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Masters Thesis

Electrification of Industrial Process Heat Production

Techno-Economic Analysis of Molten Salt Storage Systems and Electric Heating

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Abstract:

This Masters thesis aimed to investigate the effects of electrifying the production of process heat demands in the industrial sector, and to what extent the created flexible demand could contribute in mitigating the cannibalization effect created by increased reliance on variable RE sources. A techno-economic optimization analysis investigated the feasibility of using molten salt storage systems (MOSS) to electrify high-temperature process heat production at Randers Tegl's Hammershøj Teglværk. The analysis, employing energyPRO modeling, revealed that MOSS, combined with electric heating, offers a feasible pathway to significantly reduce natural gas consumption and create significant flexible electricity demands. Sensitivity analyses highlighted that electricity and natural gas prices influenced the economic viability of the proposed solutions. However, the study emphasized the need for a comprehensive organizational analysis, including stakeholder engagement, to mitigate potential project management challenges and ensure successful implementation of these technologies. The integration of both analyses highlights the complex interplay between technological feasibility, and effective project management in mitigating the cannibalization effect through electrification of the industrial sector.

Preface

This masters thesis was written during the spring of 2025, and was made possible due to collaborations with HYME energy and Randers Tegl.

The goal of the masters thesis was to investigate the potential benefits in mitigating the cannibalization effect through electrification of the process heat production in high temperature industrial processes. For the analyses the case of Hammershøj Teglværk was used in which a sensitivity analysis showed that gneeralizing the results on the specific brickwork to the full industrial sector could lead to the creation of flexible demands of 4.3 TWh/year.

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Additionally we want to express our gratitude to HYME energy for providing us with the economic and technical data that was needed to perform our techno-economic analyses.

We would also like to extend our gratitude towards Eoghan Rattigan at Green Lab Skive, the information that was given to us through the interview proved very useful in the considerations that needed to be taken throughout our analyses

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Contents

1 | Introduction

In the pursuit of climate neutrality for the members of the European Union, the European Commission has launched multiple initiatives to promote the implementation of renewable energy. The European Green Deal from 2019, set targets of net-zero emissions for the member nations by 2050 and since, initiatives has followed to further promote RE-integration [Commision, 2019]. In 2023 the Renewable Energy Directed from 2009 was revised and set new targets for renewable energy production, with at least 42.5 % of the total consumption being covered by RE by 2030 [Commision, 2023b]. Furthermore, the Green Deal Industrial Act was launched in 2023 to aid in the transition away from fossil-fuel usage in industries in addition to promote an increased renewable energy utilization for industrial processes through RE and storage solutions [Commision, 2023a]. The net-zero target of the Industrial Act seeks to reduce the current consumption of fossil-fuels in the EU, which in 2022 accounted for 50.4 % of the total energy consumption, where natural gas usage amounts to 31.4 % [Commision, 2022]. Denmark as a member of EU, has obligations in relation to achieving these targets, where a contribution of a 58 % RE-share is expected by 2030 [Klima, 2024, p.48]. Additionally, the danish obligations include an increased RE utilization within industries in the pursuit of substituting fossil-fuel usage for process heat of an 1.1 % increase annually towards 2030, with a final share of 60 % in 2030 [Klima, 2024, p.48]. The danish RE-integration goals include a quadrupling of the total electricity production from PV and wind turbines on land towards 2030 [Klima, 2024, p.109], which raises the question of:

Which challenges are associated with an increased RE-integration and what are the possible solutions?

2 | Problemanalysis

This chapter aims to analyze problems and possibilities surrounding the renewable energy transition, in particular the increased reliance on variable renewable energy sources (VRE) and the associated challenges. Energy storage will be introduced as possible solution that can mitigate the challenges of relying on VRE, which will be followed by a state of the art analysis, which aims to investigate what current solutions are available, and how commercially viable they are at their current state. Lastly, the industrial sector will be mapped in relation to potential industries that can be electrified through high temperature storages.

2.1 Challenges of the renewable energy transition

The transition towards renewable energy and the perceived associated challenges, have shifted in the last decade from mainly focusing on the investment cost of RE in comparison to new fossil-fuel driven plants to the intermittent nature of the production from RE-sources and the impact it has on electricity markets [Pommeret and Schubert, 2022, p.2]. The investment costs from an investors perspective is still the main focus, but in relation to market uncertainties due to the variable production of a fluctuating energy source, as the payback time of investments are reliant on the ability of the investors to export the produced electricity at prices equal to or higher than the LCOE of the RE-assests [Peña et al., 2022]. In this context, increasing RE-production results in increasing electricity price volatility and lowering electricity prices when production is high, which affect the payback time of the investment and ultimately can cause value deflation of RE-assets [Reichenberg et al., 2023, p.1]. This effect can be seen on figure 2.1 as electricity prices are lower when the share that RE covers of the total consumption increases:

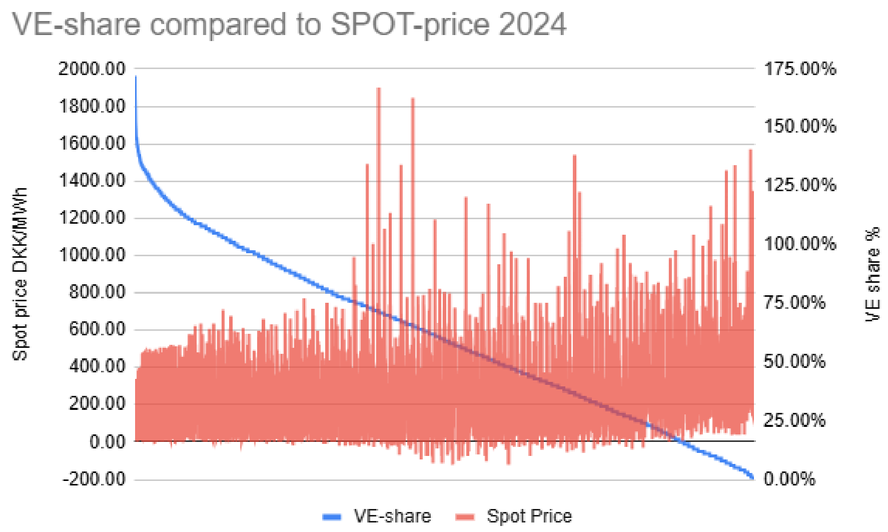

Figure 2.1: The share of RE for each hour of 2024 compared to consumption (blue line) and the corresponding electricity price for that hour. Made by the project group [Energidataservice, 2024]

In 2024 the danish energy agency published a projection of the development of RE productions and flexible electricity demand in the form of PtX and data centers which can be seen as countermeasures to the increased price volatility [Danish Energy Agency, 2024]. These projections follow the policy goals of the danish climate deal on green electricity, in which a goal of quadrupling the production from VRE before 2030 was set [p.2 The Danish Government, 2022; Danish Energy Agency, 2024, p.15].

Key developments in the projections can be seen in Table 2.1:

Technology	**Year**			
(TWh)	**2025**	**2030**	**2040**	**2050**
Demand				
PtX	0.5	13.9	35.4	56.2
Data centers	4.6	17.1	29	29
Renewable electricity production				
Onshore Wind	12.2	17.7	18.8	19.6
Offshore Wind	11.15	18.24	155.93	208.16
Photovoltaics	5.6	29.6	53.1	62.1

Table 2.1: Projected development of the electricity demands for PtX and Datacentres, and the renewable energy production from Onshore wind, Offshore Wind and Photovoltaics in 2025, 2030, 2040 and 2050 [Danish Energy Agency, 2024].

The key developments shown in Table 2.1 do not include the classical electricity demand, since it is not projected to change significantly. Contrarily it can be seen that for PtX and Data centers drastic increases are seen. These increases in demands must be seen as a result of developments in the synthesis of biofuels, which needs corresponding capacity in PtX. The increase in Data centers is projected due to increased demands for digital storage centers [Danish Energy Agency, 2024].

While the demands increase drastically, the production of Renewable Energy is additionally increasing. However, as per the deal on green electricity, the main increases are seen for Offshore wind and Photovoltaics, which see twenty-fold and ten-fold increases in production [Danish Energy Agency, 2024]. These increases in production being of such higher magnitude than the development in demands, would can results of the aforementioned value deflation of RE-assest, which has been termed the cannibalization effect. This effect and the corresponding merit order effect will be further described in the following section.

2.1.1 The Cannibalization and Merit Order effects

The cannibalizing effect is a result of increased investments in VRE, resulting in large renewable shares of electricity production [Peña et al., 2022]. The increase in renewable share results in lower electricity prices on the wholesale market, which is due to the merit-order effect [Antweiler and Muesgens, 2021].

The Merit Order effect assigns VRE a large factor to the impact of the prices on the wholesale electricity market, by factoring that the low marginal costs of VRE influence the electricity prices to decrease during high production hours, whereas low production hours causes the electricity prices to rise, thus creating a more volatile electricity market. Additionally the demand of electricity also affects the electricity market prices, and as such it is implied that in order to keep the price volatility at acceptable levels the demand must follow the invested capacities of especially VRE, with one such way being the increase in flexible demands [Shimomura et al., 2024].

The cannibalization effect thus happen where an increase in the renewable energy share results in higher electricity price volatility, which causes lower investment returns of VRE. This causing future investments in VRE to become less advantageous, thereby potentially slowing down the renewable transition [López Prol et al., 2020].

Furthermore, the volatility of the electricity market is not only affected on a national scale but also internationally. High productions of VRE in one country does not exclude neighboring countries experiencing high renewable shares as well, resulting in an inability in exporting the excess electricity production in such hours, which forces curtailments of multiple facilities, resulting in increased overall LCOE for the facilities that the curtailments are forced upon [Klinge Jacobsen and Schröder, 2012, p.664-665]. This further disincentivizes investments in VRE producing facilities under the uncertainties of ensuring the necessary return on investments. As such, it is further emphasized that there is a need for flexible demands to counter curtailments by utilizing the excess electricity production through direct consumption or by storage for hours with less production of renewable energy, with storing the excess electricity enabling a decrease in price volatility.

Therefore, a need for investigating solutions that enable flexible demands by storing electricity in high producing hours for later use is needed, in order to achieve renewable energy systems that rely minimally on these backup capacities.

2.1.2 Storage as a catalyst for the transition - Effects and possibilities

Storage as a catalyst for the transition can be put in the perspective of the IEA's framework for VRE integration which includes six phases, with each phase representing new challenges and required solutions [Agency, 2024]. Depending on the case-specific context, the location analyzed will have different challenges and required solutions according to the current phase of VRE integration. Each phase with the attributed description, challenges and required solutions are shown in table 2.2:

Phase	Description	Challenges	Solutions
1	VRE has no significant impact at the system level	None	None
2	VRE has a minor to moderate impact on the system	Faster and more frequent ramping of generators	Opgrades to operating practices, including forecasting and more efficient use of existing resources
3	VRE determines the operation pattern of the power system	Greater swings in supply and demand balance Increased uncertainty and variability of netload	Increase system flexibility
4	VRE meets almost all demand at times	Power system stability Maintaining stability during disruptions in supply or demand	Advanced operating practices and regulatory changes
5	Significant volumes of surplus VRE across the year	Surplus must be managed	Implementation of demand response, storage and grids
6	Secure electricity supply almost exclusively from VRE	Supply and demand management during extended periods of low wind and sun availability	Long-duration storage, extensive electricity trade

Table 2.2: Sixphases

In a danish context, the current degree of VRE integration is within phase 5, with hours where production exceeds demand as was highlighted in section 2.1. The challenges of grid stability and variability in production has caused an increased interest in storage research and implementation possibilities. Furthermore, achieving phase six entails a further increase in the implementation of storage solutions thereby creating a flexible electricity demand that is able to both supply the demand when production from VRE is low and increase the utilization of VRE in hours when production exceeds demand [Agency, 2024].

As mentioned above, it is necessary to investigate the possibilities and effects of implementing energy storage solutions in the the energy system, when planning for a 100 % renewable energy transition. Energy storages are essential in the creation of fully decarbonized energy systems, in which the energy markets are stable as well. These However, as stated by [Lund et al., 2016], researchers mostly investigate the application of storage opportunities in an electricity context, in which smart electricity grids are achieved. These power-to-power storages should not be disregarded, but the disadvantages relating to the costs and losses of storing electricity emphasize a need to also investigate other storage types, namely thermal and gas storages. Since gas storages are viewed as quite cheap, they would need additional investments in PtX electrolysis systems and other gasification, which themselves carry additional costs surrounding investments, operations and maintenance, and as such, would not lead to an investigation in storage, but rather the conversion technologies from electricity to gas. Additionally, as mentioned in section 2.1, the projected development of PtX does not suffice in relation to the expected increase in RE-production. Therefore, gas storages will not be investigated. Thermal storages however, have a multitude of application areas ranging from utilizing electricity to produce thermal energy for use either in district heating, industrial process heat or conversion back to electricity. These applications of thermal storages indicate that their possibilities include both Power-to-heat-to-Power and Power-to-Heat, and as such the next paragraph will focus on how these two application types can be utilized by thermal storages, and what potential challenges there are for each application area.

Power-to-Heat

Thermal storages for Power-to-Heat (PtH) applications are not a new technology and, as such is already implemented in a multitude of fields such as for residential heating and industrial process heating. The advantages of utilizing PtH solutions in energy systems relying on larger shares of VRE are based on the creation of increased flexible demand and decreasing fossil-fuel usage.

There are differences to potential benefits and challenges for PtH solutions depending on the desired application field, whether it is for residential or industrial demands. Thermal storages for residential heating benefit from somewhat low CAPEX investments, due to a history of development of the technology, which also results in a technology that is optimized for low maintenance and installation costs [Steinmann, 2022, p.374]. Recent developments in heat pump technologies, however, creates competition where heat pumps are more feasible under some conditions.

Thermal storages for industrial process heat become more interesting when dealing with temperature ranges where heat pumps are not a possible solution. however, due to less technological advancements in thermal storages with higher temperatures, and different industries having different demand profiles, there is a lack of commercialized solutions. Therefore, the utilization of thermal storages in industrial heat processes can lead to higher CAPEX and OPEX. Increased developments in thermal storages for industrial process heat could therefore reduce both CAPEX and OPEX, and as such would increase the feasibility of different solutions [Steinmann, 2022, p.375].

It is therefore important when investigating PtH solutions to find optimized solutions that are either competitive with other technologies or are optimized in the specific context that is being investigated.

Power-to-Heat-to-Power

In general, processes that utilize thermal storages for conversion back to electricity function by storing electrical energy in a thermal storage system, which can be used to convert back to electricity in a separate cycle [Steinmann, 2022, p.329]. While the concept of storing excess electricity for hours with higher spot prices is important to create an energy system that has more stability through flexible demands, there are certain limitations to the overall

Power-to-Heat-to-Power (PHP) concept.

While the conversion from electricity to thermal energy is well established as a commercialized technology, the main limitations lie in the conversion back to electrical energy, where the biggest factor is determining the round trip efficiency [Steinmann, 2022, p.330]. The implementation of these PHP systems can be in unison with a multitude of different energy producing facilities, such as commercial power plants and renewable energies.

When introducing PHP in commercial power plants, the round trip efficiency becomes important since requirements of the thermal storage become strict in order to keep an efficiency that matches the power plant. For commercial power plants high efficiencies place in the 60 % range, which for the round trip efficiency to stay in the same range when PHP is included, requires the storage to reach temperatures of 1400°C [Steinmann, 2022, p.330]. However, when temperatures exceed 600°C the corrosion and thereby costs would increase significantly [Steinmann, 2022, p.70]. Additionally, Eoghan Rattigan from Green Lab Skive verified that in their research on possible high temperature thermal storages resulted in certain solutions decided as infeasible due to the increased costs concerning different alloys B.

While the multitude of applications for thermal storages enable a greater flexibility of the energy system, thus emphasizing a need for a widespread implementation throughout all sectors, this thesis will mostly focus on the implementation of thermal storages for Power-to-Heat due to the high efficiency in the range of 80 % to 90 % confirmed by HYME, and as such the next section will investigate the state of the art of high temperature storage (HTTS).

2.2 State of the art of HTTS

Thermal energy storages (TES) have gained traction in academic research as part of the solution to the challenges associated with increased renewable energy electricity production covered in section 2.1. The application potentials are currently being investigated within multiple sectors as a way to reduce fossil fuel usage by increasing the utilization of energy produced from renewable energy sources, in addition to being able to help balance electrical supply and demand by creating a flexible electricity demand through the implementation of storage systems [Steinmann, 2022, p.10-11]. To be able to contribute to the academic field of TES, the current landscape of the technology will be explored in this section. This includes;

- A description of the different types of high temperature thermal storages and the storage mediums currently in use and under development with their respective technological readiness levels
- The temperature ranges and application potentials of the heat produced
- The technical and economic limitations of the different types of thermal storage and storage mediums and the current sectors utilizing active facilities, in addition to application areas currently being researched and facilities in development

2.2.1 Types of HTTS and storage mediums

The categorization of different designs of HTTS systems is dependent on the storage medium applied in the system, which can be defined through three categories of storage; Latent, thermochemical and sensible heat storage [Pantaleo et al., 2024, p.2].

Latent heat storages utilize phase-change materials (PCM) and are currently commercialized for residential application in both cooling and heating [Pantaleo et al., 2024, p.17] and have a TRL for industrial heat of 4-7. Energy is stored when the storage medium changes its aggregate state e.g., from a solid to a liquid state and released when cooled [Salunkhe and D., 2017, p.2]. Latent heat storages will be excluded from this project as latent heat storages are most effective with limited temperature differences of a given operation, which is commonly not the case for industrial processes [Pantaleo et al., 2024, p.17]. Furthermore, the scalability of the TES unit, availability of PCM materials and the general cost are addressed as challenges reflected by an early stage of development of this type of heat storage [Pantaleo et al., 2024, p.17]. Examples of facilities in the testing phase are seen with the companies *1414 Degress* and *MGA Thermal*, where 1414 Degress have installed a PCM based unit which targets temperature deliveries of up to 1000°C. MGA Thermal tested a pilot scale facility with a thermal capacity of 5 MWh, but dangerous heat build-up occurred causing the maximum designed temperature of 700°C reaching up to 1200°C, which called for further investigation of this technology [Pantaleo et al., 2024, p.18].

Thermochemical storages utilize reversible chemical reactions to store heat, where during charging an endothermic chemical reaction takes place absorbing from injected heat, later during discharge the reverse exothermic reaction is performed to release heat [Johnson et al., 2019]. This type of storage is the least developed with ongoing research on a TRL 4-6 [Pantaleo et al., 2024, p.18], with the main advantages of this type of storage having a high energy storage density with minimum heat losses for long-term applications [Behzadi et al., 2022, p.5]. The main disadvantages are high complexity and costs [Behzadi et al., 2022, p.5].

Sensible heat storages utilize solid or liquid state materials where thermal energy is stored through a change in temperature of a single-phase material, which entails the material does not change its aggregate state and remains in solid or liquid form [Pantaleo et al., 2024; Steinmann, 2022, p.15 and 2]. The TRL level of sensible heat storages varies where Kyoto Group has the highest TRL level of 8-9 using molten salts [Pantaleo et al., 2024, p.7]. Some examples are water, rocks, thermal oil, sandstone, brick, clay, concrete, steel and molten salts [Pantaleo et al., 2024, p.2]. The system design is, as mentioned, dependent on the storage medium used, where for example liquid storage mediums such as molten salts are stored in two tank systems used in concentrated solar plants (CSP) to generate electricity or in an industrial setting used to generate process heat [Pantaleo et al., 2024, p.7]. Figure 2.3 illustrates the candidates for liquid storage and the estimated costs and thermophysical properties including maximum temperature;

Storage Medium	Temperature range [°C]	Spec Heat capacity [J/kgK]	Density [kg/m^3]	Estimated Material cost [€/ton]
Molten salts				
KNO_3-$NaNO_3$ [Solar Salt, Draw salt, Partherm 430]	240–560	1500	1840	700
$NaNO_2$-KNO_3-$NaNO_3$ [Heat transfer salt (HTS), HITEC-HTS (Coastal Chemical Co.)]	142–500	1570	1800	1200
KNO_3-$NaNO_3$-$Ca(NO_3)_2$	130–480	1400	1900	1100
Liquid metals				
Sodium	98–873	1300	900	2000
Lead	327–1740	130	11,300	1500
Mineral oil				
Mobiltherm 605	−10–315	2900	700	3000
Synthetic liquid				
Therminol VP1 (vapor pressure at 400 °C: 10.9 bar)	15–400	2400	750	5000
Element				
Sulfur	115–445	980	1700	400
Vegetable oil				
Sunflower oil	0–200 °C	2200	820	200–1000

Figure 2.2: Candidates for liquid state storage mediums [Steinmann, 2022, p.33]

It is important for the temperature range of the storage medium and the operating temperature of a given process to match in order to ensure applicability, in addition to designing the system to be able to produce the type of heat required by the application e.g., heat in the form of steam or dry air [Steinmann, 2022, p.263]. Due to the success of solar salt used in CSP, other application areas have gained traction in the academic field with specifically appliances for industrial process heat [Steinmann, 2022, p.10]. Generally HTTS for industries have three application areas; In batch processes used to store waste heat which is fed back into the production process, secondly, as a thermal rectifier used to compensate for fluctuations in the electricity demand and thirdly, used to increase the utilization of electricity produced from renewable energy by converting electricity to process heat [Steinmann, 2022, p.13]. For liquid materials, molten salts and liquid sulfur have the lowest capacity-specific costs and molten salt has the highest volume specific storage densities [Steinmann, 2022, p.32]. The main disadvantage of molten salt is the relatively high freezing point, which causes a need for constant temperature calibration with e.g resistance heaters preventing the salts from returning to a solid state [Steinmann, 2022, p.32]. Additionally, when utilized in a two tank system, achieving higher temperatures than 600°C becomes difficult, due to corrosion of the metal insulation, thereby limiting applications areas to specific industries. With high temperature systems, stainless steel is the preferred material, but temperatures above 600°C increase corrosion of this metal significantly, another option can be nickel alloys but with considerably higher costs [Steinmann, 2022, p.69-70]

For solid state materials, examples of rocks gaining traction as a storage medium being used in a system defined as packed beds, have potential due to the low cost of the storage material, but cost-efficient temperature levels occur within the range of 160-250°C as the thermal conductivity decreases at higher temperatures [Muhammad et al., 2023; Steinmann, 2022, p.12 and p.81]. A general drawback of solid-state storage systems are the thermal conductivity and within research there is a focus on identifying heat transfer concepts that ensures a high heat transfer rate during charging and discharging [Steinmann, 2022, p.83]. On figure 2.3, candidates for solid-state storage mediums are illustrated in a table with the maximum temperature and thermophysical properties in addition to the estimates costs of the material.

	Storage Medium	Maximal Temperature [°C]	Spec Heat capacity [J/kgK]	Density [kg/m^3]	Estimated Material cost [€/ton]
Metals					
	Aluminium	660	920	2700	1500–2000
	Cast iron	1200	550	7200	300–600
Rocks					
	NaCl	800	850	2150	<50
	Granite	570	670–1550	2600	<50
	Limestone	800	820–1700	2500	<50
	Sandstone	800	750–3300	2200	<50
	Basalt	800	880	2800	<50
Ceramics					
	Al_2O_3	2050	1080	3990	500–1500
	SiO_2	1720	730	2200	200–1000
	MgO	2830	1150	3570	400–1000
Castable					
	Concrete	400–500	915	2750	<50
	Castable ceramic	1000	860	3500	100–200
Others					
	Graphite	3500	700	2500	1500–5000

Figure 2.3: Candidates for solid state storage mediums [Steinmann, 2022, p.79]

While solid-state thermal storage systems generally achieve higher maximum temperatures and are therefore suitable for industrial processes such as cement manufacturing, liquid state systems such as molten salts have a higher thermal conductivity, allowing rapid heat transfer and therefore a better optimization of charging and discharging cycles [Steinmann, 2022, p.83]. Additionally, recent developments in the utilization of sodium hydroxide (NAOH) as a sensible storage medium, which has a higher thermal conductivity and energy density than the already commercialized solar salt storage medium [Mahmoudinezhad et al., 2023], has increased interest in molten salts and opened a gap in research in optimization of systems using NaOH as a storage medium. As of the writing of this report, a singular techno-economic optimization of a HTTS using NaOH has been performed specifically for a steam generator [Mahmoudinezhad et al., 2023] and one facility has been built in Esbjerg Denmark by HYME Energy.

2.2.2 Active facilities and current application areas

The current facilities for sensible heat storage are showcased in table 2.3. The table has been modified to only show active sensible heat storage facilities due to the scope of this project, with the argumentation of sensible heat storage mediums currently having the highest TRL, lowest cost and optimal thermophysical properties for industrial process heat.

Company	TES technology	TRL	Max Temperature	Storage medium	Charge	Discharge	End-use
Energynest	Sensible solid	8-9	400 °C	Cement	Thermal oil or steam	Thermal oil or steam	Industrial heat
Brenmiller	Sensible solid	7-8	750 °C	Crushed rocks	Heat recovery and electricity	Inner steam generation	Industrial heat
Kraftblock	Sensible solid	7-8	1300 °C	Ceramic pellets and bricks	Hot air	Hot air	Industrial heat
Rondo Energy	Sensible solid	7-8	1000 °C	Refractory bricks	Hot air	Hot air	Industrial heat
Storworks power	Sensible solid	7-8	600 °C	Concrete	Hot air	Inner steam generation	Industrial heat
Ecotech ceram	Sensible solid	6-7	1500 °C	Waste ceramic	Hot air	Hot air	Industrial heat
Caldera	Sensible solid	6-7	1000 °C	Volcanic rocks	Electricity	Inner steam generation	Industrial heat
Lumenion	Sensible solid	7-8	600 °C	Steel Bars	Electricity	Hot air	Industrial heat
Magaldi Power	Sensible solid	6-7	600 °C	Silica Sand	Electricity and hot air/steam	Inner steam generation	Industrial heat
Polar Energy Night	Sensible solid	6-7	1000 °C	Sand	Hot air	Steam	Industrial heat
Electrified Thermal Solutions	Sensible solid	5	1800 °C	Bricks	Electricity	Gaseous	Industrial heat
Echogen	Sensible solid	5-6	600 °C	Sand	Heat pump	Transcritical CO_2 power cycle	Electricity, Grid stability
EnergyDome	Sensible solid	7-8	600 °C	Aluminum scrap	Heat pump	CO_2 power cycle	Electricity, Grid stability
HighView power	Sensible solid	7-8	600 °C	-	Air liquefaction	Air Brayton cycle	Electricity, Grid stability
Antora Energy	Sensible solid	5-6	2000 °C	Carbon	Electricity	Thermophotovoltaic	Electricity, Industrial heat
Fourth Power	Sensible solid	5-6	2400 °C	Graphite	Electricity	Thermophotovoltaic	Electricity, Industrial heat
Kyoto Group	Sensible liquid	8-9	400 °C	Ternary molten salts	Electricity	External steam generator	Industrial heat
Hyme Energy	Sensible liquid	7-8	600 °C	NaOH	Electricity	External steam generator	Industrial heat
Malta Inc	Sensible liquid	7-8	580 °C	Binary molten salts (Solar salt)	Air heat pump	Air Brayton cycle	Electricity
Built to zero	Sensible liquid	6	400 °C	Ternary molten salts	Electricity	External steam generator	Industrial heat

Table 2.3: Active sensible heat storage facilities for HTTS [Pantaleo et al., 2024]

As previously mentioned, recent advancements utilizing NaOH as a storage medium for industrial application have increased interest within research, and with the current limited research there is a gap within the academic field. The demonstrative facility from HYME in Esbjerg has proven technically viable with a storage capacity of 1 MWh, charging capacity of 1.2 MW and discharging 1.1 MW [HYME, 2024b] and has led to a new project between HYME and ARLA being announced in december 2024 [HYME, 2024a]. This new facility is upscaled to 200 MWh of storage capacity with 32 MW of charging capacity and 16 MW discharge. Additionally, AalborgCSP performed research during 2022-2023 regarding a molten salt storage with a capacity of 1,000 MWh in cooperation with Copenhagen Atomics [AalborgCSP, 2024], but no recent announced has been made regarding this project. A competitor to HYME energy is Kyoto Group, which in 2023 implemented their HeatCube technology in Norbis Park in Vodskov Denmark in collaboration with Aalborg Forsyning but for district heating instead of industrial process heat, which also utilizes molten salts as a storage medium reaching steam temperatures up to 460°C [Group, 2024a]. Kyoto Group has announced a collaboration with KALL Ingredients in Hungary supplying industrial process heat with a 56 MWh capacity and 7 MW discharging molten salt storage facility installed in 2024 [Group, 2024b]. The new facilities announced by both HYME and Kyoto are both for dairy production, but other industrial sectors have potential end-use applications that matches the temperature range of molten salt storage, these industries will be mapped in the following section in addition to the general potential of the industrial sector in Denmark.

2.2.3 Potential industries and end-use application areas

As mentioned in section 2.2, the application potential of sensible heat storage depends on the operation temperature of the end-use application for a given industry, which must to be within the interval of the temperature range of the storage system. The current active and in development facilities for industrial process heat are for dairy production, which requires temperatures of 220°C. The dairy industry is currently using 60 % natural gas for heat production [Energistyrelsen, 2022a, p.47], and molten salt storage is a solution that enables these industries to reduce fossil fuel usage through either purchasing electricity from the grid or through behind the meter renewable energy production for charging the storage system. The DEA released an industrial mapping in 2022 based on data from DST and energy audits performed during 2019-2021 [Energistyrelsen, 2022b]. This report contains data on the agricultural, manufacturing and construction industry, where the manufacturing industry is the only sector with process heat demands requiring temperatures above 200°C, which is the current lower limit of molten salt storage systems using NaOH as a storage medium due to the melting point of the medium [of Medicine, 2024]. The manufactoring sector has a total process heat demand of 23.774 TWh in 2019 with projections highlighting that the demand is not expected to increase significantly towards 2035 [Klima-, Energi- og Forsyningsministeriet, 2022, p.5-6]. The 23.774 TWh heat demand can be categorized by end-use application, which is shown in table 2.4.

End-use application	**>200°C**
Other process heat	5,787 TWh
Burning	5,726 TWh
Distillation	1,889 TWh
Evaporation	2,527 TWh
Heating/boiling	12,033 TWh
Melting/Casting	2,668 TWh
Drying	13,301 TWh
Total	23,774 TWh

Table 2.4: Manufacturing sector end-use applications and process heat demands [Energistyrelsen, 2022b, p.38-39]

The specific types of industries, which have a process heat demand above 200°C is outlined in the report by the DEA with maximum temperatures within an appendix [Energistyrelsen, 2022b]. The maximum temperature serves as a limiting factor of the potential application areas of the molten salt technology due to corrosion of the metal insulation above 600°C, but exploring the option of adding a booster to the system to reach the required temperature is not explored in literature for NaOH. This type of solution has the potential to expand the viable list of industries and was explored through conversations with Randers Tegl, who currently utilizes natural gas in their burning and drying processes. The expanded list of potential industries when a booster is present is shown in table 2.5.

Industry type	**End-use application**	**>200°C**	**Maximum temperature**	**Current supply method**
Extraction of Gravel and Stone	Drying/Burning/Evaporators	747 TWh	1,000°C (>700)	Rotary and Tunnel Kilns
Slaughterhouses	Baking	269 TWh	200°C	Direct Gas Combustion/Steam
Fish Industry	Incineration	12 TWh	>200°C	Steam
Dairies	Milk Condensation/Drying	411 TWh	220°C	Natural Gas Boilers
Bakeries, Bread Factories, etc.	Baking	381 TWh	>200°C	Gas Burners (Natural Gas)
Manufacture of Feed Mixtures	Drying	626 TWh	1,000°C	Combustion of Fossil Fuels Natural Gas
Manufacture of Sugar	-	58 TWh	-	Direct Heat or with Steam
Other Food Industry	Deodorization	751 TWh	>220°C	High-Pressure Boilers - Fuel Oil and Coal/Coke
Wood Industry	Heat Exchange Press Drying plus Flash Drying	2,069 TWh	300°C	Hot Oil Systems
Printing Houses, etc.	Drying	7 TWh	300°C	Direct Firing - LPG, Mains Gas, and Gas/Diesel Oil
Manufacture of Enzymes	Distillation	29 TWh	300°C	Distillation Plants (Steam)
Manufacture of Paint and Soap, etc.	Drying	320 TWh	>500°C	Direct Firing, but also Steam.
Plastic and Rubber Industry	Regenerative Thermal Oxidizer Catalytic Oxidizer	152 TWh	800°C	Natural Gas
Glass Industry and Ceramic Industry	Melting/Burning	875 TWh	1,200°C	Natural Gas/Biogas Used in Direct-Fired Furnaces
Manufacture of Cement	Drying/Heating/Burning	11,181 TWh	1,500°C	Petroleum Coke, Coal, and Coke as well as Waste in Direct-Fired Rotary Kilns
Manufacture of Bricks, etc.	Burning/Drying	1,098 TWh	1,050°C	Natural Gas Used in Direct-Fired Furnaces
Manufacture of Stone Wool, etc	Heating/Melting/Incineration Hardening	2,206 TWh	700°C	Petroleum Coke, Coal, and Coke as well as Natural Gas/Biogas - Direct-Fired Furnaces
Other Concrete Industry and Brickworks	Calcination	320 TWh	∼200°C	Natural Gas Used in Direct-Fired Furnaces
Manufacture of Metal	Heating/Normalizing/Melting Heat Retention	1,832 TWh	1,300°C	Direct Natural Gas-Fired Furnaces Electricity/Gas for Melting and Heat Retention
Metal Goods Industry	Heat Retention/Melting	298 TWh	1,100°C	Natural Gas Used in Direct-Fired Baths and Furnaces
Manufacture of Motors, Wind Turbines, and Pumps	Hardening	52 TWh	900°C	Natural Gas or Oil Used in Direct-Fired Furnaces
Manufacture of Other Machines	-	61 TWh	-	-
Manufacture of Motor Vehicles and Parts Thereof, and Manufacture of Ships and Other Means of Transport	Casting	21 TWh	>200°C	Direct Firing

Table 2.5: Potential MOSS applicable industries [Energistyrelsen, 2022b,a]

Randers Tegl is included in the manufacture of bricks industry type, which has a total process heat demand of 1,098 TWh. The total potential flexible electricity that is possible to create with MOSS is yet to be mapped, and due to burning processes with maximum temperatures of 1,050 C, the amount of natural gas that can be replaced by MOSS has to be determined to address the flexible electricity demand possible.

