NEW ENERGY STRATEGY

HELSINKI ENERGY CHALLENGE

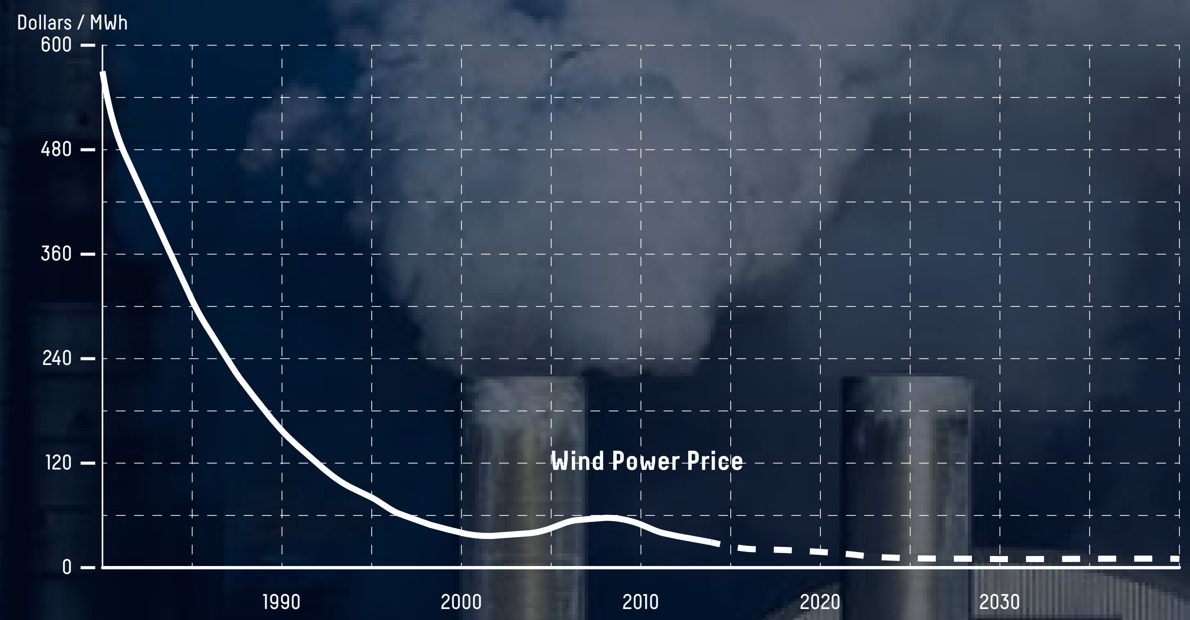
HELSINKI'S HOT HEART

Decarbonising the city—
And making a global attraction

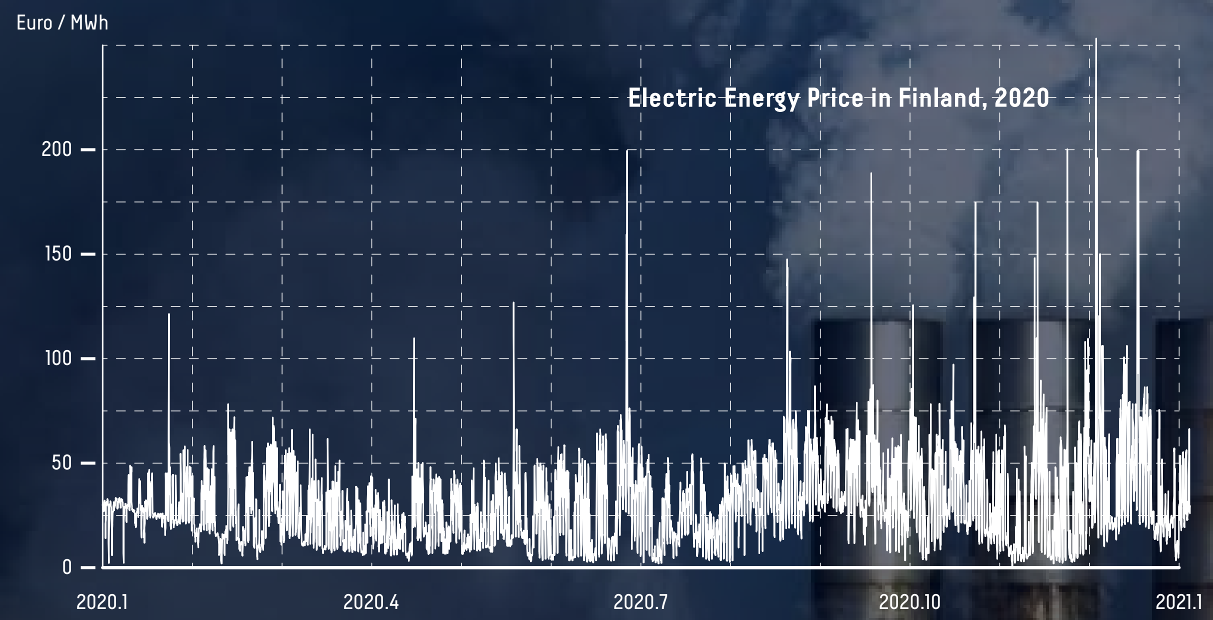
January 22, 2021

TABLE OF CONTENTS

Energy Context



***Changes in Wind Power Price Over Time** [1]*



***Changes in Electric Energy Price Over Time, Finland, 2020** [2]*

Let's look towards 2029: we don't know what the best energy mix will be to heat the city of Helsinki—it will depend on future technological development and market conditions.

However, we know that the price of renewable electric energy has been falling swiftly over the past 20 years and today is lower than that of all other sources.

However, renewables are intermittent... and as a result, we are seeing increasing imbalances on the network and variable energy prices—sometimes even negative.

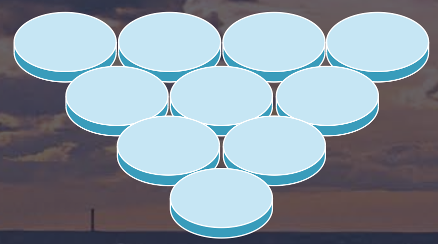
Therefore, it is imperative to find cheap energy storage—but the price of electric storage has been falling slower than the price of production and is still extremely high.

[1] "How Steady Can Wind Power Blow?" , Ramez Naam, accessed Jan 18, 2021, https://rameznaam.com/2015/08/30/how-steady-can-the-wind-blow/

[2] "Elspot-prices_2020_hourly_eur", Nord Pool, accessed January 18, 2021, https://www.nordpoolgroup.com/historical-market-data/

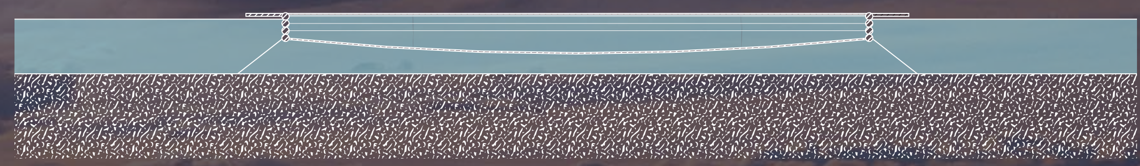
Our Proposal

VS



1 MWh
Battery Storage
= €200,000 [1]

1 MWh
Thermal Storage
= €200



Floating Structure

Embedded Structure

The percentage of renewables in the Finnish grid is increasing rapidly—in particular wind energy. According to the Finnish Wind Power association, 18.5 GW [2] of wind farm projects are currently being planned—which is more than a double of the Fingrid grid average load of 8.9 GW [3] in 2020.

All of this means that Finland will experience larger variations in the price of electricity (including negative prices) and require significantly more load balancing. While electric energy storage is getting cheaper, it is still significantly more expensive than thermal energy storage.

Helsinki's Hot Heart is an array of cylindrical basins filled with hot seawater. They can be floating or partially dug into the seabed near the city and provide heat storage at a cost as low as 200 Euros per MWh, 1000 times cheaper than electric storage (~200,000 Euros per MWh). With heat generated by electricity, thermal storage will act like a battery storage, because the time periods to use electricity can be chosen almost freely.

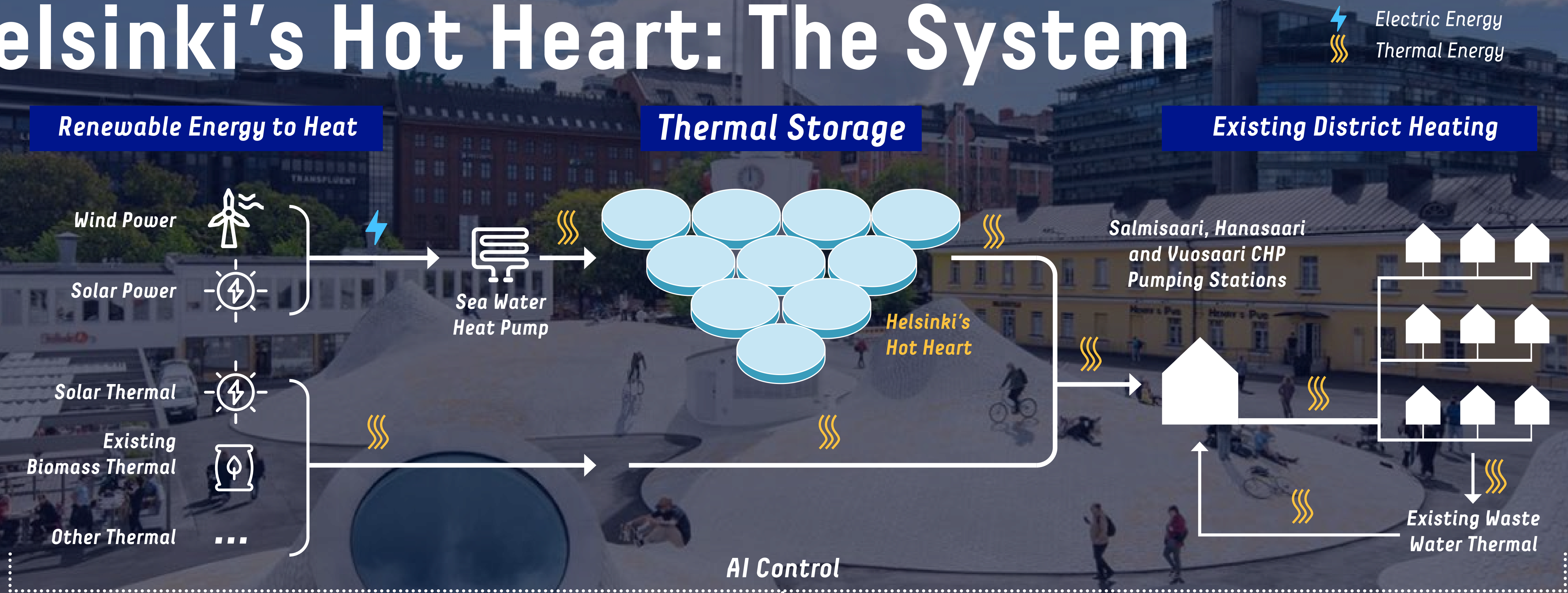
The overall system uses seawater heat pumps to convert primarily carbon free electrical energy into heat. It helps decarbonize the Helsinki district heating system while providing a needed balancing effect on the national grid of Finland—so that even more renewables can be used in the future.

[1] "A Behind the Scenes Take on Lithium-ion Battery Prices" , Bloomberg NEF, last modified March 5, 2019, https://about.bnef.com/blog/behind-scenes-take-lithium-ion-battery-prices/

[2] "Wind Power Projects in Finland." *Suomen Tuulivoimayhdistys*, tuulivoimayhdistys.fi/en/wind-power-in-finland/projects-under-planning

[3] Load and Generation." *Fingrid*, 18 May 2017, www.fingrid.fi/en/electricity-market/electricity-market-information/load-and-generation/

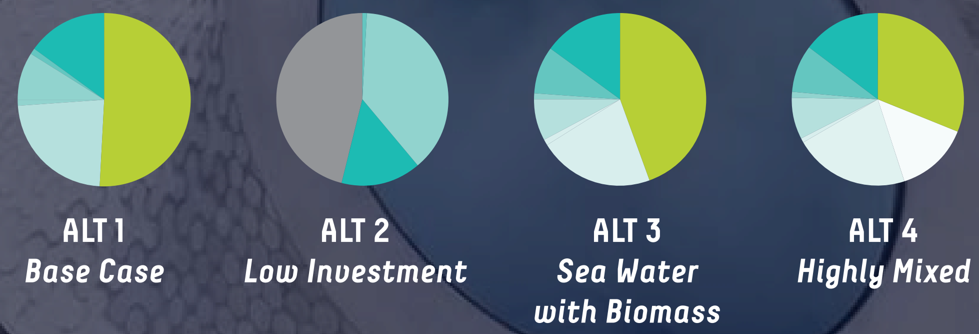
Helsinki's Hot Heart: The System



Helsinki's Hot Heart is a flexible system made of 10 cylindrical reservoirs with a diameter of 225 meters (total volume approximately 10 million m³), which can receive different energy sources as input. Electric energy is converted into thermal energy using heat pumps exchanging with the sea. Conversely, sources of heat are directly plugged into district heating.

The output of Helsinki's Hot Heart is heat that can be distributed across the existing district heating system. Today's existing district heating network is maintained, in order to minimize environmental cost, and connected with Helsinki's Hot Heart at Salmisaari, Vuosaari and Hanasaari.

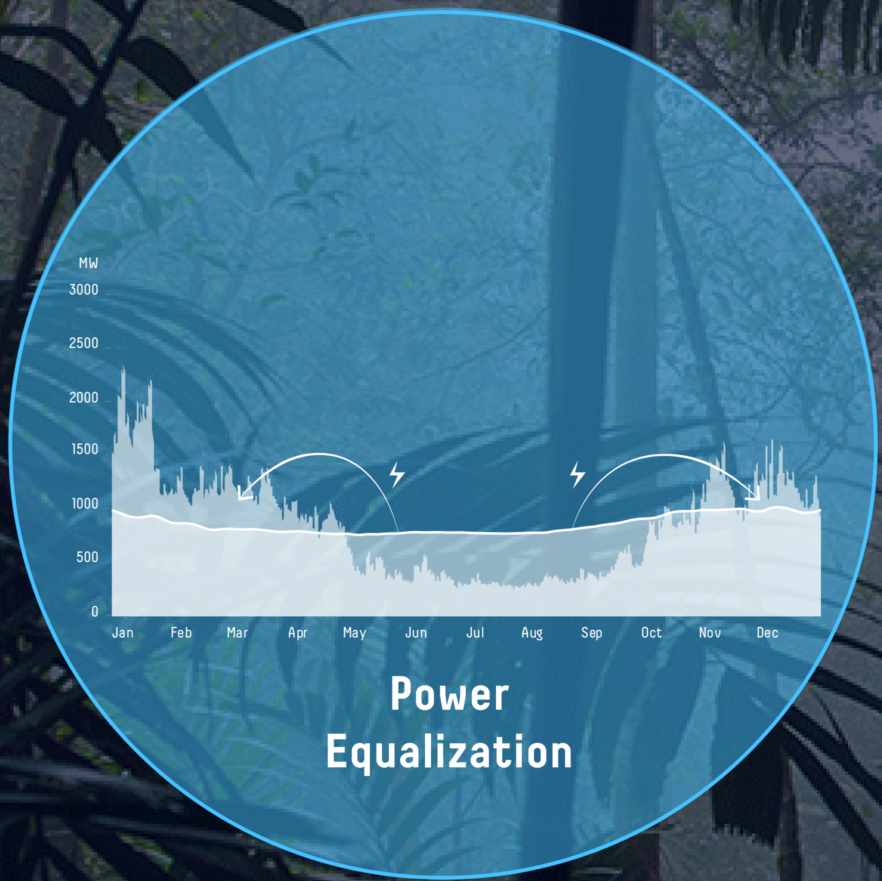
Our calculations, detailed later in this report, show that we are able to cover the full heating demand of the city of Helsinki, estimated at 6,000 GWh at the end of the decade, without any carbon emissions and at a price for citizens significantly lower than the one they pay today—with a discount of ~10%.



