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Abstract:

The thesis examines which energy production methods are suitable together with seasonal storage of energy at UiT the arctic university of Norway in Narvik. Nordkraft has provided the subject which has been examined. The location of UiT Narvik together with its areas and storage volumes have been examined for what power production methods and energy storage methods are suitable for this location. The costs of clearing out the current storage location, preparing it for storage, filling it, and using it has been examined. The power price has been examined to find potential earnings of the storage system. The price history for power, and what it might be in the future has also been examined. It has been determined that the storage can be economically viable given that the current storage is perfectly insulated and the price difference between when the energy is bought and used is big enough. The largest contributing factors for this are the number of charges of the storage, the cost of establishing the system, the power price and low operational and maintenance costs.

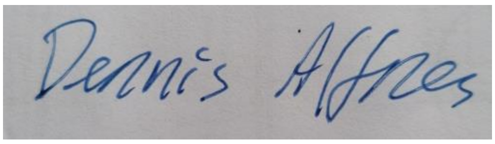
Preface

I am a student at UiT Narvik who has worked on completing my Master education. I have been given a task from Nordkraft and have cooperated with them during this last semester. The purpose of the task was to find out what energy storage methods are suitable for UiT Narvik and if this campus has any unique opportunities.

With the work of this task a lot of knowledge from both within and outside the scope of my study has gone into this thesis. I have had great meetings with my contact person at Statsbygg, Leif Erik Nordberg who I give a great thanks to. The meetings have resulted in informative conversations and a lot of helpful information regarding the campus. Matthew Homola, which is the client, have also assisted with a lot of insight and constructive criticism. My supervisor, Pawan Sharma, has also been helpful in guiding my task towards what it is. I have been lucky that I have had cooperative and supportive contact persons and supervisor.

The task itself have been both exciting and very relevant with what it can be used for. There have been obstacles, but with perseverance and guidance most of these have been surpassed. The process has been enlightening and challenging, which have made the academic development large.

Narvik, May 2023.



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Words and abbreviations	**Description:**
A	Area [m^2]
V	Volt (Voltage)
CSP	Concentrated solar power
PV	Photovoltaic, which is voltage produced by the exposure from light.
STC	Solar thermal collector
W	Watt (Power)
kWh	Kilowatt per hour (1000 Wh) [10^3]
MWh	Megawatt per hour (1000 kWh) [10^6]
GWh	Gigawatt per hour (1000 MWh) [10^9]
TWh	Terrawatt per hour (1000 GWh) [10^{12}]
WP	Watt-peak is a measure of given effect from a solar panel under standard test-conditions, when the radiation reaches its top
ES	Energy storage
TES	Thermal energy storage
STES	Seasonal thermal energy storage
CAES	Compressed air energy storage
FCES	Fuel cell energy storage
LAES	Liquid air energy storage
PHES	Pumped hydro energy storage
TCES	Thermochemical energy storage
HTF	Heat transfer fluid
RES	Renewable energy sources
PCM	Phase-change material

Inverter	Changes voltage from DC-voltage to AC-Voltage
CAPEX	Capital expenditure
CPI	Consumer price index. Describes the price development on wares and services.
OPEX	Operational expenditure
SSB	Statistical central bureau. Has the agency for statistics in the Norwegian society.
NO1-NO5	Norway’s price areas for Norway set by NordPool.
NPV	Net present value. Describes what a future investment is worth in today’s money.
LCOE	Levelized cost of energy. How much money goes into 1 kW of installed capacity or 1 kWh of energy.

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1 Introduction

This thesis examines the possibilities for seasonal storage of energy at UiT Narvik and whether this campus has special opportunities. It investigates the financial aspects of implementing said methods and what economic benefits this will give the university as well as if it will also benefit the energy producers by putting less strain on the grid during the demanding winter season.

1.1 Driving force

As energy production from the renewable sources solar and hydropower are greatest during the summer, but energy demand is larger during the winter due to heating, it is beneficial to store this production during the summer and use it during the winter. By storing this energy for later use the demand put forth on the producers can be reduced and the costs for the consumers can be lowered. Wind is producing more electricity during the winter, but it does not cover the energy demand during the winter. With the appropriate method implementation and proper cost to performance calculations storage of energy can be beneficial.

1.2 Background

With a continuous fall in solar cell prices, and the technology is continuously improving, it is becoming more implemented in Norway and the neighboring countries. While also instalments of more wind farms are happening around the country to cover the demands of a continuously increasing population as well as more electrical implementations in the daily life instead of fossil solutions. This increase in green-energy production, both from production companies and homeowners, indicate a downward pressure on power prices throughout the summer season, due to an uncontrolled production from both. This together with Norwegian hydropower system having the strongest inflows during the summer, and filling up the reservoirs, creates a problem. The problem that is what to do with all the excess energy. That is why it is important to provide solutions to manage these energy situations.

1.3 The problem

What sustainable energy storage solution can be implemented for the university in Narvik?

- How will the energy be created?
- How will the energy be stored?
- How will it be used?
- Will it be economically viable for the university?
- How is this storage beneficial for the university, the producers and society?

1.4 Limiting the problem

To detain the task from getting too large given the amount of time available for the thesis, restrictions are made. The task will only consider the University of Narvik as a case study. Real-time simulations will not be used but earlier works regarding seasonal storage will be used together with calculations.

1.5 Why store energy

During the summer Norway covers its own, as well as the small power flow demands going back and forth between the neighbor countries [22]. Due to the intermittent production of electricity from both wind and solar, extra regulations are made to hydropower to avoid too high of a grid frequency. If there is lacking flexibility of the production system, such that the production cannot be reduced at said time, it will be forced to produce. This can be due to a required flow rate from the reservoirs, snow melting and rapidly filling reservoirs or rain, so they need to be drained. When production is too high compared to the demand, the power prices are low. This is beneficial to consumers because of the low power prices this brings, but not so much for the producers as the producers are missing out on surplus. So, if the produced energy can be stored over a long time to be used later, it would both put less pressure on the producers' generators during a season of high demand, as well as benefit the consumers with lower prices due to low production cost. It will also provide stability to the grid if the chosen solution allows for evening out the flow of power with the peaks and dips of the energy flow. There are a lot of plans for phasing out the use of fossil fuels, going net zero emission and instead implementing electric solutions for transportation as well as more electric implementations for other uses. With this increase in electric demand, and lopsided energy production from solar during the summer compared to the winter, which is installed to move towards a greener future, it is important to be able to provide for these demands when the time comes.

Figure 1 shows the power production in Norway compared to the consumption in 2022, where the orange numbers and graph is the production, while the blue ones are consumption [83].

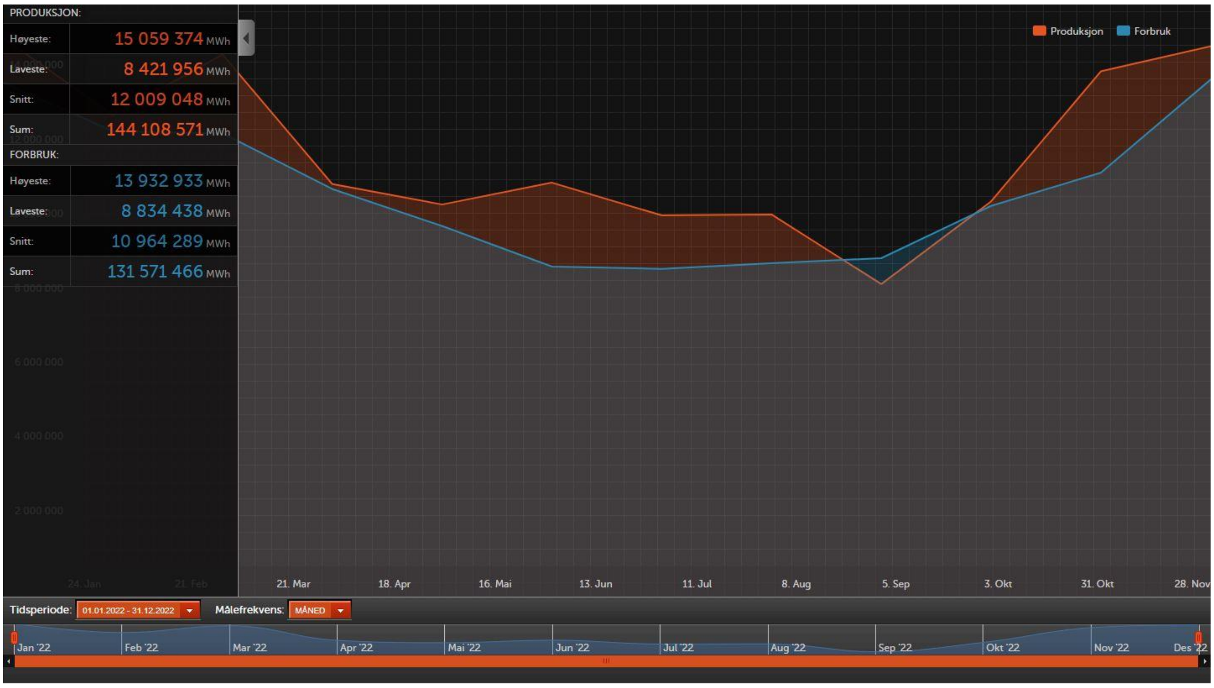

Figure 1 Electricity production and consumption 2022, acquired from Statnett's webpage

2 Theory

In chapter 2 the reason for energy on Earth will be introduced, together with multiple ways to harness this energy. The necessary size, location and materials/fuel for these methods will be included along other factors which impacts these methods.

2.1 The Earth’s orbit around the sun

2.1.1 Solar hours

During the year the amount of sunlight hours during the day changes, with more hours being present during the summer season. With the amount of energy provided by the Sun being higher than during the winter. There is a potential to gather energy during Spring and Fall, but mostly during the summer. The website timeanddate.com [37] shows the number of daylight hours available during the year for Narvik. It is important not to confuse the amount of daylight hours for a location with the number of sunlight hours of said location. As daylight hours will not necessarily provide power production from certain methods while sunlight hours will, as sunlight hours are hours where something is irradiated. And as Figure 2 shows, there is no daylight in Narvik until the seventh of January, and it is only for 20 minutes during that day. The website shows that there are great opportunities for harnessing the power of the Sun from April to September, with lesser opportunities before and after this period.

Figure 2 shows January 7 from [37], where the darkest areas is the amount of nighttime, the three lighter colors are different kinds of twilight and the brightest is daylight.

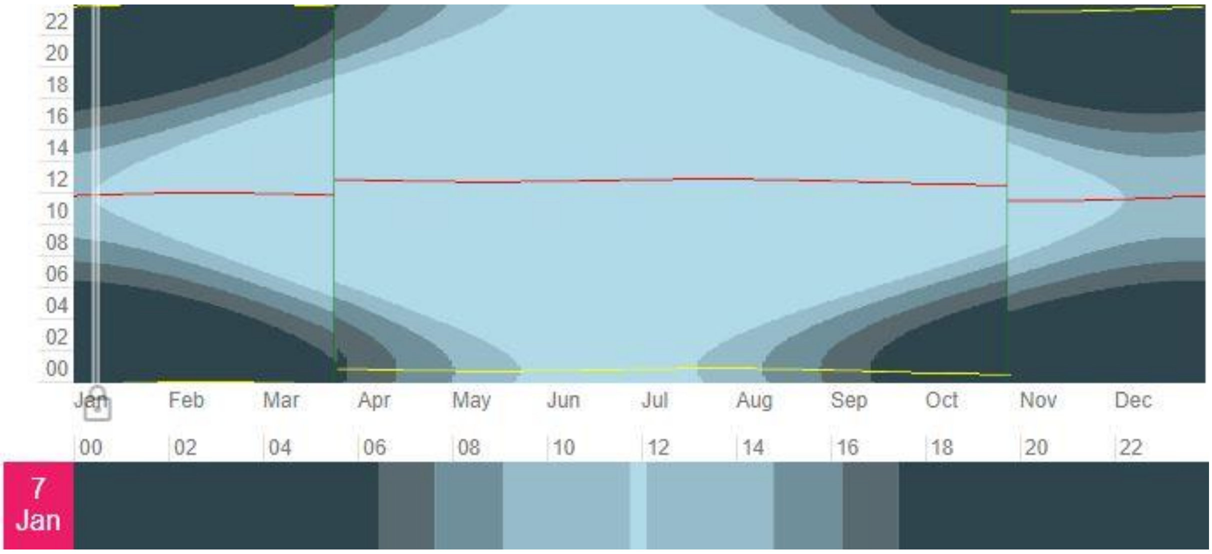

Figure 2 Time and date Sun graph for January 7

2.1.2 Solar radiation

Solar radiation is electromagnetic radiation from the Sun in the form of visible light and invisible light for humans. This energy is heating up the Earth and is the reason for life on this planet. The Sun heats up the atmosphere and the ocean, leading to buildup of wind, waves, and rain. This energy also heats up residences and buildings, there are also devices created to capture this energy directly [65]. The devices that capture the light directly are photovoltaic panels (PV), also known as solar panels, and devices that capture the heat from the Sun are solar thermal collectors (STC).

2.1.3 Irradiance

Irradiance, which is the energy density of radiated energy onto a flat area and is measured in Watts per square meter (W/m^2). The irradiance declines with the square distance from the Sun and varies during the year following the elliptic course of the Earth [66]. The solar constant is at 1370 W in the outer atmosphere layer, but a part of this is reflected into space. This results in approximately 1000 W/m^2 reaching the surface of the Earth [65].

2.1.4 Albedo

When sunlight hits the ground, it will be absorbed or reflected. The relation between total solar irradiation and reflected light is called albedo. A surface with low albedo will absorb a lot of energy, while a high one will reflect a lot of it. Snow for example reflects a lot more sunlight than a dark surface. This is due to snow being white and reflecting a lot more visible light compared to a darker color which absorbs it. It is not solely the surface that affects albedo, but also the latitude. The sunlight that hits Norway is coming in at a higher angle than sunlight that hits the equator, making the ability to absorb of a horizontal surface lower in Norway compared to the equator [64].

2.1.5 Azimuth

Azimuth is the angle of the Sun's placement on a horizontal level and is used together with longitude to show where the Sun is compared to where it is measured from. On the northern hemisphere the Sun is always directly south when the Sun is at its peak during the midday [67].

2.2 Ways to create energy for storage as a consumer

2.2.1 Cheap electricity from the grid

One very simple way to collect energy is to buy electricity when the price is low and use this energy later. This can be done with advanced control systems or looking up the spot price at the time and then buy it. This method is best suited for charging electrical batteries directly, as there will be few losses as battery storage is a highly efficient process. The fewer steps implemented into the system will also decrease the losses over each transformation. It is also possible to buy cheap electricity and store it as another form of energy. The charging and use efficiency of electrical batteries, namely li-ion batteries are about 90% [1], which gives it a distinct advantage over other methods with higher losses. A downside of using batteries however is that batteries degrade the more cycles it goes through. Where some batteries only last a few years and at most about 15 years. While certain other methods can last for 30+ years. Electricity can also be bought and stored in other forms, but those methods will require several transformations of the power to use it again. It can be only one transformation over to heat, over to heat and back to electricity again or from electricity to hydrogen and back to electricity.

