste heat in a district heating network requires a heat pump because the temperature of waste heat from industry and data centers is often too low to be directly usable. A heat pump raises the temperature to a suitable level, allowing the heat to be fed into either the supply or return side of the district heating network.

Economic benefits and costs:

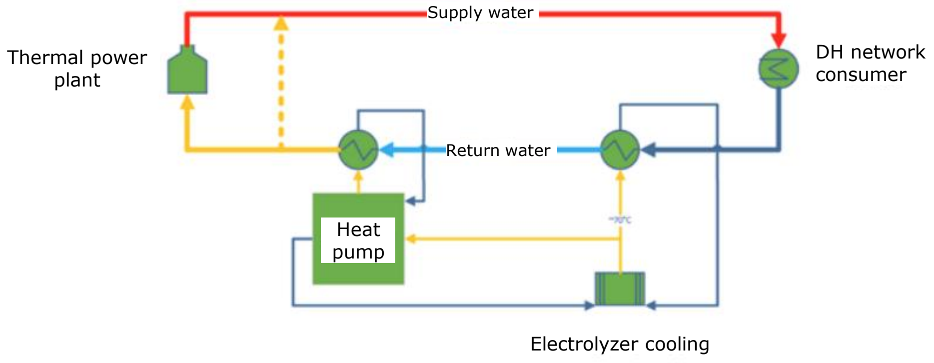
- Savings are generated if waste heat can reduce district heating production and simultaneously reduce cooling needs for the data center.
- Additional costs may arise from expanding the district heating network, purchasing and installing heat pumps, and potential transfer pipelines.

Importance of location:

The waste heat source should be located near the district heating network users to keep transfer losses and investment costs low.

Connecting to the district heating network can be particularly profitable in urban areas with high heat demand and developed infrastructure.

Illustration



he figure shows the connection of an electrolyser to the district heating network, where waste heat can be utilized in two ways: direct heating and with a heat pump.

Utilizing electrolyser waste heat in the district heating network can be achieved either through direct heating or with a heat pump. The electrolysis process produces waste heat, which is transferred to the return water of the district heating network either directly, if the temperature is adequate, or through a heat pump, if the temperature needs to be raised. The heat pump receives low-temperature heat from the electrolyser's cooling water and raises it, for example, to 70 °C so it can be fed into the district heating network.

The district heating network's return water, cooled when returning from consumers, can be preheated with waste heat, reducing the need for additional heating. Ultimately, the heat transferred through the pump or direct heating moves to the district heating network's supply water, which is distributed to consumers. The heating plant supplements the heat production when the amount of waste heat is not enough to cover the entire demand.

This solution improves the energy efficiency of district heating, reduces the need for primary energy, and enables the use of low-temperature waste heat, supporting emission reductions and the sustainability of district heating systems.

Industrial Heat – Energy as a Service (EaaS)

- In industrial companies, energy management often takes a back seat to core operations. Energy as a Service (EaaS) offers significant advantages to industrial companies, such as
  - Optimization of energy efficiency.
  - Reduction of initial investments.
  - Enabling the use of the latest technology.
  - Reduction in carbon dioxide emissions.
- Reasons contributing to the adoption of the EaaS model include:
  - Technological advancements.
  - Increasing demands for energy efficiency.
  - Transition to renewable energy.
- The increase in renewable energy sources and price fluctuations have complicated energy management. Due to these factors, industrial companies are now seeking simpler and cost-effective energy solutions through outsourcing.
- While EaaS offers considerable benefits, it may not be suitable for all industries. In sectors where the quality of energy and reliability of supply are critical to production, outsourcing energy management may be viewed as more of a risk than a benefit.

Energy-as-a-Service (EaaS)

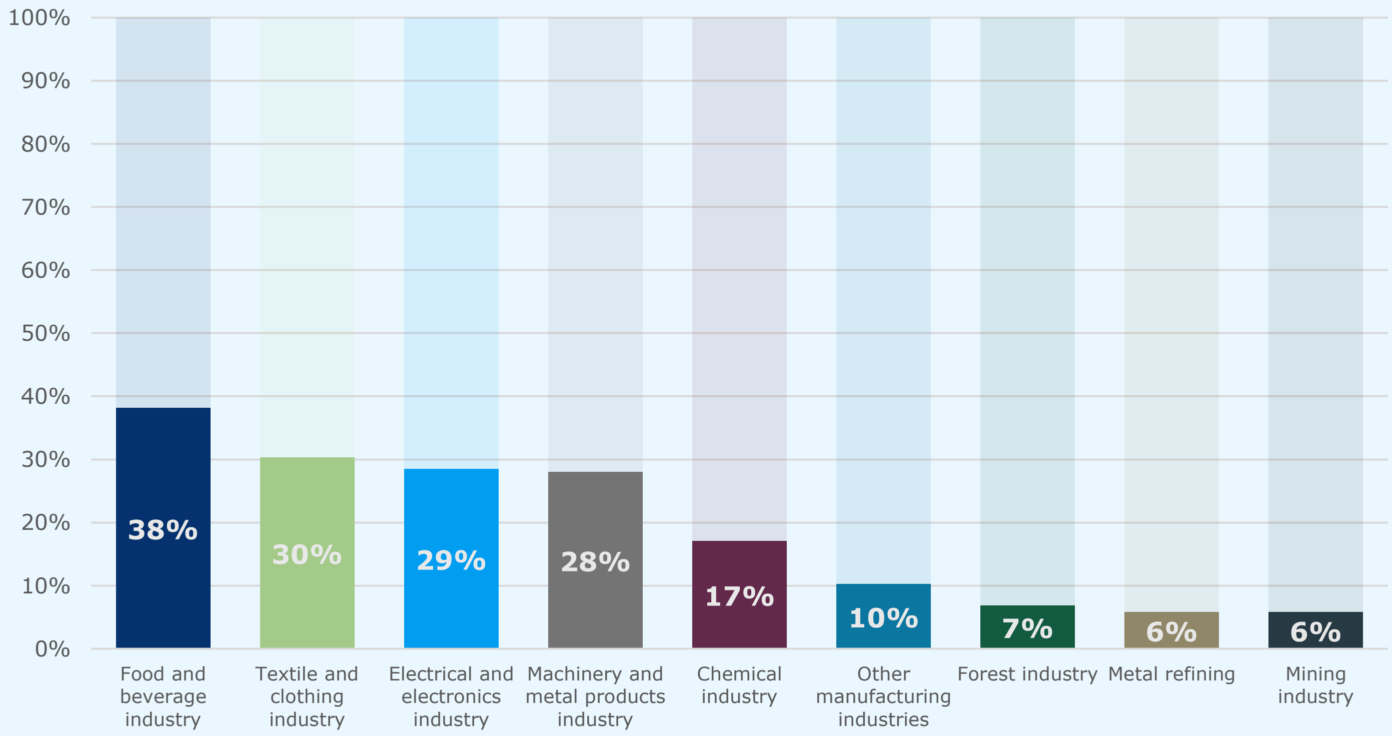
EaaS is a service model where industrial companies procure the energy they need, such as heat and steam, outsourced instead of producing it themselves.

The company only pays for the energy used and does not bear the costs associated with its production.

The EaaS model can offer several advantages to industrial companies, but in certain industries, outsourcing may be perceived as a risk.

Industrial Heat – Outsourcing rate

Share of purchased heat in total energy consumption by industry in 2023



Source: Tilastokeskus, teollisuuden energiankäyttö 2023 https://stat.fi/tilasto/tene

Outsourcing of heat supply

Industries that already procure a significant portion of their heat externally are likely to be more willing to utilize waste heat from other entities as part of their heat acquisition.

Industries where the proportion of purchased heat is small may be less willing to outsource their heat acquisition, as they generate most of their energy themselves. In such industries, the quality of heat and the reliability of supply are often critical to production processes.

Industrial Heat

Entities that do not use higher temperatures in their processes, such as greenhouses and aquaculture facilities, are especially suited to utilize low-temperature waste heat.

Food industry is one of the most significant users of low-temperature heat. In the food industry, more than half of the heat used is below 100 °C.[1,2] Low-temperature heat can be utilized in the food industry for:

- Pasteurization (60–90 °C)
- Washing (60–90 °C)
- Drying processes (30–90 °C)

Textile industry can utilize low-temperature heat in processes such as bleaching and dyeing. In these processes, water heating can be managed with low-temperature waste heat, improving energy efficiency.

Chemical industry and paper industry often use heating and process temperatures below 100 °C. However, these industries are not the most likely buyers of waste heat, as they produce a large portion of the energy they need themselves. Outsourcing heat acquisition may be less attractive to these industries because their production processes require precise temperature control and high reliability of heat supply.

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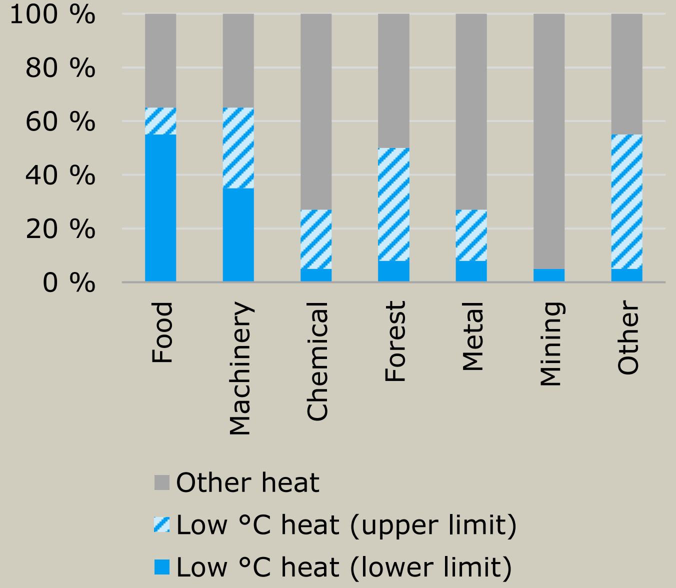
All of these industries also have processes that utilize higher temperatures. Therefore, industrial companies generally already have the capability to use their own waste heat, which may reduce their interest in utilizing external low-temperature waste heat.

Low-temperature waste heat can still be used, depending on the process, for example, for preheating feed water, raw materials, or air.

The proportion of low-temperature heat (< 100 °C) in total heat consumption across different industries:[1,2]



[1] Rehfeldt, M., Rohde, C., Fleiter, T. & Toro, F. (2018). A bottom-up estimation of heating and cooling demand in the European industry.
[2] Vannoni, C., Battisti, R. & Drigo, S. (2008). Potential for solar heat in industrial processes.

Examples – Greenhouse and Aquaculture

Greenhouse - RegEnergy Frövi

In Frövi, Sweden, tomatoes are cultivated in a 10-hectare greenhouse.[1]

The greenhouse produces over 8,000 tons of tomatoes annually, accounting for about 10% of Sweden's tomato consumption

The greenhouse is heated using waste heat from the nearby Billerud paper mill. Heat is transferred in a closed circuit with a supply temperature of 43 °C to the greenhouse and a return temperature of 21 °C.[2]

To heat the greenhouse approximately 35 GWh of waste heat is used annually.

Greenhouse area:
10 ha

Tomato production:
8 000 t/a

Waste heat consumption:
35 GWh/a

Aquaculture - Hima Seafood

Hima Seafood's fish farm is the first large (30 000 m²) and-based trout farm in Norway. The farm produces 9,000 tons of trout annually.[3]

The fish nedd a temperature of 14 °C, which is achieved by utilizing waste heat from a data center. The farming is based ona Recirculating Aquaculture System (RAS), which purifies the water before and after use. Fish are raised without antibiotics and stress factors, improving their well-being.

Waste generated from fish farming is recycled into organic fertilizer, producing 4500 tons annually.

The investment in the fish farm was 213 million euros (NOK 2,5 miljardia).

Fish farm area:
3 ha

Trout production:
9 000 t/a

Fertilizer production:
4 500 t/a

[1] From Paper to Pomodoro. https://wa3rm.com/projects/regenergy-frovi/
[2] From waste heat to juicy tomatoes: The story of RegEnergy in Frövi. https://selectedgroup.gi/reg-energy-news-from-waste-to-juicy-tomatoes-the-story-of-reg-energy-in-frovi
[3] Land-based trout farm will use data center waste heat. https://greenmountain.no/land-based-trout-farm-will-use-data-center-waste-heat/
[4] Hima Seafood. https://himaseafood.com/

Direct Air Capture – Technology

Technology description

Direct Air Capture (DAC) is a technology that captures carbon dioxide (CO_2) directly from the atmosphere.

The carbon dioxide capture process occurs in two stages. First, atmospheric CO_2 is absorbed by either a liquid or a solid material called a sorbent. Then, the sorbent is processed in a manner that releases the absorbed CO_2.

Captured CO_2 can be either permanently stored or used as a raw material in industries based on Carbon Capture and Utilization (CCU). CO_2 can also be used, for example, in greenhouses to enhance plant growth or in the food industry for carbonating beverages.

The highest energy consumption in the DAC process comes from regenerating the sorbent, which is the phase where CO_2 is released from the sorbent and then stored or prepared for further use.

Low Temperature Direct Air Capture (LT-DAC) technologies, which operate at lower temperatures using solid sorbents, are suitable for utilizing waste heat due to their temperature range requirements.

LT-DAC processes require 850–2500 kWh/tCO_2 of thermal energy, but more energy-efficient solutions have been reported with the thermal consumption as low as 300 kWh/tCO_2.[1]

Technology options

Solid Direct Air Capture (S-DAC):

Based on solid sorbents that operate at ambient or low pressures and temperatures of 80-130 °C.

The technology based on solid sorbents is also known as **Low Temperature Direct Air Capture (LT-DAC)**.

Liquid Direct Air Capture (L-DAC):

Uses liquid sorbents that release captured CO_2 in a high-temperature process, ranging from300-900 °C.

The technology based on liquid sorbents is also known as **High Temperature Direct Air Capture (HT-DAC)**.

[1]Krull, L., Baum, C. & Sovacool, B. (2025). A geographic analysis and techno-economic assessment of renewable heat sources for low-temperature direct air capture in Europe.

Direct Air Capture – Example

DAC facility Mammoth[1]

Climeworks' Mammoth in Iceland is the world's largest DAC (Direct Air Capture) plant. It began operations in May 2024 and is designed to remove up to 36,000 tons of carbon dioxide annually.

The plant uses the TVSA (Temperature Vacuum Swing Adsorption) method for CO_2 regeneration, which utilizes vacuum and heat. It uses Iceland's geothermal energy as its heat source.

Captured CO_2 is permanently stored underground in basalt rock layers. This process involves dissolving CO_2 in water and pumping it underground into basalt rock formations, where it chemically reacts with the rock minerals and mineralizes permanently into carbonates, turning CO_2 into solid rock-like material.

Typical values for LT-DAC technology used at the Mammoth plant[2]	
Thermal energy consumption	1400-2500 kWh/tCO_2
Electricity consumption	200-700 kWh/tCO_2
CO_2 adsorption temperature	20-25 °C
CO_2 desorption temperature	75-120 °C

Balance of a DAC plant like Mammoth

36 000 tons of CO_2 per year:

The plant requires an area of approx. **4.4 ha**.

Thermal energy consumption: **50-90 GWh per year**.
Electric energy consumption: **7-26 GWh per year**.

The captured CO_2 can be stored or alternatively used to produce:

approx. **13 000 tons of methane (CH_4) per year**
- Requiring additionally about 4900 tons of hydrogen (H_2) per year, corresponding to a PEM electrolyser capacity of 32 MW.

Or approx. **25 000 tons of methanol (CH_3OH) per year**
- Requiring additionally about 6 800 tons of hydrogen (H_2) per year, corresponding to a PEM electrolyser capacity of 26 MW.

[1]Climeworks (2024). Climeworks switches on world's largest direct air capture plant. https://climeworks.com/press-release/climeworks-switches-on-worlds-largest-direct-air-capture-plant-mammoth
[2]Krull, L., Baum, C. & Sovacool, B. (2025). A geographic analysis and techno-economic assessment of renewable heat sources for low-temperature direct air capture in Europe.

Keeping Harbor Basin ice-free

Kemi has two ports: Ajos Deepwater Port and Veitsiluoto Port, which serve the needs of industry and freight traffic. Additionally, there is a natural harbor in Karsikko, Simo area, with potential for future development for logistics or tourism activities.

