VAASAN AMMATTIKORKEAKOULU
UNIVERSITY OF APPLIED SCIENCES

Tuuli Hallasmaa

IMPLEMENTATION OF AN ENERGY STORAGE FOR A WASTE-TO-ENERGY PLANT

Case Westenergy

Technology and Communication
2022

VAASAN AMMATTIKORKEAKOULU
Energia- ja ympäristötekniikka

TIIVISTELMÄ

Tekijä	Tuuli Hallasmaa
Opinnäytetyön nimi	Implementation of an Energy Storage for a Waste-to-energy Plant
Vuosi	2022
Kieli	Englanti
Sivumäärä	34
Ohjaaja	Adebayo Agbejule

Tämän opinnäytetyön tavoitteena oli tutkia erilaisia energian varastointijärjestelmiä ja valita ratkaisu, joka soveltuu pohjoisen ilmaston jäte-energiavoimalaitokseen

Tutkimuksessa hyödynnetään tapaustutkimuksen tutkimusmenetelmää ja kvalitatiivista analyysiä. Tiedot kerättiin lukemalla ja analysoimalla tutkimusartikkeleita ja haastattelemalla jäte-energia yritystä.

Tutkimuksen tulos osoittaa, että lupaavimpia varastointijärjestelmiä ovat Li-ion akut, CAES, polttokennot ja maanalainen lämpöenergian varastointi. Näistä teknologioista jäte-energialaitos hyötyy eniten maanalaisesta energiavarastosta.

Käytännön näkökulmasta tämä tutkimus voi toimia ohjeena energian varastoinnin toteutuksessa jätteistä energiaa käyttäville laitoksille.

Avainsanat energiavarasto, jäte-energialaitos

VAASAN AMMATTIKORKEAKOULU
UNIVERSITY OF APPLIED SCIENCES
Energia- ja ympäristotekniikka

ABSTRACT

Author	Tuuli Hallasmaa
Title	Implementation of an Energy Storage for a Waste-to-energy Plant
Year	2022
Language	English
Pages	34
Name of Supervisor	Adebayo Agbejule

The objective of this thesis was to study various energy storage systems and to select a solution that is suitable for a waste-to-energy powerplant in northern climate.

The research utilizes a case study research method and qualitative analysis. Data was collected by reading analyzing research articles and interviewing a waste-to-energy company.

The findings of the study show that the most promising storage systems are Li-ion batteries, CAES, fuel cells and underground thermal energy storage. Out of these technologies, the waste-to energy powerplant benefits most from an underground energy storage.

From the practical point of view, this study can work as a guideline for energy storage implementation for waste-to-energy plants.

Keywords Energy storage, waste-to-energy

CONTENTS

TIIVISTELMÄ

ABSTRACT

LIST OF FIGURES AND TABLES

1 INTRODUCTION

Global electricity consumption has continued increasing at a faster rate than energy consumption. The World's annual electricity consumption rose from 7300 TWh to 22,100 TWh between 1980 and 2013. /28/ The number of energy resources has increased substantially from fossil fuels to nuclear and renewable energy resources. There is a large difference in per capita energy use depending on a country, which point to a disparity to wealth and opportunity. Countries with developed economies usually show modest increases or small decreases in energy use. Changes in energy resources and the growth of energy use in countries with developing economies influences economies and politics, as more people compete for limited energy resources at viable price. The demand for energy will in turn impact the distribution of other limited resources such as food and water. /1/

The measured amount of CO_2 in the atmosphere has grown steadily and is currently over 400 ppm, which will cause the global temperature to increase. /1/ Global warming will cause a rise in ocean temperature, acidity, temperature extremes and sea level, which will in turn have an impact on human life and ecosystem around the world. Relying solely on fossil fuels will increase CO_2 levels, and therefore adopting alternative energy sources that do not produce CO_2 will be the best strategy for long term future. /29/

As population increases and the global demand for energy rises, the role of energy becomes ever more important and pressing. Important things to consider in the future will be which energy technologies should be developed, how to manage environmental impact of energy sources and how to store energy.

1.1 Research Problem

Energy consumption per capita in Finland is one of the highest in the world. /25/ The total energy consumption in Finland from January to September amounted to 966 petajoule and electricity consumption was 62.1 TW in 2021. /24/ Energy and electricity demand are at their highest during the winter, during which daily peak electricity consumption can be around 15 100 MW. The domestic market-based production can produce approximately 10 700 MW during peak consumption. Finland needs approximately 3 800 MW of imported electricity to meet demand for electricity during peak consumption. /31/ Finland is strongly dependent on energy import both in primary energy and electricity especially during the demand peaks. The majority of the import originates from Russia, which mainly imports coal, fossil fuels and natural gas to Finland. The current political situation involving Russia and Ukraine can accelerate the energy industry development in many countries.

Currently critical issues facing humanity are climate change, the overconsumption of natural resources and declining biodiversity. Any increase in the temperature beyond 1.5 ℃ will significantly accelerate extinction of species, render areas of the world inhabitable and pose a risk for food production, access to clean water and the function of ecosystem. Swift and systemic changes in society are required to solve sustainability crisis. As part of the European union, Finland is committed to the Paris Agreement on climate change and aims to become carbon-neutral by 2035. /26/

These problems cocreate the need to study energy storage systems and determine a suitable technology for energy producers.

1.2. Research Objectives and Questions

Based on the problems discussed above the thesis aims to find an answer to the following questions:

1. What are current energy storage technologies available in the market?
2. How is energy storage employed at Westenergy?

1.3 Research Method

This thesis utilizes qualitative research method, which is a scientific method of observation to gather non-numerical data. A case study is a strategy of doing research, which is an observation-based investigation of a current phenomenon withing its real-life context by using multitude sources of evidence. The study uses Westenergy as a case study and aims to identify, analyze and to find a suitable solution for waste-to-energy powerplants.

Primary data directly collected information by the researcher and secondary data is information which is collected by someone else. Secondary data for this case study was collected from research articles. Structured interview means that the interviewee was given questions, which were planned and created in advance. In a semi-structured interview, the interviewer asks only a few predetermined questions, and the rest of the questions are not planned. A structured interview was conducted for primary data collection, but the interview shifted to semi-structured interview during it.

Data analysis is the process of inspecting, cleansing, modelling, and transforming data with goal of finding useful information, forming conclusions, and supporting decision-making. Qualitative research collects data in phases or side by side using various methods, because of that the analysis is done during the collection of data. During the study, analyzing was done throughout the collection of data, with a bulk analysis done at the end stage of the thesis.

1.4 Outline of Study

Chapter 2 describes currently available energy storage technologies, the way each system works, and strengths and weaknesses attributed to each technology.

Chapter 3 describes the case study of the Westenergy waste-to-energy powerplant and how the energy storage is used there.

Chapter 4 presents the conclusions and discussion of the study.