3 | Research Question

Throughout the problem analysis, challenges of increased RE-production and fossil-fuel usage in industries were investigated and the potential solutions were addressed through a state of the art analysis of high temperature storage. Storage has the potential to add flexible electricity demand in the danish energy system and thereby act as a countermeasure to the cannibalization effect of increased RE-production. Furthermore, it can serve as a measure to mitigate fossil-fuel usage in industries through the electrification of their process heat production. Through the state of the art analysis, it was highlighted that the current only commercialized molten salt storage system is using solar salt as the storage medium, but HYME energy have developed an alternative solution using NaOH, where currently only one article has been with a focus of the optimization of a kettle boiler, thereby leaving a gap in the field of research in relation to the optimization of a system in terms of the volume of the storage tanks and capacity of the resistance heater. Furthermore, the potential industries where MOSS using NaOH is applicable are limited by the temperature requirements of the required process heat and the maximum temperature the MOSS can deliver, therefore an additional aspect to investigate is the addition of an electric heater that can supply the remaining temperature requirement from 600°C and above. This has lead to the following research question and sub-questions:

How can a techno-economic optimization of a molten salt storage system be performed to reduce fossil-fuel usage and create flexible electricity demands through the electrification of the production of high temperature process heat in industries?

Sub-question 1: *How can a technological optimization be performed and how does the limitations of the technology affect the optimization and choice of technologies?*

Sub-question 2: *How can the economic feasibility of the system be determined based on a technical optimization foundation and to what degree does economics affect the optimal scenario?*

Sub-question 3: *How can the development of a project management strategy involving relevant stakeholders aid in the evaluation/implementation of techno-economically feasible scenarios?*

4 | Methodology

4.1 Theories of science

This section aims to present the theories of science, which for the perspective that the research question is approached, by presenting the approach, it is possible to address how the disposition of the analyses later in the project should be formed. Additionally the choice of theories of science will thereby directly affect the creation of a research design and its structure.

4.1.1 Design Science Research

In order to answer the research question and sub-questions there is a need to address the perspective that is used in the analyses. The perspective of DSR will be used as a basis for how the problem is being viewed, and thereby what influences the results that are found in the analyses.

While the topic of investigating high temperature thermal storages in industrial processes requires a technical optimization, there is a need for the utilization of a methodology that focuses on finding feasible solutions, that would be seen as more fitting than other solutions. As such an iterative process with a multiple scenario analysis would be able to help find such optimal solutions.

A way to approach these kinds of iterative processes is by utilizing Design Science Research (DSR), which focuses on the investigation of an 'artifact', which in this case is high temperature thermal storages. The goal of utilizing DSR is then focused on investigating how the idea of implementing high temperature thermal storages can be converted to actual implementation, thus transitioning from an abstract theoretical standpoint to a more material existence, hereby through techno-economic optimization analyses that show the feasibility of implementing such high temperature thermal storages [Gregor and Hevner, 2013, p.341].

By following DSR, six steps are crucial to follow [Gregor and Hevner, 2013, p.342]:

1. Identify problem
2. Define Solution objectives
3. Design and development
4. Demonstration

5. Evaluation
6. Communication

step 1 and 2 have been covered in the problem analysis and research question by finding the need for electrification of the industries and then finding the solution objective of utilizing high temperature thermal storages, step 3 was covered partly in section 2.2, and will be further covered by the research design and in the analyses. Steps 4 and 5 will be covered in the analyses and discussion in which the techno-economic optimization will be demonstrated and thereafter evaluated through discussion. Lastly, step 6 will be followed dynamically through meetings with HYME and Randers Tegl, where updates between the different actors and data sharing will occur.

While DSR as a methodological approach works well at investigating the implementation of high temperature thermal storages in industries in a techno-economic perspective, there is a lack of the societal contexts that may surround the specific case. Therefore, another methodological approach will be presented, that focuses more on the people and contexts that influence the realization of the techno-economic optimization.

4.1.2 Social Constructivism

While DSR focused on optimization of artifacts through a technological perspective there is an additional aspect which influences the feasibility of implementing the artifact. This aspect is found by viewing the topic of electrification of industrial processes through a social constructivism view.

Social constructivism views aspects of society as being constructed by the people and institutions that surround it [Lynch, 2016]. This also applies to more specific contexts, such as individual companies and the markets that they are trading with. Therefore, the application of social constructivism is applicable to the case of Randers Tegl and how they can electrify their process, in which there is a need for a technical solution through a new innovative solution. When dealing with such innovative solutions two different institutions are important to consider; The electricity market and Research and Development. In order to increase the feasibility of HTTS solutions there is a need for continuing and further evolving research and development, which could lead to more types of industries that can utilize HTTS, whereas the electricity market is quite important since spot prices determine part of the operational costs of such HTTS. This means that the renewable energy transition as described in section 2.1, with its influence on the electricity market prices directly influences the feasibility of HTTS.

While the institutions are important to the feasibility and development of HTTS, another aspect of social constructivism is important to acknowledge; the people within the individual companies. These people are important since they will be the ones working with HTTS in their daily operations, as such, they will demand a solution that is functional that they can operate, while the company, being the one that invests in the solution can have different goals and purposes of investing in the technologies.

Since both external and internal actors surrounding the company can influence the feasibility of implementing HTTS, they all need to collaborate to ensure a stable development. A way of achieving this collaboration is by utilizing tools such as actor-networks, contractual agreements and regular meetings, which ensure stable environments for collaboration [Detel, 2015, p.230-231]. Focusing on such tools creates the possibility of also utilizing qualitative methods to supplement the quantitative methods that are utilized through DSR. These qualitative methods that will be utilized will be in relation to interviews with relevant stakeholders, stakeholder analysis and organizing actor-networks and meeting structures through organizational and project management theory.

By using an approach that not only focuses on DSR or social constructivism separately it becomes possible to use both in unison to achieve a more holistic point of view, which ensures that the problem of electrifying industrial processes is not only perceived from a techno-economic point of view but also from the people and markets that surround the technologies, which can help achieve successful project management and project implementation.

4.2 Research design

The framework for answering the research question and sub-questions will be presented in this section and will be based on *Social Research Methods 4th Edition* by Alan Bryman [Bryman, 2012a]. A research design is the framework for the generation of evidence in relation to answering the research question [Bryman, 2012a, p.44]. Five different types of research design frameworks are mentioned by Bryman:

- Experimental design
- cross-sectional design
- Longitudinal design
- case study design
- comparative design

The case study design will be the foundation for the framework in this project, given a singular case has been chosen in Randers Tegl. A case study is often placed in the method section, but as Bryman argues, the choice of doing a case study itself will not provide data and does not in itself outline the approach to collecting data as it will differentiate based on the type of case. In an energy planning perspective, choosing a case study design enables the design of the framework to have emphasis on replication possibilities for similar cases, adding to the reliability of the project which entails the results should be replicable [Bryman, 2012a, p.46-47]. An additional focus is on the validity of the results, which should be generalizable for other cases, where for energy planning, the specific context of the energy system of Randers Tegl is based on the provided data of the current supply methods and hourly process heat demands. The research design will therefore by designed in accordance with methods and theories that would enable the research conducted in this project to be replicated onto a similar company. Both qualitative and quantitative methods will be applied to the case given both quantitative data will be analyzed as well as the project management perspective of the proposed energy system, which will have a focus on organizational aspects uncovered through qualitative methods such as semi-structured interviews and stakeholder analysis. An illustration of the research design is shown on figure 4.1.

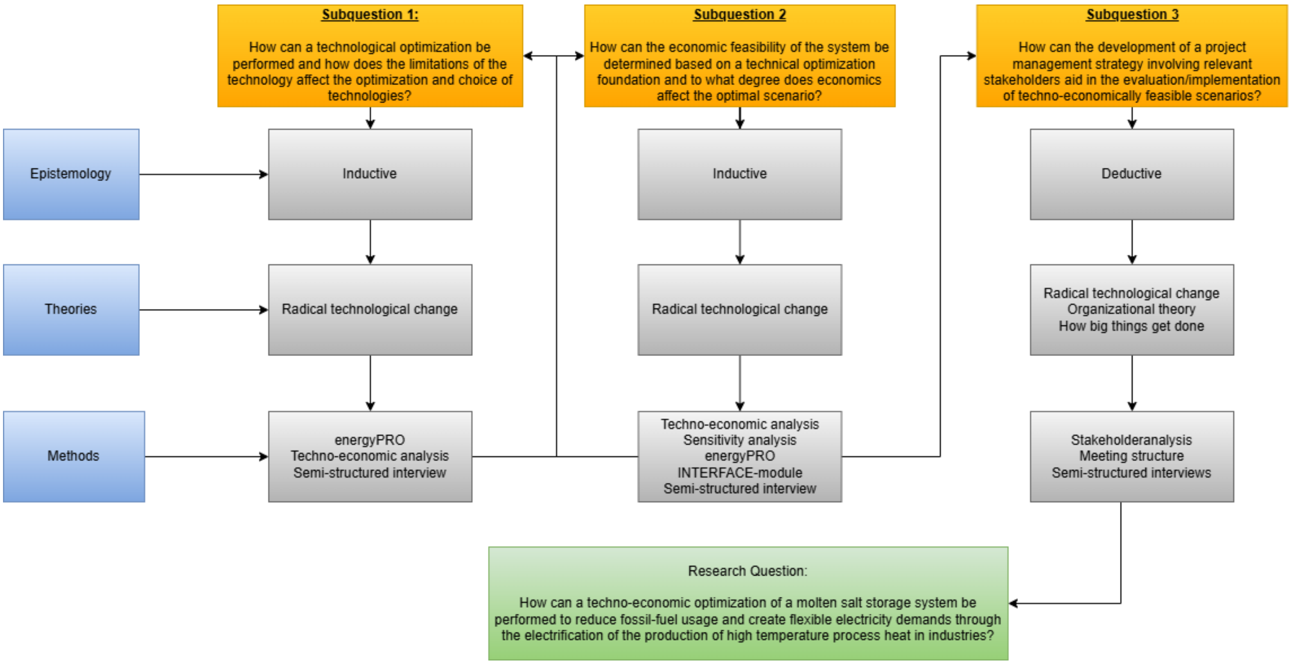

Figure 4.1: Research design

The illustrated research design shows the attributed epistemology approach, theories and methods to each sub-question. Furthermore, the arrows connecting from the methods applied to the next sub-question, indicates that the results from sub-question 1 will be carried over to answer sub-question 2 and ultimately sub-question 3. The double-sided arrow from sub-question 1 and 2, indicates an iterative process, in which the results from sub-question 2 is used to evaluate the results from sub-question 1. This entails, that the technical scenarios created from the energyPRO analysis will be analyzed in an economic perspective, which ultimately influence the choice of the optimal scenario and therefore the design of the system.

The epistemology attributed to each sub-question, is based on the theories of science perspectives used in this project. DSR highlights inductive approaches to science research with methods that have a focus on optimization, specific validation criteria and in general data analysis. Therefore, DSR is used as the argument for the epistemology approach and theories and methods applied to sub-question 1 and 2, where quantitative data is the foundation behind the analyses. The inductive reasoning used, follows three steps: First observations, in this case the data collected from the case industry and semi-structured interviews, second analyzes and thirdly a generalized conclusion [Sprogøe and Brandi, 2019, p.28-29]. This allows for both the process and results for creating an energy system scenario to be generalizable to other industries with high temperature process heat demand. For the third sub-question, which seeks to answer the project management aspect, social constructivism is the foundation behind the applied epistemology, theories and methods. Social constructivism is paired with DSR, which enables an additional perspective of a reality that is constructed through social interactions, experiences and cultural aspects within the specific context of the case being analyzed, which is uncovered through qualitative methods in this project. This approach aligns with the deductive reasoning applied, where organizational theory and project management theory both have an emphasis on cultural, social interactions and experiences. This deductive reasoning approach, starts with applying a theoretical perspective and testing the hypothesis made by this theory in the case specific context of the industry, by collecting data from interviews with people from the organization and generally within the field, and finally validation of the hypothesis and reevaluating the applied theories [Sprogøe and Brandi, 2019, p.28-29].

5 | Methods

5.1 Utilization of Artificial Intelligence

In this project, the AI tool *Scispace* was utilized throughout the problem analysis for finding literature. Scispace is a tool made for students and researchers, which enables the user to both categorize sources based on search terms and content. The AI tool was primarily used in the beginning phase of the project, where a broad search was performed to create a foundation of knowledge. The general purpose of using the AI tool, was to collect a list of scientific articles as a starting point, where the cited sources within the provided articles created a snowball effect of finding additional literature within the scope of this project. The reasoning behind using the AI tool in the beginning phase and less in e.g. the literature review of HTTS, was to avoid that the AI tool can miss essential sources, which could impact the validity of the results of the state of the art analysis of HTTS.

5.2 Qualitative methods

As mentioned in section 4.1, the social constructivism perspective in the context of the electrification of Randers Tegl includes not only the technological aspect that DSR highlights, but the people and institutions that surround the implementation of a new system. To analyze these aspects, the qualitative method of semi-structured interviews was utilized to gain insight into the organization and enable a stakeholder analysis to be conducted. Furthermore, a literature review was conducted to acquire knowledge on the current state of HTTS for industrial process heat through a state of the art analysis as seen in section 2.2.

5.2.1 Literature review

To determine the degree of which this project can contribute to the field of research of HTTS for industrial process heat, a literature review was conducted of the current state of the art of HTTS. The aspects considered in the literature review was inspired by Bryman and his recommendations for conducting literature reviews in his book on social research methods [Bryman, 2012b, p.51]:

- what is already known about the topic
- what research methods have been applied to the topic

- who the key contributors to research on the topic are

To conduct a state of the art analysis, the aspects covered by Bryman was contextualized to HTTS and expanded;

- what is already known about HTTS
- What is the TRL of different types of HTTS and storage mediums?
- What research methods have been applied to HTTS for industrial usage
- who the key contributors to research on HTTS for industrial process heat are
- What facilities have already been implemented
- What are the potential industrial and end-use applications for HTTS

To be able to replicate the process of answering the question above, the search terms used to find literature on HTTS is listed in table 5.1. Additionally, the project group followed an approach for finding literature described by Rienecker and Jørgensen in their book on writing papers in higher educations. The *Chain search* approach was applied, which enabled the project group to find related literature within a source through the listed citings, thereby starting a chain where one source leads to another [Rienecker and Jørgensen, 2015, p.148-150]. The project group utilized peer-reviewed articles found within academic databases, including Sciencedirect, AAU library and Researchgate, in addition to books published on the topic of HTTS, specifically; *Thermal Energy Storage for Medium and High Temperatures* by Wolf-Dieter Steinmann.

Search terms	**Article/Books**	**Method**	**Findings**
High temperature thermal storage State of art of high temperature thermal storage Storage mediums for high temperature storage	*Thermal Energy Storage for Medium and High Temperatures (Book)* *Innovation trends on high-temperature thermal energy storage to defossilize energy systems (article)*	Descriptions of existing systems Data collection on active facilities	End-use application potentials Current commercialized molten salts TRL levels of HTTS systems and storage mediums
Techno-economic analysis molten salt storage Sodium hydroxide molten salt storage	*Design and techno-economic analysis of a molten-salt driven energy conversion system for sustainable process heat supply (Article)*	Techno-economic analysis of a kettle boiler optimization LCOH calculation	NaOH cheap and stable at high temperatures
Danish industrial temperature requirements Danish industrial process heat demands	*Mapping of Energy Consumption and Assessment of Energy Saving Potentials in Manufacturing Industries (report)*	Energy audits	Temperature requirements for different process heat demands Process heat demands for different industries
Sensible, latent and chemical heat storage	*Smart design and control of thermal energy storage in low-temperature heating and high-temperature cooling systems: A comprehensive review (Article)*	Optimizations methods for integrating Thermal heat storage for low-temperature heating	Thermochemical heat storage suitable for residential heating. Disadvantage: High costs and complexity

Table 5.1: Search terms

The result of the literature review can be seen in section 2.2, which ultimately showed that HTTS using NaOH as a storage medium currently only have been described in one scientific article, with a focus on the optimization of a kettle boiler. This leaves a gap in the field of research in terms of a general optimization of the molten salt storage system in terms of volume and resistance heater capacity. Additionally, an analysis of using electric heaters in combination with a molten salt storage in industries where the process heat temperature demand exceeds what MOSS can supply have not been studied, which could expand the list of potential industries that can be electrified through the utilization of MOSS when coupled with a electric heater as a temperature booster.

5.2.2 Semi-structured interviews

As described in section 4.1, the theories of science perspectives of DSR and social constructivism, each highlights different aspects of knowledge and approaches to gathering knowledge, either through quantitative or qualitative methods. When combined, the approach to answering the research question and sub-questions for the case of Randers Tegl is broadened from not only analyzing MOSS through a techno-economic perspective, but also with the organizational project management aspects, which require qualitative methods such as interviews to properly address. Therefore, a series of semi-structured interviews have been conducted to be able to address problems and potential solutions seen from the perspective of experts within the field to both the technical and project management aspects. This follows approaches described by Steiner Kvale and Svend Brinkmann in addition to Alan Bryman in their respective books concerning social research methods and specifically, qualitative research interviewing.

Expert interviews were conducted to fill out gaps in knowledge through conversations with people who works with and have experience with the technology and project management to gain knowledge of system design and structuring projects [Kvale and Brinkmann, 2009, p.147]. The semi-structured interview approach was chosen to enable the interviewee to elaborate on a set of questions which were sent before each interview in the interview guide. The interview guide functions as the scope for the interview, which was specifically related to the research question and sub-questions [Bryman, 2012a, p.471-473], thereby enabling the answers to be used directly in both analysis 1 and 2. The approach to creating questions was through open questions, which do not lead the interviewee into giving specific answers [Bryman, 2012a, p.247]. The downside to this approach, is that the interview can veer off course into topics not related to the research question or sub-questions, therefore, leading questions were utilized in instances where the interview went out of scope [Bryman, 2012a, p.257].

Generally throughout the project period, the project group collaborated with HYME and Randers Tegl which will be elaborated upon later in this chapter. The project group setup interviews with both HYME and Randers Tegl outside of email correspondences to be directly used and transcribed in this project. Furthermore, an interview was conducted with Eoghan Rattigan from Greenlab Skive, who has experience with the organizational aspect of implementing projects and has been researching HTTS for their industrial park. HYME as a main collaborator enabled the project group to gather knowledge regarding the technical design of HTTS using molten salts. The interviews with Randers Tegl, set the foundation for the system design, their current project management process and their overall strategy and goals. Their current reference system was discussed in addition to their goals of substituting natural gas in their production. A full overview of each interview with the date, purpose, and main topics discussed can be seen in table 5.2

List of interviews and meetings			
Interviewperson	**Date**	**Purpose of meeting**	**Results of meeting**
Nis Benn CCO & Co-founder of HYME	3/3-2025	Initial meeting for collaboration, focus on brainstorming potential case opportunities. What data can be provided between meeting participants	- Big focus on heat contracts as main decider for project feasibility. - 4 different case possibilities found.
Eoghan Rattigan Industrial Sustainability Specialist at Green Lab Skive	11/3-2025	Understanding the technical and organizational aspects that feed into planning for thermal storages in industrial settings	- High technical limitations when exceeding 600°C celcius - Important to secure contracts between customer and heat producer
Jonas Bønsø Project Manager at Randers Tegl	18/3-2025	Initial meeting with focus on understanding the current process at Hammershøj Teglværk What temperatures are there demands at, and how are the demand profiles	- Walkthrough of the technical process - Demand profiles for driers and oven - RE-project dimensions
	13/5-2025	Follow up questions after earlier meetings, as well as after guided tour at the Hammershøj Teglværk facilities	- Implementation focused technical aspects - General project management proces currently used at the brickwork - Organizational structure - Important internal stakeholders for later analysis
Gro Kallehave Hansson Cost Estimator and Proposal Engineer at HYME	30/4-2025	Discussion of the proposed solutions in the report analyses Uncertanties regarding different kind of heat production from MOSS Tehcnical aspects of MOSS	- Using MOSS to produce dry air heat should not be a problem - Assumptions on MOSS to be used in the analyses - Techincal limitations of reaching 1050°C celsius

Table 5.2: List of interviews and meetings including the purpose of the meetings and what the results of the meetings were.

5.2.3 Stakeholder analysis

A stakeholder analysis was conducted with the purpose of analyzing relevant stakeholders that should be involved in a project management strategy and to what degree. To perform the stakeholder analysis, the salience model developed by [Mitchell et al., 1997] was utilized, which categorizes stakeholders based on power, legitimacy and urgency. The salience model can be seen on figure 5.1.

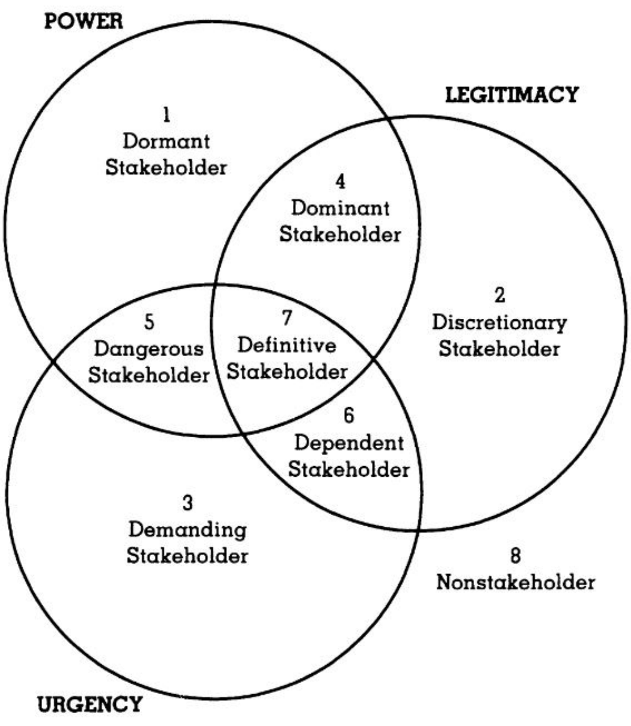

Figure 5.1: The salience model [Mitchell et al., 1997, p.874]

Each type of stakeholder on figure 5.1 have different attributes in the form of the aforementioned power, legitimacy and urgency the stakeholder holds. These attributes are described by Mitchel as follows:

- Power: To gain the attribute of having power, one has to have the ability to exert power over others in the form of either coercive, utilitarian or normative power. Coercive power is described as control through physical means. Utilitarian power involves the use of materials or services, such as money, to control others. Normative power involves control through utilizing societal norms to make people adhere to ones own agenda [Mitchell et al., 1997, p.865].
- Legitimacy: To gain the attribute of having legitimacy, the individual's actions/input has to be desirable, proper and appropriate within a given context and their position within the system/environment [Mitchell et al., 1997, p.866].
- Urgency: To gain the attribute of having urgency, involvement of this type of stakeholders calls for immediate attention due to their claims/input [Mitchell et al., 1997, p.877]

Each of these attributes have a specific stakeholder class, where a stakeholder having only power is labeled as a dormant stakeholder, having only legitimacy is labeled as a discretionary stakeholder and having only urgency is labeled as a demanding stakeholders. As figure 5.1 illustrates, given only one attribute is present for a given stakeholders, a low level of salience is given in class 1,2 or 3 termed latent stakeholderse. A moderate level of salience with two attributes is class 4,5 and 6 termed as expectant stakeholders and a high level of salience are class 7, which are stakeholders with all three attributes termed as definitive stakeholders [Mitchell et al., 1997, p.873]. An overview of each stakeholder category, class and level of salience can be seen in table

Table 5.3: Overview of stakeholder categories, classes and level of salience based on attribute(s) [Mitchell et al., 1997]

Stakeholder category	**Stakeholder class**	**Attributes(s)**	**Level of salience**
Definitive stakeholders	Definitive (7)	Power, legitimacy and urgency	High
Expectant stakeholders	Dependent (6)	Legitimacy and Urgency	Moderate
	Dangerous (5)	Power and Urgency	Moderate
	Dominant (4)	Power and Legitimacy	Moderate
Latent stakeholders	Demanding (3)	Urgency	Low
	Discretionary (2)	Legitimacy	Low
	Dormant (1)	Power	Low

The definitions, classes and level of salience were utilized in the stakeholder analysis and ultimately served as an indicator in the project management stategy, of the degree of involvement Randers Tegl should expect in the planning process of each stakeholder.

5.2.4 Stakeholder meeting structure

Based on the stakeholder analysis, proposed meeting structures were created with the purpose of both categorizing relevant stakeholder interactions and proposing a meeting structure that enables the project manager of Randers Tegl to facilitate these meetings. The meeting structure was inspired by Kausholt and his book on Project Management Theory and Practice [Kousholt, 2020, p.294] and can be seen in table 5.4

Stakeholder	**Stakeholder A**	**Stakeholder B**
Purpose	What is the purpose of the meeting	
Who conducts	Who facilitates the meeting and controls the narative	
Output	Expected output	

Table 5.4: Meeting structure, inspired by Kausholt

The meeting structure seen in table 5.4, is a simplified version of the structure proposed by Kausholt, where the frequency of meetings and a measurement of communication is also present. These two elements were excluded from the applied meeting structure in analysis part two, due to the frequency of meetings being dynamic based on the project manager's need for information that can occur spontaneously during the project period. Therefore, the meeting structure proposed is within the scope of starting the process of evaluating the proposed scenario from analysis part one, where the baseline for what should be discussed during the meetings are based on the results from analysis part one and the stakeholder analysis. Given a measurement of the communication were to be addressed in the meetings, further communication strategies should be considered through communication theory, which is outside the scope of this project.

5.3 Quantitative Methods

This section will introduce the quantitative methods that are used in the analyses, with a primary focus on the techno-economic analysis in section 7.2.

The methods that will be introduced vary between analytical methods and tools that are used to perform the analytical methods, and are as follows:

- Techno-Economic analysis
- energyPRO
- Two-dimensional optimization matrix
- INTERFACE-module
- Sensitivity analysis

While each method and tool will be introduced separately, they will be utilized in unison with each other in the analysis in order to better answer the sub questions of *How can a technological* *optimization be performed and how does the limitations of the technology affect the optimization and choice of technologies?* and *How can the economic feasibility of the system be determined based on a technical optimization foundation and to what degree does economics affect the optimal scenario?*

As the sub questions emphasize a focus on technological optimization and economic feasibility the quantitative methods and tools reflect aspects that are used for performing the analyses in section 7.2.

5.3.1 energyPRO

energyPRO is a techno-economic optimization software that enables the user to perform intricate analyses of energy systems that are focused around individual sites, however energyPRO is not limited on a geographical scale, and as such can be used for analyses where municapilities or regions are modelled and optimized. In this report, energyPRO is used to model three different possible scenarios of Randers Tegls Hammershøj Teglværk, first a reference scenario to be compared to the other two scenarios, thereafter a scenario in which electric heating is added in order to electrify the process heat production at the brickwork, and lastly a scenario in which MOSS is included to cover the heat demand at 600°C and lower, with electrified heating to help cover temperatures above 600°C. When utilizing energyPRO to perform optimization on energy systems the results are based on an hourly time resolution, making it possible to perform optimizations at a high quality resolution [Østergaard et al., 2022].

A particular strength of using energyPRO is the customization possibilities, where the program enables the user to personally define topics such as:

- Fuels
- Demands
- Energy conversion and storage units
- Environmental impacts
- Costs and Investments
- Taxes

The level of customization enables the user to analyze solutions such as MOSS using NaOH, which incidentally is not a fully commercialized solution, and as such could prove difficult to model in other software.

5.3.2 Two dimensional matrix optimization

This section will focus on the optimization method used for determining the configuration of the MOSS system used in the techno-economic analysis, with a focus on finding the limitations to the capacities of the different components. The optimization method draws inspiration from [Andersen and Østergaard, 2020] in which a two step optimization is used to find the optimal capacities of both the resistance heater and the storage volumes. The way in which the optimization requires to first set lower limits for capacities of the components, in which the resistance heater capacity is determined through goals to how quickly the hot storage tank can be fully charged. This charge period is found through a comparative analysis of the distribution of the electricity prices compared to the cost of natural gas for each hour of the day, in which the aim is to find a concentration of hours in which the spot prices are lower, such that charging MOSS would be cheaper, as such finding a distribution with 6 amount of hours with lower spot prices, results in the minimum capacity of the resistance heater being able to fully charge the hot tank in the TES in 6 hours.

Additionally, the storage tank volume upper and lower limits were determined through talks with HYME, where the minimum volume was determined through a minimum storage duration of 12 hours and maximum volume of 1,400 m^3 was due to physical constraints. It should be noted, that a 12 hour storage duration with the corresponding peak demand of Randers Tegl, entails a storage system with 38 MWh of capacity, which is described by HYME as being outside of the scope of their usual business-cases A.

While [Andersen and Østergaard, 2020] followed a somewhat simple method, in which intervals for capacities were investigated in order to find the optimal NPV of the system. When the capacity of one component decreased the NPV, the other component would be investigated until an optimum was found. However, this method might result in missing the optimum, and only finding capacities close to the optimum. As such, [Andersen and Østergaard, 2020] proposed a simpler solution, in which all capacities are investigated, which in turn results in higher computational stress. Therefore, the optimization used in section 7.2.3 will follow the intervals based on a 6 hour charging period, thereby increasing the volume of the storage tanks and the capacity of the resistance heater in accordance with being able to fully charge the system within the 6 hours where electricity prices are lower than natural gas prices. The analysis resulting in this 6 hour charging interval being determined can be seen on figure 7.5.

Through the optimization method 113 scenarios were made in which the storage tank duration was increased from 12 hours to 124 hours, with the capacity of the resistance heater always set to fully charge the hot storage tank in 6 hours.

INTERFACE-module

In order to perform the two dimensional matrix optimization method in a more efficient way than manually changing parameters in energyPRO, the INTERFACE-module is used.

The INTERFACE-module is an extension to energyPRO in the form of an Excel document with XML connectivity allowing to perform multiple scenario analyses in energyPRO, in which the user defines a set of parameters to be investigated. By inserting different values of these parameters the INTERFACE-module is able to run the different scenarios in energyPRO and provide desired key numbers from the reports generated within energyPRO [EMD International, 2025].

Utilizing the INTERFACE-module enables the user to perform upwards of hundreds of scenarios at a time, thus reducing the work load.

In the analyses, the INTERFACE-module is used for the optimization of 113 scenarios for the solutions involving MOSS, while also being utilized for the sensitivity analysis, in which the 113 scenarios are run under different constraints relating to electricity spot prices and gas prices, and was used to gather the annual operational income and the shares of demand that the proposed solutions are able to cover for each scenario to be used for comparing the net present value and utilization of MOSS of each scenario, in order to determine optimal scenarios.

5.3.3 Sensitivity analysis

The sensitivity analysis is performed based on inspiration from [Lund et al., 2018] in which fluctuations to electricity and natural gas prices over the last couple of years have greatly influenced the feasibility of different energy solutions, this resulted in the sensitivity analysis in this report to focus on how the reference, expected development and MOSS scenarios will behave under electricity and gas prices not only in the reference year 2024 but also 2020 and 2030, in which 2020 serves as a historical year that has been described by HYME as a year where there was no business case for MOSS, and with 2030 being a year with available projected prices for electricity and natural gas to gain insights into the projected price levels.

By performing the sensitivity analysis it is possible to better understand the feasibility of the solutions presented in the expected development and MOSS scenarios and also whether it is the same scenarios that are the optimal for each year. Thus it becomes possible to determine a more analytically founded optimal scenario that Randers Tegl should pursue.

5.4 Company collaboration

Throughout the project period the project group have had collaborations with HYME and Randers Tegl. The baseline for the analyses is both the molten salt storage system using NaOH that HYME has developed and Randers Tegl as the primary case. Quantitative data was supplied from both companies through email correspondence, specifically the cost concerning the components of MOSS from HYME and process heat demands and production layout from Randers Tegl. Qualitative data was gathered through interviews as described in section 5.2.2. One interview was conducted with HYME, where the nature of the production of Randers Tegl was discussed in relation to compatibility of MOSS and Randers Tegl's current production layout and temperature demands. The collaboration with HYME also entailed signing a non disclosure agreement due to sensitivity information that was used in the energyPRO model containing MOSS. The interview conducted with Randers Tegl served as the foundation behind the organizational analysis and proposed roadmap for a project management strategy. The project group also visited Randers Tegl, where each production component were explained step by step, the purpose of the excursion, was to gain an understanding of how the production process functioned.

6 | Theory

In this chapter the theories of science perspectives of DSR and social constructivism will be contextualized to specific theories with both a technical and organizational project management perspective. For the technical perspective, the theory of *Radical Technological Change* will be applied in an industrial perspective. The two perspectives that will be analyzed are the following; a techno-economic and organizational project management perspectives. Given that the electrification of the industrial sector entails a radical technological change away from fossil-fuels, how can these projects be implemented through project management and what should be included in the analysis of achieving successful project management? These questions will be uncovered through *organizational theory* and the theory of *How big things get done*.

6.1 Radical Technological Change

The implementation of HTTS in Randers Tegl marks a change in technology, therefore, this section will focus on how changes in technology can be defined and what considerations are necessary to include from the standpoint of a radical technological change [Lund, 2024, p.20-21].

Radical Technologial change is defined as consisting of four elements:

- Technique
- Knowledge
- Organization
- Products

In the context of an electricification in an industrial setting such as Randers Tegl, there is a need to define what each of the four elements cover:

Technique
Technique in this context is seen as how the heat utilized in the industrial processes is generated, in which a change to the technique when implementing HTTS is seen as a shift from direct fired boilers based on natural to the utilization of thermal storages and electrical heat boosters. This change in technique is the primary change that is investigated in the techno-economic analyses and will affect how the next three elements of radical technological change behave.

Knowledge

Knowledge pertains to two aspects, the overall knowledge of the technology that is being changed and thereby relates to the TRL of the technology as shown in section 2.2, which currently for MOSS systems is somewhat limited, and the knowledge of the people working within Randers Tegl. The limited knowledge surrounding MOSS would thereby indicate limited knowledge within Randers Tegl towards MOSS, and as such creates for an important aspect to ensure. However the increase in knowledge about MOSS for some groups within Randers Tegl, such as the workers in the daily operations is not within the scope of this project.

Organization
The Organization in this context relates to Randers Tegl, and how the company is organized and the people within the company work. Given a new technology is introduced, the organizational aspect has to be addressed in terms of the effect the change has on Randers Tegl's organization and vice versa, how the organization's structure and current approaches affect a potential implementation of a new technology. This focus on organization also relates to the creation of project management road maps, and is therefore part of the organizational analysis in section 7.3

Products
Products relate to the goods that are produced. While the change to HTTS does not directly influence the goods, in form of bricks, this is an aspects that is less likely to be influenced as much as the others.