- The heat loss from open water areas in winter can be as high as **300–500 W/m²** during severe cold and windy weather
- For example, maintaining a harbor basin of 5000 m² (0,5 ha) ice-free can require:
  - **Up to 2.5 MW–3 MW of power** on winter days
  - Annually, this could mean **2–5 GWh of energy**, depending on the length of the winter and weather conditions
- Maximum temperature of waste heat water supplied +10 °C
- The flow of waste heat discharge should be kept within the basin to prevent spreading into the environment.

Harbor Basin	Estimated basin size	Energy amount / year	Power
Ajos	290 000 m² (29 ha)	417,6 GWh/a	116 MW
Veitsiluoto	125 000 m² (12,5 ha)	180 GWh/a	50 MW
Karsikko	For example 175 000 m²	252 GWh/a	70 MW

Environmental impacts of keeping harbour basin ice-free

Maintaining an ice-free harbour basin can significantly impact the local ecosystem. The continuous discharge of warm water disrupts the natural temperature rhythm to which the coastal waters' biota are adapted. During winter, warmer-than-normal water can accelerate the metabolism and growth of aquatic organisms, potentially **leading to eutrophication, especially in nutrient-rich waters.** Simultaneously, the biota may become stressed due to the absence of natural winter dormancy.

Instances of thermal pollution from power plants demonstrate that areas kept ice-free **extend the growing season and shorten winter dormancy**. **This can affect, for example, the development of aquatic flora along shores**. For fish populations, the effects are mixed: warmth favours spring and summer spawning species like perch and cyprinids but harms cold-water species such as salmon, trout, and burbot. These species may retreat from the warm area, shrinking their habitat. Ice-free water attracts waterfowl that would typically migrate south for the winter.

Thermal emissions can also cause local currents and create sharp ice edges, mechanically eroding the shores. Warm water may stratify at the water surface until it cools down and sinks, affecting the distribution of oxygen and nutrients. Additionally, ice-free areas could serve as wintering grounds for invasive species.

Therefore, environmental impacts are closely monitored. Environmental permits often require surveillance, including monitoring water quality, benthic fauna, and fish populations. If necessary, operations may be limited, or compensatory measures such as fisheries compensation fees may be imposed.

With climate change causing milder winters and reducing ice cover, the need for ice-free maintenance may decrease in the future. During the transition period, energy demands will vary from winter to winter, necessitating meticulous planning of ice-free maintenance. It is crucial to use only the necessary amount of heat, limit the ice-free area, and ensure ecosystem preservation. Environmental Impact Assessment (EIA) is a vital tool for sustainable planning.

In Finland, an environmental permit is required if:

- Discharged water is **significantly warmer** than the receiving seawater (e.g., over +10 °C in winter)
- The water temperature rises more than 2–3 °C in the affected area
- Ice-free maintenance affects **natural conditions, ice conditions, or biota**

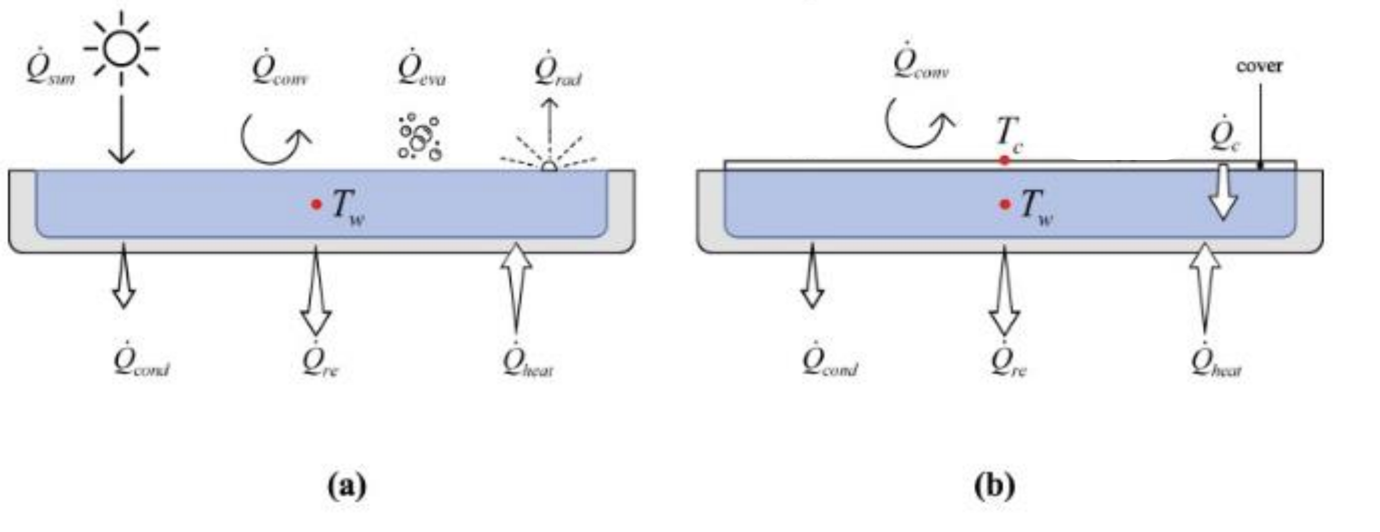
Water temperature	ΔT vs. seawater (0 °C)	Required flow rate
+4 °C	4 °C	4,18 m³/s
+6 °C	6 °C	2,79 m³/s
+8 °C	8 °C	2,09 m³/s
+10 °C	10 °C	1,67 m³/s
+12 °C	12 °C	1,39 m³/s

Outdoor swimming pool – Heat flows

Maintaining outdoor swimming pools requires significant energy for heating the water. The illustration examines heat losses from an outdoor swimming pool in two scenarios: without a cover (a) and with a cover (b). The purpose of the illustration is to demonstrate how different heat transfer mechanisms affect the water temperature in the pool at different times of the day and how covering the pool can reduce energy consumption

Outdoor pool heat flows without a cover (a) and with a cover (b)[1]

During the day | During the night

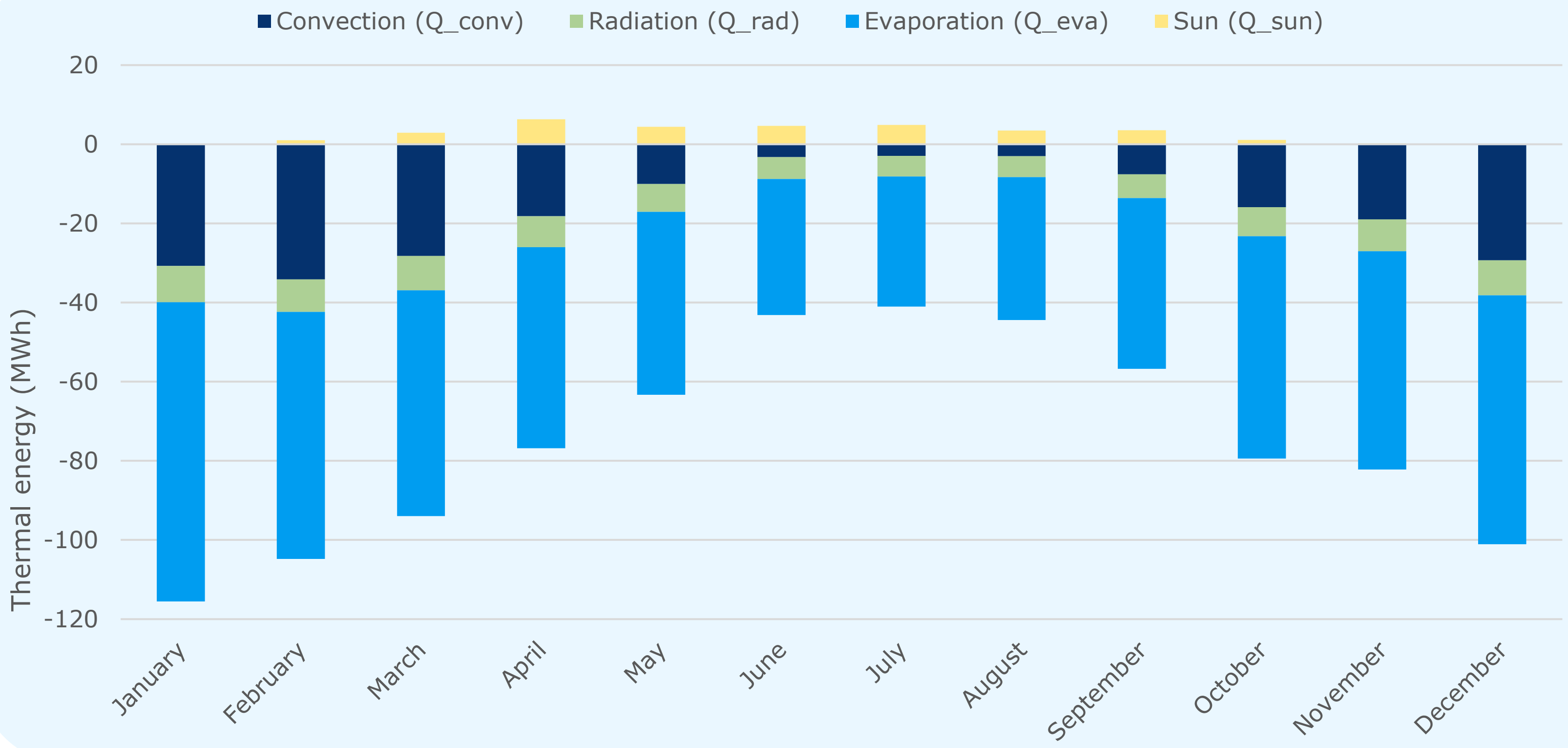


- **Q_conv:** Convective heat loss, caused by air movement over the surface of the pool water.
- **Q_rad:** Radiative heat loss, resulting from thermal radiation from the pool surface to the environment
- **Q_eva:** Evaporative heat loss, which is the heat loss due to water evaporation.
- **Q_sun:** Solar heat input, which warms the pool water.
- **Q_heat:** Energy required to heat the pool water

[1] Buscemi, A., Biondi, A., Catrini, P., Guarino, S., Brano, V. (2024). A novel model to assess the energy demand of outdoor swimming pools.

Outdoor swimming pool – Energy requirements

The annual energy requirement for an outdoor pool can be around 870 MWh/a. Even after utilizing the waste heat for district heating, approximately 152,000 MWh/a remains unutilized from Veitsiluoto's 70 MW data center, and 53,319 MWh/a from Ajos's 30 MW hydrogen production



Calculation assumptions:

- Calculation was based on Kemi's monthly average temperatures and wind speeds.
- Outdoor pool surface area: 50 m².
- Water temperature: 33 °C (spa temperature)[2]
- Total solar radiation energy based on values from Sodankylä (nearest measurement station).
- Ground heat losses were not calculated, but similar studies indicate they are about 10 % in relation to evaporation.[1]
- Pool operation hours: 9:00-22:00.
  - Outside operating hours, a cover is placed over the pool, reducing heat losses by 50-70 %.[1]

[1]The Smart Energy Design Assistance Center, SEDAC (2017). Energy smart tips – pools
[2]Fluidra S.A. Heating a pool and spa (website). Heating a pool and spa

Spa

Heating of spas

- In spas, waste heat can be utilized for:
  - Heating of pools (indoor and outdoor)
  - Heating saunas and shower areas
  - Heating and ventilation of buildings
- The energy needs of spas vary greatly, but the heating demand can range between 765-2415 MWh/a.
- According to a source[1] the annual heat and electricity consumption of the Kirkkonummi spa has been estimated. The charts also present empirical results from a project conducted by VTT. Especially the size of the spa and various functions affect the energy requirements. In Kirkkonummi's case, heat consumption is approximately 1809 MWh/a and electricity consumption is about 1000 MWh/a.

[1] Saari, A., Sekki, T. (2008). Energy consumption of a Public Swimming Bath.

Thermal Energy

Figure 1: Heat consumption per building volume[1]

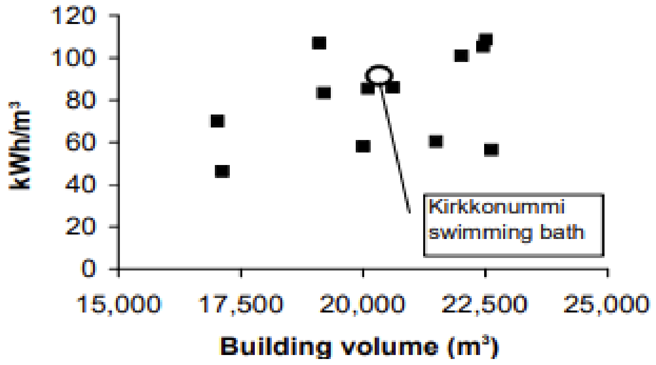
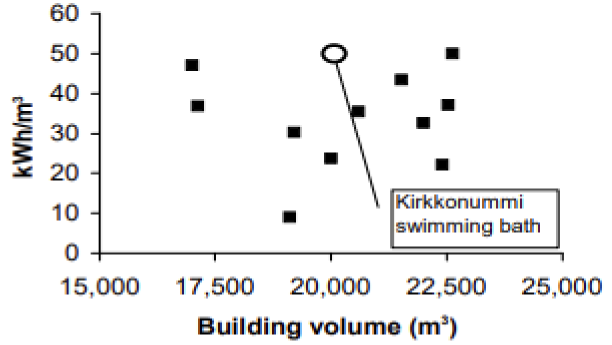


Figure 2: Electricity consumption per building volume[1]



Current research trends

Waste heat utilization is being widely studied across various fields

Hybrid Systems

Hybrid systems combine two or more waste heat recovery technologies, enabling improved energy efficiency and broader application possibilities.

Examples of studied combinations include:

ORC and thermoelectric generators (TEG)[1]

ORC and adsorption cooling[2]

Heat pumps

Heat pumps are a key technology in utilizing low-temperature waste heat, as they can increase the temperature level of waste heat and make it suitable for industrial processes requiring higher temperatures or for district heating networks.

Research focuses particularly on improving the energy efficiency of heat pumps, achieving higher temperature levels, developing new refrigerants, and integrating heat pumps into hybrid systems and thermal energy storage.

Thermoelectric materials

Thermoelectric materials are semiconductors that convert a temperature difference directly into electrical energy through the Seebeck effect. These materials are used in thermoelectric generators (TEG) to utilize waste heat.

Most TEG applications achieve an efficiency of 5–10%, which is still too low for large-scale commercial use without further innovations. Additionally, the material costs of thermoelectric generators are high.[1]

TEG applications are being studied particularly as part of hybrid systems, where they can, together with ORC processes or heat pumps, enhance energy utilization and waste heat recovery in the future.