2 STORAGE METHODS

2.1 Storage of Mechanical Energy

Mechanical energy can be stored for example as potential energy in elevated object, as kinetic energy of linear or rotational motion or compression energy in gas. /3/

2.1.1 Pumped-hydro Energy Storage

The PHES (Figure 1) is an energy storage that stores energy in form of gravitational potential energy of water. The water is pumped into an upper reservoir, and it is stored there until the energy is required after which water is released through turbines to lower reservoir. It is a large-scale energy storage technology that is most used for high-power applications

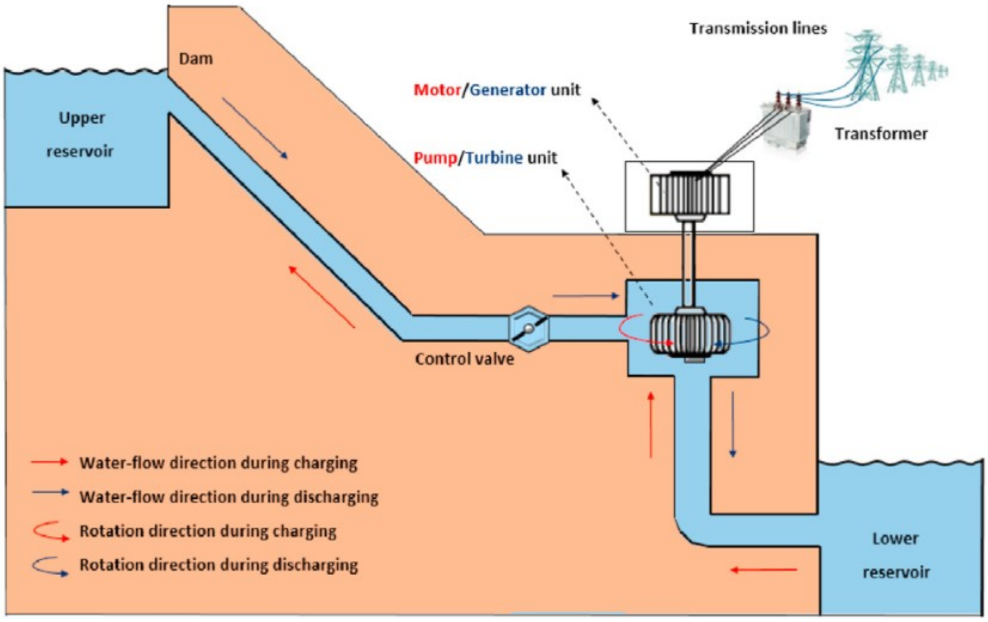


Figure 1. Pumped-hydro storage /8/

The PHES is flexible and has a short response time and can ramp up to full production capacity withing minutes, which provides a quick response for peak-load energy supply. It has high efficiency in power, which ranges between 75-85% and has competitive cost of 600-1,000€ /kWh /4/. Typical capacity of PHES ranges around 1 000 MW but can be as high as 4 000 MW. /30/ Two pumped hydro-storage units can reduce the excess emissions of thermal units by 60 %. /5/

PHES plants have both low specific energy and power. However, they also have relatively low power and energy densities. To work efficiently the pumped-hydro energy storage needs to be in suitable geological sites, which contain a geodetic head, natural upper and lower basins or there needs to be a possibility to build an artificial reservoir. These make the initial cost relatively high. The PHES also has an environmental impact on land occupation and modification. It can cause disturbance in aquatic life and natural water flow is changed.

2.1.2 Compressed Air Energy Storage

During the charging of compressed air energy storage (CAES)(see Figure 2), the air is compressed and stored in an underground cavern or any other pressure vessel. When electricity is required, the compressed air is released from the cavern. The released air is then heated, and the expanded air is made to turn high- and low-pressure turbines, which converts the energy of the compressed air into rotational kinetic energy. The process is called adiabatic, if the heat generated during expansion is collected and stored to use later in preheating the air, which increases the round-trip efficiency. On other hand, the process is called diabatic, if external heat input by means of combustion is used. In an isothermal process, the process is controlled to maintain the temperature with minimum changes or kept unchanged to minimize the generated by the compression. In energy applications the CAES is suitable for both medium and large energy storage. A small-scale CAES plant can be used to replace traditional chemical batteries in various suitable applications. It can also work well with intermittent power generation from renewable energy for load shifting, back-up power, smoothing power output among other things. /1,8/

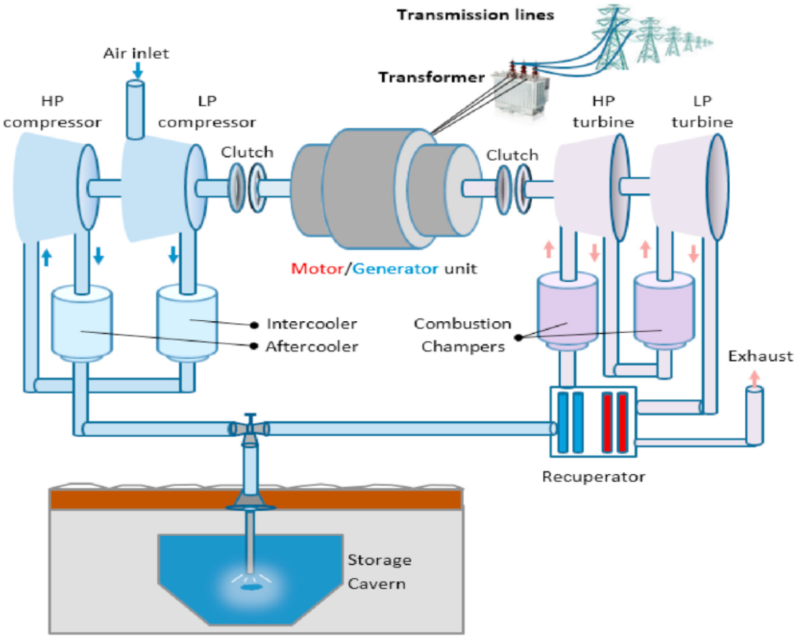


Figure 2. Compressed air energy storage system /8/

A compressed air energy storage system can work for a range of power scales from small scale (kW) to large (>100 MW). Depending on the volume of the storage reservoir used, it can be used for short (minutes) to long (days) storage time durations. The storage capacity of the CAES system can range from 50 to 300 MW. The diabatic process has an efficiency of around 54% /10/. The adiabatic process has not achieved the optimal level for energy efficiency, but the technology aims to bring the cycle efficiency to over 70%. /10, 11/ The isothermal process has aims to achieve 80% efficiency, but currently the efficiency is only 38%. /10/

A barrier for building a CAES with underground caverns is the availability of suitable geographical storage locations for electricity generation and grid location. A salt cavern is the most favourable option, with initial capital cost of a storage system about 2-10$/kWh. Hard rock formations can also be used but they have a high initial capital cost of construction (typically 30$/kWh). CAES plants have low energy and power densities (typically around 2-6 Wh/L pressure and 0.5-2 W/L), which means that they require a large storage volume /13,14/. Due to heat and mechanical losses in the compression and expansion phases, the CAES plants have relatively low round-trip efficiency (around 42%). To improve the system round-trip efficiency CAES is often combined with a thermal energy storage to store heat generated in the compression process and expansion phase (from exhaust), after which it can be reused during the expansion process. Using ES methods, the round-trip efficiency increases to around 54%, but 70 % efficiency is expected in the future. Currently traditional large scale CAES plants require combusting fossil fuels, which lead to CO2 emissions and environmental pollutions.