While each of the four elements are important for a technology, they are not independent, but rather interconnected in the sense that when a technology changes it will be seen as a change in one of the four elements. When one of these elements changes a counter-reaction will happen in at least on of the other elements [Lund, 2024, p.21].

This is also seen as a radical technological change, in which a change to HTTS and or electric heating in technique would influence the overall knowledge of the technology, but would necessitate that the knowledge within Randers Tegl also follows this technological change in order to ensure that the organization and the people within know how to utilize the HTTS.

6.2 Organizational Theory

To enable an organizational project management analysis of HTTS for Randers Tegl, the general organizational perspective applied in this project will be outlined in this section. The argument behind utilizing organizational theory, is that the radical technological change that occurs when substituting natural gas with HTTS and or electric heating for industrial process heat production, requires organizational aspects to be taken into consideration and these aspects have to be defined within the scope of the context analyzed. In the book *Organizational theory and design* by Richard Daft, multiple aspects of organizations are uncovered, where in the context of Randers Tegl and HTTS/electric heating, the following perspectives will be utilized in the organizational analysis;

- The purpose of organizations

- Dimensions of organizational design
- Innovations and change within organizations

The purpose of organizations

Daft describes seven core objectives of organizations [Daft, 2010, p.14];

- Bring together resources to achieve desired goals and outcomes
- Produce goods and services efficiently
- Facilitate innovation
- Use modern manufacturing and information technologies
- Adapt to and influence a changing environment
- Create value for owners, customers, and employees
- Accommodate ongoing challenges of diversity, ethics, and the motivation and coordination of employees

Accommodating all seven core objectives in the perspective of HTTS/electric heating implementation is not the scope of this project, where diversity, ethics and coordination of employees will be left to Randers Tegl. The general perspective in this project of an organization, will be in the context of project management, where utilizing resources to achieve goals, producing goods efficiently, facilitating innovation, using modern manufacturing technologies, adapting to a changing environment and creating value for owners, customers and employees are the core objectives that will be sought to be upheld in this project. Daft describes:

A company can be profitable only when the value it creates is greater than the cost of resources. [Daft, 2010, p.14]

Due to this perspective, the techno-economic analysis will compare technical scenarios to the reference scenario and determine the feasibility of investing in HTTS and or electric heaters. Additionally, the aspect of adapting to a changing environment is contextualized to the necessary substitution of natural gas and electrification of the industrial sector described in the problem analysis. To determine which stakeholders should be involved in facilitating innovation through the project management aspect of a new technology and acquiring the resources necessary to achieve goals and desired outcomes, Randers Tegl as an organization will be further contextualized through Dafts description of organizational dimensions.

Dimensions of organizational design

To understand an organization and uphold the aforementioned seven purposes, Daft describes two dimensions of an organization; The structural and contextual dimension. The structural dimension contains labels to describe and analyze internal characteristics of an organization and will be utilized in this project in analysis part 2 as determining factors for successful project management. The labels of the structural dimensions are the following [Daft, 2010, p.15]:

- Formalization
- Specialization
- Professionalism
- Hierarchy of authority
- Centralization
- Personnel ratios

In the context of HTTS, some labels are not within the scope of the analysis, where *Personnel ratios* refers to a classification of employees in different departments, e.g. the number of employees in the administrative department [Daft, 2010, p.17]. *Specialization* refers to the degree of which organizational tasks are divided into separate jobs, thereby either requiring each employee to perform a wide or narrow amount of different tasks [Daft, 2010, p.17]. *Formalization* refers to the degree of legal documents, which can be contextualized to the ownership of the HTTS, where if HYME owns the facility, a heat contract will be made between HYME and Randers Tegl, which through conversations with HYME has proven to be a difficult aspect in negotiations between supplier and costumer, which HYME proposed a master's thesis could be made solely focusing on this aspect. It was excluded from considerations due to legal documents in itself being outside the scope, as the project management strategy does not focus on ownership models. Furthermore, evaluating the proposed new system in relation to the effect on existing contracts for biogas certificates can be taken into account, but given Randers Tegl signs one year contracts for certificates and the project group was unable to get a response from Biogas Denmark in relation to projected biogas certificate price levels, this aspect was excluded in considerations. These three aspects will not be covered in the analyses.

The remaining three labels; Hierarchy of authority, centralization and professionalism will serve as terms to be utilized when analyzing Randers Tegl in the perspective of project management. Professionalism refers to the level of education and training of employees, which in the perspective of HTTS will be contextualized to the degree Randers Tegl is capable of conducting system analysis and cost estimation of MOSS and the electric heater, and the degree of technical knowledge relevant to the system changes. The hierarchy of authority refers to the vertical lines within the organization of who reports to whom, which when combined with the aspect of centralization that refers to where decisions are made within the organization [Daft, 2010, p.17], create a foundation for the internal stakeholder analysis evaluation.

The argument behind performing a stakeholder analysis in analysis part 2 is related to the contextual dimension which is illustrated in Figure 6.1, where the environment refers to external factors that can influence the organization, which e.g. can be other organizations, science institutes and suppliers [Daft, 2010, p.17]. In the context of HTTS, the environment can refer to HYME as an external organization that develops the technology or the Danish Technical Institute that can develop the electric heater. Additionally, the scope of the environment will be broadened to internal stakeholders within Randers Tegl, to determine relevant people within the organization that should be a part of the project management planning process of the proposed new system. The project group will utilize interviews with Randers Tegl and Greenlab Skive, whom have experience with company collaborations in an energy project perspective.

The contextual dimension is illustrated on figure 6.1

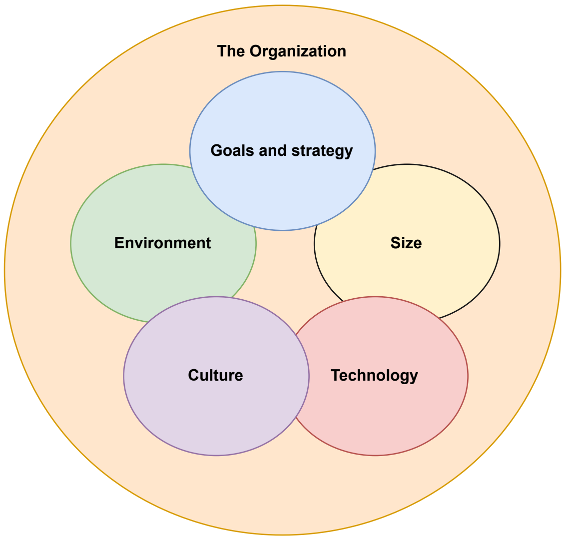

Figure 6.1: The contextual dimension - Created by the project group insprired by [Daft, 2010, p.15]

The core elements of an organization that is within the scope of this project are; Technology, Goals and Strategy and Environment. Culture refers to the underlying norms, beliefs and understandings of the employees and size refers to number of employees [Daft, 2010, p.17]. Culture will not be taken into consideration due to the shared understanding between the project group and Randers Tegl that phasing out natural gas is a necessity in the perspective of a future fossil-fuel free energy system. The size of the organizations is relevant not in terms of number of employees, but rather the production output and current natural gas input which influence the required capacities of the proposed new energy system. Technology refers to the technologies used in the manufacturing process within Randers Tegl to produce products and will lay the foundation of analyzing their current system and comparing to the new proposed systems in a technical optimization perspective in addition to the economic feasibility. The goals and strategy of Randers Tegl will be analyzed through interviews and described in the case description, which will influence the techno-economic and organizational implementation analysis in terms of how to achieve these goals through a technical and economic optimization of the system in addition to a project management road map.

Innovations and change within organizations

In order to create a project management road map inspiration from Dafts descriptions of elements for successful change will be used. Daft describes five aspects [Daft, 2010, p.416];

- Idea

- Need
- Adoption
- Implementation
- Resources

The five aspects are illustrated on figure 6.2:

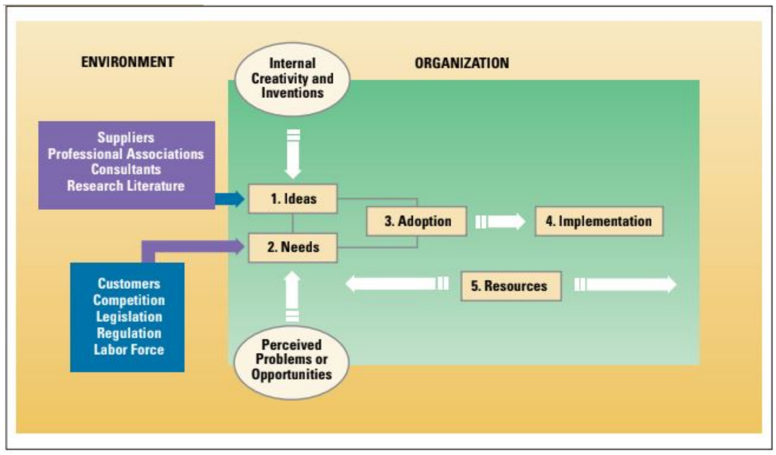

Figure 6.2: Sequence of elements for successful change [Daft, 2010, p.416]

The idea and need behind the change has been established through the problem analysis, furthermore, the need for change will be analyzed further through the techno-economic analysis, where legislation and regulation aspects of e.g. an increased biogas certificate price can influence Randers Tegls' current utilization of natural gas and create opportunities for change. The perceived problems or opportunities can be related to the general consensus in literature that an electrification of the industrial sector is necessary to phase out fossil-fuels. For the road map specifically, resources are the main focus due to adoption referring to the legal documents necessary to proceed with the implementation after it has been decided to implement the project, which is outside the scope. Implementation refers to both acquiring materials and the necessary training of employees to utilize the new technology, this perspective of implementation will be primarily handled by Randers Tegl. Through Bent Flyvberg's *How big things get done*, a theoretical perspective of project management will be applied, and recommendations made in the road map of how to avoid going over budget and over the time schedule. This aligns with the final phase of managing resources, which includes economic and stakeholder aspects [Daft, 2010, p.416].

6.2.1 How big things get done

As of the writing of this project, only one HTTS test facility has been implemented by HYME in Esbjerg and one project is currently in the beginning phase between ARLA and HYME with a 200 MWh capacity facility. Therefore, the project management aspect of a project of a larger scale concerning HTTS in Denmark using NaOH for process heat production is without a framework for how it can be performed. This project management aspect will be uncovered through part two of the analysis based on a techno-economic analysis as the foundation. The theoretical perspective of how big projects can be done by Bent Flyvberg will be utilized with considerations of the corresponding fallacies and recommendations he uncovered through experience. The primary concern outlined in his book, is that the majority of projects go over budget and over schedule with 91.5 % of 16.000 recorded projects suffering from both and 99.5 % a combination of either over budget, over schedule or under the benefits expected [Flybjerg and Gardner, 2023, p.17]. To avoid these pitfalls, Flyvberg presents paradigms with principles for success in addition to common fallacies which should be avoided:

- The planning fallacy (Fallacy to be avoided)
- The commitment fallacy (Fallacy to be avoided)
- Think slow, act fast (recommendation)
- Reference cast forecasting (recommendation)
- Take the outside view (recommendation)

The planning and commitment fallacies are the core pitfalls behind the recommendations by Flyvberg. He describes that the *planning fallacy* occurs when project planners use the best-case scenario as the planning foundation for the assumed costs and deadlines of the project, thereby underestimating the associated risks of unforeseen obstacles occurring during the project period [Flybjerg and Gardner, 2023, p.38-39]. To avoid this fallacy, Flyvberg recommends a careful planning phase that follows the *think slow, act fast* principle, which entails that the purpose, goals, potential difficulties, risks and possible alternatives are carefully considered, such that a roadmap of the project can be established [Flybjerg and Gardner, 2023, p.33]. This approach to planning aligns with how to avoid *the commitment fallacy*, which Flyvberg describes as planners rushing to decisions based on a shallow analysis [Flybjerg and Gardner, 2023, p.33]. Additional measures to *think slow, act fast* can be performed and are recommended by Flyvberg; *Reference cast forecasting* is the approach of predicting the outcome of the project, based on similar experiences with other projects. The fault of thinking your project is unique is the core behind unsuccessful risk management and project forecasting [Flybjerg and Gardner, 2023, p.96]. *Take the outside view*, which means not relying sorely on internal project projections but comparing through reference cast forecasting through similar projects. Given, molten salt storage using NaOH is not widely implemented in Denmark with only one test facility in Esbjerg experiences will be drawn from Greenlab skive and their project management processes.

This theoretical perspective on successful project planning shapes the elements included in the roadmap for Randers Tegls project management of the proposed system, where these fallacies and recommendations help shape which perspectives that should be included in Randers Tegl current project management approach.

7 | Analysis

In this chapter, the research question and sub-questions will be answered through a techno-economic and an organizational analysis of a new system for Randers Tegl. The contents of the analyses are based on the theories of science of DSR and social constructivism, which entails considering both technical and social perspectives. These perspectives have been further contextualized through the perspective of a radical technological change from section 6.1, which highlights that given either aspects of; technique, knowledge or organization is affected by a change of technology, it is then categorized as a radical technological change, and how these three aspects are affected should be analyzed. Therefore, the contents of this analysis covers both the technical aspect through the techno-economic analysis, where knowledge of the technology is included and the organizational aspect through the organizational analysis of the proposed system and how it would effect Randers Tegl and the stakeholders involved. Ultimately, the optimal scenario considerations will be included in a project management roadmap of how Randers Tegl can manage the process from initial screening of the scenario to proposing it to the board.

7.1 Case and MOSS technical description

In this section, the case will be presented with a description of the molten salt storage system that will be analyzed through a techno-economic analysis. The purpose is to lay a foundation of knowledge about both Randers Tegl and their goals for the future of the production of bricks in their factory and the molten salt storage system in terms of the technical aspects to consider when modeling the system. This entails a general understanding of how the system functions with the individual components and the storage medium used.

Case description

Randers Tegl is a bricks and roof tiles manufacturing company who have four brickworks in Denmark and one in Germany. The project group have established a collaboration with Hammershøj Teglværk located in Randers, which currently uses natural gas in their production of bricks and roof tiles. The data provided by Randers Tegl, which includes Hammershøj Teglværks natural consumption and general production setup, will be modeled in energyPRO to analyze to what degree a storage system and heat exchanger can lower natural gas usage.

Randers Tegls strategic vision, includes general support for the Danish Governments reduction targets, but no specific reduction targets or strategies have been published by the company. As Bønsø states:

I do not know if we can say we have concrete targets... We want to adapt the production to green energy sources that gain ground, that is our strategy also

Furthermore, three wind turbines with a total capacity of 18.6 MW and photovoltaics covering 50 hectares with 50 MW capacity are in the implementation phase, Bønsø comments:

The thought behind the implementation is to be able deliver electricity that accounts for all our factories at a minimum

Specifically for Hammershøj Teglværk, the goal is to use the produced electricity from the facilities. Through conversations with Randers Tegl, it was established that there is an interest in investigating technical solutions that would enable a higher utilization degree of the electricity produced from RE. Originally, Randers Tegl have had conversations with Danish Technological Institute concerning the design of an electric heater that would be able to produce process heat up to temperatures of 1,050°C. Ultimately, this solution was never put into a development phase due to the development price. Therefore, in this project the electric heater tested is under the assumption that such a technology is possible to develop, where the techno-economic analysis can give insights into economic evaluation parameters such as net present value and payback time in addition to determining the degree of which natural gas usage can be mitigated. In relation to natural gas usage, Randers Tegl currently purchase biogas certificates with a one year contract

The data supplied by Randers Tegl will be specified for the reference scenario later in the analysis, but the existing system configuration can be seen on figure 7.1.

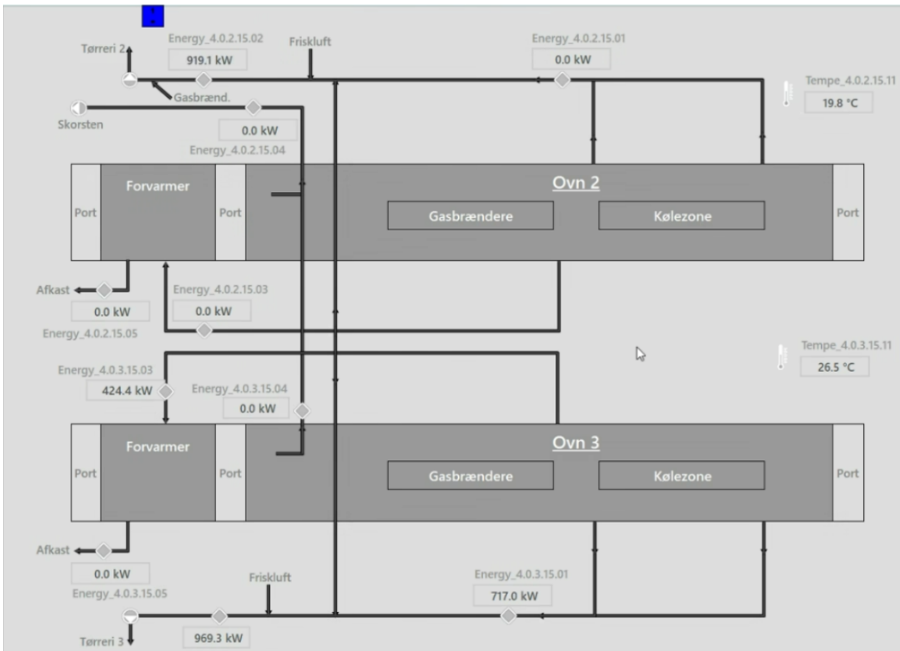

Figure 7.1: Hammershøj Teglværk current system

The process shown on the figure can be described in 5 steps:

- Molding clay into bricks/tiles
- Drying bricks/tiles
- Preheating in the oven
- Heating oven up to 1,050°C
- Cooling

Two ovens are shown on the figure, but in practice only one oven is operational which is oven 3. In their current system, excess heat from the oven is used in both the driers and the preheating process. As described in section 5.1, the temperature requirements of a given process determines the choice of storage solution, where a molten salt storage using NaOH have a maximum temperature of 600°C, it is necessary to determine the temperature levels of the oven and driers. The temperature curve within the oven can be seen on figure 7.2

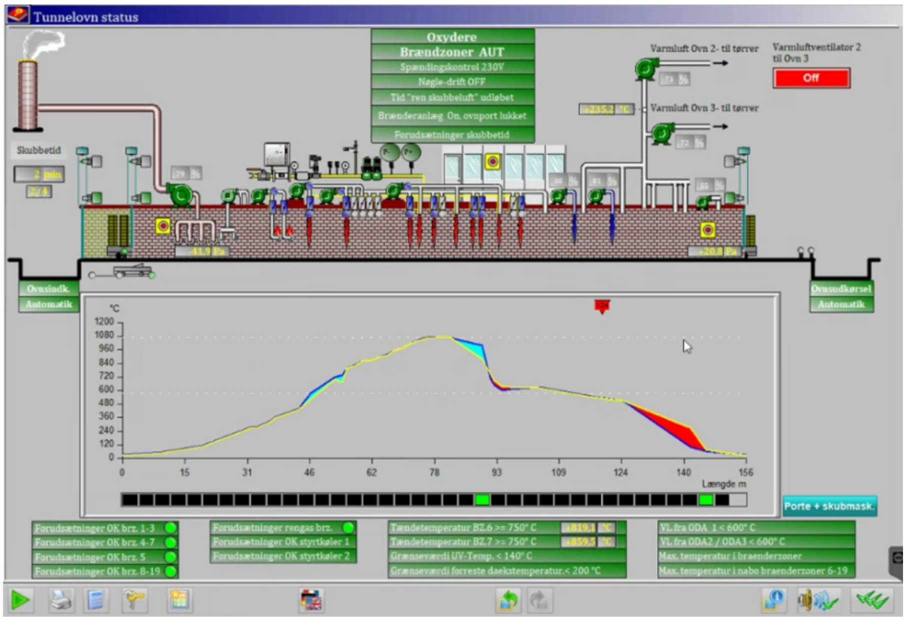

Figure 7.2: Temperature curve of the oven

The length of the oven is 156 meters and the temperature increases as the bricks/tiles move through the oven. As mentioned, the maximum temperature for MOSS is 600°C, which limits the amount of process heat demand that can be covered by MOSS, therefore, the existing natural gas boiler will remain and an electric heater that can boost the temperature from 600 to 1,050°C will be modeled. For the driers, the temperature requirement is between 180-200°C, which is within the temperature range of MOSS. To create a knowledge foundation of the molten salt storage system, the system will be described in the next paragraph.

Molten salt storage technical description

The core technology being investigated in this project is MOSS using sodium hydroxide (NaOH) as a storage medium. The current only company that develops MOSS using NaOH is HYME energy and the project group has as described in section 5.4, established a collaboration, where both the technical aspect of their system and the economics behind it were shared by HYME. This served as the primary data for modeling the investigative scenarios in energyPRO and evaluating the economic feasibility of investing in MOSS for Randers Tegl. In this paragraph, a technical description and a visualization of the system will be presented, where the temperature limitation will be explained as the primary reason behind the need for an electric heater to reach the required 1,050°C in Randers Tegls production process.

On figure 7.3 HYME's solution is visualized:

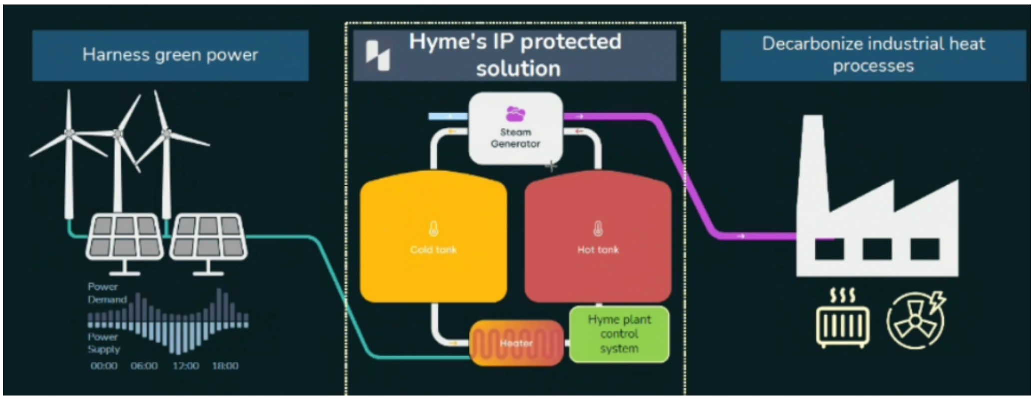

Figure 7.3: HYME's system solution

The general concept of the system is to utilize electricity produced by renewable energy sources to charge the storage through heating NaOH with resistance heaters. The salt is moved from the cold tank through a pipe system into the hot tank, where the salt is heated to a temperature up to 600°C. The high temperature salt is then used in a steam generator to produce steam which can be used to replace natural gas for process heat. The current application areas are limited to production processes with temperature requirements in the range of 200 to 600°C, which has to be within the range of the maximum temperature of the produced steam. As highlighted in section 5.1, the industries with temperature requirements within this range use natural gas which is not direct fired, but instead is used to produce steam, where MOSS can be a direct replacement. The recent announced project between ARLA and HYME in december 2024 is an example of such a system [HYME, 2024a]. Therefore, in the case of Randers Tegl, who currently uses natural gas through direct firing in an oven, there is a mismatch between the visualized system which includes a steam generator. Instead, it is necessary to have a heat exchanger that does not produce steam, but uses the salt from the hot tank to produce hot air. For Randers Tegl, who have two driers, one oven and an additional process using steam to mend the clay before it enters the oven, multiple heat exchangers would be necessary, with both a steam generator for mending the clay and heat exchangers for the dryers and oven. Through conversations in field trip to Randers Tegl, the scope of the system was limited to not include a steam generator for mending clay due to a low steam demand and a temperature requirement of 180°C which an electric boiler can supply. As the general concept for the system has been described above, the system relation to electricity utilization and harnessing in addition to each component will be explained further in the following paragraph.

The first aspect of figure 7.3 is the harnessed electricity, which can be both produced by behind the meter renewable energy facilities like the one Randers Tegl is in the phase of implementing, or bought through the spotmarket. This aspect of the system can serve as the foundation behind the optimization of both the capacity of the resistance heater and the volume of the storage tanks. While the capacity of the resistance is the indicator of how fast the storage can be charged, the optimal volume of the storage tanks are dependent on both the process heat demand and the storage duration[1] requested by Randers Tegl. As mentioned in section 5.3.2, there are multiple approaches to determining the optimal system configuration, where one option is to run scenarios for all possible configurations of resistance heater capacity and tank volume in a two-dimensional matrix optimization to find the best NPV [Andersen and Østergaard, 2020]. Another option is to exclude configurations in the matrix through an analysis of the frequency of hours during the day over the course of year, where the electricity price pr. MWh is lower than the price of the amount of natural gas required to produce 1 MWh. The results show that these prices occur between 00:00 to 06:00, which entails that the optimal charging duration is 6 hours, thus leading to the exclusion of scenarios in which the capacity of the resistance heater is not able to fully charge the hot tank in 6 hours, thus creating a foundation behind the optimization.

The second aspect is the system the molten salt storage system which is more accurately showcased on figure 7.4 compared to the simplified version on figure 7.3. The system is composed of four main components; resistance heaters, a cold and hot tank and a heat exchanger with the storage medium NaOH.

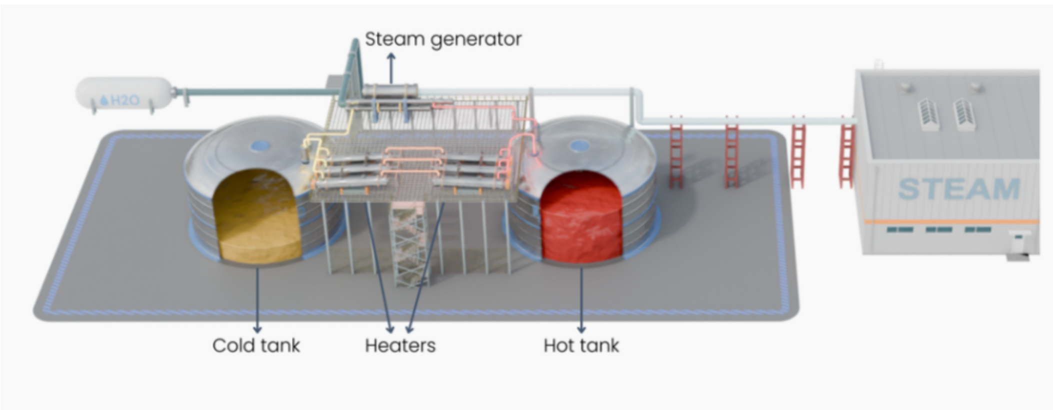

Figure 7.4: Detailed system visualization

The resistance heaters serves two purposes; maintaining the temperature in the tanks to avoid the salt from going back to a solid state by accounting for heat losses and heating the salt

[1]Storage duration refers to how many hours a fully charged tank can supply peak demand

from 318°C to 600°C. The resistance heater passes an electric current through a resistive element converting electric energy into thermal energy, which is used to heat the salt. The system modeling performed in energyPRO does not include resistance heaters for maintaining temperature levels as it was determined through conversations with HYME, that the electricity usage is insignificant due to a heat losses of less than 1 % per day, which only occurs when the system is inactive A. The core function of the resistance heater shown on figure 7.4, is to heat the salt that is moved from the cold tank which is 318°C to 600°C in the hot tank. Therefore, the thermophysical properties of the NAOH are used in calculations of how much salt can be moved in an hour based on the capacity of the resistance heater and its efficiency.

$$\frac{\text{RES}_{\text{MW}} \times 1000 \times 3600\,\text{J}}{2.11\,\text{kJ/kg}\cdot\text{K} \times \Delta T \times 1690\,\text{kg/m}^3} = \text{salt}_{\text{heated}}\ \text{m}^3/\text{h} \tag{7.1}$$

The equation 7.1 was directly inserted into energyPRO for the resistance heater, which when combined with the INTERFACE module enabled energyPRO to adjust the amount of salt heated depending on the resistance heater capacity tested. The thermophysical properties of NaOH used in the equation are shown in table 7.1, it should be noted that the maximum temperature is defined as the value where corrosion occurs of the metal insulation of the molten salt tanks and not the maximum temperature of NaOH, which has a boiling point of 1.388°C [of Medicine, 2024]. The calculation of the energy density in MWh/m^3 can be seen in the attached excel-sheet.

Table 7.1: Thermophysical properties of NaOH for MOSS

Thermophysical properties	**Value**	**Unit**
Heat capacity	2.11	kJ/kg · K
Energy density (mass basis)	0.1653	kWh/kg
Energy density (volume basis)	0.2793	MWh/m^3
Melting point	318	°C
Maximum temperature	600	°C
Density	1690	kg/m^3

The storage tanks contain the salt used, where NaOH is maintained at 318°C in the cold tank and 600°C in the hot tank. When it is economically viable to use the system, salt is extracted with a pump and circulated through a heat exchanger in a closed system. The overall efficiency of the system is 90 % for the production of heat and would be 30-40 % for the production of electricity determined through conversations with HYME, which is out of the scope of this project. The system is designed to be able to both charge and discharge simultaneously, which enables the system to take advantage of low electricity prices while supplying the process heat demand. This approach is common, which was determined through an interview with Greenlab Skive, who are planning to implement a rockbed storage which also can charge and discharge simultaneously B. The dimensions of the storage tanks are as mentioned in section 5.3.2 modeled after the spatial limitations in terms of maximum volume of 1,400 m^3, which is where spatial issues can occur and the minimum volume, which can be determined through the storage duration, determined through conversations with HYME A. The storage duration is how long a fully charged storage can supply the peak demand and is the relation between the energy content of the storage tanks and the capacity of the heat exchanger. The energy content in the storage tanks is determined through the energy density of the molten salt, which as shown in table 7.1 is 0.279 MWh/m^3. An additional aspect to consider, is that the density in kg/m^3 and heat capacity of NaOH changes depending on temperature, which ultimately influences the amount of salt that can be moved and stored in the tanks [Mahmoudinezhad et al., 2023]. For example, the density of NaOH at 350°C is 1733 kg/m^3 and at 600°C 1609 kg/m^3, therefore, the tank volume required to obtain the requested storage duration varies in the cold and hot tank, but this aspect was discussed with HYME and it was determined that the volume of each tank remains the same despite the density changes. An example of the varying densities for the molten salt is when utilizing a 500 m^3 hot tank the resulting higher density at lower temperatures would result in a 465 m^3 cold tank, this size difference would thus enable the implementation of a more affordable system given that a smaller cold tank could be invested in. However, keeping the cold tank an equivalent size as the hot tank can simplify the implementation of the system, since two equally sized tanks would be assembled.

The third and final aspect shown on figure 7.3, is the industrial heat process to be decarbonized. As mentioned in the case description of Randers Tegl, hot air is required in the oven and driers which currently is produced using natural gas. To perform a technical optimization of a system that includes a heat exchanger and a storage system, the peak process heat demand of the oven and driers will be used to determine the capacity of the heat exchanger, which then can be used for salt flow calculations in terms of the minimum amount of salt the resistance heater should be able to heat per hour, the minimum amount of salt that should be moved from the hot tank to the exchanger and volume optimizations in terms of storage duration.

7.2 Techno-economic analysis

In order to answer sub-question 1 and 2, this section of the analysis will focus on performing a techno-economic analysis optimization of MOSS and/or electric heaters in the reference scenario of Randers Tegl that was introduced in section 7.1. The goal of the analysis is to find a possible optimization of MOSS and/or electric heaters that does not only pertain to the technical part but also the economic feasibility of the system.

In order to perform the techno-economic optimization there is firstly a need to be perform a technical optimization that will be utilized as input for energyPRO.

7.2.1 Technical optimization

In order to enable energyPRO to run different technical scenarios where MOSS is included, the input and output for the resistance heater, the cold and hot tank and the heat exchanger must be calculated. The first aspect to be determined, is the amount of salt required, to be able to produce the peak demand of the oven and driers combined. The calculated is performed below:

$$\text{Salt Required (m}^3) = \text{Peak Demand (MWh)} \times \text{Energy Density (MWh/m}^3)$$

$$\text{Salt Required (m}^3) = \frac{3.17\,\text{MWh}}{0.279\,\text{MWh/m}^3} = 11.36\,\text{m}^3$$

The amount of salt required is 11.36m^3 per hour, which serves as the input for the heat exchanger. The output is therefore set to 3.17 MWh per hour with part-load enabled. For the resistance heater, it is necessary to calculate the minimum capacity to be able to heat enough salt to be able to produce the peak demand, the calculation is shown below:

$$\text{RES}_{MW} = \frac{11.36\,\text{m}^3/\text{h} \times 2.11\,\text{kJ/kg}\cdot\text{K} \times \Delta T \times 1690\,\text{kg/m}^3}{1000 \times 3600J} = 3.17_{MW}$$

The resulting minimum capacity of the resistance heater is 3.17 MW. As described in section 5.3.2, the optimization method is based on storage duration and the frequency of hours during a day over the course of 1 year, where the electricity price is lower than natural gas prices. The intervals shows that the lowest electricity prices occur between 00:00 to 06:00 or 10:00 to 14:00 as shown on figure 7.5.

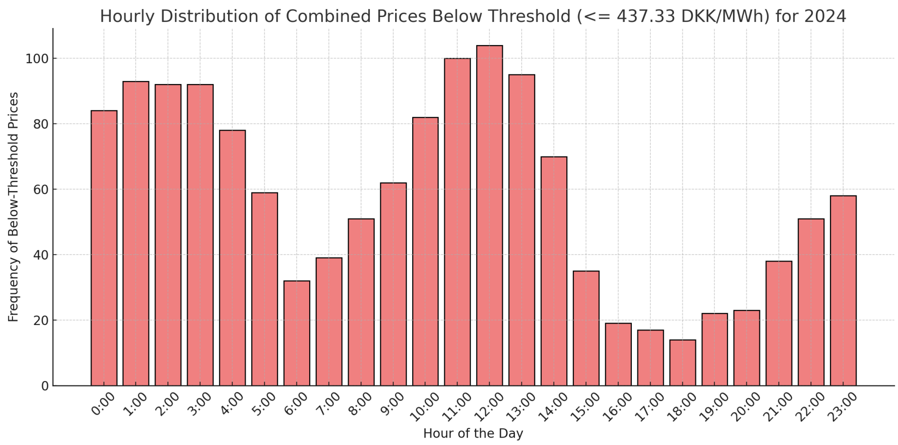

Figure 7.5: Frequency of hours from 00:00 to 23:00 for 2024 where the spotprices with included season low load, high load and peak load tariffs are lower than the natural gas price in DKK/MWh

Therefore the capacity of the resistance is set to be able to fully charge the storage hot tank within 6 hours. Additionally, it was determined in the interview with HYME, that the minimum operation period of the resistance heater is 2 hours, therefore, charging in intervals of hours where prices are lower than natural gas prices are preferred. An example would be a storage duration of 48 hours would equal a storage volume of 545 m3 which is 152 MWh of capacity. To be able to fully charge the storage in 6 hours, the minimum capacity of the resistance heater would be 25 MW. Accordingly, the formula shown in 7.1 calculates the amount of salt that can be heated based on a new MW capacity entry, such as 25 MW, therefore energyPRO can adjust the amount of salt heated in the different scenarios tested.