Researches in the world

Massachusetts Institute of Technology (MIT): Studied thermoelectric materials, that transfrom waste heat into electricity, especially in the steel and glass industries

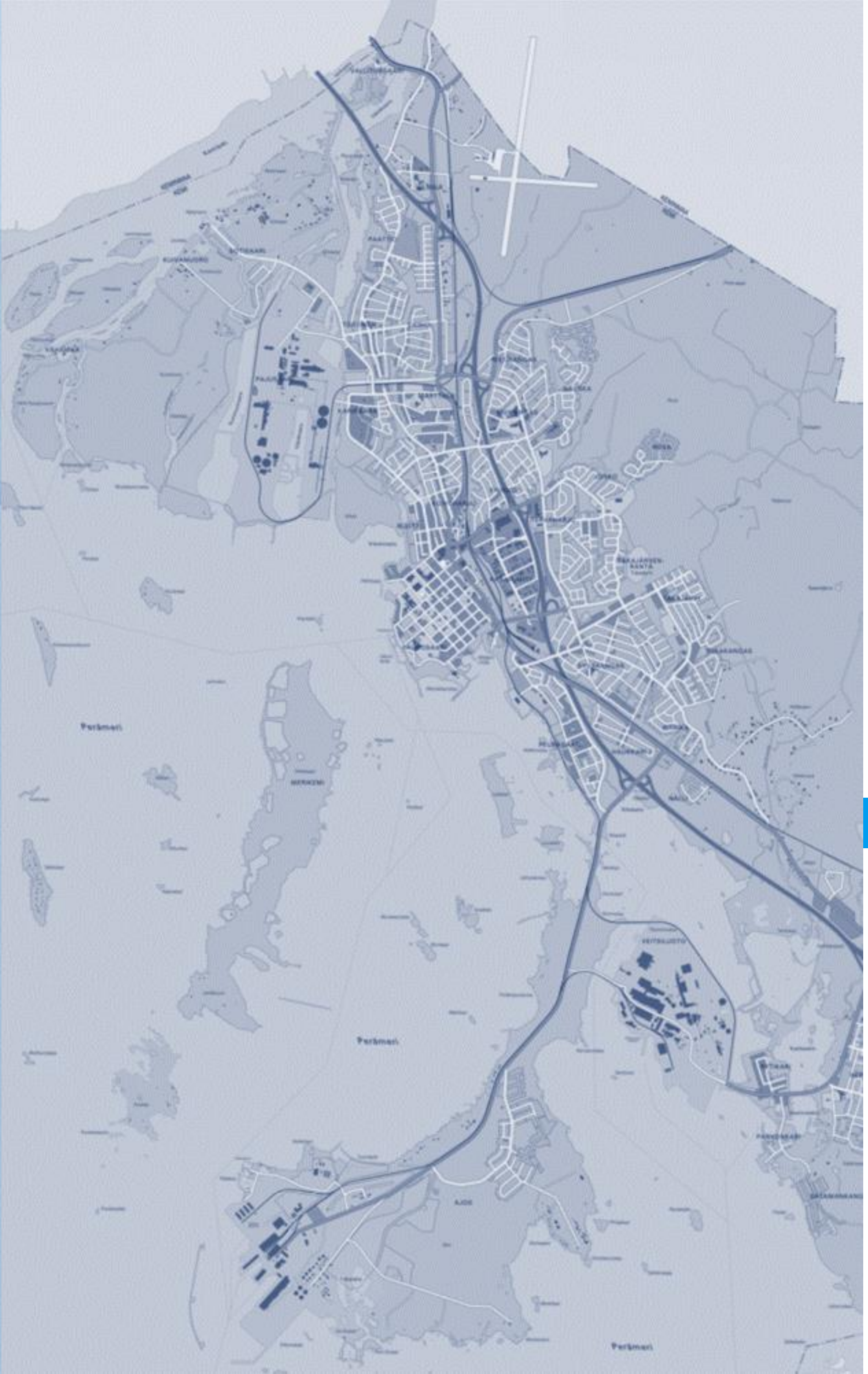
Oak Ridge National Laboratory (ORNL): Developing ORC-based systems for converting low-temperature waste heat into electricity in the chemical industry.

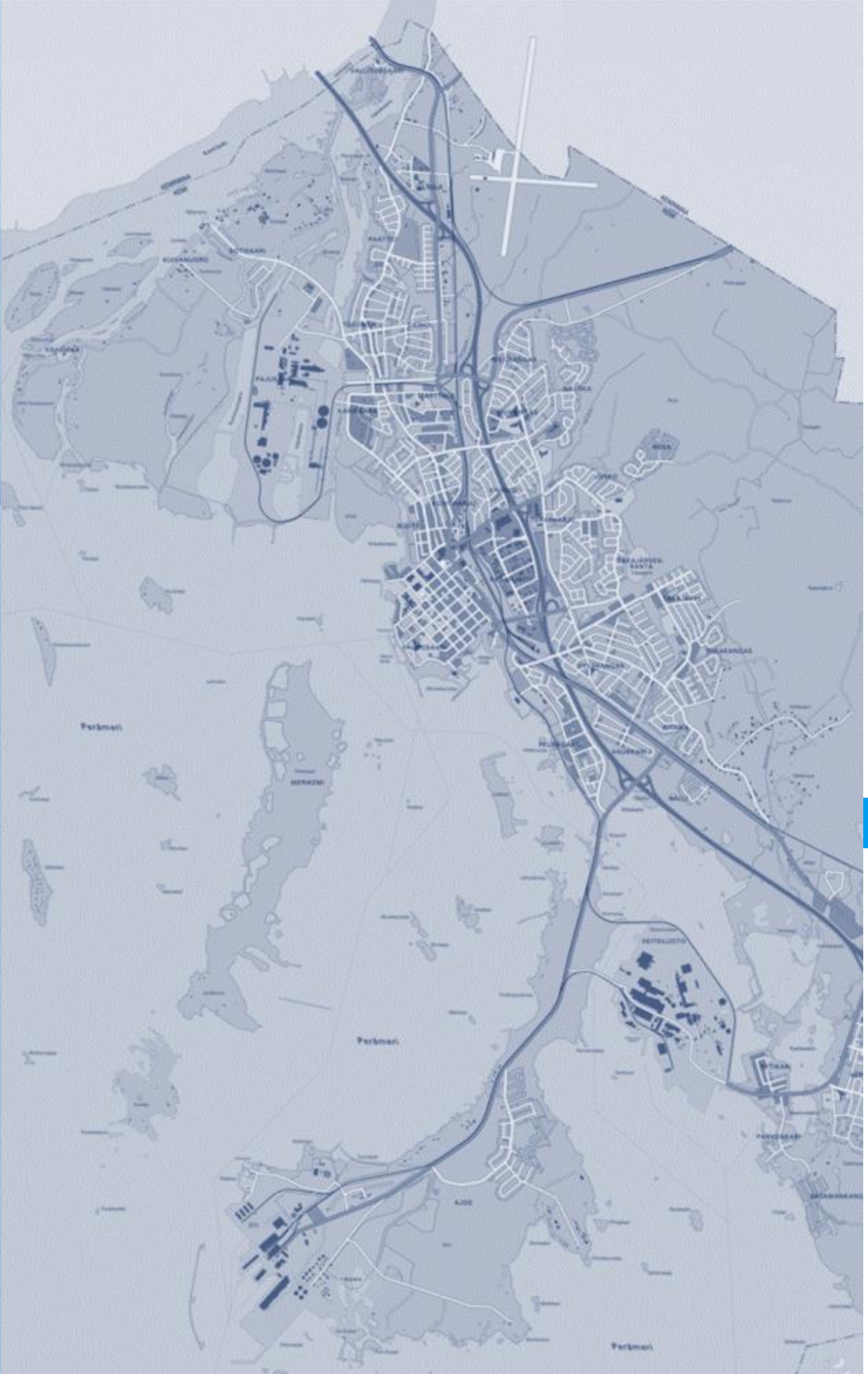
Deutsches Zentrum für Luft- und Raumfahrt (DLR): Studying waste heat utilization in high-temperature processess, focusing on heat storage and electricity production.

University of Tokyo: Investigating the use of **Stanford University**: Kehittänyt suolapohjaisia lämpövarastoja pitkäaikaiseen lämpöenergian säilytykseen.

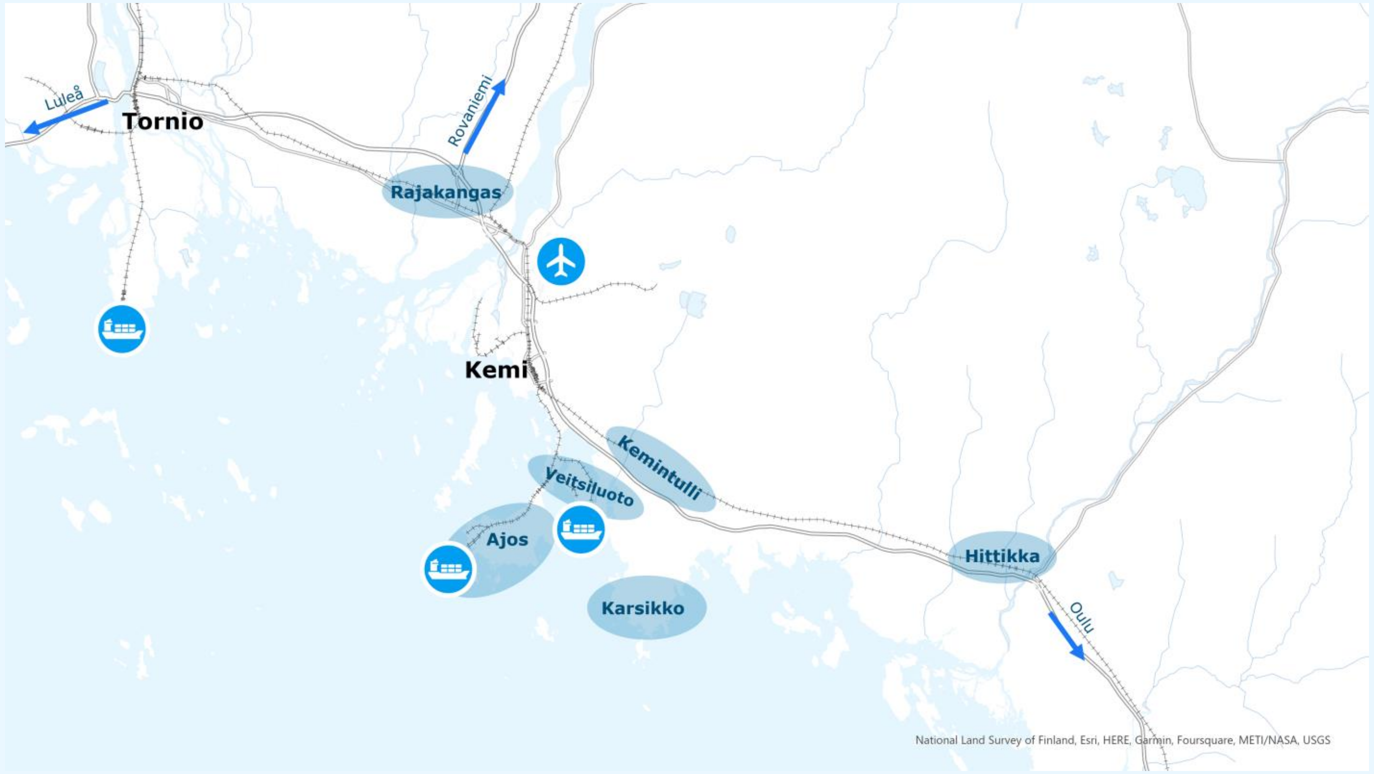
[1] Farhat, o., Faraj, J., Hachem, F., Castelain, C. & Khaled, M. (2022). A recent review on waste heat recovery methodologies and applications: Comprehensive review, critical analysis and potential recommendations.

[2] Lombardo, W., Sapienza, A., Ottaviano, S., Branchini, L., De Pascale, A. & Vasta, S. (2021). A CCHP system based on ORC cogenerator and adsorption chiller experimental prototypes: Energy and economic analysis for NZEB applications.





4.1. Introduction of sites to be examined



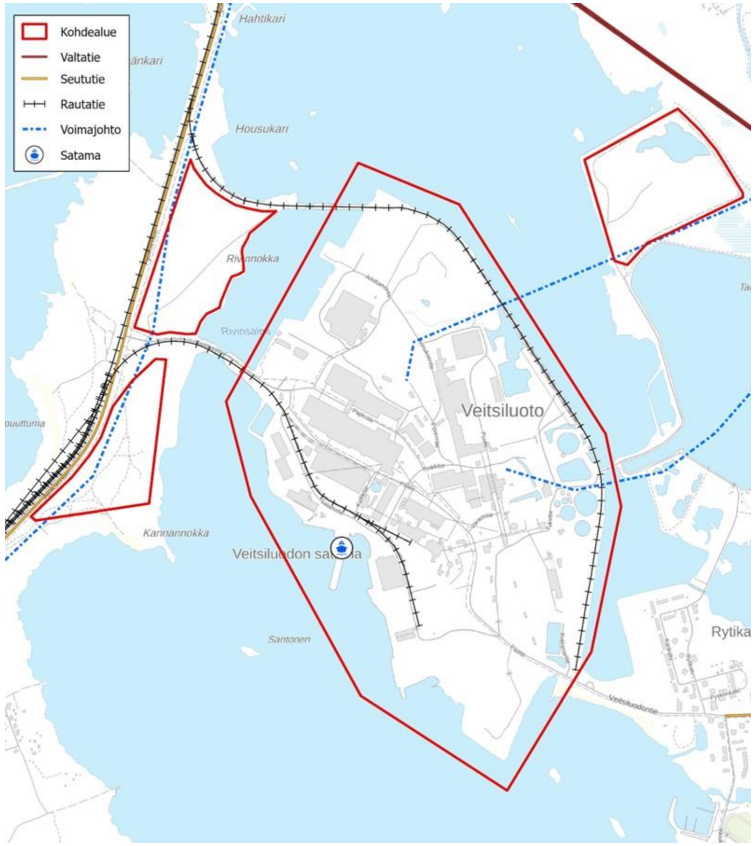
The local potential is analyzed through six example sites.

The sites to be examined are:

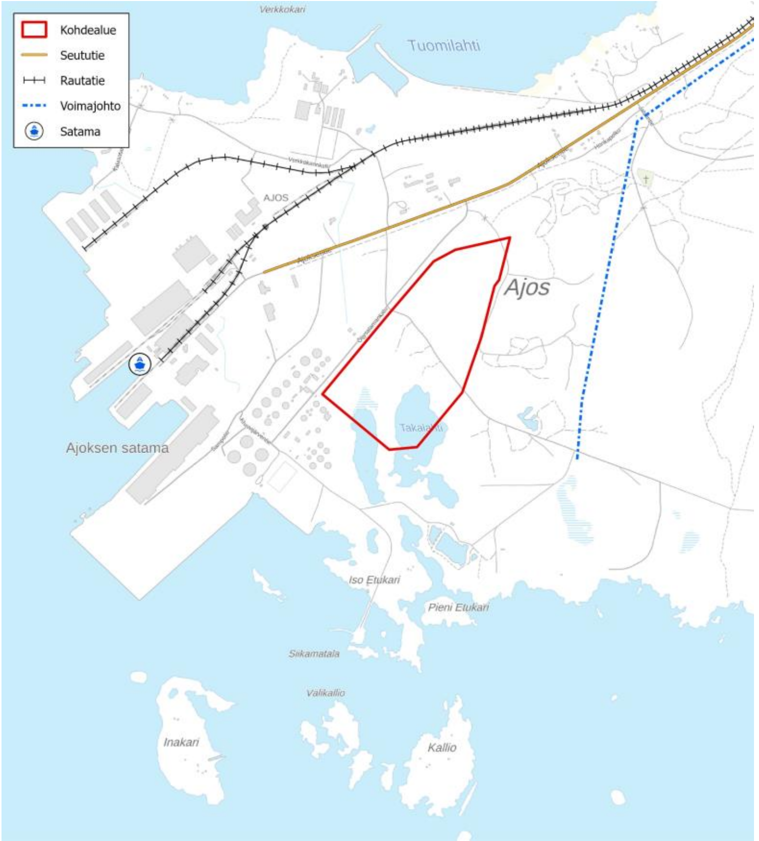
- **Veitsiluoto, Kemi**
- **Ajos, Kemi**
- **Karsikko, Simo**
- **Rajakangas, Keminmaa**
- **Hittikka, Simo**
- **Kemintulli, Kemi**

