Large heat storages in future energy systems

Rock Cavern Hot Water Accumulators

FUTURE ENERGY SOLUTIONS CONFERENCE 2022

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AFRY at a glance

INDUSTRIAL & DIGITAL SOLUTIONS

Advanced Automation
Connected Products
Automotive Design & Engineering
Food & Pharma
Specialized Technical Services
Systems Management

PROCESS INDUSTRIES

Bioindustries
Chemicals
Pulp, board, paper & tissue
Mining & Metals
Smart solutions:
– Health & Safety
– Sustainability
– AFRY Smart Site & digitalisation

ENERGY

Renewable Energy & Thermal Power
Hydro
Transmission & Distribution
Nuclear
Contracting

INFRASTRUCTURE

Transportation
Buildings
Project Management
Water
Environment
Architecture & Design

MANAGEMENT CONSULTING

Energy Sector
Bioindustry Sector
Market Analysis
Strategic Advice
Operational Excellence
M&A and Transactions

AFRY X

Digital Services:
- Analytics, AI & Big data
- Cyber Security
- Design
- Software dev’t & integration
- Digital Quality
Digital Products
Digital Advisory

WE HAVE

17,000

Employees globally (as of 2021)

WE HAVE APPROX. NET SALES

20 bsek

in 2021

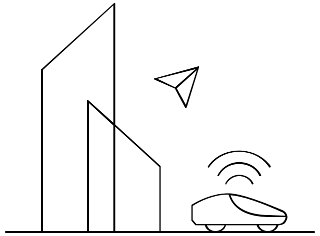
NUMBER OF COUNTRIES WITH OFFICES

>40

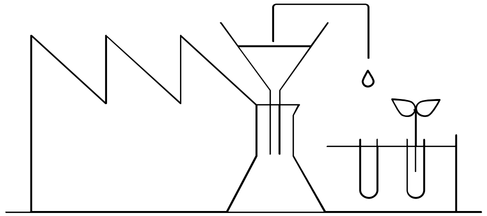
NUMBER OF COUNTRIES WITH PROJECTS

>100

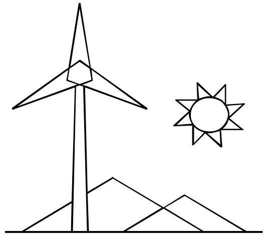
4 Growth Drivers



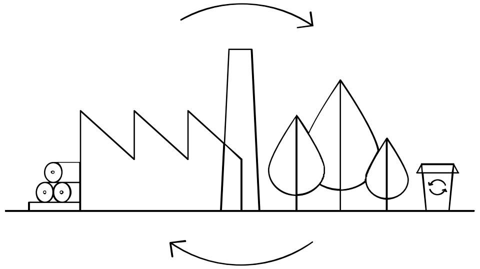
Infrastructure



Food & Life Science



Clean Energy



Bioindustry

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TRANSPORTATION FINLAND

—Unit of 250 experts in Finland

Three market areas

- ROCK ENGINEERING & UNDERGROUND SPACES
- INFRASTRUCTURE SERVICES
- ROAD & RAIL ENGINEERING

Rock Engineering and Underground Structures

market area unit is the largest one in Finland.
Head count at the moment about 55.

Tunnels and underground facilities

- Tunnels and underground facilities are important elements of an integrated infrastructure system.
- Road and rail tunnels, underground car parks and depots form an important part of transportation networks and help relieve congestion in city centers.
- Technical tunnels are necessary to convey electricity, data, fresh water, wastewater, district heating and cooling especially in the urban areas.
- Rock caverns and underground bunkers are secure facilities to place command centers, data centers and civil shelters.

Energy Division

No. of employees: 2,250

Approx. annual revenue: 3,3 BSEK

Offices in countries: 32

Projects in more than 80 countries

We speak more than 30 languages

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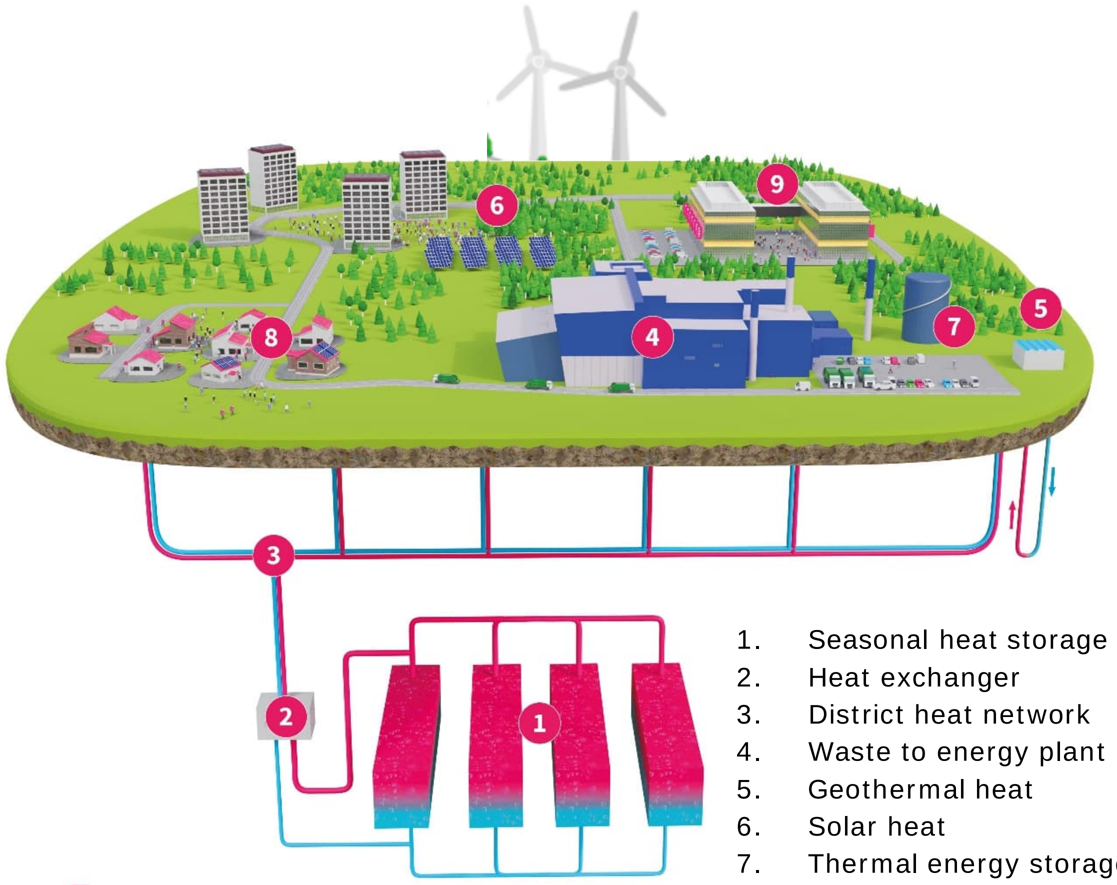
District Heat System



1. Seasonal heat storage
2. Heat exchanger
3. District heat network
4. Waste to energy plant
5. Geothermal heat
6. Solar heat
7. Thermal energy storage
8. Combined heat and power production
9. Recovery of waste heat

District heating plants can provide higher efficiencies and better pollution control than localized boilers.

Yearly and daily variations of district heat load is high. Without heat storage the consumed heat has to be generated at the same time as the demand occurs.

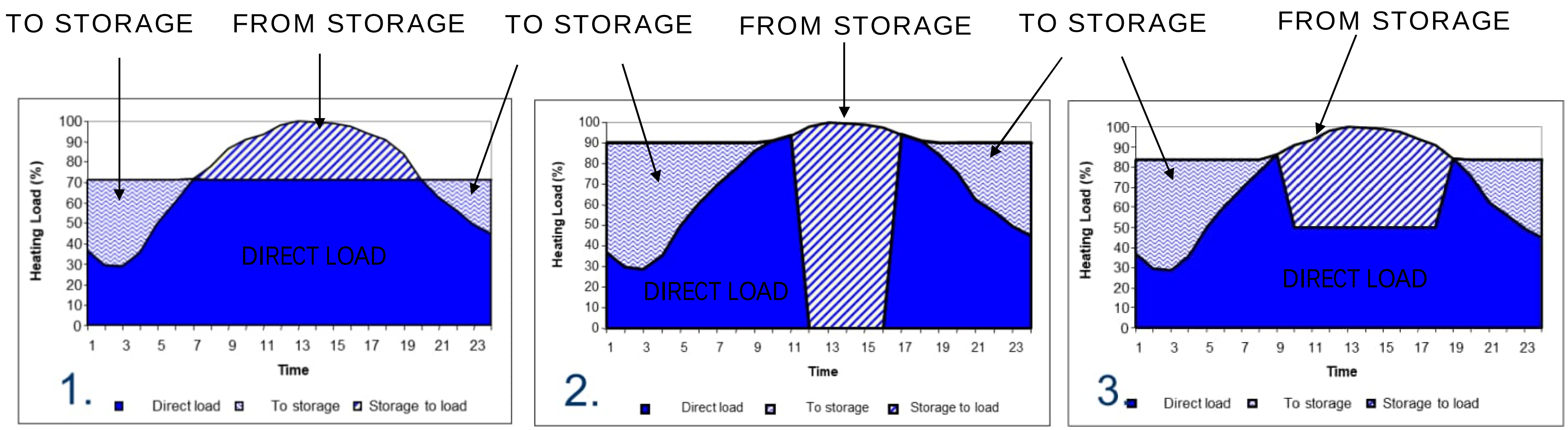
District heat will be charged in the heat storage during high efficiency production and discharged during peak consumption.

Operation modes of heat accumulators

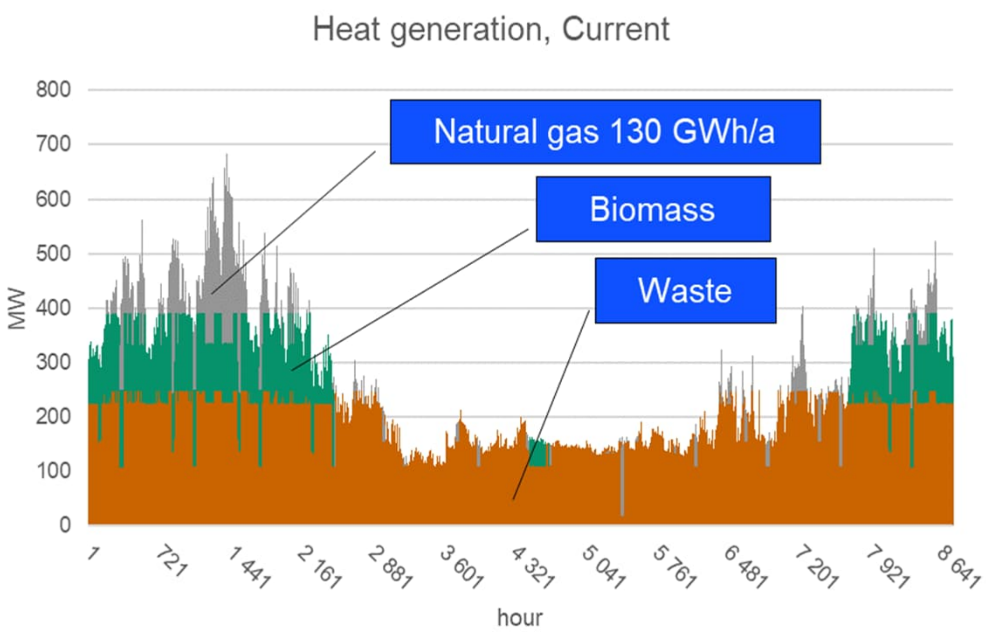
1. Load levelling (peak shaving, accumulator as main control device)
2. Full load-shifting (transfer of the load, readjustment of a fault situation with a high-capacity accu)
3. Demand limiting (cutting and transfer of heat load to a more economical time)