7.2.2 Economic data

This section aims to present the economic data that will be used in the energyPRO modelling of the different scenarios and the later calculations of net present values in order to determine the optimal scenario. Therefore, the section will focus on both CAPEX and OPEX of the technical components that are included in the scenarios, as well as the costs associated with electricity and natural gas. Shared for all scenarios is that they will be utilizing a discount rate of 5 %

Technical component costs

Economic data pertaining to the technical components will only include OPEX for natural gas boilers, wind turbines and photovoltaics, this is due to the technologies already being invested in, and thus creating the foundation for the reference scenario. Consequently for the technologies: electric direct firing, and MOSS, divided into resistance heater, heat exchanger and storage tank, both CAPEX and OPEX will be included.

Economic data for technical components			
	Investment cost	Variable O&M's	Fixed O&M's
Natural gas direct firing	0 DKK/MW	8.5 DKK/MWh	0 DKK/MW/y
Wind turbine	0 DKK/MW	14.9 DKK/MWh	10414.4 DKK/MW/y
Photovoltaics	0 DKK/MW	0 DKK/MWh	5937.5 DKK/MW/y
Electric direct firing	450000 DKK/MW	1.4 DKK/MWh	0 DKK/MW/y
Resistance heater	522200 DKK/MW	7.2 DKK/MWh	8488.1 DKK/MW/y
Heat exchanger	746000 DKK/MW	7.2 DKK/MWh	8488.1 DKK/MW/y
Storage tank	150000 DKK/MWh	0 DKK/MWh	1500 DKK/MWh/y

Table 7.2: Economic data for the technical components that will be used in energyPRO alongside investment costs used in excel.

fuel and electricity related costs

The economic data that pertains to fuel and electricity will focus on the electricity spot prices and their characteristics alongside the tariffs that are included in the scenarios with both import related tariffs and availability tariffs, additionally, this section will include the natural gas prices used alongside the biogas certificate prices that are paid per m^3 gas bought.

Economic data for fuels and electricity 2024	
Natural gas	
-Market price	2.3 DKK/m^3
-Biogas certificate	1.1 DKK/m^3
Electricity Tariffs (TSO)	
-System Tariff	74 DKK/MWh
-Export Tariff	11.5 DKK/MWh
Net Tariffs (DSO)	
-Low Load	55.6 DKK/MWh
-High Load	166.8 DKK/MWh
-Peak Load	333.7 DKK/MWh
-Availability Tariff	152.7 DKK/MWh

Table 7.3: Economic data for the electricity and fuel related costs used in energyPRO

the net and availability tariffs in table 7.3 are based on the tariffs by Hammershøj Teglværks distribution system operator N1's advisory tariffs in which it was found that Hammershøj Teglværk is a "b-lav" customer.

7.2.3 energyPRO scenarios

This section will focus on modelling the energyPRO scenarios that will be investigated in the techno-economic optimization that will be performed later this chapter.

The aim of presenting the energyPRO scenarios are to show a visual presentation of how they function, while also presenting the key numbers that will be used for the comparison in the techno-economic optimization.

Reference scenario

The reference scenario of Randers Tegl is focused on presenting the current energy system within the company, in which the inclusion of the planned wind energy and photovoltaics will be used since the planning process for those renewable energy projects have entered the implementation phase.

The data for the reference scenario was received by Jonas Bønsø from Randers Tegl, in which the resolution was given as typical daily demands for each of the 7 days in a normal week. The data received consisted of data for the 2 driers and the oven and is presented in the tables below:

Drier 2								
	Gas (m_3)	Gas (Nm_3)	Gas (Kwh)	Effect (Kwh)	Electricity (Kwh)	Heat Total (kWh)	Heat Total (kJ)	Fired (%)
Monday	2041	2019	21514	18968	705	40482	145734507	53 %
Tuesday	1227	1214	12934	16005	444	28939	104178897	45 %
Wednesday	1222	1209	12881	16539	427	29420	105911562	44 %
Thursday	1582	1565	16676	22411	575	39087	140711661	43 %
Friday	1124	1112	11848	24940	676	36788	132436362	32 %
Saturday	2016	1994	21250	21204	869	42454	152835433	50 %
Sunday	2868	2836	30231	14658	899	44889	161600627	67 %

Table 7.4: Reference data for Drier 2

Drier 3								
	Gas (m_3)	Gas (Nm_3)	Gas (Kwh)	Effect (Kwh)	Electricity (Kwh)	Heat Total (kWh)	Heat Total (kJ)	Fired (%)
Monday	2	2	22	26400	761	26422	95117659	0 %
Tuesday	37	37	399	27600	830	27999	100796689	1 %
Wednesday	109	110	1176	26400	825	27576	99272408	4 %
Thursday	101	102	1089	24000	759	25089	90321772	4 %
Friday	2	2	22	21000	706	21022	75677659	0 %
Saturday	1	1	11	26400	766	26411	95078829	0 %
Sunday	0	0	0	26400	768	26400	95040000	0 %

Table 7.5: Reference data for Drier 3

Oven		
	Gas (Nm_3)	Gas (kWh)
Monday	7874.5	83908.9
Tuesday	7407.6	78920.8
Wednesday	7596.0	80929.8
Thursday	7889.0	84062.0
Friday	7819.8	83317.4
Saturday	7468.8	79594.8
Sunday	7633.0	81365.7

Table 7.6: Reference data for the oven

Since the data is based on the normal demand for each day and energyPRO relies on an hourly resolution, there is a need to find the hourly demands of electricity and natural gas, this was done by equally distributing the demands of each day onto 24 hours, thus resulting in each day having the same demands for each hour during that day. Additionally the "Fired (%)" column defines the share of the demands for each table that the actual demand, whereas the rest of the heat stems from excess heat derived from the oven. Therefore, there is a need to find the actual heat demands for the driers, which takes the excess heat from the oven into account. As such the actual demands for the oven and the 2 driers can be seen in the table below:

	Total annual heat demand	Peak heat demand
Oven	29749.2 MWh	3.48 MW
Drier 2	6619.9 MWh	1.25 MW
Drier 3	124.1 MWh	0.05 MW

Table 7.7: Total annual heat demands and peak hourly hear demands for the oven and the two driers while accounting for excess heat transferred from the oven to the two driers.

Additionally, the electricity demands for the driers were equally distributed, whereas the regular electricity demand for the rest of Hammershøj Teglværk was received at an hourly resolution for the same week, thus the characteristics for the electricity demands can be seen in the table below:

	Total annual electricity demand	Peak electricity demand
Regular demand	4676.6 MWh	1.3 MW
Driers demand	121.3 MWh	25.1 kW

Table 7.8: Electricity demand characteristics for the regular electricity demands and the drier electricity demands.

Based on the data in Tables 7.7 and 7.8, the energyPRO reference scenario was modelled, in which the heat demands for the oven and driers were split as process heat and regular heat demands respectively. The reason for splitting the heat demands is regarding the implementation of MOSS covered in section 7.1, and will be applied further in the representation of the MOSS scenario. Additionally the reference scenario includes the proposed photovoltaics and wind turbines, that were described in section 7.1.

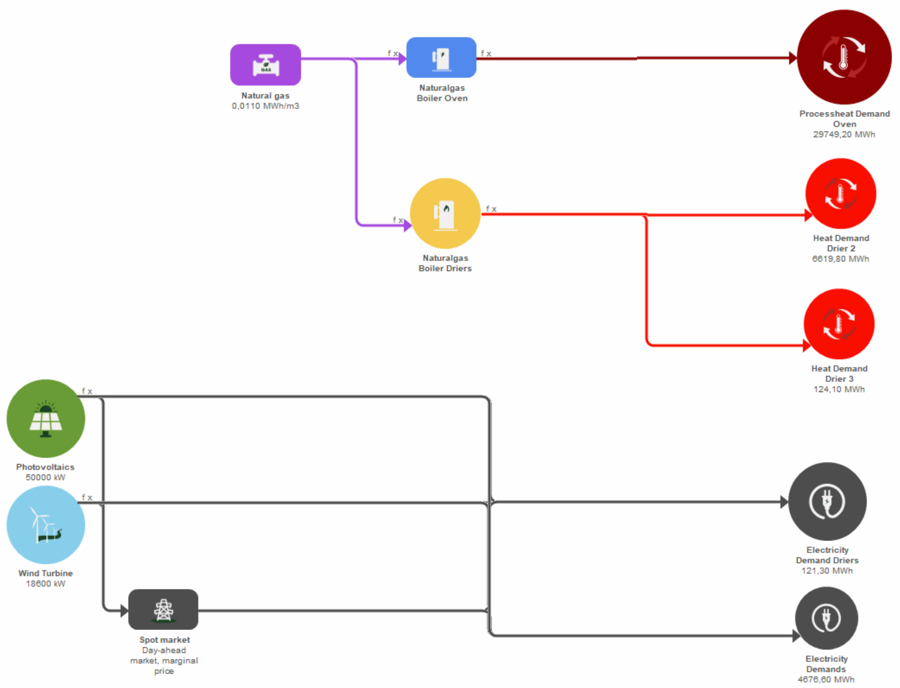

Figure 7.6: Visualisation of the reference scenario in energyPRO

As seen in Figure 7.6 the two electricity demands are covered partly by the photovoltaics and wind turbines, which are connected to a spot market that will be utilized for export and to import the electricity that they cannot cover. Additionally two natural gas boilers are modelled due to the split of heat types needed for the oven and driers respectively.

From the energyPRO model it is possible to find the key parameters that characterize the system, being, for the purpose of comparing the different scenarios, export and import of electricity, natural gas consumption and payments, investments, total annnual operation income and the renewable energy share utilization. These key parameters follow the goals presented in section 7.1, in which Jonas Bønsø argued that one of the key goals of the implementation of the 50 MW photovoltaics and 18.6 MW wind turbines was to utilize as much of the renewable energy produced as possible in order to also reduce the amount of natural gas used in their processes. The key parameters of the reference scenario are therefore:

Reference Scenario key parameters (2024)		
Export of Electricity		
Export Revenues	20.1	Mio. DKK
Quantity	48580.2	MWh
Import of Electricity		
Import costs	0.6	Mio. DKK
Quantity	792.2	MWh
Natural Gas		
Payments	15.2	Mio. DKK
Quantity	3.7	Mio. m^3
Investments	0	Mio. DKK
Total annual operation income	-5.9	Mio. DKK
Renewable Energy Share Utilization	7.6	%

Table 7.9: Key parameters of the reference scenario using spot market prices of 2024, seasonal tariffs and fixed natural gas prices with bio certificates.

These key parameters will be used in the two-dimensional optimization of the MOSS scenario in section 7.2.3 and in order to choose the scenario that would be optimal for Randers Tegl, it's important to note that investments for the wind turbines and photovoltaics are not included, since they are seen as an already implemented solution, even though they are still in the implementation phase.

Expected development scenario

The expected development scenario follows the reference scenario quite closely but with an addition to adding direct fired electricity to substitute part of the current natural gas direct firing, and in order to utilize a larger share of the produced renewable energy that is produced by the photovoltaics and wind turbines. Additionally, this scenario will include CAPEX and OPEX of the electric direct firing.

By adding the electric heating units the system will be modelled in energyPRO the following way:

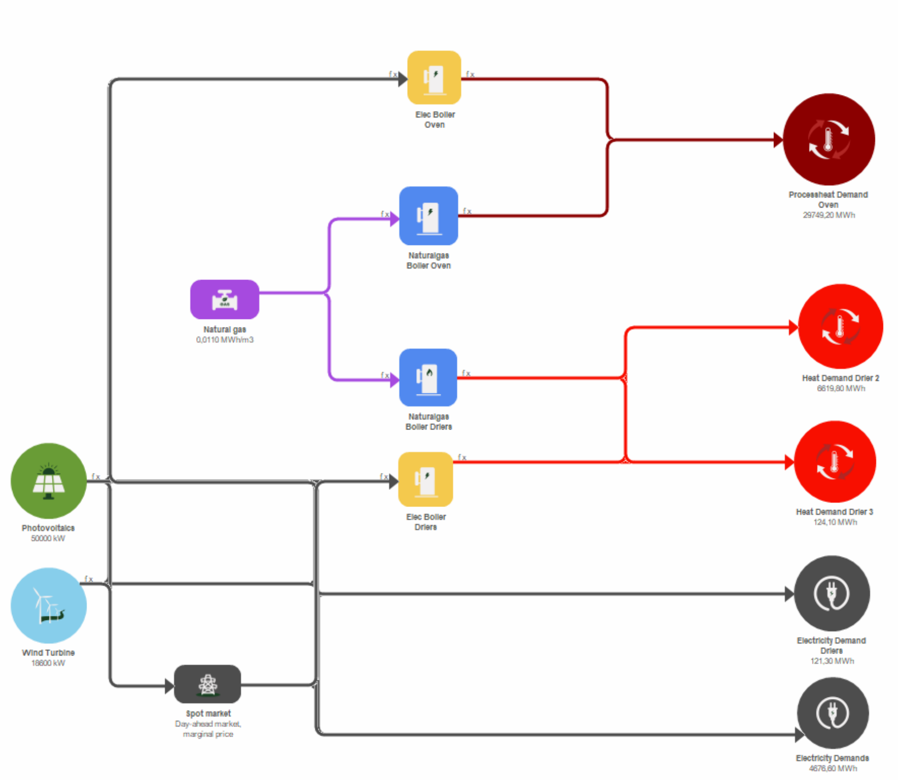

Figure 7.7: Visualization of the expected development scenario, in which, electric heaters have been added in order to simulate the inclusion of electric heaters as a substitution for parts of the natural gas direct firing.

Using energyPRO to simulate the operations of the system, the key parameters that were found for the reference scenario can also be found for the expected development scenario, and are as follows:

Expected Development Scenario key parameters (2024)		
Export of Electricity		
Export Revenues	18.7	Mio. DKK
Quantity	42284.3	MWh
Import of Electricity		
Import costs	1.2	Mio. DKK
Quantity	4520.5	MWh
Natural Gas		
Payments	10.3	Mio. DKK
Quantity	2.5	Mio. m^3
Investments	2.1	Mio. DKK
Total annual operation income	-3.5	Mio. DKK
Renewable Energy Share Utilization	22.3	%

Table 7.10: Key parameters of the electric boiler scenario using spot market prices of 2024, seasonal tariffs and fixed natural gas prices with bio certificates.

Two-dimensional optimization for MOSS scenario

Before modeling the implementation of MOSS utilizing the rationales from section 7.1 it is necessary to discuss how the capacities for the resistance heater and storage tank volumes were set. However prior to finding finding the capacities for the storage volume and resistance heater, there is a need for addressing the limitations of MOSS being at 600°C, resulting in only parts of the modelled demand for the oven to be able to be covered by the MOSS. Using the thermophysical properties of heating a medium to certain degrees the share of the oven demand that can be covered by MOSS can be found:

$$Q = c_p \times m \times \Delta T \tag{7.2}$$

in which Q is the energy needed to heat the medium, c_p is the specific heat capacity of the medium, m the mass of the medium, and ΔT the temperature difference of the medium.

given that specific heat capacity of air at constant pressure is 1.005 kJ/kg×K and the temperature ranges investigated are from 0°C to 600°C and then from 600°C to 1050°C, using an example of 1 kg of air, 57 % of the energy would be required in the first heating, thus separating the oven heat demand in high temperature oven heat demand consisting of 43 % of the original oven heat demand and a low temperature oven heat demand consisting of 57 % of the original oven heat demand is performed.

After separating the oven heat demand in low temperature and high temperature demands it is possible to find the specific the storage volumes and resistance heater capacities. The storage tank volumes were set to be able to cover at least 12 hours of peak demand resulting in 136m^3, whereas the maximum volume was as mentioned in section 5.3.2 set to a maximum of 1400 m^3 equalling to 124 hours of peak demand. Additionally it was determined that the resistance heater should always be able to fully charge the hot tank in 6 hours, thus setting the minimum and maximum capacities to 6.3 and 66.5 MW respectively. Utilizing the optimization method the interface module describe in section 5.3.2 was used with parameters 1 and 2 being the storage volume in m^3 and resistance heater capacity in MW, with the storage volume being defined in the range from 12 to 124 hours with 1 hours incrementations, whereas the corresponding resistance heater capacity was always set to be able to fully charge the storage in six hours.

The Interface module was then used on the MOSS scenario which is visualized in Figure 7.8

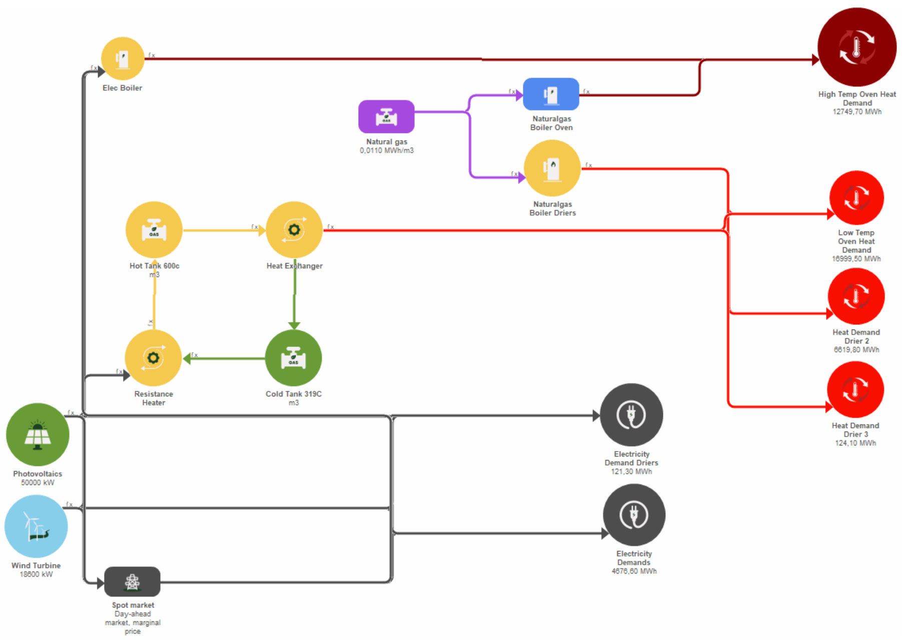

Figure 7.8: Visualization of the MOSS scenario, in which, a MOSS storage system has been included alongside the inclusion of electric direct firing as a substitution for parts of the natural gas direct firing for the 1050°C demand in the oven.

When using the interface module to find the operation income when implementing the different capacities of storage volume and resistance heater it becomes possible to calculate the net present value of each scenario, in order to find the optimal MOSS scenario. the optimal scenario was found to have a storage volume of 216 m^3 and a resistance heater capacity of 10 MW, which corresponds to a storage volume able to cover 19 hours of peak demand. The key parameters of the optimal MOSS scenario can be seen in table 7.11

Optimal MOSS Scenario key parameters (2024)		
Export of Electricity		
Export Revenues	18.4	Mio. DKK
Quantity	40529.1	MWh
Import of Electricity		
Import costs	1.6	Mio. DKK
Quantity	9780.8	MWh
Natural Gas		
Payments	6.3	Mio. DKK
Quantity	1.5	Mio. m^3
Investments	17.8	Mio. DKK
Total annual operation income	-0.9	Mio. DKK
Renewable Energy Share Utilization	28.9	%

Table 7.11: Key parameters of the optimal MOSS scenario using spot market prices of 2024, seasonal tariffs and fixed natural gas prices with bio certificates.

In order to better compare the different scenarios and thereby evaluate the optimal scenario, the key parameters from each of the 3 scenarios from tables 7.9, 7.10 and 7.11 will be listed side by side, while also adding the electric heat and moss heat shares, the NPV and payback time of investment. The reference scenario will naturally be given an NPV and payback time of 0, since it is the scenario that the expected development and MOSS scenarios will be compared to.

Comparison of key parameters (2024)				
		Reference Scenario	**Expected Development Scenario**	**Molten Salt Scenario**
Export of Electricity				
Export Revenues	Mio. DKK	20.1	18.7	18.4
Quantity	MWh	48580.2	42284.3	40529.1
Import of Electricity				
Import costs	Mio. DKK	0.6	1.2	1.6
Quantity	MWh	792.2	4520.5	9780.8
Natural Gas				
Payments	Mio. DKK	15.2	10.3	6.3
Quantity	Mio. m^3	3.7	2.5	1.5
Investments	Mio. DKK	0	2.1	17.8
Total annual operation income	Mio. DKK	-5.9	-3.5	-0.9
Renewable Energy Share Utilization	%	7.6	22.3	28.9
Electric Heat Share	%	0	32.6	11.8
MOSS Heat Share	%	0	0	47
NPV	Mio. DKK	0	32.8	53.7
Payback time	years	0	0.9	3.5

Table 7.12: Comparison of the 2024 scenarios from tables 7.9, 7.10 and 7.11 with the addition of NPV in Mio. DKK and Payback time in years

As can be seen in table 7.12, the molten salt scenario achieves the highest NPV of 53.7 Mio. DKK with a payback time of 3.5 years, whereas the expected development scenario achieves an NPV of 32.8 Mio. DKK with a payback time of 0.9 years. A main factor for the different technologies lies in the associated investment costs, with the expected development scenario having a total investment cost of 2.1 Mio. DKK, whereas the 19 hour MOSS scenario has total investment costs of 17.8 Mio. DKK. This difference in investment costs is substantial and therefore it is important to take Randers Tegls ambitions and goals into consideration. Finally the share of heat demand that is covered by the electric heaters or from the MOSS is also relevant, since it helps determining the actual effect on the current utilization of natural gas from investing in the different solutions. While the electric heater is able to cover 32.6 % of the total heat demand in the expected scenario, the MOSS system is able to cover 47 % independently, while the electric heater in the moss scenario is able to cover 11.8 % resulting in the MOSS scenario able to cover 58.8 % of the total heat demand at Randers Tegls brickwork.

Additionally, while the results of the three scenarios with 2024 prices on electricity and natural gas resulted in a 19 hour storage duration MOSS system having the highest NPV, the same results might not apply for different electricity and gas prices for other years, thus resulting in other scenarios being the optimal solution. Therefore, the next section will focus on a sensitivity analysis of changing electricity and gas prices.

7.2.4 Sensitivity analysis

For the sensitivity analysis of the 115 scenarios that were investigated in the prior sections, an analysis will be performed testing different spot price years and average natural gas prices. By performing the sensitivity analysis, the optimal solution for Randers Tegl will be chosen from a standpoint that does not only rely on a singular year of reference data, but will be determined through multiple years of operation periods. For the sensitivity analysis, two extra years of data was chosen, with one being 2020 which HYME has stated was a year where there was no business case for MOSS, whereas the other year is 2030, which relies on forecasted prices.

Prior to performing the sensitivity analysis, the electricity and gas prices for 2020 and 2030 compared to 2024 will be presented, though it is important to note that the sensitivity analysis will still use the same tariffs and biogas certificate prices, which is a simplified approach. The project group reached out to Biogas Denmark to ask about estimated future biogas certificate prices with no response. Therefore, the reasoning for not using different tariffs and biogas certificate prices is due to difficulties in finding proper projections for these prices in 2030.

The key characteristics of the electricity spot prices can be seen in Table 7.13:

Economic key characteristics of Electricity				
		2020	**2024**	**2030**
Average price	DKK/MWh	187.8	526.9	219.2
Minimum Price	DKK/MWh	-437.5	-448	-635.4
Maximum Price	DKK/MWh	1488.3	6982.4	2921

Table 7.13: Comparison of electricity spotprice key characteristics for 2020, 2024 and 2030

It is visible from the key characteristics of the spotprices for each year that the price levels has been impacted by geopolitical conditions in addition to fluctuating production from RE, where the share of the total consumption in Denmark covered by RE increased from 49.8 % in 2020 to 63.4 % in 2024 [Energinet, 2025]. The prices do become a bit more stable in terms of minimum and maximum price in 2030 compared to 2024. This stability is contributed to the fact the Danish Energy Agency projects an increase in flexible demand towards 2030 [Danish Energy Agency, 2024].

Economic key characteristics of Natural Gas				
		2020	**2024**	**2030**
Average price	DKK/m^3	1.3	4.1	2.3

Table 7.14: Comparison of Natural gas prices for 2020, 2024 and 2030

The development of the natural gas prices somewhat follows the same patterns with the natural gas prices in which the energy crisis of the early 2020's affected gas prices to skyrocket, where the aftereffects are reflected in the 2024 prices. The Danish Energy Agency projects a stabilization of gas prices resulting in the decrease towards 2030 [Danish Energy Agency, 2024].

Comparison of 2020 scenarios

While the results of 2024 clearly depicted both the expected development and the moss scenario of 19 hours storage duration as feasible solutions with positive NPVs, it is important to investigate with 2020 electricity and gas prices given it is a year with low natural gas and average electricity prices compared to 2024. The input for the interface module was as described in section 5.3.3 the same technical modeling used in the 2024 scenario for the reference, expected development and MOSS scenarios. Thus enabling a comparison of the 2024 and 2030 operation incomes to an updated reference scenario based on 2020 price levels.

The result of the optimization of the 113 different MOSS scenarios resulted in the minimum capacity of 12 hours with a storage volume of 136m^3 and a resistance heater capacity of 6.3 MW being the optimal MOSS solution in 2020 as one of three MOSS scenarios with a positive NPV. Increasing the volume and capacity of the resistance heater beyond the 12 hours storage scenario does not yield the necessary improved annual operation income to counteract the increases in investment costs that follow such higher capacities in addition to the decrease in natural gas prices from 4.1 DKK/m^3 in 2024 to 1.3 DKK/m^3 in 2020, which causes a decrease in operation income from -5.9 Mio.DKK in 2024 to -4.6 Mio.DKK in 2020 in the reference scenario. In table 7.15, the key parameters of the reference, expected development and the 12 hour MOSS scenarios can be seen:

Comparison of key parameters (2020)				
		Reference Scenario	**Expected Development Scenario**	**Molten Salt Scenario**
Export of Electricity				
Export Revenues	Mio. DKK	10.9	10.6	10.7
Quantity	MWh	56495.7	52639.2	52816.4
Import of Electricity				
Import costs	Mio. DKK	0.1	0.2	0.4
Quantity	MWh	812.3	4764.8	10416.9
Natural Gas				
Payments	Mio. DKK	4.9	3.7	2.9
Quantity	Mio. m^3	3.7	2.8	2.2
Investments	Mio. DKK	0	2.1	11.5
Total annual operation income	Mio. DKK	-4.6	-4.0	-3.7
Renewable Energy Share Utilization	%	6.6	14.4	14.5
Electric Heat Share	%	0	24.1	9.1
MOSS Heat Share	%	0	0	30.8
NPV	Mio. DKK	0	6.5	1.2
Payback time	years	0	3.5	12.8

Table 7.15: Comparison of the reference scenarios, expected development scenario and the optimal MOSS scenario with 2020 electricity and gas prices.

When comparing the three scenarios with 2020 electricity and natural gas prices, it is evident that the expected development scenario has the highest NPV of 6.5 Mio. DKK, whereas the MOSS scenario "only" achieves an NPV of 1.2 Mio. DKK, thus both scenarios are feasible, however similar results as for 2024 when focusing on the investment costs further deincentivizes the MOSS scenario, especially now that the expected development scenario sees a better NPV, while also has lower investment costs and a shorter payback time of 3.5 years compared to 12.8 years for the MOSS scenario. The different prices for electricity and natural gas has additionally affected the shares of the heat demand that can be covered by electric heaters and MOSS in the investigative scenarios, the changed prices has resulted in both electric and MOSS heat shares to decrease with the MOSS scenario dropping form 58.8 % in 2024 to 39.9 % with 2020 prices. whereas the electric heating scenario "only" drops from 32.6 % to 24.1 %, further emphasizing that the expected development scenario has a historical greater feasibility given that natural gas prices drops to the same level. The lower prices on both natural gas and electricity are strong contributors to why the MOSS scenarios are less feasible despite lower electricity prices favoring MOSS, since the reduced costs of the imported electricity for the resistance heater is outweighed by loss of revenues from export, while the lowered natural gas prices results in a lower cost on the import of natural gas.

Comparison of 2030 scenarios

Since the 2024 and 2020 scenarios yielded different results in the case of finding the optimal scenario, the goal of the analysis using 2030 prices on electricity and natural gas is to assist in choosing an optimal scenario which not is not only feasible based on historical prices from 2020 and 2024, but also with prices related to future projections. Thus, creating a basis for a projected evaluation of the scenarios. Similar to the 2020 sensitivity analysis, the reference and expected developments scenarios are the same, whereas the MOSS scenarios undergo the two dimensional matrix optimization. The results from the optimization showed multiple feasible solutions with MOSS, however, the optimal scenario based on the NPV is a MOSS system with the capacity to cover 13 hours of peak demand, with a storage volume of 148 m^3 and resistance heater capacity of 6.9 MW. A comparison of the key parameters of the reference, expected development and 13 hour MOSS scenarios with 2030 prices on electricity and natural gas can be seen in table 7.16:

Comparison of key parameters (2030)				
		Reference Scenario	**Expected Development Scenario**	**Molten Salt Scenario**
Export of Electricity				
Export Revenues	Mio. DKK	9.1	8.0	7.9
Quantity	MWh	48920.8	40881.6	39291.7
Import of Electricity				
Import costs	Mio. DKK	0.2	0.6	0.8
Quantity	MWh	807.4	5897.7	11014.5
Natural Gas				
Payments	Mio. DKK	8.5	5.0	3.0
Quantity	Mio. m^3	3.7	2.2	1.3
Investments	Mio. DKK	0	2.1	12.4
Total annual operation income	Mio. DKK	-10.0	-8.4	-7.2
Renewable Energy Share Utilization	%	7.5	25.5	30.9
Electric Heat Share	%	0	41.3	15.6
MOSS Heat Share	%	0	0	49.7
NPV	Mio. DKK	0	20.3	26.0
Payback time	years	0	1.3	4.5

Table 7.16: Comparison of the reference scenarios, expected development scenario and the optimal MOSS scenario with 2030 electricity and gas prices.

When using 2030 prices on electricity and natural gas, both the expected development and MOSS scenarios achieve positive NPVs with the MOSS scenario reaching the higher NPV of 26 Mio. DKK, thus resulting in it being considered the better solution. It is however interesting to once again consider the investment costs for each of the scenarios, with the MOSS scenario having an investment cost of 12.4 mio. DKK, being more than 10 mio. DKK more than the expected development scenario. As such, the same results as in 2024 appear, in which the MOSS scenario has the higher NPV, but the accompanying investment costs might deter Randers Tegl from investing due to high initial costs. An interesting point when comparing the 2030 results to the 2024 results is the shares of which the heat is covered by electric heating or through MOSS, in which, the expected development scenario increases from 32.6 % covered by electric heating in 2024 to now 41.3 % covered by electric heating. The same results appear for MOSS in which 2024 saw the MOSS scenario achieving 11.8 % electric heating share and 47 % MOSS heating share resulting in a total of 58.8 % of the total heat demand covered by the newly invested solutions, in 2030 these numbers increased to 15.6 % and 49.7 % respectively resulting in a total coverage of 65.3 % covered by the electric heating and MOSS. Before summarizing the results of the sensitivity analysis, the optimal scenario of each year based on NPV can be seen in table 7.17:

Comparison of optimal scenarios for each year				
		2020	**2024**	**2030**
		Expected Development Scenario	**19 hour MOSS Scenario**	**13 hour MOSS Scenario**
Export of Electricity				
Export Revenues	Mio. DKK	10.6	18.4	7.9
Quantity	MWh	52639.2	40529.1	39291.7
Import of Electricity				
Import Costs	Mio. DKK	0.2	1.6	0.8
Quantity	MWh	4764.8	9780.8	11014.5
Natural Gas				
Payments	Mio. DKK	3.7	6.3	3.0
Quantity	Mio. m^3	2.8	1.5	1.3
Investments	Mio. DKK	2.1	17.8	12.4
Total annual operation income	Mio. DKK	-4.0	-0.9	-7.2
Renewable Energy Share Utilization	%	14.4	28.9	30.9
Electric Heat Share	%	24.1	11.8	15.6
MOSS Heat Share	%	0	47.0	49.7
NPV	Mio. DKK	6.5	53.7	25.0
Payback Time	years	3.5	3.5	4.5

Table 7.17: Comparison of optimal scenarios from 2020, 2024 and 2030 based on NPV

Summarizing the results of the 2020, 2024 and 2030 scenarios it is evident that it is possible to find feasible solutions for both the expected development and the MOSS scenarios. However, the MOSS scenario showed for both 2024 and 2030 to be able to generate higher NPVs and at the same time higher shares of the heat covered by the newly added solutions. In total the resulting optimal capacities of the MOSS solution indicates that a minimum capacity of 13 hours and a maximum capacity of 19 hours holds the optimal solutions for MOSS at Randers Tegls Hammershøj Teglværk.

Generalizing results of the sensitivity analysis

While the results of the techno-economic analysis have been focused around the operations at one brickwork, in which investments in MOSS could provide shares upwards of 65.3 % of heat covered. These result in the possibility of the creation of flexible demands if the technology finds widespread implementation throughout not only the brickworks industry, but also industries with similar types of demand for temperature. This section will therefore generalize the results of the analysis in order to comment on the possible impacts of implementing MOSS/electric heating throughout multiple industries.

Based on the categorization of industrial proces heat demands in the attached excel document, it can be seen that the industry of production of bricks and tiles has a total heat demand of 1588 TJ/year, though the investigated technologies in the analysis would only be used for temperatures exceeding 200°C, thus resulting in a total annual demand of 1098 TJ/year, converting this to TWh/year and then using the result of covering upwards of 65.3 % of the total demand could result in a total flexible demand through electrifying the industrial sector of 0.2 TWh/year, it must however be noted that not all brickworks have the same operational processes and thus the same demand profiles, thereby this number has a degree of uncertainty.