4.1. Introduction of sites to be examined

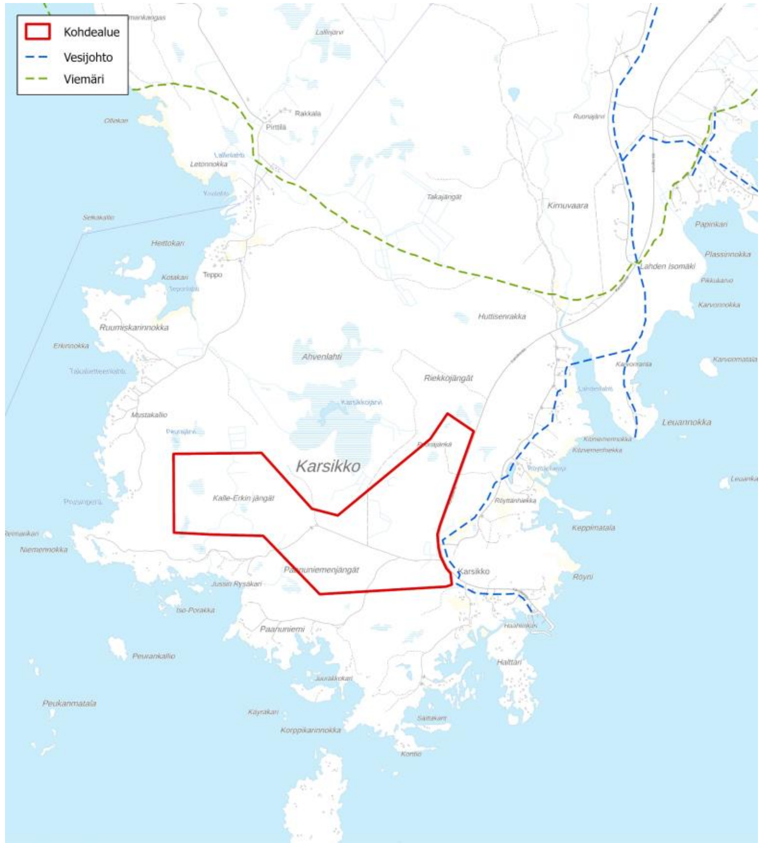
Veitsiluoto, Kemi



Ajos, Kemi

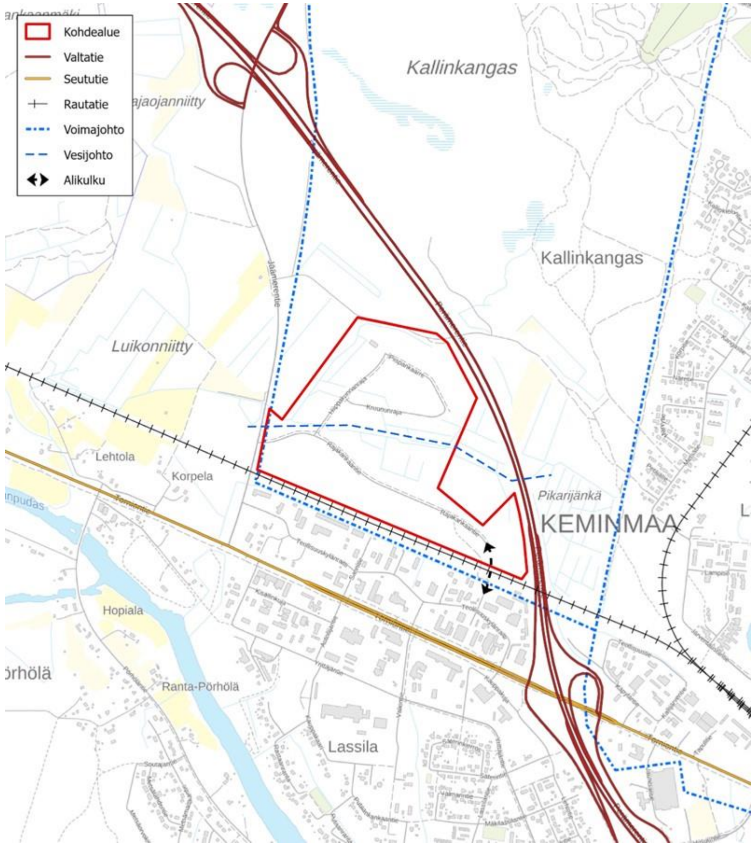


Karsikko, Simo

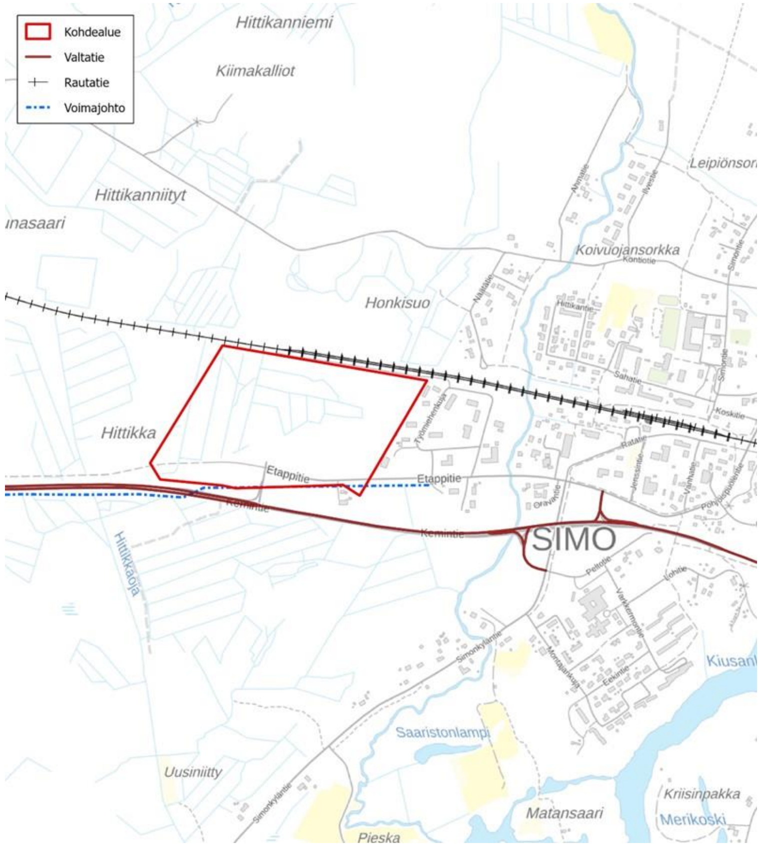


4.1. Introduction of sites to be examined

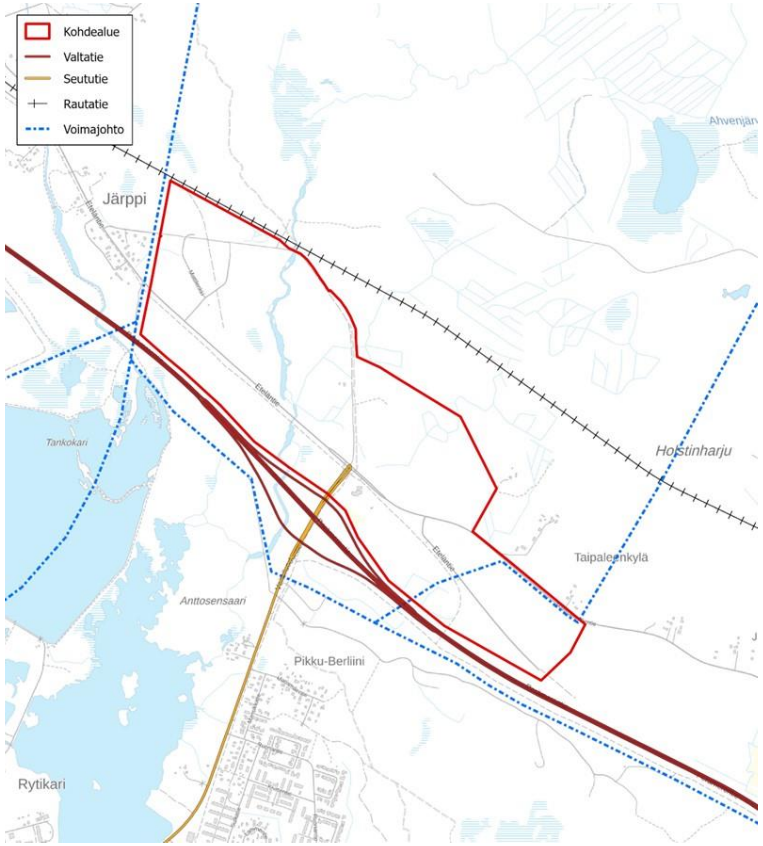
Rajakangas, Keminmaa

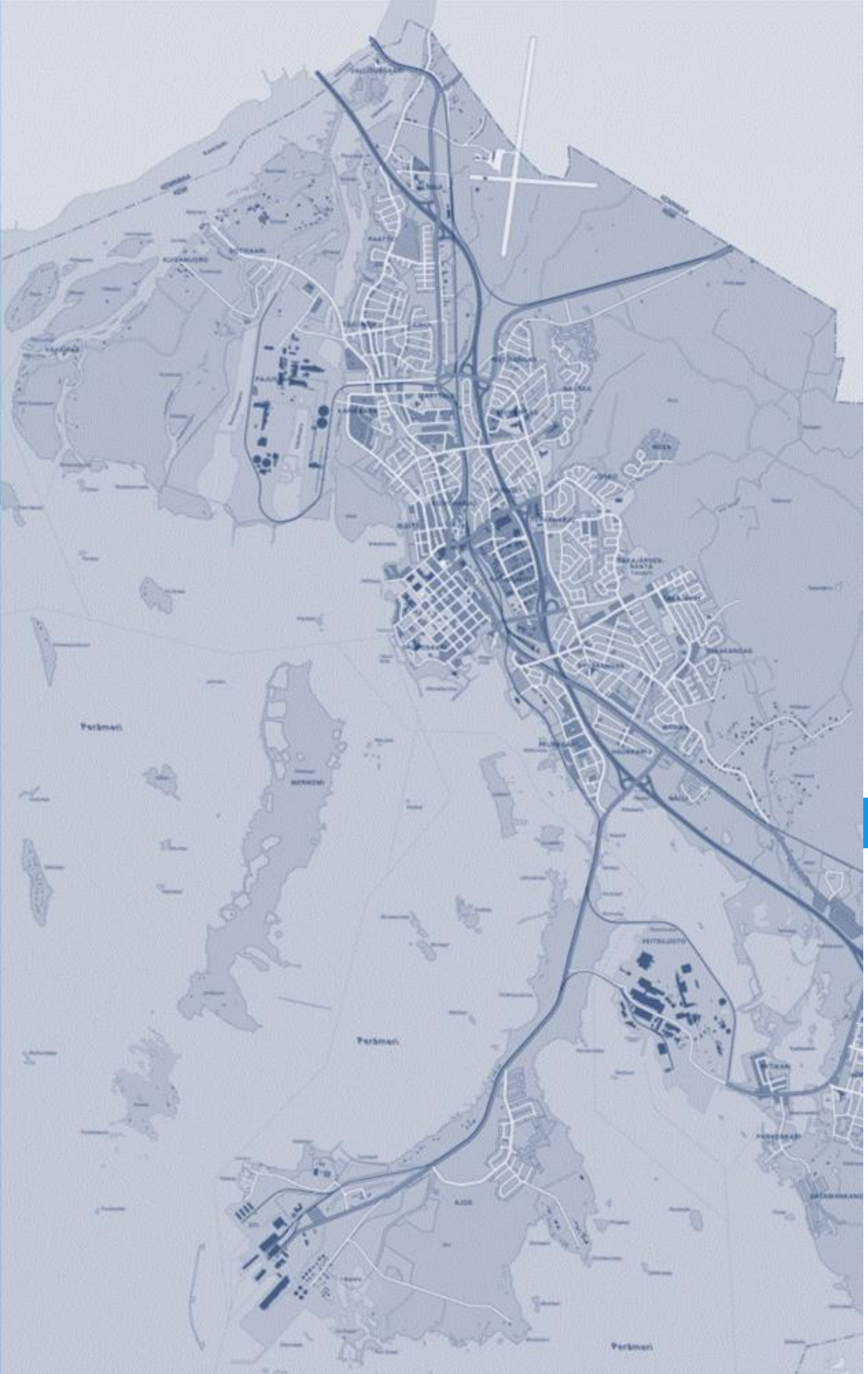


Hittikka, Simo



Kemintulli, Kemi





Introduction to site cards

The site cards illustrate how the selected areas could potentially utilize waste heat generated through various investment options. The cards present, for each area, the potential investment (such as a data center or hydrogen production), its estimated waste heat capacity, and different utilization options like ORC electricity production, outdoor pools, harbor ice-free maintenance, greenhouses, fish farming, or CO_2 capture (DAC).

The presented capacities (MW) and the derived waste heat amounts (GWh) are based on theoretical scenarios, not current entities. Estimates have been calculated for utilization options regarding how much heat could be directed to each application annually.

The goal is to identify area-specific scalability and utilization potential. The figures should not be seen as investment decisions but as tools for comparing utilization possibilities. The estimates consider available space, zoning, infrastructure, and location (e.g., proximity to water bodies or harbors).

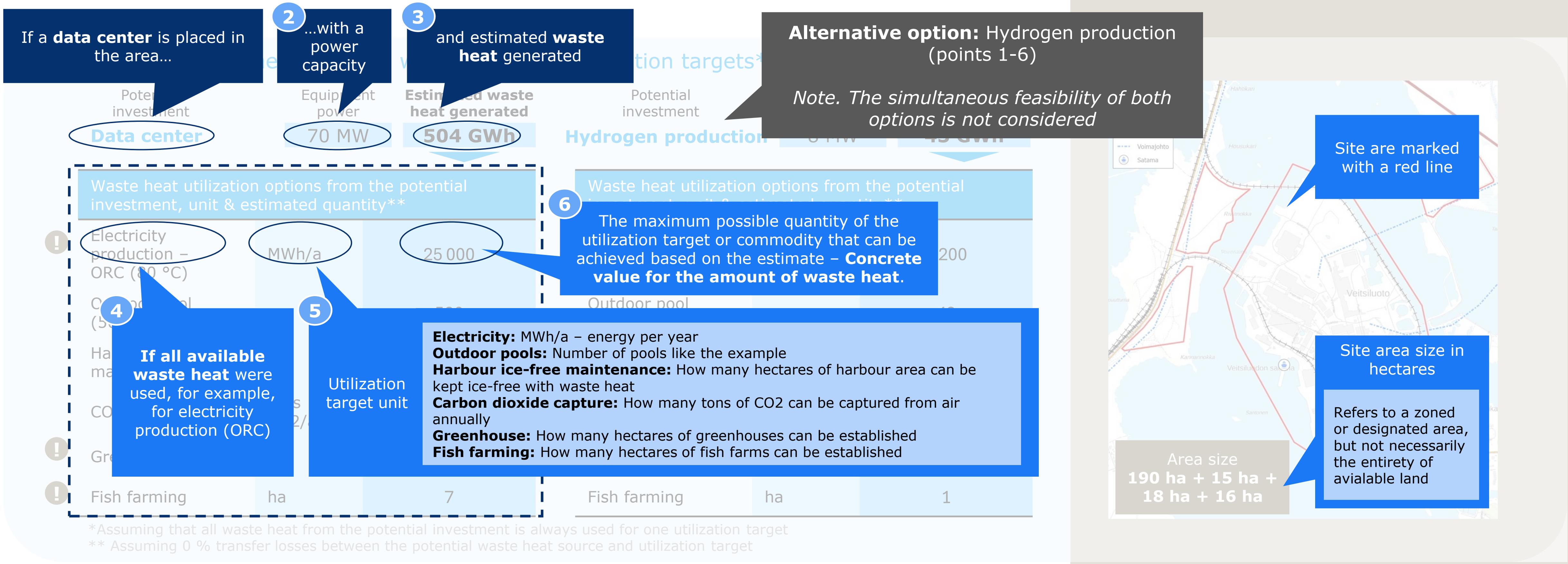
The marked area on the map (ha) refers to zoned or designated areas but not necessarily the entirety of available land. For example, Veitsiluoto has about 50 ha of free area, even though the total area exceeds 200 ha. The usability of space needs to be clarified during the planning phase.

Important Notice

All presented waste heat capacities and applications are based on calculated assumptions (e.g., 0% transfer losses, full utilization rate). They do not reflect the current situation but the potential if the planned investment materializes. Practical feasibility always requires detailed technical and economic evaluation.

Site card - Anatomy

The site card outlines what can be potentially implemented with the incoming investment that produces waste heat (utilization targets)



Site card - Veitsiluoto

Veitsiluoto is best suited for large-volume waste heat utilization targets, particularly CO_2 capture (DAC) and greenhouse production. The area has significant waste heat potential, approximately 50 ha of free land, established infrastructure, and its own harbor, which also enables harbor ice-free maintenance. The T/Kem zoning supports demanding industrial use.