2.2.2 Solar thermal collectors

A way to directly harness the power of the sun is to use solar thermal collectors. These take the heat from sunlight which is absorbed in the heat transfer fluid (HTF) of the collectors and then to transfer this heated fluid into a storage medium or use it directly for heating rooms and return the cooled HTF back into the collector. This fluid is transferred using pumps and heat exchangers and this fluid usually consist of a combination of water and glycol to avoid freezing of the fluid during winter. There are pressurized and unpressurised systems with multiple construction methods for these with different efficiencies, lifetimes, and payback periods. The pressurized systems can deliver higher heat than the unpressurised systems, due to the unpressurised systems having only clean water as the HTF. The unpressurised systems are called “drain-back” systems due to the construction of these systems must allow for the HTF to flow into the storage medium if the fluid starts to freeze or starts to boil with only gravity to guide it as the system follows atmospheric pressure. When it is not operational the solar collector tubes will be empty. Solar thermal collectors have the capacity of up to 700 W/m2 and can be integrated into walls, roofs and more [33], [34]. There are multiple construction methods which include:

- **Evacuated tube solar thermal systems (vacuum tube)**

Among the different types of solar thermal collectors this method is proven to be the most efficient. It has an efficiency of about 70% and this efficiency is achieved by the construction of the tube system together with an insulation that protects more against heat loss during cold periods but might cause overheating during the summer. This method has in recent years overtaken flat plate systems as the most common installation and this method is only used in pressurized systems. This system has an absorber inside cylindrical vacuum tubes which can be a copper pipe with the HTF inside and the HTF is in forced circulation. On the top of the collection of tubes there is a collector or heat exchanger which does the heat transfer. This collector must always be on top of the panel because the heat rises. A benefit of vacuum tubes is that the tubes can be replaced one by one, and thereby avoiding having to install a brand-new complete set if one tube breaks.

- **Flat plate solar thermal systems**

A very mature technology that has been used since the 50s is the flat plate collector. It consists of a flat absorber which has HTF flowing through channels inside it or under the absorber. This absorber can also be made of copper, but also of aluminum or plastic. The absorber tends to have an aluminum frame at the back and insulation in-between and on the sides and a cover glass in the front. Although this type of collector is less efficient than vacuum tubes, it is cheaper and more durable.

- **Thermodynamic panels**

This kind of panel is a new introduction into the field. The panel is made of aluminum which is coated to avoid corrosion and is resistant to overheating. This panel does not only harness sunlight heat directly, but also uses the heat of the surroundings to produce heat. Thermodynamic panels contain a refrigerant fluid that flows through it, when this fluid is exposed to heat it will expand into gas form. This heated gas will travel from the panel into a compressor which will increase the pressure, and with it the heat, which will then be transferred to a coil inside a storage medium. The medium will absorb the heat and the cold gas will flow into an expander which is part of the compressor. After being expanded and returning to liquid form this fluid will flow back into the panel and renew its cycle.

As this panel does not rely on direct sunlight, but it does benefit from it, it is very useful for locations which have its sunlight blocked by surrounding mountains during certain periods of the year. Depending on the manufacturer of the panels, the operation can continue down to -5, -10 or -15℃, so it useful for early spring, summer, fall, and locations with mild winters. Since this panel is only reliant on heat, it will continue to produce heat during the night when the sun is down. Also, since it is not reliant on sunlight, it can be installed inside buildings with hot rooms like engine rooms and the like, giving it a unique advantage over the other kinds of panel which mostly are installed outdoors. This panel will act a bit as a cooler for areas as it absorbs the nearby heat. This type of panel is not very well known yet but has been implemented at houses in the UK and is being tested at other locations. This panel is not yet introduced in Norway and the prices for individual panels can be difficult to find, as mostly the panels are sold as packages and on a per location quota. Where these packages contain one or more panels, a heat tank for storage, the compressor, and fittings [45],[46],[47].

The efficiency of STCs is calculated by [36]:

$$\eta_{STC} = \eta_o - b_1 * K - b_2 * K^2 \tag{2.1}$$

Where b_1 and b_2 are correction factors and K is the difference between ambient temperature and the mean temperature of the collector fluid.

2.2.3 PV systems

Another way to harness the power of the Sun is to use photovoltaic panels. These panels consist of semiconducting materials which are incapsulated to offer protection from the weather and other factors. The properties of the panels allow for collecting of photons from the Sun and converts it to electricity. The lit side of the panel contains an anti-reflection coating which minimize losses by reflection. The theoretical limit of production from PV panels are higher than the practical production, due to non-perfect conditions. The produced electricity from PV is DC-current and this electricity is sent through an inverter before being used by households and other applications [68],[69].

There are different construction methods for the panels. Such as monocrystalline, polycrystalline, and thin-film. The efficiency of the types varies, with monocrystalline being the most efficient, but also most costly, polycrystalline being the middle of the road in both efficiency and costs, and thin-film is the least efficient but can easily be put on curved surfaces or other ways. Solar cells have in recent years been researched to see if it can be cost effective to implement solutions where the cells are integrated into roof-tiles as well as walls and windows. These methods are as of now not as efficient as dedicated solar panels but can see great potential in the nearby future [68].

PV panels have listed an efficiency with them. This efficiency is the amount of sunlight hitting the panel compared to how much of it is converted into electricity. The panels are also listed with a watt-peak showing how much is produced by each square meter of the panel [58].

A factor that affects PV panels is the temperature. The temperature will mostly affect the voltage of the panels and the efficiency of the panels will be lower at higher temperatures than lower temperatures, due to the lower voltage. The reason for this is that the electrons will move more at higher temperatures leading to higher energy losses. For every degree of heat increase, the losses will be higher [68].

The clarity index is a factor between one and zero which tells how much of the sunlight that hits the upper atmosphere hits the ground. As in how much is reflected to space and how much is blocked by clouds. This index is mostly used in advanced simulation programs to simulate different practical scenarios [89].

The performance of PV systems is calculated by [36]:

$$\eta_{PV} = \eta_{BoS} * \eta_{M,ref} * \left(1 - \beta * \left(T_c - T_{c,ref}\right)\right) \tag{2.2}$$

Where the efficiency of the PV system η_{PV} consists of the efficiency of the balance of the system η_{BoS}, the efficiency of the solar modules $\eta_{M,ref}$, the temperature penalty coefficient β and the temperature T_c and reference temperature $T_{c,ref}$.

2.3 Ways to store energy

There are many ways to store energy. It can be done by storing it as electricity, heat, potential energy or creating fuel for later use. Energy can be stored as one form of energy, for it then to be converted into another form of energy when the need arises. The different storage methods will have different use cases and different power outputs for the appropriate application. Some methods are meant for very short bursts of very high energy to compensate for errors, incidents, or stability. As in when ground faults occur on the power lines or power plants fall out of production and supercapacitors and flywheels have a very short start-up time to compensate. Some methods are meant as a backup source for a few hours, while others are meant for long continuous use. Some methods are meant solely for producers for the grid, other methods can be used by industries, and some can also be used by households. As this thesis focuses on UiT as a case study it is important to focus on the methods which the university can use.

Table 1 shows a quick comparison between mature technologies for storing energy, most of these methods will be further explained. Some other methods that are not as equally mature will also be explained moving on.

Table 1 Quick comparison of mature storage methods [1]

	Max power rating (MW)	Discharge time	Max cycles or lifetime	Energy density (watt-hour per liter)	Efficiency
Pumped hydro	3000	4h-16h	30-60 years	0.2-2	70-85%
Compressed air	1000	2h- 30h	20-40 years	2-6	40-70%
Molten salt (thermal)	150	Hours	30 years	70-210	80-90%
Li-ion battery	100	1 min -8h	1000-10000	200-400	85-95%
Lead-acid battery	100	1 min -8h	6-40 years	50-80	80-90%
Flow battery	100	Hours	12000-14000	20-70	60-85%
Hydrogen	100	Mins – week	5-30 years	600 (at 200bar)	25-45%
Flywheel	20	Secs-mins	20000-100000	20-80	70-95%

2.3.1 Pumped hydro energy storage (PHES)

A conventional method of storing energy is to fill up water reservoirs to be used later for power production. This method takes advantage of the potential energy of water, due to the height difference between the reservoir and the turbine connected to the generator. It converts this potential energy into kinetic energy, and said kinetic energy is used for power production by driving a turbine.

Where the formula for potential energy is [76]:

$$E_p = mg\Delta H = \rho V g \Delta H \qquad (2.3)$$

Where m is the mass, g is the gravity acceleration which is 9.81 m/s^2 and ΔH is the height difference. ρ is the density of water in this case and V is the volume.

And the correlating formula for kinetic energy is:

$$E_k = \frac{1}{2}mv^2 = \frac{1}{2}\rho V v^2 \quad (2.4)$$

This method can store the water for much later use, which is very beneficial. Depending on the height difference and inclination of the penstock, a different implementation of the turbine will be used. A penstock is the tube that guides water from the reservoir to the turbine.

The different turbines that are used are the Kaplan, Francis, and Pelton. Where Kaplan is used for the smallest fall heights, typically 10 to 70 meters [3], with the widest penstocks of two to eleven meters wide. This turbine has generally the lowest power production of five to 200 MW, lowest operating rpm of 70 to 429 and requires the most amount of water flow to operate. The water flows in from the side and then is expelled through the bottom of the turbine and the Kaplan turbine is placed over the water level of where it expels it to. The Francis turbine requires fall heights of 40 to 600 meters, penstock width of 0.91 to 10.6 meters, has potential to produce 800 MW of power, and has an rpm of 75 to 1000. The Francis has a tube going around the turbine itself which leads the water to it which it then expels at the bottom, the Francis turbine needs to be below the water level of what it expels the water to, and it requires less water than the Kaplan. The Pelton turbine requires great fall heights from 250 to 1000 meters, penstock width of 0.8 to 0.6 meters, and can generate about 400 MW. Its operating speed is 65 to 800 rpm, it focuses its water into a focused beam that is shot onto the turbine through great pressure, and it requires the least amount of water.

A way to replenish the reservoir is to use pumped hydro. Which is when the water is pumped back into the higher levels from the lower levels. This is done for locations with fresh water at both ends, but not sea water. As the sea water would cause corrosion through the pumping mechanism due to all the salt content in the water.

Hydro is the largest power producer in Norway with a calculated energy production of 136.7 TWh with an installed effect of 33 691 MW as of 01 November 2022 [19]. Pumped hydro has no problem with being stored over several months, as it only requires the reservoirs to be filled up. As the reservoirs fill up naturally by rain, as well as the pumping, there are little costs in storage and there is little evaporation of the water. Pumped hydro can store many hours of maximum power output depending on the reservoir and generator size. Cost to performance for rearmaments of pumped hydro and other hydro power plants are continuously being done, mostly with older plants to see which plants can keep going and will gain efficiency from new parts or automation, and which should have a new plant installed parallel to the existing one to replace it [20]. Most available rivers and lakes which can be used for pumped storage have already been installed in Norway, certain areas cannot have pumped hydro installed due to the areas being protected. There are new commissioned plants, rearmaments and other improvements to the systems being done all the time to get the maximum out of the production [21]. This is due to hydro being a such mature technology in Norway, with a lot of success, which is a much less contested power production compared to other sources such as windfarms. With this method already being continuously improved as much as it can and being employed by the producers at its utmost limit, there are other options for storage that can possibly give a great additional benefit if implemented properly.

2.3.2 Sensible stored heat

A way of storing heat for later use is with Thermal energy storage (TES), where heat is built up in a material and stored over either a short or long period of time. This material can be in the form of solids such as concrete, rocks, or sand particles [4]. It can be liquid such as water or molten salt. If this method goes on for several months, it can be considered seasonal thermal energy storage (STES). Depending on the material, different amounts of energy can be stored given a set storage volume due to the energy density of said material. There are different technologies implemented for storing heat, such as sensible, latent, and thermochemical. Where sensible thermal storage is stored in the material as just has been mentioned. Latent heat storage stores heat in a material that takes advantage of the latent energy in a material when it undergoes a state change from a solid to a liquid state. Thermochemical storage converts heat into chemical bonds that are reversible.

Sensible heat storage takes advantage of the differential temperature within a storage medium to use that energy and perform work. The heat from the medium can be used to heat water enough to generate steam to spin a turbine for power production or the heat can be used to heat buildings or other heating. The thermophysical properties such as the density, specific heat capacity and the volume of the storage material are therefore crucial to determine the energy capacity, be it in Joules or kWh.

The formula for the energy in sensible heat is [4]:

$$Q_{sensible} = mc_p\Delta T = \rho V c_p \Delta T = \frac{kg}{m^3 3} m^3 \frac{J}{kgK} \Delta T \tag{2.5}$$

Where m is the mass, ρ is the density, V is the volume, c_p is the specific heat capacity of the material at a constant pressure and ΔT is the temperature difference. As seen in (2.5), large densities, specific heat capacities as well as large temperature differences are desirable traits for sensible heat storage. Some advantages of sensible storage are that it is a very mature technology, the cost of certain storage mediums is low and said material have high energy capacities.

Table 2 shows the thermophysical properties of different sensible materials, both solid and liquid. As of now most high temperature implementations use molten salts for liquids or concrete/rocks for solids. Water is often used for temperatures below 100℃.

Table 2 Thermophysical properties of some sensible storage mediums. Calculations of volumetric and gravimetric storage densities assume a temperature differential of 350 ℃ [4].

Storage medium	Specific heat capacity (kJ/kg*K)	Density (kg/m³)	Temperature range (℃) Cold	Hot	Gravimetric storage density(kJ/kg)	Volumetric storage density (MJ/m³)
			Solids			
Concrete	0.9	2200	200	400	315	693
Sintered bauxite particles	1.1	2000	400	1000	385	770
NaCl	0.9	2160	200	500	315	680
Cast iron	0.6	7200	200	400	210	1512
Aluminium oxide	1.3	4000	200	700	455	1820
			Liquids			
Nitrate salts	1.6	1815	300	600	560	1016
Carbonate salts	1.8	2100	450	850	630	1323
Hydroxide salts (NaOH)	2.1	1700	350	1100	735	1250
Silicon	0.71	2300	1900	2400	250	575

For liquids, an implementation of molten nitrate salt (60% $NaNO_3$ and 40% KNO_3) is used in commercial concentrated solar plants (CSP) around the world to provide gigawatt-hours' worth of thermal energy storage [4]. Due to its low vapor pressure, which is the tendency of a material to change into a vapor state and it increases with higher temperatures, it is not pressurized at typical storage temperatures up to ~600℃, allowing for it to be pumped from one location to another. In power plants using this setup, molten salt is in a receiver on top of a tower which is surrounded by mirrors that concentrate the reflected sunlight on the receiver to heat it up. The heated molten salt will flow to a hot storage tank, and when need arises, it will be pumped from the hot storage to a heat exchanger where it will heat water to generate steam to drive a turbine. This turbine will produce the electricity, and the used molten salt, which is now cooler, will be pumped to a cold storage tank, and then back to the receiver on top of the tower.

For solids, there are many implementations of commercial and demonstration facilities. The company Graphite Energy developed a 3 MW CSP plant in Lake Cargelligo in New South Wales, Australia which utilizes graphite blocks in the receiver [4]. This method uses graphite blocks as both storage system and boiler for the creation of steam to be used for power production.