Examples of possible energy mixes for our system

[Reference 1.2 for more detail]

Additional Benefits



But there is more... In addition to providing carbon-free heating to the people of Helsinki for a price lower than what they pay today, our system features a number of exciting benefits!

Helsinki's Hot Heart will use electric energy when it is cheap, contributing to balancing the national grid as it moves toward a higher percentage of renewable energy generation.

"Moreover, Helsinki's Hot Heart will establish a new, spectacular attraction and public facilities available for locals and tourists alike. An inflatable structure will cover four cylinders of Helsinki's Hot Heart, allowing the area underneath to enjoy a warm climate all year long. There, a tropical forest will grow, and all around it, people can swim into hot pools, or relax in the saunas.

Such an attraction would embody an ideal life familiar to Finnish culture: island, nature, silence, a peaceful space for anybody to freely think, relax, or just roam around - almost a new take on Finland's 'Jokamiehen Oikeudet' (Everyman's right) - albeit transposed into a tropical climate, amidst its lush vegetation.

Helsinki's Hot Heart can become a model for cities around the world—cementing Helsinki as a city that always pushes the boundaries of innovation, ingenuity, and sustainability in public space.

All of the above points come with economic benefits, which have been estimated at several hundred million Euros. However, we have not included them in our financial calculations and consider them as a 'bonus'.

1.1
ENERGY CONCEPT FOR 2029
HEAT GENERATION

As described in the introduction, the system uses electric energy during times of overproduction and underconsumption, and stores it in Helsinki's Hot Heart. It can work with a variety of energy sources. However, two key components are electric power from wind and heat pumps exchanging with seawater. The resulting heat is then distributed using the existing district heating network. The three components of the system are described in more detail here.

Wind as the main source of electric power

Currently, wind farms are being built in Finland without subsidies and typically generated electricity is sold in advance through Power Purchase Agreements. The price level is currently 25-30 Euros per MWh, although such price is decreasing fast.

When all electricity from one wind park is bought, the price of the electricity is fixed during the whole contract period—typically 10 to 20 years. For example, Google recently signed Power Purchase Agreements for several hundred MW and the wind farms are under construction.

Also, the price of electricity is close to zero during night and weekends, and has started entering negative territory at times. The heat storage in Helsinki's Hot Heart makes it possible to use electricity for heat pumps primarily when the price is low.

In general, heat pump capacity in terms of Euros per MW is expensive, but thanks to the heat storage capacity of Helsinki's Hot Heart, they can be dimensioned for smaller overall capacity and hence lower investments.

Seawater as the main heat source

It is known that seawater heat pumps work. For example, Stockholm, Sweden, has approximately 200 MW seawater heat pump capacity in operation at a similar latitude to Helsinki. Helen energy company is already planning to implement seawater heat pumps. Our solution is similar, but at a larger scale.

Seawater is an unlimited heat source for heat pumps. However, we need to carefully consider sea temperatures. During 7 month of the year, sea temperatures are above 5 °C, but during the remaining 5 winter months, the temperature is lower and could cause freezing next to the heat pumps.

One conservative approach to this issue—which incidentally is included in plans by Helen—is to build a tunnel to get seawater from a depth of approximately 60 m during the winter, where the temperature does not go below 3 °C. Such water is then fed into the heat pumps.

However, there could also be other more cost-efficient solutions, although they have not yet been proven to work on a large scale. Therefore the seawater tunnel to 60 m deep is the baseline solution in our proposal, although the following alternatives could be investigated in more detail.

Surface water could be supercooled. It is well established that moving seawater freezes at a temperature of -4 °C. In such a case, it could be possible to use heat pumps by cooling constantly moving surface water from +1 C to -3 °C without freezing affecting the system.

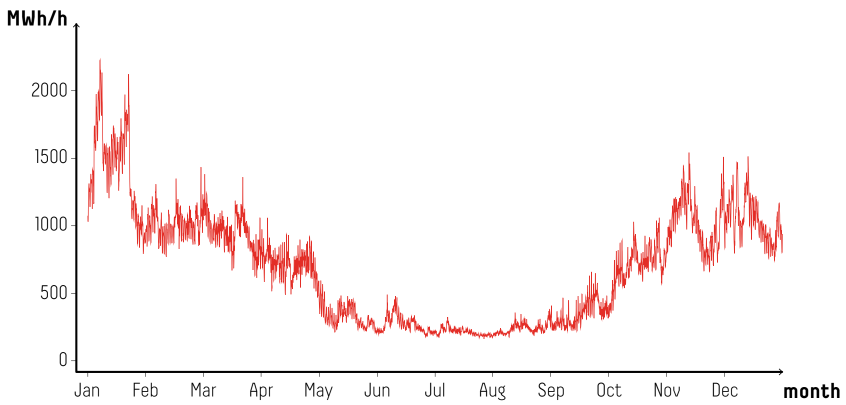
Alternatively, one could generate snow from seawater. Such an approach would significantly decrease the need for seawater and the heat pumps would have an unlimited 0 °C heat source. The solution is currently used on a small scale to generate snow for ski centers—as in the Snow factory of Technoalpin (it is a commercial solution to generate snow from 5-20 °C water, when the outdoor temperature is approximately 15 °C).

Heat distribution in the district heating system

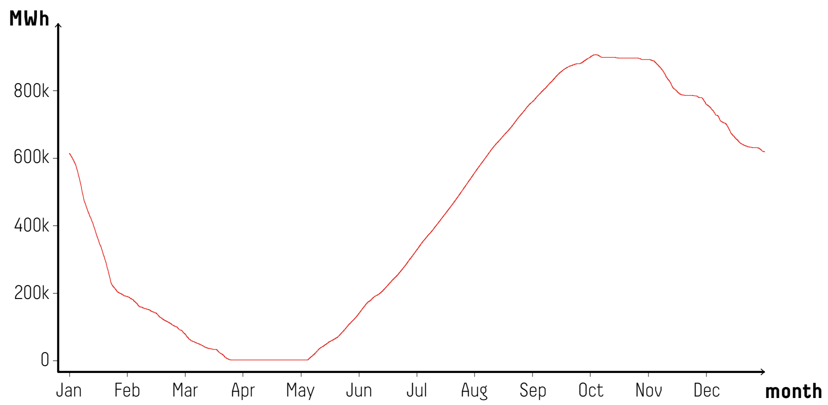
Our baseline solution is that heat from Helsinki's Hot Heart will be distributed through the district heating system at the current temperatures, so that no changes are needed to the existing network of substations. However, it would be possible to improve the proposed base solution by installing heat-demand management systems adjacent to customers.

Heat pumps would be cooling the seawater and generating approximately 80 °C heat for Helsinki's Hot Heart or directly for customers depending on the operating situation. Additional heat pumps will raise the temperature as needed in the district heating network while cooling down the storage. Higher than 80 °C supply temperatures are needed approximately for one month per year.

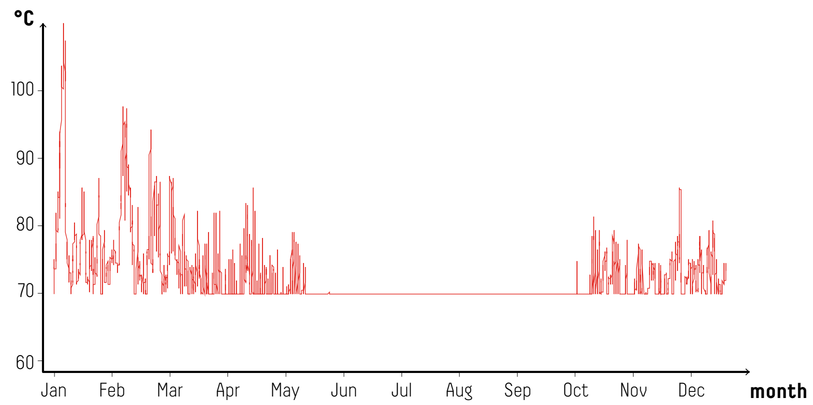
The heat storage is always full of water, but the temperature of the water in the storage is 5 °C, when it is empty and 80 °C, when it is fully loaded. The volume of the storage is approximately 10 million m^3 with the energy capacity of 870,000 MWh.



District Heat Demand
Source: Helsinki's Hot Heart team



Heat in Storage
Source: Helsinki's Hot Heart team



Supply Temperature
Source: Helsinki's Hot Heart team

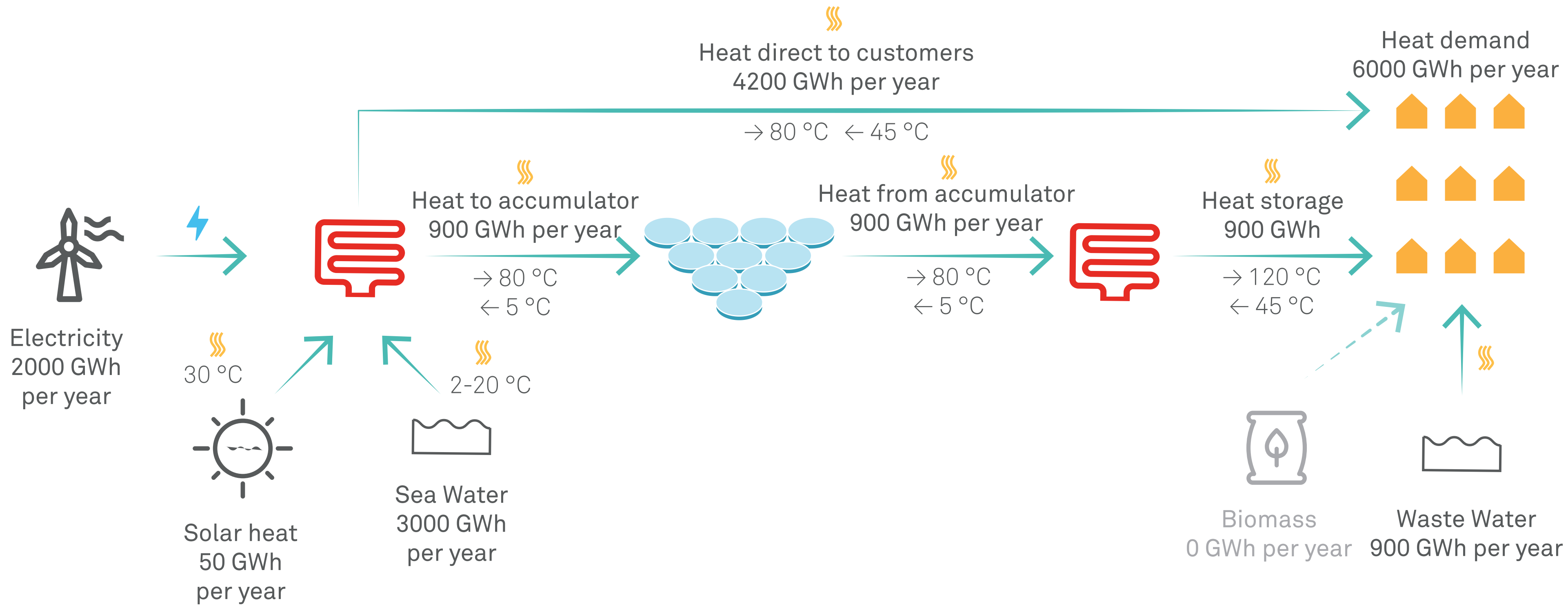
1.2
ENERGY CONCEPT FOR 2029
ENERGY BALANCE

Heat generation details

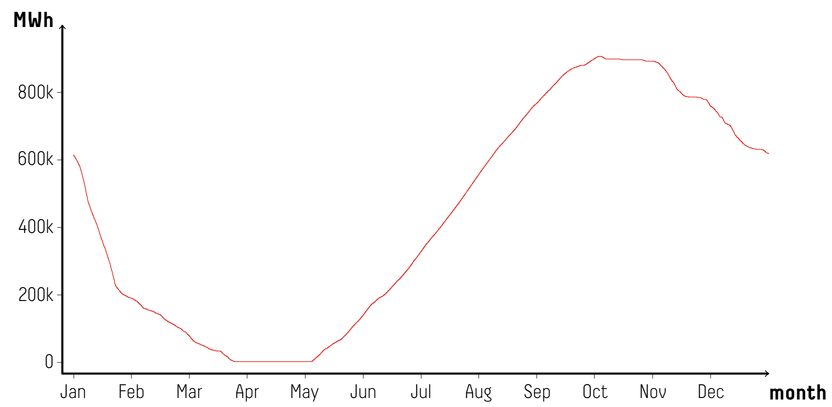
Let's look now in more detail at all the assets needed for district heating. In addition to electric energy from wind and heat pumps, based on our analysis the baseline would be the following:

- Seawater heat pumps, with thermal capacity of 750 MW
- Wastewater heat pumps with the thermal capacity of 100 MW (aoready existing)
- 250 MW biomass fired heating plant, which will be used as back-up capacity, but in normal situations is not needed (already existing)
- Boilers for back-up, to secure heat supply in case failure of other assets (already existing)
- Use of Helsinki's Hot Heart for heat storage

Helsinki's Hot Heart storage will be fully loaded at the end of summer, while its energy content will reduce during the autumn and winter. The figure below illustrates the energy content variation during the year. The storage will be loaded using solar energy and seawater heat pumps. Because of the long time period (approximately 6 months) to load the storage, the specific time periods and loading capacities can be selected freely and adjusted to the time periods when wind power is available and therefore the electricity has the lowest costs.