> ! A typical wind turbine with a power of 6 MW can produce approximately **8700** MWh of electricity per year.
>
> Large greenhouse (RegEnergy Frövi): **10 ha**, meets 10% of Sweden's tomato consumption
>
> Large fish farming (Hima Seafood): **3 ha**

Potential waste heat sources, waste heat, and utilization targets*

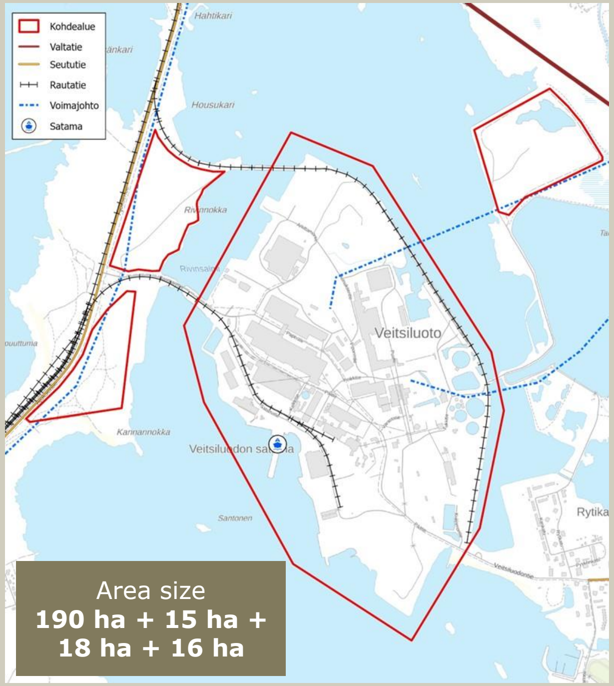
Potential investment	Equipment power	**Estimated waste heat generated**
Data center	70 MW	**504 GWh**

Waste heat utilization options from the potential investment, unit & estimated quantity**		
! Electricity production – ORC (80 °C)	MWh/a	25 000
Outdoor pool (50 m2)	pcs	580
Harbour ice-free maintenance	ha	50
CO2 capture – DAC	tons CO2/a	200 000
! Greenhouse	ha	140
! Fish farming	ha	7

Potential investment	Equipment power	**Estimated waste heat generated**
Hydrogen production	8 MW	**43 GWh**

Waste heat utilization options from the potential investment, unit & estimated quantity**		
Electricity production – ORC (80 °C)	MWh/a	2 200
Outdoor pool (50 m2)	pcs	49
Harbour ice-free maintenance	ha	4
CO2 capture – DAC	tons CO2/a	17 000
Greenhouse	ha	12
Fish farming	ha	1

*Assuming that all waste heat from the potential investment is always used for one utilization target
** Assuming 0 % transfer losses between the potential waste heat source and utilization target



Site card - Ajos

Ajos is best suited for harbor ice-free maintenance and CO_2 capture (DAC), supported by its direct connection to Kemi's deepwater port, excellent logistical accessibility, and moderate waste heat potential (159 GWh/a). Available space (32 ha) is sufficient for medium-sized solutions, and the area is also suitable for process industry and logistics operations.

! A typical wind turbine with a power of 6 MW can produce approximately **8700** MWh of electricity per year.

Large greenhouse (RegEnergy Frövi): **10 ha**, meets 10% of Sweden's tomato consumption

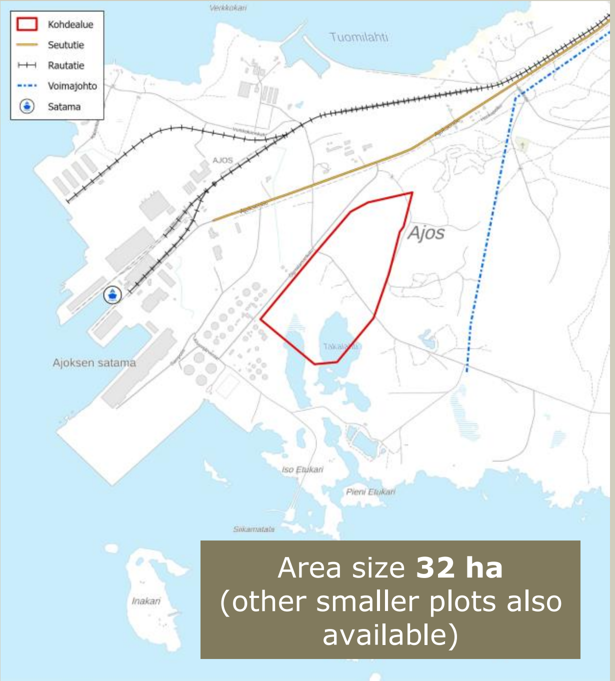
Large fish farming (Hima Seafood): **3 ha**

Potential waste heat sources, waste heat, and utilization targets*

Potential investment	Equipment power	**Estimated waste heat generated**
Data Center	30 MW	**159 GWh**

Waste heat utilization options from the potential investment, unit & estimated quantity**		
! Electricity production – ORC (80 °C)	MWh/a	8 000
Outdoor pool (50 m2)	pcs	180
Harbour ice-free maintenance	ha	20
CO_2 capture – DAC	tons CO_2/a	64 000
! Greenhouse	ha	45
! Fish farming	ha	2

Potential investment	Equipment power	Estimated waste heat generated



*Assuming that all waste heat from the potential investment is always used for one utilization target
** Assuming 0 % transfer losses between the potential waste heat source and utilization target

Site card - Karsikko

Karsikko is best suited for CO_2 capture (DAC) and greenhouse production, thanks to its very large size (100 ha), vast waste heat potential (2637 GWh/a), and extensive zoning for environmentally significant industry. Two natural harbors (14 m draft) also enable maritime logistics operations, but the primary strength of the area lies in its scale and suitability for large-volume solutions.

A typical wind turbine with a power of 6 MW can produce approximately **8700** MWh of electricity per year. !

Potential waste heat sources, waste heat, and utilization targets*

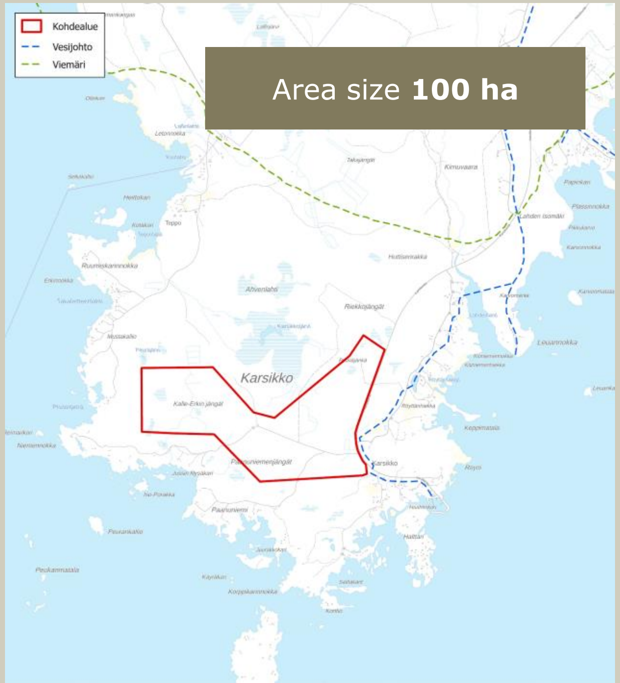
Potential investment	Equipment power	**Estimated waste heat generated**
Datakeskus	300 MW	**2 637 GWh**

Waste heat utilization options from the potential investment, unit & estimated quantity**		
Electricity production – ORC (80 °C)	MWh/a	130 000
Outdoor pool (50 m2)	pcs	3 000
Harbour ice-free maintenance		300
CO2 capture – DAC	tons CO2/a	1 100 000
Greenhouse	ha	750
Fish farming	ha	35

Potential investment	Equipment power	**Estimated waste heat generated**
Vedyn tuotanto	90 MW	**475 GWh**

Waste heat utilization options from the potential investment, unit & estimated quantity**		
Electricity production – ORC (80 °C)	MWh/a	24 000
Outdoor pool (50 m2)	pcs	550
Harbour ice-free maintenance		50
CO2 capture – DAC	tons CO2/a	190 000
Greenhouse	ha	140
Fish farming	ha	6

*Assuming that all waste heat from the potential investment is always used for one utilization target
** Assuming 0 % transfer losses between the potential waste heat source and utilization target



Site card - Rajakangas

Rajakangas is best suited for CO_2 capture (DAC) and ORC electricity production, whose compact space requirements, good compatibility with industrial areas, and ready electrical and thermal infrastructure (4 MW electricity, 5 MW district heating) support implementation. Small-scale greenhouse production is also possible, and the area's location along Highway 4 allows efficient logistics.

A typical wind turbine with a power of 6 MW can produce approximately **8700** MWh of electricity per year.

Large greenhouse (RegEnergy Frövi): **10 ha**, meets 10% of Sweden's tomato consumption

Large fish farming (Hima Seafood): **3 ha**

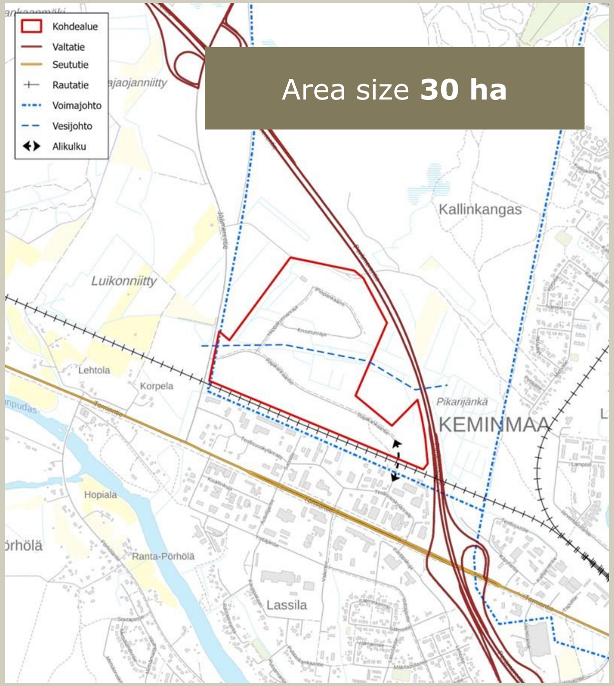
Potential waste heat sources, waste heat, and utilization targets*

Potential investment	Equipment power	**Estimated waste heat generated**
Datakeskus	5 MW	**22 GWh**

Waste heat utilization options from the potential investment, unit & estimated quantity**		
Electricity production – ORC (80 °C)	MWh/a	1 100
Outdoor pool (50 m2)	pcs	25
Harbour ice-free maintenance		N/A
CO2 capture – DAC	tons CO2/a	8 800
Greenhouse	ha	6
Fish farming	ha	0

Potential investment	Equipment power	**Estimated waste heat generated**

*Assuming that all waste heat from the potential investment is always used for one utilization target
** Assuming 0 % transfer losses between the potential waste heat source and utilization target



Site card - Hittikka

Hittikka is best suited for ORC electricity production and CO_2 capture (DAC), whose compact implementation is feasible in a relatively small area and benefits from the proximity of electrical and rail infrastructure. The area's location amid renewable energy production and industrial zoning also allows activities related to the circular economy or energy industry's lower value chains. The waste heat potential supports smaller-scale but continuous energy flow applications

A typical wind turbine with a power of 6 MW can produce approximately **8700** MWh of electricity per year.

Large greenhouse (RegEnergy Frövi): **10 ha**, meets 10% of Sweden's tomato consumption

Large fish farming (Hima Seafood): **3 ha**

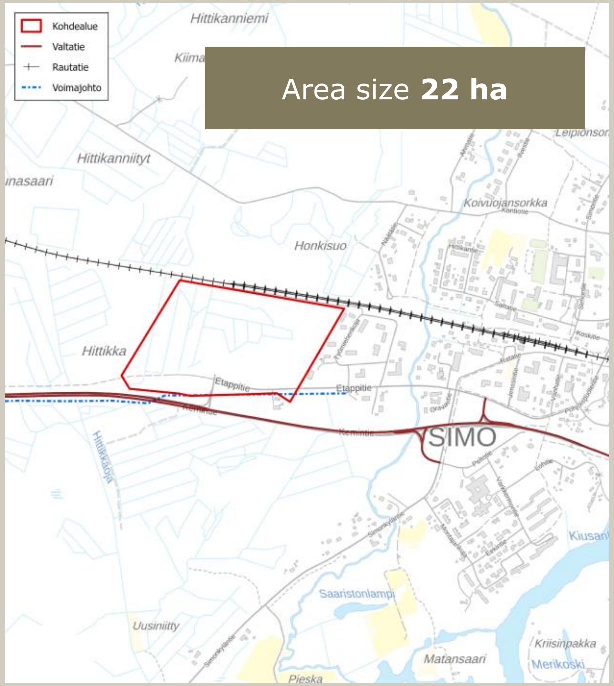
Potential waste heat sources, waste heat, and utilization targets*

Potential investment	Equipment power	**Estimated waste heat generated**
Datakeskus	5 MW	**42 GWh**

Waste heat utilization options from the potential investment, unit & estimated quantity**		
Electricity production – ORC (80 °C)	MWh/a	2 100
Outdoor pool (50 m2)	pcs	48
Harbour ice-free maintenance		N/A
CO2 capture – DAC	tons CO2/a	17 000
Greenhouse	ha	12
Fish farming	ha	1

Potential investment	Equipment power	**Estimated waste heat generated**

*Assuming that all waste heat from the potential investment is always used for one utilization target
** Assuming 0 % transfer losses between the potential waste heat source and utilization target



Area size **22 ha**

Site card - Kemintulli

Kemintulli is best suited for ORC electricity production and CO_2 capture (DAC), which utilize the area's ready infrastructure, logistical location, and small waste heat potential (16 GWh/a). Small-scale greenhouse production might be possible, but the area is not suitable for large space-demanding solutions. Kemintulli is primarily a compact industrial and logistics area.

A typical wind turbine with a power of 6 MW can produce approximately **8700** MWh of electricity per year.

Large greenhouse (RegEnergy Frövi): **10 ha**, meets 10% of Sweden's tomato consumption

Large fish farming (Hima Seafood): **3 ha**

Potential waste heat sources, waste heat, and utilization targets*

Potential investment	Equipment power	**Estimated waste heat generated**
Datakeskus	100 MW	**880 GWh**

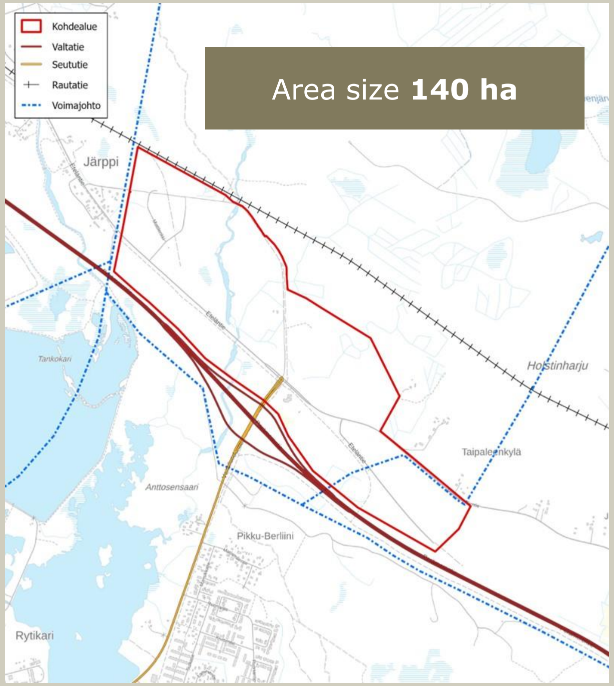
Waste heat utilization options from the potential investment, unit & estimated quantity**

Electricity production – ORC (80 °C)	MWh/a	44 000
Outdoor pool (50 m2)		N/A
Harbour ice-free maintenance		N/A
CO2 capture – DAC	tons CO2/a	350 000
Greenhouse		250
Fish farming		N/A