2.1.3 Flywheel

Flywheels store energy in the form of kinetic energy. A flywheel is driven by an electric motor that can work as a generator or as a motor. During charging, a torque is applied in the direction of rotation, which accelerates the rotor to higher speed. Discharge is achieved by applying a braking torque that decelerates the flywheel. They are currently used as UPSs, voltage, and frequency control, as a support for wind farms or to provide steady power during electrical disturbances

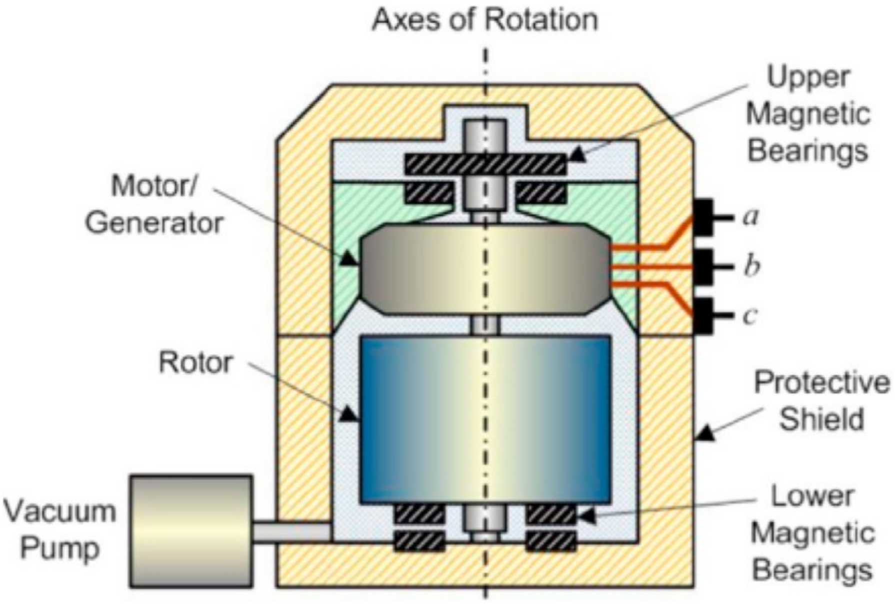


Figure 3. Flywheel storage system /8/

This storage method has a long cycle life often exceeding 10^6 cycles because the material properties of the metals and composites used are well understood. Another advantage that flywheel systems have are low maintenance cost, fast response, and a roundtrip efficiency of around 90%.

Flywheels have a high initial capital cost of 1000-5000 $/kWh. Other disadvantages are that they have high self-discharge rates, low specific energy and that they are only suitable for a short-term storage.

2.2 Electrochemical Storage

Electrochemical storage systems store energy in systems composed of one or more chemical compounds that release or absorb energy as they react to form other compounds.

2.2.1 Batteries

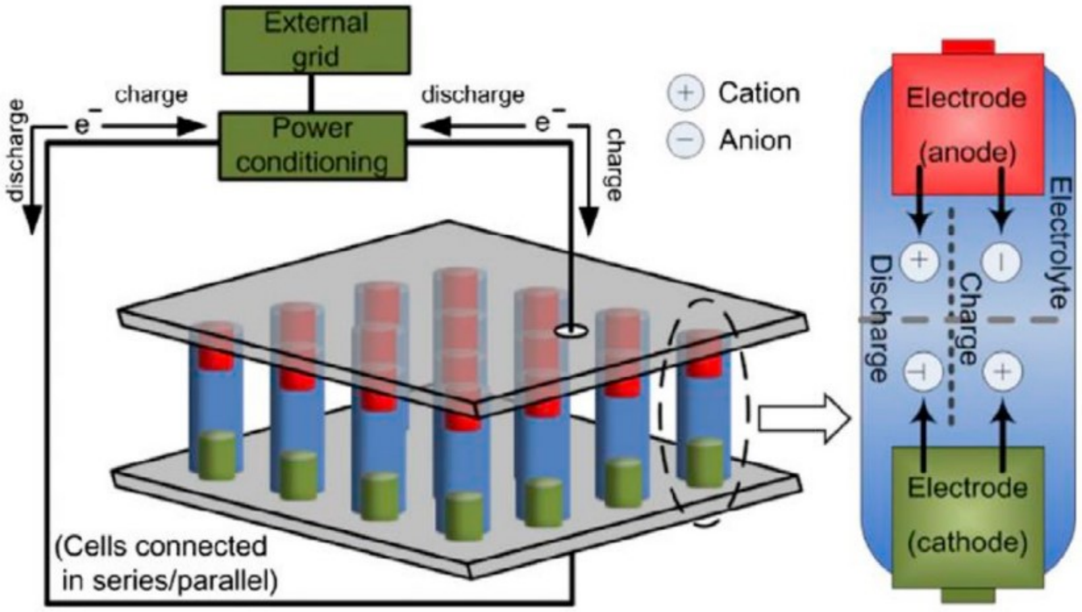


Figure 4. Battery energy storage /8/

A simple definition is that the batteries are electrochemically based electrical storage devices that are self-contained. They are based on a single device, which can store energy and discharge electricity. Electricity is produced by oxidation- reduction reaction, where a flow of electrons is created from an anode to cathode by means of electrolyte. The reverse process can recharge the battery. Different batteries available differ in design and the materials used in cathode, anode, and the electrolyte. Depending on the material used, the battery storage system will have its own strengths and weaknesses while also having some common ones. Listed below are different types of batteries and their characteristics.

Table 1. Different types of batteries and characteristics /1,18/

Battery types	**Energy density (Wh/kg)**	**Energy efficiency (%)**	**Cycle life (cycles)**	**Advantages**	**Disadvantages**
Lead-acid	30-40	70-90	200-2000	-High reliability -Operate within wide range of temperatures -Cheap per unit - Long lasting	-Heavy -Low specific energy -Toxic materials -Low capacity per unit
Ni-Cd	40-60	60-90	500-2000	-Long cycle life -Low maintenance requirements -Good capacity -High energy density	-High toxicity -Lose capacity with partial discharge -High capital cost -Lower efficiency -Higher self-discharge

Table 1. Different types of batteries and characteristics (continued)

Battery types	**Energy density (Wh/kg)**	**Energy efficiency (%)**	**Cycle life (cycles)**	**Advantages**	**Disadvantages**

NaS	150	80-90	2500	-Stable electrolyte - Long cycle life -High power density -High efficiency - No self-discharge - Low-cost materials	-High temperature - Operation more difficult -Increased operational cost - Dangerous leaks
Li-Ion	100-250	75-90	500-2000	-High energy density - Deep discharge rates -A considerable number of charge-discharge cycles -Low maintenance	-High capital cost -Overcharge & overdischarge are damaging - Requires protection circuits -Developing technology

2.2.2 Fuel cells

A fuel cell can be described as an energy conversion device that produces electricity. The fuel cell comprises four essential components: two electrodes, the anode and cathode, which are separated by electrolyte and the external circuit. The way they work can be explained as by feeding the fuel to the anode, it oxidizes and releases electrons to an external circuit. The oxidant is fed to the cathode, where it is reduced using the electrons delivered by the external circuit. Direct current electricity is produced, when the electrons flow through the interconnect from the anode to the cathode. In theory, any gas that is capable of electrochemical oxidation can be used. The most promising energy vector for fuel cells at this moment is hydrogen because of it has the highest energy density per unit mass. There are a variety of fuel cells that have the same basic operating principle but have different characteristics stemming from the nature of electrolyte involved. The operating temperature, materials, advantages, and disadvantages of the different types of fuel cells are presented in Table 2.