The company EnergyNest from Norway, developed a concrete-based thermal energy storage system that consists of a collection of long concrete blocks which have tubes going through the concrete that guide hot HTF from top to bottom, transferring the heat to the HEATCRETE [4],[5],[6]. The tubes can guide thermal oil or steam. When using thermal oil and the energy needs to be discharged from the HEATCRETE, cold HTF flows in at the bottom of the system and the hot energy exits at the top of the thermal battery [6]. If steam is used as the HTF, the HEATCRETE will acts as a steam cooler and condenser when it charges up the battery, and act as a boiler and superheater when it needs to discharge the energy. One module of HEATCRETE of length 6 meters can store 1.5 MWh of energy, multiple of these can be combined to grant greater storage of energy. Usual sizes tend to range from 5 to 1000 MWh worth of energy, with less than 2% heat loss per 24 hours for large scale systems [4], with discharge durations from several minutes to several hours [6].

Siemens Gamesa in Germany has developed an Electric Thermal Energy Storage (ETES) system that consists of volcanic rocks stored in a building [4]. These volcanic rocks are kept at ambient pressure and are heated directly with heat or by using electricity when the power price is very low, to heat up a resistive heater that warms up the rock. This heat can be stored up to two weeks and can be used directly for district heating or together with a steam turbine to produce electricity. Existing or shutdown coal power plants can be repurposed for this system with little extra costs.

Some challenges for sensible heat-storage are that due to the low energy density, it will require large volumes of storage medium for big capacity energy storage as well as more construction/insulation for the volume. Furthermore, some materials need to be kept at certain operating temperatures to function properly, such as molten salt. If the temperature of molten salt falls below 220℃ it will begin to freeze, which may cause blockage in the system [4]. This heating process will require more energy being pumped around. If the storage tanks become too pressurized or too hot, there are chances for structural damage.

Another method is to heat sand-like particles and exchange the energy of the heated particles through a heat exchanger [4]. Through this process, the exchanged heat will power a turbine for electricity production. This can be done by having a tower, with cold particles stored at the bottom, which will be lifted with an elevator to the top, where CSP will heat it up, the heated particles will be moved to the exchanger, the exchanger sends the heat to the turbine and then the cold processed particles will be at the bottom of the tower again. A similar method can be used as with the volcanic rocks, where the particles are heated when the power prices are low, and the energy can be used later.

A benefit of solid storage mediums is that it has no moving parts, is cheap, non-corrosive and easy to handle. A lot of the materials have large operating ranges of several hundred degrees, which gives large energy potentials. With larger volumes, the volume to surface area becomes lower, and it loses less energy through this area through conduction, convection, or radiation.

As the task of this thesis is to store energy seasonal, at the university, large power plants are unsuitable. With this in mind, the use of molten salt plants is out of the question. Other solid storage mediums are much more viable, such as HEATCRETE, which not only can be increased in storage size by simply adding another module but does not have the downside of the medium freezing. In [7] a long-term performance was done on a 2*500 kWh HEATCRETE module to measure its performance. In the test it reached temperatures up to 380℃ and was tested over 20 months where it was operational for 6000 hours. At the end of the test the system was taken apart and inspected, the concrete was inspected for cracks and the tubes were checked for deformity, there was none. This proved that there was no degradation of the storage medium over this testing period at the given values. This can however vary from implementation of concrete mix.

The HEATCRETE requires very few parts, is highly modular and has low CAPEX in comparison to more complex sensible heat storage methods. It loses about <2% heat in 24 hours for large-scale systems and loses more for smaller scale systems where the surface area is bigger compared to the volume [4], [6]. It can prove to be useful for longer storage, although small amounts of energy will be needed to compensate for the losses the system has. The storage medium also has an expected lifetime of about 50 years and requires little maintenance due to few moving parts and the simplicity of the system. The system can hold several hours' worth of energy to be used later. The applications for HEATCRETE can be to handle waste heat recovery to process heat/steam and or electricity, balancing a steam demand and supply, electrification of process heat/steam and concentrated solar to process heat/steam [29].

Another method to store heat over long time is to use boreholes [42]. This method bores very deep holes where hot and cold water is stored separately to be used for heating and cooling [41]. This method is reliant on location having the possibility to drill this depth. This method is often used together with heat pumps as well as thermal collectors to create the heated water. This method also uses the natural heat of the earth as a heat source.

A natural occurrence which can be utilized for heat storage is aquifers [42]. These are large underground water storages that have two separate wells, one for high temperature usage, and one for low temperature usage. This heat goes through a heat exchanger which can be used to heat houses or districts.

The capacity for energy in sensible heat storage in kWh for water is given by:

$$E_{TES,th,max} = \frac{V_{TES} * \rho_w * c_w * \Delta T}{3600 * 1000} \tag{2.6}$$

If a storage medium is water and intended for STES, the maximum temperature this water should be at is 95℃. This is to avoid the evaporation of water which occurs at 100℃. For STES to be viable for floor heating it needs to reach a higher temperature than what the desired floor temperature should be.

When STES is combined with solar thermal collectors (STC), the efficiency of STES systems is given by:

$$\eta_{STES} = \frac{E_{STES,th\rightarrow u} + E_{STES,end}}{E_{STC,th\rightarrow STES} + E_{STES,start}} \tag{2.7}$$

2.3.3 Latent heat storage

As mentioned prior, latent heat storage is another way to store energy by taking advantage of the energy in the phase change of materials (PCM). Those ways are fusion, where the phase goes from solid to liquid form, and evaporation which is from liquid to gas. When materials such as salt and metals are melted, the storage method can be a combination of sensible and latent to store the energy.

The formula for energy in latent heat is:

$$Q_{latent} = \frac{Q}{m} = \frac{Q}{\rho V} \tag{2.8}$$

Table 3 shows the thermophysical properties of some phase-change materials.

Table 3 Thermophysical properties for latent heat storage materials [4]

Storage medium	Specific heat capacity (kJ/kg*K)	Latent or reaction heat (kJ/kg)	Density(kg/m^3)	Melting point (°C)	Boiling point (°C)	Gravimetric storage density(kJ/kg)	Volumetric storage density (MJ/m^3)
Liquid/Solid phase change materials							
Aluminium	1.2	397	2380	660	-	397	945
Aluminium alloys	1.5	515	2250	579	-	515	1159
Copper alloys	-	196	7090	803	-	196	1390
Carbonate salts	-	607	2200	726	-	607	1335
Nitrate salts	1.5	100	1950	222	-	100	195
Bromide salts	0.53	215	2400	730	-	215	516
Chloride salts	1.1	481	2170	801	-	481	1044
Fluoride salts	2.4	1044	2200	842	-	1044	2297
Lithium hydride	8.04	2582	790	683	-	2582	2040
Silicon	0.71	1800	2300	1414	-	1800	4140
Nitrogen	1.04	199	809(Liquid)	-	-196	199	161
Oxygen	0.92	213	1140(Liquid)	-	-183	213	243

Currently phase change materials (PCMs) are formed into packs which consists of tiny spheres where the PCMs encapsulated [8]. The behavior of the PCM is that it will absorb heat from the surroundings, turning the PCMs from solid form into liquid form, and when the surrounding temperatures cool the PCMs will release heat and turn back into solid form. HTF can be passed through these packs to either charge or discharge energy from the PCMs. Due to phase changes happening at the given material's isothermal temperature, which is the temperature at which a material changes form, PCMs can be used when heat addition needs to occur at specific temperatures. If the needed temperature range needs to be large, cascaded PCM systems can be setup, this requires more system complexity as well as increased costs.

A company in the UK called Highview Power have created systems that use the power of liquid air [9]. It operates by using excess power production during off-peak hours and creates liquid air from this. This liquid is stored in vacuum tanks at ambient pressure. The inlet of the system takes in surrounding air to be cleaned and compressed. Part of this air is then cooled by a large refrigerator and sent to the liquid air storage tank. The other part is stored in hot thermal storage tanks to be used later for the expansion process. When power production is required, the system will take the liquid and run it through a heat exchanger and add heat from the hot storage to turn the liquid back into gas, which will drive the turbine to produce electricity. Waste heat and cold is stored in the respective thermal and cold storage tanks to improve efficiency of the system. Benefits of this system is that it is highly modular, the components are easily obtainable and a very mature technology, and it can be scaled to many different sizes.

Liquid air energy storage (LAES)/ cryogenic energy storage is a method meant for large scale energy storage ranging from 5 MWh to 100+ MWh. Where the fluid used is liquified air or liquid nitrogen which is mostly what air is comprised of. LAES systems can harness waste heat or cold from industries as well as surplus electricity from the grid to liquify air for storage. This form of energy storage is capable of long-term storage and the components have a long lifespan of over 30 years. As the storage medium is air, it has no cost to acquire and can be placed anywhere. The method will benefit from a proximity to renewable energy sites and industries, taking advantage of the waste heat from industries and a short transfer range from production. A downside of this technology however is that the charging cycle is of a lower efficiency than AA-CAES and pumped hydro at about 50+%. This method has very little losses over long-term storage however, needing little to none of additional energy to be stored. Compared to pumped hydro LAES is much more energy dense, requiring much less volume for more energy to be stored.

The company Highview power in the UK have constructed two LAES systems in the UK. Where the pilot in Pilsworth is at 5 MW and 15 MWh had its construction completed in June 2018 and have been operating since [30], [31]. The other system in Yorkshire has a power output of 200 MW and an energy capacity of 2.5 GWh. Another construction is currently being developed in Manchester which will consist of a 50 MW output and 300 MWh capacity. A project for Spain is currently being developed which will have an energy capacity of 300 MWh, there are also projects planned for Australia to reach Australia's goal of Net zero emissions.

In [32] it is said that during the charging of the liquid air tanks the boiloff at that stage is about 0.1- 0-07%. The paper furthermore explains the differences between the different kinds of LAES systems. Where there are the standalone, hybrid and integration of LAES systems. Standalone LAES systems have electricity as the only input and output, no fluids other than air and there is the heat and cold that is being reused. Hybrid LAES consists of all layouts of the system where LAES includes external processes, making it non-standalone. This can be with heat extracted from other processes or fuel being used for combustion. The paper explains that the roundtrip efficiency η_{RT} has been used in other papers as a performance indicator, but that it is mostly suitable for standalone systems. The paper also says that more experimental evidence should be gathered and spread in the research community to further develop LAES.

In Table 4 there is a comparison of the typical operating parameters of the LAES liquefication process.

Table 4 Typical LAES liquefaction processes [32]

Parameter	Typical values
Compressor isentropic efficiency	85-90%
Number of compression stages	2-4
Cryoturbine efficiency	65-85%
Heat exchangers effectiveness	90-95%
Heat exchangers pinch point	1-10°C
Maximum cycle pressure	40-200 bar
Storage vessel pressure	1-45 bar
Liquefaction work (with cold recycle)	163-297 kWh/ton
Liquid yield (with cold recycle)	0.6-0.95
Recirculation fraction	0-0.3

In the conclusion of [32] it is said that LAES looks very promising with a lot of potential. There has been a rising number of publications of research papers the last few years and an increased interest in the technology. Given that the technology is being greenlit for construction by Highview power in different locations in the world it is safe to say that the technology is ready for testing, making LAES a potentially viable option for seasonal energy storage.

2.3.4 Thermochemical storage

Thermochemical energy storage (TCES) allows for storage of heat through chemical reactions. There is a lot of potential in this storage method as chemical reactions can reach several hundred degrees and they are reversible with little losses depending on the material used. The reactant AB is split into the two products A + B with the use of heat in an endothermic reaction, which is when the reaction absorbs heat from the surroundings. The split products can be stored separately over an indefinite time, allowing for recombination of the products when thermal demand is needed. The recombination process is an exothermic reaction, meaning it releases heat.

There are many possible TCES processes available but not many have been implemented on an industrial scale [10]. These processes differ from one another in terms of what heat is necessary for operation, what heat is created when the chemical splits, what pressure is needed and more.

Table 5 shows TCES reactions by what medium is used, the enthalpy, which is the amount of energy in the solution, reaction temperatures, gravimetric storage density and volumetric storage density. The letters in parenthesis are g for gas and s for solid, and ΔT is for temperature difference.

Table 5 TCES materials [12,11]

Storage medium	Reaction enthalpy (kJ/mol)	Temperature range (°C)	Gravimetric storage density (kJ/kg)	Volumetric storage density (MJ/m^3)
Carbonates				
$CaCO_3(s)+\Delta T \leftrightarrow CO_2(g)$ + $CaO(s)+CO_2(g)$	178	850-1273	1764	2491
$SrCO_3(s)+\Delta T \leftrightarrow SrO(s)$ + $CO_2(g)$	234	900-1200	300-1000	1200-1500
Hydroxides				
$Ca(OH)_2(s)+\Delta T \leftrightarrow CaO(s)$ + $H_2O(g)$	104	400-600	1406	1640
Hydrides				
$MgH_2(s)+\Delta T \leftrightarrow Mg(s)+H_2(g)$	75	300-480	2880	2088
$Mg_2FeH_6(s)+\Delta T \leftrightarrow$ $2Mg(s)+Fe(s)+H_2(g)$	74	300-500	2106, 1921	5769, 2344
$CaH_2(s)+\Delta T \leftrightarrow Ca(s)+H_2(g)$	186	1000-1400	3587	7374
Ammonia				
$NH_3(g) \leftrightarrow 0.5N_2(g)+1.5H_2(g)$	67	400-700	3924	2682
Redox active oxides				
$2Co_3O_4(s)+\Delta T \leftrightarrow$ $6CoO(s)+O_2(g)$	205	900	844	-
$2BaO_2(s)+\Delta T \leftrightarrow$ $6BaO(s)+O_2(g)$	79	693-780	474	-

Table 6 shows the advantages and disadvantages of the different types of the thermochemical materials as well as the status of the respective implementations [12,11].

Table 6 Pros and cons of TCES materials

Material	Advantages	Disadvantages	Technology status
Carbonates	• Cheap, abundant, non-toxic • High energy density • High operating temperatures suitable for high-temperature power generation	• Less reversibility • Low cyclic stability (10-20 cycles) • Sintering	Lab-scale and pilot-scale
Hydroxides	• Low material cost • Abundant • Non-toxic	• Agglomeration of material • Side reactions with CO_2	Lab-scale and pilot-scale
Metal hydrides	• High energy density • High reversibility • A lot of experimental feedback on H_2-storage and heat pump applications	• Poor reaction kinetics • Hydrogen embrittlement • Sintering • Higher material cost	Pilot-scale
Oxides	• High reaction enthalpy (205 kJ/mol) • Wide operating temperature (400-1473 K) • Low operating pressure (0-10 bar) • No catalyst • No side reaction (BaO/BaO_2) • High reversibility (500-1000 cycles) • Can take advantage of sensible heat to increase storage density	• Toxicity of some products • CoO • Cost of products • Heat transfer • Sintering • Low maturity level	Lab-scale
Ammonia synthesis/ dissociation	• Easy to control • No side reactions • Vast industrial experience	• Toxic • High cost of containment • Lower volumetric energy density • Higher operating pressures	Pilot-scale
Sulfur-based cycles	• Cheap and commercially available • Stable storage	• Corrosive • Toxic	Lab-scale

	• Energy density of 9 MJ/kg • Sulfur is a cost-effective material • Vast industrial experience	• Highly protective containment required

As Table 6 shows, most of the materials are still in the laboratory- or pilot-scale. Ammonia-based reactions have been studied by the Australian National University for over 40 years, but systems for it have not been introduced into industrial scale [10]. There are companies and laboratories that also have experimented with different solutions, but also not made it into industrial-scale. Due to the capacity for high-temperature operation, energy density, ease of storage and number of possible cycles, metal oxide TCES systems have seen an increased interest.