Helsinki's Hot Heart System Diagram

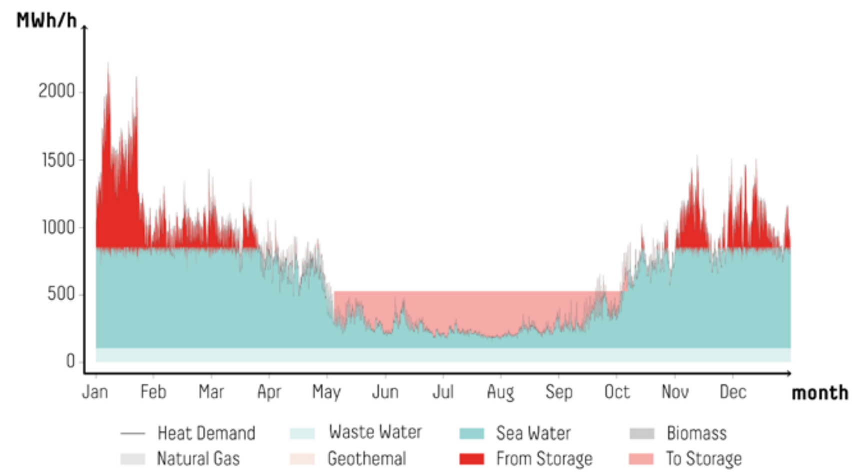


Heat in Storage
Source: Helsinki's Hot Heart team

Energy Balance

Total heat demand is estimated to be 6,000 GWh per year in 2029. Seawater heat pumps would generate approximately 5,100 GWh heat annually using approximately 2,000 GWh of electricity. Part of the generated heat (4,200 GWh per year) would be transferred directly to the district heating network and part of it (900 GWh per year) would be stored in Helsinki's Hot Heart.

Existing wastewater heat pumps would generate 900 GWh per year as base load during the whole year and biomass boilers could be used for peak demand during the coldest winter days and during sustained high electricity prices, but the estimated need is 0 GWh per year.



District Heat Generation, Case 1
Source: Helsinki's Hot Heart team

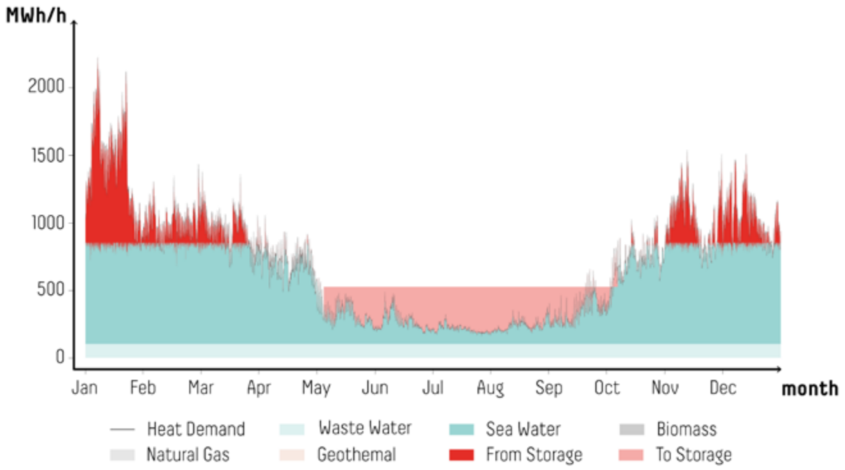
1.3
ENERGY CONCEPT FOR 2029
ENERGY MIXES

The proposed system can use several heat sources in an extremely flexible way. The figures illustrate some alternative mixes.

Case 1 - Most economical heat generation

The most economical heat generation case is based on wind powering heat pumps exchanging with seawater, which would have thermal capacity of 750 MW. Total investment is estimated at 940 million Euros and variable heat generation cost at 11.6 Euros per MWh.

BASE CASE	GWh / year	%
Seawater thermal	3,050	51 %
Wind Power	1,400	23 %
Solar Power	50	1 %
Other power	550	9 %
Solar thermal	50	1 %
Biomass thermal	0	0 %
Wastewater thermal	900	15 %
Total	6,000	100 %

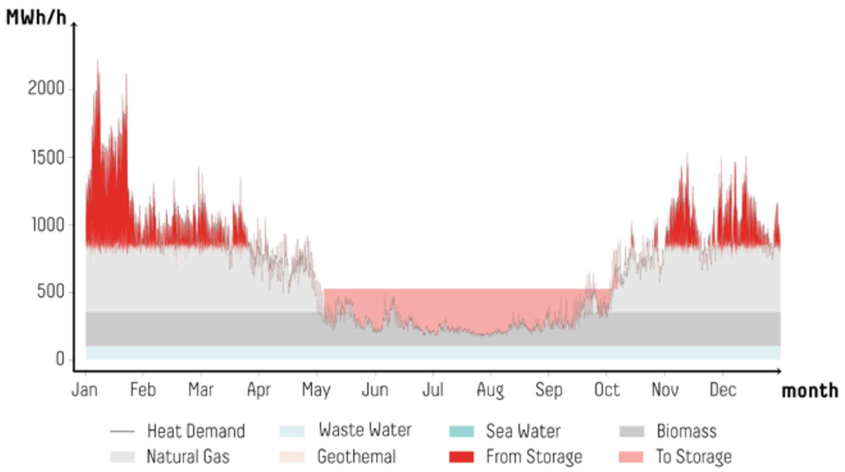


District Heat Generation, Case 1
Source: Helsinki's Hot Heart team

Case 2 - Lowest investment

In order to minimize capex, natural gas could be used initially to partially offset coal, while additional carbon-free heat generation could be added in later years (by 2035). Investment would be 300 million Euros, although variable heat generation cost would be high.

LOW INVESTMENT	GWh / year	%
Seawater thermal		0 %
Wind Power		0 %
Solar Power	50	1 %
Other power		0 %
Solar thermal		0 %
Biomass thermal	2,300	38 %
Wastewater thermal	900	15 %
Natural gas	2,750	46 %
Total	6,000	100 %

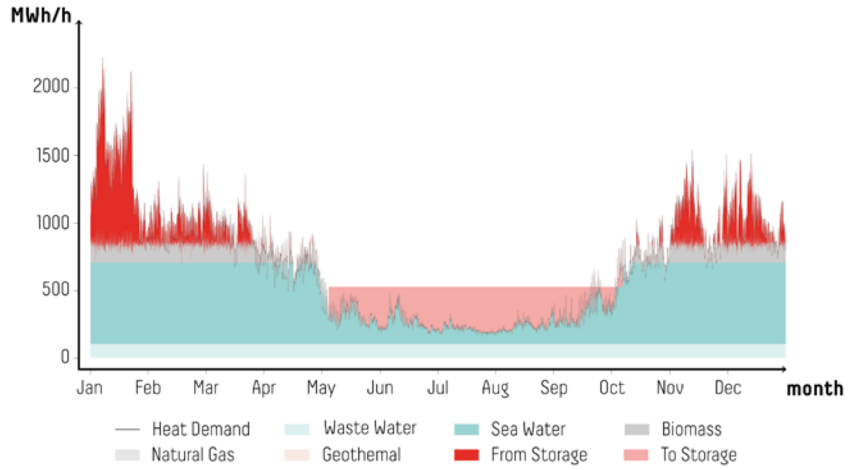


District Heat Generation, Case 2
Source: Helsinki's Hot Heart team

Case 3 - Wind powered heat pumps with biomass thermal energy

The total capacity of heat pumps and the total investment could be reduced by utilizing the existing biomass heating plant during the winter. In such case the total investment cost would be 880 million Euros and variable heat generation cost 13 Euros per MWh.

BIOMASS + SEAWATER	GWh / year	%
Seawater thermal	2,700	45 %
Wind Power	1,300	22 %
Solar Power	50	1 %
Other power	450	8 %
Solar thermal	50	1 %
Biomass thermal	550	9 %
Wastewater thermal	900	15 %
Total	6,000	100 %

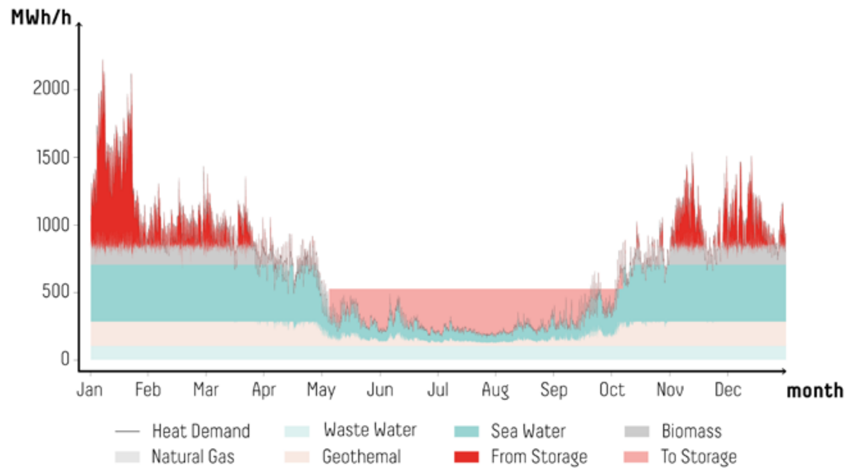


District Heat Generation, Case 3
Source: Helsinki's Hot Heart team

Case 4 - Highly mixed energy sources

Heat pumps could use multiple heat sources. In addition to seawater, heat could be taken from the ground (geothermal) or air (air-to-water heat pump). Geothermal is not a commercial solution yet in Finland and therefore there would be uncertainties. Total investment would be approximately 950 million Euros and variable heat generation cost 13 Euros per MWh.

HIGHLY MIXED	GWh / year	%
Seawater thermal	1,890	32 %
Geothermal	810	14 %
Wind Power	1,300	22 %
Solar Power	50	1 %
Other power	450	8 %
Solar thermal	50	1 %
Biomass thermal	550	9 %
Wastewater thermal	900	15 %
Total	6,000	100 %



District Heat Generation, Case 4
Source: Helsinki's Hot Heart team

1.4
ENERGY CONCEPT FOR 2029
"HELSINKI'S HOT HEART" STORAGE

Storage Volume

The energy content of the heat storage in Helsinki's Hot Heart depends on the volume (m^3) and the temperature difference (°C) between the empty and full storage. Dimensioning the storage is an optimization task, which has led us to approximately 700-1,100 GWh depending on the energy mix.

Our baseline is of a storage volume of 10 million m^3, with an energy content of 870 GWh based on a temperature difference of 75 °C (which means the temperature of full storage is 80 °C and temperature of empty storage is 5 °C).

The figure below illustrates the energy content in the storage based on the temperature. The temperature of the empty storage can be achieved with a heat pump at the supply side of the storage. The electricity use of the supply side heat pump is taken into account in the seaside heat pump values.

Construction Type

Helsinki's Hot Heart is made of cylinders of 225 m diameter filled with seawater. We have imagined two different types of storage—excavated and floating. The former is a more conservative solution. The design is similar to a standard pit heat storage, whereby most of the pit already exists thanks to the sea.

The volume of the biggest existing pit heat storage is 200,000 m^3. The structure of the seawater storage could be planned in detail during the planning phase. In areas where seawater is 20 m deep, only a 5 m excavation of sea bed would be needed. The amount of excavated ground would be 2.7 million m^3, which would allow building 30 m thick lateral walls.

An alternative is a fully-floating storage. This solution is more experimental and will need to deal with the shallow seabed near Helsinki and the forces generated by tides and frozen sea during the winter. However, such a solution could draw on recent developments in offshore wind farm technology and would be easily replicable across the world.

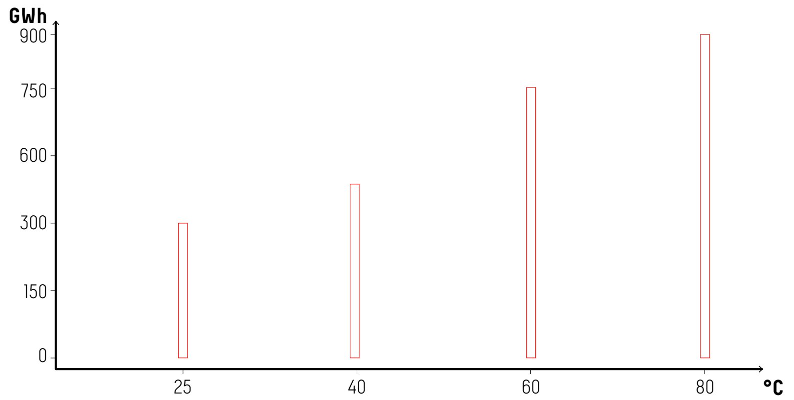
Insulation

Heat losses of the storage can be minimized with insulation and they are relatively small when compared to the total stored energy amount. Estimated heat losses would be 3 GWh per year, or an equivalent value of 50,000 Euros per year.

There is a lot of available data about the existing pit heat storages and the insulation principles developed during the past 30 years. The same insulation principles can be utilized in the proposed storage. A conservative insulation solution is described below.

For the excavated storage, 30 m thick rock walls will insulate the sides of the storage—similar to how ground material insulates pit heat storages. It is not difficult to add insulating materials on the vertical walls, which are also covered with waterproof membranes.

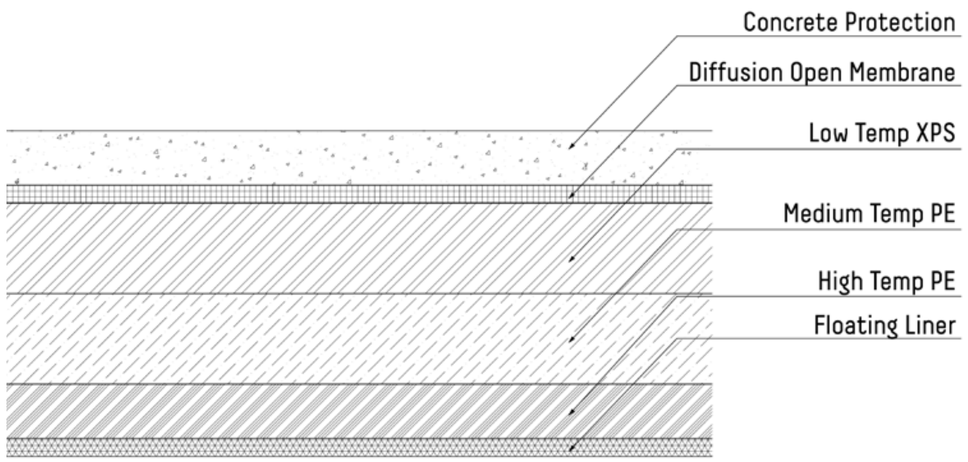
The top of the storage would have a floating insulation cover with another kind of insulation. Such insulation would cover all surfaces in a floating solution. The precise type of insulation can be optimized during the planning phase of the project.



Energy Content Based on Temperature
Source: Helsinki's Hot Heart team

Parameters		Sides Rock Material (or similar)	Roof Polystyrol (or similar)
k-value	W/mK	3	0.043
Thickness	m	30	1.5
u-value	W/m²K	0.1	0.029
Heat Loss	MW	0.2	0.4
Heat Loss	MWh per year	1,564	3,265
Heat Loss	Euro per year	17,209	35,910

Assumption for Energy Losses Calculations considering an avg. temperature difference to surrounding of 32.5 °C
Source: Helsinki's Hot Heart team



Possible Insulation Layering Detail
Adapted from: "Insulation Material", *PTES the next generation of storing energy*, Morten Vang Bobach, October 21, 2020, page 5.