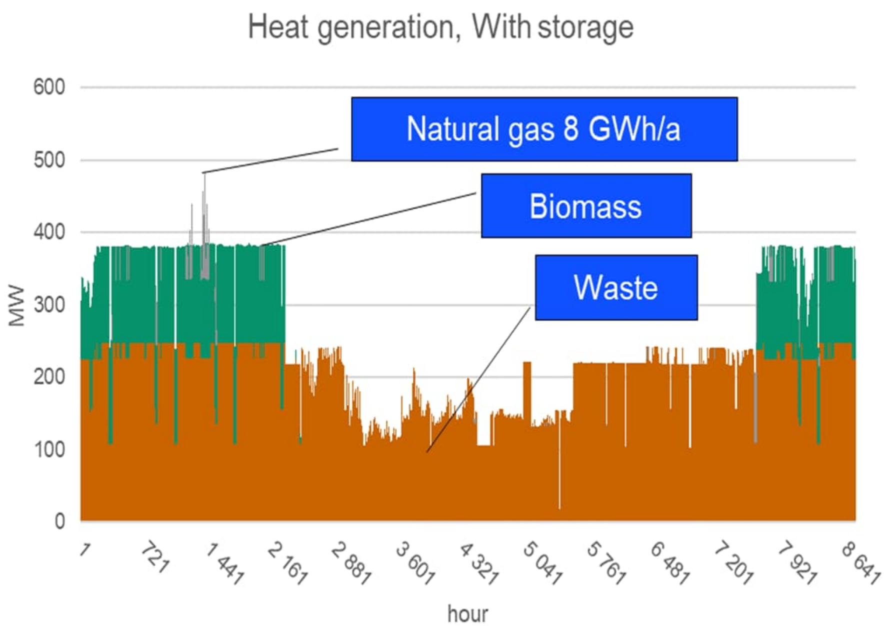
Depending on the heat storage capacity, the accumulator can be utilised as daily, weekly or seasonal operations

Models for daily control below



Operating of the heat storage





Heat storage will cut peak energy production.

Needed extra heat during the peak load is typically generated with units with good adjustability but using more expensive sources of energy and often fossil fuels.

Heat generated will be stored in the storage for use at another, more suitable time. On discharge, the heat can be utilized as such as district heat. The heat storage facility will provide flexibility to the energy system as it will balance variable heat consumption.

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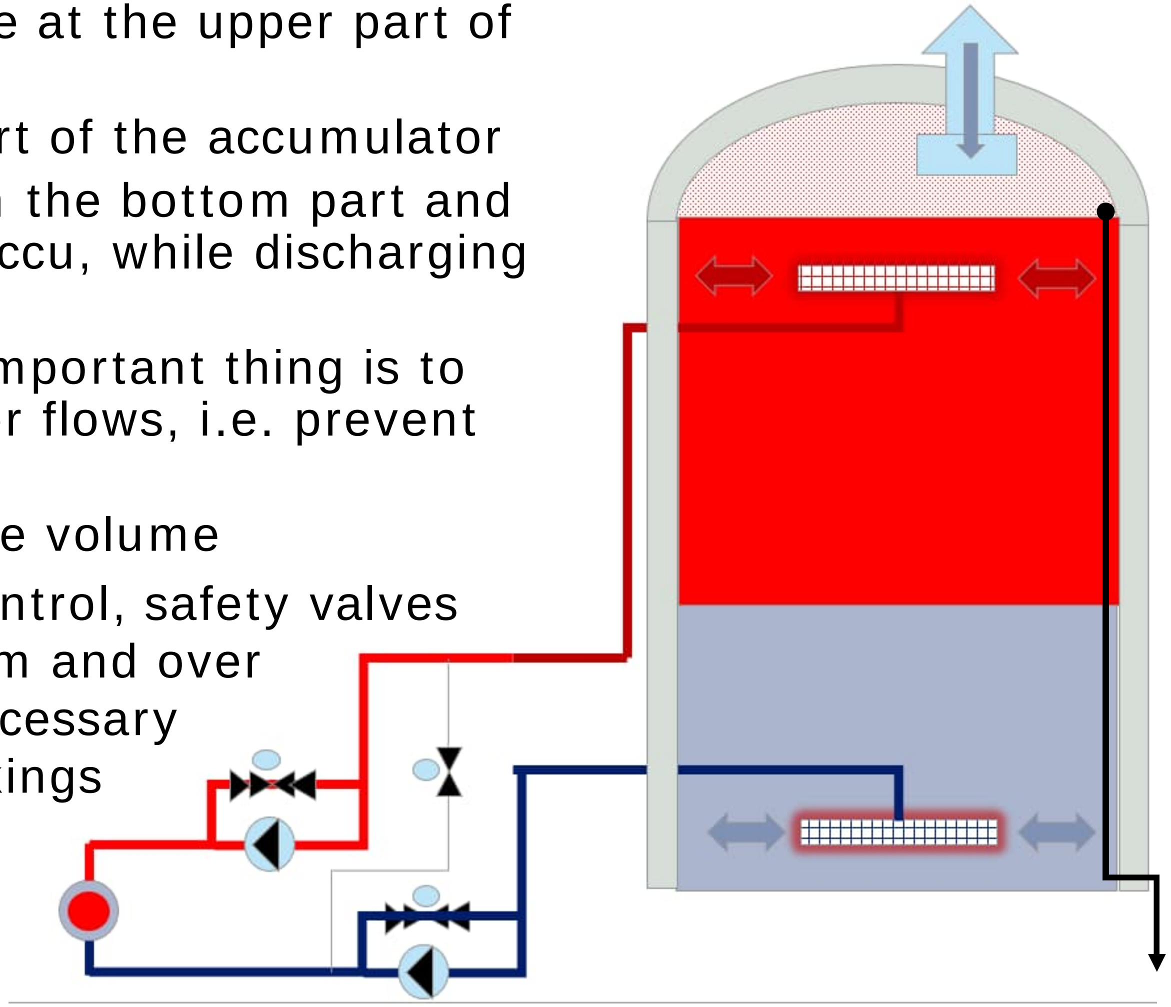
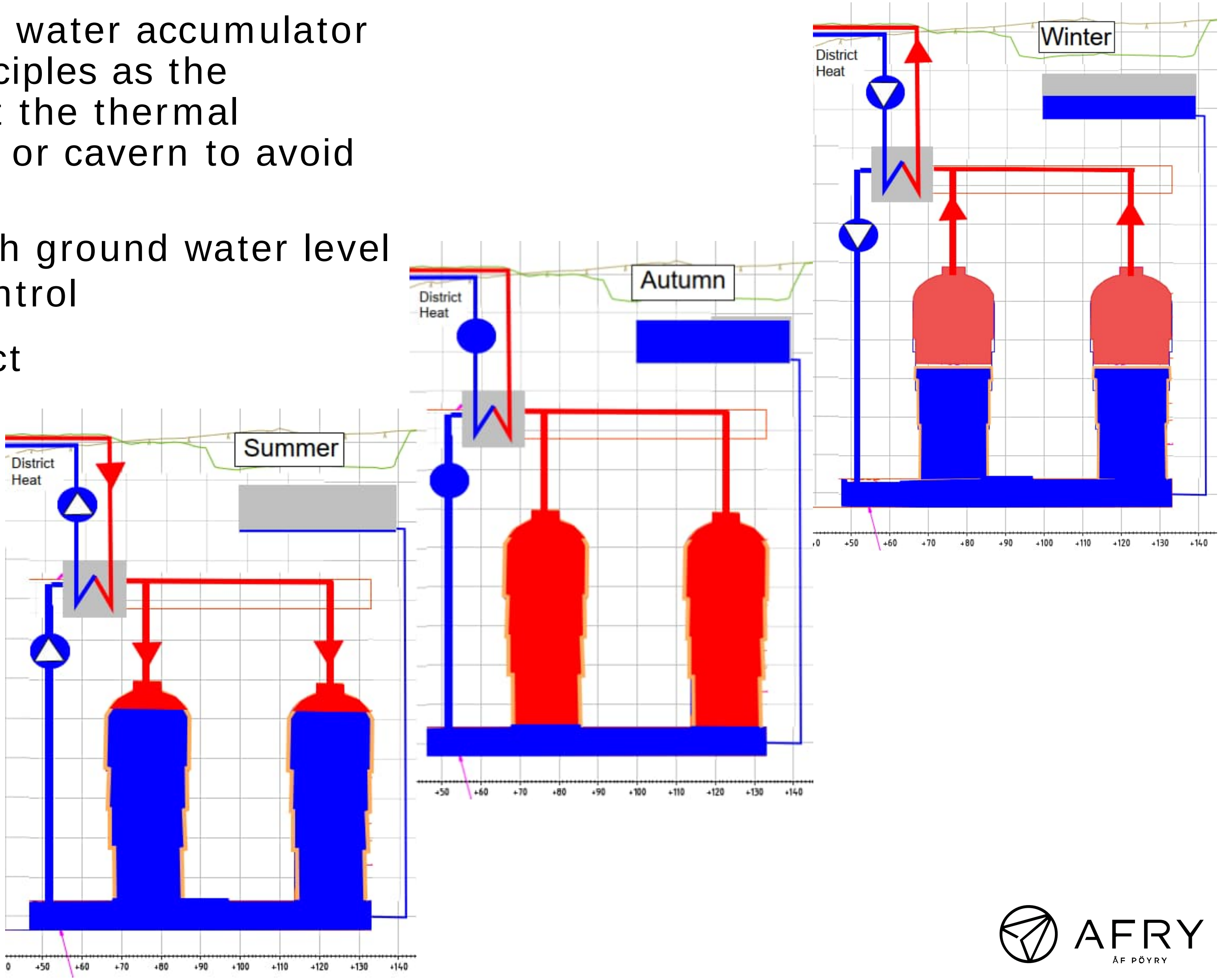
Principle of the hot water tank accu

- Operation of accumulator is based on stratification of different temperature water
  - Hot water is less dense and stays therefore at the upper part of the accumulator
  - More dense cold water is in the bottom part of the accumulator
- While charging, the cold water is drained form the bottom part and the hot water is fed to the upper part of the accu, while discharging the procedure is reversed
- From the operational point of view the most important thing is to carefully control the incoming / outgoing water flows, i.e. prevent the mixing of the water layers
- Thermal expansion of water is about 2% of the volume
- The accumulator is equipped with pressure control, safety valves and overflow for the protection against vacuum and over pressure The tank also is equipped with all necessary interlockings and automation system interlockings and to ensure the safe operation



Principle of hot water cavern accumulator

- The operation of rock cavern hot water accumulator is based much on the same principles as the stratified tank on the ground but the thermal expansion takes a separate tank or cavern to avoid changes in the ground water
- The accumulator is equipped with ground water level sensors and precise pressure control
- The accu water is in direct contact with the ground water and heat exchanger is needed to avoid the contamination of district heat system.
- The operation cycle of seasonal heat storage is presented here