A pilot-scale TCES system was set up inside a solar power tower plant using cobalt oxide [12]. Even though that system was gas-powered and not solar-thermal powered, it proved that the system is feasible. It performed 22 thermochemical charge/discharge cycles with almost no performance degradation between the cycles. The system also demonstrated a doubled storage capacity compared to sensible heat storage, of 47.0 kWh versus 25.3 kWh.

A way to produce electricity with thermochemical energy is to use fuel cells. Fuel cells are cells stacked together to get a proper operating voltage. The cells use fuel, in this case hydrogen, and air to produce electricity. At both ends of the fuel cell stack there is a bipolar plate for sturdiness of the stack, followed by the electrodes which are the negative anode and positive cathode. In-between the electrodes are a semiconducting membrane. An external circuit between the anode and cathode will lead the negatively charged electrons while the membrane will lead the positively charged ions from the anode to the cathode, recombining the electrodes and ions together with air, and creating water and heat as a by-product. As long as there is fuel being provided at the anode side, and air to the cathode side, electricity is produced. This process can be reversed with an electrolyzer and the electrolysis process, creating hydrogen from water. It is possible to use other fuels, but some of them will produce CO_2 as a by-product [1],[16].

The operation of the electrolyzer is that water and electricity are used as inputs, and the output is hydrogen and oxygen. With the use of an electrolyzer and fuel cell in tandem, it is possible to create fuel to be used later, for both power production as well as vehicle applications [17].

Thermochemical energy storage systems have the potential to be a viable solution for energy storage, but there are some problem areas that need to be improved for large-scale and small-scale implementations. Those being better integrations into other systems to have better efficiency, better heat transfer efficiency, more large-scale testing, material cyclability and lifetime, and cost to performance and environmental impact improvements.

2.3.5 Compressed air energy storage

Compressed air energy storage (CAES) is a method that pumps air into underground holes/caverns or storage tanks during off-peak hours. When energy need arises, this compressed air is released into the production facility through a heat exchanger that expands the air with heat to drive a turbine connected to a generator which produce power. Some facilities that use this method are in Mcintosh, Alabama and in Huntorf, Germany [1]. Another plant of generator capacity 324 MW with a storage capacity of about 16000 MWh is being constructed in Anderson County, Texas [13].

There are different variants of CAES systems such as Adiabatic and Diabatic systems, and within these are also other differences in construction. The systems already mentioned are within the Diabatic CAES (D-CAES) systems variants [26]. This means that the systems do not retain the heat from the compression stage but dissipate it as waste heat. Adiabatic CAES (A-CAES) systems retain the heat from the compression by having perfectly insulated the storage/cavern and then uses that heat for expansion later. Advanced adiabatic CAES (AA-CAES) is when the heat from the compression is stored in a separate chamber from the storage/cavern and used later for the expansion. This chamber will be above the air storage and contain rocks or another medium to store the heat before the air is sent down through another compressor and into the high-pressure storage. Utilizing the stored heat for expansion will increase the efficiency of the system as less energy needs to be provided for the expansion process. While isothermal CAES (I-CAES) maintains a constant temperature within the storage medium, it does this by removing the heat during compression and transferring it to, for example a water tank, and then supply that heat during the expansion process.

The CAES system in Huntorf, which was established in 1978, is still operating with about 42% efficiency [23]. This system has two caverns, where one cavern was in the early life intended for black start for nuclear production units, while the other cavern was intended for peak-shaving. This system can black start and reach full output within 6 minutes. These caverns have a volume of about 310 000 m^3 which are used together with the 321 MW turbine. Nowadays the system is meant as reserves to back up PHES system as well as take the surplus energy production from renewable energy sources (RES) and use it for balancing the grid due to the intermittency of RES. This system does not contain a separate chamber to store the heat from the compression stage into sensible heat storage, it vents the hot air in order to not store it with the high-pressure air. This system uses natural gas to get more expansion from the high-pressure air, if there was a heat storage available, it could use some of this heat to use less fuel for the expansion and increase its efficiency.

The CAES system in McIntosh Alabama, which was established in 1991, has a power output of 110 MW with an efficiency of 54%. The salt cavern has a volume of 570 000 m^3 and can reach full power output within 10 minutes capable of supplying 26 hours of energy at peak output [23]. This system was built for peak-shaving and uses the excess energy production from other power plants at low-price hours for compressing the air. The air is compressed to a maximum of 76 bar and when energy is needed the air is released through three pressure chambers where it goes from 315℃, to 537℃ and finally 871℃ with the use of natural gas. The excess heat is released into the air at a temperature of 178℃. Both the Huntorf and McIntosh system are D-CAES systems, with the difference being that the McIntosh system has a heat recuperator and exhaust gas heat exchanger to heat up the air from storage. This brings a higher efficiency to the McIntosh system, and it uses less fuel for the heating process.

Table 7 compares the two different systems.

Table 7 Huntorf and McIntosh CAES details [23]

Characteristics of CAES systems	Huntorf	McIntosh
Location	Germany	USA (Alabama)
Construction date	1978	1991
Power capacity	321 MW	110 MW
Hours of peak power output	3	26
Type of reservoir	Salt cavern	Salt cavern
Number of caverns	2	1
Cavern volumes	140 000 m3 and 170 000 m3	570 000 m3
Depth of caverns	650 m to 800 m	125 m to 459 m
Operational cavern pressures	20-70 bar	Max 76 bar
Fuel	Gas	Gas/oil
Efficiency	42%	54%

A company that has implemented different solutions than the Huntorf and Alabama plants is the company Hydrostor based in Toronto, Canada which works on Advanced CAES solutions [27]. In 2015 the company completed construction of a grid connected A-CAES system with Toronto Hydro as the utility host for the project. The project demonstrated the ability of the technology to store energy over long periods of time and serves as a testbed for the technology. That project stores air in balloons three km from the cost 55 m underwater, which is then pumped back into a facility on ground when needed to produce 1 MW of power [28]. Another project from the company which was completed in 2019 is the A-CAES Goderich energy storage facility project which was commercially contracted. Which has an output of 1.75 MW and requires 2.2 MW to charge the 10 MWh storage [27].

The company has more projects in the works where some of them have an expected lifespan of over 50 years which are shown in Table 8 together with the existing plants.

Table 8 Existing and planned CAES plants

Characteristics of CAES systems	Toronto island	Goderich	Willow rock	Silver city	Cheshire	Pecho
Location	Canada	Canada	USA (California)	Australia	Britain	USA (California)
Construction date	2015	2019	Expected ready in 2028	Expected ready in 2025	In development	In development
Power capacity	1 MW	1.75 MW output 2.2 MW charging	500 MW	200 MW	Undisclosed	400 MW
Energy capacity	~1+ MWh	~10+ MWh	4 000 MWh	1 600 MWh	Undisclosed	3 200 MWh
Hours of output at max capacity	~1+ h	~5+ h	8 h	8 h	Undisclosed	8 h
Efficiency		60%				

Through the experiences from the Huntorf and Alabama CAES, it is shown that large scale systems can work for taking the excess energy from power production and storing it for later use, as well as supplement the grid when the need arises. This method is not dependent on hot or cold climates, but it needs large storage volumes for large scale applications. As explained in [23] and with the projects of Hydrostor, there are multiple CAES projects planned at many locations in Europe, USA and more, showing a great interest in the potential of this storage method. Even though this method does not have a very high efficiency, it has proven to be quite useful for Huntorf and McIntosh. This method requires quite a bit of surface area for all the components which are necessary, in addition to the massive storage volumes. It also has a large price tag for initial investment, even bigger if caverns need to be dug.

2.3.6 Battery storage

In terms of batteries for storage, there are multiple options. An older technology is the lead-acid batteries, which have been mostly replaced by Lithium-ion batteries due to the higher energy density of the Lithium-ion batteries as shown in Table 1. Lead acid batteries have been used a lot in cars, but as more vehicles are turning fully electric, lead-acid is being phased out.

As of now Lithium-ion batteries are in everything from cell phones to vehicles and energy storage, the batteries are very versatile. The construction of the lithium-ion batteries consists of electrodes on both sides of the battery, with two chambers of liquid electrolyte being in contact with the electrodes separated by a polymer separator. The Hornsdale power reserve in South Australia has the biggest Lithium-ion battery on earth, consisting of a power capacity of 150 MW and an energy capacity of 193.5 MWh [14]. This battery started out as a 100 MW/129 MWh installation, but due to a great success with this project, it was expanded to the size it is now. The system has saved South Australian consumers over 150 million dollars [14] in its first two years of operation. The battery system helped in stabilizing the grid as well as store up energy for later use. A downside of lithium-ion batteries is that if it gets damaged and the electrolytes are exposed to air, it can cause a fire or explode. Therefore, proper construction and use of the batteries is crucial.

To better improve the safety of lithium-ion batteries, many companies have started developing solid-state batteries to replace them. These batteries are constructed in the same manner as liquid lithium-ion batteries but are wholly solid instead. And thereby avoiding the chemical reaction that cause fire if the battery is damaged. Solid-state batteries are however more expensive as of now [85].

Another form of battery is the flow batteries. These batteries are constructed with two external tanks, one for each electrolyte. There is one membrane in the middle of the battery cell, with the different electrolytes on each side, and the electrodes are on the outside of the electrolytes. The amount of energy stored in these batteries can be increased by simply increasing the sizes of the tanks. These batteries can store excess energy from the grid and are implemented to around 5% of the world’s batteries [1]. Dalian, China has constructed a 100 MW/400 MWh flow battery system that will be eventually upgraded to 200 MW/800 MWh [15].

A benefit of using batteries as an electrical storage method, is that the battery packs can be connected to the grid using electrical transformers and rectifiers. The stored energy can then easily be used for electrical appliances using another set of transformers and inverters. The expansion of electrical storage can also be easily increased, by adding the batteries in series to increase the amount of voltage and putting them in parallel to increase the current. A downside of using batteries is that the lifespan of the batteries is not as long as some other methods, but with proper cycling periods and maintenance. The lifespan of the batteries can be improved. Batteries are used for basically anything, and can be very viable for storage of energy, either short-term or long-term.

2.4 Weather conditions and degradation

2.4.1 Lack of rain and too much rain

A lack of rain over long periods of time can be problematic for hydro-storage. As this will lessen the potential output duration the power plants can supply if the reservoirs start to empty. Most of the Norwegian reservoirs are large with no problem to last a season with little rain, but it can be damaging if multiple smaller reservoirs start to dry out.

Too much rain can be detrimental for solar thermal collectors as well as PV solutions. As the weather is very cloudy when it rains, the clouds will block out the sun and most of the solar thermal and PV panels will produce much less or stop producing energy. If only a small amount of rain occurs on the PV panels and the clouds pass however, will prove beneficial. As the water on the panels will act as cooling keeping the panels closer to optimal performance.

2.4.2 Snow

Snow is beneficial for PHES as the more it snows during the winter, the more the reservoirs will fill up during the spring when it melts. Snow can both be bad and good for PV panels. It can be good if it does not cover the panels but surround the panels. As the sunlight that hits the snow will be greatly reflected due to the reflective properties of snow. As the sunlight travels through the panels and are reflected onto the panels, alongside the light from the surrounding snow, this will increase the efficiency of the panels. If one cell of the panel is covered by snow however, this will greatly reduce the efficiency of the panel compared to small parts of different cells being covered by snow. This makes it crucial for cleaning protocols to be in place to avoid loss of energy. Snow is mostly a problem during the early stages of winter and the start of spring. There is no need to worry about it during the winter as there is no sunlight to gather in Narvik at said time.

2.4.3 Shadow

With shadow the placement of both solar thermal collectors and PV panels are crucial. As shadow will greatly impact the energy created by these methods. Shadow works on the PV panels the same way as snow with entire cells being covered, if one whole cell is covered, the total output of the panel will be greatly diminished unless bypass-diodes are installed [87]. And thermal collectors will collect much less energy if it is placed in the shadows. Narvik is a special case in this scenario, as it is at the foot of Fagernesfjellet. The university is higher up on the mountain than the city, which is problematic with regards to sunlight in Narvik. During parts of the year the Sun is directly behind Fagernesfjellet, blocking all sunlight to the University. This is problematic for PV panels during this time, but during the summer the sun is directly above the city. With no obstruction for the sunlight except for cloudy days, the angle of the PV panels will however remain important. The website suncalc.org allow inspection of locations to see when there will be dawn, sunrise, peak of the day (culmination), sunset, dusk, and shadow cast of different heights of a location during the day along with a lot of other useful information [77].

2.4.4 Temperature

High temperature affects PV panels badly, while thermal collectors benefit from it. The reason PV panels suffer from high temperatures is that the higher temperatures will lead to higher resistances in the electrically conductive materials such as copper and more. PV panels benefit from cold climates to a degree. The panels have better efficiency down to about -15 degrees Celsius, but the efficiency start to drop off below that. Solar thermal collectors do not benefit from cold temperatures, as this is counterproductive for the product [34],[68]. If a water storage is used, freezing can be an issue. As this will cause the water to expand and possibly damage its container.

Figure 3 shows the temperature of 2022 from January till December gathered from yr.no which is supplied by the meteorological institute [44].

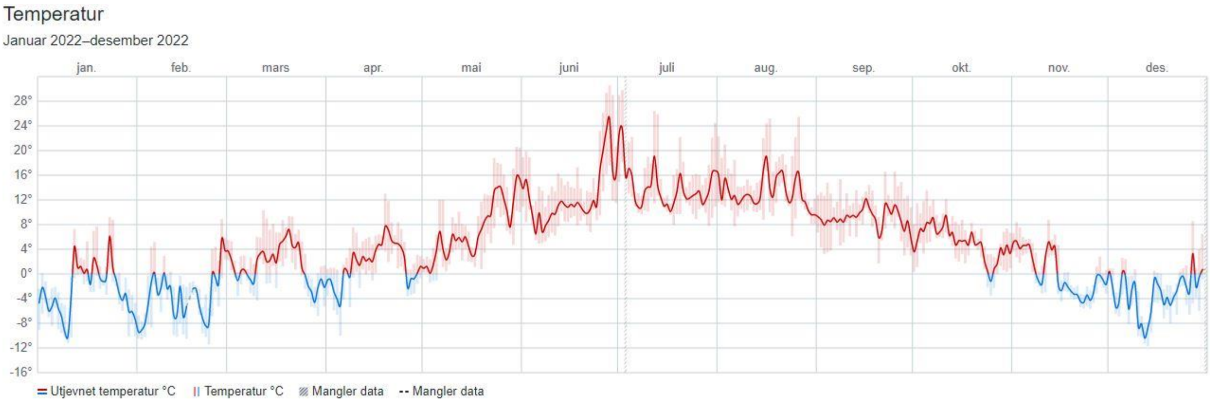

Figure 3 Temperature of Narvik 2022

As Figure 3 shows, the temperature in Narvik during the year was mostly positive. This temperature will vary from year to year but is useful as a guideline. If the temperature in the coming years is somewhat equal as shown here, STCs will have great appliance to the Narvik area.