1.5
ENERGY CONCEPT FOR 2029
STRUCTURAL CONCEPT

As mentioned, Helsinki's Hot Heart is made of 10 basins, each 225 m in diameter with a varying depth averaging 25 m. Each could either be a floating structure or partially excavated into the seabed. The latter is more conservative and could work well in Helsinki due to its shallow sea nearby. The former could use innovative wind offshore technologies, have lower impact, and be replicated in cities around the world.

The excavated basin would require digging the sea bed. Excavated rock will be used for the vertical walls, which could be up to 30 m thick when the sea is 20 m deep. Excavating the seabed by about 5 meters would provide enough material for it—and also provide most of the required water volume. Thermal insulation would be included on all surfaces to inhibit heat loss. Standard polystyrene could be used—or more innovative materials such as Tri-iso-Super-10.

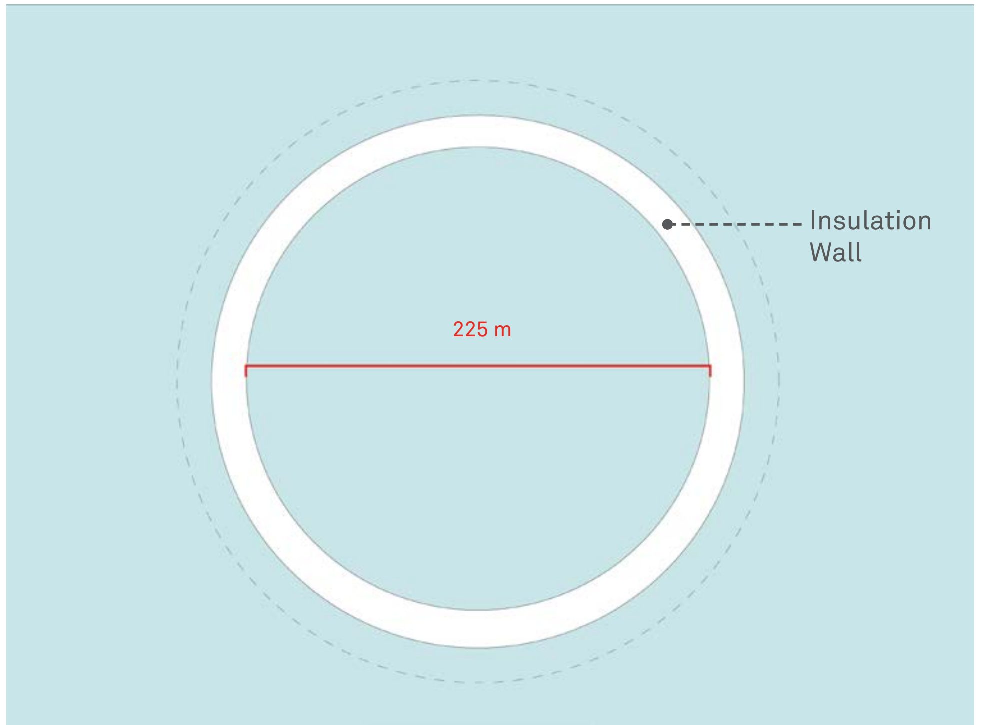
The walls of the floating basin would be made out of 100-inch (approximately 2.5 m) diameter tubes, which are commercially available for standard oil and water pipelines. They create a ring to which prestressed radial cables are added to stabilize them (like bicycle wheels and as done in the Schmehausen Cooling Tower in Germany). Up to 5 or 10 pipes would be put on the top of each other, creating large cylindrical reservoirs of 225 m diameter and 10-25 m high.

The rings are anchored to the seabed to prevent motion from wind as well as sea and ice currents. At the bottom, they are closed by a metal membrane. Water inside the floating reservoir is 0.5 m higher than sea level, which generates higher pressure inside, keeping the lower membrane in tension (the higher water level is compensated by the floating power of the hollow rings).

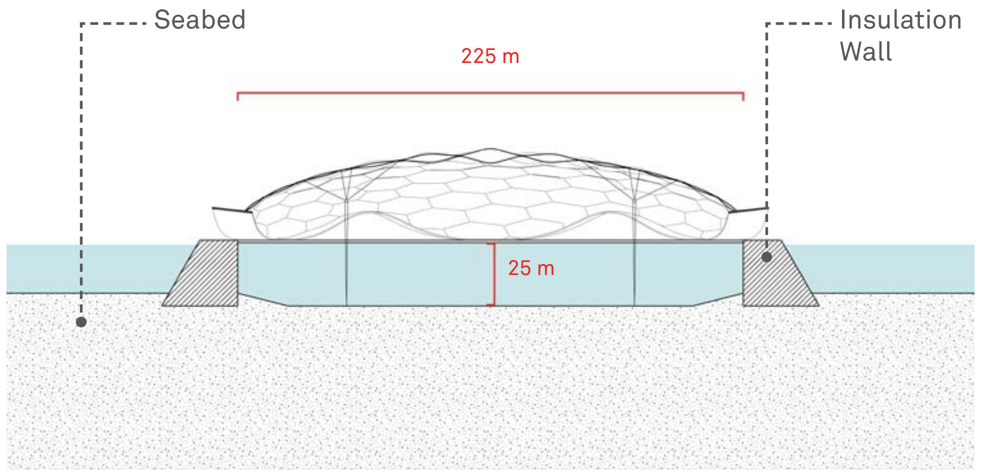
Both basin types—excavated and floating—are able to carry domes that enclose attractions within. The domes are formed by an inflatable structure made of ETFE. Each pillow of ETFE will also contain nanogel to improve its insulating properties while allowing natural light through them.

The top floating ring will also act as a cable-stiffened ring, utilized at the base of the dome to counteract its outward-pushing forces. Around the dome's perimeter is a series of arches that allow entrance to the dome and have a stiffening effect. The structural floor of the attractions could be created using floating polystyrene pontoons with bolted connections and thermal insulation.

Seabed Embedded Storage

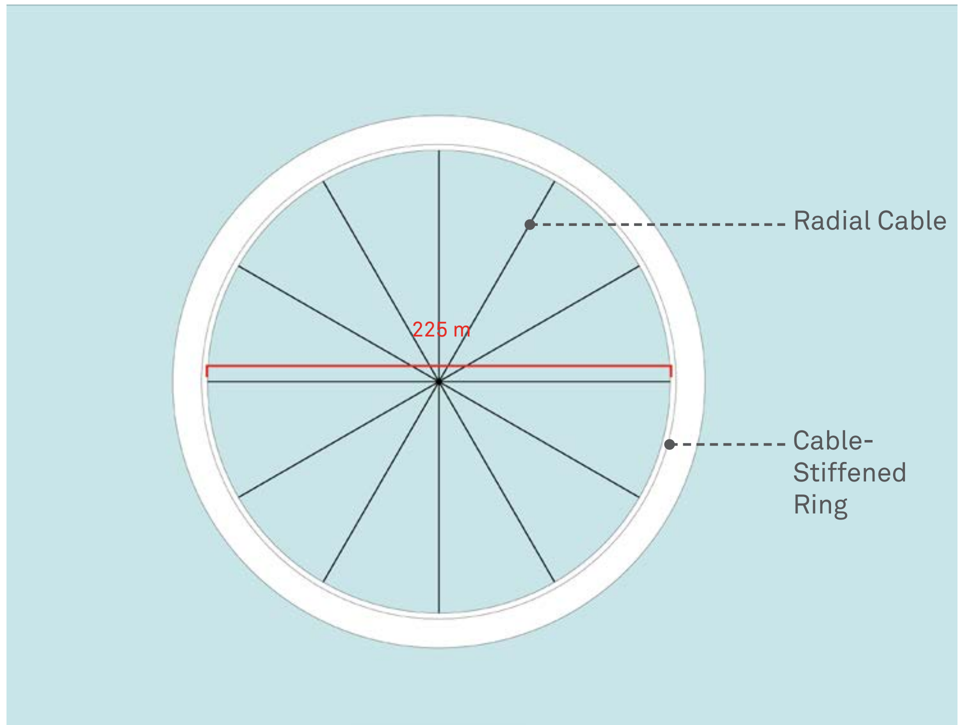


Structural Plan

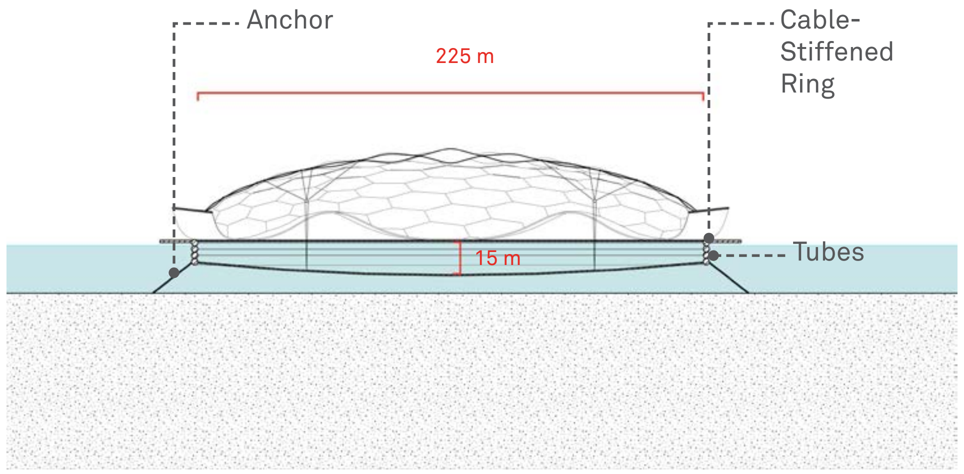


Structural Section

Floating Storage



Structural Plan



Structural Section

1.6
ENERGY CONCEPT FOR 2029
"HELSINKI'S HOT HEART" LOCATION

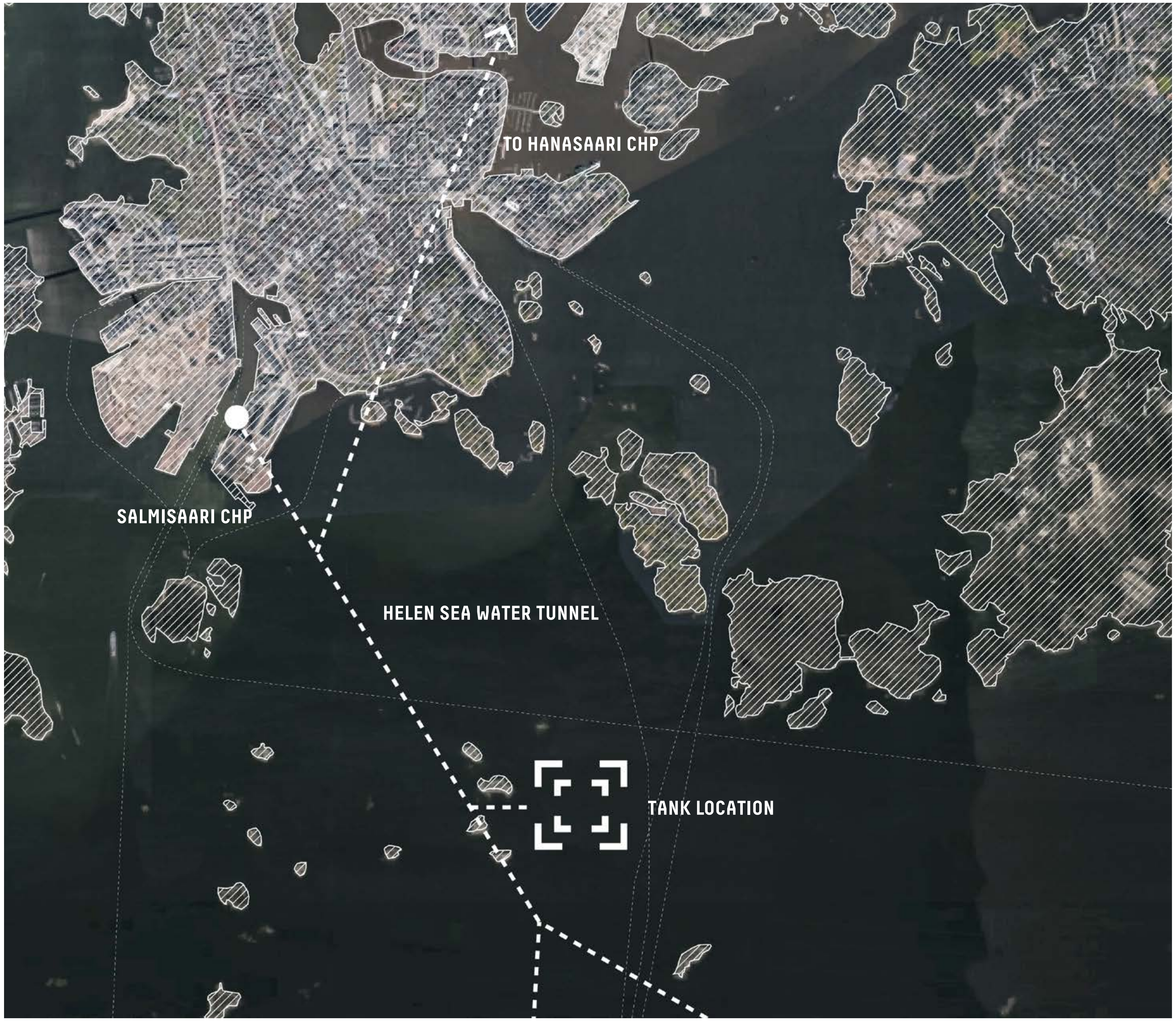
Location Scouting

Locations close to the coast might be too difficult in terms of permits, so we have been looking at areas farther away. As mentioned above, Helen has already started planning and permitting for a 20 km long seawater tunnel from Salmisaari to the deep sea to get warmer water for heat pumps during the cold winter months.

A possible location for Helsinki's Hot Heart and the heat pumps could be close to Pitkäouri Island, where the depth of the sea is approximately 10-20 m (on the east side) and the sea bed is made of solid rock. Helen is planning to have an access tunnel from the Pitkäouri island to the seawater tunnel. Therefore it would be easy to connect Helsinki's Hot Heart storage to the seawater tunnel.

The aforementioned areas, military areas, ship routes etc. would support the choice of the proposed location. The location is approximately 3.5 km away from the shoreline of Helsinki. This location could allow connection to the city in terms of heat pipes and electricity for heat pumps.

A heat tunnel from Salmisaari to Hanasaari would also be needed to allow the heat delivery to the whole district heating network. Helsinki's Hot Heart storage must be connected to 2 or 3 Combined Heat-and-Power (CHP) sites of Helsinki (Salmisaari, Hanasaari, or Vuosaari) in order to have enough heat transfer capacity.



Potential location in the sea near Helsinki

1.7
ENERGY CONCEPT FOR 2029
AI, ANALYTICS, AND CONTROL

Helsinki's Hot Heart and all its systems will be equipped with a predictive energy management system. Predictive energy management adds an additional layer for control and automation and allows the new installations to work synergistically with Helen's district energy system and with the electrical grid.