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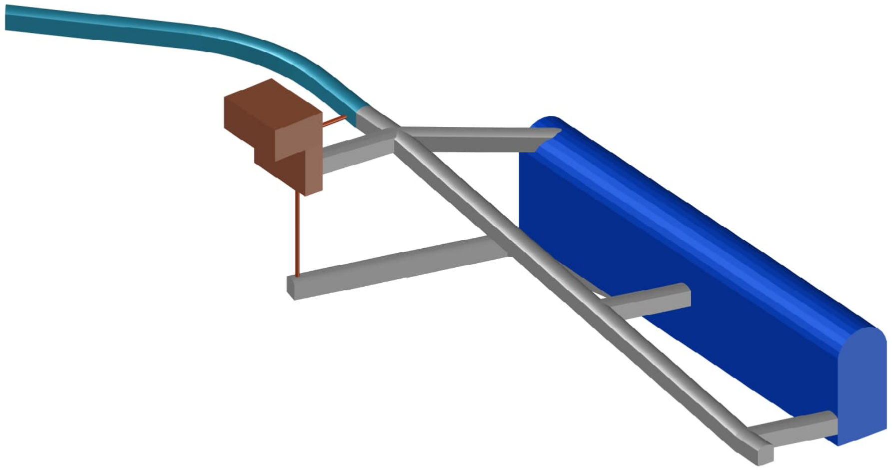
Types of rock heat accumulators

Existing rock caverns

- Old oil storages
- Other tunnels or underground spaces



Heat store designed caverns

- Specially design and optimized for heat storage use
  - Under 100 ℃
  - Over 100 ℃
  - Underground technical spaces in tunnels
  - Technical spaces above ground

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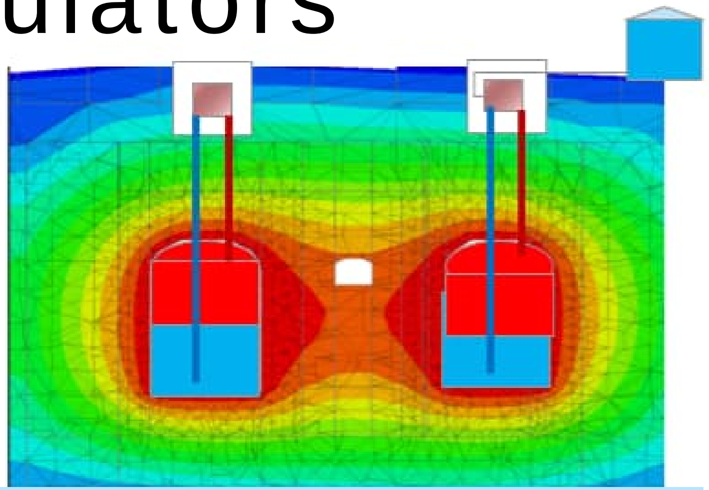
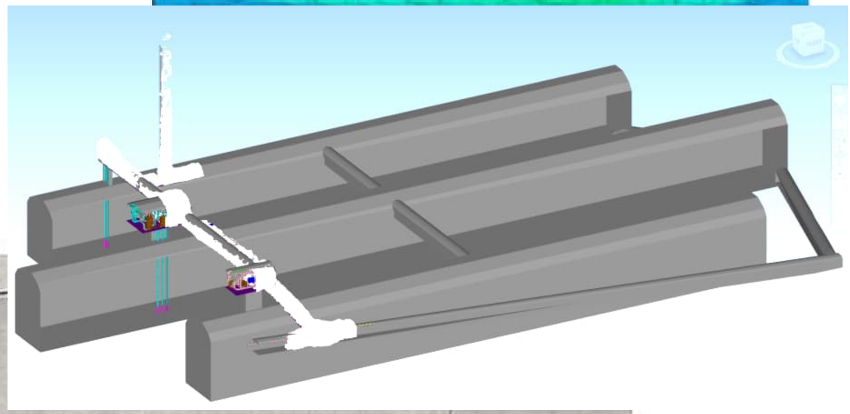
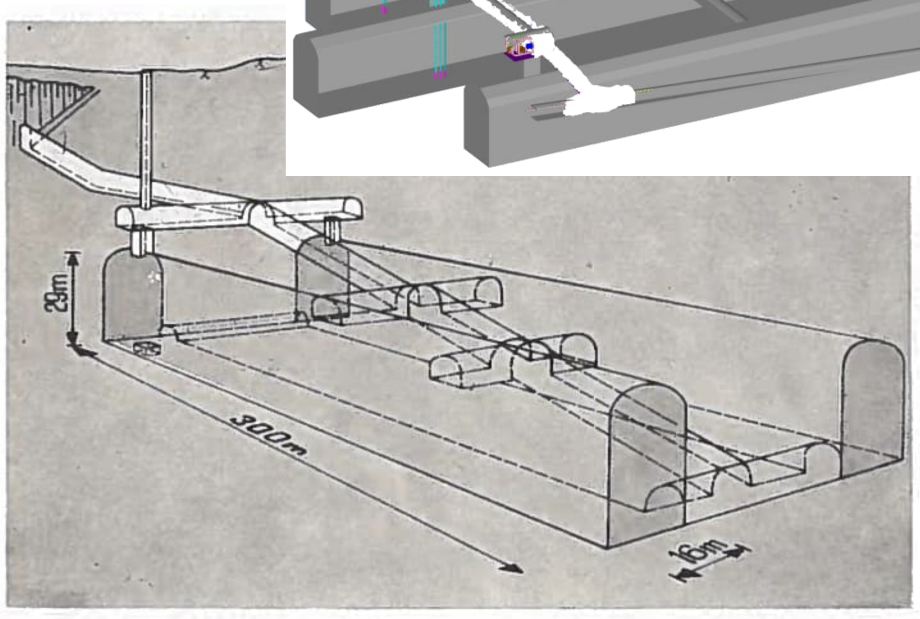
Types of rock cavern heat accumulators

Existing rock caverns

- Oil safety stocks and other deep storage facilities are typically located deep in the rock, below the groundwater level.
- Caverns are typically large >200,000 m^3.
- Temperatures below 100 °C depending on the quality of rock and ground water as well the level of ground water.
- Storage cavern has a lot of rock surface area in relation to volume resulting relative high heat loss.
- The heating of rock mass consumes a lot of energy during the first years of operation.
- Suitable for connection to large district heating networks.
- The expansion space can be located in an above-ground tank or in a cavern.
- Heat exchanger connection with suitable filters is necessary due to impurities of water and possible remains of previously stored material.



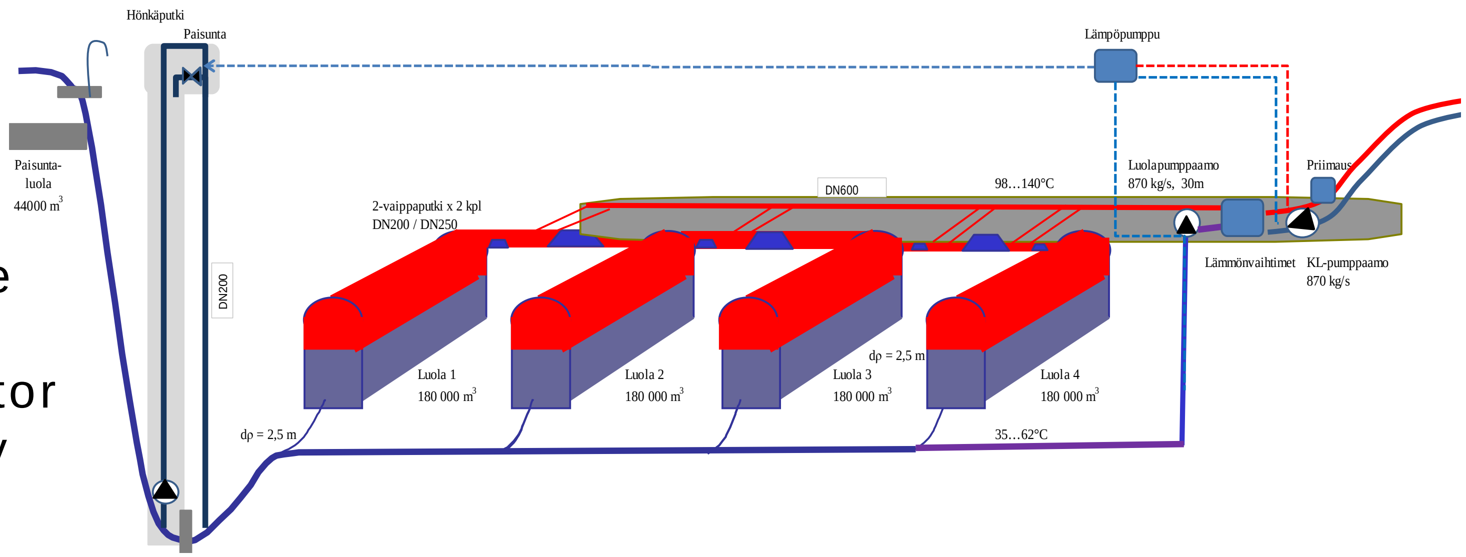




Types of rock heat accumulators

Heat store designed caverns

- The facility is designed and built specifically for thermal energy storage
- In deep located cavern the maximum temperature of the stored water can be well over 100 ℃, which significantly improves the capacity of the accumulator
- Large volume and high energy capacity can be optimized according to needs
- Higher performance compared to low temperature heat storages
- Optimized location.
- Pressure level is equal to surrounding groundwater, which minimizes water and heat leakage into the environment.
- No existing pressurized heat storages excavated in rock.



- Utilization of groundwater pressure enables high storage temperatures.
- Pressure level is similar with groundwater, minimizes water and heat leakage into the environment.
- The temperature stratification of water is maintained in storage caves for a long time.