Table 2. Different types of fuel cells and characteristics /16,17/

Fuel cells	**Electrolyte**	**Working temperature (℃)**	**Anticipated scales**	**Electrical efficiency (%)**	**Advantages**	**Disadvantages**
PEMFCs	Ion exchange membranes	80-120	1-100 kWe	40-50	-Solid electrolyte reduces corrosion & electrolyte management problems -Low temperature -Quick startup	-Sensitive to fuel impurities -Expensive catalyst -Difficulties in thermal & water management
AFCs	KOH solution	80	10-100 kWe	60	-Faster cathodic reaction -Wide range of electrocatalyst	-High purity hydrogen
PAFCs	H_3PO_4	180-200	100-500 kWe	40	-Tolerance to impurities in hydrogen	- Slow cathodic reaction -Corrosive electrolyte -Expensive catalyst

Table 2. Different types of fuel cells and characteristics (continued)

Fuel cells	Electrolyte	Working temperature (℃)	Anticipated scales	Electrical efficiency (%)	Advantages	Disadvantages
MCFCs	Immobilized liquid molten carbonates	650-700	300 kWe-3 Mwe	45-50	-Fuel flexibility -Low-cost catalysts	-Corrosive electrolyte -High operating temperature -Long term reliability of materials due to high temperature -Relatively expensive materials
SOFCs	Ceramics	600-1000	1 kWe-2 MWe	60	-Solid electrolyte -Fuel flexibility -High efficiency - No electrolyte flooding	-High operating temperature -High manufacturing cost - Long term reliability of materials due to high temperature

Fuel cells produce much less pollutants in use, producing only water when fueled by H2 and air. The technology has a high energy density and can possibly store very large quantities of hydrogen for a long time. The size flexibility and modular construction make them well suited for decentralized applications. Because of its features, chemical storage is suitable for energy management applications and can also be used as a seasonal storage.

However, important advances are required in in transport, storage, and production of hydrogen before hydrogen-based economy can be considered. Hydrogen is typically bonded to other elements and must be isolated to be used. A most common method is to extract hydrogen from natural gas, which is expensive and produces carbon dioxide. Another method to obtain hydrogen is through electrolysis, where electrical current is used to extract hydrogen from water by separating it from oxygen. The hydrogen fuel production process is complicated, which makes using fuel cells more costly than other forms of energy. Hydrogen can be stored either as gas in high pressure tanks or as a liquid in cryogenic temperatures, however, both methods involve an inherent loss of energy. Infrastructure used for the transport of nature gas can be used, but hydrogen embrittlement of steel requires the pipes to be coated on the inside or new pipelines to be installed. PEMFCs and SOFCs are considered to have the most potential to achieve cost and efficiency targets for extensive use in power generation.

2.3 Electromagnetic Energy Storage

Energy storage systems are categorized as electromagnetic or electrical store energy in form of an electric field or a magnetic field.

2.3.1 Supercapacitor (ECES)

Supercapacitors store electrical energy in an electric field between two electrodes separated by a dielectric field and immersed in a liquid electrolyte. They store energy by means of electrolyte solution between two solid conductors. Currently supercapacitors are mainly being used for electronics and batteries.

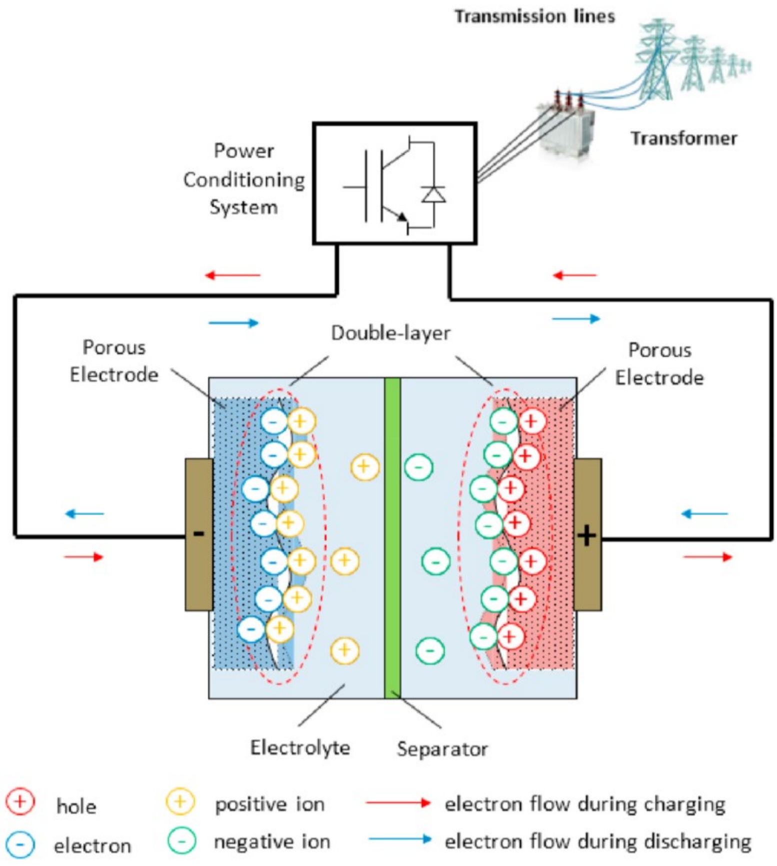


Figure 5. Schematic diagram for a capacitor /8/

Supercapacitors have a high power density and specific power 40-120 kW/L and 500-2000 W/kg respectively, which makes them ideal for systems in need of power smoothing. ECES have a high round-trip efficiency that ranges from 90 to 95 % and are expected to have long lifetime. Supercapacitors can guarantee a very high number of charge discharge-cycles.

Supercapacitors have energy density of around 10-30 Wh/L which is lower than the batteries and have lower power than traditional capacitors. Supercapacitors can store only a small amount of energy; this results in a short discharge time. They have yet to reach commercial maturity.

2.3.2 Magnetic superconductors (SMES)

In a magnetic superconductor, energy is stored in the magnetic field of one or more superconducting coils, which are characterized by very low losses. The condition is reached by working at very low temperatures.

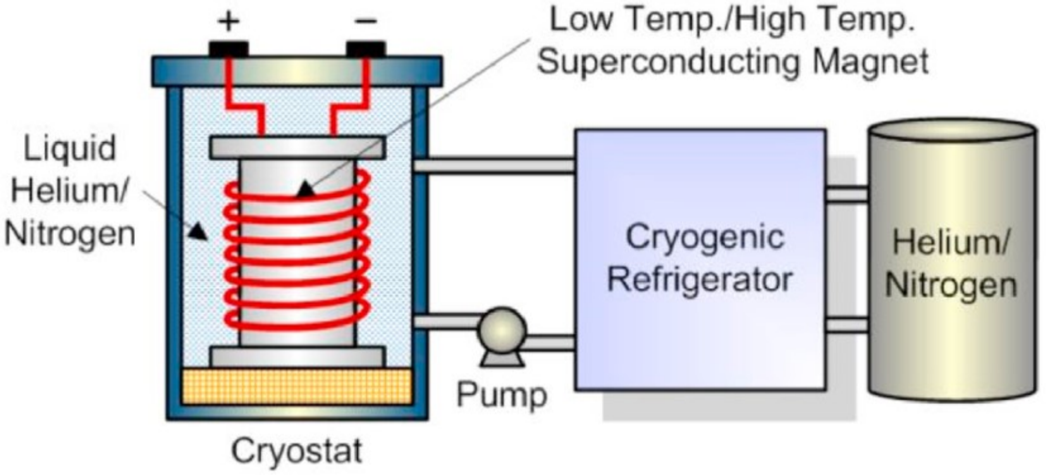


Figure 6. Superconducting magnetic energy storage /8/

Magnetic supercapacitors have very fast delivery of high power at high cycle efficiency, because of this, the technology is suitable for power application, which require continuous operation with many charge-discharge cycles. SMES systems have a round-trip efficiency of over 95%, which means that the electricity loss during the storage process is small.