Predictive energy management systems use data from sensors, machine learning, and AI algorithms to optimize the use of the seawater heat pumps and other system components according to weather and thermal load forecasts. The system also allows Helsinki's Hot Heart to be used as a load balancer towards the national electrical grid.

The predictive management system also conducts operational and fault diagnostics to make sure that the system components will be used in the most optimized way, minimizing the maintenance and life-cycle cost. The predictive energy management system consists of the following components.

Energy monitoring and forecasting

Both electricity and heat generation / demand will be constantly monitored and forecasted.

Tarif management (hour- or minutes-based data)

Heat pumps will operate using electricity price information to minimize production cost.

Peak load shaving

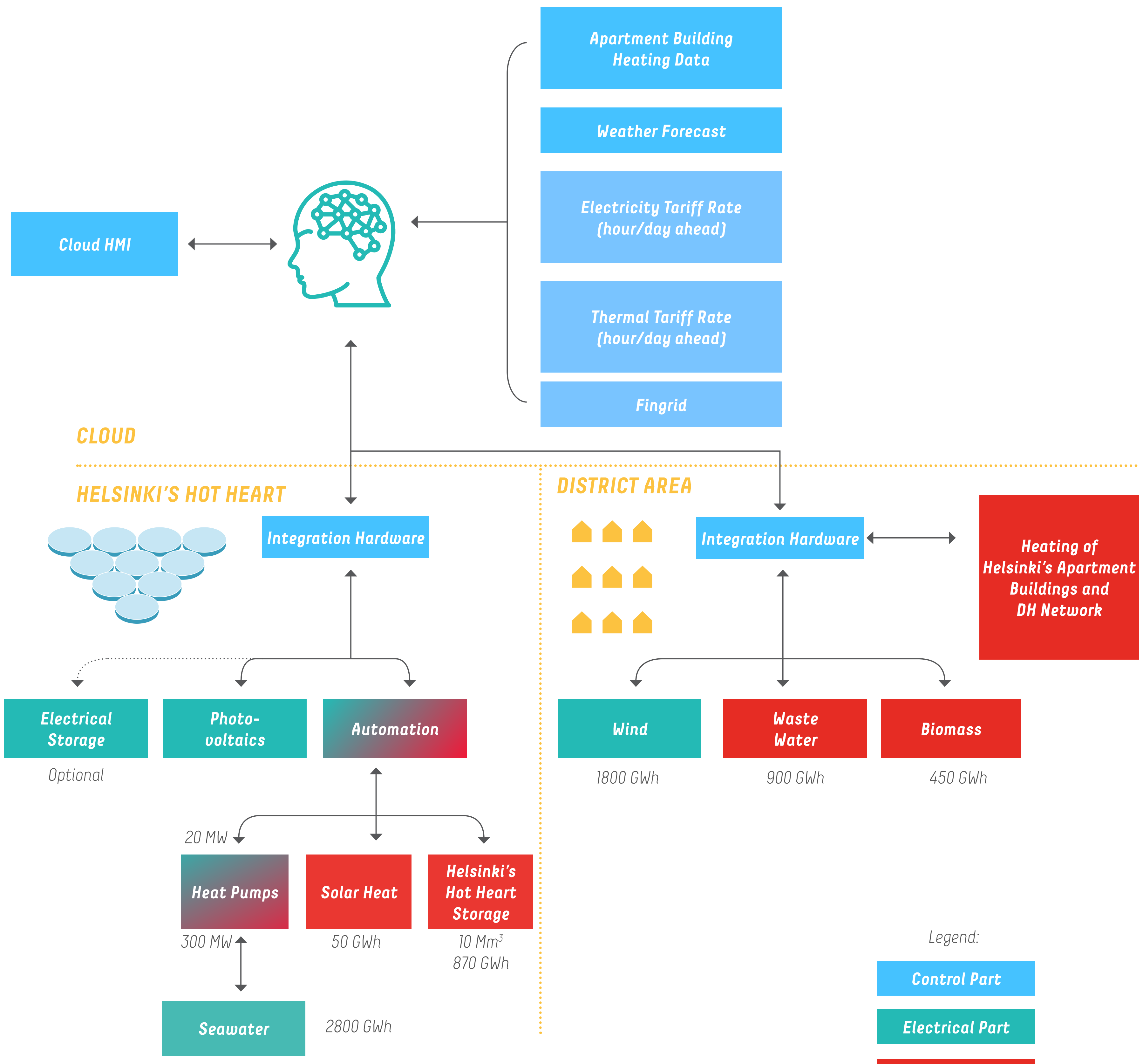
The energy management systems will minimize electric peak power demand.

Electrical network frequency control

The high power consumption of heat pumps helps with the electricity network frequency control market to generate additional income. The heat pump system will be sized and designed to enable controlling according to electrical grid frequency.

Integration into the existing district heating system

The predictive energy management system will be connected and integrated with the control systems of the existing district heating. The district energy system can be holistically optimized to enable carbon neutrality and load balancing.



Helsinki's Hot Heart Energy Management System Diagram

1.8
ENERGY CONCEPT FOR 2029
AI, ANALYTICS, AND CONTROL

Heat demand response of end users

Additional benefits can be achieved by optimizing heat usage in Helsinki's apartment buildings. The main benefits of this approach include reduced total heat demand, smaller heating power peaks, and resiliency of the district heating network.

Such benefits can be achieved from day one while Helsinki's Hot Heart is still being built. The proposed optimization method is based on widely used and proven technologies and hence carries little risk.

The district heating utility, Helen, could update the energy contracts of its customers and install control equipment at substations. The equipment gathers data and enables remote control of heating. AI and machine learning algorithms can then control and optimize the heat usage in the district heating network.

Benefits for building owners include reduced energy consumption and a positive image coming from the participation in the transition to carbon neutrality. At the same time, better real-time knowledge of the heating substations allows the district heating utility to operate the network more efficiently.

Also, it would be possible to perform predictive maintenance beforehand to improve the network's resiliency. In case of emergency, the utility can prioritize repairs, activate contingency boilers, and notify the customers on what procedures to take to minimize the risk of damage to their buildings. Furthermore, data allows the utility to optimize the temperature in the network—hence improving efficiency and reducing cost and emissions.

Initially, the reduced overall energy demand will immediately reduce carbon emissions while coal is still in use. Later, it will reduce the capacity needs of Helsinki's Hot Heart. Similarly, when power peaks are shaved, the need for biomass based peak boilers will be reduced. In short, such investment would be very competitive against current and future investment opportunities in energy efficiency, peak power generation and resiliency.

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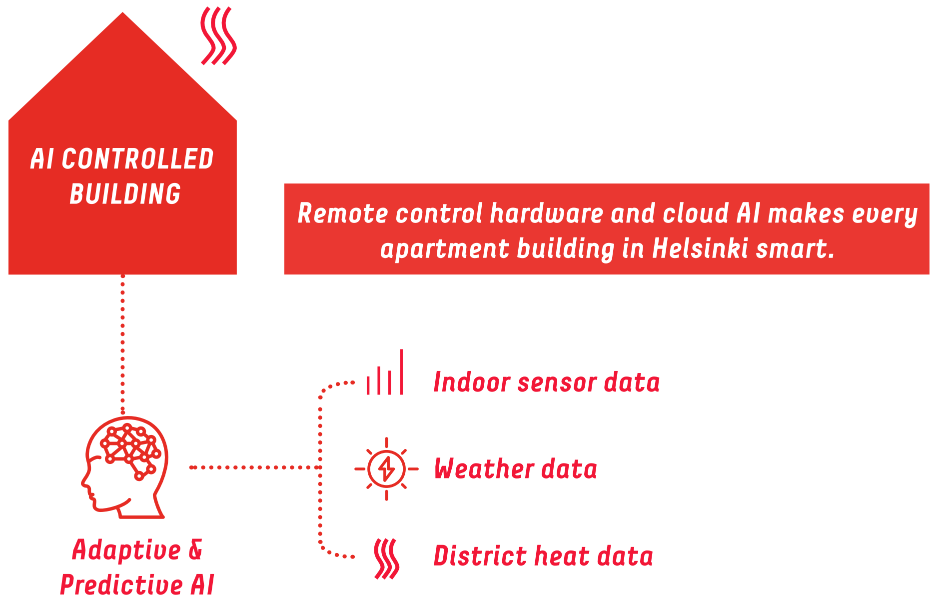


System Diagram for Building with AI-Controlled Heat

Quantity of Apartment Buildings in Heat Remote Control	100% 12,000	50% 6,000	30% 3,600
Estimated Yearly Energy Savings (GWh)	420	210	126
Savings compared to 2035 Consumption (6,000 GWh)	7.4%	3.7%	2.2%
Peak Power Savings (MW)	480	240	144
Total one-time Investment Cost Estimate (million Euros)	€ 18.0	€ 9.0	€ 5.4
Yearly Operating Cost (million Euros)	€ 3.0	€ 1.5	€ 0.9
Price for Saved Energy - 10 year life time (Euro per MWh)	€ 9	€ 9	€ 9
Price for Saved Peak Power (Euro per MW)	€ 18,750	€ 18,750	€ 18,750
CO2 Emission Reduction (t) - Helen heat 2019: 198 g/kWh	83,160	41,580	24,948

Data Projections based on Percentage of Helsinki Apartment Buildings in Heat Remote Control
Source: Helsinki's Hot Heart team

1.9

HELSINKI'S HOT HEART AS WORLD-CLASS ATTRACTION

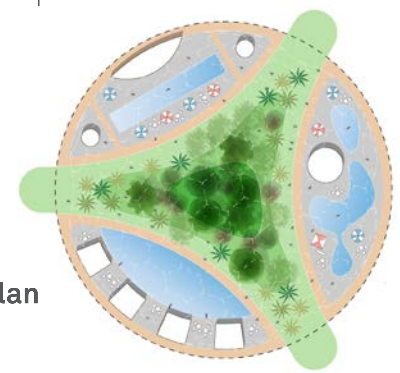
A FLOATING TROPICAL FOREST BECOMES A NEW DESTINATION FOR LOCALS AND TOURISTS

Helsinki's Hot Heart is an unprecedented infrastructure that will allow the city to achieve its ambitious carbon neutrality goals. However, it can also do double-duty as an exciting, engaging attraction for locals and tourists alike. It will become a new type of urban experience, which will cement globally Helsinki's leadership in innovation and ingenuity and contribute to the wonder and joy of being in the city.

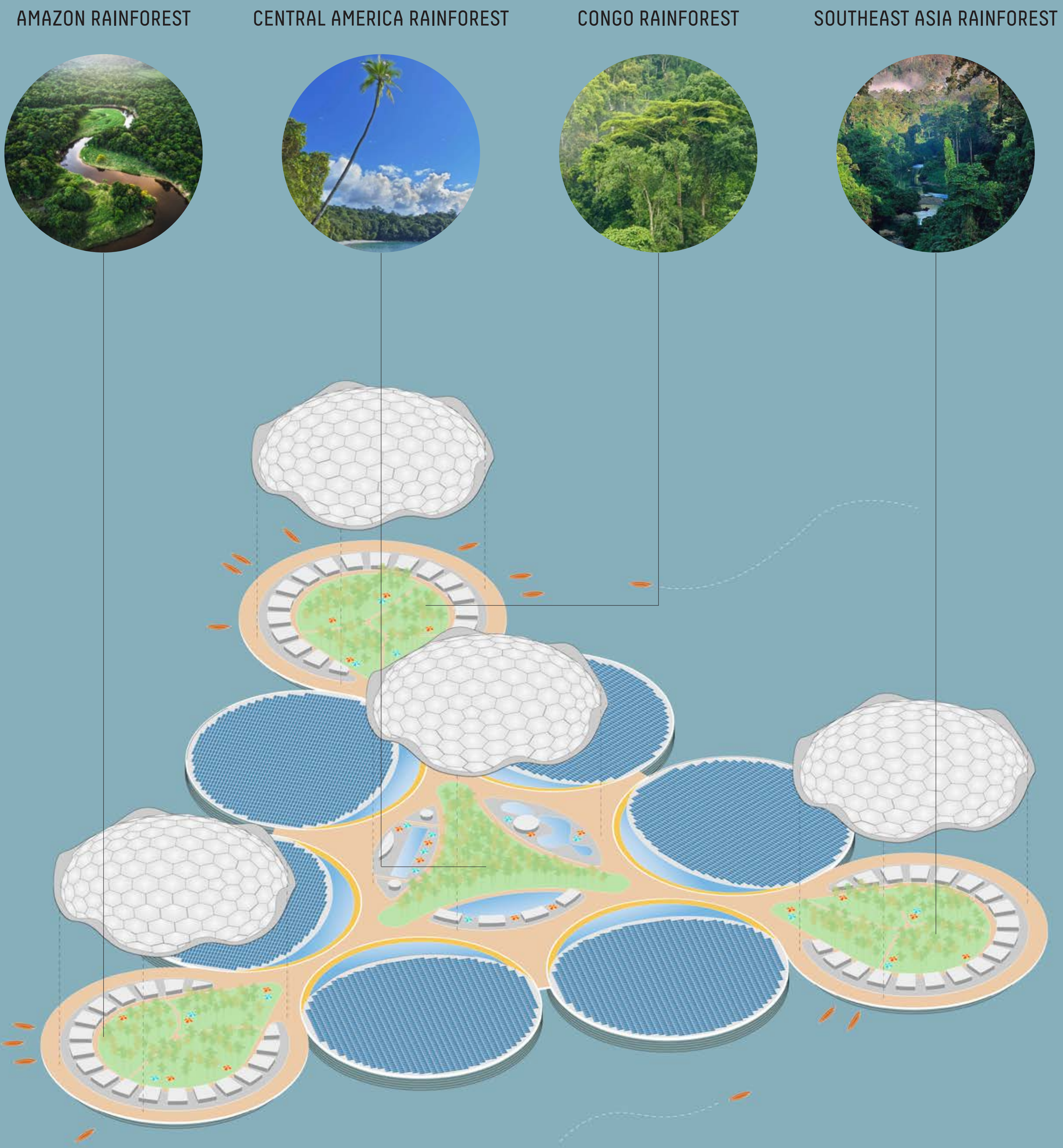
We envision that four of the ten proposed 225 m diameter storage basins would be each covered by a dome to create a climate-controlled environment that we call the "Floating Forests". Each of these four domes would contain a year-round tropical forest—one each from four key rainforest zones of the world (Amazon, Central America, Congo, Southeast Asia). Visitors would spend the day exploring and bathing in pools, immersed in the climate and vegetation from faraway tropics.

These domes would provide an important service to local Helsinki citizens as a way to experience warmth, light, and a change of scenery during the long, cold winter months. For tourists (in all seasons of the year), the Floating Forests would be a fun and engaging attraction. The use of so-called sun-like LEDs, which emit with the same spectrum of solar light, could also provide much-needed exposure to sunlight during the cold winter months.