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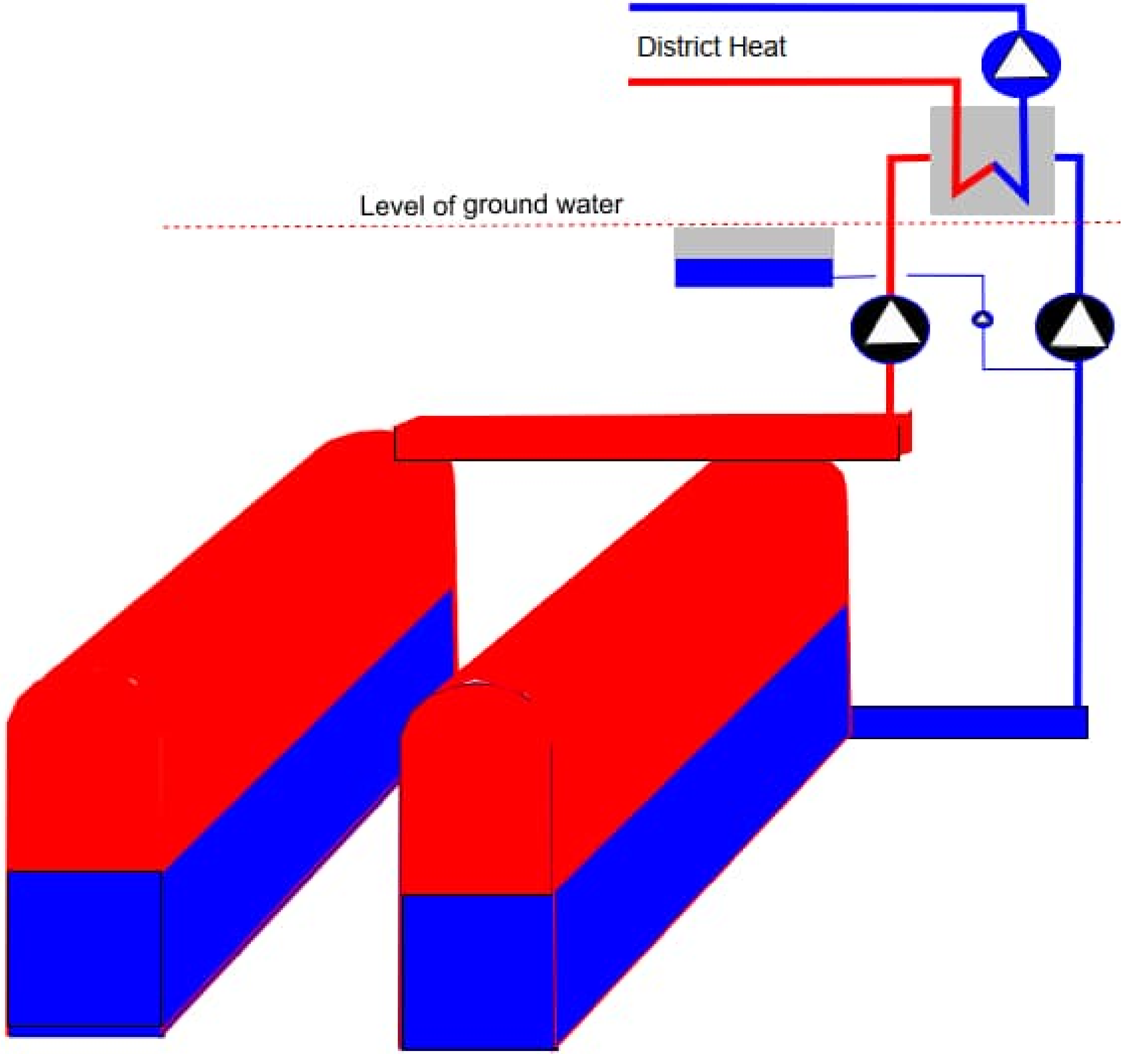
Types of rock heat accumulators

Heat storages with lineshaft or submerged pump installations

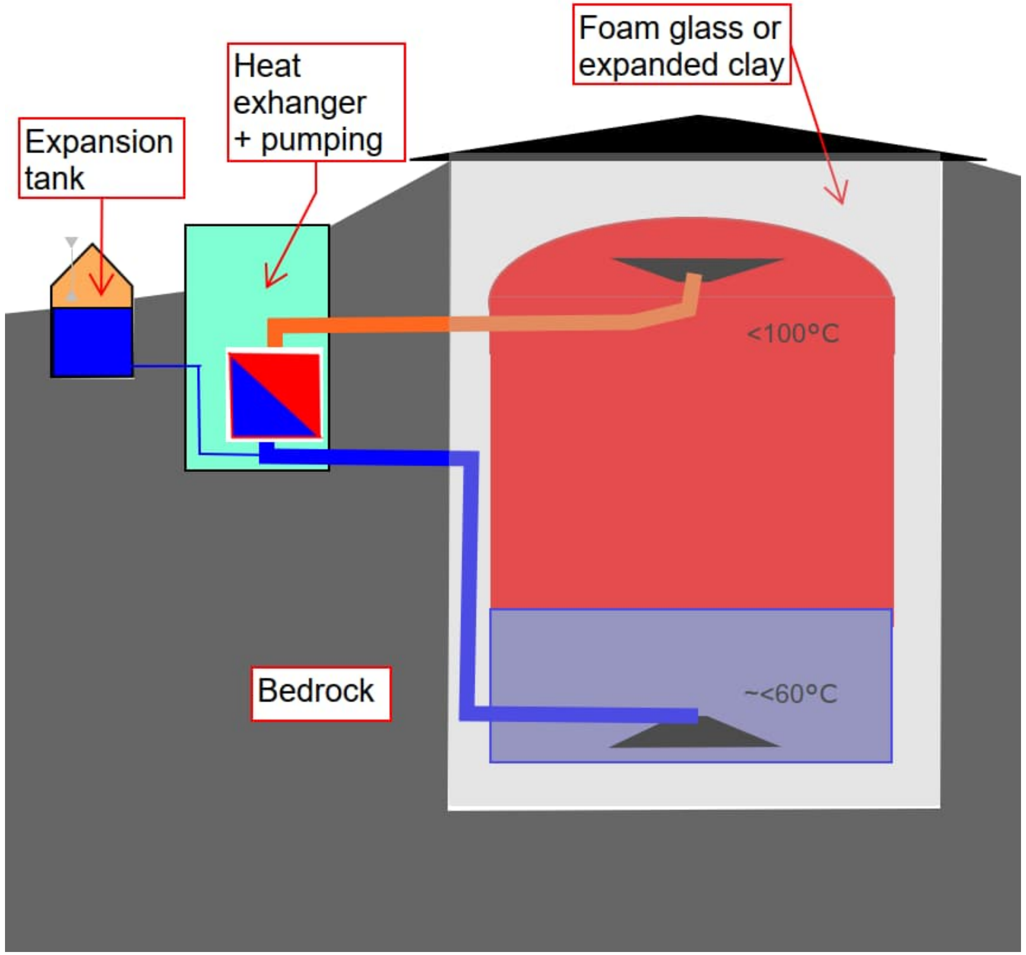
- Heat storage cavern can be equipped with above ground heat exchanger installation using lineshaft or submerged pumps.
- The pumps are equipped with diffuser to enable smooth flow into the storage cavern and/or existing partitions of cavern are utilized for flow control
- Submerged pump technology limits the maximum charge temperature (60 ℃ … 90 ℃)
- The maintenance of lineshaft and submerged pump installations is more complicated therefore this installation is suitable for small capacity (low flowrate) systems.



Types of rock heat accumulators

Heat store designed open excavation

- The facility is designed and built specifically for thermal energy storage
- The maximum temperature is below 100 ℃ Volume and energy capacity can be optimized according to needs
- Insulation of roof (and jacket) mimimizes the heat loss
- Watertight construction is needed when the level of ground water is below the surface of accumulator water
- Excavated area takes large on ground footprint which restricts the other uses of the site.



AFRY Heat storage references
Selected Case Studies

Mussalo and Katariina oil storages in Kotka

- Conversions of old oil storages in Kotka into heat storages. Preliminary study in two different locations.

Rauma

- Conversions of old oil storages in Rauma into heat storages. Preliminary study.

Lappeenranta

- New excavated heat storage specially design for heat storage purpose. Preliminary study.

Helsinki, Mustikkamaa

- Old oil storages conversion to heat storages. Ready and in test use phase.

Vantaa

- Pre-design and Environmental impact assessment. New pressurized excavated heat storage.

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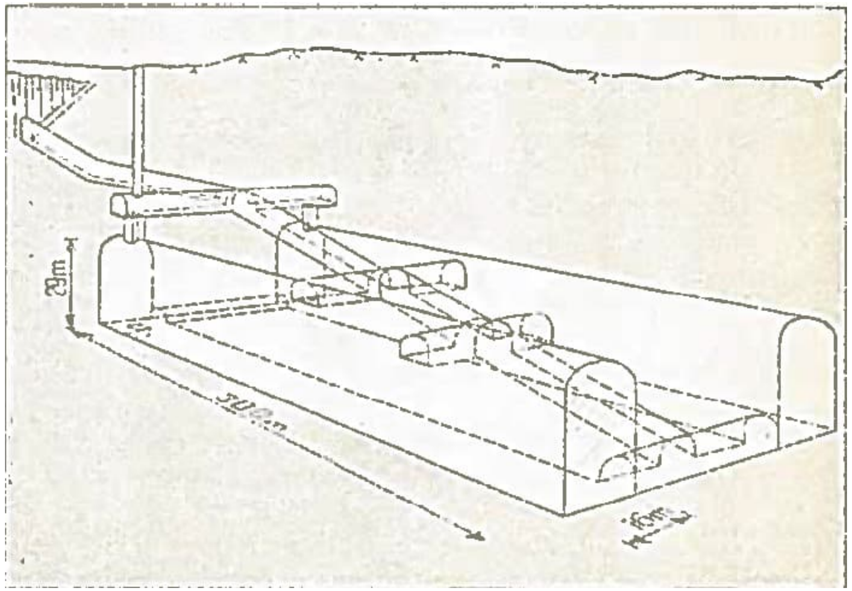
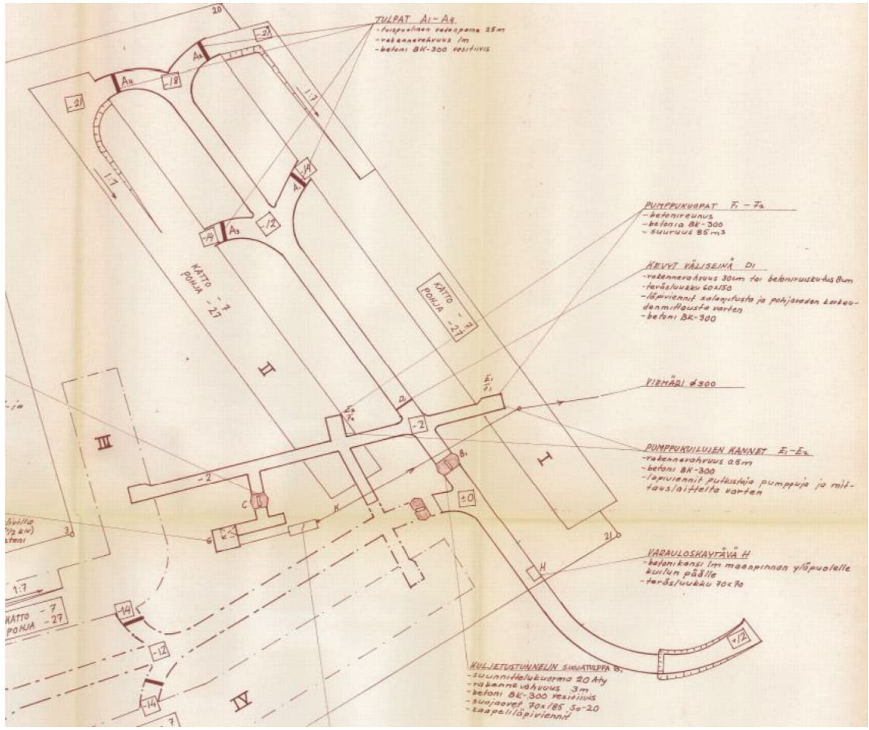
Kotka, Mussalo and Katariina

Preliminary studies for oil storage conversions to heat storage in two locations.





AFRY design tasks

- Modifications and renovations for existing rock spaces.
- Rock quality evaluations.
- Process technology.
- Energy balance and. operating model.
- Investment value.

Mussalo oil storages

- The volume of the cave is 260 000 m³.
- Capacity 10.0 GWh.
- Not in use, filled with water
- The project was not continued after the preliminary study.

Katariina oil storages

- The volume of the cave is 78 000 m³.
- Capacity 4.0 GWh.
- Not in use, dewatered
- The project was not continued after the preliminary study.