Expanding the implementation of MOSS and electric solutions to all industries that have heat demands of either the same temperature as Randers Tegl or lower temperatures would instead result in the creation of flexible demands of 4.3 TWh/year. The argument for being able to do this generalization is that if it is feasible to supply heat of upwards of 1050°C then all temperatures below that level should also be feasible for the technology. As such, the potential flexible demand created is substantially higher than only implementing for the brickworks industry. However to put these amounts of flexible demand into perspective there is a need to investigate the projected main sources of flexible demand and how large flexible demands these are projected to create. Two of the main sources of creating flexible demands stem from the increasing demand for building data centers as well as the increased demand for producing hydrogen for different synthesizes, the Danish Energy Agency projects these two sectors to increase in capacity and thereby their demands for electricity will increase substantially as well. In their report on analytical assumptions data centers are projected to increase in electrical demand from 3 TWh/year in 2024 to 17 TWh/year in 2030, with and additional increase towards 2050 to 29 TWh/year, while the demand for PtX and in particular electrolysis plants is projected to reach upwards of 56 TWh/year of electricity demand for electrolysis plants connected to the transmission grid in 2050 [Danish Energy Agency, 2024, p.20] as was also mentioned in section 2.1. These quantities of flexible demand that will possibly be created towards 2050 are significantly higher than the possible 4.3 TWh/year created by implementing MOSS and electric heating, it must however be noted that there are uncertainties connected to both projected development of data centers and PtX, and also for electrifying the industrial sector to the degree portrayed in the analysis. The goal of this sector has therefore primarily served a purpose of portraying the potential flexible demand that electrifying the industrial sector can contribute and thereby reduce the cannibalization effect described in section 2.1.1. Furthermore, the aspect of reducing fossil-fuel usage from the research question was determined through upwards of 65.3 % of the total process heat demand being covered by MOSS and electric heating, thereby reducing natural gas usage by the same amount. This results in natural gas consumption using 2030 prices levels, being reduced from 3.7 Mio. m^3 to 1.3 Mio.m^3 resulting in natural gas payments being reduced from 8.5 Mio.DKK to 3.0 Mio.DKK.

7.3 Organizational analysis: Project management of MOSS/-Electrification of Randers Tegl

In order to answer sub-question 3 of how a project management strategy can ensure that the optimal techno-economic scenario can be implemented, the theoretical perspectives outlined in section 6.2 will be applied. Based on analysis part 1, the optimal scenario includes both electric heating and MOSS, which changes the organizational aspects to consider given e.g. solely electric heating was the best techno-economic scenario. As highlighted, there are two dimensions of an organization to consider; the structural and contextual dimension. Within the contextual dimension illustrated on figure 6.1 are the four aspects within the scope of this project; *Goals and strategy*, *Technology*, *Size* and *Environment*. The goals and strategy of Randers Tegl was described in the case description in section 7.1, where a key aspect to consider for the project management strategy, is the cost-effectiveness of the proposed technical scenario. Technology was analyzed through the current energy system in the reference scenario in addition to the proposed new system with the electric heater and MOSS, the technology aspect was further contextualized through the excursion to Randers Tegl, where the necessary production changes to be able to implement MOSS and electric heating were uncovered. The secondary oven currently not in use can be modernized while production continues in oven 1. The size of the organization, was as described in section 6.2, analyzed through the size of the production in terms of process heat demands and natural gas usage. These three first aspects of the contextual dimension, which have been covered in the case description and analysis part 1, can be summarized in terms of their effect on the project management roadmap as following:

- Goals and strategy: Ensure a match between Randers Tegl's goals determined in section 7.1, specifically cost-effectiveness and the proposed scenario
- Technology: Ensure that a transition from the existing system can be done without impacting production flow while constructing in addition to mapping relevant stakeholders for successful implementation of the new system
- Size: Ensure the proposed scenario can cover process heat demands

The last aspect to be covered is the environment, which as described in section 6.2 includes both internal and external stakeholders and their potential influence and role in the project management process. Furthermore, in order to conduct the stakeholder analysis, an analysis of Randers Tegl's structural dimension will be conducted, which includes the following aspects:

- Hierarchy of Authority
- Centralization

- Professionalism

These structural dimension aspects will determine relevant stakeholders to include in the stakeholder analysis and after the influence and role of the mapped stakeholders have been analyzed through the stakeholder analysis, the current project management approach of Randers Tegl will be analyzed using the interview conducted and Flyvbjergs recommendations and fallacies to avoid will lay the foundation behind project management recommendations that will be included in the roadmap. Lastly, the general purposes for organizations, which were highlighted in section 6.2 will be evaluated through the proposed road-map for optimal project management, to ensure the core objectives of Randers Tegl are upheld through planning.

7.3.1 The structural dimension of Randers Tegl

As mentioned in section 6.2, analyzing and understanding the structural dimension of an organization is a necessary aspect of project management and determining relevant stakeholders. In the context of implementing MOSS and electric heating, the three aspects; Hierarchy of authority, centralization and professionalism will be analyzed.

Hierarchy of authority and centralization

Throughout the project period, the project group has been in contact with Jonas Bønsø who has the role of project manager within Randers Tegl. In the interview conducted with Bønsø, the hierarchy of Randers Tegl was determined and can be seen on figure 7.9.

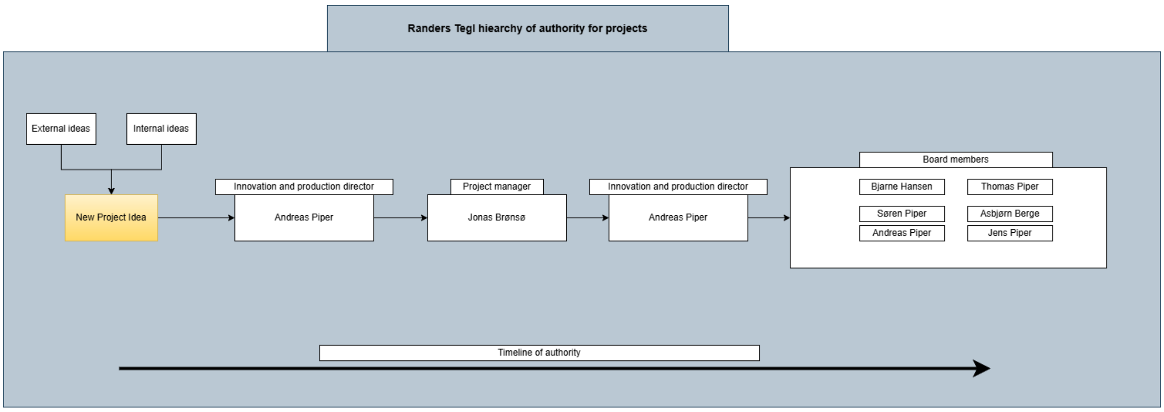

Figure 7.9: Hiearchy of authority made by the project group based on interview with Jonas Bønsø

As highlighted on figure 7.9, the project manager reports to the innovation and production director and in the scenario where a new project idea shows potential it will go to the board members. In terms of centralization, the board members have the power to decide whether or not a project should move into the implementation phase. Bønsø gave an example of the renewable energy project that is currently in the implementation phase:

The RE-project has uncharacteristically been driven top-down, it is the owners project and has been seen through an economic perspective and not a teglværk perspective. The way in which it *is uncharacteristic, is that it's one of the only projects that has been run top-down*

The RE-project started with an idea from the owners, but generally this top-down approach is not the standard. In terms of new project ideas, it is first taken to the innovation and production director who has responsibility for the green transition of Randers Tegl and the decision in then made to involve the project manager. Bønsø states:

My boss, one of the owners, the innovation and production director, he has the responsibility for the green transition and innovation and production projects, it would typically run through him, whether or not it someone who gets a good idea or it is me and then I will as the project manager do the initial process and screen the project... If there is a business case, then our innovation and production director will take it to the board

Ultimately, the aspect of centralization can be divided into multiple different decision-making areas, where the project manager has the power to make decisions in relation to the initial process of investigation a new project idea and how the investigation should be conducted, the innovation and production director has the power to evaluate which project ideas should be investigated and which gets taken to the board and the board ultimately decides whether to continue into an implementation phase based on the investigation. An argument can be made, that despite Bønsø stating that a top-down process is not the norm, given Andreas Piper is both on the board, one of the owners and acts as innovation and production director, and as such acts in multiple roles, there is a degree of top-down in all aspects of project evaluations. This hierarchy as the figure 7.9 highlights, entails a necessary degree of involvement from specific internal stakeholders, where their specific role within project management will be expanded upon in the stakeholder analysis.

Professionalism

In the perspective of investigating the feasibility of investing in new technologies in the form of MOSS and electric heating, there is a degree of involvement from internal and external stakeholders in terms of performing system analysis and cost evaluations based on the required professionalism. As Bønsø states:

I met with the Danish Technology Institute who has made this new heating component, i want to be a part of it and share knowledge, but I had to leave the project due to the projected costs

As the Danish Technology Institute is the organization that can develop the required electric heating technology that can reach temperature up to 1,050°C, they as a stakeholder would be necessary to involve, both in terms of being able to conduct scenario simulations with the technical specifications of the new component and in terms of price estimates. The same applies for MOSS, where HYME currently is the only company utilizing NaOH as a storage medium and have the required knowledge that was also supplied to the project group to enable cost estimates of the proposed system, in addition to knowledge sharing of their approach to system optimization, which entails spot market analysis and the properties of each component and the storage medium. An additional factor is the relation between the new technologies and the aforementioned five steps in the production flow, where internal stakeholders with technical knowledge of these processes can supply knowledge and mitigate risks of mismatches if involved in the project management process, as Bønsø states:

We have some process operators that handles burning, that would be good to involve in considerations, we also have our factory director who has a degree in engineering, that would already just in terms of the concept would be able to consult on how it would match or provide sparring on what should be considered and have we remembered this or that

There is a distinct relationship between the required knowledge of the internal processes within Randers Tegl and the proposed new technologies, this specifically became evident through the interview with HYME where the relation between the spatial design of MOSS and the oven and driers became speculation:

I am not super well known in this process, but what you typically do in process plants is that you heat in steps

Involving both engineers from HYME and Randers Tegl would therefore enable the spatial design of the system to be performed without mismatches and specifically for MOSS an evaluation of the spatial requirements could be performed to determine the design feasibility in terms of pipe connections and heat distribution. Furthermore, involving scientific institutions e.g. the Danish Technological Institue can prove necessary in terms of the technical properties and cost estimations of the electric heaters.

7.3.2 Stakeholder analysis

This section aims to perform a stakeholder salience analysis of the actors that will need to be involved in a project management strategy based the on method described in section 5.2.3.

The included actors in this section are based on the structural dimension analysis of Randers Tegl. The goal of this section is therefore to categorize each actor as a stakeholder with a level of salience according to the *Power*, *Legitimacy* and *Urgency* described in section 5.2.3, in which a higher level of salience is allocated to a stakeholder in terms of the attributes that can be associated with them.

Production and innovation director

The production and innovation director Andreas Piper is as described in section 7.3.1 a central actor in all processes focusing on green transition, innovation and production, and through his position as not only production and innovation director but also part owner and member of the board of directors, acts as the initial decision maker on which projects will be sent the analysis phase on whether they should included in the agenda at board meetings. This level of inclusion in all parts of the process not only provides a level of power on both coercive, utilitarian and normative power, but thereby also a level of legitimacy and urgency, which contributes to Andreas Piper, the production and innovation directors, being a definitive stakeholder with a high level of salience and thereby a critical need to be included in the project management strategy.

Board of directors

The board of directors consists of six people including the CEO, Thomas Piper, the innovation and production director, Andreas Piper, who both are 2 of the owners, additionally Søren and Jens Piper, who are the 2 other owners are a part of the board of directors. Lastly, the board of directors additionally consist of Asbjørn Berge and Bjarne Hansen, who in finishes the lineup of board members. The Board of directors ultimately decides on all projects within the organization of Randers Tegl, and as such constitutes levels of utilitarian and normative power. Additionally, being the board of directors, they are granted a level of legitimacy pertaining to their status within the company. Thereby, the board of directors' decisions will be given credibility and legitimacy. Lastly urgency of a stakeholder is defined in section 5.2.3 as the stakeholder being either time sensitive or their claims to be of such urgency that they may disrupt the success of a project. Given that the board of directors is directly working for the company, and are not included in other parts of the planning process other than the final choice of which projects to implement they are not necessarily time sensitive, urgency regarding the success of the process is somewhat present but not necessarily contributed to the board of directors, but more so to individual members of the board, such as Andreas Piper. To summarize, the board of directors is given a Moderate to high level of salience in which they achieve power and legitimacy, with a low level of urgency, resulting in the board of directors being a dominant stakeholder with possibility of definitive stakeholder.

Scientific institutions

Scientific institutions in this project relates to institutions such as the Danish Technological Institute or universities among others. The reasoning for including scientific institutions is both that as described in section 7.1 and 7.3.1 that Randers Tegl has already had prior experience with collaborating with the Danish Technological Institute in investigating the electrification of parts of their process. Additionally, it is described in section 7.3.1 that scientific institutions such as the Danish Technological Institute could work multiple different roles in the project management of innovating the production of Randers Tegl, ranging from consulting to directly performing the techno-economic analyses, pertaining to their knowledge regarding solutions and components. Given that Randers Tegl does not have the means to perform all of the analyses relating to innovating the production processes it creates more urgency to involve scientific institutions. Additionally legitimacy is awarded to the scientific institutions since they are attributed a societal position that enables their concerns and conclusions to be viewed as legitimate solutions. Lastly, power is not attributed to the scientific institutions, since they do not have coercive, utilitarian or normative power, since they act as an external stakeholder with a main goal to assist Randers Tegl. As such the scientific institutions are attributed levels of legitimacy and urgency and are classified as a Dependent Stakeholder.

HYME

HYME could serve the same role as scientific institutions, however as described in section 7.3.1, their urgency is higher due to their uniqueness when it comes to the specific MOSS technology choice in utilizing NAOH as a fuel. Therefore, HYME is attributed both urgency and legitimacy. However, depending on the role that HYME takes they can also obtain certain levels of power, this happens primarily if they enter the project, and stays as the owner of the MOSS facility, and then sells the produced heat to Randers Tegl. As such, they would achieve utilitarian power through their material power over the production at Randers Tegl. Therefore HYME will be classified as a Dependent Stakeholder with the possibility of becoming a Definitive Stakeholder, if they enter the project as an owner of the MOSS facilities.

Project manager

As described in section 7.3.1 and throughout the project, Jonas Bønsø is the Project Manager at Randers Tegl. As Jonas Bønsø described his part of investigating potential projects, he said:

> *As a project manager, I initially screen incoming project proposals, and analyze what fits with our demands, and then what knowledge we have of the market, development and all those related things.*

Therefore, all projects will not only come by the production and innovation directors office, but also by Jonas Bønsø's office, thus he is attributed urgency to the innovation process. In the process of innovating the production of heat at their factories, he is also responsible for the analysis sections of investigating potential projects, and thereby closely works with Andreas Piper the production and innovation director, by working close to Andreas Piper, Jonas Bønsø achieves a small level of utilitarian and normative power. Lastly, his position as project manager at Randers Tegl automatically attributes him levels of legitimacy to his concerns and ideas. To summarize, Jønas Bønsø, project manager at Randers Tegl is given both Power, Legitimacy and Urgency, and is therefore seen as a definitive stakeholder.

Chief of Factory

During the interview with Jonas Bønsø, when talking about the different employees at the factory, he mentioned the chief of factory as an important person to include in processes dealing with changing the production at the factory:

> *Our chief of factory is an engineer, and could definitely provide great sparring and bring ideas for solutions.*

Additionally, the chief of factory works as the representative of the other workers at the factory, and therefore he will be a communication portal for a multitude of people dealing with the operational aspects of Randers Tegl, this attributes legitimacy and normative power to the chief of factory, however, he is not necessarily time sensitive nor critical for the success of innovating the production at Randers Tegl, though including him could make adapting to the new solutions for the workers easier. As such, he can possible find urgency.

To summarize, the chief of factory holds power and legitimacy, but only limited possible urgency, and is therefore a Dominant Stakeholder with a possibility of becoming a minor Definitive Stakeholder.

Factory workers

The factory workers are not necessarily the most powerful, legitimate or urgent stakeholder, however, they are still important to recognize as influential on the process and how the innovation should be implemented. The reason for this is that they are the primary users of the equipment that will be implemented, and as such holding their interests can make for an easier transition. However they lack power in all three categories, and while they are not urgent as time sensitive or critical for the innovation to be able to happen they are not urgent either. Their biggest salience comes from the legitimacy which is described through their role as primary users of the equipment, while Jonas also mentioned in section 7.3.1 that the workers that are process operators are quite valuable to include in considerations, thus also increasing their legitimacy, and as such they become a stakeholder with low salience in only legitimacy, thus becoming a Discretionary Stakeholder.

In Figure 7.10 a visualization of the salience of each of the previously covered stakeholders can be seen, the closer towards the center of the figure and the most different kinds of salience hold between power, legitimacy and urgency, means increased salience, thereby the project manager and production and innovation director holds the most salience, while the factory workers hold the least salience.

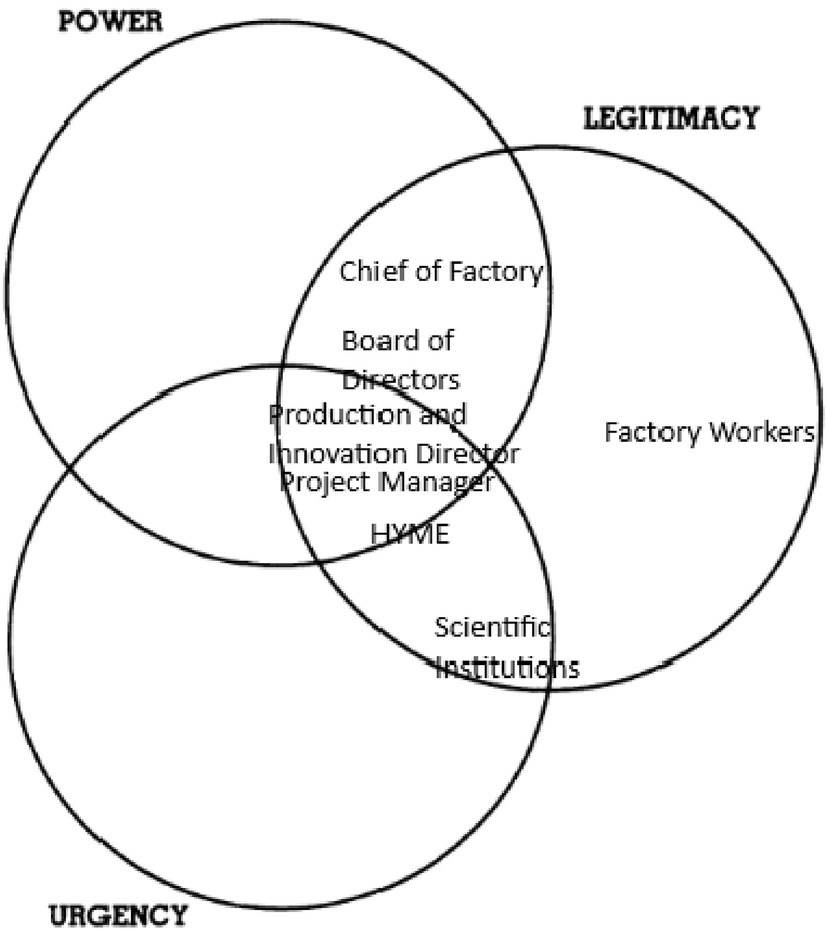

Figure 7.10: Visualization of the salience of the stakeholders.

Finally to summarize the salience of the stakeholders they can be seen listed in Table 7.18, in which they are ranked based on overall salience, and thereby, importance for the project management process for innovating the heat production at Randers Tegl:

Stakeholder Salience				
Stakeholder	**Power**	**Legitimacy**	**Urgency**	**Overall Salience**
Production and Innovation Director	High	High	High	High
Project Manager	High	High	High	High
Board of Directors	High	High	Moderate	Moderate-High
HYME	Low-Moderate	High	High	Moderate-High
Chief of Factory	Moderate	High	Low-Moderate	Moderate-High
Scientific Institutions	None-Low	High	Moderate-High	Moderate
Factory Workers	None-Low	Moderate-High	None-Low	Low-Moderate

Table 7.18: Summary of the salience of each of the stakeholders with power, legitimacy and urgency ranked.

7.3.3 Project management strategy for Randers Tegl

Based on the analysis of the structural dimension of Randers Tegl, the stakeholder analysis and the theory of *how big things get done*, recommendations for a project management strategy that can aid in the successful implementation of the optimal techno-economic scenario will be presented. Figure 7.11 illustrates the project group's process and the current step towards the project management roadmap, the figure itself serves as replicable process that can be applied to similar industries and is an expanded/reevaluated version of figure 6.2.

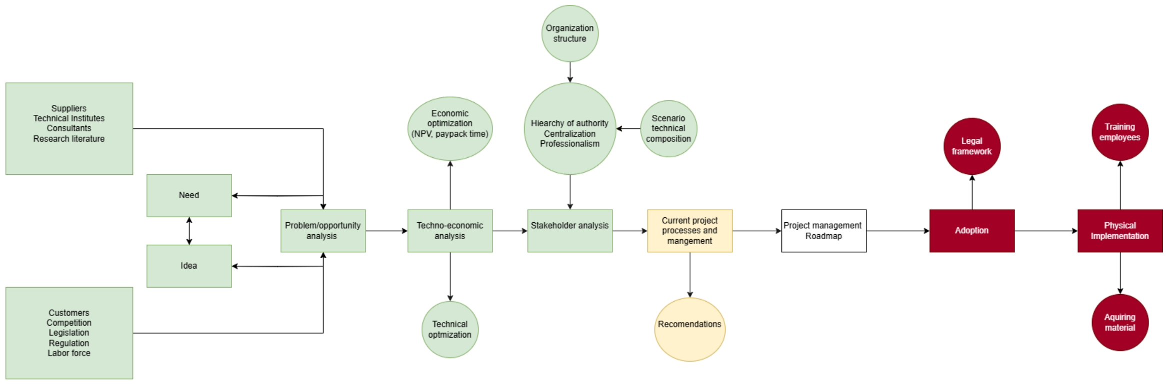

Figure 7.11: Figure inspired by [Daft, 2010, p.416] and adapted by the project group. Green implicates already completed steps and yellow is the current step

The current project management process in Randers Tegl

In order to create a project management strategy for the proposed scenario, a baseline is required of the current project management process in Randers Tegl. This baseline will then be expanded upon in the roadmap in relation to the context of proposed scenario, the mapped stakeholders in section 7.3.2 and project management perspectives from Flyvberg 6.2.

In the interview with Bønsø he described their project management process, which can be read in bilag C. An illustration of the process can be seen on figure 7.12:

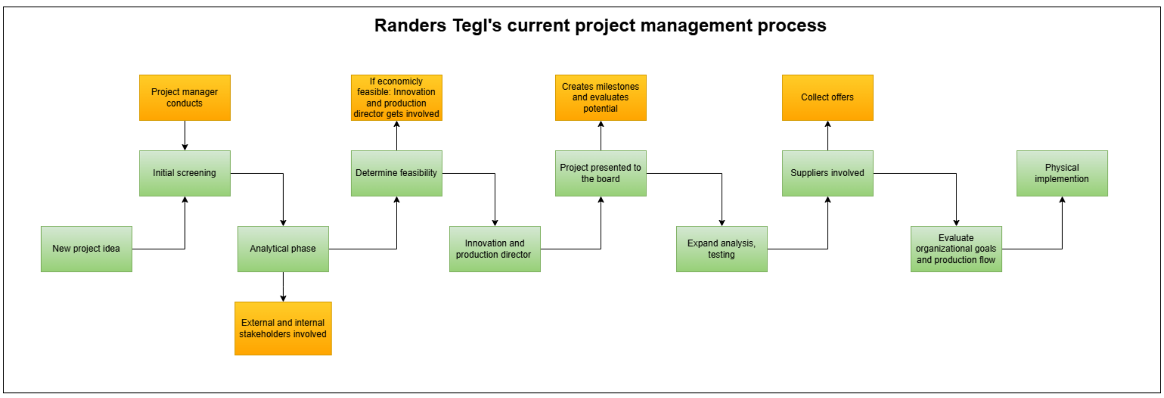

Figure 7.12: An illustration of Randers Tegl's project management process based on interview. The green boxes are each step and the orange boxes are elaborations of each step

The process on figure 7.12 is a generalized description/illustration of their current project management without context specifications. The process follows the hierarchy of authority which was illustrated on figure 7.9. The project manager is in charge of project planning and given the project has potential, it is then taken to the innovation and production director and ultimately the board. In order to contextualize the generalized approach to the proposed scenario from analysis part 1, the pitfalls and countermeasures presented by flyvbjerg will be applied with Greenlab Skives experience with company collaborations. Additionally, the internal and external stakeholder interactions mentioned by Bønsø, will be contextualized to the specific stakeholder interactions required based on the their salience level from section 7.3.2.

Potential project pitfalls and countermeasures

Randers Tegls current process as it is illustrated on figure 7.13 is a start-to-finish representation of a project. Therefore, in order to contextualize it to the context of a optimal techno-economic scenario having been calculated, the steps have been updated and how the theoretical perspective from Flyvbjerg will be applied is illustrated on figure 7.13

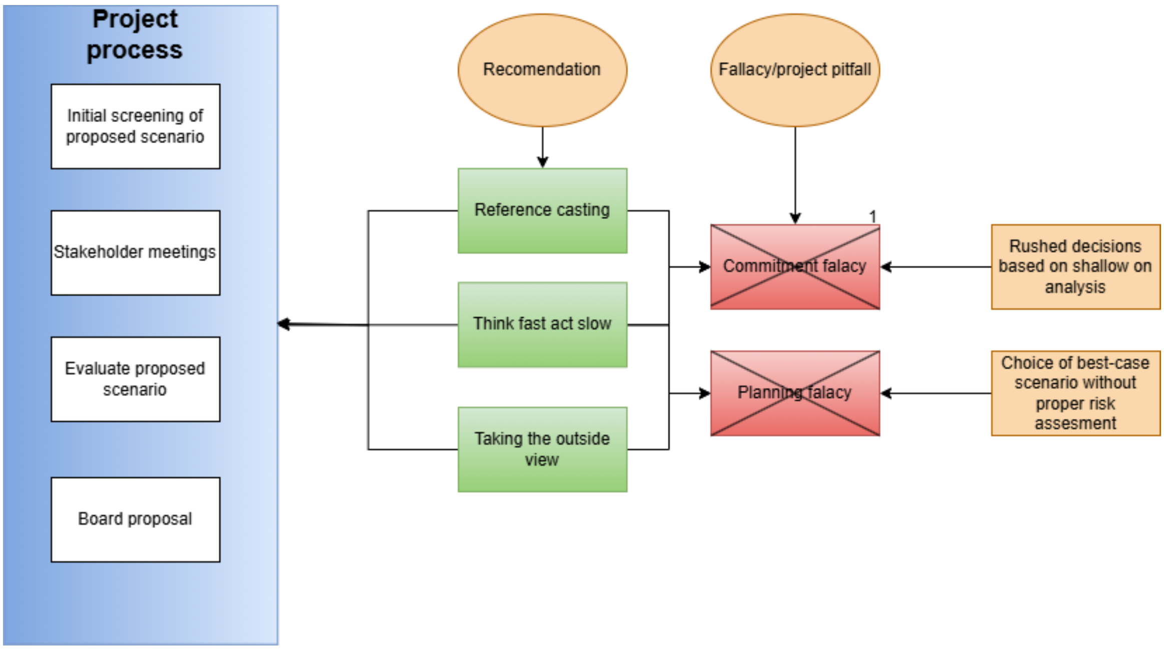

Figure 7.13: Illustration of the steps from optimal scenario to board proposal with the inclusion of how project fallacies/pitfalls can be avoided through the recommended countermeasures by Flyvbjerg

The figure highlights the steps towards a board proposal, in which the three recommended approaches to project management have been applied to counteract the potential pitfalls a project can experience given the fallacies are not thoroughly planned for. In the middle of the three recommendations, is the approach of thinking slow and acting fast, which entails having a clear purpose between stakeholders, aligning the goals between stakeholders and accessing potential difficulties and alternatives. Reference casting is one aspect of think slow act fast, where risks can be accessed through comparing to similar projects and avoiding only relying on internal projections by taking the outside view. For Randers Tegl, given both MOSS using

NaOH and the electric heater are not yet commercialized, there is associated risk in terms of the lack of being able to validate from already functioning systems with these components. A way to mitigate this risk, is for Randers Tegl to gain insights into the on-going project between ARLA and HYME in addition to visiting the test facility in Esbjerg. Furthermore, through this approach, a comparison of the techno-economic results could be made in addition to gathering insights into potential difficulties that can occur during the physical implementation period, which could compromise production flow. An additional risk mitigation option, is to modernize the second oven which is currently not in use, to avoid that going over time schedule potentially effecting production plans, which Bønsø agreed with:

It would be a good test, both ovens are practically identical, that way you at your own pace reconstruct the one that is already not in use and given the reconstruction functions, then you could do the same to the other oven

An additional aspect of the aforementioned taking the outside view is to evaluate potential risks/difficulties in relation to the alignment of the purpose and goal of the project. Flyvbjerg highlights that project efficiency is dependent on having a shared agenda. This perspective was explored through the interview with Greenlab Skive, who have an on-going project with a rock-bed storage solution. Eoghan highlighted that the goal and purpose of the project should be aligned within the stakeholders involved, in the interview he highlighted that negotiations between organizations can prove challenging, Eoghan explained finding middle ground and creating shared goals and purposes e.g both an environmental fossil-fuel reduction perspective and the economic feasibility of the project can be difficult. Eoghan stated:

Where we found our business-case, it is about 30 % of the time a cheaper solution than natural gas. This biogas facility has two owners, where one of them have need for production to be more green and the other have no issue with using natural gas

Therefore, in the context of Randers Tegl where scenarios have been analyzed with MOSS and electric heating and one with expected development towards only electric heating, evaluating these scenarios in the aforementioned context of shared goals and purposes, could change the optimal scenario based e.g on investment costs and payback time which is significantly higher when MOSS is included and vice versa, natural gas usage is higher when MOSS is not which entails higher emissions. By aligning goals, purpose and investigating alternatives and potential difficulties, both the planning and commitment fallacy can be avoided, when also coupled with reference cast forecasting of the experiences drawn from HYME and Greenlab Skive. Similarly the board might have specific milestones that could cause a reevaluation, as Bønsø mentioned in the case description 7.1. The chief of factory and factory workers, specifically process operators could also help mitigate risks, in terms of potential space limitations and production flow insights that could influence the optimal scenario in terms of volume of the storage tanks. The project manager in this case, should act as the facilitator, where purpose, goals, potentials difficulties and alternatives are accessed in stakeholder meetings after the project managers initial screening of the proposed scenario. Organizing these meetings in accordance with who should be present at specific meetings and what the output for the next step of evaluating the next scenario should be, will be proposed through meeting structures in the next paragraph.

Proposed stakeholder meetings and expected output

Based on the potential project pitfalls and the recommended countermeasures in addition to the salience mapped in the stakeholder analysis, an overview of the purpose and expected output of different stakeholder meetings were created using the method of meeting structures described in section 5.2.4.

Table 7.19 is the proposed meeting structure between HYME, DTI and the project manager, where the purpose of the meeting is to access the proposed scenario's costs and technical componements. This entails an evaluation of the development costs of the electric heater with DTI and the cost of MOSS with HYME. Furthermore, a development timeline of the proposed system can be determined and the modernization of the second oven can be debated.

Stakeholder	**HYME**	**DTI**	**The project manager**
Salience level	Two entities of high level of salience and DTI with moderate to high salience indicates a high priority of involving these stakeholders		
Purpose	Access the proposed scenario's costs and required technical components		
Who conducts	The project manager		
Output	Economic assessment, debate the modernization of the second oven, Timeline for development of MOSS and the new electric heater		

Table 7.19: Proposed meeting structure between HYME, the project manager and DTI

Table 7.20 is the proposed meeting structure between HYME, the project manager and the chief of factory. The purpose of the meeting is to determine the effect that the proposed system would have on the current production flow, both MOSS and electric heating. Furthermore, given the COF have responsibility over the factory and the workers, a shared goal in relation to ensuring the COF can maintain his obligations to the workers and production flow during construction must be obliged.

Stakeholder	**HYME**	**Project manager**	**Chief of factory (COF)**
Salience level	Two entities of high level of salience and one with moderate to high level of salience indicates a high priority of involvement, COF having a moderate level of urgency indicates a lower priority than DTI in initial meetings,		
Purpose	Determine the effect the new system have on the production of bricks and evaluate the proposed scenario in a technical implemenation perspective.		
Who conducts	The project manager		
Output	Production flow changes, technology spatial limitations, debate modernizing the second oven, align purpose and goals through shared evaluation parameters, debate alternative scenarios.		

Table 7.20: Proposed meeting structure between HYME, the projet manager and the COF

Table 7.21 is the proposed meeting structure between HYME and the project manager. The purpose of the meeting is the establish a project timeline and ensure that the goals and purposes of the project are aligned. These goals and purposes can address the aforementioned considerations made by Greenlab skive, in relation to the proposed scenarios, natural gas mitigation and estimated costs. Furthermore, through these aligned goals, the alternative scenarios can be evaluated and an assessment of the optimal scenario can be made in relation to the determined evaluation parameters. These parameters can include; NPV, paypack time, investment costs, natural gas mitigation, the *Green production* perspective highlighted by Greenlab skive. The aforementioned planning and commitment fallacy countermeasures include reference cast forecasting, where it was proposed that risk mitigation can occur through project forecasting by acquiring knowledge through similar projects; the test facility in Esbjerg and the project between ARLA and HYME.

Stakeholder	**HYME**	**Project manager**
Salience level	Two entities of high level of salience indicates a high level of priority of involvement. The meeting should therefore take place after the intial meeting where DTI are present.	
Purpose	Establish a project timeline, evaluate the goals and purpose of present stakeholders, forecast project development.	
Who conducts	The project manager	
Output	Project timeline, align purpose and goals through shared evaluation parameters, project comparison (reference cast forecasting, taking the outside view). Evaluate alternative scenarios	

Table 7.21: Meeting structure between HYME and the project manager

Table 7.22 is the proposed meeting structure between the project manager, the COF and the factory workers (process operators). The priority of this meeting is based on the salience level of the involved stakeholders lower than the previous meetings. Therefore, this meeting should take place after. The purpose of this meeting, is to share information with the factory workers of the new system and align the goals and purpose of the project is with the factory workers daily operations. Therefore, the technical aspect of system can be evaluated through the required production changes and knowledge from the process operators can determine potential risks and limitations that should be addressed in the physical design of the system. Furthermore, given the second oven is identical to current oven in operation, the modernization of the second oven can be debated with considerations from the process operators.