2.4.5 Wind

Wind can have a cooling effect on PV panels if the wind blows over the panels. This cooling will in similar ways to small amounts of rain cool the panels keeping them closer to optimal conditions during the hot summer weather. Wind can be a bit counterproductive against thermal collectors as these panels perform better the higher the ambient temperature is [34],[68]. Wind will also act as a cooling on heat storages, as it will cool surfaces with convection which will be explained further in Fourier's law.

2.4.6 Degradation of production units and storage units

As mostly everything degrades over time PV panels, batteries and some other storage mediums are no exception. PV panels have an approximate degradation in efficiency for each year at different ranges, where some panels degrade about 0.45% a year [58]. The degradation of efficiency will lead to less production of energy being available, and for less savings to be made each following year.

2.5 Heat transfer

2.5.1 Fourier's law of conduction

Heat transfer is the exchange of thermal energy due to a temperature difference. There are different ways for heat to transfer. One of these is conduction, which is when heat is transferred between materials in direct physical contact.

Fourier's law of heat conduction is [78]:

$$q_x'' = -\lambda \frac{\mathrm{dT}}{\mathrm{dx}} = -\lambda \frac{\Delta T}{L} = -\frac{W}{mK} \frac{T_2 - T_1}{m} = \frac{W}{mK} \frac{T_1 - T_2}{m} \tag{2.9}$$

Where q'' is the heat flux per unit area and is given W/m^2, λ (lambda) is a property called thermal conductivity in W/mK, T_2 is the lower temperature side and T_1 is the higher temperature side, and L is the thickness of a material. Thermal conductivity explains how well a material can transfer heat, thermal conductivity often uses the letter k, but to avoid confusion with Kelvin, lambda can be used instead. Figure 4 shows the one-dimensional heat transfer through a wall.

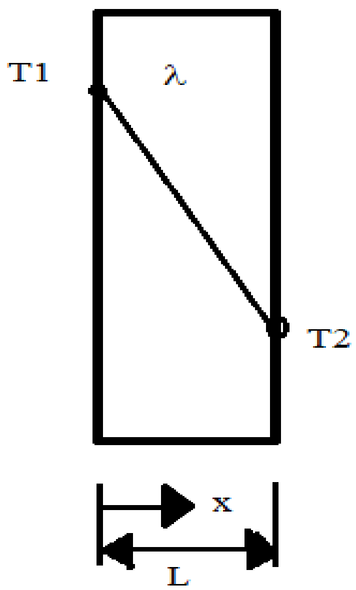

Figure 4 One dimensional heat conduction

If the heat flux is multiplied with the area of a surface, the result will be the heat rate/transfer. Which is given as:

$$q_x = \frac{\lambda A \Delta T}{L} = \frac{\frac{W}{mK} m^2 T1 - T2}{m} \tag{2.10}$$

The heat rate is given in Watts and tells how much heat transfers at a given time. This is useful for calculating how much heat is transferred from a storage and away from it.

2.5.2 Fourier's law of convection

Another way for heat to be transfer is with convection, which is when a fluid or gas is flowing over a surface. The rate equation used for the convection heat transfer between the surface and fluid is Newton's law of cooling. Which is [78]:

$$q = hA(T_s - T_\infty) = \frac{W}{m^2 K} m^2 (T_s - T_\infty) \tag{2.11}$$

The letter h is the convection heat transfer coefficient which depends on the properties of the fluid, geometry, pressure, and flow regime. Flow regime means how a fluid flow. For gases h can range between 25-250, and for liquids it ranges from 100-20000 [78]. By increasing the surface area of something that needs cooling, by for example putting fins on a CPU-cooler, even air which has a very low h, can cool better.

2.5.3 Radiation heat transfer

Radiation heat transfer is when heat radiates from an object, it can occur even in vacuums. It is known as the emissive power and is in W/m^2. The equation that is used for this when it is an ideal emitter is the Stefan-Boltzmann law [78]:

$$E_b = \sigma T_s^4 = 5.67 * 10^-8 \frac{W}{m^2 K^4} T_s^4 \tag{2.12}$$

Where E_b is for black body and σ (sigma) is the Stefan-Boltzmann constant. In both conduction and convection, the K for Kelvin can be swapped out for C for Celsius, but in radiation it must be Kelvin.

When it is a non-ideal emitter the formula changes to:

$$E = \epsilon\sigma T_s^4, 0 \leq \epsilon \leq 1 \tag{2.13}$$

Where ε (epsilon) is the surface emissivity, if it is 1 it is a black body which is an ideal emitter.

If an object is placed within a larger enclosure the radiation heat transfer between them in Watts is:

$$q = \epsilon\sigma(T_s^4 - T_{surr}^4) \tag{2.14}$$

Where epsilon is the emissivity of the object, T_s is the surface temperature of the object and T_{surr} is the temperature of the surrounding walls.

The absorbed energy by the surface in W/m^2 is called the absorbed incident radiation and the formula for it is [81]:

$$G_{abs} = \alpha G, 0 \leq \alpha \leq 1 \tag{2.15}$$

Where α is the absorptivity of a surface, which is how well it absorbs.

2.5.4 Thermal diffusivity

Thermal diffusivity is the ability of a material to conduct energy compared to its ability to store energy. A material with a high diffusivity will change its temperature much faster than a material with low thermal diffusivity. Meaning a material with low diffusivity works great as an insulator. So, for long storage of energy a material with low conductivity and high volumetric heat capacity is a good combination.

The formula for thermal diffusivity is [82]:

$$\alpha = \frac{rate\ of\ heatflow\ into\ mat}{ease\ of\ stored\ energy} = \frac{\lambda}{\rho c_p} = \frac{\frac{W}{mK}}{\frac{kg}{m^3}\frac{J}{kgK}} \tag{2.16}$$

α is the thermal diffusivity in m^2/s, ρ together with cp is the volumetric heat capacity in J/m^3K which is the ability for a material to store energy.

2.5.5 Thermal resistance

A value that determines how resistant a material is against heat flow to its surroundings is the R-value, it can be called thermal resistance. Adding greater thickness or more material increases the R-value. It is also important to note whether the R-value is imperial or metric, as the metric version has higher values due to the use of SI units. The metric version is often called RSI-value to differentiate between the two.

The R-value for conduction is given as [83]:

$$R_{cond} = \frac{Thickness}{Thermal\ conductivity * Area} = \frac{L}{\lambda A} = \frac{m}{\frac{W}{mK}m^2} \quad (2.17)$$

The R-value for convection is:

$$R_{conv} = \frac{1}{hA} = \frac{1}{hm^2} \quad (2.18)$$

The R-value for both is listed as °C/Watt. If for example two materials are used as walls, and there is air flowing on both sides of it, such as shown in Figure 5.

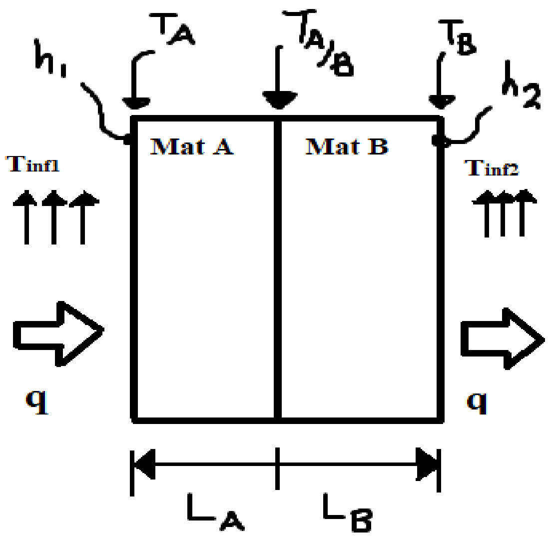

Figure 5 Composite wall

It can be drawn in the way of thermal resistances which is shown in Figure 6.

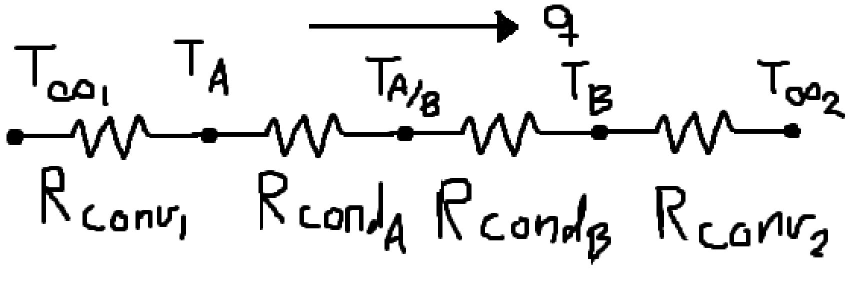

Figure 6 Thermal resistances

Where the heat transfer, q over this will be [83]:

$$q = \frac{T_{\infty 1} - T_{\infty 2}}{R_{conv1} + R_{condA} + R_{condB} + R_{conv2}} = \frac{T_{\infty 1} - T_{\infty 2}}{\frac{1}{h_1 A} + \frac{L_A}{K_A A} + \frac{L_B}{K_B A} + \frac{1}{h_2 A}} \qquad (2.19)$$

Table 9 shows the thermal properties for certain substances, it is an excerpt from page 146 in [60] and some details from [61],[62].

Table 9 Thermal properties for materials

	Density ρ [10^3 kg/m^3]	Thermal conductivity λ [W/mK]	Specific heat capacity C_p [J/kgK]
Brass	8.4-8.7	80-115	330
Brick	1.6-1.8	0.38-0.52	840
Brickwork	1.6-1.9	0.5-0.9	
Bronze	8.7-8.9	55	210-240
Clay (dry)	1.45	1.28	880
Concrete	1.9-2.3	0.8-1.4	880
Dirt	1.0-2.0	0.5-2.0	
Fir	0.4-0.8	0.1-0.2	2700
Gabbro	2.92	2.2	460
Glass	2.4-3.0	0.7-1.1	500-880
Gneiss	2.75	2.6	1400
Granite	2.3-3.1	3.5	750
Limestone	2.62-2.64	1.5	880
Marble	2.5-2.7	2.8	800
Pine	0.4-0.8	0.1-0.2	2700
Plaster	0.97	0.45	1100
Rockwool	0.2	0.041	
Sand	1.6-1.7	0.6-1.7	
Water	1.0	0.59	4184

2.6 Power usage of UiT Narvik

At UiT Narvik the heated areas consist of 26 373 m^2 according to a measure assessment done by Rejlers in 2022. In 2020 the E-wing at the campus was renovated where windows were swapped, and rooms were additionally insulated [35]. UiT has an electric boiler, as well as an oil boiler, the latter will be phased and swapped out according to the report. This heating system supplies heating to the ventilation, radiators, tap water and floor heating. In addition to this the building also has coolers for the ventilation.

The total energy usage of UiT Narvik from 2017 to 2022 is displayed in Table 10, this data was supplied by Statsbygg at UiT. The data from 2020 to 2021 must be taken with a grain of salt when considering the years to come. As during these years, the covid pandemic took place, which might have impacted the general power usage of the campus. There were also done renovations during this time so certain power tools and other equipment might have influenced the power usage in this time. 2022 will be most proper to use for study of further years, as with the new measures being put in place, there are more savings in terms of energy use.

Table 10 Total energy usage at UiT Narvik from 2017 to and with 2022

Energy carrier	Bio-oil [kWh]	Direct electric [kWh]	Electric to el-boiler [kWh]	Electric to cooling system [kWh]	Oil (Fossil) [kWh]
Jan	0	2576882	711096	633	99819
Feb	0	2506642	691875	659	60749
March	4670	2602985	675714	1614	7047
April	330	1863619	510357	4324	130190
May	0	1755607	370679	10600	5043
June	356	1392013	236139	7985	6224
July	444	1171397	234879	590	16673
August	9889	1388420	220376	234	2510
September	20001	1639687	340947	130	29419
October	1514	2110509	487011	129	13696
November	24475	2343903	648317	132	29281
December	48951	2371277	753469	232	3746
Sum	110630	23722941	5880859	27262	404397

Table 11 shows the average energy usage each year between 2017 and 2022 at UiT Narvik.

Table 11 Average energy usage at UiT Narvik from 2017 to and with 2022

Energy carrier	Bio-oil [kWh]	Direct electric [kWh]	Electric to el-boiler [kWh]	Electric to cooling system [kWh]	Oil (Fossil) [kWh]
Jan	0	429480	118516	106	16637
Feb	0	417774	115313	110	10125
March	778	433831	112619	269	1175
April	55	310603	85060	721	21698
May	0	292601	61780	1767	841
June	59	232002	39357	1331	1037
July	74	195233	39147	98	2779
August	1648	231403	36729	39	418
September	3334	273281	56825	22	4903
October	252	351752	81169	22	2283
November	4079	390651	108053	22	4880
December	8159	395213	125578	39	624
Sum	18438	3953824	980143	4544	67400

The graph in Figure 7 shows the consumption of energy for the electric boiler at UiT Narvik from the first quarter of 2022 to and with the first quarter of 2023. Which is solely the heating provided for UiT.

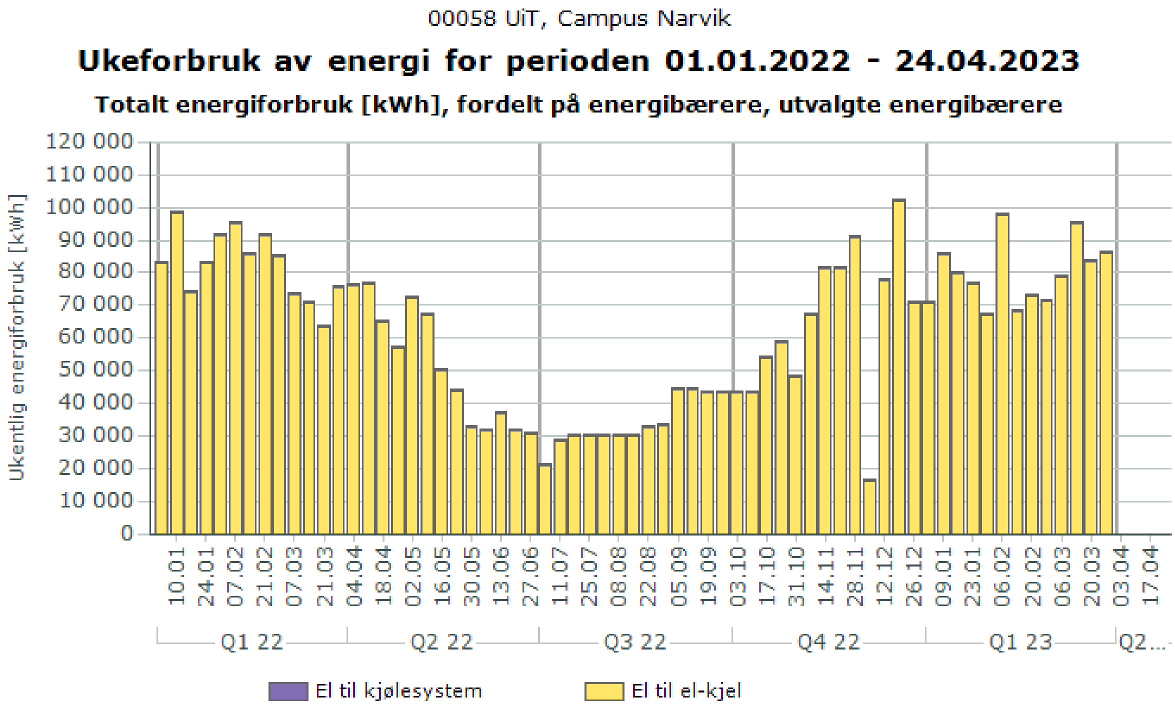

Figure 7 Yearly consumption from the electric boiler

If a focus is only on heating, Figure 7 is the primary focus. The graph was supplied by Statsbygg at UiT Narvik. As the other numbers consist of electric equipment such as computers, machines, lighting, coffee machines, floor heating which run on electricity and many other things. With a focus to explore options for heating which is not reliant on electricity, an optional installation of a heat battery which can be supplemented by the electric boiler when needed can be the target. As prior years will not be as accurate as year 2022, due to recent refurbishments to half of UiT which happened during the covid-period [35]. As the energy demands have changed since previous years and the refurbishments have lowered the energy loss in the university. The dip in the graph between 28 of November and 12 of December was an error with the electric boiler at which point the oil-boiler took over during this time. Therefore, it can be corrected as being on an in-between level of the week before and after.