Currently only small commercial SMES storage units with capacities of between 100 kW and 100 MW can be built. The largest one to be built could deliver around 10 MW. The commercial devices have a storage capacity of between 10 and 30 kWh. /15/ The problem currently faced is the necessity of a cryogenic temperature with the prohibitive cost and high energy requirement. This means that the technology will have a low energy density and low round-trip efficiency.

2.4 Thermal Energy Storage (TES)

Thermal energy storages are used for many heating and cooling applications, for example, where heat supply and demand are not often simultaneous or to utilize peak shaving of heating demand. This type of energy storage can be very long-term, even seasonal. The TES can be used for electric applications to support renewable energy plants. Using the TES and energy system increases the overall efficiency and makes the system more reliable and can lead to better economics and reduce investment and running costs. Support to the grid can be given by storing heat from electric boilers, working as fast balancing service, or helping limit the demand for electric power from electric boilers. /1,2/

Thermal energy storages have a relatively low overall cycle efficiency of 30-50 %, but they make up for that with low self-discharge rates and high energy discharges. Another advantage for the storage technology is that they are environmentally friendly and have low initial capital cost. /8/

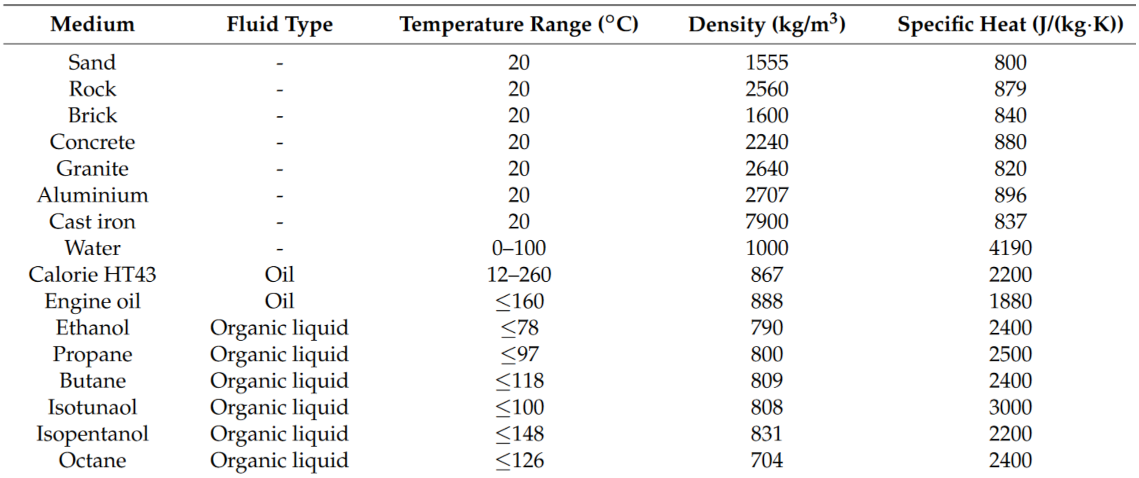
Thermal energy storage includes many technologies where energy is stored in form of heat, which can be stored as sensible heat, latent heat, or thermochemical heat. Low temperature thermal energy storage is most ideal for load shavings, industrial cooling, and power management. Sensible and latent heat storages are useful in high temperature thermal energy systems. /8/

2.4.1 Sensible Heat

The sensible heat method is based on storing thermal energy by heating or cooling a liquid or solid storage medium. The amount of heat that is stored depends on the specific heat of the medium, the temperature change, and the amount of storage material. Sensible heat storage systems are suitable for domestic systems, district heating and industrial needs.

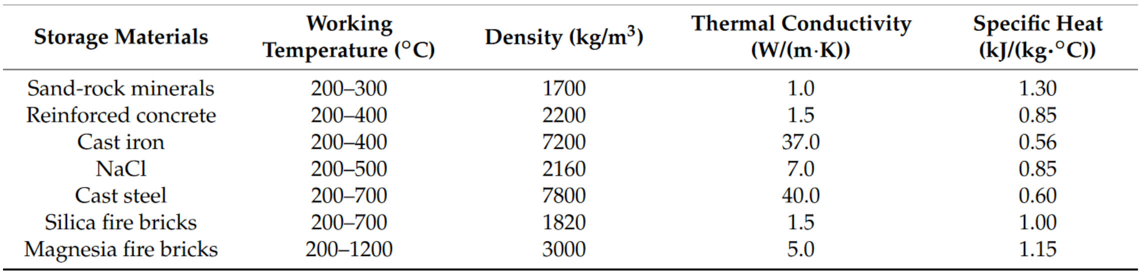
Figure 7 shows sensible heat storage materials and their properties. Water is most popular and commercially viable as a heat storage medium because it is both inexpensive and has a high specific heat. Oils, molten salts, and liquid metals are used, when the temperature of stored heat is above 100 ℃. The main characteristic of most used solid-state thermal storage materials among some others are show in Figure 8. The working temperature of these materials ranges from 200 and 1200 ℃ and the thermal conductivity ranges from 1.0-7.0 ($W/m \cdot K$) for sand-rock minerals, concrete, and fire bricks and 37.0-40.0 ($W/m \cdot K$) for ferroalloy materials. The materials are low-cost ranging from 0.05 to 5.00 $/kg. Solid-state thermal storage materials have rather low heat capacities, ranging from 0.56 to 1.3 ($kJ/kg \cdot$ ℃), which can cause the storage unit to become large.

Two main advantages of the sensible heat storage are that it is cheap and there is no risk associated with the use of toxic material. Depending on the specific heat of storge medium and thermal insulation technologies sensible heat storages can offer a storage capacity that ranges from 10 to 50 kWh/t and storage efficiencies from 50 to 90 %. The cost of complete system ranges between 0.1 and 10 €/kWh, depending on the size, thermal insulation technology and application.



Medium	Fluid Type	Temperature Range (°C)	Density (kg/m^3)	Specific Heat (J/(kg·K))
Sand	-	20	1555	800
Rock	-	20	2560	879
Brick	-	20	1600	840
Concrete	-	20	2240	880
Granite	-	20	2640	820
Aluminium	-	20	2707	896
Cast iron	-	20	7900	837
Water	-	0–100	1000	4190
Calorie HT43	Oil	12–260	867	2200
Engine oil	Oil	≤160	888	1880
Ethanol	Organic liquid	≤78	790	2400
Propane	Organic liquid	≤97	800	2500
Butane	Organic liquid	≤118	809	2400
Isotunaol	Organic liquid	≤100	808	3000
Isopentanol	Organic liquid	≤148	831	2200
Octane	Organic liquid	≤126	704	2400

Figure 7. List of solid- liquid materials for sensible heat storage /20/



Storage Materials	Working Temperature (°C)	Density (kg/m^3)	Thermal Conductivity (W/(m·K))	Specific Heat (kJ/(kg·°C))
Sand-rock minerals	200–300	1700	1.0	1.30
Reinforced concrete	200–400	2200	1.5	0.85
Cast iron	200–400	7200	37.0	0.56
NaCl	200–500	2160	7.0	0.85
Cast steel	200–700	7800	40.0	0.60
Silica fire bricks	200–700	1820	1.5	1.00
Magnesia fire bricks	200–1200	3000	5.0	1.15

Figure 8. Solid-state sensible heat materials /21/

Hot water tanks can be used for the purpose of energy saving in a water heating system both by solar energy and co-generation in energy supply systems. A major advantage that water tank storages have is that they are a cost-effective way to store heat. Its efficiency can be improved further by ensuring optimal water stratification in the tank and using highly effective thermal insulation. This technology can be used as seasonal storage of solar thermal heat in combination with small district heating systems. Another use for hot water tanks is to act as a buffer storage for domestic hot water supply. The system pressure needs to be increased when sensible heat storages use water as a medium for high temperature applications, the system pressure needs to be increased, because of the boiling point constraint.