Stakeholder	**Project manager**	**Chief of factory (COF)**	**Factory workers (process operators)**
Salience level	One entity of high level of salience and two with generally a moderate level of salience indicates a priority of involvement after other meetings have taken place.		
Purpose	Information sharing, technical system evaluation and goal/purpose determination		
Who conducts	The project manager		
Output	Production flow changes, align purpose and goals through shared evaluation parameters, debate modernizing the second oven and technology spatial limitations.		

Table 7.22: Meeting structure between the project manager, COF and factory workers (process operators)

The contents of each stakeholder meeting can be contextualized to the aforementioned purposes of an organization from section 6.2; *Utilizing resources to achieve goals* by involving relevant stakeholders both internally and externally to achieve goals. *Producing goods efficiently* through optimizing the proposed systems to be able to cover peak demands and evaluating the proposed system through stakeholder interactions with employees to mitigate risk of disrupting production flow. *Facilitating innovation* through the development of new technologies, specifically the electric heater capable of reaching 1,050°C and a MOSS system that is yet to be commercialized. *Adapting to a changing environment* through the proposed system that can mitigate natural gas usage. *Creating value for owners, customers and employees* through respectively; optimizing the system in an techno-economic perspective, adding environmental consideration in conversations between stakeholders and the involvement of employees in stakeholder meetings, where aligning goals and purposes are a priority. Upholding these core objectives/purposes of an organization is as described in section 6.2 important in the perspective of a radical technological change which entails a change in both technology, knowledge and the organization.

7.3.4 Summary: Project management roadmap

To summarize the aspects covered in the organizational analysis, a visualization of a project management roadmap is illustrated on figure 7.14:

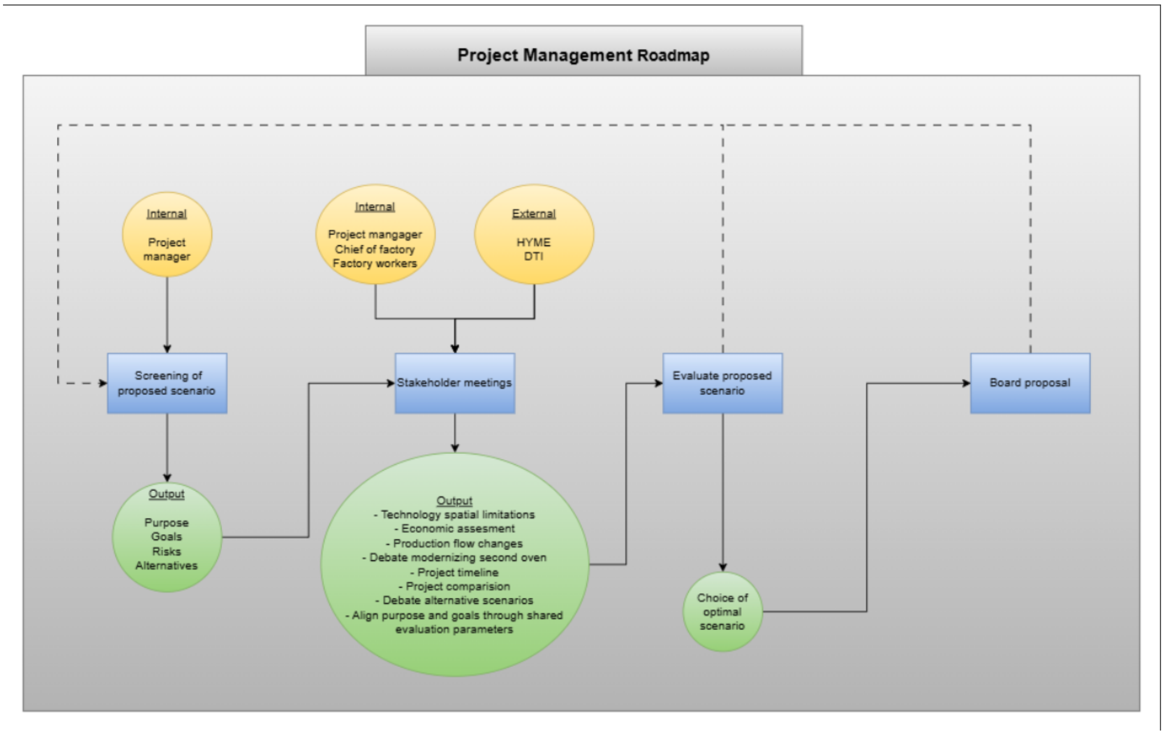

Figure 7.14: Project management roadmap

The roadmap covers from the initial screening of the proposed scenario, which is performed by the project manager, where the initial purpose, goals, risks and alternatives are evaluated so that the project manager can bring these aspects of the proposed scenario into the stakeholder meetings. Through these stakeholder meetings, additional analysis is performed of the proposed system, where the core objectives of Randers Tegl is sought to be upheld and an evaluation of the proposed scenario can be performed in relation to the specified output from the meetings. The dotted line from "evaluate proposed scenario", indicates that given these stakeholder meetings effect the optimal scenario in terms of e.g physical limitations that limits the volume of the tanks possible or an economic assessment of investment costs that lead to a different scenario being chosen, an iterative process would take place with a reevaluation, and additional stakeholder meetings of the new system configuration chosen would be performed before it is presented to the board. The dotted line from the board proposal indicates that the board can disapprove of the proposed scenario. As Brønsø highlighted, the board makes milestones and evaluates new project ideas and given there is a mismatch between the goals of the board and the proposed scenario, a reevaluation would take place in accordance with these milestones and goals set by the board. Therefore, an option would be to present scenarios including both MOSS and electric heating and a scenario containing only electric heating, in order for the board to have holistic view of their options for the electrification of their factories.

8 | Discussion

8.1 Techno-Economic analysis discussion

In this section the Techno-Economic analysis will be discussed, with a focus on the results that were found for the different scenarios as well as some of the assumptions that were made in order to model the systems in energyPRO. Afterwards the section will aim to discuss the results of the sensitivity analysis and some of the potential pitfalls that might influence the behavior of the scenarios tested and thus how plausible the results are in reality. Finally a discussion of the optimal scenario compared to the generalization of implementing in similar industries will be made in regards to the potential effects and flexible demands that can be created.

8.1.1 The static parameters of the technological optimization

For the analyses involving MOSS the heat capacity of NAOH was important to calculate the specific capacities and efficiencies of the resistance heater as well as determining the required storage volume of the two tanks in the system and required flow rates of the salt. The heat capacity of NAOH is directly proportional to the density and thereby the temperature at which it is stored in the two different tanks, and due to the temperature difference of approximately 300°C would potentially require the hot tank to be larger than the cold tank to the salt expanding under higher temperatures. it was however for ease of calculations decided that the average density of NAOH at the two temperatures was used, and as such there are some parts of the results found in the Techno-Economic analysis that could be questioned to their applicability in reality.

8.1.2 Estimated economic inputs

This section will aim to discuss the economic inputs used to calculate the NPVs of the different scenarios, with a particular focus on the costs surrounding the MOSS and electric heating solutions.

Due to MOSS using NaOH being a innovative solution that has not seen as widespread testing and implementation, some uncertainties arrive when it comes to the costs pertaining to CAPEX and OPEX. During talks with HYME, who have provided the economic data for MOSS, the group received price investment estimates which included ranges in investment costs, for the analyses in section 7.2 the investment costs used fell into the lower end of the ranges, and therefore resulted in finding the optimal scenarios that were found. Given that the costs used were closer to the higher end of the range, it would most likely affect the feasibility of MOSS, such that the MOSS scenarios NPVs would decrease and likely not be the optimal scenarios.

The electric heater used in the analyses was based on direct electrical firing from the technology catalogs from [Energistyrelsen, 2025], in which it was described that the technology was not at current time able to provide heat at temperatures above 800°C, however it is described in the technology catalog, that currently there are investigations on possible expansion to the cement industry, and as such a possible future technology application for temperatures above 800°C could be feasible. An important factor is though, that both CAPEX and OPEX of such a technology would probably increase due to a change in materials surrounding insulators and other components.

8.1.3 The sensitivity analysis

The two aspects investigated in the sensitivity analysis were the spotprices and natural gas prices, the results were therefore primarily affected by changes to the flat prices, and therefore potential changes to tariffs and biogas certificate prices were not investigated. The reasoning for this was due to difficulties in finding reliable projected prices for electricity tariffs and developments regarding the biogas certificate prices. However the prices for biogas certificates would likely increase as a way to address the increases in CO_2 taxes and as such testing the results of the sensitivity analysis with projected biogas certificate prices could impact the feasibility of the different scenarios, especially if the biogas certificate prices were to change substantially. Another important aspect of this investigation ties to what Jonas Bønsø stated in appendix C:

> *We are a quota company, vi have got some free quotas on CO_2 emissions [...] These quotas are slowly phased out, but it's still quite a large sum that makes only buying biogas certificates on 95 % of the gas still economically viable.*

which is further backed by [Klima-, Energi- & Forsyningsministeriet, 2023] in which it is stated that the free quotas are to be phased out starting in 2026. This would most likely lead to Randers Tegl converting to 100 % certified biogas, thus making them even more dependent on the development of the biogas certificate prices, and thereby further affecting the feasibility of the expected development and MOSS scenarios, through avoided costs in reduced gas consumption.

8.1.4 The optimal scenario and the generalization of the results to similar industries

In the sensitivity analysis it was found that implementing MOSS together with electric heaters to cover the heat demand of Randers Tegl that the technologies could cover upwards of 65.3 % of the total heat demand, with the electric heaters covering 15.6 % and MOSS covering 49.7 %. These potential coverages by the technologies was described as being able to create flexible demands if implemented throughout the brickworks industry of upwards of 0.2 TWh/year, whereas further generalizing the results to cover industries having heat demands at temperatures of 1050°C and below could create flexible demands of 4.3 TWh/year. These potential flexible demands however rely on all industries to have the same demand profiles as Randers Tegl, and as such, the potential flexible demands created would most likely be substantially different. While the possible flexible demand is not in the same magnitude as the present flexible demands that data centers and PtX could provide, the electrification of industries with heat demands could still prove to be an invaluable part of the transition towards mitigating the cannibalization effect from section 2.1.1. Another important aspect pertains to the fact that PtX is especially connected to the currently somewhat stagnant development of offshore wind turbines, thus establishing questions towards the projected increase in PtX capacities towards 2030 [Danish Energy Agency, 2024, p.20].

As described for the 2020 scenarios, the MOSS scenario did not, contrary to 2024 and 2030, achieve the highest NPV, due to the historical electricity and gas prices. One important aspect to consider is that the inclusion of the 50 MW photovoltaics and 18.6 MW of wind turbines overshadowed the potential benefits of the different solutions. Thus it is uncertain whether the same scenarios would be optimal if no investments were made in such capacities in renewable energy. Additionally the total amount of exported electricity resulted in all scenarios achieving large export revenues which often times almost counteracted the total operation costs. One potential problem surrounding the invested RE facilities is that the quantities of exported electricity could lead to curtailments when the flexible demand is not sufficient, which further affects the feasibility of the different scenarios.

8.2 Organizational analysis discussion

In this section, the results of the organizational analysis will be discussed, specifically the project management roadmap and the realism of a potential implementation in a techno-economic perspective.

8.2.1 The project management roadmap

The foundation behind the roadmap is the techno-economic analysis performed in analysis part one. Therefore, an argument can be made that the starting point of the roadmap is inherently without proper considerations of alternative technologies that are suitable for Randers Tegl. This perspective was discussed in conversations with HYME, where it was stated, that due to the process heat demand of Randers Tegl being significantly lower than the usual cases where HYME's system is considered, other companies such a Kyoto Group could have been better suited. Kyoto Group generally develops smaller systems than HYME, HYME's current business model entails developing systems with preferably a storage capacity of 200 MWh or more A. The argument behind choosing HYME's solution for the case, is that using NaOH as a storage medium instead of the commercialized solar salt, is an under researched technology that shows promise in terms of the cost-effectiveness of NaOH compared to other molten salts [Mahmoudinezhad et al., 2023].

In the perspective of evaluating the roadmap based on the replicability of the process, given other similar technologies were investigated, the approach to determining stakeholders and the desired output from the stakeholder meetings would remain. The argument being that the internal characteristics determined through applying the structural dimensions would be the same, but with a different technology. The involvement of internal stakeholders such as the chief of factory and process operators would still be necessary in the evaluation of the new system in relation to the current production flow and possible limitations of the physical implementation in the factory. The baseline behind the approach to determining relevant stakeholders, which included organizational theory by Daft and the salience model by Mitchell can be criticized in a theoretical perspective. Daft's organizational theory could have been substituted by Kausholt's project management theory. The argument behind this is that Daft's theoretical perspective is generally in relation to how organizations are defined and understood, where Kausholt's is specified to project management. Kausholt goes in depth with different phases of project management, which includes considerations of stakeholder analysis, risk management, schedule management and resource management [Kousholt, 2020, p.6]. The argument behind the choice of using Daft, is using the supplement of Flyvbjerg theoretical perspective of effective project management, this is due to flyvbjerg's coverage of fallacies and recommendations include the project management perspective excluded by Daft, and by using both a specific organizational and project management theory it was possible to analyze Randers Tegl in an organizational perspective and apply these considerations to the project management strategy.

An additional aspect of the roadmap is the late involvement of the board of directors and the innovation and production director. The argument behind including the board earlier in the process, is that as Brønsø stated, they have specific milestones for the organizations to uphold, which if included earlier in the process could help shape the optimal scenario both in terms of e.g. natural gas mitigation targets and costs limits. The argument for the boards current placement in the roadmap, is that through an evaluation of the outputs specified from the figure from the stakeholder meetings, both the project manager and innovation and production director have a baseline that encompasses potential differences in the board members goals and milestones which can be presented to better enable the board in their decision.

8.2.2 The realism of a potential implementation in an organizational and techno-economic perspective

The purpose of the project management strategy is to create a foundation of a planning process so that the chosen scenario can be implemented. In this perspective, based on the interview with Randers Tegl, their current strategy does not entail facilitating innovation to the degree present in this project. As was stated by Bønsø, the strategy from Randers Tegl in relation to being a part of the green transition is to follow the development of suitable technologies for their production as they get tested and proven viable. Both MOSS and the electric heater are not commercialized in terms of the temperature requirements of the production of bricks, therefore as Bønsø stated, they exited negotiations with DTI concerning the development of an electric heater that can supply temperatures up to 1.050 degrees due to costs. Therefore, an argument can be made that the optimal scenario in a techno-economic perspective is not feasible due to the investment costs far exceeding the cost of only investing in electric heating as seen in section 7.2.4. An argument can be made to start the electrification process with the driers, which has a temperature requirement of 180 degrees where electric heaters are a viable option. As of the writing of this report, electric heaters that can produce hot air up 800 degrees have been commercialized [Energistyrelsen, 2024, p.120]. Despite the investment cost of the electric heater and MOSS, the argument behind proposing these technologies to the board of directors, is due to the NPV and payback time mentioned in section 8.1 of the discussion, which indicates a feasible investment when compared to the reference scenario.

Looking at a potential implementation in terms of the physical design of the system and the current production layout of Randers Tegl with the oven and driers, it was debated with HYME whether their MOSS solution could be physically implemented. HYME's solution is currently highlighted as a storage system that produces process heat in the form of steam and not hot air, but HYME stated the following:

It would be a giant reconstruction of their oven and driers, but other than that, i do not see that it should be a big problem to implement

The option of modernizing the second oven that is currently not in use, is the argument behind such a reconstruction process would be feasible, given it would not impact the current production flow of bricks since the oven currently in use would remain functional during construction.

9 | Conclusion

This section aims to present the results from the analyses and how they relate to answering the research question and sub-questions from section 3:

How can a techno-economic optimization of a molten salt storage system be performed to reduce fossil-fuel usage and create flexible electricity demands through the electrification of the production of high temperature process heat in industries?

Sub-questions:

1. How can a technological optimization be performed and how does the limitations of the technology affect the optimization and choice of technologies?
2. How can the economic feasibility of the system be determined based on a technical optimization foundation and to what degree does economics affect the optimal scenario?
3. How can the development of a project management strategy involving relevant stakeholders aid in the evaluation/implementation of techno-economically feasible scenarios?

The first aspect of the research question is how a techno-economic optimization can be performed, so that the results are replicable to similar industries. Sub-question 1 determined that a technical optimization is required based on the thermophysical properties of the storage medium in order to determine the amount of salt that can be heated by the resistance heater and the required amount of salt to be able to produce the peak process heat demand. To determine the economic feasibility, a reference scenario was modeled, which served as the reference point for comparison to the investigative scenario. It was found that modeling solutions for Randers Tegls Hammershøj Teglværk with an expected development scenario focusing on adding electric heating to support the current natural gas direct firing, and a MOSS scenario that focused on a MOSS system that covers the heat demand at temperature of 600°C and lower, with electric heating to cover heat demands at higher than 600°C, resulted in both scenarios being feasible.

In the sensitivity analysis in section 5.3.3, it was found that through 2024 and 2030 prices MOSS was feasible at storage durations between 13 in 2024 and 19 hours in 2030. Using the projected price developments towards 2030 resulted in covering 65.3 % of the heat demand through MOSS and electric heating, thus also reducing the natural gas usage from 3.7 Mio. m^3 to 1.3 Mio. m^3. Expanding the results of covering 65.3 % of the heat demand with MOSS and electric heating to similar industries could potentially create upwards of 4.3 TWh/year of flexible demand, and as such contribute in mitigating the cannibalization effect. It was determined through the sensitivity analysis, that the average natural gas price to a higher degree affect the optimal scenario than lower average electricity prices. Furthermore, the addition of the investments in photovoltaics and wind turbines proved to affect each scenario through high electricity exports, but the introduction of electric heating and MOSS increased the utilization share of the electricity produced from 7.5 % in the reference scenario to 30.9 % in the molten salt scenario using 2030 price levels.

While the techno-economic analysis presented concrete results, it does not suffice as the sole evaluator of the optimal scenario through a radical technological perspective. Therefore, the organizational analysis in section 7.3 was performed with a theoretical focus through [Daft, 2010], [Flybjerg and Gardner, 2023] and stakeholder analysis described in section 5.2.3. By analyzing the salience of external and internal stakeholders it was possible to determine which stakeholders should be included in what part of the project management process, it was then determined that in order to avoid the two fallacies of the commitment and planning fallacies described by [Flybjerg and Gardner, 2023] that Randers Tegl with Jonas Bønsø as the main facilitator should aim to establish meetings with the different stakeholders in which the results of the meetings should include aligning the purpose and goals of the project between the stakeholders and create a framework for how to evaluate the proposed scenario on a well based reasoning.

As such an answer to the research question is that a techno-economic optimization of a MOSS-system can be made by first performing a technological optimization and using a reference scenario as the economic baseline, where the modeling of different investigative scenarios creates the foundation for a comparative analysis. However, in order to make an evaluation of an optimal scenario it is necessary to perform a sensitivity analysis to ensure that the optimal scenario is decided on a basis of possible parameter changes. Additionally there is a need to ensure a project management process that takes relevant stakeholders into account such that the project process does not fall to one of the fallacies outlined in [Flybjerg and Gardner, 2023].

In summary, it was found that implementing MOSS and electric heating in the industrial sector could lead to upwards of 4.3 TWh/year flexible demand and can contribute to a reduction in natural gas usage of up to 65.3 %. Furthermore, the flexible electricity demand when compared to the projected PtX and data center integration estimation, can contribute to mitigating the cannibalizing effect described in section 2.1.1, but to asses the specific contribution, additional analysis is required.

Bibliography

AalborgCSP (2024). High-temperature energy storage. https://www.aalborgcsp.com/eu-or-co-funded-projects/next-generation-thermal-storage. accessed: 06-03-2025.

Agency, I. E. (2024). Infographic: Six phases of variable renewables integration. https://www.iea.org/reports/integrating-solar-and-wind/infographic-six-phases-of-variable-renewables-integration. Accessed: 27-05-2025.

Andersen, A. N. and Østergaard, P. A. (2020). Support schemes adapting district energy combined heat and power for the role as a flexibility provider in renewable energy systems. *Energy*, 192:116639.

Antweiler, W. and Muesgens, F. (2021). On the long-term merit order effect of renewable energies. *Energy Economics*, 99:105275.

Behzadi, A., Holmberg, S., Duwig, C., Haghighat, F., Ooka, R., and Sadrizadeh, S. (2022). Smart design and control of thermal energy storage in low-temperature heating and high-temperature cooling systems: A comprehensive review. *Renewable and Sustainable Energy Reviews*, 166:112625.

Bryman, A. (2012a). *Social Research methods*. Number ISBN: 978-0-19-958806-3 in Paperback. Oxford university press.

Bryman, A. (2012b). *Social Research Methods*. Oxford University Press, 4th edition.

Commision, T. E. (2019). The european green deal. https://commission.europa.eu/strategy-and-policy/priorities-2019-2024/european-green-deal_en. Accessed:27-05-2025.

Commision, T. E. (2022). Final energy consumption in industry - detailed statistics. https://ec.europa.eu/eurostat/statistics-explained/index.php?title=Final_energy_consumption_in_industry_-_detailed_statistics. Accessed:27-05-2025.

Commision, T. E. (2023a). A green deal industrial plan for the net-zero age. https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX%3A52023DC0062. Accessed:27-05-2025.

Commision, T. E. (2023b). Renewable energy directive. https://energy.ec.europa.eu/topics/renewable-energy/renewable-energy-directive-targets-and-rules/renewable-energy-directive_en. Accessed:27-05-2025.

Daft, R. L. (2010). *Organisation Theory and Design*. Number ISBN: 978-0-324-59889-6 in Paperback. South-Western Cengage Learning.

Danish Energy Agency (2024). Analyseforudsætninger til energinet 2024 (af24). https://ens.dk/analyser-og-statistik/analyseforudsaetninger-til-energinet.

Detel, W. (2015). Social constructivism. https://www.sciencedirect.com/science/article/pii/B9780080970868630817. Accessed:26-03-2025.

EMD International (2025). The interface-module in energypro. https://www.emd-international.com/files/energypro/HowToGuides/The%20INTERFACE-module%20in%20energyPRO.pdf. Accessed:26-03-2025.

Energinet (2025). Production and consumption - settlement. https://www.energidataservice.dk/tso-electricity/ProductionConsumptionSettlement. Accessed:27-05-2025.

Energistyrelsen (2022a). Bilagsrapport a kortlægningsnotater. https://ens.dk/analyser-og-statistik/analyser/analyser-af-dansk-erhvervslivs-energiforhold. Accessed:09-03-2025.

Energistyrelsen (2022b). Kortlægning af energiforbrug og opgørelse af energisparepotentialer i produktionserhvervene. https://ens.dk/analyser-og-statistik/analyser/analyser-af-dansk-erhvervslivs-energiforhold. Accessed:09-03-2025.

Energistyrelsen (2024). Teknologikataloger. https://ens.dk/analyser-og-statistik/teknologikataloger. Accessed:02-01-2025.

Energistyrelsen (2025). Teknologikatalog for procesvarme. https://ens.dk/analyser-og-statistik/teknologikatalog-procesvarme. Accessed:27-05-2025.

Flybjerg, B. and Gardner, D. (2023). *How big things get done*. MACMILLAN.

Gregor, S. and Hevner, A. R. (2013). Positioning and presenting design science research for maximum i mpact. https://www.researchgate.net/publication/262350911_Positioning_and_Presenting_Design_Science_Research_for_Maximum_Impact#full-text. Accessed:25-03-2025.

Group, K. (2024a). Project background. https://www.kyotogroup.no/customers/norbispark. accessed: 06-03-2025.

Group, K. (2024b). Project background. https://www.kyotogroup.no/customers/kall-ingredients. accessed: 06-03-2025.

HYME (2024a). Hyme energy paves the way for massive co2 reductions in industry. https://www.hyme.energy/press-arla-collaboration-hyme. accessed: 06-03-2025.

HYME (2024b). The moss project (molten salts storage) brings a strong consortium of partners together to build the first hyme energy storage facility. https://www.hyme.energy/project/moss. accessed: 06-03-2025.

Johnson, S. C., Todd Davidson, F., Rhodes, J. D., Coleman, J. L., Bragg-Sitton, S. M., Dufek, E. J., and Webber, M. E. (2019). Chapter five - selecting favorable energy storage technologies for nuclear power. In Bindra, H. and Revankar, S., editors, *Storage and Hybridization of Nuclear Energy*, pages 119–175. Academic Press.

Klima, E.-o. F. (2024). Klimaprogram 2024. https://www.kefm.dk/Media/638632332369380008/Klimaprogram%202024%20-%20Digital.pdf. Accessed:27-05-2025.

Klima-, Energi- & Forsyningsministeriet (2023). Klimahandling: Danmark kommer 400.000 ton tættere på klimamål med nyt kvotehandelssystem. https://www.kefm.dk/aktuelt/nyheder/2023/nov/klimahandling-danmark-kommer-400000-ton-taettere-paa-klimamaal-med-nyt-kvotehandelssy Accessed:27-05-2025.

Klima-, Energi- og Forsyningsministeriet (2022). 22 fremstillings- og byggeanlægserhverv. https://www.kefm.dk/Media/638500588668234437/KF24%20Kapitel%2022%20Fremstillings-%20og%20bygge-anl%C3%A6gserhverv.pdf. Accessed:09-03-2025.

Klinge Jacobsen, H. and Schröder, S. T. (2012). Curtailment of renewable generation: Economic optimality and incentives. *Energy Policy*, 49:663–675. Special Section: Fuel Poverty Comes of Age: Commemorating 21 Years of Research and Policy.

Kousholt, B. (2020). *Project Management- Theory and Practice*. Praxix- Nyt Teknisk Forlag.

Kvale, S. and Brinkmann, S. (2009). *Interview- Learning the Craft of Qualitative Research Interviewing*. Sage.

Lund, H. (2024). *Renewable Energy Systems*. Academic Press, 3rd edition.

Lund, H., Sorknæs, P., Mathiesen, B. V., and Hansen, K. (2018). Beyond sensitivity analysis: A methodology to handle fuel and electricity prices when designing energy scenarios. *Energy Research & Social Science*, 39:108–116.

Lund, H., Østergaard, P. A., Connolly, D., Ridjan, I., Mathiesen, B. V., Hvelplund, F., Thellufsen, J. Z., and Sorknæs, P. (2016). Energy storage and smart energy systems. https://journals.aau.dk/index.php/sepm/article/view/1574/1314.

Lynch, M. (2016). Social constructivism in science and technology studies. https://link.springer.com/article/10.1007/s10746-016-9385-5. Accessed:26-03-2025.

López Prol, J., Steininger, K. W., and Zilberman, D. (2020). The cannibalization effect of wind and solar in the california wholesale electricity market. *Energy Economics*, 85:104552.

Mahmoudinezhad, S., Mandø, M., and Arabkoohsar, A. (2023). Design and techno-economic analysis of a molten-salt driven energy conversion system for sustainable process heat supply. *Renewable Energy*, 219:119510.

Mitchell, R. K., Agle, B. R., and Wood, D. J. (1997). Toward a theory of stakeholder identification and salience: Defining the principle of who and what really counts. *The Academy of Management Review*, 22(4):853–886. http://www.jstor.org/stable/259247.

Muhammad, Y., Saini, P., Knobloch, K., Frandsen, H. L., and Engelbrecht, K. (2023). Rock bed thermal energy storage coupled with solar thermal collectors in an industrial application: Simulation, experimental and parametric analysis. *Journal of Energy Storage*, 67:107349.

of Medicine, N. L. (2024). Sodium hydroxide. https://pubchem.ncbi.nlm.nih.gov/compound/Sodium-hydroxide. Accessed:09-03-2025.

Pantaleo, A. M., Trevisan, S., Matteucci, F., and Cabeza, L. F. (2024). Innovation trends on high-temperature thermal energy storage to defossilize energy systems. *Energy Storage*, 103:22.

Peña, J. I., Rodríguez, R., and Mayoral, S. (2022). Cannibalization, depredation, and market remuneration of power plants. *Energy Policy*, 167:113086.

Pommeret, A. and Schubert, K. (2022). Optimal energy transition with variable and intermittent renewable electricity generation. *Journal of Economic Dynamics and Control*, 134:104273.

Reichenberg, L., Ekholm, T., and Boomsma, T. (2023). Revenue and risk of variable renewable electricity investment: The cannibalization effect under high market penetration. https://www.sciencedirect.com/science/article/pii/S0360544223018133. Accessed: 05-12-2024.

Rienecker, L. and Jørgensen, P. S. (2015). *The good paper: A handbook for writing papers in higher education*. Samfundsliteratur 2015.

Salunkhe, P. B. and D., J. K. (2017). Investigations on latent heat storage materials for solar water and space heating applications. *Journal of Energy Storage*, 12:243–260.

Shimomura, M., Keeley, A. R., Matsumoto, K., Tanaka, K., and Managi, S. (2024). Beyond the merit order effect: Impact of the rapid expansion of renewable energy on electricity market price. *Renewable and Sustainable Energy Reviews*, 189:114037.

Sprogøe, J. and Brandi, U. (2019). *Det Magiske Øjeblik*. Number ISBN: 978-87-412-6867-5 in Paperback. Hans Reitzels Forlag.

Steinmann, W.-D. (2022). *Thermal Energy Storage for Medium and High Temperatures*. Springer.

The Danish Government (2022). Klimaaftale om grøn strøm og varme 2022. https://www.regeringen.dk/media/11470/klimaaftale-om-groen-stroem-og-varme.pdf.

Østergaard, P. A., Andersen, A. N., and Sorknæs, P. (2022). The business-economic energy system modelling tool energypro. *Energy*, 257:124792.

A | Interview with HYME

Frederik Botin Carøe Villum 0:05
Jamen, Vi er jo egentlig bare lige nogle korte få spørgsmål her. Holdningsbaserede spørgsmål, og jeg tænkte bare, at vi kunne starte med måske at snakke lidt om tegnproduktionen som helhed fordi.

Ja.

Gro Kallehave Hansson 0:06
Ja.

Frederik Botin Carøe Villum 0:27
Det er jo ikke mejeri, og Det er nogle andre temperaturkrav. Jeg tror vi så ovnen havde 1050 grader som den maks temperatur den var oppe på og tørrerierne de ligger så på omkring 180 grader og bruger også direkte fyring på nuværende tidspunkt med naturgas og så har de en formningsprocess af ler som kommer før, som vi ikke har forbruget på endnu, men der bruger de så til gengæld damp, så der er noget der så det system vi vil design hvis det skulle være der vil jo så ville det også være en steam generator til formningsprocessen så der kan de bruge dampen direkte fra, men ellers så skulle vi jo over i og snakke med vejledere om at det ikke er damp der skal ind i ovnen, men så vil det være en form for varmluft, men jeg kommer lige lidt foran, men tegnproduktionen kunne du sætte nogle kommentarer på om det er noget, eller hvorfor i har valgt det fra eller det med temperatur behovene og så videre.

Gro Kallehave Hansson 1:25
Jeg er ikke bekendt med, at vi har kigget på teglproduktion. Det er dermed ikke sagt, at vi ikke har kigget på det, men at vi på en eller anden måde har udelukket det. Mit umiddelbare bud ville være, at netop fordi at vi ved at vi ikke kan komme højere eller. Med saltet kan vi i princippet komme på 1300, 1400, 1500 grader før det fordamper. Så i princippet kunne vi godt. Når vi kigger på elektricitetsproduktion, som er der hvor vi startede, så er dampen til dampturbine til elektricitetsforbrug meget ofte 450-650 grader som regel ikke over. Det vi også har konstateret, er at langt de fleste metaller, holder op med at have ret meget styrke over 650 grader. Nogle få af dem op til 700. Men selve det at opbevares smeltet salt, bygge smeltet salt bliver et helt andet koncept, hvis vi skal over 600 grader, så vi ikke i metal tanke og metal varmeveksler og metalrør, det er det ikke.

Frederik Botin Carøe Villum 2:46
Nej.

Gro Kallehave Hansson 2:49
Ikke så længe vi har et flydende medie som salt. Jeg tror nok at man med luft kan man gøre andre ting. Også fordi at med luft der kan man bruge det der hedder udmuring som basically er mursten man putter på som isolering på indersiden, så sætter man luft igennem, og så er der en metalkant som er de der 400 grader varme.

Sebastian Bach Johannessen 3:09
Altså så man bruger keramisk i stedet for.

Frederik Botin Carøe Villum 3:09
Ja.

Gro Kallehave Hansson 3:11
Ja.

Sebastian Bach Johannessen 3:12
OK.

Gro Kallehave Hansson 3:14
Og keramik kan som regel ikke holde til flydende ting, kan ikke holde til væsker. Det kan holde til luft og til gas og alt afhængig af hvordan man gør og hvad det er for noget og så videre, så bruger man forskellige keramiker og hvad for nogle gas det er og så videre. Men de 2 ting passer sammen og væsker passer bare meget, meget dårligt til keramik. Som regel, så vi er ude i et eller andet der skal glaseres, og så ved jeg ikke lige. Det vidst en teknologi der ikke er så gennemprøvet endnu, tror jeg vi må sige.

Frederik Botin Carøe Villum 3:43
Ja.

Gro Kallehave Hansson 3:45
Det er muligt den findes. Det skal jeg ikke kunne sige, men vi er ikke lige stødt på den.

Frederik Botin Carøe Villum 3:45
Yes.

Gro Kallehave Hansson 3:50
Så jeg ville tro, at vi simpelthen har sagt, nå men altså med det koncept vi kører med lige nu, er det svært for os at komme over 600 grader.

Frederik Botin Carøe Villum 3:51
OK.

Gro Kallehave Hansson 4:04
En anden tanke jeg stod og fik var at der var ikke nogen grund til umiddelbart at køre over damp for at varme teglproduktionen op.

Sebastian Bach Johannessen 4:15
Nej.

Gro Kallehave Hansson 4:16 Der kunne man muligvis bare lave en saltsnorkel eller et rør med salt i også køre det direkte rundt.

Sebastian Bach Johannessen 4:27
Jamen det er også. Det er også det vi snakker lidt om, at det scenarie hvor vi kigger på hvor MOSS er inkluderet i, altså i stedet for at have en steam generator på, så er det en form for varmeveksling man kører. Så du genererer bare tør luft i stedet for.

Gro Kallehave Hansson 4:38
Ja.

Sebastian Bach Johannessen 4:41
Ja.

Frederik Botin Carøe Villum 4:42
Ja.