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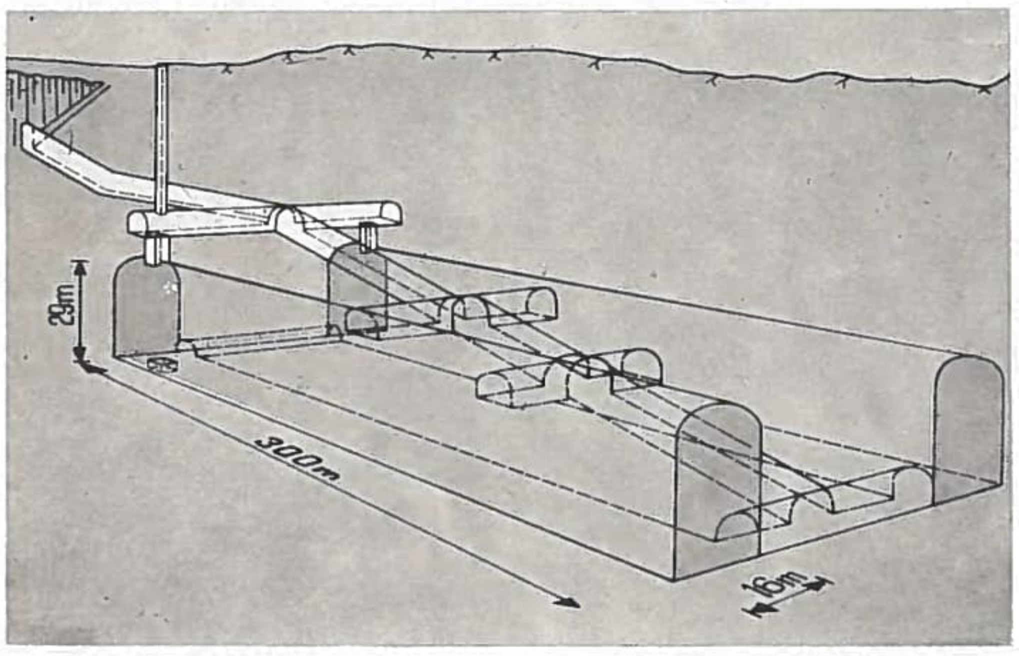
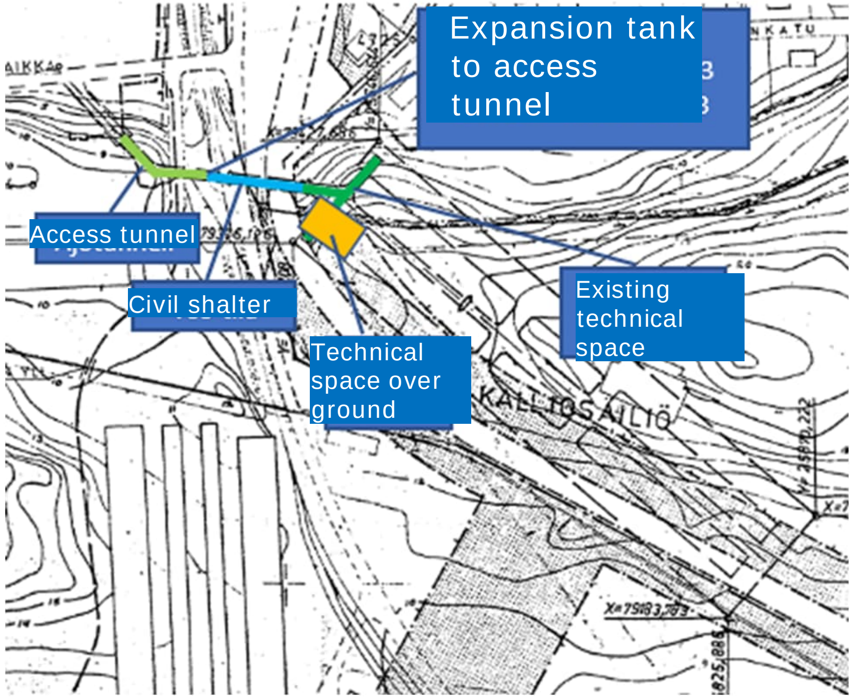
Rauma

Preliminary study for oil storage conversions to heat storage





- UPM-Kymmene Corporation has a decommissioned oil safety storage facility.
- The volume of the cave is 280,000 m^3.
- The storage capacity more than 13 GWh.
- Charging or discharge capacity of 40 MW for almost two weeks.
- The project was not continued after the preliminary study.

AFRY design tasks

- General design for layout and new structure.
- Modifications and renovations for existing rock spaces.
- Process technology.
- District heat pipelines.
- Energy balance and operating model.
- Investment value.

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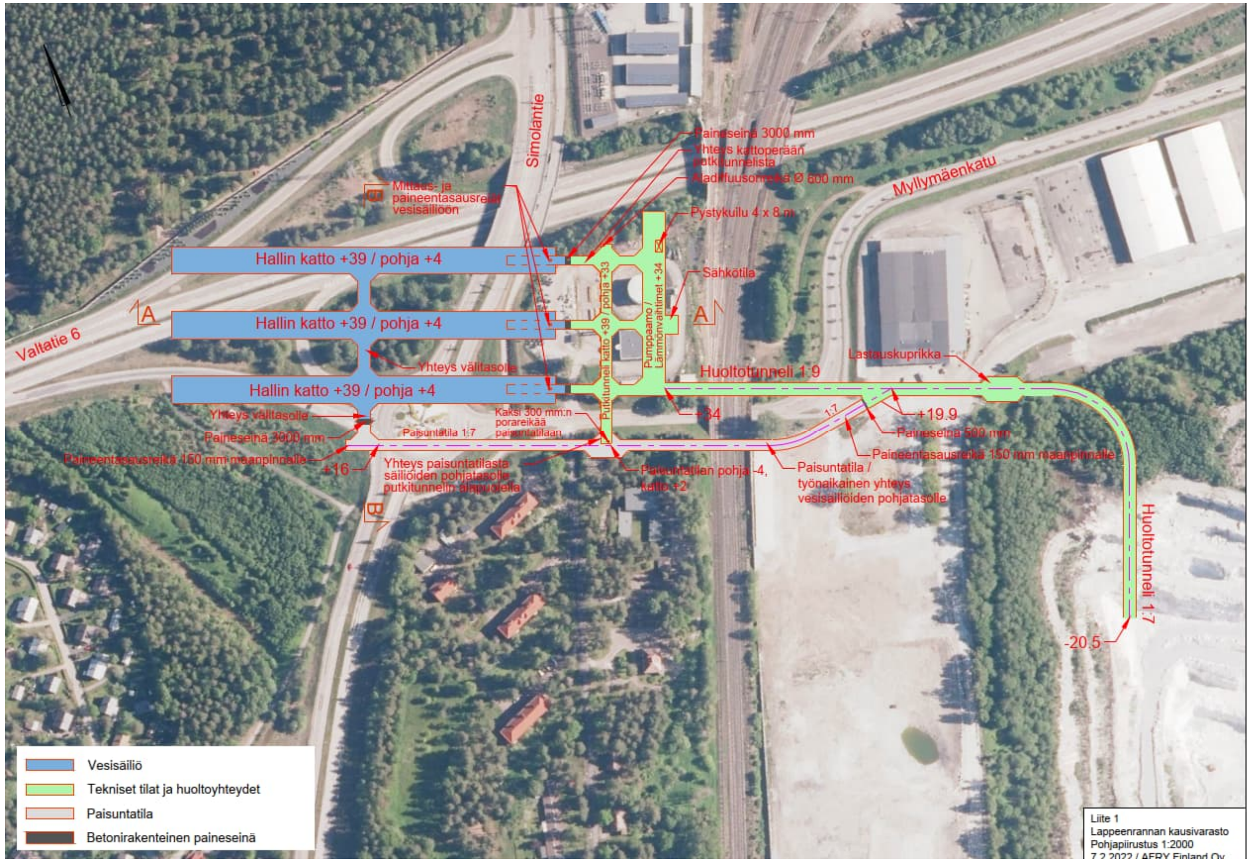
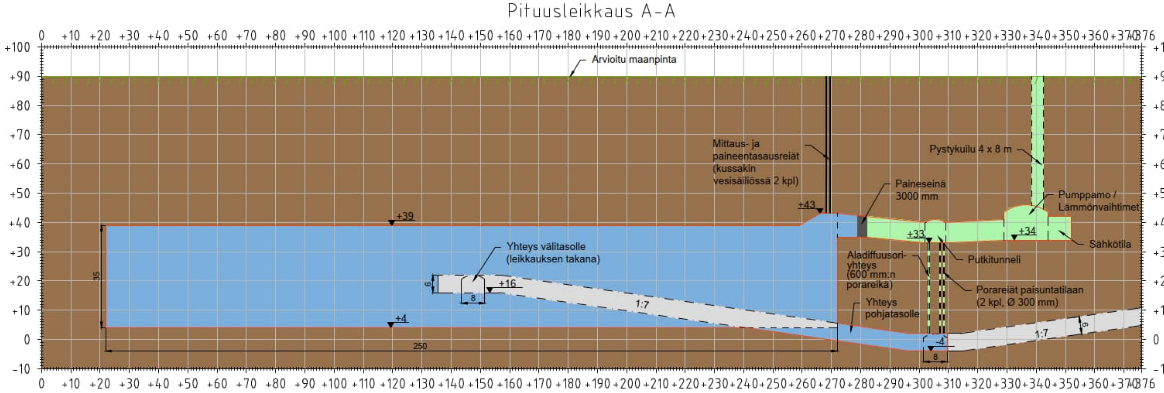
Lappeenranta

Preliminary study for new heat storage





- Technical spaces in tunnel spaces
- Water temperature below 100 °C.

Version 1.

- The volume of the storage is 450 000 m^3.
- The storage capacity 23 GWh.
- Charging or discharge capacity of 80 MW

AFRY design tasks

- General design for layout and new structure.
- Two different size and layout solutions
- Process technology.
- Energy balance and operating model.
- Investment value.