The simple pleasures of "island life" have been long praised by Finnish writers and authors, as in Tove Jansson's famous "Summer Book". Helsinki's Hot Heart project imagines a new place where people can live and roam amidst nature, in harmony and peace, bringing about a new vision for Finland's life in public spaces, as enrishined in the country's everyman's right ("Jokamiehen Oikeudet"). In addition to the forests and hot pools, there could be saunas, huts, a museum and a research center on the future of sustainable energy. Helsinki's Hot Heart could become a global tourist destination—one based on silence and respect of nature.



Rainforest Dome Plan

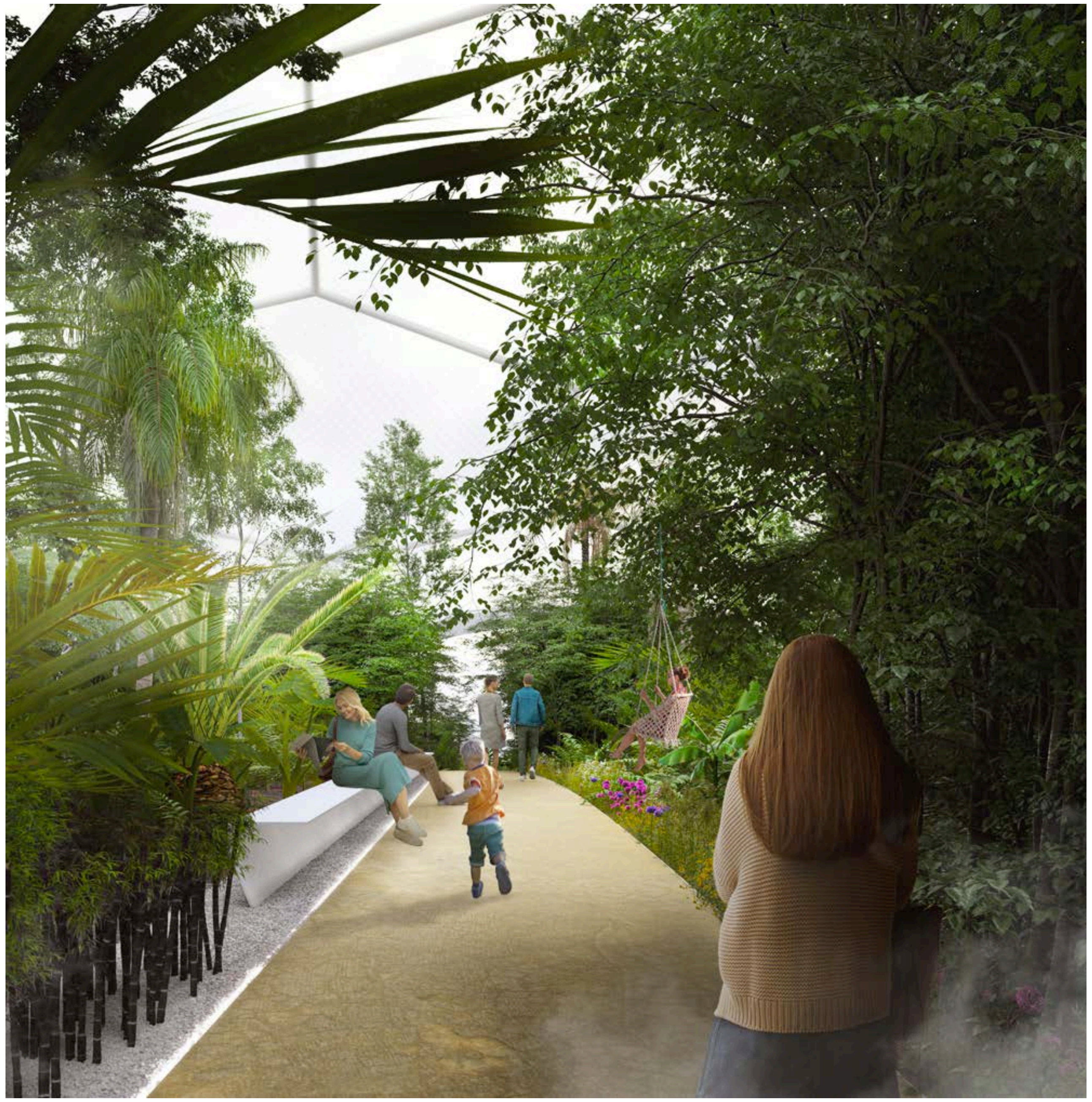


Exploded Axonometric View

1.10

HELSINKI'S HOT HEART AS WORLD-CLASS ATTRACTION

A FLOATING TROPICAL FOREST BECOMES A NEW DESTINATION FOR LOCALS AND TOURISTS



The domes on Helsinki's Hot Heart that would add a significant financial benefit to the city in both direct and indirect revenue. While this revenue has not been included in our financial calculations, it has been estimated as several hundred million Euros per year. For all people, the opportunity to visit Helsinki's Hot Heart would also be of educational value so they can learn about energy and how the city has made its way to carbon-neutrality.

1.11
HOLISTIC ENERGY CONCEPT FOR BEYOND 2029
SCHEMATIC CONCEPT

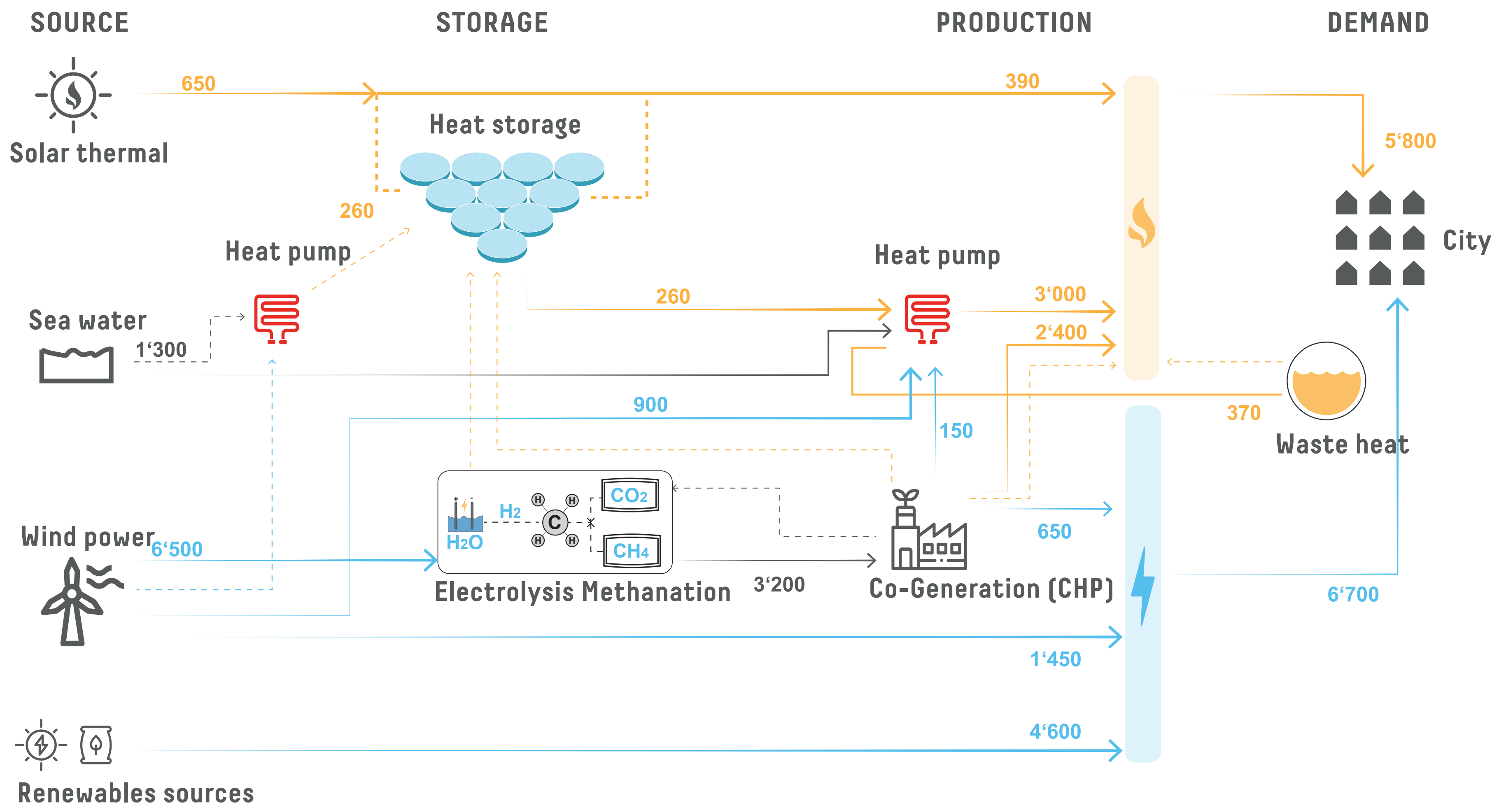
The system described above contains all the elements to generate carbon-free heat at a price lower than today. Still, this section integrates Helsinki's Hot Heart within a holistic reflection and proposes renewable energy technology add-ons in order to integrate electricity production and flexibility of supply. We will focus in particular on the following two points.

First, instead of a Power Purchase Agreement to buy electric energy, we could build a dedicated wind farm. The feasibility study has been done with one of the top utilities in the world and is summarized below. Second, while the storage of electric energy is still very expensive, new systems based on Power-to-Gas (P2G) are being developed and could become competitive by the end of the decade. We have tried to include them as possible long-term add-ons.

Dedicated wind farm

As an additional possibility for adding to the holistic post-2029 energy vision for Helsinki, we have explored the possibility of a new wind farm which is dedicated to providing the electric energy for Helsinki's Hot Heart's heat pumps. Such an approach could be an alternative to the Power Purchase Agreement discussed above.

The new wind farm would most likely be located on the west coast or in the north of Finland. Considering Finland's current wind farms and average resource availability, we estimate a wind capacity needed to be developed around 700 MW (approximately 140 wind turbine generators) to provide the energy needed by the heat pumps.



System Diagram for Holistic Concept for Beyond 2029 [1]

Electric energy storage

The implementation of hydrogen production and optionally methanization, completed with a co-generation process (which would be used as CO2 source) opens the opportunity to support both the heating system and electricity grid independently from the temporal fluctuation of the renewable source availability. Indeed, wind energy excesses are stored as gas, which, when needed, is in turn used for powering a Combined Heat-and-Power plant.

Such an approach would contribute to decarbonizing other sectors—such as mobility and industrial sectors—using existing gas infrastructure for the transport of renewable methane.

Together with Helsinki's Hot Heart heat storage and other electricity storage technologies available in decentralized and smaller scales, this would bring Helsinki comprehensively in a cross-sectorial way towards a climate-positive future.

[1] Based on approximation of total heat and electricity required for Helsinki. Unit: GWh

1.12
EVALUATION CRITERIA
CLIMATE IMPACT

Heat generation in 2029 will entail zero carbon emissions. Electricity for heat pumps will be generated primarily from wind, either through a Power Purchase Agreement or through a newly constructed wind park. Partial use of other carbon-neutral electricity and heat sources is also envisioned, as discussed in the section related to different energy mixes.

Climate impact of operations

The competition material estimates carbon emissions of electricity in 2030 at 30 kgCO2 per MWh. Through the approach discussed above, the CO2-emissions would be reduced from the competition estimates. This would occur in particular though a Power Purchase Agreement to buy wind power only/partly or building an ad-hoc wind park.

The wastewater and seawater heat pumps need approximately 2,300 GWh per year of electricity. If the capacity of the newly constructed wind park is 700 MW, 70% of the electricity needed (1,600 GWh per year) will be generated with wind power and 700 GWh per year can be bought from the electricity market. The wind park would generate 2,300 GWh per year electricity, and 30% of it would be sold to the electricity market. Therefore, the net carbon impact of the electricity would be zero.

If the CO2-emissions of electricity bought on the market are considered, we get 23,000 tons per year of CO2, i.e. 3.9kg CO2 per MWh of heat generation. The total annual CO2 savings of Helsinki's Hot Heart are estimated to be 1,188,000,000 kg of CO2. Our 6,000 GWh carbon-neutral thermal energy compares favorably with the current district heating production and its average emissions of 198 kgCO2 per MWh of district heating.[1]

Climate impact of construction

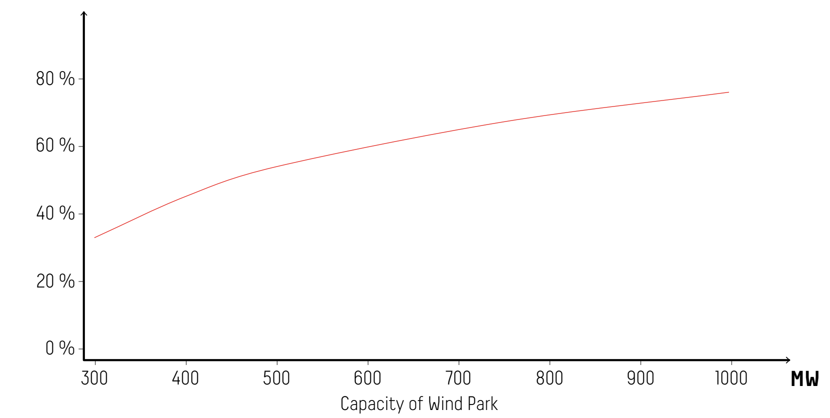
The estimated emissions from the main construction materials are presented in the following table. The crushed stone used for the construction of the storage option that is excavated into the seabed is considered carbon neutral. The estimation doesn't include emissions from construction work; this will be analyzed further during the actual design phase as well as the embodied emissions of different technical systems like the heat pumps.

According to a recent study at Tampere University, the average life cycle for an onshore wind farm is estimated to be 11.2g per kWh per year. With 2,300 GWh per year electricity required, the wind farm's life cycle emissions are 25,760,000 kg CO2 per year or 644,000,000 kg CO2 for the whole life cycle. The overall estimation shows that the construction-related emissions can be covered with one year's CO2 savings gained from Helsinki's Hot Heart.