Gro Kallehave Hansson 4:42
Salt til tør luft. Det ville jeg også synes gav mere mening end at køre den over damp også damp til luft.

Frederik Botin Carøe Villum 4:49
Ja.

Gro Kallehave Hansson 4:50
Som udgangspunkt i hvert fald. Og så tænkte jeg, at når der er noget damp involveret til den der formningsproces. Så er det vigtigt at afklare, om det er noget der bliver forbrugt, eller om det er et lukket loop. Det ved jeg ikke, om I har tænkt over men normalt når vi kigger på et damp genererings system så viser det sig, at det næsten altid er i et lukket loop. Sådan så der er vand der bliver varmet op. Det vand det afgiver så sin varme et andet sted i processen, men kommer ikke i kontakt med processen og bliver så kondenseret sådan så det kan blive varmet op igen.

Sebastian Bach Johannessen 5:40
Ja. Men det giver også god mening, fordi at... Vi skal ud og besøge dem i morgen, så der får vi jo svar på det og det giver selvfølgelig god mening, hvis de bruger det damp i processen, at så er det jo noget helt andet vi skal finde hvor man tilføjer vand.

Gro Kallehave Hansson 5:54
Ja nemlig og det vi normalt kigger på det er lidt ligesom det varmesystem man har i sit hus, hvor man ender med at have dødt vand som man bare skal supplere en lille smule ikke.

Sebastian Bach Johannessen 6:10
Ja.

Frederik Botin Carøe Villum 6:11
Ja.

Gro Kallehave Hansson 6:12

Men hvis de rent faktisk forbruger damp, og det kunne jeg godt forestille mig når man har ler, at det er sådan noget fugtigt noget der skal holdes fugtigt og sådan nogle ting, at der er noget vand der bliver tilsat agtigt, så er det en helt anden ting.

Frederik Botin Carøe Villum 6:24
OK.

Gro Kallehave Hansson 6:26
Så men, men altså baseret på at det ved jeg ikke noget om, bare være opmærksom på det.

Frederik Botin Carøe Villum 6:33
Ja, og det får vi også lige skrevet ned, fordi så vi kan lige tage nogle af de her ting, altså overvejelser, vi hører dem om hvordan deres system fungerer og de her ting vi ikke er helt afklaret med endnu.

Gro Kallehave Hansson 6:42
Ja.

Frederik Botin Carøe Villum 6:43
Ja, ja det er super.

Gro Kallehave Hansson 6:45
Og den der booster teknologi. Den ved jeg simpelthen intet om. Så det lyder super spændende. Det er så noget andet. Jeg kunne forestille mig at sådan nogle trin var en rigtig god måde at komme videre på i hvert fald. Med elektrificering. Om det er for dyrt eller ej det er det i skal finde ud af.

Frederik Botin Carøe Villum 7:01
Okay.

Sebastian Bach Johannessen 7:05
Der har vi også en overvejelse at det så skulle være noget i at, at vi når vi så altså sammenligner NPV'erne så kan man jo komme med et komme med et forslag altså hvor det ligger henne i, hvor meget må det maksimalt koste, hvis der er nogen der vil prøve at udvikle det?

Gro Kallehave Hansson 7:24
Ja.

Frederik Botin Carøe Villum 7:24
Ja, men hele den der grundtanke i at vi har en ovn hvor vi bruger MOSS til at varme den op til de 600 grader og så tager en elektrisk booster til 1050 grader. Det er ikke noget du ser som værende urealistisk, hvis man har sådan et system

Gro Kallehave Hansson 7:43
Nej, ikke, ikke som udgangspunkt. Det man måske skal være opmærksom på, er en af grundene til, at man er rigtig glad for vand som varme overføringsmedie er jo, at det er bare leder varme godt. Det gør luft ikke.

Sebastian Bach Johannessen 8:04
Ja.

Gro Kallehave Hansson 8:05
Så man skal have større volumener af alting.

Frederik Botin Carøe Villum 8:12
OK.

Gro Kallehave Hansson 8:13
Det har jeg heller aldrig regnet på, så det har jeg ikke nogen fornemmelse af hvor meget i skal regne på. Men der er en forskel i varme overgangstallet fra salt til luft i forhold til fra salt til vand.

Frederik Botin Carøe Villum 8:25
Okay.

Gro Kallehave Hansson 8:27
Det tænker jeg at i kan finde en måde at holde styr på.

Frederik Botin Carøe Villum 8:30
Ja det giver god mening. Det giver god mening.

Gro Kallehave Hansson 8:33
Ja så man kan ikke sammenligne en liter vand og en liter luft og hvor meget energi det tager, eller det kan man måske godt, men man skal lige have fat i, hvor meget man kan få det til at lede.

Frederik Botin Carøe Villum 8:48
Ja okay så er der jo også, fordi at det det er jo egentlig godt, ja vi kan lige prøve at undersøge hvordan og hvorledes med de aspekter der, men for lige at skifte lidt retning det er fordi det er vi også nogle gange har snakket om det det med når der er VE-anlæg til stede så det det er helt retningsskift der, men fordi Randers tegl de har faktisk valgt at investere i både vindmølleanlæg og solcelleanlæg, hvor at vi så også er modelleret dem ind, så vi kan få undersøge effekten af ja behind the meter. Opladning af tankene. Jeg prøver at komme over i et når man har de her systemer Randers tegl har med et forbrug på et peak demand på 4,8 MW. Vi har de her store solceller og VE anlæg, og vi regner frem til en kapacitet på MOSS på omkring 100 megawatt timer eller lignende. Det vi startede med at snakke om med i vil jo gerne op på de 200 megawatt timer eller over, når du hører sådan et system her er det noget, man vil overveje at gå ind i, når det godt nok er lidt lavere kapaciteter, af de økonomiske overvejelser der er i at det ikke er dyrere at opskalere det. Eller jeg ved ikke om der er nogle overvejelser der, eller om det vil være fint nok at prøve at lave sådan et system her. Størrelsesmæssigt.

Gro Kallehave Hansson 10:12
Altså en af grundene til at vi snakker om de store kapaciteter er fordi at vi har nogle konkurrenter som laver de små kapaciteter. Det ville måske ikke være HYME teknologi, men nogle af de andre som laver noget der ligner, enten med smeltet salt eller nogle af de andre varme teknologier.

Fordi de har optimeret for en anden markedsstørrelse og et andet layout og nogle andre ideer, så som udgangspunkt tænker jeg ikke det er fuldstændig dumt og urealistisk altså. Med den forudsætning, at man ikke synes at grøn omstilling og grøn energi i det hele taget er dumt og urealistisk og for dyrt, fordi det er dyrere end den eksisterende teknologi. Og der er en Green premium. Det tror jeg ikke, vi kommer udenom.

Frederik Botin Carøe Villum 11:03
Ja.

Gro Kallehave Hansson 11:12
Men hvad de har råd til at betale og det er jo svært at vide, så som udgangspunkt, så tænker jeg at et udmærket skridt på vejen i hvert fald kunne være; jamen så lad os tage noget af det. Det kunne også være at man kunne tage noget af det som elektrisk med salt og så tage resten med naturgas, så man i hvert fald fik sat naturgasforbruget ned.

Frederik Botin Carøe Villum 11:40
Lige præcis.

Gro Kallehave Hansson 11:40
Hvis der nu ikke lige er en elektrisk varmeveksler eller en elektrisk heater der kan klare 1000 grader eller det kan de formentlig godt, så længe det er luft de skal varme og så videre.

Frederik Botin Carøe Villum 11:48
Ja OK. Vil du ikke lige prøve at vise en modellen her fordi så kan vi lige det. Der er lige et enkelt teknisk spørgsmål mere nemlig, og det er nemmere bare lige at forklare ud fra modellen.

Sebastian Bach Johannessen 12:00
Hvad for et af dem?

Frederik Botin Carøe Villum 12:07
Det hvor du har fået hot tanken med. Hvis du har, kan man kan du zoome lidt ind her måske jeg ved ikke om det er et lille ved mig.

Sebastian Bach Johannessen 12:11
Det kan den i hvert fald.

Frederik Botin Carøe Villum 12:17
OK. Det er vores initierende modellering vi har her hvor vi har solcelleanlægget og vindmøllerne nede i bunden af venstre hjørne. Du kan se, og så har vi selvfølgelig de forskellige varmeforbrug, som er de røde, hvor vi har ovnen og de 2 tørrerier, så har vi de eksisterende naturgaskedler og naturgasforbruget til direkte fyring, der på nuværende tidspunkt går ind i systemet, og så har vi den kolde tank, resistance heater, den varme tank og så den heat exchanger varmepumpe. Den der skal booste det til de 1050 grader og er det der egentlig mangler her i det her system. Men så spørgsmålet går på, hvis når man rent rørlægningsmæssigt fra den varme tank ud i lad os sige det går ud i forbi en heat exchanger og det går ud forbi en steam generator til formningen af leren, og så går det lige ud forbi en ekstra heat exchanger der er koblet på tørreriet. Hvis man simpelthen skal have en der går ud til ovnen, en der går ud til tørrerierne, og en der går ind i en

steam generator ud til, hvad hedder det, formningsprocesserne, så har vi jo lige pludselig, jeg ved ikke så meget om det, men det lyder som mange rør der skal fra den varme tank og cirkulere salt rundt til de forskellige og hvis nu man på et tidspunkt kunne lige vil have til ovnen, man ikke i gang med at forme noget ler, man er ikke i gang med at tørre noget, så skal vi jo kun har det ene rør til cirkulære noget salt, hvor der salten ikke kommer ud til de andre og så videre. Så mit spørgsmålet er egentlig ud fra de her tanker er, vil der være nogle praktiske udfordringer eller system design mæssigt i forhold til rørlægning og salt flow og så videre, når man skal have det forbi så mange komponenter, eller hvad der lyder som om at være mange komponenter i forhold til bare én steam generator?

Gro Kallehave Hansson 14:13
Nu begynder vi at spekulere på ting, jeg ikke nødvendigvis ved så forfærdelig meget om, eller i denne her proces er jeg jo ikke super velkendt eller hjemme kendt, men det er man meget typisk gør i procesanlæg, det er at man varmer op i trin. Også når det bare er vand man gerne vil koge, og jeg mener at have nogle tommelfingerregler som siger noget i retningen af; I en metalvarmeveksler og dermed sagt.. hvordan forklarer man det her? Jo hvis vi har væske på begge sider af varmeveksler og den er et eller andet antal meter lang, så er der en varmeudvidelse i den varmeveksler. Men der er jo også en varmeudvidelse i de rør, der så er i varmeveksleren, hvis de 2 ting er for forskellig så kan metallet ikke lide det. Så derfor er der et eller andet temperatur spænd, som jeg ikke rigtig kan huske, men Jeg tror den ligger på nogle 100 grader. Så hvis man vil varme noget op, og så er der simpelthen en fysisk størrelse af heat exchanger. Den kan ikke være uendelig stor. Det plejer at være sådan. Ja, hvad er det egentlig det er. Det er jo også trykke afhængig. Ja et par meter i diameter plejer at være et meget godt bud på noget man skal holde sig omkring eller indenfor det. Det kan godt være større, det begynder bare at blive mere besværligt. Det kan også godt være lang og så videre, men sådan noget i den stil så under alle omstændigheder, når man skal varme vand, så plejer jeg det nemmeste at være og lave en preheater eller en economizer kan man også kalde dem. Det kan i også hvis man kigger på elektricitets dampgenerator eller dampturbiner, så kan man se, at det vandflow der er meget ofte har en economizer eller preheater, hvor man varmer vandet op fra hvad det nu er for en temperatur det har til kogepunkt. Og så har man en separat varme veksler, som rent faktisk koger vandet, altså hvor faseovergang sker. Og så har man en hvor man superheater dampen. Fordi de 3 processer er så forskellig, er de er meget svære at styre. Det ville sige, at man formentlig godt kunne gøre noget der lignende så man koblede preheateren på jeres proces heat demand og boileren eller superheateren på heat demand til ovnen og 650 grader varmt damp. Det ville det jo ikke være det ville være luft, men hvis vi nu siger det var damp fordi det er lige der jeg tænker. Så ville man have dampen der, og så ville man sende den over i ovnen når den var super heatet, men det issue man så kunne have er at man formentlig ville, hvis man kun kører den ene af varmevekslerne, hvis man kun kører den der skal lave proces heat så ville man ikke få kølet sin salt så meget som man ville gøre, hvis man brugte alt varmen. Så jeg ville tro at der kunne være design issues, men når jeg tænker over det så tænker jeg også at det må være noget man må kunne designe sig ud af. Altså en varmeveksler der skal kunne. Hvad hedder det egentlig ramp? Altså den skal den skal kunne have en kapacitet fra et eller andet 20 % til 120 %.

Frederik Botin Carøe Villum 18:35
Ja.

Gro Kallehave Hansson 18:36
Og så den mindre effektiv når den skal køre 20 % men hvis man designer den ordentligt, så tror jeg egentlig godt man kan.

Frederik Botin Carøe Villum 18:37
Okay.

Sebastian Bach Johannessen 18:42
OK.

Gro Kallehave Hansson 18:44
Så jeg tror måske, at hvis man fører den over i at det ikke er damp men luft, så vil man med fordel kunne kigge på, altså der er så forskellen at med luften ville man, jeg sidder og digter så tag det med et gran salt ikke, men med luften ville man jo ikke have en fase overgang, men man ville stadigvæk måske også af praktiske hensyn, kunne lave en damp varmeveksler til ovnen eller til process heat og en luftvarme veksler luft til salt varmeveksler til ovnen.

Frederik Botin Carøe Villum 19:29
Ja.

Gro Kallehave Hansson 19:30
Og så sidder jeg og tænker videre at den ovn de har kunne jeg forestille mig at fungerede som en det der hedder en fired heater eller man kunne forestille sig noget der lignede en fired heater, hvor at man i gåseøjne har en skorsten. I olieindustrien hvis man har fired heater, så har man mere eller mindre end skorsten, hvor man så har olie rørende løbende indeni også har man en brænder nede i bunden, så der er naturgas brænder ned i bunden som varmer luft op og den luft overfører så varmen til rørene i olie processen og der sidder jeg og tænker at det burde man måske bare kunne gøre uden at man havde varmekilden nede i bunden, men man har saltet der løber inde i noget der ligner.

Frederik Botin Carøe Villum 20:20
Åh ja.

Gro Kallehave Hansson 20:21
Varmer luften, sender den varme luft direkte ind i ovnen.

Frederik Botin Carøe Villum 20:27
Ja.

Gro Kallehave Hansson 20:28
Så rent fysisk tror jeg ville kigge på en det en fired heater layout.

Frederik Botin Carøe Villum 20:36
Ja.

Gro Kallehave Hansson 20:36

Noget der lignede det, så det kan jeg egentlig. Så det vil jo være en kæmpe ombygning af deres ovn og tørring formentlig, men bortset fra det.

Frederik Botin Carøe Villum 20:45
Hvis vi glemmer det, så ikke helt umuligt.

Gro Kallehave Hansson 20:52
Hvis vi glemmer det, så kan jeg egentlig ikke se, at det skulle være det store problem. Anden end jeg ikke ved så meget om hvor mange... Jeg ville som udgangspunkt tro, at man skulle bruge mere salt, fordi det er sværere at overføre varme til luft.

Sebastian Bach Johannessen 21:13
OK.

Gro Kallehave Hansson 21:14
Men ellers også har man et lavere luftflow og det er så der, at jeg ikke er procesingeniør nok til lige at kunne forholde mig til størrelser og sådan nogle ting.

Frederik Botin Carøe Villum 21:14
Vi også skrevet det med salt til luft ned fordi det virker ret vigtigt. Det er også noget vi lige vil få undersøgt, så det det var godt lige at få med.

Gro Kallehave Hansson 21:30

Ja, jeg tror det er sådan noget man kan finde i litteraturen.

Frederik Botin Carøe Villum 21:38
Ja ja.

Sebastian Bach Johannessen 21:38
Ja.

Gro Kallehave Hansson 21:39
Ellers så sig lige til, så har vi måske fundet et eller andet, men det er ikke noget vi har kigget ekstensivt på. Lad os sige det på den måde.

Frederik Botin Carøe Villum 21:45
Det skal vi nok lige prøve at undersøge, eller en hurtig mail hvis det er, vi ser om vi ikke kan vi ikke kan finde det, men Jeg tror faktisk det var det. Det var vel sådan lidt tekniske systemmæssigt tanker vi også havde gjort os, som vi lige ville høre om og få nogle overordnede tanker omkring og så køre videre med det og snakke med Jonas ude på Randers Tejl om de her aspekter, og så er der vel egentlig tilbage det vi skrev i vores mail omkring, det er beregningseksempeler på omkostninger og vi snakkede om det med minimum operation period, så det er egentlig bare det vj mente med det, vi havde den der samtale i sidste projekt jeg skrev om det med at når vi tænder for steam generator og vi tænder for resistance heater, at vi ikke helts bare skal starte og stoppe dem hele tiden, så metallet ikke går i stykker og vi snakkede om der var et spænd på om de kørte 3 timer kørte eller i 6 timer og det var lidt utroligt på det

tidspunkt. Jeg ved ikke på baggrund af NDA om vi om Vi har lov til at få og vi kan sætte en værdi ind på sådan et cirka operation period man skal køre dem i

Gro Kallehave Hansson 22:51
Mon ikke det er okay, i øjeblikket der.. Altså, det er jo altid en costbenefit analyse og jo oftere man tænder og slukker jo kortere tid holder udstyret og vi har kigget et par steder og snakket lidt frem og tilbage og er nået frem til i øjeblikket, der tror vi at det er 2 timers spænd er et meget godt bud på hvornår at det koster for meget på udstyret og på opstartstid og hver gang man slukker noget, så får man også problemer når man skal tænde det igen og så videre.

Frederik Botin Carøe Villum 23:32
Sådan der omkring 2 timer, så kan vi bare sætte det til 2 timer det den mindst køre i 2 timer før at de går ind og slukker den igen. Det giver lidt mere realistisk bud på hvordan det ville operere.

Gro Kallehave Hansson 23:32
Ja, det ikke minutter i hvert fald, men kan sikkert også godt sætte den ned på 1 time og den behøver ikke være 24 timer.

Frederik Botin Carøe Villum 23:47
Nej nej. OK.

Sebastian Bach Johannessen 23:55
Der har jeg et hurtigt spørgsmål også, nu siger vi så minimum operation time ligger på omkring 2 timer så. Hvad så med start op, altså starte op og shutdown perioder altså. Hvor fleksibel er den, kan den skal den bruge en x mængde tid til at starte op også.

Gro Kallehave Hansson 24:17
Ja og nej. Dejligt svar ikke. Nej det man kan sige er at, hvis vi holder os til salg til damp, fordi det er det system jeg kender, så må i selv overveje hvordan det virker for luft, men med salt til damp der skal den bruge relativt lang tid på at varme op til metallet er varmt, altså fra vi starter ved stuetemperatur til metallet er varmt også skal man jo også have saltet smeltet. Og det tager lang tid. Det tager så altså og jeg var ved at sige uger. Det må i ikke hænge mig op på, fordi det tal har jeg slet ikke styr på. Men det heller ikke minutter og det er formentlig nærmere dage end det er timer.

Frederik Botin Carøe Villum 25:06
OK.

Gro Kallehave Hansson 25:06
Også ved jeg fra anden industri at man tit siger at sådan noget metal det må varmes op med 5 grader per time, også er der et eller andet med per kilo eller noget i den stil.

Frederik Botin Carøe Villum 25:24
Okay.

Gro Kallehave Hansson 25:26
Men altså hvis man tager 5 grader per time. Også er der en eller anden opvarmnings rate per

kilo også fordi man kan jo ikke bare.. Men så skal vi op på 400 grader, ikke? Det tager noget tid, hvis det skal være ved 5 grader i timen, og det er simpelthen det med metallet kan tåle for ikke at slå sig.

Frederik Botin Carøe Villum 25:40
Ja.

Gro Kallehave Hansson 25:47
Så derfor gør man det at man holder anlægget varmt med det der hedder heat tracing. Vi bruger så elektrisk heat race tracing, man kan bruge damp, man kan bruge alt muligt, hvad man nu lige har.

Frederik Botin Carøe Villum 25:47
OK.

Gro Kallehave Hansson 26:01
Men, man kunne sikkert også bruge varmluft og naturgas, men vi har så valgt elektrisk heat tracing i øjeblikket. Så derfor så holder man rørene varme på de der 400 grader og så er den opstartstid der er den tid det fysisk tager saltet og flytte sig det stykke det nu skal flyttes gennem varmeveksleren. Og hvis man har damp, så kan man have en det der hedder en steam drum, hvor man allerede har noget damp til rådighed, som man så bare åbner, så der en bufferkapacitet, selv når den er slukket.

Frederik Botin Carøe Villum 26:41
Ja.

Gro Kallehave Hansson 26:42
Så ja og nej. Der er en opstartstid. Det tager også noget tid fra man trykker på en knap til til pumpen, der skal flytte saltet gennem resistance heateren har pumpet saltet hen til resistance heateren sådan den har noget at varme på så den ikke brænder af.

Sebastian Bach Johannessen 27:03
Ja.

Gro Kallehave Hansson 27:05
Men altså, hvis det flytter sig med 5 m/s hvad er det nu? Der er nogle tommelfingerregler for flowhastigheder, jeg kan dem kun for gas for gas er de 20 m/s, men for fluorider kan jeg altså ikke lige huske det. Det er 3, 5, 10 Sådan noget i den stil meter i sekundet, så kan i begynde at snakke om hvor stort er anlægget, hvor mange sekunder er det så?

Frederik Botin Carøe Villum 27:24
Okay ja.

Gro Kallehave Hansson 27:30
Så det det. Det er den størrelsesorden, vi snakker.

Frederik Botin Carøe Villum 27:33
Ja okay.

Sebastian Bach Johannessen 27:34
Okay.

Gro Kallehave Hansson 27:38
Ja det er ikke hundrededele sekunder, men det er formentlig heller ikke halve hele timer. Det er nok minutter.

Frederik Botin Carøe Villum 27:38
Ja.

Gro Kallehave Hansson 27:51
Men man skal hele tiden huske, at der er noget fysisk I det der salt der skal flyttes rundt.

Frederik Botin Carøe Villum 27:58
OK. Det er godt lige at få hørt, fordi ja nu selvfølgelig skal vi lige snakke om hvor meget I dybden vi går med det element. Så tror jeg også tiden næsten ved at være der, men lige det sidste det var sådan set bare det vi spurgte om det var egentlig bare hvis i havde beregningseksempel, fordi du sendte jo den der formel med nogle estimater på hvad hvad det koster og du sagde der var sammenspil mellem charge og discharge og så skulle man trække lidt fra, men vi gennemgik den der formel hvor du sagde det er sådan en gennemsnitlig bud jeg kunne kan lege lidt med den.

Gro Kallehave Hansson 28:08
Ja.

Frederik Botin Carøe Villum 28:35
Jeg ved ikke om I har fra tidligere lavet nogle beregningseksempler til nogle virksomheder på nogle anlæg størrelser hvor man kan se omkostninger i systemet og man kan se nogle formler, så vi har ligesom nogle beregningseksempeler på et typisk system.

Gro Kallehave Hansson 29:04
Det må jeg lige tænke over, hvad jeg kan dele der.

Frederik Botin Carøe Villum 29:10
Ja.

Gro Kallehave Hansson 29:11
Den jeg delte sidste gang?

Frederik Botin Carøe Villum 29:15
Ja.

Gro Kallehave Hansson 29:15
Har du den så jeg lige kan få genopfrisket hvad det var for en?

Frederik Botin Carøe Villum 29:20
Ja det bare lige at få åbnet den her, fordi at der er heller ingen problem i at tage de estimater du gav os sidst og så kan vi kan sagtens lave nogle sådan estimerede beregninger og hvad de her systemer. Det tænker jeg ikke der at et problem i.

Gro Kallehave Hansson 29:48
Nej.

Frederik Botin Carøe Villum 30:11
Ja. Hvis de ikke har ændret sig super meget,

Gro Kallehave Hansson 30:17
Nej Jeg tror det er bedste bud stadigvæk.

Frederik Botin Carøe Villum 30:21
Ja super, fordi så tænker jeg bare at vi bare kører videre ud ad den tangent og laver nogle estimerede priser på det her det ser jeg ikke noget problem i.

Gro Kallehave Hansson 30:39
Ja.

Frederik Botin Carøe Villum 30:40
Så var der en sidste ting. Jeg ved vi er lidt over tid det beklager vi, men det er fordi Vi har også tænkt os og modellerer varmetabet eller forsøge at modellere varmetab fra systemet og jeg kan sådan fjernt huske fra møderne tilbage i september, det er mange måneder tilbage, at der var noget med under 1-2 % dagligt?

Gro Kallehave Hansson 30:42
Ja, vores påstand er at de salgsmængder vi regner med og at vi forudsætter at de opbevares i tankene at det så er under en procent om dagen, hvis anlægget ikke kører.

Frederik Botin Carøe Villum 31:24
Ok ja.

Gro Kallehave Hansson 31:27
Det er påstanden og der eventuelt varmetab fra rør men det det.

Frederik Botin Carøe Villum 31:38
Okay, så kan vi jo godt se hvor mange driftstimer anlægget har, og så kunne man jo bare sige trække det fra et år og så sige én procent af det. Man kan godt lave sådan en estimeret beregning af hvad varmetabet er.

Gro Kallehave Hansson 32:20
Det kunne man formegentligt godt. Du kunne også vende den om at sige hvis tanken taber 1-2 graders temperatur pr. døgn hvor det ikke køre. Så skal den varme tilføres igen, så det jo et varmeforbrug du skal regne ind på en måde. Men hvis du regner 1 % pr. døgn når det ikke køre også omsætter det til et antal timer med energi der så skal ind igen, eller under 1 % men kald det 1 % for at være konservativ.

Frederik Botin Carøe Villum 33:20
Simplificering ja okay ja, men det er også bare så vi lige har nogle overvejelser om hvordan man kunne gøre det med, men så tænker jeg at det var det.

Gro Kallehave Hansson 33:28
Ja.

Sebastian Bach Johannessen 33:34
Jo, det kunne i hvert fald være det kunne være fint at have med på, for også det er et meget ideelt system. Hvis man ikke tager det i hvert fald jo.

Frederik Botin Carøe Villum 33:42
Ja fordi vi snakkede nemlig om det med at der var nogle resistance heaters som bibeholder salt temperaturen i tankene. 318 grader eller hvad det var i den kolde tank, så det ikke stivner. Tilføjer man noget energi for at modværge. Det var bare det vi lige skulle have sat nogle ord på.

Gro Kallehave Hansson 34:09
Ja. Jep.

Frederik Botin Carøe Villum 34:11
Så godt som muligt, jeg lige kunne få formuleret det.

Gro Kallehave Hansson 34:12
Ja.

Frederik Botin Carøe Villum 34:18
Ja, Jeg tror faktisk vi var kommet igennem de spørgsmål vi lige havde, og det var bare super, så tænker jeg vi bare lige transskriberer det her, og så sender vi det lige til dig før vi bruger noget som helst, så kan du lige få tjekket og streje ud eller hvad der nu skal til også kan vi tage den derfra så.

Gro Kallehave Hansson 34:22

Super.

Sebastian Bach Johannessen 34:23
Jep.

Gro Kallehave Hansson 34:23
Godt. Det ville være super det. Det tror jeg må være måden at gøre det på. Jeg tror ikke at der er nogen problemer, men jeg dobbelttjekker lige.

Frederik Botin Carøe Villum 34:36
Det får vi lige gjort. Så stopper jeg optagelsen her.

B | Interview with Eoghan Rattigan

AAU

Vi tænkte lidt at vi ville starte med at fortællel om hvad vi skriver om for at danne et godt grundlag. Vi er i gang med vores speciale på AAU og kigger på hvordan man kan koble varmetemperatur lagring på industrien. Ikke nødvendigvis en 100 % substituering men også som backup form. Formålet er at undersøge hvordan industrien kan elektrificeres. I den forbindelse har vi et samarbejde med HYME dette semester. Givet det er der en stærk interesse i hvordan det gået for jer med høj temperatur lagring, da vi i projektet vil lave en tekno-økonomisk optimering der skal lede over i et organisatorisk perspektiv. Vi sidder nu og har en problemanalyse der er færdig og er ved at finde frem til hvilke aspekter kunne være vigtige at have med i analysen og få jeres erfaringer inddraget. Vi vil også tilføje vi har lavet et lignende projekt tidligere og er ikke helt grønne på området, vi på nuværende tidspunkt i snak med Randers Tegl som mulig case. I dette møde er vi også interessede i at høre om hvad status er med Greenlab Skive's projekt vedrørende høj temperatur lagring og hvor i er henne i processen. Det var egentligt en kort intro til vores projekt og hvad vi undersøger, og vi tænkte du kunne fortælle lidt om ja, hvad status er og hvad i har haft kigget på i forbindelse med jeres tidligere samarbejde med HYME og AAU.

Greenlab

Ja fedt, jeg vil starte med at introducere mig selv, jeg hedder Eoghan og arbejder her i Greenlab og arbejder i en afdeling der hedder forskning og uddannelse og primært jeg arbejder lidt som en program manager og facilitere nogle af de projekter vi arbejder med, primært på forskningssiden vi har mange forskningsprojekter som vi laver castede funding til, nogle af dem er termisk energilagring, jeg sidder også på x arbejder gruppe, termisk lagring, der mange folk at snakke med ift. Til det. Min program er jeg var en fysisker og har lavet en PHD i fysik og kemi og arbejder nu her i Greenlab. Så det er mit perspektiv, jeg er mere på termodynamiske side når vi snakker termisk lagring, jeg er ok god til det tekniske perspektiv, men arbejder også lidt med det organisatoriske. Så jeg skal gøre mit bedste. Vores ide om termisk lagring og hvorfor vi gerne vil lave det, vi kan godt sige når vi tænker om den grønne omstilling og hvad vi kan gøre bedre, vi skal stoppe fossil-fuels og bruge mere, der hard to get sektorer, men hvis vi kan bruge mindre er vi på den rigtige vej til at gøre verden bedre. Vores ide er termisk lagring er low hanging frugts vi godt kan arbejde med. Primært i industrien bruges varme, og som siger til folk at vi stopper med at tænke på energi som et fuel, men hvad har du behov for, er det varme er det andet og vi kigger den vej, hvis vi distribuere varme til vores kunder i Greenlab industripark, vi ejer ikke virksomhederne men står for infrastruktur og land, vi laver alt for, distribuere alt for dem og udbygger vores netværk så vi kan distribuere varme også. Et stort eksempel lige nu vi har et virksomhed der bruger biogas, i deres process når du skal tage den carbon dioxid ud af biogas så du kan få biometan, du skal have en process der har behov 150 graders varme, som 5 MW. Og de skal have det 24/7 der fuld proces. Og det er ikke så høje temperatur men der et stort behov for varme i parken lige nu. Vi har startet der, vi underskrevet for et varmelagringssytem fra en virksomhed fra USA. Der er termisk brick der opvarmes med el der kan levere varme til biogas anlægget. I det hvor vi har fundet vores business case, der er 30 % om året er det billigere end gas pris og der hvor biogas har et behov for. Det ikke så uvigtigt for dem og det biogas anlæg har 2 ejere, den ene ejer har behov for det skal være mere grønt og den anden har ingen problem med at bruge gas. Hvis vi kan lave varme under gaspris skal de ikke købe det, vi arbejder hårdt for at lave det, vi har en PPA med Eurowind, som laver wind and solar for os og der er under Greenlabs, vi er i gang med nogle gode samtaler med kommuner og få et stort test cite hvor vi kan vi behind the meter fra Eurowind og en grid connection. Det giver os grund til at lave noget med VE og sende det rundt i parken, hvor vi fokusere på termisk lagring. Vi har lavet en investering i nogle termiske anlæg systemer og det er den vej vi køre. Vi kan godt se 30 % vi kan levere varme under gas pris til kunder og det skal være nogle andre kunder der skal betale premium for det, og vi håber det skal gøres og vi kan levere til flere. For nu er det et start punkt, vi skal også købe en elkedel så vi kan charge og levere på samme tidspunkt og vi skal også have et andet termisk lagrings system, jeg ved ikke om vi kan sige hvem, vi ved at komme ind i et projekt og det skal hjælpe med det andre ting i parken. Vores håb er med det lagringssystem og den mulighed for at sælge varme til folk uden at købe en gasbrænder, at vi kan tage deres CAPEX ned og vi kan bidrage til den grønne omstilling i virksomheder. Men det er phase 2, lige nu gør vi all ind og tænker det er den vej industrien skal gøre. Og vi er en klynge så vi skal stå for infrastruktur og køre videre med det.

AAU

Nu er det med i er en klynge af virksomheder hvor der et præmis om man gerne vil finde løsninger med virksomheder, men der også gør vi ud fra en del processer bag ved om hvordan får man samarbejder på plads og hvordan får man virksomheder med på vognen og hvordan håndtere men udfordringer undervejs.

Greenlab

Det kommer an på virksomheden, nogle tænker det en god ide og vi skal tage og køre med på det, vi synes det en bedre vej. Andre tænker, prisen er ikke god nok ellers tak, det lidt dynamisk og er nogle af de ting vi arbeder med er de her personlige forhold til kunderne i parken, hvor vi promovere den gode sag, men de siger der en stor pris på de anlæg hvorfor skal vi lave det. Vi kommer frem og tilbage og bliver lidt tættere på hinanden og håber at arbejde som en klynge her, hvor vi lidt bedre til de personlige forhold mellem virksomheder. Nogle ting går hurtigt nogle ting går langsomt, vi har fået VE i parken, som har stået snart 3 år, men vi har lige fået vores transformer station, så det først nu det os der levere el direkte ind i parken. Der er tid mellem og det kan være hårdt, hvorfor har vi ikke fået billig strøm endnu, når du skal sælge en vision, skal folk nogle gange høre det skal være billigere, det skal være VE og når vinden blæsere skal alt være billigere, vi skal gøre det selv og vi tænker nej nej, det har kostet os mange penge at sætte det op så du kan få billigere strøm og varme og balancere system, så der er en pris på alt. AAU

Det også noget vi finder frem til, vi har haft nogle år med høj volativitet i elpriser også når vi kigger ind i fremtiden med en højere grad af VE vi får nogle større udsving. Kræver det vel at man går ned med virksomhederne og kan sikre en hvis pris, kræver det når i gør det sætter i jer ned og laver nogle kontrakter med dem på varmen skal kunne købes på en gennemsnitlig pris, vi tænker umiddelbart det kunne være en stor hemsko.