The data for the electric boiler in 2022 is shown in Table 12.

Table 12 Electric boiler usage 2022

	Electric boiler [kWh]
January	386482
February	357875
March	316214
April	294857
May	215179
June	135972
July	130224
August	147340
September	189804
October	225511
November	323567
December	321690
Sum	3044715

As the total heating needs for the university with the electric boiler was 3.044 GWh in 2022, a look at the need for heating during the winter needs to be examined. As the storage needs to cover most energy demand for the winter season, the energy need for the months October-March are put together and 1931339 kWh, or 1.931 GWh of energy is needed for seasonal storage. This energy is spent over six months to heat up the 26 373 m^2 heated areas of UiT, yielding in 73.2 kWh/m^2 in the winter. This amount of energy needs to be stored during the summertime. During the earlier parts of the summer, energy can be stored when the price is very low to use it during the summer if needed, and then be recharged later during the end of summer.

2.7 Storing the energy at UiT and utilizing it

2.7.1 Storage

Beneath UiT Narvik there is an old tunnel which no longer is in use. It has previously been used as a bar for the university as well as other activities. It has been shut down for over a decade and is not in use according to Statsbygg. It has ventilation and electricity installed, with a few rooms on the side. It is an uneven tunnel that varies in shape, but can be considered almost rectangular in shape, is about 109 meters long, and varying width and height with one entrance at each end.

A drawing of the tunnel is displayed in Figure 8.

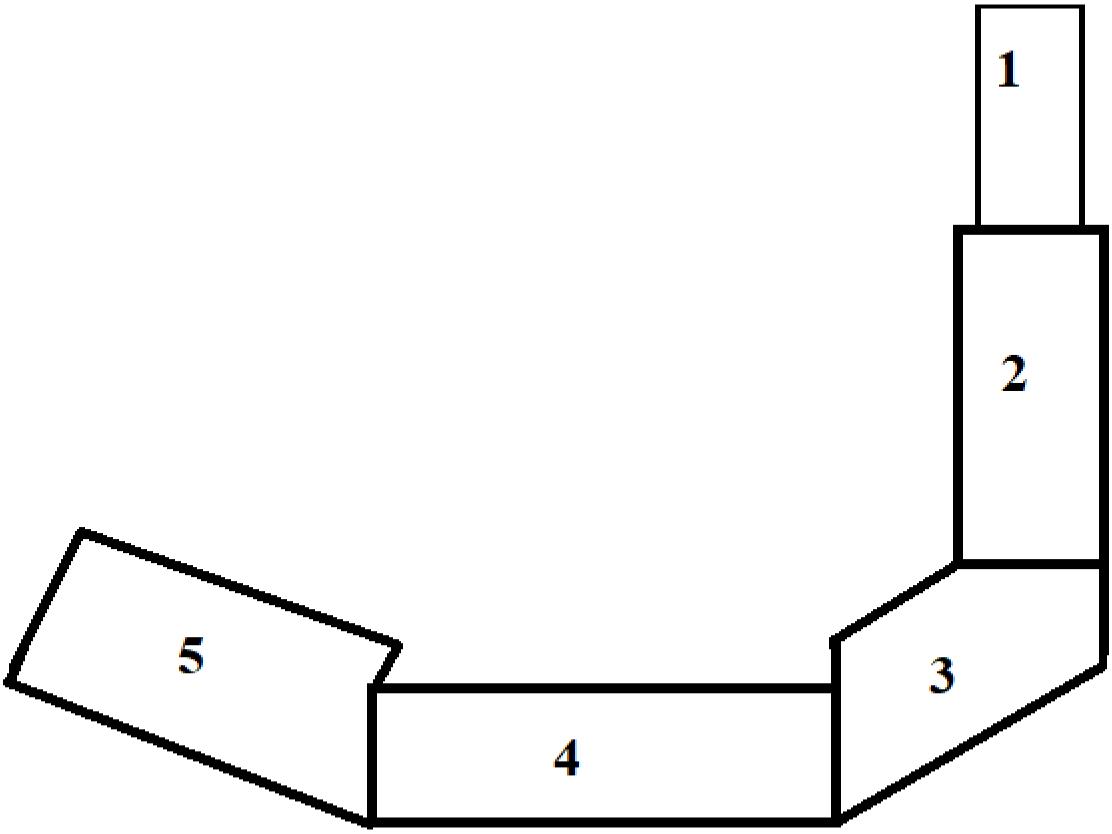

Figure 8 The tunnel with its sections

The current parameters for the tunnel are as of now, without insulation or alterations are shown in Table 13.

Table 13 Tunnel parameters

Section:	Length [m]	Width [m]	Height [m]	Roof and floor surface areas [m^2]	Side surface areas [m^2]	Entrance surface area [m^2]	Volume [m^3]
1	13	4.5	3.5	117	91	15.75	204.75
2	24	6	3.7	288	177.6		532.8
3	18	8	4.7	288	169.2		676.8
4	31	5	3.7	310	229.4		573.5
5	23	7	4	322	184	28	644
Sum	109			1325	851.2	43.75	2631.95

There is also another section above the tunnel which goes to the old student bar with another access point. The tunnel can be repurposed as a storage medium for seasonal storage of energy. This can be done by clearing out all the equipment, ventilation, and electric components and cleaning the area. After this is done the side rooms can be plugged, the exits on the ends can be blocked, and the tunnel can be insulated to keep heat better, making the tunnel a storage for water. The bar section above can be used as an access point to the storage, or the area can be cleared out along with the rest of the area between both exits to expand the storage and create a larger storage. It is also possible to further expand the width and height of the tunnel to a certain extent as there is not many meters it can go higher, to provide more volume. This tunnel can function similarly to the energy storage in [2], or storage buffer by the company Ecovat [48]. To heat up the water a heating element will be necessary [50]. The method implemented by Ecovat claims to only lose 10% of the stored energy over six months [49], [52]. These losses will vary from implementation to implementation of this method. As in how long it will be stored, the ratio of surface area to volume, the materials used to house the water and what insulation is used to keep the heat. Where the higher the ratios will lead to higher losses through the surface area. It is also possible to use the tunnel as a storage for electrical equipment. This requires the area to be cleaned up, ventilation and electricity to be turned back on, as well as improve the infrastructure to use it for another storage method.

Making it quite costly. The tunnel was originally shut down due to the costs of having it running was quite high according to Statsbygg at UiT.

If the tunnel is to be repurposed for storage of water, since 1 m^3 of water is 1000 liters the storage can be:

$$Storage = 2631.95 * 1000 = 2631950\ liters = 2.63195\ million\ liters \tag{2.20}$$

Water has a specific heat capacity of 4184 J/kg [43], and 1 liter of water equals 1 kg, and if it assumed that the water will be heated to 95 °C, the total storage capacity will be:

$$W_{water95} = c_{water} m \Delta T = 4184 \frac{J}{kg} * 2.63195 * 10^6 kg * 95 = 1.046147 * 10^{12} J \tag{2.21}$$

In terms of kWh this is divided by 3600 seconds (1 hour) times a thousand (kilo) which gives:

$$E_{water} = \frac{W_{water}}{1hour * kilo} = \frac{1.046147 * 10^{12}}{3600 * 1000} = 290596kWh = 290.596MWh \tag{2.22}$$

Is the amount of energy that can be stored inside the tunnel if it is filled with water.

2.7.2 Energy production

The locations available for energy production UiT are a very few. There is a sizeable area on the roof where either PV panels, solar collectors or thermodynamic panels can be installed. The roof area suitable for installation is about 2458 m^2, but with regards to access and spacing between panels it is more realistic with 1475 m^2, which is 60% of this roof area. These values were taken from measurements on maps.google.com [70]. It is not an area suited for very large machinery or very heavy constructions as it is the roof, and it will need reinforcements to support heavy loads. There is also a slope outside of the cantina of the university, which is directly above the tunnel. This area can be cleared of smaller trees and the area can be flattened if needed or make brackets where panels can be mounted on. This area is not very suited for PV panels and thermal collectors as it is on a level where sunlight will be blocked by nearby blocks and houses during certain times of the year. Thermodynamic panels have no problem with this slope as the panels can be stacked right next to each other. The slope is also not suited for very large constructions as it is a very uneven area and is not wide enough for large machinery.

None of the areas the university has available are suitable areas for massive constructions. The storage underneath the university is long, but it will be too narrow and low to use it as a production area for many of the methods mentioned in this thesis as most of those turbines and storage tanks are too large, if it switches to a production area instead of storage area.

2.7.3 Utilization

Creating the energy and storing it is not enough, it also needs to be put to work. UiT already has installed a lot of water radiators around the school for heating classrooms, offices, hallways, and study rooms. UiT also has water heating under the floors as well as the entrance areas to the university. There are also heat pumps planned for certain rooms in the university. If a water heat storage method is implemented, it can be integrated into the heating system of the university. With the electric boiler being repurposed for both heating the water and pumping it around the floor heating. There will be no need for further heating elements around the university, as well as no new boiler being needed for the storage.

2.8 Economic factors

Before the energy storage system at UiT can be implemented, costs must be considered. Whether or not the entire cost of the system shall be paid for up front, or if loans need to be taken. There are some organizations that offer support for introducing green solutions, if it can be proven that the solution reduces greenhouse gas emissions. There will be operational and maintenance fees for the system, which include cleaning, fixing, and swapping parts. If loans are taken, then the inflation and rate must be taken into consideration. The sum of all the costs over the system lifetime compared to the potential earnings must prove to be profitable for the solution to be implemented.

2.8.1 Tariff

Tariff is the fee given to the local grid owner for transporting electricity to the user. This fee is important because by producing energy itself UiT will reduce the amount of energy that need to be bought to provide heating. This price comes in kr/kWh or øre/kWh which is the energy fee and the power fee which is for kr/kW. The power fee is determined by the highest power peak usage in the previous month [38].

By reducing the peak power usage by producing energy itself, UiT can reduce costs monthly. Noranett is the grid owner for Narvik, and their prices as listed in [39] are shown in Table 14.

Table 14 Noranett rates and taxes

Grid rental from 01.04.2023						Included consumption-tax and ENOVA-tax for households
	kW from	**kW to**	**Fixed price kr/meter/month**	**Power tax kr/kW/ month**	**Energy tax øre/kWh**	**Energy tax øre/kWh**
Gridlevel 4/5 Large consumer low voltage over 3*125A						17.64*
Winter**	0	9999	1000	99	0.8	
Summer**	0	9999	1000	38	0.8	
Gridlevel 3 Large consumer high voltage						
Winter			2500	90	0.0	15.84*
Summer			2500	34	0.0	15.84*
	*In the period 1.1-31.3 the consumption tax is reduced to 9.16 øre/kWh. The price for large consumers is without taxes **Summer prices are between 1.5-1.11 Winter prices are between 1.11-1.5					

As UiT is a large consumer with low voltage with a main fuse larger than 125 A it will go into gridlevel 4/5. So, for each kW peak that is reduced during a month, it is possible to reduce the power tax by 99 kr for each during the winter, and 38 kr for each during the summer. The consumption of energy dedicated to heating shown in Table 11 and 12 shows that it is possible to greatly reduce the amount of electricity bought from the power provider.

2.8.2 Spot-price

Spot-price is the price for the electricity at a given area. It is constantly being regulated by Nord Pool which is the market for electricity in Norway, Sweden, Denmark, and Finland [40]. This price changes from hour to hour depending on the supply and demand of electricity. If the production is high but the demand is low, then the price is low. If the production is low but the demand is high, the price is high. Due to the intermittency of RES this price varies depending on the weather and the season. Nordland is the county which UiT Narvik is in, and it is designated as area NO4. This area tends to have quite cheaper power prices than the rest, as it has more power production compared to the citizens of the region. NO1 tends to have quite high prices, due to it containing the capital Oslo with all its citizens.

Figure 9 shows the spot-price zones in Norway and neighbor countries as well as the electricity flow between the zones. This flow varies depending on which zones produce more than the demand in said zones, supplying the zones which are more in need. The blue arrows are the flow directions, and the red numbers are the spot-prices for the current hour.

Figure 9 Spot-price zones in Norway NO1-NO5 and neighbor countries [71]

Figure 10 shows the power prices for the area NO4 which Narvik is in for the years 2012-2022.

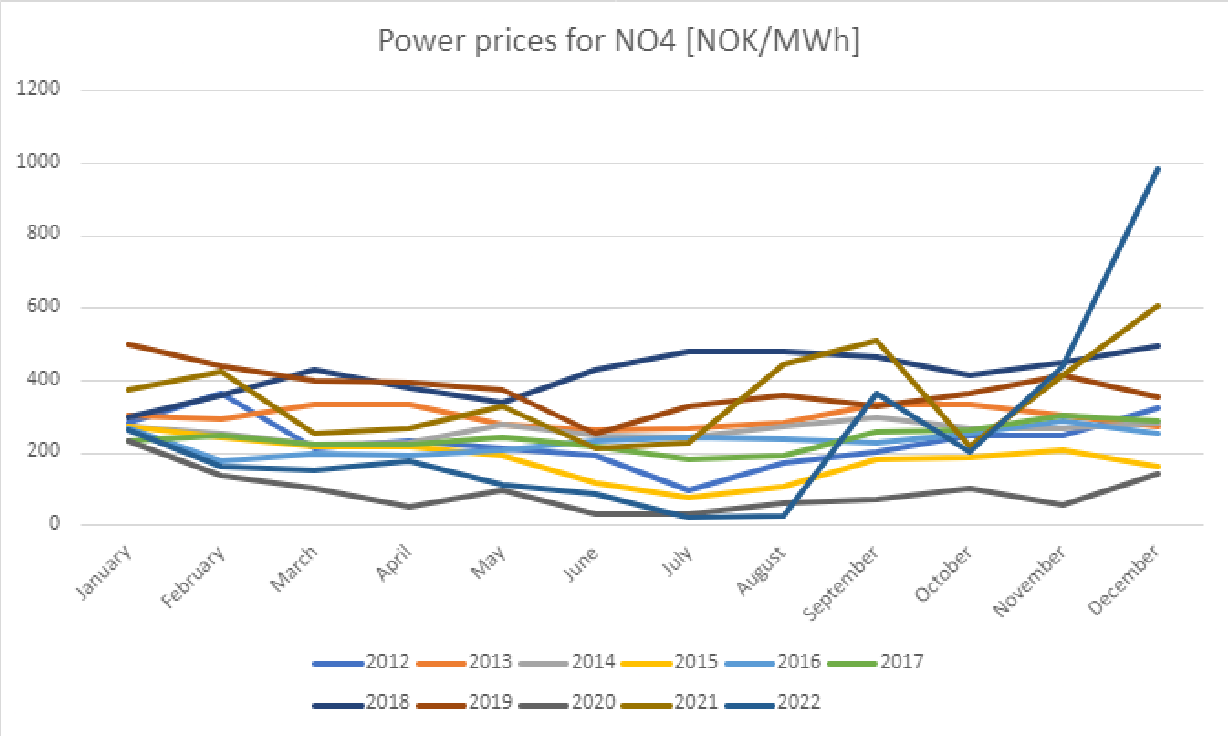

Figure 10 Power prices for NO4 (2012-2022)

Table 15 shows the average monthly prices for the years 2012-2022 for NO4.