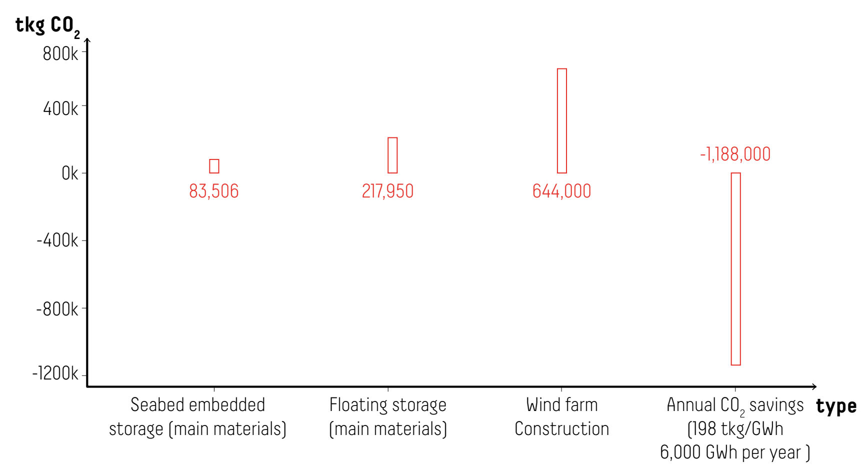
[1] "Specific emissions of energy ". Helen. Accessed 17 January 2021. https://www.helen.fi/en/company/energy/energy-production/specific-emissions-of-energy-production

Climate impact of 'Holistic Energy Concept for Beyond 2029'

The holistic concept Helsinki's Hot Heart and add-ons are anticipated to be completely climate neutral, as this is the exact purpose of considering a holistic energy concept. This concepts do not only target a sustainable heat supply for the district heating of Helsinki as a replacement from the coal Combined Heat-and-Power (CHP) plant, but also recognize the fact that, by turning down coal CHPs, a certain amount of electricity also has to be replaced, as well as the fact that, heat pumps might require electricity during times of low wind. Therefore, it proposes add-ons in the form of a power to gas installation, coupled to a cogeneration plant, in order to store the excess wind power. This system is then able to produce heat and power in a very flexible way and to provide renewable heat and electricity to the city, even when the wind is still.



Share of Wind Power
Source: Helsinki's Hot Heart team



Estimated Emissions by Material
Source: Helsinki's Hot Heart team

Key Material		Seabed Embedded Storage		Floating Storage	
	Emissions rate [kg CO2/m^3]	Volume [m^3]	Emissions [tkgCO2]	Volume [m^3]	Emissions [tkgCO2]
Steel	12,000	13	150	12,450	149,400
Concrete	600	137,000	82,200	110,200	66,120
Insulation	2	520,500	1,156	1,094,400	2,430
Crushed Stone	0	2,128,743	0	0	0
Total			83,506		217,950

Estimated Emissions by Material
Source: Helsinki's Hot Heart team

1.13
EVALUATION CRITERIA
IMPACT ON NATURAL RESOURCES

Artificial Islands

No fuels or materials are needed during operations. The impact of building Helsinki's Hot Heart needs to be carefully assessed. However, we believe that any impacts will be rather limited and local. Several artificial islands have been planned in the Baltic sea and some of them are currently being built after careful assessment of their impact on natural resources.

For instance, the City of Espoo, not far from Helsinki, is planning the new residential area of Finnoonsatama for15,000 inhabitants to be built on an artificial island. An environmental impact assessment for Finnoonsatama is publicly available (over 300 pages)[1] and no major environmental challenges have been identified. The study investigated the impact of building the artificial island on, for example, master planning, people, traffic, noise, emissions, climate, people, ground, seabed, ecosystems, animals, plants, insects and cultural issues, etc. Finnoonsatama is located 14 km from our planned heat storage location.

1 https://www.ymparisto.fi/fi-FI/Asiointi_luvat_ja_ymparistovaikutusten_arviointi/Ymparistovaikutusten_arviointi/YVAhankkeet/Finnoon_sataman_ruoppaus_taytto_ja_lajitys_Espoo/Finnoon_satamaalueen_rakentaminen_Espoo(17077)

The energy storage will be built in the sea as an artificial island or as a floating solution. Therefore no existing land area is needed. The surface area of the storage is approximately 400,000 m^2. We do not anticipate major environmental concerns related to Helsinki's Hot Heart, although its exact location will have to be carefully selected based on the environmental considerations.

With the excavated basin option, the excavated seabed material will be used to build the walls of the storage. If the use of the storage would someday be discontinued, the wall material could be put back to the sea bottom where it was taken, according to circular economy principles.

Local Cooling in Seawater

The cooling of seawater, as a result of the operation of heat pumps, will only have a very minor impact on the marine ecosystem. The heat pumps decrease the temperature of the water very locally and only 1-2 °C especially in winter. The outlet water of heat pumps will be mixed to the sea water and therefore the temperature impact is minor. Condensing power plants heat the sea remarkably more.

Again, we believe that this could be addressed in a similar manner to how it has been addressed in already-built systems (such as the Stockholm one mentioned above) or in other examples under planning such as the Helen tunnel.

Impact on natural resources for 'Holistic Energy Concept for Beyond 2029'

In this concept, hydrogen is being created through electrolysis and then turned to methane through methanation. This last step enables the use of the existing gas network for gas (methane) transport. In the process of electrolysis, H2O (the source of hydrogen) is being split using electrical energy coming from excess wind power, a renewable energy. Finally, in order to create methane, CO2 from the co-generation plant is used and so the CO2 circle is closed: the emissions produced by burning the renewably sourced methane is used for creating this methane. A cogeneration system based on renewably-sourced methane allows the avoidance of systems relying on biomass, for which culture is necessary, as the necessary resources for operation are simply water and wind.

1.14
EVALUATION CRITERIA
COST IMPACT - CAPITAL EXPENDITURE

The cost of Helsinki's Hot Heart overall system consists of the following main items: heat storage, heat pumps, tunnels, and electricity connections. The system can be optimized by adding solar thermal and/or PVs, although they are not essential. The total investment cost estimation is 940 million Euros.

Storage (10,000,000 m³)	€ 200,000,000
Heat Pumps (300 MWe)	€ 420,000,000
Solar Thermal	€ 20,000,000
Tunnels (25 km)	€ 100,000,000
Electricity Connection	€ 50,000,000
Other and reserves	€ 150,000,000
Total	**€ 940,000,000**
4%, 25 Years	60,171,245 Euro per year
	10.03 Euro per MWh

Helsinki's Hot Heart Investment Cost Estimation (VAT 0%)
Source: Helsinki's Hot Heart team

Marstal (75,000 m³)	Cost (1,000 Euro)	Euro per m³
Excavation	601	8.0
Side and bottom liners	180	2.4
Lid	1,069	14.3
In and outlet	172	2.3
Water and water treatment	195	2.6
Pipes and heat exchanger	413	5.5
Total	**2,630**	**35.1**

Comparison: Cost of Storage in Marstal (SUNSTORE 4)
Source: Kallesøe, A.J. & Vangkilde-Pedersen, T. (eds). 2019: Underground Thermal Energy Storage (UTES) – state-of-the-art, example cases and lessons learned. HEAT-STORE project report, GEOTHERMICA – ERA NET Cofund Geothermal. P109,P110.

Investment in the storage

Detailed construction solutions of the storage system can be selected in detail during the next phase. However, the costs of existing pit heat storages are publicly available. One of the most expensive parts of the investment is the floating insulation on the top of Helsinki's Hot Heart storage.

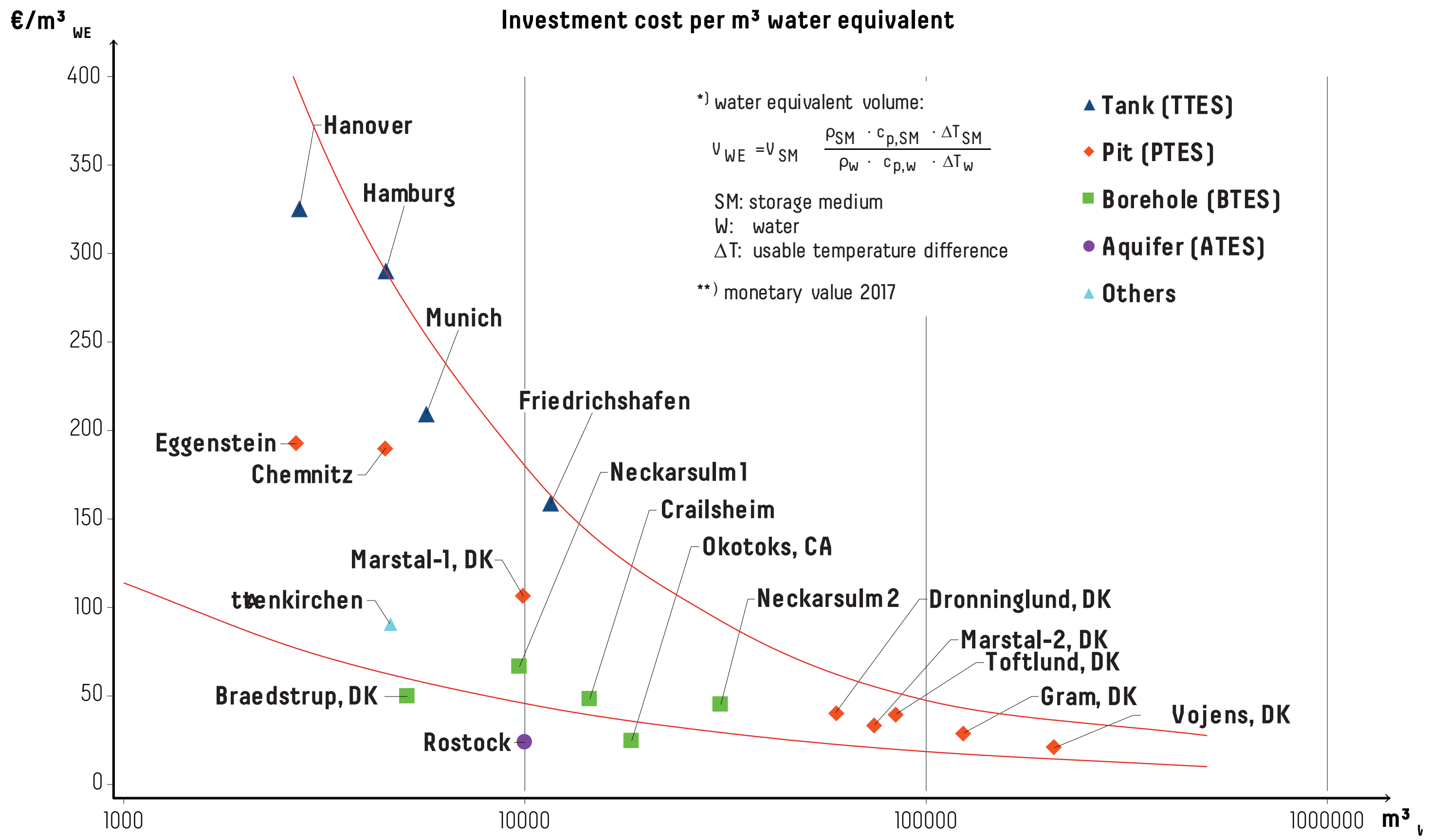
The investment cost of existing large pit heat storages has been 20-40 Euros per m³. Construction at the sea will be more expensive than on land, but most excavation work will not be needed thanks to the presence of the sea. For the excavated solution, only 5 m out of 25 m must be removed, and the resulting material could be used as the wall material of the storage

The realistic investment cost for the storage would be 20 Euros per m³, so a 10 million m³ storage would cost 200 million Euros.

Investment of heat pumps and other items

Heat pumps: the investment cost of heat pumps is well known, and it is approximately 560 Euros per kW (thermal). The investment costs also includes the required automation systems of each technology as well as the construction and integration of the predictive energy management system. Electricity is likely not available there with 300 MW capacity, so the grid must be improved.

Seawater tunnel: 20-30 km long tunnels are needed to exchange seawater and to contain district heating pipelines and electrical cables. The cost of tunnels with equipment is approximately 4000 Euros per meter.



Cost Comparison of Global Heat Storage Projects
Source: SOLITES 2019

1.15
EVALUATION CRITERIA
COST IMPACT - OPERATING EXPENDITURE

Heat generation costs for 6,000 GWh per year in the existing heat generation system are approximately 165 million Euros. The heat generation costs of our proposed solution is 70 million Euros per year—95 million Euros less expensive than current heat generation and 80 million Euros less expensive than a fully biomass-based solution.

Personnel costs and other operational costs of the heat pumps and storage are remarkably lower than Combined Heat-and-Power (CHP) plants currently have. However, the cost impact is estimated to be zero. Typical Capex costs of heat pumps are estimated to be 1.5 % of the investment, and other O&M may cost 0.5 Euros per MWh, but the CHPs being replaced have higher costs.

The table includes estimated heat generation costs. Costs are based on a solution of 10,000,000 m^3 heat storage and 300 MWe heat pump without the use of biomass. The total energy generating costs would be 70 million Euros per year without capital costs and the average cost of generated heat would be 11.6 Euros per MWh.

Cost of electricity

Most of the heat will be generated with heat pumps using electricity. The electrical tax for heat pumps generating district heat will be 0.5 Euros per MWh in 2022. The electrical grid cost of Fingrid is 8.80 Euros per MWh from December through February between 7:00 and 21:00, Monday through Friday. At other times, the cost is 2.50 Euros per MWh. Because of the high electrical capacity, the heat pumps would be connected to the grid of Fingrid instead of the grid of Helsinki.

The price of the electricity can be secured at least partly with wind Power Purchase Agreements, so that wind electricity from constructed wind parks would be bought in advance. The current Power Purchase Agreement price level is 25-30 Euros per MWh and the realistic price level at the end of the 2020s decade is likely 20-25 Euros per MWh. Thanks to the seasonal heat storage, the heat pumps do not need to be used during the highest electricity prices.

Wastewater heat pumps will be used all the time and the use of them cannot be adjusted based on the electricity price. Therefore, the electricity price is estimated to be 40 Euros per MWh on average.

Seawater heat pumps can be utilized when low cost electricity is available and can avoid the highest electricity prices. The average price of the electricity for seawater heat pumps is estimated to be 30 Euros per MWh including the grid cost of Fingrid and the electrical cost in addition to the energy.

Wastewater heat pumps utilize approximately 15-20 °C wastewater as a heat source. The average efficiency (COP) of the heat pump is estimated to be 3, but could be also higher. Wastewater heat pumps generate 900 GWh per year heat and consume therefore 300 GWh electricity per year. The cost of electricity is approximately 9 million Euros per year..

Seawater heat pumps utilize a 3 °C heat source in Winter and a 20 °C heat source in summer. The average efficiency (COP) is 2.5. When the heat pumps generate 5,000 GWh per year heat, they consume 2,000 GWh per year in electricity. The cost is approximately 60 million Euros.

Current heat generation cost

Based on the open district heating purchase prices, the heat generation cost with the current production structure would be 165 million Euros per year (27.6 Euros per MWh) and with biomass only 150 million Euros per year (27.5 Euros per MWh).