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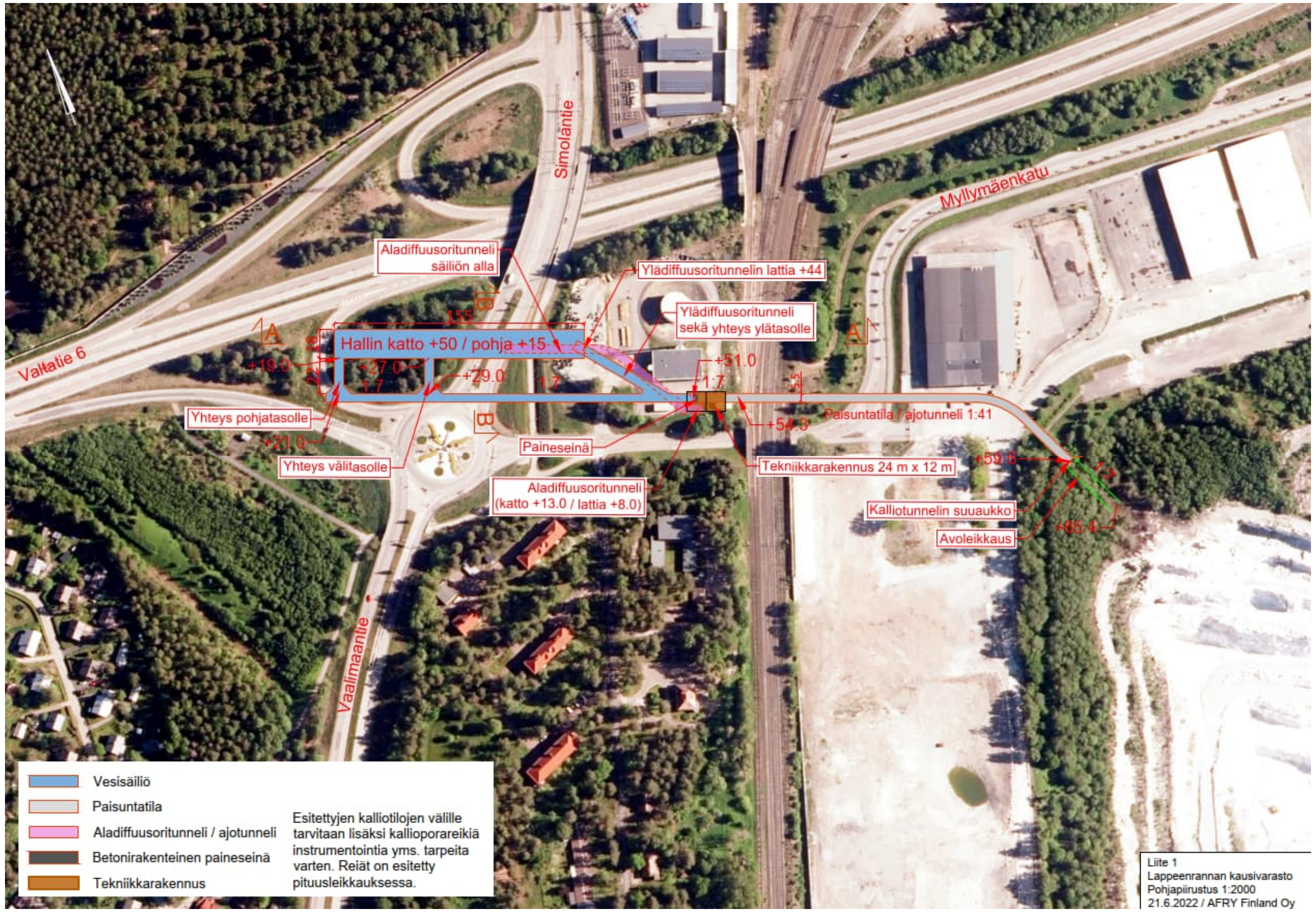
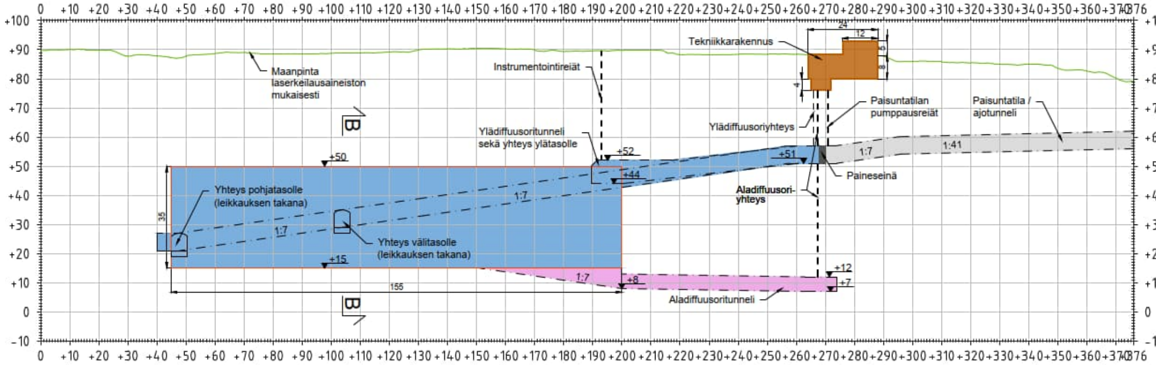
Lappeenranta

Preliminary study for new heat storage





Version 2.

- The volume of the storage is 100 000 m^3
- Max. possible volume is 200 000 m^3.
- The storage capacity
  - 100 000 m3, 5,3 GWh
  - 150 000 m3, 8 GWh
  - 200 000 m3, 10,6 GWh.
- Charging or discharge capacity of 80 MW

- Technical spaces above ground.
- Only water storage and expansion in tunnels
- Water temperature below 100 °C.

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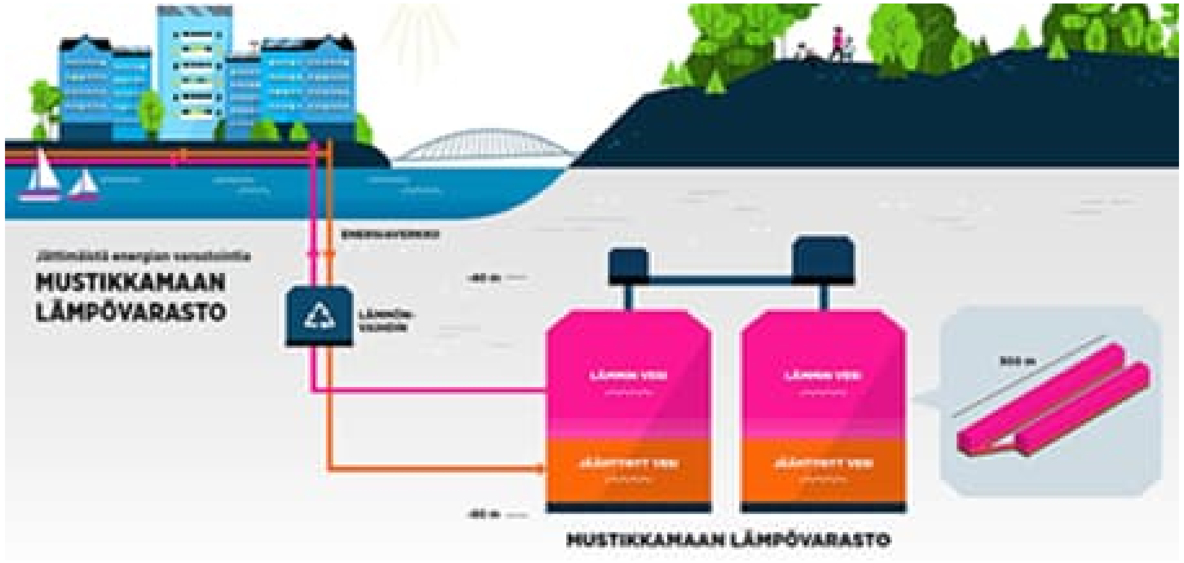
Helsinki, Mustikkamaa

Existing old oil storage conversions to heat storage



- Helsinki City energy company Helen has started to build Finland's largest district heat storage facility in the old oil caverns in Mustikkamaa.

- The volume of the cave is 320 000 m^3.
- The storage capacity more than 11,4 GWh.
- Charging or discharge capacity of 120 MW for four days.
- The caves are 30 meters high and their bottom is 80 meters below sea level.

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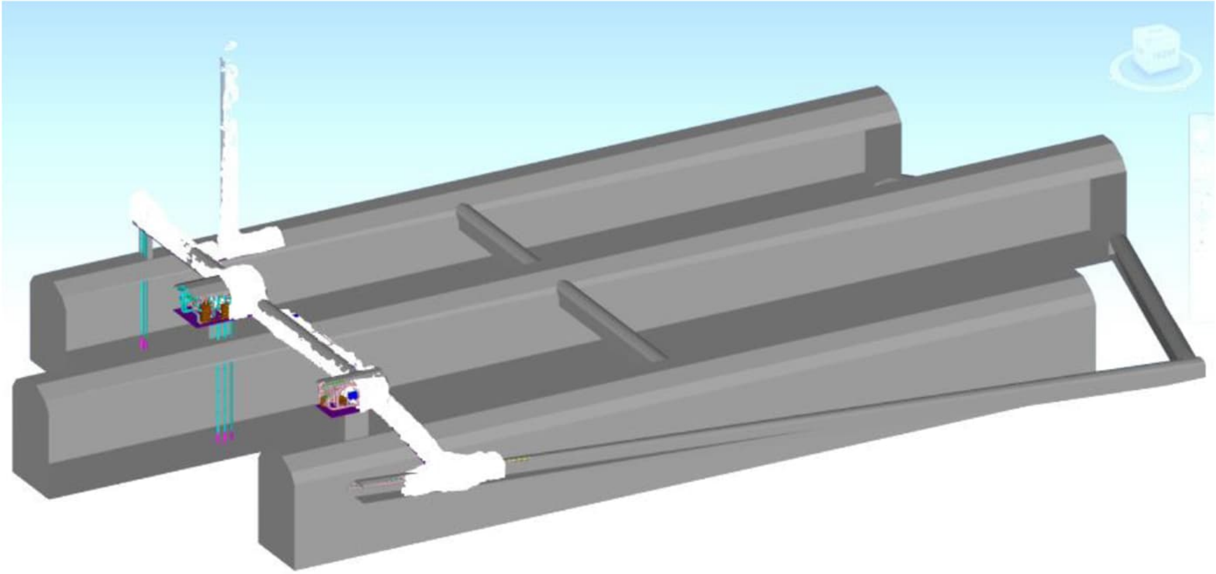
Mustikkamaa Heat Storage

- The oil storage facilities were built in the early 1980s.
- Oil storages have been emptied in the late 1990s.
- AFRY has started the preliminary design of the Cave Heat Battery in 2014.
- The actual planning started in 2018.
- Construction began with demolition work in 2018.
- The project will be completed in 2021, when the heat accumulator will be operational.
- AFRY has been responsible for the design of facilities, structures and process.



- The technical implementation has been designed without extra rock excavation in the caverns.
- Only new space for electrical room and transformer is needed to be excavated.
- New drill holes from surface for cables and pipes.
- The storage caverns will remain as they currently are and no additional support or repair is done there.