Table 15 Average monthly price for NO4

Month (2012-2022)	Price [kr/MWh]
January	301.04
February	283.15
March	249.28
April	246.07
May	242.07
June	207.78
July	200.80
August	241.36
September	295.78
October	261.59
November	310.07
December	379.24

Figure 11 shows a graph of the average power prices for NO4 from 2012 till 2022.

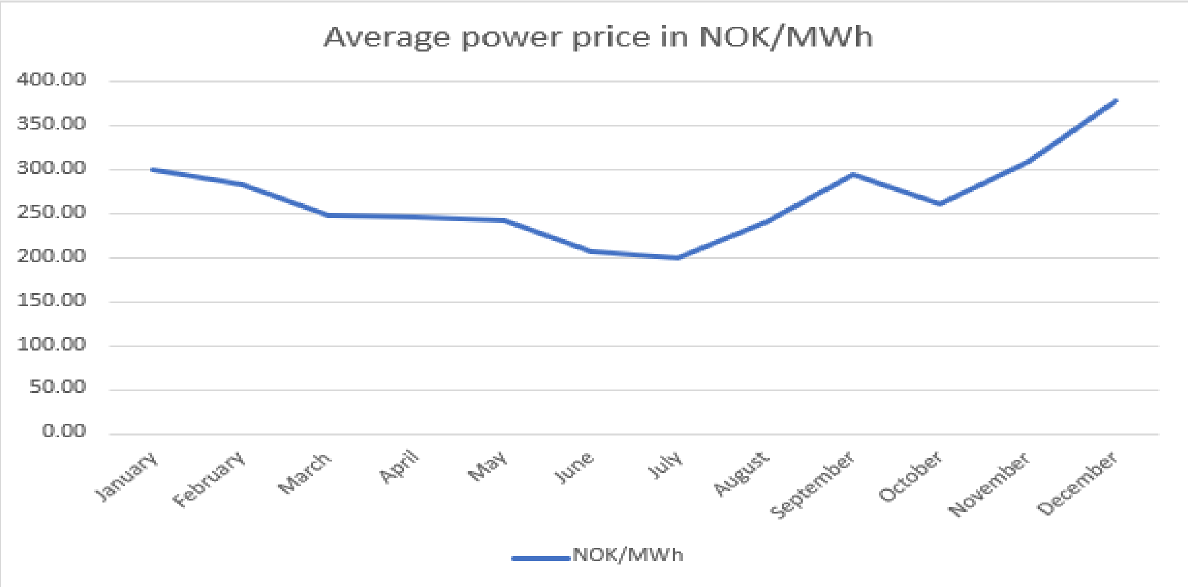

Figure 11 Average power prices for NO4 (2012-2022)

As Figure 10, Figure 11 and Table 15 shows, the months during winter, December, November, and January are the more expensive months for consumers. Further proving that money can be saved by saving electricity produced during the summer for later use.

A lot of large consumers tend to make an Energy management arrangement. This means that the energy use history of the consumer is considered, and then a set amount of energy is bought at a given price. This plan avoids the spot-price of going above an agreed upon price limit [79]. UiT uses such a plan, but the contract is private and will not be shared publicly. With an installed seasonal storage, the amount bought in the plan may change.

2.8.3 CAPEX and OPEX

Capital expenditures (CAPEX) is a measure of how much investment a producer, business or consumer must pay to acquire, maintain, or upgrade assets. This is usually a large one-time investment at the start of a project, or several over a loan period.

Operational expenditures (OPEX) are the costs considered for maintaining operation and various fixes during the lifetime of a system or business. OPEX consist of fixed costs which are day to day, month to month and so on. This can be maintenance as well as services required to keep the system or business operational. Variable costs are also included in OPEX and consist of additional maintenance where parts break or improvements on parts can be installed and so forth.

2.8.4 Support

A company called Enova specializes in investing in systems that provide a green shift from the use of fossil fuels. Enova used to invest in a lot of PV panel installations in the past for consumers, businesses, and power producers. Nowadays Enova only invests in the installation of PV panels or similar green solutions that has hard proof that the installation will reduce CO_2 emissions by the user or private households [59]. The other groups that still see support are households that fulfill certain criteria as listed on Enova’s homepage. As nowadays the green shift has been much more accepted and is the goal of society.

2.8.5 Inflation

Inflation is that the availability of wares is less than the availability of money, which results in an increase in the price level. In Norway the Bank of Norway stands for the regulation of the inflation level and the target for the bank is that the yearly consumer-price index is about 2% a year [54]. The consumer-price index (CPI) is a measurement of inflation and gives an overview of the inflation in Norway. According to SSB the average inflation from 2012 to 2022 is about 3.34% which is a bit higher than the target. That is most likely due to a quite drastic price increase in the last few years due to the war in Europe. It can be assumed that it will stabilize and get closer to the Bank of Norway's target once the conflict has been settled.

The increase from the CPI shows that 1000 kr in 2013 amounts to 1334.4 kr in 2023. Instead of using the 2% increase of the CPI, it can be more realistic to use about 3.34% for now. As it will take time for the economy to turn back to normal. So, 1000 kr in 2023 will be worth about 1389 kr in 2033.

2.8.6 Term amount

If an annuity loan with fixed annual costs is set as the loaning method. The yearly payments of the loan will be [72]:

$$term\ amount = \frac{Loan\ amount * (1 + interestrate)}{\frac{\left(\frac{1}{1+interestrate}\right) - 1}{\frac{1}{1+interestrate} - 1}}^{"number\ of\ payments"} \tag{2.23}$$

2.8.7 Real interest-rate

Real interest-rate is the difference between nominal interest and inflation. Real interest-rate determines how much the interest in reality gives in the form of purchasing power.

The formula for real interest-rate is given as [73]:

$$r_R = \frac{r_N - J}{1 + \frac{J}{100}} \tag{2.24}$$

Where r_R is the real interest-rate, r_N is the nominal interest and J is the inflation.

2.8.8 NPV

Net-present-value (NPV) is a value that shows how the value of an investment expressed as the present value of money. This value is calculated by taking the investment costs and future costs and calculating them to the present value of said money. An investment is considered profitable if it is positive, and not so if it is negative.

The formula for NPV is given as [74]:

$$NPV = -K_0 + \frac{K_1}{(1+r)^1} + \frac{K_2}{(1+r)^2} + \cdots + \frac{K_n}{(1+r)^n} \tag{2.25}$$

Where K_0 is the investment cost, K_1 is the cashflow of the first year, K_2 for the second, K_n for the given year. K_0 can be split up into negative cash flow each year if annual payments are used.

2.8.9 LCOE

Levelized cost of energy (LCOE) are all the costs of a system compared to all the energy produced by the system. This can be for the entire lifetime of the method, but it is mostly used for a yearly basis to compare between different methods and the respective lifespans of these methods, showing which have better price to performance. It can be represented as a measurement of price compared to energy NOK/kWh or as a measurement of price compared to installed capacity of the system NOK/kW. LCOE is very beneficial in comparing different methods to each other to see which solution is better at cost to performance. Since some solutions can seem cheaper up front but may require more maintenance and swapping of parts compared to other systems which require few additional costs after installation.

The formula for LCOE is [75]:

$$LCOE = \frac{CAPEX + OPEX_{lifetime}}{Energy\ produced_{lifetime}} = \frac{\sum_{t=1}^{n} \frac{\mathrm{I_t + M_t + F_t}}{(1+\mathrm{r})^{\mathrm{t}}}}{\sum_{t=1}^{n} \frac{\mathrm{E_t}}{(1+\mathrm{r})^{\mathrm{t}}}} \tag{2.26}$$

Where I_t is the investment expenditure in year t, M_t are the maintenance and operational costs, F_t is the fuel cost, E_t is the electricity generation in year t, r is the discount rate, and n is the lifetime of the system. This formula can also be used with yearly values.

3 Methodology

3.1 Final selection of methods

Now that methods for creating, storing, and using the energy has been presented, it is time to select which should be used. There are several factors that needed to be examined. And those are:

- Application – can the university install it with proper scale
- Capability – does it have enough energy for seasonal storage
- Volume – can it be stored at the university
- Area – is the installation area suitable to the university
- Loss rate – is the loss rate acceptable for seasonal storage
- Maturity – is the technology thoroughly proven

With these factors in mind the selection process will now proceed in Table 16.

Table 16 Storage methods compared

	Storage methods							
	PHES	**Flywheels**	**Sensible heat storage**	**Latent heat storage**	**TCES**	**CAES**	**LAES**	**Battery storage**
Application	No	No	Yes	No	No	No	No	Yes
Capability	Yes	No	Yes	Yes	Yes	Yes	Yes	Yes
Volume	No	No	Yes	No	No	No	No	Yes
Area	No	No	Yes	No	No	No	No	Yes
Loss rate	Yes	No	Yes	Yes	Yes	Yes	Yes	Yes
Maturity	Yes	Yes	Yes	No	No	Yes	No	Yes

As Table 16 shows, the suitable storage methods with regards to the factors are only sensible heat storage and battery storage for UiT Narvik. As most of the methods will be too large to implement with regards to the installation area, necessary storage volume, energy amount for several hour's use and technology maturity. With the electric boiler at UiT of 1200 kW power which can heat water already installed, it is possible to integrate it to the tunnel which can be repurposed for storage.

Table 17 Power production methods compared

Production methods				
	Buying cheap electricity	**Solar thermal collectors**	**Thermodynamic panels**	**Photovoltaic panels**
Application	Yes	Yes	Yes	Yes
Area	Yes	Yes	Yes	Yes
Maturity	Yes	Yes	No	Yes

As Table 17 shows, most of these methods are all suitable for implementation at UiT except for thermodynamic panels which has not proved its maturity yet. UiT has enough roof space for both production and storage for electricity, but if the energy is to be stored as water, the tunnel beneath UiT is more suited.

With all this info presented, it is chosen that the storage method will be heated water in the tunnel. This is due to the lifespan of the system which can last possibly over 30+ years, while batteries will need replacements after maybe 10-15 years. The production method will be buying cheap electricity and introducing the electric boiler as a heater for the storage. These choices are made due to the unique opportunity that the university has, as not many places have such a tunnel for storage available and this method may have longer longevity and sustainability. With this the thesis proceeds.

3.2 Electric boiler

The electric boiler which will be used is the SB 1200 kW 400 V version [53]. This will heat up the water during cheap electricity hours, most often at night when electric consumption is lower since people sleep and less heating is needed for the university at this time. It has a max operating temperature of 100°C making it capable of heating water to 95°C for storage. It can handle 622 liters at a time and has a max operating pressure of 6.0 bar. Its power connection and nominal output are both listed as 1200 kW, indicating a very high efficiency.

3.3 Tunnel storage

Table 13 shows the parameters for the storage without any insulation or blocked entrances. Assuming that a one-meter-thick concrete wall with reinforcement is placed at both entrances, reducing the volume in section 1 and 5. There will be one scenario considered which takes perfect insulation of the storage as a basis. There is not considered an additional thickness of the perfect insulation, which will reduce the volume. This is due to the unevenness of the walls, floor and roof and said insulation can technically fill in these gaps.

The new values for section 1 and 5 together with the other sections are in Table 18.

Table 18 Tunnel parameters with blocked entrances

Section	Length [m]	Width [m]	Height [m]	Roof and floor surface areas [m^2]	Side surface areas [m^2]	Entrance surface area [m^2]	Volume [m^3]
1	12	4.5	3.5	108	84	15.75	189
2	24	6	3.7	288	177.6		532.8
3	18	8	4.7	288	169.2		676.8
4	31	5	3.7	310	229.4		573.5
5	22	7	4	308	176	28	616
Sum	107			1302	836.2	43.75	2588.1

3.4 Charging and number of charges

The water in the tunnel will be charged to 95℃, using the electric boiler with a power of 1200 kW. The initial value is assumed to be 1℃, even though it will be very likely that it is higher during early spring and maybe also during winter. So, the energy for 94℃ will be needed for the initial heating in the early spring, and subsequent reheats will be from 34℃ up to 95℃. Due to the floor heating needing 34℃ to heat up the floor. It is assumed a total charging efficiency of 90% due to conduction, convection, and radiation heat losses, requiring more energy for heating.

With new values for the storage, using (2.5) this results in a needed energy for the 2.5881 million liters being:

$$Q_{water95} = c_{water} m\Delta T = 4184\frac{J}{kg} * 2588100kg * 94 = 1.017889 * 10^{12} J \qquad (3.1)$$

Using (2.6) in kWh this results in:

$$E_{water95} = \frac{W_{water}}{1hour * kilo} = \frac{1.017889 * 10^{12}}{3600 * 1000} = 282747kWh \qquad (3.2)$$

With the 90% efficiency the energy needed for reheating will be:

$$E_{water95corrected} = \frac{282747}{0.9} = 314163kWh \qquad (3.3)$$

The time to fully heat up the storage, using the electric boiler will be:

$$t_{heating95hours} = \frac{E_{water95corrected}}{P_{boiler}} = \frac{314163}{1200} = 261.8h \qquad (3.4)$$

Changing this to days will be:

$$t_{heating95days} = \frac{t_{heating95}}{hours\ a\ day} = \frac{261.8}{24} = 10.9 \approx 11days \qquad (3.5)$$

The energy for recharging from 34℃ will be:

$$E_{water34corrected} = \frac{4184 * 2588100 * 61}{3600 * 1000 * 0.9} = 203872kWh \tag{3.6}$$

The time to recharge it will be:

$$t_{heating34hours} = \frac{203872}{1200} = 169.9h \tag{3.7}$$

Changing this to days will be:

$$t_{heating34days} = \frac{169.9}{24} = 7days \tag{3.8}$$

With the amount of time it takes to fully heat up the storage, and assuming it will not be spent immediately, it is assumed that one full charge will be for two months, meaning from April till May. The subsequent reheat will be for June till July. A final charge will be during August, and it will be stored from the start of September till November/December.

The amount of energy in the storage which is usable for floor heating compared to the winter needs of UiT is:

$$Energy\ coverage = \frac{\frac{4184 * 2588100 * 61}{3600 * 1000}}{1931000} = 0.095 = 9.5\% \tag{3.9}$$

This shows that the storage, as it is now without being excavated further, only has storage for 9.5% of UiT Narvik's need during the winter months.