Potential investment	Equipment power	Estimated waste heat generated

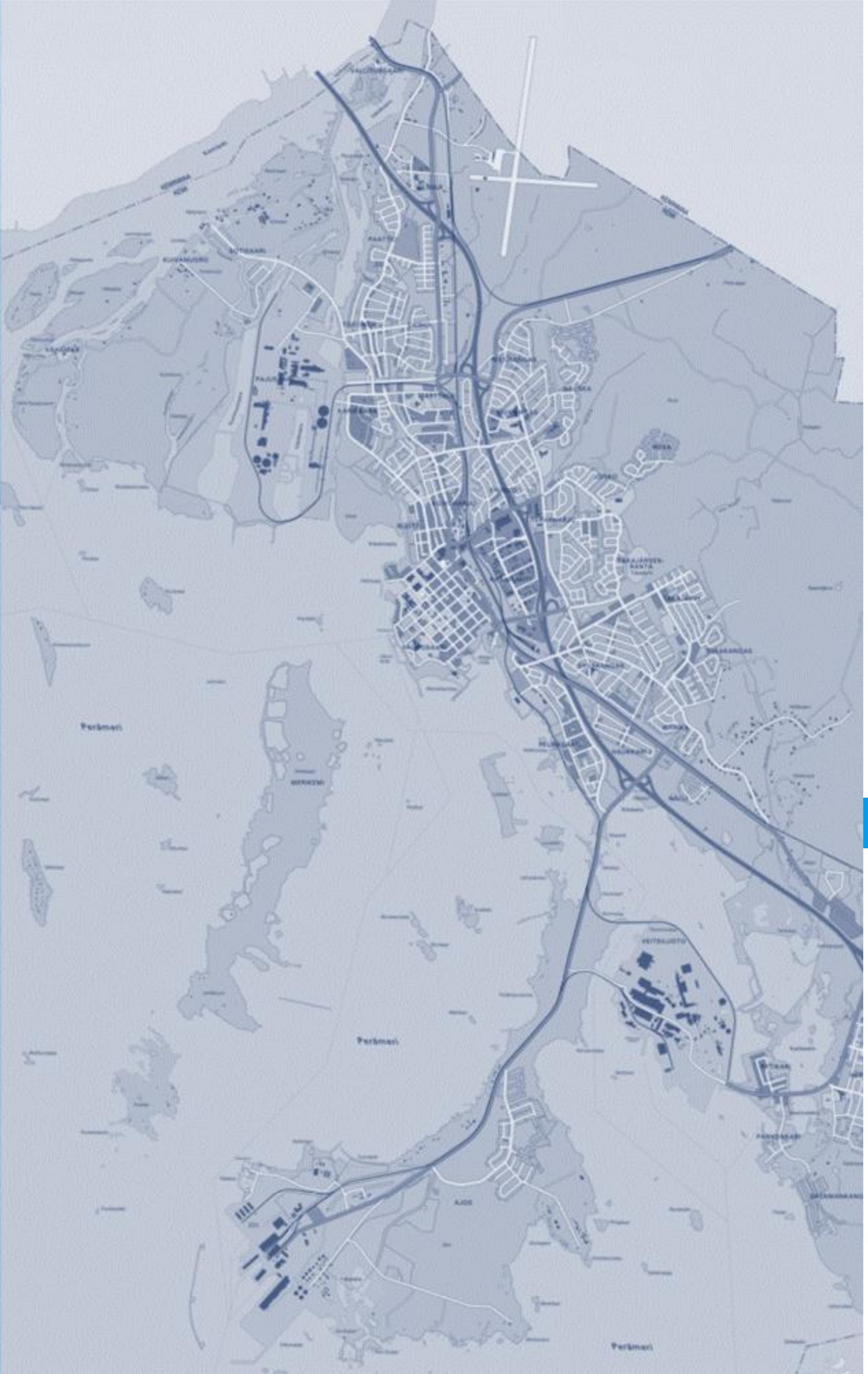
*Assuming that all waste heat from the potential investment is always used for one utilization target
** Assuming 0 % transfer losses between the potential waste heat source and utilization target

Area size **140 ha**



Summary table

		Veitsiluoto		Ajos	Karsikko		Rajakangas	Hittikka	Kemintulli
Possible investment		**Data center**	**Hydrogen production**	**Data center**	**Data center**	**Hydrogen production**	**Data center**	**Data center**	**Data center**
Equipment power	MW	70	8	30	300	90	5	5	100
Waste heat amount	GWh	504	43	159	2 637	475	22	42	880
Electricity production – ORC (80 °C)	MWh/a	25 000	2 200	8 000	130 000	24 000	1 100	2 100	44 000
Outdoor pool (50 m2)	pcs	580	49	180	3 000	550	25	48	-
Harbour ice-free maintenance	ha	50	4	20	300	50	-	-	-
CO2 capture – DAC	tons CO2/a	200 000	17 000	64 000	1 100 000	190 000	8 800	17 000	350 000
Greenhouse	ha	140	12	45	750	140	6	12	250
Fish farming	ha	7	1	2	35	6	0	1	12
Especially suitable for:		DAC, greenhouse, harbour ice-free maintenance		Harbour ice-free maintenance, DAC	DAC, greenhouse, maritime logistics		DAC, ORC, small-scale greenhouse	ORC, DAC, circular economy pilots	ORC, DAC, small-scale greenhouse
Area not suitable for:		Outdoor pools (space constraints), fish farming		Greenhouse (limited space), outdoor pools	Outdoor pools, extensive fish farming		Fish farming, outdoor pools	Greenhouse (extensive), outdoor pools	Greenhouse (extensive), outdoor pools
Considered constraints		Limited available space (50 ha), industrial zoning, harbour environment, not suitable for outdoor pools		Limited land area (32 ha), harbour environment, not suitable for space-intensive applications	Suitable for extensive operations, not protected, no water-based activities		Mainland, limited space (14 ha), no direct water access, zoning in progress	Small area (22,7 ha), no direct water access, zoning in progress	Compact business area, small plots, urban environment, no water bodies or large field areas



Utilization of waste heat as district heating

Starting points and assumptions for calculations

Starting points

- The utilization of waste heat from hydrogen production and data centers as district heating is examined for the district heating networks of Sea Lapland area, to Kemi, Keminmaa, and Simo.
- Of the waste heat sites examined, Karsikko is located in the Simo area, but the utilization of waste heat produced in Karsikko is considered for the district heating network of Kemi.
- The starting data for the calculations are presented briefly on page 71. Starting data include:
  - the estimated waste heat capacities and assumed temperature levels for hydrogen production and data centers.
  - Distance from the waste heat sites to the connection point of the district heating network, where the district heating produced from waste heat is likely to be fed in.
- Preliminary calculations are performed for the waste heat sites to determine what portion of the waste heat is technically maximally utilizable as district heating and what waste heat energy remains unused after utilization as district heating.
- Indicative investment estimates are determined for connecting waste heat targets to the district heating system. The targets are compared by forming a total cost estimate for the produced district heating energy (€/MWh).

Assumptions for calculations

The following assumptions are considered for simplifying the calculations:

1. Waste heat is the primary heating source for district heating. The temperature of waste heat is raised using heat pumps. Current heating plants in the examined areas are not considered.
2. Electric boilers are installed at the waste heat targets to ensure district heating production when the available waste heat capacity or temperature level is insufficient. The size of the electric boiler is determined based on the estimated peak district heating capacity of the areas.
3. The price of waste heat is assumed to be 0 €/MWh. The acquisition costs for thermal energy consist of the purchase costs for SPOT electricity for the heat pumps and electric boilers, as well as transfer fees. SPOT electricity prices are based on actual prices from 2024. Transfer fees are simplified to Fingrid's transmission network charges.
4. Out of the four alternative waste heat sites examined for Kemi, only one (1) can be connected to Kemi's district heating production. The Kemi examinations are mutually exclusive, but preliminary calculations are performed for each site.
5. Investment estimates for the targets are based on typical €/MW unit cost prices and the investment estimates are indicative. Investment costs for district heating transmission lines and pumping costs are based on estimated distances from the district heating network and the amounts of thermal energy to be transferred.

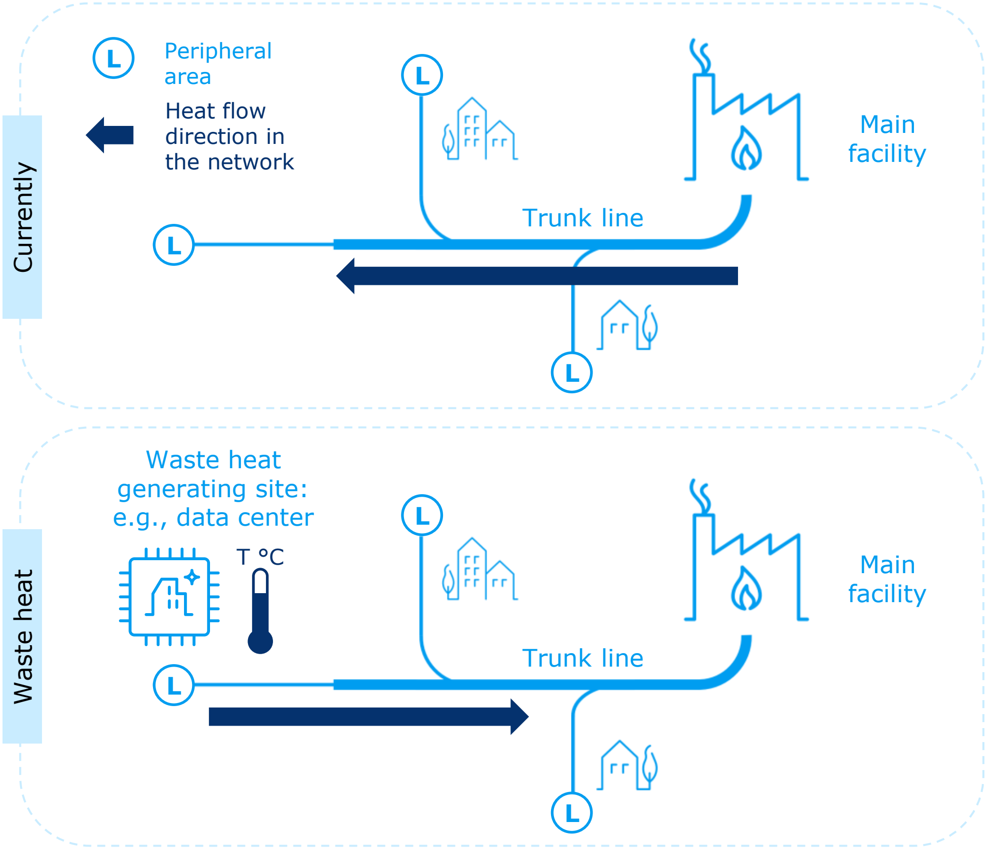
Transfer of waste heat to the district heating network

Technical requirements for heat transfer and examined transfer directions

Technical requirements for heat transfer

- The utilization of waste heat as district heating is **optimal, from a heat transfer standpoint, if the sites are located near the major trunk lines or main facilities of the district heating system**, making technical connection simpler without major modifications to the district heating network.
- **The examined waste heat targets would mostly be located on the outskirts of the network, leading to a situation where the direction of heat delivery would change from the current setup**. The existing district heating network is likely not designed to accommodate heat transfer from the examined directions in terms of pipe sizing.
- Challenges in changing the direction of heat transfer may include:
    1. Increased pressure losses in the existing district heating network pipes due to the change in heat supply direction, potentially requiring network renovation to increase pipe sizes.
    2. Inadequacy of current intermediate pump station locations, necessitating investment in new intermediate pump stations on the new transfer line or elsewhere in the network.
    3. Summer supply temperature, which must be sufficient for long transfer distances even for the farthest district heating consumer.
- Technical evaluations of heat transfer are conducted using district heating network simulation programs to model the network's flow technical functionality under various operating conditions. A deeper examination of the connectivity of waste heat sites using network simulation programs is recommended in further studies. Simulation requires the compilation of comprehensive network data from regional heat companies.

Examined transfer directions



Waste heat for district heating

Input data for the calculations

Site	Industry producing waste heat	Waste heat-power, MW	Assumed temperature level of waste heat	DH-network, where heat is injected	DH-production, MWh/a	Estimated distance to DH-network, km
Veitsiluoto	Data center Hydrogen production	70 8	Low High	Kemi	182	6
Ajos	Hydrogen production	30	High	Kemi	182	6
Karsikko (Simossa)	Data center Hydrogen production	300 90	Low High	Kemi	182	9
Kemintulli	Data center	100	Low	Kemi	182	2
Rajakangas	Date center	5	Low	Keminmaa	36	0,5
Hittikka	Data center	5	Low	Simo	4	0,5

* District heating production volumes for Kemi and Keminmaa are based on publicly available statistics from Energiateollisuus ry (2023). Simo’s district heating production is based on an estimate, as public starting data was not available.

- The table presents the starting data for the various examinations. The hourly district heating power for Kemi, Keminmaa, and Simo is estimated based on district heating production volumes from 2023
- **Assumptions for Data Centers' Waste Heat:**
  - Temperature level is low, around 30-40 °C (e.g., air-cooled data centers)
  - Waste heat power is steady
  - Waste heat is boosted with heat pumps if necessary, up to a supply temperature of 90 °C
- **Assumptions for Hydrogen Production Waste Heat:**
  - Temperature level is high, around 75-80 °C (e.g., AEL or PEM technologies)
  - Waste heat power is variable
  - Waste heat is boosted with heat pumps if necessary, up to a supply temperature of 90 °C

Waste heat for district heating

Utilizible waste heat and surplus waste heat amount, MWh

Site	Industry producing waste heat	Waste heat-power, MW	Waste heat to district heating MWh/a*	Total district heat produced, MWh/a**	Share of region's DH production	Surplus waste heat energy, MWh	
Veitsiluoto	Data center	70	112 000	167 000	92 %	504 000	Kemi
	Hydrogen production	8	41 000	42 000	23 %	2 000	Kemi
Ajos	Hydrogen production	30	105 000	113 000	62 %	54 000	Kemi
Karsikko	Data center	300	112 000	167 000	92 %	2 525 000	Kemi
	Hydrogen production	90	136 000	151 000	83 %	339 000	Kemi
Kemintulli	Data center	100	112 000	167 000	92 %	768 000	Kemi
Rajakangas	Date center	5	22 000	33 000	92 %	22 000	Keminmaa
Hittikka	Data center	5	2 500	3 700	92 %	42 000	Simo

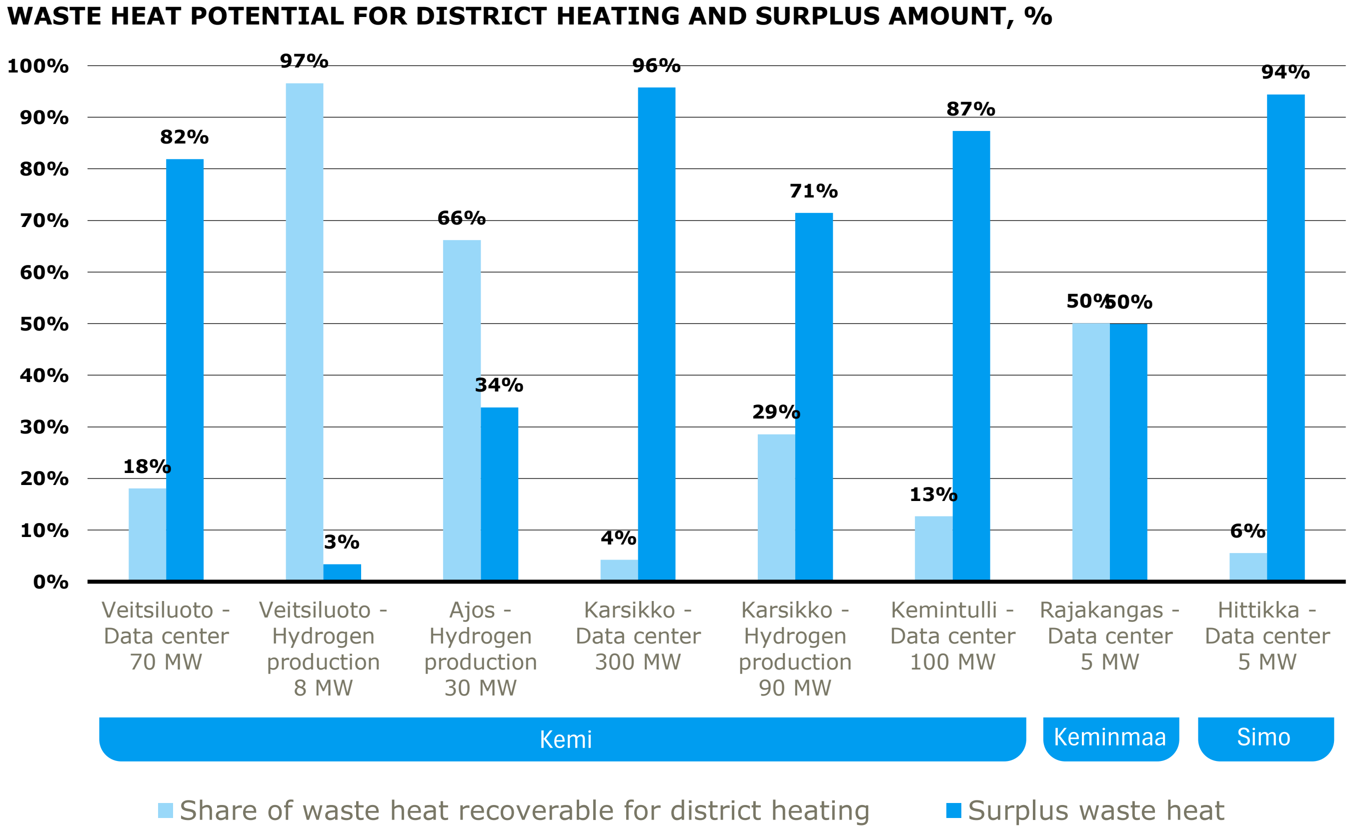
* The value includes only the amount of waste heat that is captured and utilized for district heating production.