An underground thermal energy storage is a widely used storage technology, where ground is used as a storage medium for both heat and cold storage. Heat transfer fluids are needed to add and remove energy from the medium, which is done by pumping fluids through pipe arrays in the ground. Energy transport can be done through evaporation and condensation and the movement of water through medium, if the storage medium is porous. Insulation is not usually used for this storage method, but it can be provided at ground surface. An underground storage using both liquid and solid medium is typically used for large-scale applications. Limiting factors for rates of charging and discharging are the area of the pipe arrays and the rates of the heat transfer through the ground surrounding the pipes.

Boreholes and heat pumps are used in combination when low-temperature heat is extracted from soil or can be used as seasonal storage. During a study on using borehole thermal energy storage system (BTES) for a seasonal storage, annual efficiencies ranging from 48 to 69 % were obtained. The heat output from BTES was 1380-5717 MWh. /23/

An aquifer storage is equivalent to the ground storage, except it uses water as its primary storage medium. Water is used to pump heat into and out of the ground to heat it and extract energy from it. Water flow works as heat exchanger with the ground itself. Aquifers cannot be insulated, and it can only be used if flow rate is slow through the storage field. Another barrier to the aquifer is that heated water may have chemical reactions with the ground materials.

A packed-bed storage makes use of heat capacity of a bed of loosely packed particulate material to store energy. When energy is needed to be removed or added fluid is circulated through the bed. The addition of heat flow is maintained through the bed in one direction and in the opposite direction during the removal of heat. Unlike with water storage systems, heat cannot be added or removed simultaneously with packed-bed storage system. The technology has a high degree of stratification, and the temperature is constant when the bed is fully charged. During a study on using ceramic bricks as material for packed-bed storage high efficiencies were achieved, 72-93% for an airflow rate of 0.0050 m^3/s and 74–96% for an airflow rate of 0.0068 m^3/s. As filling material bricks are easily available and have good thermal properties. They are highly resistant to high temperatures and tolerate a high number of charge/discharge cycles. /22/

2.4.2 Latent Heat/ Phase-change Storage

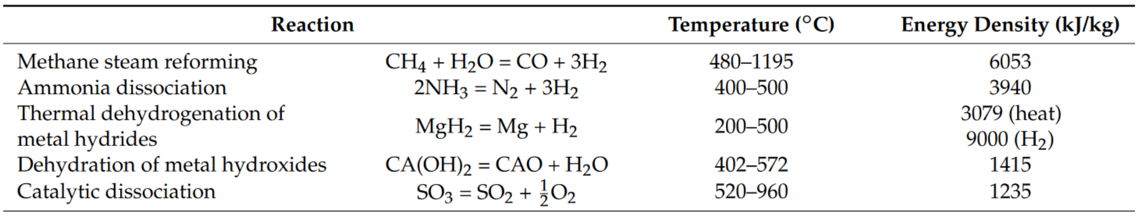
Phase-change storage materials change their physical state during release or absorption of energy. The storage is connected to a phase transition of the storage material, for example from solid to liquid and liquid to gas. The heat is mostly stored in phase-change process and is directly connected to the latent heat of substance. The phase-change storage has a high energy storage density, and the nature of the storage process is isothermal. Another advantage is that the tank volume can be reduced for given amount of energy stored, if operating temperature range is very narrow around phase-transition temperature. The technology can be used for both long-term and short-term energy storage, by using variety of technologies and materials. Material used for storage can be inorganic, organic, or eutectic (combination of two or more low melting materials with similar melting and freezing point).

Phase-change can offer a higher storage capacity than sensible heat storage and the storage efficiencies range between 75 to 90%. The storage is based mostly on a solid-liquid phase change with energy densities 100 kWh/m^3. The cost of phase-change storage systems ranges between 10 to 50 €/kWh, depending on the material that is used.

Compared to the water tank storage the investment cost is higher and the technology has higher risks, because of leaks of stability and erosion of material. Currently the technology is under development and demonstration and is yet to be commercially available.

2.4.3 Thermochemical Heat

A thermochemical heat storage uses materials, which store and release heat by a reversible endothermic and exothermic reaction processes. The charging process takes place by applying heat to the material, resulting in a separation of two parts. The reaction product can be separated and stored until a discharge process takes place. During the discharge phase two reaction products are mixed at suitable pressure and temperature condition, which releases energy. Figure 9 shows some chemical reaction and their characteristics.



Reaction		Temperature (°C)	Energy Density (kJ/kg)
Methane steam reforming	$CH_4 + H_2O = CO + 3H_2$	480–1195	6053
Ammonia dissociation	$2NH_3 = N_2 + 3H_2$	400–500	3940
Thermal dehydrogenation of metal hydrides	$MgH_2 = Mg + H_2$	200–500	3079 (heat) 9000 (H_2)
Dehydration of metal hydroxides	$CA(OH)_2 = CAO + H_2O$	402–572	1415
Catalytic dissociation	$SO_3 = SO_2 + \frac{1}{2}O_2$	520–960	1235

Figure 9. Chemical reactions for thermal energy storage /21/

Thermochemical storage systems can have a storage capacity of 250 kWh/t with operating temperatures of over 300°C and its storage efficiencies range from 75 to nearly 100%.

The storage system is very expensive, when taking into consideration the materials, containers, and auxiliary thermochemical heat storage equipment for both heat and mass transfer during energy charging and discharging. The estimated cost of the system is ranges between 8 to 100 €/kWh. The thermochemical heat storage has some issues related to physical and chemical stability. In addition, the storage system is still under development and demonstration.

3 WESTENERGY

Westenergy is a Finnish company that operates a waste incineration plant in Vaasa. The company was established 2007 and the plant was completed 2012. It operates in between two sectors, energy sector and waste management. The Waste-to-Energy plant refines combustible waste by burning into electricity, heat and recovered materials. Energy is produced in co-operation with the local energy company Vaasan Sähkö. The plant produces about 50% of the district heating needed in the Vaasa region. It is owned by six municipal waste management companies located in the western part of Finland.