3.5 Loss rate

Without taking the flow of water inside the storage and wind outside the storage, heat lost to the mountain and solely focusing on the heat transfer through the thermal resistance through the concrete. With the inside and outside temperature of 95 and 8 respectively, using (2.19) the heat transfer through section 1 and 5 will be:

$$q = \frac{T1 - T2}{\frac{Thickness}{\lambda * A}} = \frac{95 - 8}{\frac{1}{1.1 * 3.5 * 4.5}} + \frac{95 - 8}{\frac{1}{1.1 * 7 * 4}} = 4187W = 4.187kW \tag{3.10}$$

With an insulation with as good or better insulation than rockwool as shown in Table 9 and a thickness of 0.25 meters in addition to the one meter concrete the loss through the end of section 1 and 5 will be:

$$q = \frac{95 - 8}{\frac{1}{1.1 * 3.5 * 4.5} + \frac{0.25}{0.041 * 3.5 * 4.5}} + \frac{95 - 8}{\frac{1}{1.1 * 7 * 4} + \frac{0.25}{0.041 * 7 * 4}} = 0.543kW \quad (3.11)$$

With this improved insulation being put to use, a more thorough heat loss with the remaining storage temperatures is calculated. Where the average temperature in September is set to 8℃, October is 5.5℃ and November is 0℃. These temperature values are based on Figure 3. After each day with heat loss, the new temperature is calculated and used for further calculations. To solve for the for the new temperature after the heat loss, this formula is used:

$$T_{remaining} = \frac{E_{waterremaining} * 3600 * 1000}{m * c_p} \quad (3.12)$$

The results of this are presented in Table 19.

Table 19 Heat loss in storage with 1 meter concrete and 0.25 meters of insulation at the ends

Storage starts in September	Heat loss [kWh]	Remaining temperature [°C]	Remaining energy [kWh]
September 1	13.0376	94.996	285742.0
September 2	13.0370	94.991	285728.9
September 15	13.0285	94.935	285559.5
September 22	13.0240	94.905	285468.3
September 30	13.0188	94.870	285364.2
October 7	13.3888	94.839	285270.4
October 15	13.3834	94.803	285163.3
October 22	13.3788	94.772	285069.7
October 31	13.3728	94.732	284949.3
November 7	14.1921	94.699	284849.9
November 15	14.1864	94.661	284736.4
November 30	14.1758	94.591	284523.7

As Table 19 shows, the loss in temperature through the ends of the storage is so minimal it is negligible. And assuming that the mountain will reach a steady state, where there is no energy is lost to it. It is assumed that the tunnel is perfectly insulated for this thesis.

3.6 System cost

The CAPEX of the system based on estimations and calculations made together with Statsbygg and is presented in Table 20.

Table 20 CAPEX for storage system

CAPEX costs	Price [kr]	Possible price for additional boiler [kr]
Removing pipes	200000	
Removing electric components	200000	
Removing ventilation	200000	
Cleaning the tunnel	250000	
Integrating the boiler and water to the storage (2 holes dug from university and Narvik Vann each)	75000	
Temperature gauges and other monitoring equipment (3 gauges in each section)	43000	
Water price [80]	46767	
Pumps and other equipment	120000	
Concrete, armaments, and work hours	765000	
Insulation material	50000	
Sum	1949767	500000

Maintenance costs are estimated to three hours of work a year at a rate of 1000 kr. It is also assumed that small component fixes costs 3000 kr yearly, making the OPEX 6000 kr yearly. This might not be a cost at all during some years, but some years something might need maintenance, and the costs will add up. The payment for this system is going to be paid over 30 years with one payment a year at a fixed cost.

3.7 Inflation and interest rate

As said in chapter 2.7.5, the inflation can be assumed to be 3.34%, and if we assume a nominal interest rate of 4.5%, using (2.24) the real interest rate will be:

$$r_R = \frac{r_N - J}{1 + \frac{J}{100}} = \frac{4.5 - 3.34}{1 + 0.0334} = 1.1225\% \tag{3.14}$$

Making the real interest rate 1.1225%.

3.8 Term amounts

If we assume the lifespan of the storage will be 30 years, and the term amounts will be paid yearly over this duration, using (2.23) we get a term amount that is:

$$term\ amount = \frac{Loanamount * (1 + interestrate)}{\frac{\left(\frac{1}{1 + interestrate}\right) - 1^{"number\ of\ payments"}}{\frac{1}{1 + interestrate} - 1}} =$$

$$\frac{1949767 * (1 + 0.011225)}{\frac{\left(\frac{1}{1 + 0.011225}\right) - 1^{30}}{\frac{1}{1 + 0.011225} - 1}} = 76909kr \tag{3.15}$$

Making the term amounts 76909 kr a year.

3.9 Spot-price

For the spot-price it is assumed that the price during summer can vary between 0-0.4 kr, for winter and expensive periods it is assumed it varies between 0.12-3.2 kr, where 3.2 kr is one of the highest peaks recorded in 2022 by Nordpool [40]. The costs of full charges and recharges are shown in Table 21.

Table 21 Prices for charging of the storage

Power prices					
Cheap prices[kr/kWh]	**Cost for full charge [kr]**	**Cost for recharge [kr]**	**Expensive prices [kr/kWh]**	**Cost for full charge [kr]**	**Cost for recharge [kr]**
0	0	0	0.12	37700	24465
0.04	12567	8155	0.16	50266	32620
0.08	25133	16310	0.2	62833	40774
0.12	37700	24465	0.3	94249	61162
0.16	50266	32620	0.45	141374	91742
0.2	62833	40774	0.7	219914	142710
0.24	75399	48929	0.9	282747	183485
0.28	87966	57084	1.3	408412	265034
0.32	100532	65239	1.5	471245	305808
0.36	113099	73394	2	628327	407744
0.4	125665	81549	3.2	1005323	652390

The potential savings on kWp per month will not be included as there is not enough energy in the storage to cover the floor heating for a full winter month. And since the kW price per month is based on the highest peak for one hour in a month.

3.10 Profitability of the system

The cash flow for the system over the 30 years will be calculated using (2.25) and the possible savings in Table 21, the term amounts of 76909 kr, the OPEX of 6000 kr, and the real interest rate of 1.1225%. A NPV of all this cash flow of the system with all savings and expenses will be presented in the results.

4 Results

4.1 Possible savings

With one full charge during spring, and two subsequent charges, with no loss of energy while stored, and the costs for buying the charges from Table 21. The possible savings for a single year in thousands of kroners are shown in Table 22, where red areas are negative numbers.

Table 22 Spot-price buy and use prices compared together with possible savings in thousands of kroners for one year

	Expensive prices [kr/kWh]										
Cheap prices [kr/kWh]	**0.12**	**0.16**	**0.2**	**0.3**	**0.45**	**0.7**	**0.9**	**1.3**	**1.5**	**2**	**3.2**
0	87	116	144	217	325	505	650	938	1083	1444	2310
0.04	58	87	116	188	296	476	621	910	1054	1415	2281
0.08	29	58	87	159	267	448	592	881	1025	1386	2252
0.12	0	29	58	130	238	419	563	852	996	1357	2223
0.16	-29	0	29	101	209	390	534	823	967	1328	2195
0.2	-58	-29	0	72	180	361	505	794	938	1299	2166
0.24	-87	-58	-29	43	152	332	476	765	910	1271	2137
0.28	-116	-87	-58	14	123	303	448	736	881	1242	2108
0.32	-144	-116	-87	-14	94	274	419	707	852	1213	2079
0.36	-173	-144	-116	-43	65	245	390	679	823	1184	2050
0.4	-202	-173	-144	-72	36	217	361	650	794	1155	2021

The red areas are simply negative due to the price being higher than when the energy is meant to be used. The amount of money that could be saved depending on small power price changes varied greatly. When the power price difference was 0.3 kr/kWh, a bit over one tenth of the initial loan amount would be earned each year.

4.2 LCOE

The LCOE of the system with regards to one full charge and two recharges during a year, perfect insulation, term amounts of 76909 kr a year, yearly OPEX of 6000 kr and yearly stored energy of 649717 kWh. With varying prices, the yearly LCOE of the system is presented in Table 23.

Table 23 LCOE of the system

Electricity prices [kr/kWh]	LCOE [kr/kWh]
0.04	0.1637
0.08	0.2165
0.12	0.2609
0.16	0.3054
0.2	0.3498
0.24	0.3943
0.28	0.4387
0.32	0.4832
0.36	0.5276
0.4	0.5721

Showing that LCOE was greatly determined by what the prices were when the electricity was bought. The LCOE for the system surpassed land-based windfarms, which is 0.2994 kr/kWh when the power price was 0.16 kr/kWh [87]. The LCOE was almost the same as for hydropower facilities over 10 MW, which is 0.3483 kr/kWh when the power price was 0.2 kr/kWh.

4.3 Profitability

Using 30 years as the lifetime and payment time for the system, where all the cash flows are summarized. The NPV for the system with the best possible buying prices and no storage losses are presented in Table 24.

Table 24 NPV with cheapest buying price and varying use price

Power prices, buy-use [kr/kWh]	NPV 30 years [in thousand kr]
0-0.12	94.3
0-0.16	826.4
0-0.2	1558.4
0-0.3	3388.6
0-0.45	6133.8
0-0.7	10709.2
0-0.9	14369.5
0-1.3	21690.1
0-1.5	25350.4
0-2	34501.1
0-3.2	56898.7

The NPV for the system with expensive power prices and no energy storage losses is presented in Table 25.

Table 25 NPV for the system with varying buying price and use price

Power prices, buy-use [kr/kWh]	NPV [in thousand kr]
0.08-0.12	-1369.8
0.12-0.16	-1369.8
0.16-0.2	-1369.8
0.28-0.3	-1749.8
0.4-0.45	-1186.8
0.4-0.7	3388.6
0.4-0.9	7105.7
0.4-1.3	14369.5
0.4-1.5	18099.2
0.4-2	27180.5
0.4-3.2	49142.3

The values that are the same in Table 25 are the same simply due to the power price difference being the same 0.04 kr for these values. These values are negative due to the sum of the earnings being lower than the sum of the annual term amounts and maintenance fees. With the term amount being decided by the installation cost of the system. And as both Table 24 and 25 shows, the value of the system increases greatly with only a small change in power price.

5 Discussion

As shown earlier the potential for low power prices during the summer and high prices during the winter is historically speaking reasonable. This difference allows for savings to be made, especially the more energy is given to the storage, and used at the correct time. NO4 has often great summer prices, but it can also be struck by high winter prices as NO4 also has to supply the rest of Norway with power. And since Norway is continuously moving towards more electrification of transport, industry, backup power and more. It is fully possible that the power prices of the future being higher than they are now, making storage even more viable. The company LKAB is preparing to produce hydrogen in order to make the company free of fossil fuels, in order to do this it is estimated that 70 TWh is needed by 2050 [88].

As the results show savings can be quite large given a big enough difference between the buying price and price at time of use. With possible savings being viable already at a little over a 0.2 kr price difference. This price difference is not unreasonable as during the cheapest days in summer, power can be free, and during winter the prices can spike. It is important to note however that the charging of the storage takes a long time, and the prices over this time will most likely vary. This is due to the intermittency of RES as well as what hour of the day the power is being bought and what the demand is at that time. The boiler also needs to heat UiT, so it may need to interchange between heating the storage and the university. Further increasing the heating time, but that is also part of why two months is set for one heating period during the summer. It may also be necessary for an additional boiler to be installed, further raising the CAPEX of the systems, which will alter all the other results. It may also be that the installed boiler is not suited for a container that large, and a bigger one needs to be installed. If a bigger boiler with higher power draw is installed, the heating time will be reduced, and more charges might be possible to achieve. The higher installed power draw might however increase the power tariff for the next month.

The LCOE of the system as shown in the results was better than windfarms as long as the power price did not exceed 0.12 kr/kWh. This LCOE is of course reliant on the three charges during the year, as well as the cash flow for a year. If the amount of charges increases, even only by one, but the cost only increases a little for the power. The LCOE will improve much more. It may also be that the OPEX of the system will be quite different in reality, it can be much higher, due to a leak happening somewhere, the boiler breaks, more work hours are needed for the maintenance, increasing the OPEX as a result. It may also need almost no maintenance at all, further lowering the OPEX and improving the LCOE. If the additional boiler is needed, or something else entirely is needed which is not included in this thesis, the CAPEX will increase and the LCOE will suffer from it.

When looking at the NPV for the system it is important to keep in mind that even though the values are positive, the system is paid for over 30 years. UiT is a large consumer of energy, small earnings of a few thousand kr over 30 years is not a worthwile investment. At that point it can be much more viable to find other investments. So for it to be worth investing into, it would need to be worth a some millions over its lifespan. The NPV is dependent on the savings and costs of the system. If the inflation changes in the years to come, the term amounts will change, further influencing the NPV. The inflation might decrease once the conflict in Europe has stabilized, or another situation might happen, it is uncertain.

The load shifting with the use of the storage can soften the load during one winter month, which can be useful. Especially if other buildings start to follow the same course of action and install seasonal energy storages. It will require some successes at first before the rest will do the same. If the storages proves to be succesfull, a lot of consumers can avoid the bigger costs during the winter and save a lot of money. If enough install seasonal storage and use it properly, it might reduce the demand enough for the power price to fall during winter.

It is very important to point out that thermodynamics are outside of the electrical engineering field of study. The assumptions about heating the storage and keeping it warm in this thesis might not be completely correct. It may be that the mountain will never reach a steady state and it may drain a lot of heat, and it might be fast. The calculations in this thesis are done with perfect storage in mind and only a few losses during the charging process. The calculations for heat loss are done with one-dimensional and not multi-dimensional calculations. The different layers of the water inside the tunnel are not considered and it is only thought of as the same temperature all around. There may be some factors which have not been considered due to it being outside of the scope of electrical engineering.

6 Conclusion

With regards to the results, it is safe to say that it can be economically viable for UiT the arctic university of Norway Narvik, to install a sustainable seasonal storage of energy. Given the energy is bought at cheap prices and used at expensive prices over a certain threshold compared to when it was bought. Using a boiler to heat water which is stored in a storage tunnel beneath the university inside the mountain. Using the heated water as heating for the university. If storage is perfectly insulated and works as intended in this thesis. The financial gain from this effort for the university can be in the millions if the correct conditions come into play. The power producers will benefit from something to take the load during the summer and have less demand during the winter. Further developments in seasonal storage of energy can benefit society with more availability of power and possibly lower peak power prices.

6.1 Further research

Further research on seasonal storage of energy in Norway can delve deeper into the thermodynamical properties and functions of the storage mediums and its interactions with its surroundings. More realistic calculations where every factor is accounted for. Optimization of the heating process along with algorithms for when to buy power. This can be for both small and large consumers.

In the appendix are the excel files for the calculations and spot-prices. There are also included energy-mapping of the university and measurement assessments.

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9 Appendix

Appendix 1: Excel-file for UiTs energy use and calculations for the storage and prices

Appendix 2: Excel-file for NO4 spot-prices

Appendix 3: Electric boiler datasheet

Appendix 4: UiT from above

Appendix 5: Measurement assessment for Statsbygg by Rejlers

Appendix 6: Energy mapping for UiT Narvik by Rambøll

Appendices.zip