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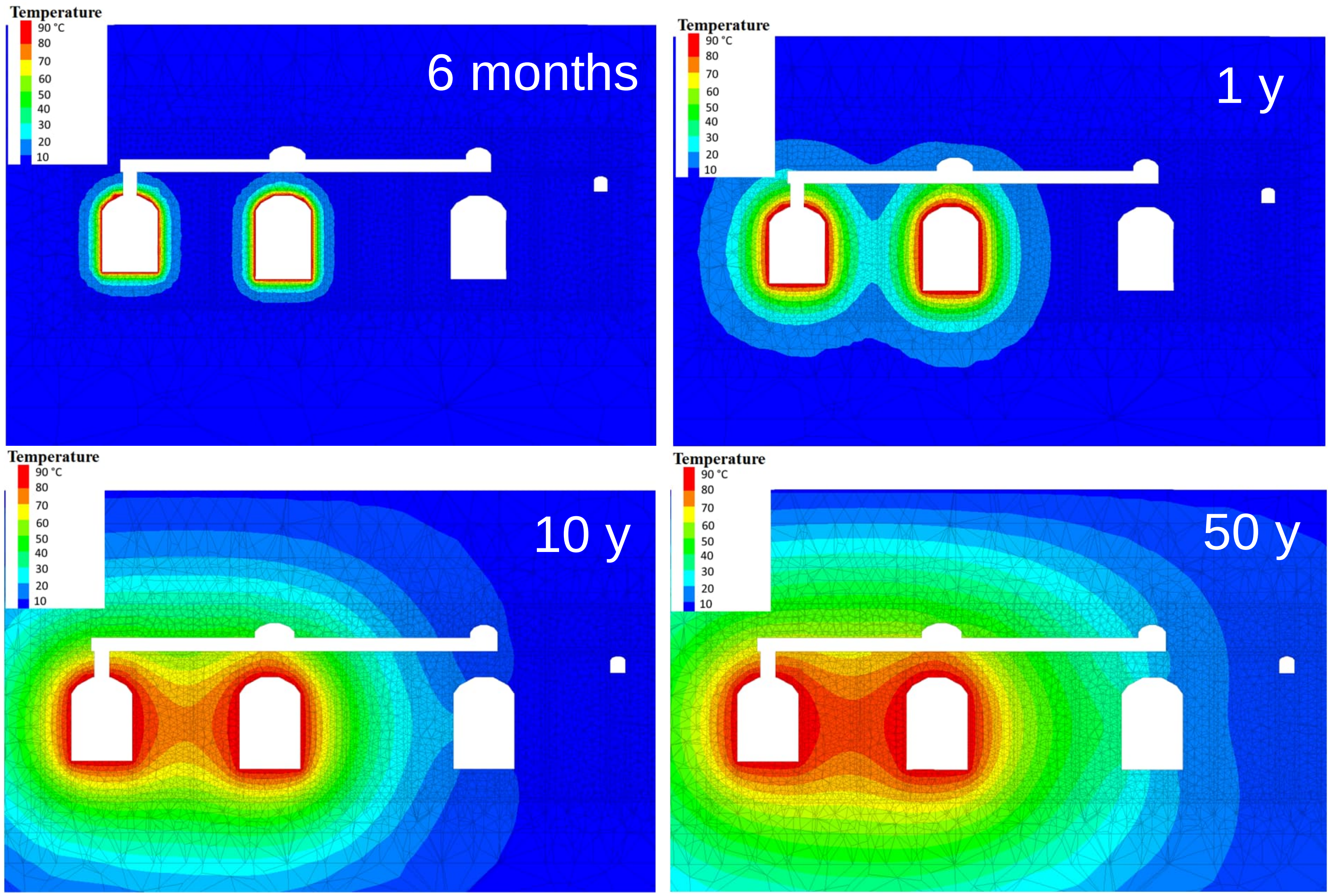
Mustikkamaa, Rock mechanical and thermal simulations

Rock mechanical and thermal simulations have been made to model the long-term behavior of the rock mass.

Water temperature in caverns will be up to 100℃ during operation.

Rock heat around technical tunnel spaces will be up to 60 ℃.

Rock displacements above ground has been modelled also.



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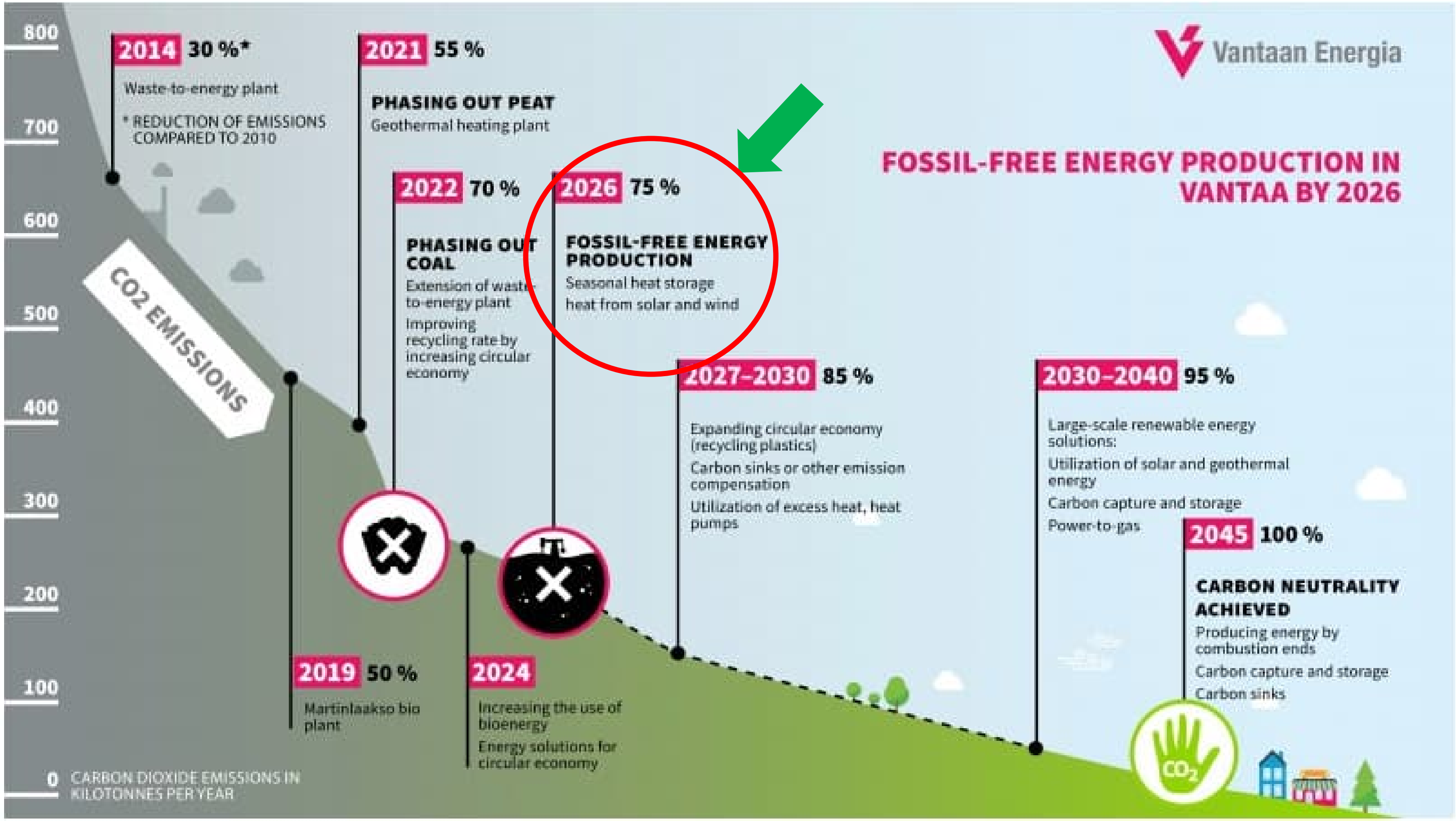
Vantaa, Cavern Thermal Energy Storage

- Vantaan Energia has decided to give up fossil fuels in 2026.
- The seasonal storage of thermal energy to be built underground is the most important part of the Fossil-free 2026 project.



Targets

Fossil Free Energy

Carbon Neutrality

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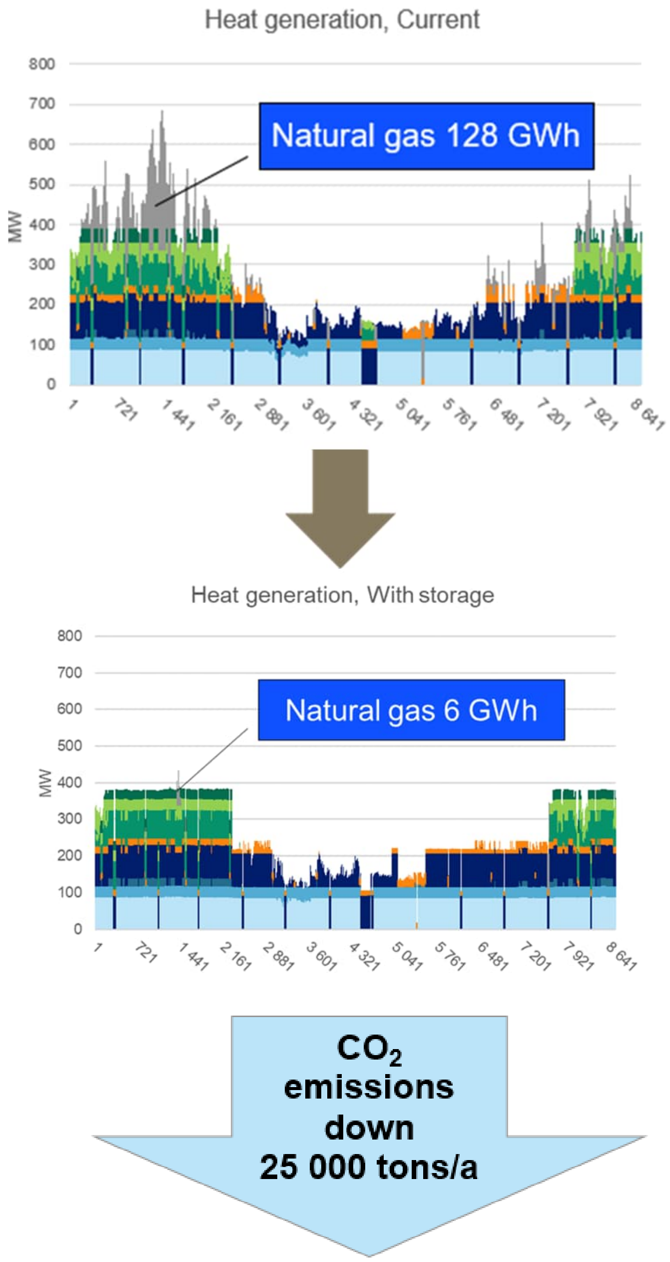
Seasonal Thermal Energy Storage

- Vantaan Energia is planning to invest in the innovative Cavern Thermal Energy Storage (CTES) System to store excess heat energy in summer.
- The temperature of the water stored in the pressurized cavern is up to 145 ℃
  - improves the capacity of the battery
  - reduces volume
  - decreases excavation costs
- Innovative design solution makes it possible to store such high temperature water without vaporization.
- Storing energy from waste heat sources, solar, geothermal and waste-to-energy plants in summer time. Waste energy available year around in Vantaa.
- The stored energy will replace expensive heat production by natural gas in cold winter days.