Figure 10. Westenergy Waste-to-Energy plant

3.1 Technology

Every day around 30 waste trucks tip their waste into waste bunker, which has room for five million trash bags. The stability of the energy generation process is ensured by mixing waste with an automatic grab so that the fuel of the plant remains as consistent as possible. Waste is incinerated at 1000 ℃, which remains consistently high due to air being constantly blown onto the grate. In boiler, heat is transferred from hot flue gases into boiler water which in turn becomes steam, which is heated up to 400 °C at a pressure of 40 bars. Under the grate bottom ash consisting of metal and ash is shoveled onto conveyers and from into automatically changing containers. The purification of flue gases takes place in several stages. First, lime and activated carbon bind acidic impurities and heavy metals, which are filtered out in fabric filter. In the last stage flue gas scrubber purifies flue gases and heat exchanger recover heat. Steam rotates the turbine that in turn rotates the generator, which has an output of 15 MW. Cold district heat water is heated by hot steam in the district heat unit, which has an output of 40 MW. The temperature produced by the district heat unit depends on the time of the year and the weather, but it ranges from 65 to 115 °C. Listed below are the different parts belonging to WtE plant. /32/

Figure 11. Waste-to-energy plant parts: 1) Tipping hall, 2) Waste bunker, 3) Grate and furnace, 4) Boiler, 5) Flue gas treatment system, 6) Generator and turbine, 7) District heat unit, 8) Bottom ash /32/

3.2 Statistics

The annual energy production and efficiency of the Westenergy plant including amount of waste brought their yearly are presented in Table 3 below:

Table 3. Annual production of Westenergy /32/

Year	**Amount of Waste (t)**	**Operating hours**	**Electricity (GWh)**	**District heat (GWh)**	**Efficiency (%)**
2016	163 118	7214	77.81	258.5	
2017	188 208	8312	92.31	320.97	89.1
2018	190 679	8369	106	364	88.7
2019	189 638	8187	113	379	90.6
2020	193 675	8263	89	402	94.1

3.3 Data Collection

One interview was conducted for this case study. The interviewee was sent the questionnaire beforehand by a text message. The interview was held when it was most suitable for the interviewee and was done by using Microsoft Teams and was conducted in Finnish. After the interview, time was given to answer more in-depth questions and more information was sent later through email.

3.3.1 Interview

The interview was conducted with the Communication Officer of Westenergy, Sanna Hautamaa. Production Manager, Kai Alavillamo, assisted in answering more technical questions. Listed below are the questions asked in Table 4.

Table 4. Interview questions

Questions
Does the plant experience any heat or energy losses?
When did Westenergy start to use energy storage system?
What type of energy storage does Westenergy use currently?
What is the energy efficiency and storage capacity of energy storage?
In what ways was the energy storage useful for Westenergy?
When was the storage system most useful?
Are there any plans related to energy storage?

3.3.2 Results of Interview

Westenergy experiences heat losses during the conversion and transportation of energy, but the powerplant building also experiences some losses. After leaving Westenergy, the hot district heat water loses some heat when travelling through pipes.

Westenergy made a deal with Vaasan Sähkö to use their heat energy storage near centrum of Vaasa in Vaskiluoto in 2020. The storage was tested during the summer of 2020 and the initial load was done by using extra heat from Westenergy. The storage is an underground thermal energy storage, which utilizes two caves underneath the Vaskiluoto powerplant. The total volume of the energy storage is 210 000 m^3. The larger cave is used to store water and transfer thermal energy to the district heating network. The smaller cave acts as an expansion tank for the heat storage water. The charging and discharging capacity of the thermal energy storage is 100 MW, which is enough for 4 to 20 days, depending on discharging capacity. The storage is capable to store between 7 000 and 9 000 MWh. /27/

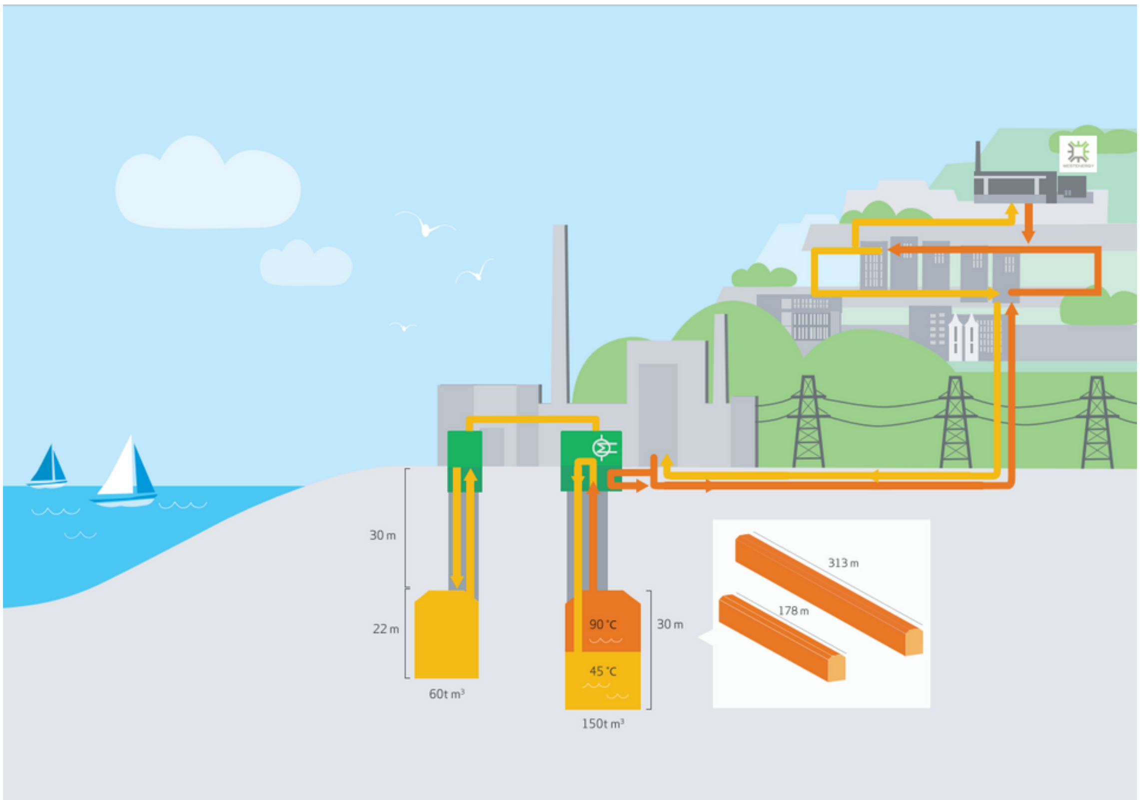


Figure 12. Vaskiluoto thermal energy storage.

The thermal heat storage helps Westenergy to make better use out of their energy production. During the summer Westenergy produces all the district heat needed in the Vaasa region but the need is lower than the heat produced, because there is a production limit that cannot be gone under to keep the process stable. The excess heat used to be released to air through the summer cooler. After Westenergy started to use a thermal heat storage, the extra heat produced could be stored and be used during high energy demand in the wintertime or problem situations during the production, which makes the energy production process more reliable.

Westenergy is looking into the possibility to shift their annual maintenance break form spring to summer. The heat storage would be used to cover for the needed heat when the needed heat is much lower.

4 CONCLUSIONS AND DISCUSSION

Demand for energy continues to rise in Finland, need for energy storing technologies increases. Russia’s pressure on Ukraine puts pressure on Finland to more become more self-sufficient in energy production and implement methods to store energy. Climate change is another factor, which pushes Finland to utilize energy storage technology to ensure a sustainable development. The study aims to give information on possible energy storage methods and find suitable storage for the Nordic countries. The case study was done on Westenergy to see how they are implementing energy storage technology and analyse its suitability for similar powerplants.

The findings of the study are that the most promising storage systems for large scale-applications are CAES, Li-ion batteries, fuel cells and underground thermal storage. A waste-to-energy powerplant located in northern climate would get most use out of an underground thermal storage because with this type of storage system the powerplant can store the excess thermal energy produced during the summer and use it later during the winter, without it getting released back to air as waste heat. The storage system also has a large energy storage capacity and low initial capital cost, especially if old cave systems were to be used. An underground thermal energy storage can help to reduce peak thermal demands and increase the efficiency of the system. Because of the benefits that the technology brings it would be counterintuitive for the Westenergy to switch to another storage method.