Electricity for wastewater HP	9,000,000 Euro per year
Electricity for seawater HP	60,600,000 Euro per year
Biomass	0 Euro per year
Personnel costs	0 Euro per year
O&M	0 Euro per yearr
Total	**69,600,000** Euro per year
	11.60 €/MWh

Helsinki's Hot Heart Heat Generation Cost (VAT 0%)
Source: Helsinki's Hot Heart team

Season	Period	Purchase Price Euro per MWh, 0% VAT	Price Coefficient of the Energy Fee for District Heat
Winter	**1/1 - 28/2/2021**	**37.95**	**70%**
Autumn	1/10 - 31/12/2020	28.22	55%
Summer	1/5 - 30/9/2020	11.25	40%
Spring	1/3 - 30/4/2020	25.08	50%

Heat Purchase Prices of Helen
Source: Helen

1.16
EVALUATION CRITERIA
IMPLEMENTATION SCHEDULE

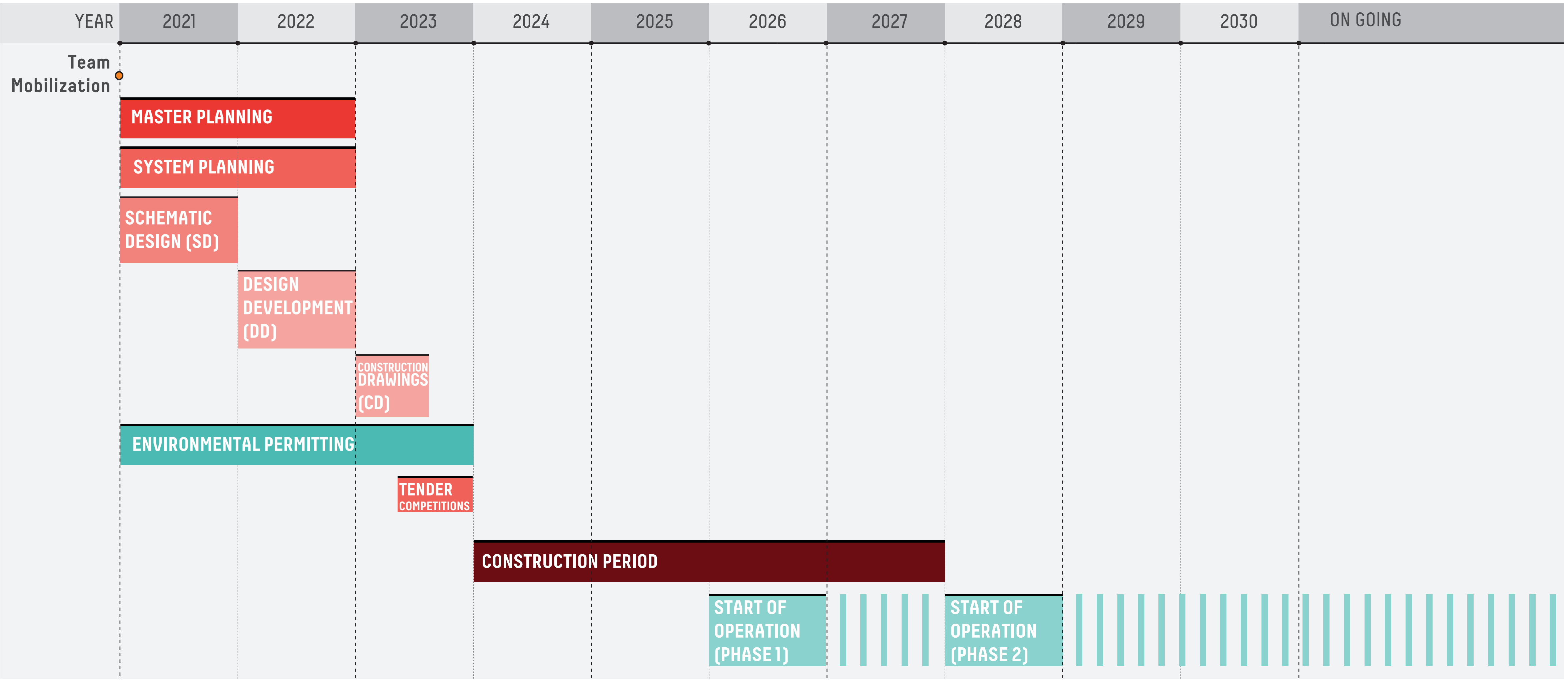
The solution can be implemented fully by 2028—two years in advance of the competition goal! The system is also built from modules (smaller heat storages and heat pump plants) which could be brought into use even earlier than 2028. With the use of biomass and natural gas, the coal could be replaced already in 2026, giving a four-years buffer for the time schedule.

The first phase of storage and heat pumps are estimated to be brought into use in 2026. Already with the first phase, the use of coal can be replaced; therefore, there is three years of buffer in the time schedule to replace the use of coal in 2029. The aim is to also replace the use of natural gas and biomass in 2028 with phase 2 of the storage and heat pumps.

Risk assessment of the schedule

The biggest risk in the time schedule is permitting. Because of the influence of the city of Helsinki, and the fact that the environmental impact of the system is minor, the time schedule estimated is realistic.

From the technical point of view, the time schedule is plausible, and gives a good margin for unexpected challenges, e.g in the permitting phase.



Anticipated project schedule

1.17
EVALUATION CRITERIA
IMPLEMENTATION FEASIBILITY

The investment estimation for the system is 940 million Euros and annual heat generation costs are 95 million Euros less expensive than currently. The payback period of the solution is 12.8 years (4% interest rate), making the system totally fuel and CO2-emission free. In addition to its financial feasibility, we believe that the solution is very feasible from a technological, legal, permitting, and cultural point of view.

Technological feasibility

The heat storage and heat generation can be built with fully-proven and commercial technologies. The technology of existing pit heat storages can be utilized, and seawater heat pumps are already commercially used. We are using proven technologies, just at a bigger scale. There would also be the possibility to improve the solution even further during the planning phase of the project.

Financial feasibility of Helsinki's Hot Heart

The aim of Helsinki's Hot Heart is to replace Helsinki's current district heating production units with a new, zero-emission storage solution and at the same time gain 10% lower production cost, which can enable a 10% lower selling price for district heating compared to the current situation. The cash flow based on heat storage only should be enough to cover the construction and operating costs, including financing. Additional possibilities relating to base load equalization in the national grid and a tourist attraction that can be built on Helsinki's Hot Heart concept would be providing an additional cash flow bonus.

Investment	940,000,000 Euro
	60,171,245 Euro per year
Annual Costs	69,600,000 Euro per year
Total Cost	129,771,245 Euro per year
	21.63 Euro per MWh
Difference to current cost	**35,228,755 Euro**

Helsinki's Hot Heart Total Cost (VAT 0%)
Source: Helsinki's Hot Heart team

The financing could be structured either a) a traditional way, i.e. Helen would take the loan to its balance sheet or b) using a PPP-structure, In the PPP-structure, an SPV company would take the responsibility of building and operating Helsinki's Hot Heart and a service agreement with the city of Helsinki (and/or Helen) would then secure the cash flow for the SPV to be able to fulfill its financial and operational obligations during the service period. We think that a PPP-structure would attract a vast scale of international investors to take part in the financing, especially since the operations of Helsinki's Hot Heart would easily fall into the category of "green financing". In addition to traditional bank financing, also EIB/NIB involvement and/or bond market could be potential sources for financing. This is especially true considering the current low interest levels: we see that the overall financing cost would be very feasible, taking into account the importance of finding the most efficient and ecological district heating system for the biggest city of Finland.

The average energy price of district heat in Helsinki has been 51.05 Euro per MWh (VAT 0%). Including the capacity fee, the average selling price of heat has been approximately 65.3 Euro per MWh (VAT 0%). Including all CAPEX and OPEX costs, the proposed solution of heat generation is approximately 6 Euro per MWh cheaper than now. When all other costs would be the same, we could provide heat to the customers approximately 10% less expensive than currently.

Legal feasibility

The solution will not need changes in the current legislation. The heat storage will need environmental and water permits, but artificial islands have already received permitting in the Baltic sea without any major environmental issues.

Administrative feasibility

The system must have an environmental permit and a water permit. Permitting can be done by current permitting procedures. The city of Helsinki can play a role in the process.

Cultural and ethical feasibility

The impact of the proposed system to cultural and ethical issues is very limited, but the impact could be also very positive due to the attractions on the storage. They can be remarkable tourist attractions, bringing new income streams to Helsinki and promoting Finnish values.

Other relevant feasibility aspects

The system has a very positive impact on the whole power system of Finland and it enables the construction of a high amount of new wind power generation in Finland.

All the district heating systems in Finland use fossil fuel at least at peak capacity. Energy storage as in Helsinki's Hot Heart could be used in all district heating systems in Finland to replace the use of fossil fuels in peak heat generation. All district heating systems also abroad have the same kind of challenges related to heat load variation and therefore this kind of solution could be implemented in many places throughout the world, especially since most cities are built near large bodies of water.

Utilizing the predictive energy management system, Helsinki's Hot Heart also has a possibility to work as a load balancer for the electrical grid. Currently the Fingrid frequency containment reserve for normal operation values 30 MW of flexible load at ~1.5 -3.0 million Euro per year (4,380-8,760 active hours) depending on the time at which the system is active on the market. The heat pump system of Helsinki's Hot Heart will be designed and sized in a way that maximizes the balancing load. Due to the large amount of potential load, the connection to the relevant markets (frequency containment reserves, balancing energy or others) will be determined together with Fingrid during the master planning.

Feasibility for 'Holistic Energy Concept for Beyond 2029'

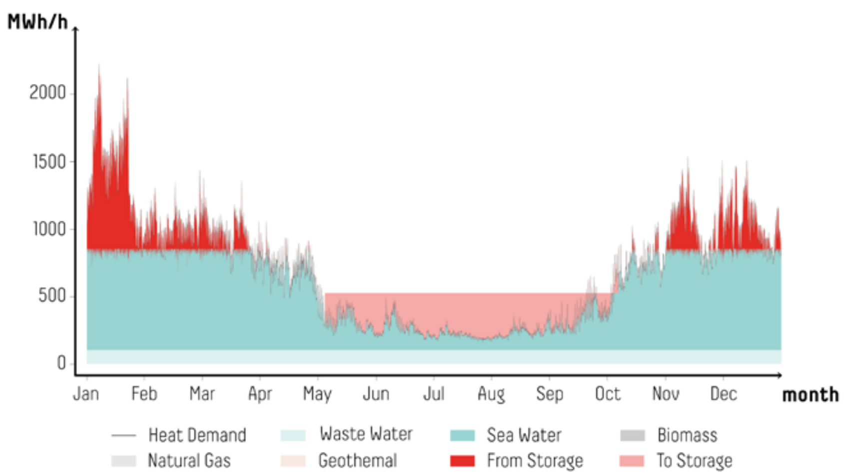
Our proposed solutions are already proven in numerous very different projects, ranging from apartment buildings to central energy systems. The technology can easily be scaled up. To quote Armin Schnettler, executive vice president of New Energy Business at Siemens Gas and Power: "There are no limits to the size of Power-to-Gas plants". In 2020 already, the planning of a Power-to -Gas installation with an electrolysis power of 600 MW was announced.

1.18
EVALUATION CRITERIA
RELIABILITY AND SECURITY OF HEAT SUPPLY

We anticipate that the heat supply will stay 100% secured with the proposed solution. Heat generation is based on heat pumps. There will be several parallel heat pumps, so the possible malfunction of one heat pump would not have a sizeable effect on heat generation. Heat pumps are also very reliable, and during summertime there is plenty of time for maintenance.

Electricity supply should be secured from at least two lines. However, the storage will have heat capacity always available and heat can be taken from the storage for times when some of the heat pumps or electricity might not be available.

The district heating system of Helsinki would also have existing natural gas fired peak boilers and biomass fired boiler plants as backup capacity. Therefore, the heat can be delivered in all circumstances. Additional back-up capacity is not needed and some of the existing back-up boilers could be taken out of service if needed, thanks to the heat capacity of Helsinki's Hot Heart.



District Heat Generation, Case 1
Source: Helsinki's Hot Heart team

Technical risk

The storage can be built with the same, very low risk of pit heat storages. There will also be additional possibilities to improve the solution during the actual planning phase of the project.

Operational risks

The heat storage and heat pumps will be built in many modules, so the malfunction of one module would not have a major impact on the operation of the system. However, there would still be back-up boilers available if something very unexpected would happen. Therefore the operational risks are significantly lower than they currently are.

System-level risks

The basis of the proposed system is very simple, but the operation of it can be optimized with AI-based solutions. The system is very flexible to accommodate future solutions, which could be most feasible in the 2030s or 2040s.

Risks associated with the supply and storage of respective fuels (and electricity if relevant)

The system does not need fuels and the supply of electricity can be secured with two separate power lines.

Capacity risks

The storage enables the capacity of new fossil-free heat generation to be 700-800 MW instead of approximately 2000 MW. It is easy to plug-in a variety of cost-efficient heat sources to the system and therefore the capacity cannot be seen as a risk.

1.19
EVALUATION CRITERIA
CAPACITY

The solution would consist of 10,000,000 m^3 heat storage, called Helsinki's Hot Heart. Seawater heat pumps with 750 MW heat capacity and existing waste water heat pumps. The storage and heat pumps can be implemented as modules enabling the optimization of the system in the future as well.

The unloading capacity of the heat storage should be 1,500-2,000 MW. Because of the high heat capacity, the storage must be connected to Salmisaari and Hanasaari power plants to enable appropriate heat distribution. The heat will be transferred from the heat storage to Salmisaari with district heating pipelines mounted inside a tunnel. A tunnel for district heating pipelines would also be built from Salmisaari to Hanasaari. The storage and heat pumps can be constructed in stages once the permitting issues are solved.

Without the heat storage, the heat capacity of the new fossil-fuel-free heat generation should be approximately 2,000 MW, not depending on the heat generation source. Helsinki's Hot Heart gives huge flexibility for what the heat sources could be, and the capacity of new fossil-fuel-free heat generation can be limited to approximately 700-800 MW depending on the size of the storage as shown in the figure.

Capacity of 'Holistic Energy Concept for Beyond 2029'

The concept considers a Combined Heat-and-Power (CHP) powered by renewably-sourced methane, therefore having the full flexibility of standard CHP. Through Power-To-Gas storage, the variability of renewable energy production is dampened. Indeed, excess wind power is being used to produce gas, which can be then easily stored and used to power the CHP whenever direct production from renewable (but variable) energy from wind or solar is not able to supply the demand. Alternatively, or should the gas storage be full, renewably-sourced methane can also be fed within the existing gas network.

1.20
CONCLUSION

Helsinki's Hot Heart in a Nutshell

- An innovative, cutting-edge system for district heating
- Completion planned by 2028, 2 years ahead of schedule
- 6,000 GWh/yr heat produced with zero carbon emissions
- Cost per heat MWh reduced by 10% compared with today
- Bonus: contributing to load balance the whole Finnish grid
- Four floating tropical forests as a new global attraction and public space
- Price tag: 940 million Euros, with a payback time of 12.8 years
- A solution for cities all over the world—the "Helsinki Model"

"The simple pleasures of "island life" have been long praised by Finnish writers and authors, as in Tove Jansson's famous "Summer Book". Helsinki's Hot Heart project imagines a new place where people can live and roam amidst nature, in harmony and peace, bringing about a new vision for Finland's life in public spaces, as enrishined in the country's everyman's right ("Jokamiehen Oikeudet"). In addition to the forests and hot pools, there could be saunas, huts, a museum and a research center on the future of sustainable energy. Helsinki's Hot Heart could become a global tourist destination—one based on silence and respect of nature."

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