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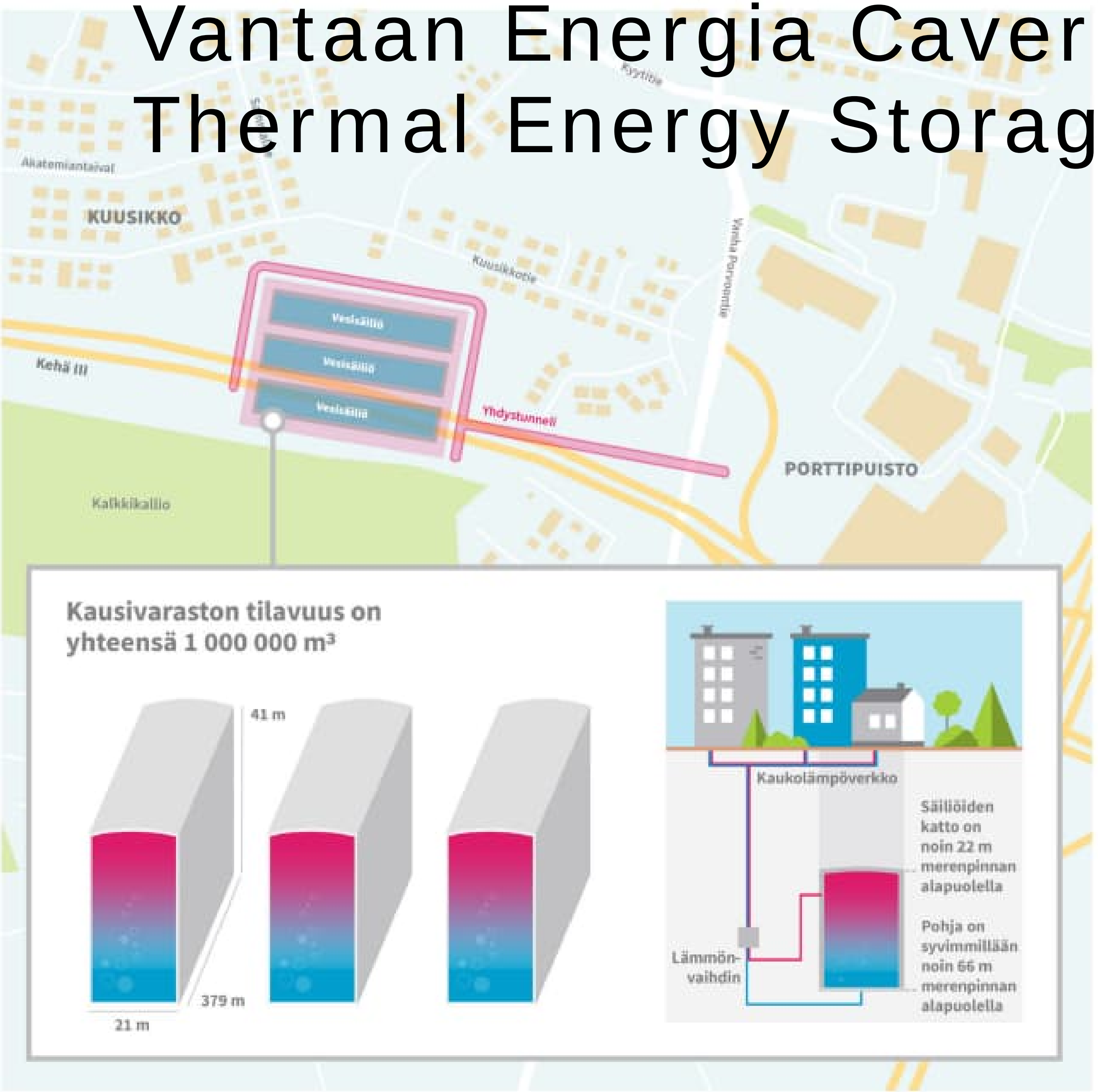
Vantaan Energia Cavern Thermal Energy Storage

- Water storages crown depth 100 meters under surface. (-47.0 / -88.0)
- 4 separate heat storages, total storage volume ca. 900 000 m³.
- Storage lengths 320 m, height 41 m, width 18 m.
- Total excavated volume 1 100 000 m³.
- Energy capacity 90 GWh.



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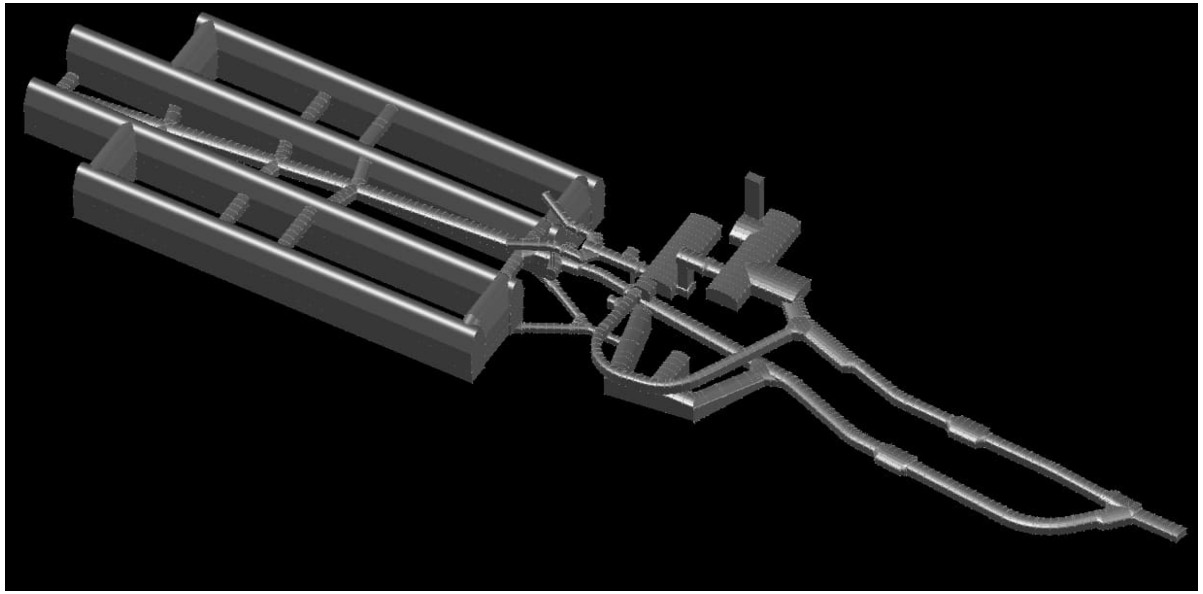
Vantaa CTES

- AFRY's tunnel, environmental and energy experts have been involved in the concept and pre-design phase of the project.

- The environmental impact assessment process has started by AFRY.

- As a result of the design, the world's largest cave with a size of about one million m^3 is being built to store energy.

- The heat storage is specifically designed for seasonal storage use, and several new innovations have been made in its design.



- Location close to Tikkurila in Eastern Vantaa 14 km north-east from Helsinki City in good granite rock.

- Excavation will start 6/2023. Duration of excavation 3-4 years. Ready by 2027.

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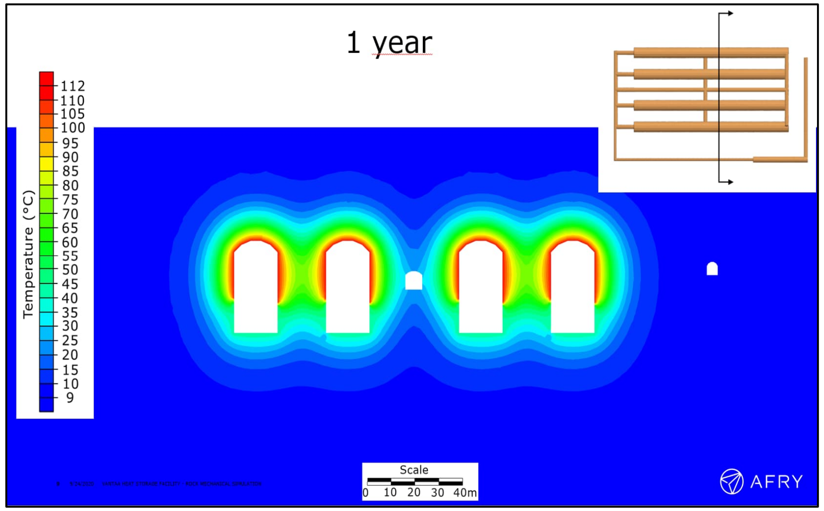
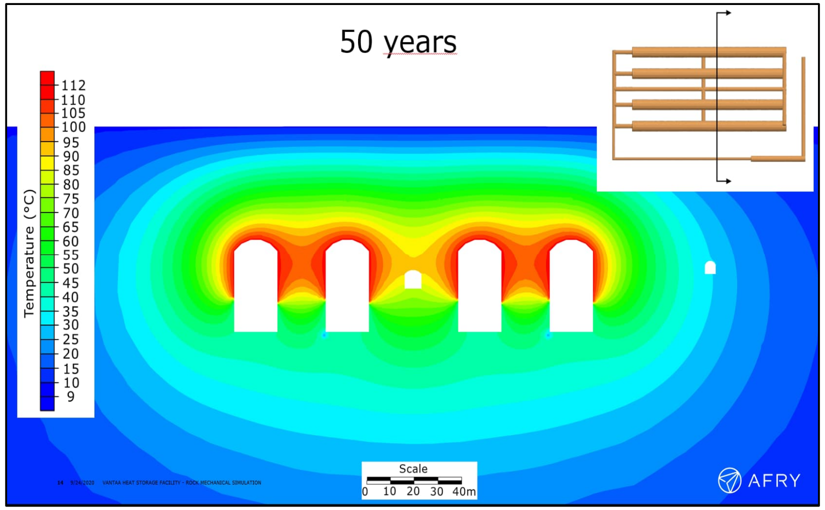
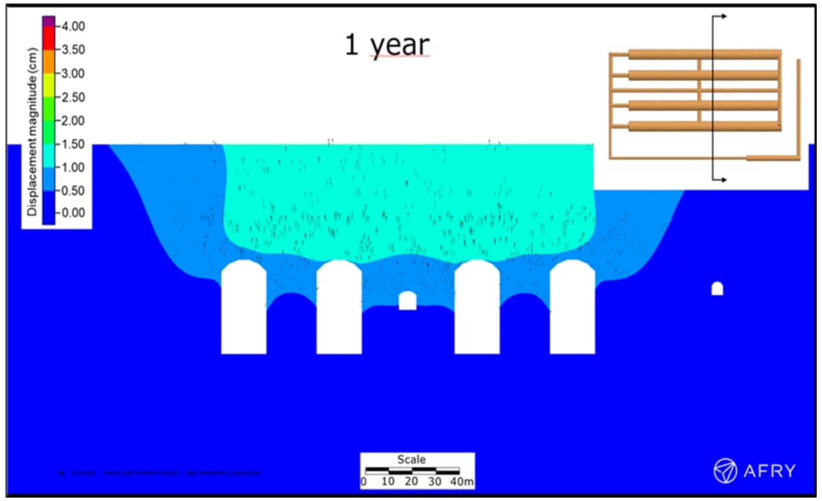
Cavern Thermal Energy Storage

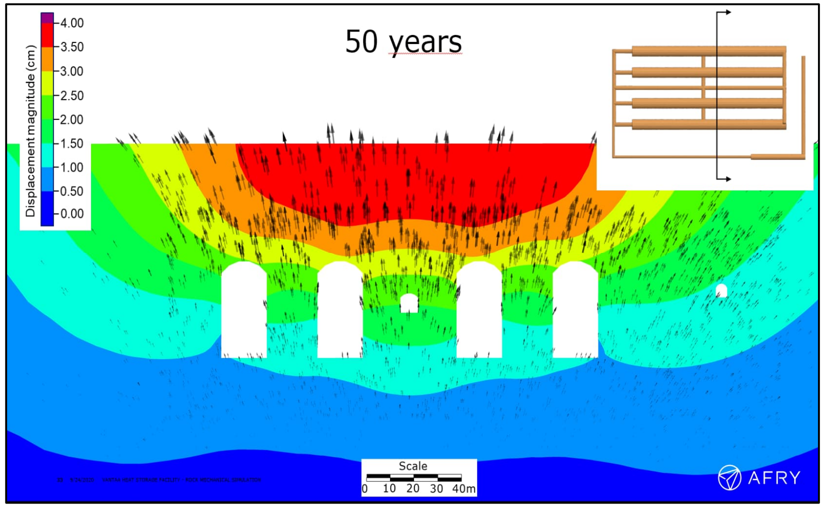




Heat modelling

- Rock temperature around heat storages up to 50 years after commissioning.





Surface and rock mass movements

- Rock movements around and above heat storages up to 50 years after commissioning.

Thank you for your attendance!

Making Future

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