From a practical point of view, the study can be utilized as a guideline to determine a suitable energy storage technology for a waste- to-energy powerplant.

The limitation of the research is related to time and data collection. Had there been more time to interview more companies utilizing waste-to-energy plant, the data could have been used to compare storage technologies and get more accurate data.

REFERENCES

/1/ Crawley, Gerard M., Energy Storage, World Scientific Publishing Co Pte Ltd [2017]

/2/ Ioan Sarbu, Calin Sebarchievici. Comprehensive Review of Thermal Energy Storage, Accessed 01.03.2021.https://www.mdpi.com/2071-1050/10/1/191/pdf

/3/ Dincer, I.; Rosen, M.A. 2011.Thermal Energy Storage: Systems and Applications; John Wiley & Sons: Chichester,UK.

/4/ Electric Power Research Institute. 2010. Electric energy storage technology options: A white paper primer on applications, costs and benefits, Palo Alto, CA.

/5/ M. E. Nazari, N. M. Ardehali and S. Jafari. 2010. Pumped-storage unit commitment with considerations for energy demand, economics, and environmental constraints, Energy 35 (2010), pp.4092-4101

/6/ Nikolaidis Pavlos, Poullikkas Andreas. 2017. A comparative review of electricalenergy storage systems for better sustainability. Journal of Power Technol-ogies 2017;97(3):220e45

/7/ Elio J, Phelan P, Villalobos R, Milcarek RJ. Nd. A Review of Energy StorageTechnologies for Demand-Side Management in Industrial Facilities, Journal of Cleaner Production, https://doi.org/10.1016/j.jclepro.2021.127322.

/8/ A.G. Olabi, C. Onumaegbu, Tabbi Wilberforce, Mohamad Ramadan, Mohammad Ali Abdelkareem, Abdul Hai Al – Alami.2021. Critical review of energy storage systems, Energy, Volume 214, 2021, 118987, ISSN 0360-5442, https://doi.org/10.1016/j.energy.2020.118987.

/9/ Molina MG. 2010.Distributed energy storage systems for applications in futuresmart grids. In: 2012 sixth IEEE/PES transm. Distrib. Lat. Am. Conf. Expo., no.0162; 2012. p. 1e7.

/10/ D. Wolf and M. Budt. 2014. LTA-CAES – A low temperature approach to Adiabatic Compressed Air Energy Storage, Appl. Energy 125 (2014) pp. 158–164.

/11/ RWE power, ADELE – Adiabatic compressed-air energy storage (CAES) for electricity supply, ADELE Brochure. Accessed 10.03. 2022. https://www.rwe.com/web/cms/mediablob/en/391748/data/364260/1/rwe-power-ag/innovations/Brochure-ADELE.pdf

/12/ LightSail Energy Ltd. We store energy in compressed air. Accessed 12.03. 2022. http://www.lightsail.com/

/13/ Electrical energy storage: White paper, Energy Storage team, IEC Market Strategy Board 2011. Accessed 12.03.2022. http://www.iec.ch/whitepaper/pdf/iecWP-energystorage-LR-en.pdf

/14/ T. Lombardo. 2013. Cryogenic energy storage. Accessed 16.03. 2022. http://www.engineering.com/ElectronicsDesign/ElectronicsDesignArticles/ArticleID/5780/Cryogenic-Energy-Storage.aspx

/15/ Breeze, Paul. 2018. Power System Energy Storage Technologies Accessed 16.03. 2022. https://doi.org/10.1016/C2016-0-03680-X

/16/ Manoj K. Mahapatra, Prabhakar Singh. 2014. Fuel Cells: Energy Conversion Technology Accessed 20.03.2022. https://www.sciencedirect.com/science/article/pii/B9780080994246000247

/17/ Fuel Cell handbook. 2014. 7th edition. US Department of Energy Southwest Washington D.C.

/18/ Md Multan Biswas, Md Shafiul Azim, Tonmoy Kumar Saha, Umama Zobayer, Monalisa Chowdhury Urmi.2013. Towards Implementation of Smart Grid: An Updated Review on Electrical Energy Storage Systems. Accessed 24.03.2022. https://www.scirp.org/journal/PaperInformation.aspx?PaperID=28145

/19/ Kavadias Kosmas, Triantafyllou Panagiotis. 2021. Wind-Based Stand-Alone Hybrid Energy Systems. https://doi.org/10.1016/B978-0-12-819727-1.00162-X

/20/ Ayappan, S., Mayilsamy, K., Sreenarayanan, V.V. 2016. Performance improvement studies in a solar greenhouse drier using sensible heat storage materials. Heat mass Transf. 2016, 52, 459—467.

/21/ Tian, Y.; Zhao, C.Y. 2013. A review of solar collectors and thermal energy storage in solar thermal applications. Appl. Energy 2013, 104, 538–553.

/22/ Nems, M.; Nems, A.; Kasperski, J.; Pomorski, M. Thermo-hydraulic analysis of heat storage filled with the ceramic bricks dedicated to the solar air heating system. *Materials* **2017***, 10, 940.*

/23/ Hirvonen, Janne, Kosonen, Risto. 2020. Waste Incineration Heat and Seasonal Thermal Energy Storage for Promoting Economically Optimal Net-Zero Energy Districts in FinlandAccessed 06.04.2022. https://doi.org/10.3390/buildings10110205

/24/ Statistics Finland. 2021. Energy supply and consumption., Accessed 12.04.2022. https://www.stat.fi/til/ehk/2021/03/ehk_2021_03_2021-12-20_tie_001_en.html

/25/ The World Bank. 2017. Electric power consumption (kWh per capita),. Accesses 13.04.2022. data.worldbank.org/indicator/EG.USE.ELEC.KH.PC?year_high_desc=true.

/26/ Finnish Government. Strategic themes. Accessed 13.04.2022, https://valtioneuvosto.fi/en/marin/government-programme/carbon-neutral-finland-that-protects-biodiversity

/27/ Vaasan sähkö. 2019 Massive underground energy storage in Vaskiluoto Vaasa, Accessed 13.04.2022. https://www.sttinfo.fi/tiedote/massiivinen-maanalainen-energiavarasto-vaasan-vaskiluotoon?publisherId=58661976&releaseId=69859866

/28/ Liu, Zhenya. 2015. Global Energy Interconnection. Accessed 15.04.2022. https://doi.org/10.1016/B978-0-12-804405-6.00001-4

/29/ Intergovernmental panel on Climate Change. Special report: Global Warming of 1.5 ℃. Accessed 15.04.2022. https://www.ipcc.ch/sr15/

/30/ Evans, Annette Evans, Strezov, Vladimir Strezov, Evans, Tim J. 2012. Assessment of utility energy storage options for increased renewable energy penetration, Renewable and Sustainable Energy Reviews, Volume 16, Issue 6. Accessed 17.04.2022. https://doi.org/10.1016/j.rser.2012.03.048.

/31/ Energiavirasto. 2021. Electricity is expected to be sufficient in Finland during the cold winter months - long periods of sub-zero temperatures may restrict the importation of electricity from neighbouring countries. Accessed 17.04.2022, https://energiavirasto.fi/en/-/electricity-is-expected-to-be-sufficient-in-finland-during-the-cold-winter-months-long-periods-of-sub-zero-temperatures-may-restrict-the-importation-of-electricity-from-neighbouring-countries

/32/ Westenergy. Westenergy's waste-to-energy plant. Accessed 21.03.2022, https://westenergy.fi/en/energy-recovery/wte-plant/ .