** The value includes the captured amount of waste heat and the electric power of the heat pump. The heat pump's COP is fixed at 3.00.

- **Heat pumps and large waste heat capacities can cover up to approximately 90% of the district heating needs of the areas.**
- Since the examined waste heat powers are very large and the utilization of waste heat is limited by the variability of district heating power and the network's power demand being low relative to the waste heat powers, the surplus waste heat remains substantial.

Waste heat for district heating

Utilizable waste heat and surplus waste heat amount, %



- The amounts of utilized and surplus waste heat for district heating vary significantly by site, due to the variability of waste heat quantities and the size of the district heating networks.
  - Up to 97% of waste heat from Veitsiluoto's hydrogen production plant (8 MW) could potentially be utilized as district heating.
  - Conversely, from the waste heat of Karsikko's data center, where waste heat power could be up to 300 MW, only about 4% of waste heat could be utilized for district heating.
- Approximately 50% of the waste heat from the small 5 MW data center in Rajakangas, Keminmaa, could be utilized for district heating in Keminmaa.
- In Simo, the demand for district heating is low; thus, only about 6% of the waste heat from the 5 MW data center in Hittikka could be utilized for district heating.

Waste heat for district heating

Investment cost assessment: Centralized District Heating production with waste heat and electric boiler

Site	Industry producing waste heat	Heat pump plant, Power MW	Heat pump plant, k€	Electric boiler, k€	DH transfer line and pumping, k€*	Electrification and other costs, k€	Total Investments, k€	
Veitsiluoto	Data center, 70 MW	36	37 800	8 400	8 580	4 620	**59 400**	Kemi
	Hydrogen production, 8 MW	5	5 250	8 400	8 580	1 365	**23 595**	Kemi
Ajos	Hydrogen production, 30 MW	17	17 850	8 400	8 580	2 625	**37 455**	Kemi
Karsikko	Data center, 300 MW	36	37 800	8 400	12 870	4 620	**63 690**	Kemi
	Hydrogen production, 90 MW	18	18 900	8 400	12 870	2 730	**42 900**	Kemi
Kemintulli	Data center, 100 MW	36	37 800	8 400	2 860	4 620	**53 680**	Kemi
Rajakangas	Data center, 5 MW	8	8 400	1 666	390	1 007	**11 463**	Keminmaa
Hittikka	Data center, 5 MW	1,3	1 365	336	228	170	**2 099**	Simo

* The required size and investment for the district heating transfer line depend on the transferable power and the design temperature difference between the supply and return pipes. For example, to transfer Kemi's peak power of 60 MW, the transfer line size would be DN500 with an investment estimate of about €1200 per meter of constructed district heating duct. For Keminmaa's peak power of 12 MW, the suitable pipe size would be DN250 (approx. €700 per meter), and for Simo's peak power of 2 MW, the suitable pipe size would be DN100 (approx. €400 per meter).

Note: Investment in the intermediate pumping station is included in the examined investment estimate.

- The table shows indicative cost estimates for centralized district heating production where:
  - Waste heat and a heat pump plant that raises the temperature of waste heat are the primary heat sources.
  - The electric boiler serves as peak and backup heating when needed.
    - The electric boiler's capacity is 60 MW for Kemi's sites, 12 MW for Keminmaa, and 2 MW for Simo.
- Based on the cost estimation, the total price of heat is calculated, enabling a preliminary comparison between different sites

Waste heat for district heating

Assessment of total heat price

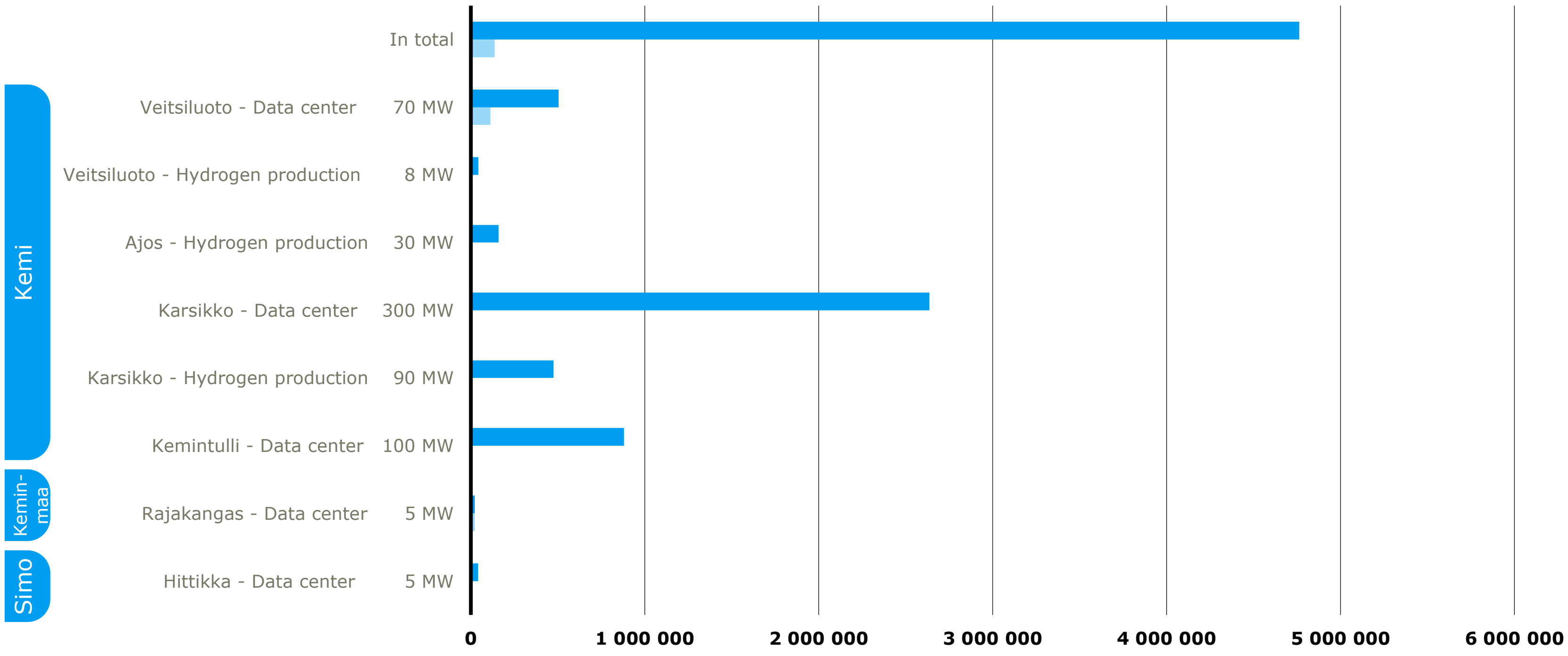
Site	Industry producing waste heat	Waste heat to DH, MWh/a	Total produced DH, MWh/a	Average price of produced heat energy, €/MWh	Investment cost, €/MWh	Operating cost, €/MWh	Total heat price, €/MWh	
Veitsiluoto	Data center, 70 MW	112 000	167 000	29	34	10	**72**	Kemi
	Hydrogen production, 8 MW	41 000	42 000	58	13	4	**75**	Kemi
Ajos	Hydrogen production, 30 MW	105 000	113 000	40	21	6	**67**	Kemi
Karsikko	Data center, 300 MW	112 000	167 000	29	36	10	**75**	Kemi
	Hydrogen production, 90 MW	136 000	151 000	25	24	7	**56**	Kemi
Kemintulli	Data center, 100 MW	112 000	167 000	29	30	9	**68**	Kemi
Rajakangas	Data center, 5 MW	22 000	33 000	29	33	10	**71**	Keminmaa
Hittikka	Data center, 5 MW	2 500	3 700	29	54	16	**99**	Simo

- For the assessment of total heat price, investments are allocated to the €/MWh price over a 15-year period with a 6% interest rate.
- Operating cost is allocated based on investment costs and generated energy amounts with a 3% operating cost factor.
- The lowest total heat price among Kemi's sites is for the waste heat from hydrogen production in Karsikko, approximately €56/MWh.
  - The price for Veitsiluoto data center is €72/MWh. Veitsiluoto is the most potential option for feeding waste heat to Kemi's district heating network due to its favorable location.
  - The price for Keminmaa data center is €70/MWh, and in Simo, €100/MWh.
- The profitability of the sites cannot be directly assessed based on the total heat price alone.
  - The profitability of waste heat utilization is better determined by considering the entire district heating system, accounting for the existing heat production in the examined district heating networks.

Waste heat for district heating

Waste heat utilized for district heating and surplus waste heat, MWh

WASTE HEAT FOR DISTRICT HEATING AND SURPLUS WASTE HEAT, MWH

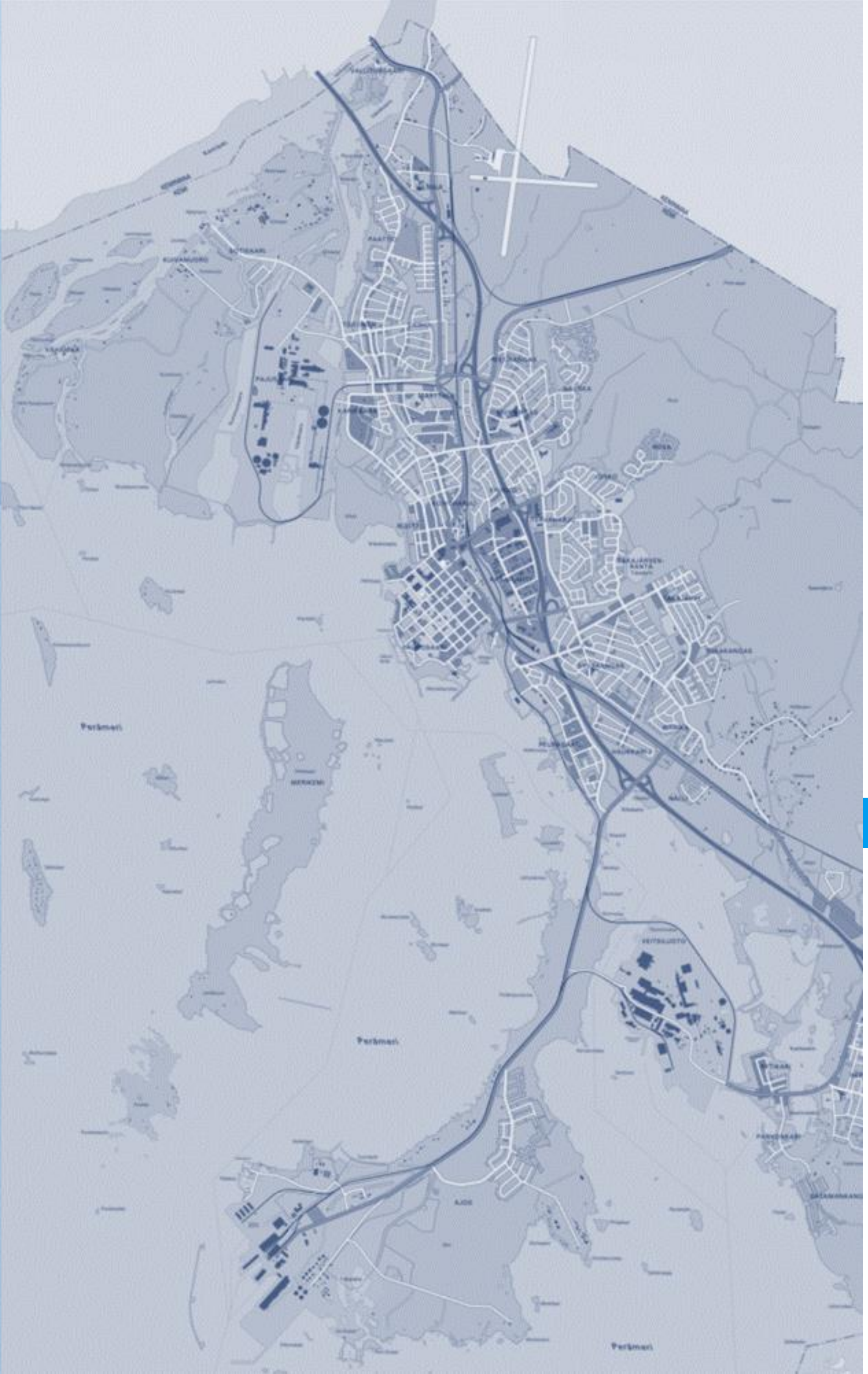


	Hittikka - Data center 5 MW	Rajakangas - Data center 5 MW	Kemintulli - Data center 100 MW	Karsikko - Hydrogen production 90 MW	Karsikko - Data center 300 MW	Ajos - Hydrogen production 30 MW	Veitsiluoto - Hydrogen production 8 MW	Veitsiluoto - Data center 70 MW	In total
Surplus waste heat	42 000	22 000	880 000	475 000	2 637 000	159 000	43 000	504 000	4 762 000
Waste heat utilized for district heating	2 500	22 000						112 000	136 500

MWH

Surplus waste heat
Waste heat utilized for district heating

- Based on the examination, approximately 136 GWh of waste heat could be utilized for district heating in the networks of Kemi, Keminmaa, and Simo.
- There is still over 4,700 GWh of surplus waste heat, meaning only about 3% of the waste heat flows from hydrogen production and data centers could be utilized in the examined district heating networks



Impact of distances and costs

Transfer of waste heat over short and long distances

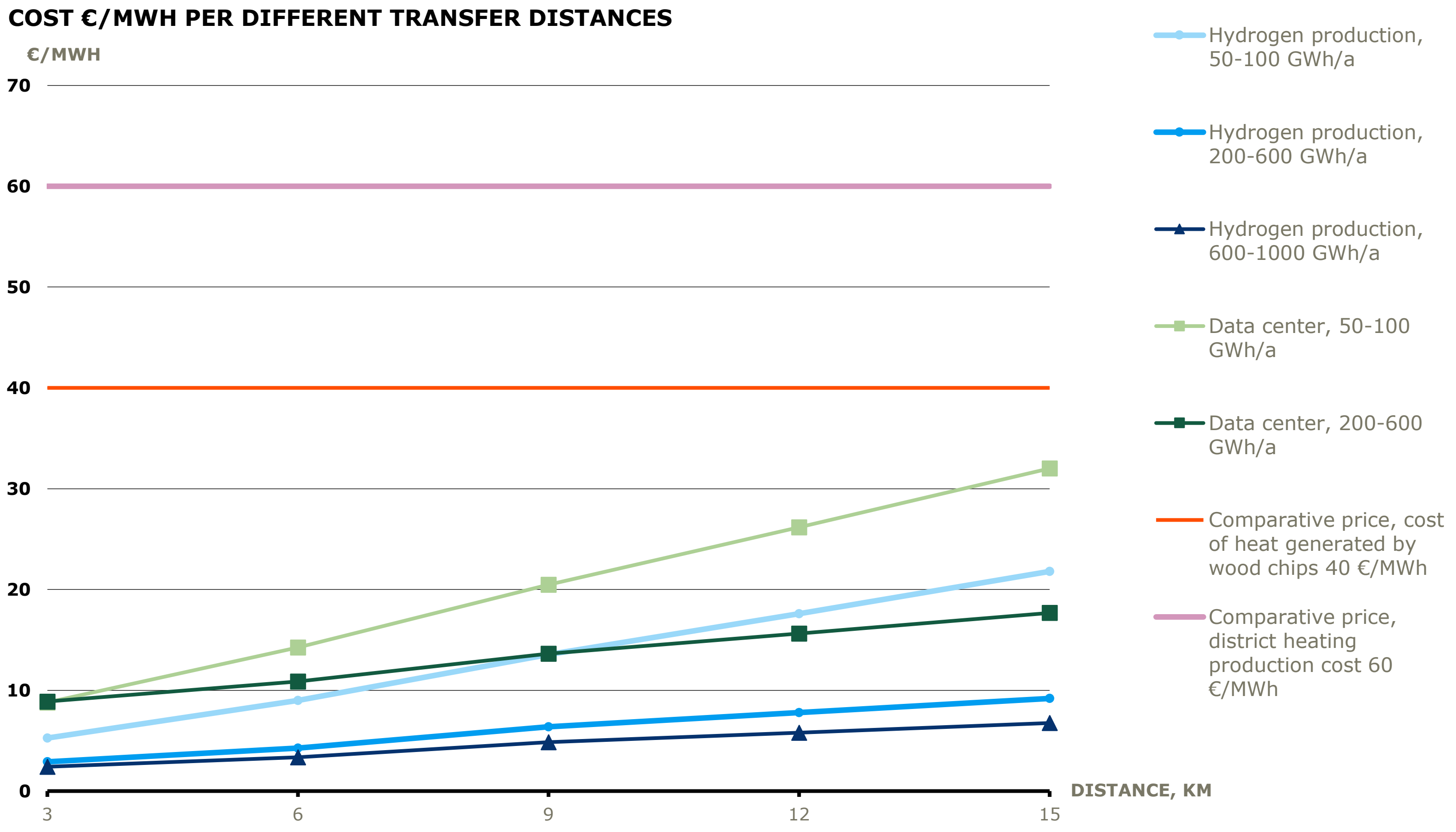
Goals

- In the section examining waste heat utilized for district heating, it was estimated that a maximum of about 3% of the generated waste heat in the target areas could be utilized as district heating in the examined networks.
- The following section assesses the cost of transferring surplus waste heat to various distances, considering the varying annual energy amounts of waste heat. It is assumed that the temperature of waste heat is not raised before transfer.
- Distances are evaluated as short and long transfer distances:
  - **Short distances** represent regional waste heat transfer within the Sea Lapland area, to locations nearby the target areas, within 3-15 km.
  - **Long distances** represent waste heat transfer to outside the Sea Lapland area, within 15-150 km.
- The price estimate formed (€/MWh) includes the investment in the transfer line and required intermediate pumping stations for the examined distances, as well as estimates of annual operating and maintenance costs (€/a).
  - Investment cost estimates are indicative and based on recent cost information. Investment costs are allocated over a 15-year examination period with a 6% interest rate.
- The examination presents comparative prices of €40/MWh (e.g., the price of wood chips) and €60/MWh (e.g., the price of pellets) for alternative heat production, illustrating the boundary value for profitability formed solely by the fuel price, without considering other costs of heat production in addition to fuel costs.

Key factors affecting transfer costs

- **Heat transfer costs consist of the required investments for heat transfer** as well as the operating and maintenance costs formed by pumping.
- Main investments required for waste heat transfer:
  - Heat transfer stations for waste heat capture and delivery points.
  - Waste heat transfer pipeline, with size based on transferable waste heat power and temperature difference.
  - Intermediate pumping stations along the transfer pipeline.
- Pumping's operating and maintenance costs constitute only a small part of waste heat transfer costs. The main part of operating costs is formed by the purchase costs of electricity used for pumping.
- The following pages present examinations for both short and long transfer distances. Annual waste heat amounts are examined for transfer energy amounts of 50-100, 200-600, and 600-1000 GWh/a.

Transfer of waste heat – Short distances
Assessment of waste heat transfer costs in Sea Lapland area



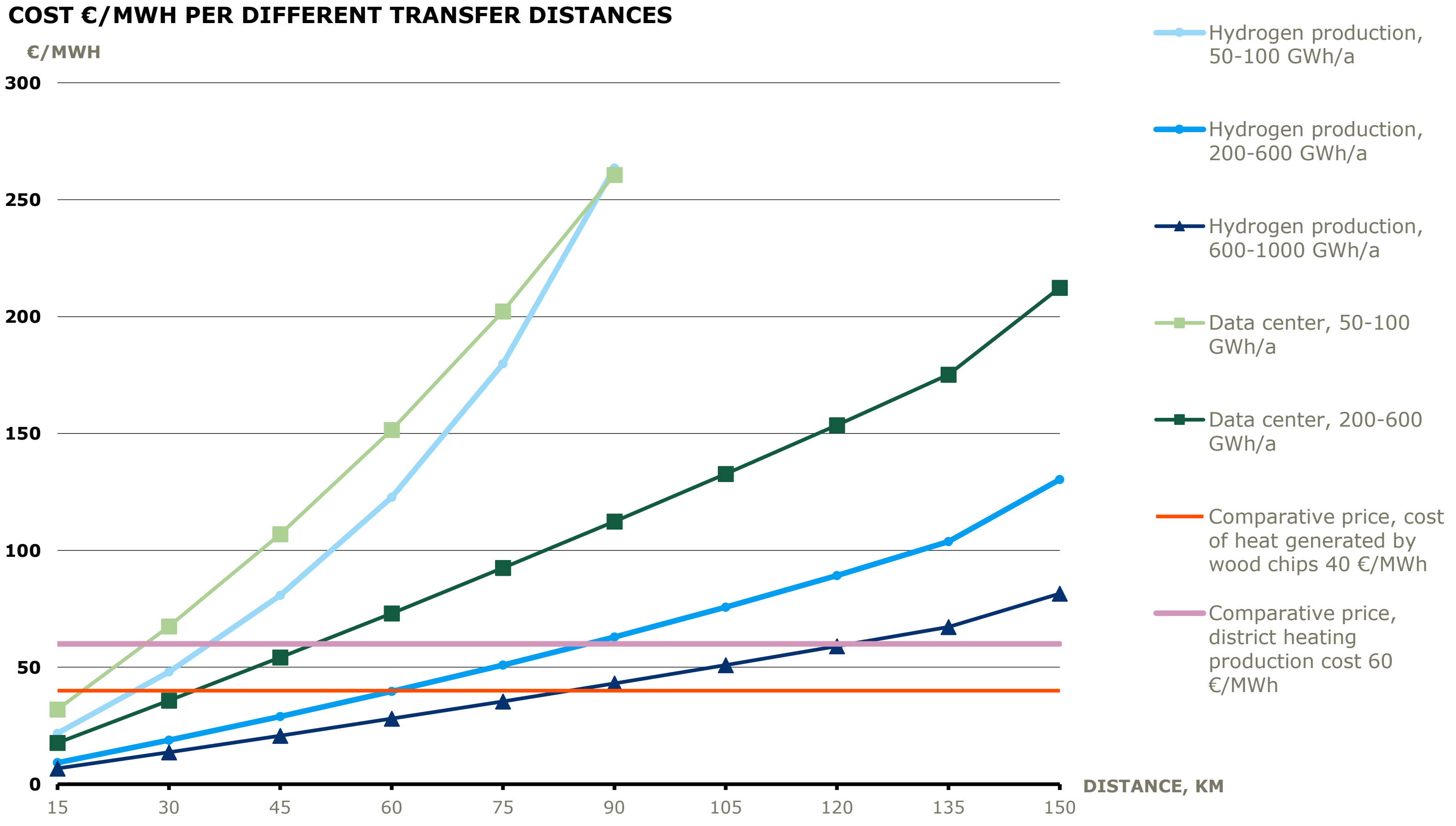
The figure shows the transfer cost of waste heat from hydrogen production and data centres (€/MWh) over distances of 3-15 kilometres from the examined target areas.

Conclusions:

- Over short transfer distances, the cost of waste heat transfer remains clearly below the comparative prices of 40 and 60 €/MWh.
- Waste heat could be transferred profitably over short transfer distances to various types of heat users, where the waste heat temperature level is suitable as-is.
- Over very short transfer distances (3 km), costs can be as low as €10/MWh.
- The cost of transferring data heat varies between approximately 10-30 €/MWh depending on the transfer distance.
- Transferring waste heat from hydrogen production with large capacities (200-600 GWh/a) is cheaper in terms of transfer cost compared to data heat due to the temperature difference.

Transfer of waste heat – Long distances

Assessment of waste heat transfer costs in Sea Lapland area



In the figure, the transfer cost (€/MWh) of waste heat from hydrogen production and data centres is depicted for distances of 15-150 kilometres from the examined target areas.

Conclusions:

- Transferring data heat is profitable compared to the comparative costs up to 15-45 km distances without temperature elevation.
- Conversely, if large capacities of hydrogen waste heat are transferred, it can be profitable up to 100 km distance.
- Although the examination is indicative, it shows that transferring large capacities can be profitable even over several tens of kilometres.
- Determining more precise profitability requires a comprehensive examination, such as assessing what heat production the waste heat displaces, the receiving capacity for waste heat, and how the temperature is elevated if necessary.

Role of utilized heat in urban development

Utilized heat plays a significant role in urban development, particularly from the perspectives of energy efficiency, environmental friendliness, and economic benefits. The waste heat from industry and energy production can be harnessed as part of city infrastructure, reducing the need for primary energy and promoting sustainable urban planning.

Improving energy efficiency

Utilized heat enables the optimization of district heating and energy production, reducing the overall energy consumption of cities. This decreases dependence on fossil fuels and supports the use of renewable energy in urban areas.

Emission reduction and environmental benefits

By using waste heat from industry and energy production for city heating, greenhouse gas emissions can be reduced. This supports municipalities and cities' strategic goals for emission reduction, aiding the transition towards carbon neutrality and sustainable development.

Economic benefits and cost-effectiveness

Utilized heat reduces fuel costs for district heating networks, potentially lowering heating costs for city residents and businesses. The sale of industrial waste heat to energy companies or its use by businesses can also create new business opportunities and support the local economy.

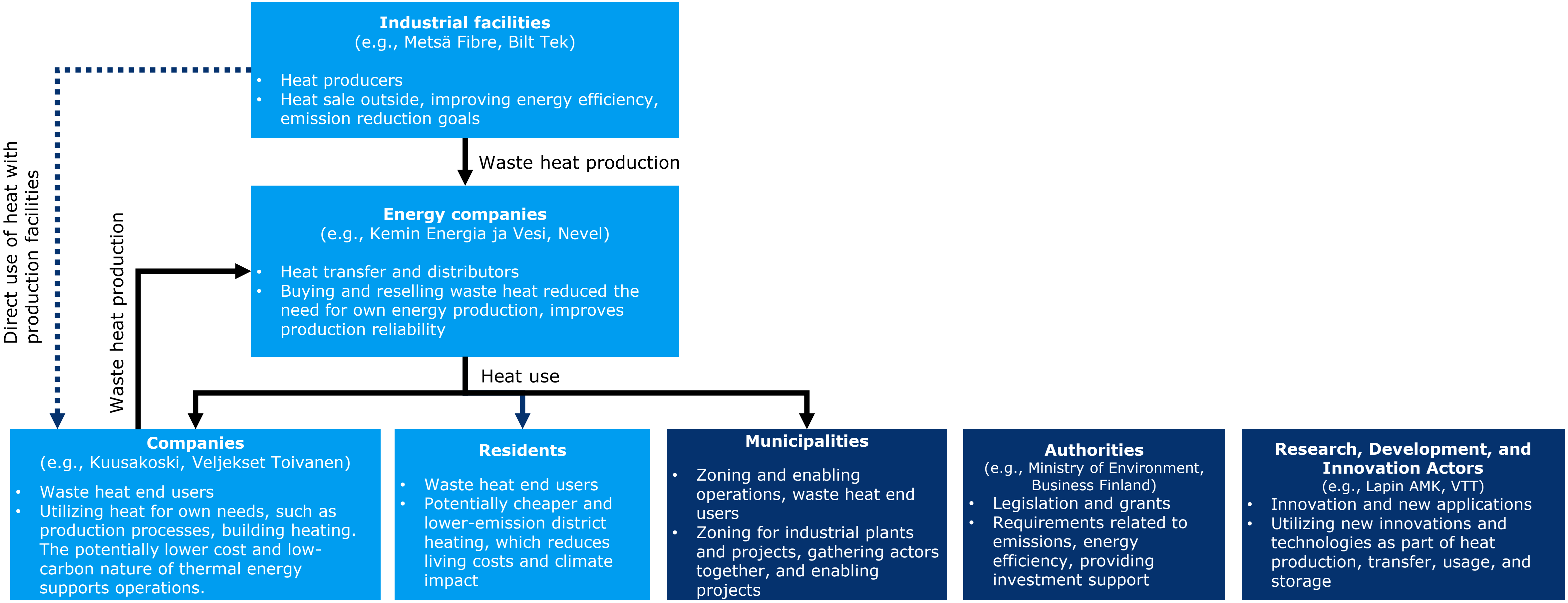
City attractiveness and vitality

The use of utilized heat as part of urban planning enables the development of renewable energy solutions, making the city more attractive to companies and residents. Sustainable energy solutions can attract investments to the area

Integration of electricity-intensive industry and data centers

High energy consumption industrial plants and data centres can feed their waste heat into the district heating network, increasing energy efficiency and reducing wasted heat energy. This improves the flexibility of the energy system and supports sector integration in cities.

The role of stakeholders and collaboration opportunities



SWOT-analysis

STRENGTHS AND OPPORTUNITIES

- ✓ **Strong existing industrial activity in the Sea Lapland area** producing waste heat and potential users.
- ✓ **Potential cost and synergy benefits** between waste heat producers and users: reducing the amount of purchased energy, integrating waste heat into production processes or selling it externally.
- ✓ **Using waste heat supports responsible and sustainable business practices** and is inherently socially acceptable.
- ✓ **Proximity to district heating networks** in Veitsiluoto, Rajakangas, and Hittikka.
- ✓ **Increasingly stringent environmental requirements support energy reuse.**
- ✓ **Waste heat can supplement or replace other energy production** and thus support regional energy security.
- ✓ **Possible utilization of investment support** for "decarbonizing" industry and improving energy efficiency

RISKS AND THREATS

- **Using waste heat requires investments** in energy capture, transfer, and dealing with temperature differences. Distance also significantly impacts costs, such as when connection to the district heating network requires new links.
- **Mismatch between the lifespan of investments in utilizing waste heat (**e.g., district heating network expansion**) and the lifespan of industrial plants**, making it important to ensure investments are not underutilized – considering both public and private perspectives**.**
- **Large industrial plants produce substantial waste heat continuously –** the challenge is finding enough use for even a fraction of this energy year-round in the Sea Lapland area.
- **Potential impact of discharging waste heat on natural ecosystems** (e.g., temperature effects on species).
- **Waste heat produced by industrial plants may not be directly usable** (e.g., data centres produce low-temperature energy).
- **Potential impact of fluctuations in energy prices** on the use of waste heat.
- **Safety distances of industrial plants –** heat energy users may not be able to get close to the source, and the industrial environment may not be attractive from e.g., a tourism perspective.
- **Limited resources of local research and educational institutions** for developing and innovating waste heat utilization.
- **Possible changes in legislation and investment support** could radically alter the operating environment.
- **Potential contractual risks between parties –** e.g., investment responsibilities, pricing, delivery reliability, and disruptions along the producer-user-intermediary axis.

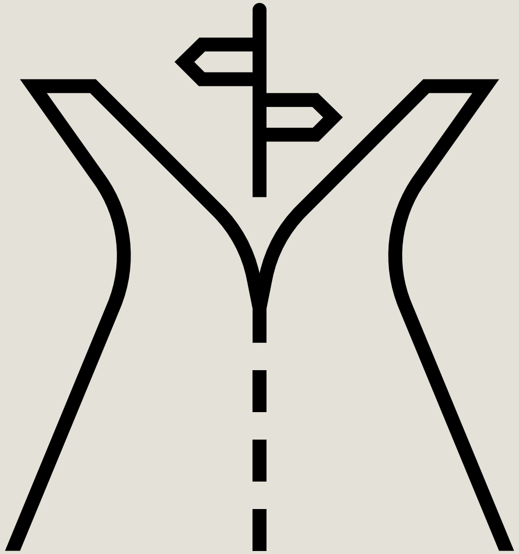
Conclusions and Recommendations

Key findings

- Waste heat can be utilized for electricity production, district heating, or directly in industrial processes. Waste heat generated in industry is mostly low-temperature, requiring temperature elevation, e.g., using a heat pump, for utilization in industrial processes or district heating networks. However, low-temperature waste heat can be used for process preheating.
- There are several electricity production processes, although the ORC process is the most promising for low-temperature waste heat.
- Among the industries, low-temperature waste heat has the greatest potential in the food industry, machinery and metal industry, and textile industry.
- Of the investment targets in Kemi, utilizing the waste heat from Veitsiluoto's 70 MW data centre for district heating would be the most cost-effective due to its proximity to the existing district heating network.
- Only a fraction (3%) of the waste heat from the examined investment targets can be utilized for regional district heating

Recommendations for Further Actions

- Identify and initiate preliminary discussions with parties interested in waste heat (producers, intermediaries, end users).
- Conduct a detailed feasibility assessment and planning for the expansion of the district heating network.
- Preliminary planning and implementation of pilot projects, including the utilization of project funding for initial planning.
- Identify potential investment supports for waste heat utilization (e.g., Business Finland).



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