Greenlab

Der nogle der køre det som PPA eller nogle gennemsnitlige priser, jeg tænker vi skal gøre som spotpriser, fordi hvis vi køber el fra nogle der er tæt på til spotprisen og det skal bruges til at lave varme, hvis det ikke er et forhold mellem spotprisen til el og vores varme, der nogle der skal løse for dig. Vi tænker her på transparency, hvis det holder næsten til spotpris og du kan el der og varme der, i alt med varme, nemt. Men der også en mulighed for hvis nogle kan der kan sige okay, vi kan sætte en gennemsnitlig pris måske det kan hjælpe til de folk der siger nej, der nogle vi kan lave et godt projekt for vi kan se vores investering hvis vi købte det, måske der en god grund for det. Det ikke sådan vi laver det nu, men vi har mulighed for det, det ikke noget vi har nej tak til. Vi kan godt se den business case når vi laver kontrakt mellem kunder, og hvis de har haft et behov for at det skal være den pris så vil vi gerne have det. Den fleksibilitet jeg tænker, pga. vi ikke har haft det system frem til nu og vi har kunder i parken. De skal have en anden vej ind i deres system udover at brænde gas fordi lige nu køre det og vi har ikke et termisk varmesystem i parken. Måske hvis vi får nye kunder, vi kan lave en kontrakt med dem der ikke er over den pris, måske der en anden vej, men vi ikke kommet dertil endnu, der stadig mulighed for det og der er god grund til det. Og hvis vi kan få skiftet flere folk over til at se energi som varme fremfor gas, ja, det vil jeg gerne bidrage til.

AAU

Jeg har lige et hurtigt spørgsmål, da du introducere det her storage i er i gang med at undersøge, hvor det ved biogassen på rimelig fast 150 graders, var det rockbed storage? Det kan vi se i har været i gang med at undersøge.

Greenlab Der en type rockbed vi kigger ind i om vi skal lave, den anden med termisk er næsten det samme, bare en størrelse og anden vej at lave det med en anden temperatur det skal varmes op til. Vi har også kigget på molten salt, og jeg tænker hvis vi har nogle som har en ammoniak leverandør, der er god grund til at have molten salt, nogle der skal have høj temperatur, men det fleste af vores kunder er lidt lavere temperaturer lige nu. Der en grund til at lave til det en kæmpe høj temperatur og lave superheated steam, det giver god mening på nogle tidspunkter, men hvis alt går i stykker og det skal dræne det molten salt, der mange ting, lad os sige forskning og security du skal tænke over. Jeg synes molten salt er en virkelig god teknologi men det passer ikke til vores kunder lige nu, måske om 15 år, hvis vi har de rigtige kunder i parken, kunne vi godt tænke os at bruge molten salt på et tidspunkt, når det matcher deres demand.

AAU Så det er temperatur behov i de industrier i har lige nu der gør i kigger på rockbed

Greenlab Ja

AAU Vi har også forsøgt at lave en state of the art om termisk lagring at det effektivt at bruge rockbed ved temperaturer på 150-260 grader det mere cost effektivt end molten salt der. Det lyder på dig som det kan næsten bekræftes at når i undersøger det er når vi snakker de her temperaturer rockbed og ved højere temperaturer molten salt

Greenlab Ja, noget andet er transfer rate, molten salt er virkelig god til, hvis du har høj behov for højere transfer rate, hvis du skal en masse MW på et tidspunkt, der den virkelig god til det, den transfer fluid i det er fantastisk til det. Nu er den proces vi har i parken her, vi har kunder der har behov for 300 grader men det skal være i varmluft, så det giver god mening at lave rockbed pga. det, hvis det har et andet transferfluid end det, måske vi så skal kigge på nogle andre eller termisk olie eller nogen af de andre ting. Men for nu, vi har ikke den rigtige proces til molten salt, synes jeg, det ikke at sige vi ikke har kigget ind i det. Vi har haft nogle gode samtaler med HYME og Aalborg CSP og nogle af de andre der laver det. Det ikke noget vi er bange for, men når vi har de rigtige kunder bliver det en mulighed.

AAU Når vi snakker transfer rate og med molten salt, vi snakkede med HYME sidste semester og sagde man kunne charge og discharge på samme tid, er det du sagde i også kiggede ind i med rockbed?

Greenlab Ja, og virksomheden fra USA kan også lave det, pga. der en continues flow, når i har sagt om at bruge deres luft til isolering, det skal flytte hurtigt for at varme op til 1.000 grader og smelte det hele, der er altid nogle continues proces, derfor matcher det bedre med biogas anlæg.

AAU Nu tænker jeg vi kan vinkle spørgsmålene over på generelt jeres processer med opstart af projekter med højtemperatur lagring. Der er noget organisatorisk bag, med man skal få de her virksomheder med. Er i støt på nogle udfordringer på de planer i på vej frem med?

Greenlab Det er godt spørgsmål

AAU Vi kan godt uddybe lidt, det vi mener når man tager projektet fra bunden og siger nu vil vi have denne virksomhed til at overveje at gå ind i en termisk lagrings løsning, laver man nogle opstartsmøder, er der nogle bestemte mennesker man tager fat i, er der nogle bestemte udfordringer fra tidligere man skal være opmærksomhed på, så virksomhederne ikke misforstår, er der nogle fremgangsmåder i har haft succes med.

Greenlab Vi har lavet det en gang, så vi har ikke en proces endnu. Vi vil gerne biogas har et stort varmebehov i parken og vil gerne have et varmesystem, for hvis vi skal lave cirkulær økonomi i system, det varmesystem det mini fjernvarme skal være det back bone til det. Så vi kigger i hvor det én mulighed, hvordan kan vi levere den bedste varme til det største behov. Vi har snakket med dem og fra deres side er det gaspris eller under. Og vi sagde ok, hvornår skal vi matche og er det en business case. Nogle kommer og siger vi har et virkelig godt varmelagring og vi har et projekt vi gerne vil sætte op og nogle gange tænke at gå den vej, der nogle teknologier der har brug for den type varme. Der mange forskellige veje i opstarts processen, når vi så har en løsning, kan vi gå ud og snakke med nye kunder og sige nu vi kan levere den her er det interessant for jer. Vi har ikke en fast proces i det vi laver, alle kunder har behov for anderledes ting. Jeg tror ikke vi skal have to af de samme virksomheder i parken, måske vi skal passe på hvis vi vil have gode forhold i parken. Vi har ikke en fast proces i det. Den vej når vi har lavet det som den tidligere, det var en mulighed for et projekt med virksomheden fra USA og vi har god financering til det, så vi er gået ind og fundet ud af der var mulighed ved biogas, det med 30 % og vi tænker ja lad os gøre med det. Fordi hvis vi altid venter til det er 100 %, kommer vi aldrig til at lave noget, vi har taget en chance, vi skal starte med 30 % og finde nogle andre kunder der har et behov for grøn energi og køre den vej. Måske om nogle år hvis i spørger igen jeg et anderledes svar, jep vi har denne process og vi køre den. Men vi er stadig med at finde ud af hvad er den bedste vej at lave det. For nu er det at gå ud og snakke med folk, hvor er der mulighed, vi skal ikke låse alle vores penge hvis vi investere i det og se hvor vi kan komme i gang.

AAU Det også det vi lære på UNI, der ikke noget case der den samme og man skal gribe det an ud fra det behov de har, så lyder til at være gældende i praktisk. Vi har jo den her del 2 analyse hvor vi kigger på det organisatoriske og prøver få en fornemmelse af de har processer så vi kan skrive noget eller tage noget ind der. For lige at gøre det lidt mere aktør bestemt, for du nævner man går ud og snakker med folk selvfølgelig for at se om der er nye kunder tilgængelig eller lignende, men når man har en virksomhed, hvor i har en teknisk løsning som de måske er interessede i. Nu kan jeg huske fra sidste semester når vi sad i et møde i praktik og skulle undersøge noget nyt, de bragte folk ind der en teknisk orienteret der havde forstand fysik og termisk lagrind så var en til stede til mødet der var økonomisk orienteret der sagde vi skal huske at holde det under gaspris f.eks. vi havde ved det her bord en der hvis noget om det ene og en om det andet og måske en leder.

Greenlab Det er næsten den samme proces vi køre, alle vil den gode ide, men hvor er den bedste vej at lave den gode ide. Der hvor vi kommer ind til og siger, er det for høj en omkostninger og hvornår får vi pengene tilbage eller er det den bedste termisk lagrings system vi kan købe, på et tidspunkt skal man bare køre med det, det måske ikke verdens bedste men det er vores. Så lad os køre med det og starte og levere ting og håber at i fremtiden skal det være bedre for alle. Men det ikke alle der har mulighed for at lave det som den der.

AAU Nu nævnte du tilidgere i allerede har PPA på plads med eurowind, hvordan er det når i sidder og udarbejder de kontrakter og det skal videre ud til virksomhederne i parken. Hvordan gør i det når det skal sættes sammen med varmelagring, er det sammen med spotpriser eller hvordan arbejder man med det for at mindske risiko.

Greenlab Det er spotprisen. Nogle tariffer hvis eurowind gerne vil sætte på grid, med den er special tilladelse i test zoner, de betaler ikke tarif når de sender til os, de giver mening for dem at sende energi til os og den tarif vi skal sende ud til kunder. Der er nogle x'er i det og jeg har ikke kigget på tarif modellen, men vi har lavet en tarif model, den fjerde tarif model i Danmark, vi er en af dem vi har lavet en ny, det var sjovt, tror det var i avisen her i Skive. Vi har lavet en ny tarif model, men det er tæt på til spotprisen. Der ikke nogen der tænker hvis spotprisen falder taber jeg penge. Når vi kommer til lagring tænker vi på hvis elprisen er negativ og hvis vi er og vi sender el til vores kunder, måske det en bedre ide og sende det direkte til lagring. Den ide om at have lagring er god, når vi taler wind og sol med høj produktion. På det samme tidspunkt er det mulighed for at producere el, men det må ikke sætte det på grid, hvis du sender det til lagring skal du sætte det op, men vi kan få penge fra grid hvis vi tager det fra grid, så har vi fikset problemet eller.. Der noget balancering i det. I Holland f.eks. alt vi laver skal gå på grid og det kan ikke sige nej tak, det skal tage det og der skal balanceres på deres side, så det får ikke negativ pris på el, men med det der flere muligheder på lagring, for den vej er der flere på grid. Der er mange komplekse ting i det, det ikke bare termisk lagring det hele systemet.

AAU Bare lige at opfølgnede til de her PPA, jeg snakkede med en fra centrica og nogle PPA er 5 år nogle er 10 år, når man laver PPA'er på spotpriser, går der så tanker omkring fremskrivninger, laver man så PPA på baggrund af fremskrivninger af både spotpris og naturgas?

Greenlab Det ikke mit område, jeg har ikke læst PPA'erne. Det sjov du nævner el og gas pris, noget jeg kan sige er vi har et stort problem i den grønne omstilling hvis el er dyre end gas. Jeg kan godt se hvorfor, pga. hvis vi bruger gas til at lave el. Vi har en monopoly på el i Danmark, så måske der en mulighed gaspris til alt andet end andre lidt billigere men for andre dyre end elprisen, hvis vi laver noget lignende er det en måde at komme i gang med at bruge el bedre. Men indtil det er billigere at lave el end med gas er det hårdt, ja jeg vil være lidt mere grøn, men den hedge fund er har købt vores farma i 2010 siger vi skal bare lave gode profit for dem, så vi kan ikke lave det.

AAU Jeg tror det var del 1 af det organisatoriske, så nu går vi over i det tekniske. Vi har skrevet om molten salt storage men også mere generelt termisk lagring, når i har designet systemerne og modelleret dem, hvor meget har du været inde over det?

Greenlab Ikke meget, det vores operations department der inde i det. Nogle af spørgsmålene har jeg nogle svar til fordi jeg synes det interessant og jeg snakker med det. Jeg kan godt se vi har lavet ting på stor skala fordi vi gerne vil have flere kunder i parken, men en % på overkapacitet har jeg ikke.

AAU Vi kan prøve løbe igennem det. Er der nogle udfordringer med systemer som har gjort i har valgt rockbed?

Greenlab Med USA case, pga. det contained system, det ikke os der skal stå for på at bygge det hele, max og min skal vi skalere det til det. (Lyden ikke tydelig i resten)

AAU Vi kan lige se om du kan give et bud på det problem Randers Tegl har, når vi snakker isolering med tanke på molten salt anlæg, saltet kan godt komme op på højere temperatur, men metallet korrodere over 650 grader. Så spørgsmålet er kan man bruge en superheater og booster det i en ovn fra 600 til 1.050 grader?

Greenlab USA casen kan også godt blive højere temperatur op til 1000 grader. Men problemet er hvor skal du sætte det og hvis du skal have nogle container over det du kan ikke lave det hele med de bedste isolerings materialer der kæmpe høj pris på det. Det var også en del af tanken når vi snakket høj temperatur med molten salt, i forhold til isolering derfor bruges luft i system som isolering for at contain og stoppe det i at smelte. For corrosion siden med superheater steam, alt du har i det, det skal være et closed loop, der skal være heat exhanger når du tager det ud af systemet, der skal være nogle closed loops. Vores max temperatur vi håber ca. 600 grader synes jeg. Lidt samme problem som med Randers Tegl og deres system, og de fordi vi vil gerne holde til det superheated steam og effektiviteten falder massivt og det er den mindste temperatur, den kan gå højere men der ikke kunder med behov for det, måske hvis behovet kommer vi sætter det op. Du har snakket med superheater efter molten salt systemet, og jeg tænker hvor er det i det skal have en superheater, vi har haft et projekt med AAU på energisiden, med design af en kettle boiler der sidder i molten salt der laver høj temperatur damp direkte fra molten salt, måske der er vej at gå med det system, men når vi kommer op på så høje temperatur er korrosion en stor faktor også materialet du skal bruge i det du kommer ind til nogle af de rare earth metals og andre ting og det koster ekstra at sætte det i gang der mange ting. Den pris over 600 grader er kæmpe.

AAU Det også det vi læst, stainless steel er det mest anvende men der metaller der bedre til højere temperatur men der stikker prisen helt af

Greenlab Ja

AAU Netop den kettle boiler artikel er den vi har læst og taget udgangspunkt i, om man kan booste det.

Greenlab Det problem jeg se er, hvad energi skal du bruge til en superheater, hvis du gerne vil lave det med el er induktion måske den bedste vej, men du får samme problem du skal varme metallet op du har, så ja, de sidste grader skal du måske tilbage til at bruge gas. Men måske det er nok bare at bruge mindre, så molten salt kan varme op til 600 grader og få de sidste 400 der bruges gas. Men måske det er en stor nok reduktion for nu indtil vi har et system der kan lave det bedre.

AAU Det også det vi har snakekt med Randers tegl, at gas skal supplere det sidste. Sebastian vil du tage det næste. Til design fasen, hvordan vægter nogle forksellige faktorer om det skal være CO2 reduktioner, eller kigge på reducere forbruget af naturgas, hvilke elementer vægter højt i de har design phaser. Det vi tænkte på er hvis vi skal design et enegisystem for randers tegl er nogle kriterier man skal opfylde.

Greenlab Noget af vores tænkning er måske ikke relevant til Randers Tegl, for nogle af tingene for os er hvor skal det sidde i parken og hvad mere gavn kan det gøre. Lave nogle lagring til virksomheder, der er en høj pris på det, vi skal tænke på hvad er logisk for termisk for hver meter vi har i grunden. Der er nogle CO2 reduktion, der noget energi vi skal reducere med den vej her, noget af det hele er vi tænker ind. Vores højeste prioritet er at bruge mere VE. Men det også pga. vi er en virksomhed der arbejder med det, vi er en test zone og vi har PPA for at få det ind i parken, for os er VE en prioritet, men det er ikke altid for vores kunder, for de vil gerne have flere VE og mindre CO2 hvis det ikke stopper vores produktion. Vi prøver tage det hele ind og tage et holistisk overblik, hvad er mulighederne og hvordan kan vi gå i gang. Hvad er vigtigt og hvad er der muligheder, hvis vi gøre med det her hvad er den bedste vej og hvis vi køre den anden vej hvad er den bedste vi kan lave.

AAU Det giver god mening og det kommer tilbage til ud fra hvad virksomhed man arbejder med har de ting de har fokus på og i har ting i har fokus på f.eks. med VE vil skubbe i den retning og derfor finde en balance. Det noget vi kan bruge i projektet at kigge holistisk på det og vægte højt hvad virksomheden har behov for og ikke skubbe for meget igennem på sin egen agenda.

Greenlab Ja

AAU Vi går ned i nogle af de sidste spørgsmål nu, som fokusere på design af systemet med optimeringer, vi kigger på optimum mellem tanke og resistance heater. Hvilke faktorer kigger i på, er det peak demand eller andre ting. For at give et eksempel, da vi modellere sidst, lad os sige der en steam profil for hver time, nogle har måske en fast profil og andre variere. Skal man dimensionere steam generator til den kan dække peak demand for en time, hvis prisen er lavere end gas. Vil man modellere tanke i et specifikt invertal hvor man kan supplere steam demand i et specfik periode eller er det mere økonomisk?

Greenlab For os vi håber vi får flere kunder, så vi har over dimensioneret det, ca. dobbelt så stor. Den kan charge til 12 eller 24 MW og kan holde til 100 MWh timer og kan levere ca. 12 MW men der en behov for 5 MW, så vi kan levere til flere. Så det er vores tækning vi skal ikke stoppe her vi skal have flere kunder. Men hvis det er til en virksomhed og dimensionere det, når vi har snakket med Eurowind med deres batteri projekter er det 4 timer, det den tidsplan der er tænkt over. De vil gerne have 4 timer lagring, i 4 timer kan vi balancere til grid, vi kan integrere til artileri services og det kan også lave noget med storage events til kunder der har behov til det. Det er den tidsplan, andre virksomheder 24 timer, vores termisk lagring er ca. 24 timer når vi har fuld kapacitet.

AAU Hvordan fastsætter i charge kapacitet? Greenlab Det har vi ikke lavet endnu, jeg tænker hvis pris er billig nok skal vi charge så hurtigt så muligt og vi skal finde ud hvornår forekommer de her priser og hvornår er de lave nok. Der skal komme noget forecasting i det, hvis vi tænker ok nu tænker vi det den laveste pris i den uge og vi skal have fuld charge og bare holde det og lade det charge. Det skal vi finde ud af, vi skal snakke med nogle forskere og lave noget modellering, men lige nu har vi ikke et svar.

AAU Det præcis det vi har kigget ind i, nogle af de overvejelser vi har kigget har kigget på at der lave priser om natten også køre men det her 6 timers charging interval, så man kan charge storage op fuldt på 6 timer også modellere man resistance heater og storage kapacitet ud fra de har charging interval, men det også pba. Hvornår forekommer det laveste priser. Bare lige et hurtigt opfølgende, de 12 MW eller 24 MW, hvor det charge eller discharge?

Greenlab Jeg tænker det 24 MW på charge og 12-10 MW på discharge, i kan godt se hvis i har det rigtige svar på hvornår i skal charge og discharge du kan lave en masse penge i energitrading og der en kæmpe industri rundt om det. Vi har også arbejdet med norlys energitrading og det er deres profession og de har mange algoritmer på hvornår du skal charge og discharge.

AAU Okay så 24 charge og 12 discharge, så med volume på tankene så tænker man 24 timers vi gerne vil dække og vi har en 5MW så vil stoarge være 24 gange 5, ca. 100 MWh. Det lyder bekendt på det vi har kigget på det. Jeg tror vi ved at løbe tør for tid, men vi har en aller sidste ting. Et aspekt der interessant med det her du nævnte det med PPA, men lad os sige vi har en virksomhed som er interesseret i termisk lagring, men de måske også interessede i VE anlæg, til at supplere el til opladning. Man vil man skulle lave sådan en vægtning af hvor meget man skal investere som investere, lad os sige jeg har et process forburg på 16 MW eller 5 MW jeg storage med kapacitet på 100 MWh, hvor meget vind eller sol skal man installere?

Greenlab Mit svar til det, skal vi på grid eller skal i være island, vi har nogle som special test case vi kan lave begge to, men det ikke alle der kan. Hvis du skal lave vind og sol lige er det fordi du gerne vil tjene penge på markedet, ift. Til lagring afhænger det af virksomheden, hvis du har fleksibilitet kan du charge når det giver mening og du kan også have fleksibilitet på el siden, hvis du har fleksibilitet til VE har du ikke så stor behov for lagring, hvis du ikke har fleksibilitet har du større behov for lagring. Hvor stor ift. Til en 16 MW, kommer an på hvilken temperatur, hvor er der mulighed for det, er det under 100 grader kan du nævnt have kæmpe stor lagring, er det høj temperatur skal du tænke på alt vi har snakket om tidligere med corrosion osv. 24 timer et det bedste for os lige nu, er det den bedste ved jeg ikke, det giver mening for det vi kan lave for vores kunder. Jo Højere temperatur jo mere varmetab, pga. thermal drift i systemet og den gradient du har, så der noget at tænke over i det. Det ikke en nem calculation, de er gode spørgsmål, der mange muligheder, hvis du tager et holistisk overblik kan du multidimensional modellering hvor er bedst og hvad er bedste vej at høre, vi har lavet et projekt lignende, hvis vi har et bebov for 40 MW varme, vi vil gerne være i parken men vi vil have 100 % VE og vi har et behov for 40 MW varme, vi kigger på hvad skal det tage at lave det for dem, hvor skal opvarmeren være i systemet, hvad skal det koste, hvad er CAPEX OPEX balancering men også lagringskapacitet hvis i kigger på VE og sagde vi har en mulighed for VE den dag her hvornår kan vi charge og hvornår kan vi discharge, det var sjovt, du får en multidimensional modellering for at finde jeres minimum hvor vi tænker det er det bedste produkt for os.

AAU Det giver god mening, det også det vi havde, et sidste spørgsmål omkring økonomi, kigger i på NPV, tilbage betalings tid eller andre?

Greenlab skive Normalt kigger vi på return of investment, nogle gange arbejder vi med 8 år andre gange 12 år, f.eks. med USA case, med hvad vi har lige nu går der 15 år, men hvis vi får flere kunder går tiden ned, så giver en incentiv til at finde flere kunder, hvis det hjælper vores business case for hele organisationen, så det normalt at kigge på den.

AAU Ja tilbagebetalingstiden. Det godt at få det bekræftet. Så var det

Greenlab

Fantasitsk, jeg håber det hjælper

AAU Det meget brugbart, vi sætter stor pris på din tid.

Greenlab Hvis i laver en rapport må i gerne sende det

AAU Vi har skrevet en NDA desværre. Men tusind tak

Greenlab Held og lykke med projektet

C | Interview with Jonas Bønsø

Frederik Botin Carøe Villum 0:04
Vi snakkede lidt om tidligere nogle af jeres jeres målsætninger for anvendelsen af vedvarende energi, og det med jeres ve anlæg projekter. Vi snakkede lidt om hvad baggrunden er for det Der er nogle Sådan i forhold til en tidshorisont på, om man i forhold til hvornår man også gerne vil måske lidt af med at bruge naturgas, elektrificere processerne. Lidt om Der er noget Sådan helt på overordnet niveau nogle målsætninger, nogle tidshorisonter, hvad det hvad det ankommer.

Jonas Bønsø 0:48
Jeg ved ikke, om man kan sige Der er en decideret målsætninger. Lige nu er er Sådan noget som bygningsreglement ret store driver for hvad? Hvordan? Byggematerialer og produktionen af byggematerialer de bliver produceret. I Danmark er vi hvis foregangsland og i år var noget, der hedder. 7,5 kg co2 per kvadratmeter per år i betragtningsperiode på 50 år. Og det Det er den klart den største driver for at at at lave omstillingen. Vi er ret godt hjulpen på eller er blevet ramt på hjælpen med at købe biogas certifikater til som jo gør, at Vores forbrug af naturgas er betegnet som co 2 neutral.

Jonas Bønsø 1:46
I forhold til selve omstillingen er det jo noget, som altså vi. Det arbejder vi selvfølgelig også på, men vi. Har svært ved at indebære. Hvad kan man sige? Vi er jo ikke energiproducent? Vi er energiforbrugere, og vi, Vi har ikke. Vi har ikke kapacitet til og i sig selv. Og man kan sige producere energi eller være med i det ræs omkring den den grønne energiproduktion, vi fortsat producerer mursten og vil gerne ligesom tilpasse produktionen til den grønne energi, der nu måtte vinde frem.

Jonas Bønsø 2:25
Det er ligesom Vores strategi også. Vi har tidligere snuset lidt i om, om man skulle blive egenproducent nu. Ej hvis du ligger gang med med med det på på el delen, men også men også på gas delen.

Jonas Bønsø 2:39
Men Det er Det er en branche sig selv, og Det er jo branche som der hvor tingene de flyver op og ned, så så vi vi koncentrerer os hovedsageligt om at at at lave mursten. Og tagsten selvfølgelig.

Jonas Bønsø 2:56
Og så passe produktionen til den energi til den omstilling der kommer i form af grøn energi.

Frederik Botin Carøe Villum 3:04
I forhold til de biogas certifikater vi snakkede om det sidst, så gik vi ind. Og prøvede at undersøge det lidt, fordi vi synes jo bare Det er spændende i forhold til at bi er vant til at modellere det med co 2 afgifter på tidligere projekter, og hvad angår virksomheder der bruger naturgas. Og så tænkte vi jo lidt i, at regeringen har været inde og sige, at selvfølgelig co 2 afgiften bliver væsentlig højere frem mod 2030 og så tænkte vi i forbindelse med de her biogas certifikater og om det så også givet de bliver mere eftertragtede kan man kan man tænke sig til på baggrund af de høje co 2 afgifter. Om om i har en kontrakt liggende langt ud i fremtiden i forhold til at købe dem ind, eller om i har tænkt, eller Der er en tanke omkring.

Jonas Bønsø 3:41
Ja Det har vi, men ikke hvor langt, nogle år fremme tror jeg etcifret antal år.

Jonas Bønsø 3:49
Jeg ved faktisk ikke hvor langt fra man kan købe det med, men.

Jonas Bønsø 3:53
Jeg vil gætte mit bedste bud. Det er Vores økonomiafdeling sidder og handler om.

Jonas Bønsø 3:59
Jeg vil gætte på endnu 3 år.

Frederik Botin Carøe Villum 4:01 Okay jeg ved vores tanke er om man kunne fordi Vi er jo vi så undersøgt lidt om om om de eventuelt kunne stige i pris på baggrund af ja at de bliver mere eftertragtet, men hvis Det er økonomiafdelingen sidder med det, men Det var egentlig bare noget vi sad og studsede lidt over.

Jonas Bønsø 4:02
Jamen Jeg tror det. Det er jo Det er jo markedet igen som som. Ja Det er jo sindssygt svært at sige hvad vej det i går, men.

Jonas Bønsø 4:21
Vi vi Vi er på 95 % biogas her. Og årsagen til at Vi er på 100. Det er vi. At Vi er Vi er kvote virksomhed, så Vi har nogle. Vi har nogle gratis kvoter på co 2 udledningen. Og de her gratis kvoter, dem får vi jo uddelt. Jeg tror et årligt afhængig af Vores Vores forbrug. Vores produktion men hvis man går helt på 100 % biogas, så har man ikke co 2 udledning længere.

Jonas Bønsø 4:56
På Gassen og så frafalder de her gratis kvoter

Jonas Bønsø 5:01
Og Det er Sådan, Det er en forholdsvis stor sum stadigvæk de. De bliver stille og rolige. Hvad hedder Sådan noget tappet ud af frafalder i etaper, men Det er stadig en ret stor sum som gør at det bedre kan svare sig de sidste 5 % Det er at vi ikke køber certifikarrer.

Frederik Botin Carøe Villum 5:05
Så tænkte vi også lidt på. I har jo det her planlagte ve anlæg til til det klassiske elforbrug i virksomheden, men i forhold til hvad Vi har snakket lidt om tidligere, været planerne er for at

anvende de her ve anlæg eller anvende egenproduktionen. Og jeg ved ikke om du bare bare kan gentage hvad tanken var med de her ve anlæg.

Jonas Bønsø 5:43
Altså tanken har været at opføre et anlæg. Som minimum kunne levere strøm, hvad der svarer til Randers tegls samlede strømforbrug på alle Vores fabrikker.

Jonas Bønsø 5:56
Og så er der selvfølgelig en økonomisk gevinst i det at kunne producere strøm og sælge det til markedet. Og så er der jo, så er der den fordel i at. Kunne levere strøm til sig selv, og det vil så være på sitet i hammershøj. Og undgå at skulle betale den fulde nettarif Det er vel de fordele som vi kan se lige nu.

Frederik Botin Carøe Villum 6:25
Men Det er jo også lige det vi bare lige skulle have frem med det. Så skal jeg lige se her det næste vi valgte at undersøge både det som Anders han kom med i forhold til el stedet for naturgas, altså en elkedel, så valgte vi så også at inkludere det her storage anlæg og se hvad det kunne give, så vi ligesom i undersøger begge dele.

Frederik Botin Carøe Villum 6:59
Så det spørgsmål, vi egentlig har med det i forhold til det her med den her lagerløsning. I forhold til at når når vi kigger på det, så Det er ofte Vi skal dimensionere. Hvor meget vil man måske kunne dække af et peakbehov behov? Og nu er det jo med jeres drift mod den løber i løbet af en uge, så har vi jo så og kigger på. Er det fordi man gerne vil have det skulle måske dække et døgn, hvis når Det var fuldt ladet op eller skulle dække 48 timer, så jeg ved ikke om du måske har nogle ideer til.

Jonas Bønsø 7:28
Ja så hvor meget lagerkapacitet man egentligt har behov for?

Frederik Botin Carøe Villum 7:31
Ja nemlig, så som du måske har nogle ideer til hvor i gerne vil hvis i skulle have en form for løsning, hvordan det ville kunne dække. Hvor i synes måske det skulle dække en hvis mængde timer. Nu kan jeg huske, men Det var fordi vi tænkte nemlig det med at at som regel så når Vi har snakket med HYME og så videre og de Både dimensionerer de her anlæg til andre virksomheder, og så snakker de om storage duration i forhold til et fuldt opladet lager, hvor lang tid Det kan dække peak behovet, og der sad vi jo tænke lidt over det du nævnte med, at det kører over weekenden, for eksempel hvor det kører også hele tiden, så vi begyndte at undersøge lidt mere. Okay, hvis Der er 48 timers lagringskapacitet eller 24, og Det var vi jo lidt nysgerrig på om om du havde et indblik i det eller en holdning til det.

Jonas Bønsø 8:19
Nej altså, men Det er jo som man kan så sige Det er jo at.

Jonas Bønsø 8:24
Processen kører jo Sådan rimelig jævnt alle ugens 7 dage der vil være lidt variation i tørreriet i og med at vi ville kunne producere. Det vil sige de de sten som skal tørres i 5 dage, men

egentlig vil vi gerne have det så jævnt som overhovedet muligt. Vi kan godt finde på at starte dem skævt af, hvordan de er producerede i tørkamrene, så forbruget er jævnt i både på tørreri og i ovne. Så selve.

Jonas Bønsø 8:52
Hvad kan man sige? Mit gæt ville være at det ikke så meget teglværkets behov, men nok mere på. Altså lager løsningen mere på altså el priserne.

Jonas Bønsø 9:08
som jeg lige kan lige se hvert fald.

Frederik Botin Carøe Villum 9:11
Men Det er også det. Det er faktisk også udgangspunktet i Vores dimensionering. Det er, at Vi har været inde og lave nogle el prisundersøgelsen i forhold til, hvor mange timer i træk der forekommer de billigste eller billigere priser på el i forhold til prisen på naturgas, hvor at det Det er selvfølgelig fra kl. 00:00 om aftenen til kl. 06:00 om morgenen hvor man så ligesom siger at at på de her 6 timer, hvor at prisen er lavere end end naturgas. Indkøb, så vil vi gerne kunne lade lageret fulgt op på det, og så ligesom starte dimensioneringen på baggrund af det, og fordi vi synes Det er det rent økonomisk, som økonomisk faktor giver det i hvert fald mening at kigge på det aspekt, men Det var også bare lige i forbindelse med.

Jonas Bønsø 9:41
Det tror Jeg vil passe. Der er selvfølgelig bare en variation, men ud over det, så kan jeg ikke se hvorfor det ikke skulle passe til teglværkets drift i og med at vi er tæt på og stræber også efter at have en ret jævn belastning på de to store energislugere i form af tørreri og ovnen

Jonas Bønsø 10:16
Det hænger fint sammen.

Frederik Botin Carøe Villum 10:18
Okay, og så var det også. Vi havde nogle overvejelser, fordi om om det. Elektrificering igennem en en elkedel eller om Det er igennem det storage anlæg, som er nogle af de 2 muligheder eller en kombinationen, som er det vi står og overvejer, når man når når vi gik rundt på fabrikken og vi så alt der allerede var installeret, så begynder vi at nogle overvejelser omkring, hvis man skulle begynde at at tage de her ting ned og man skulle omstille værket og bygge om så om du om du havde nogle specifikke eller nogle tanker omkring nogle af de økonomiske eller fysiske udfordringer der vil være i ved at omstille væk fra naturgas. Og Det kan også være i forbindelse med eksisterende kontrakter der løber ud i fremtiden eller med nogle energileverandører.

Jonas Bønsø 10:59
Selve med kontrakter og energileverandører, der vil ikke være noget. Det kan ikke se. Certifikater og alle sådan nogle ting og de her gasoptioner, det kan man handle frit. Og Vi har også i en altså såfremt man skulle bygge om, så har vi forventet at man betragter. Nogle år frem som som gør, at man sagtens kan planlægge i forhold til det, er det man nu skulle have købt ind på gasforbruget.

Jonas Bønsø 11:27

Rent fysisk er jo nok. Alt efter hvad hvad teknologi man vil ind, men Det er jo nok den. Den den største udfordring rent. Teknologi, økonomisk og så selvfølgelig kan man bygge om og, men Det er jo nok der man er størst. Den største udfordring ligger i at lave en god business case. kan man kan man få den varme Her, kan man få naturgassen udskiftet med, men med en anden varmekilde eller delvis udskiftet med en varmekilde med anlæg som, hvor det rent rent økonomisk også kan svare sig?

Frederik Botin Carøe Villum 12:02
Men, der havde vi. Vi havde en tanke, og den vil vi lige løbe forbi dig, fordi vi lagde mærke til i har jo den ene ovn lige nu. Der er oppe at køre, og så har vi den 2 ovn som ikke er i drift, og så havde vi jo, vi snakkede lidt om i forbindelse med hvis man skulle lave den her ombygning og besluttede sig for at at okay. Vi vil gerne prøve at give det et skud med det her elektrificering, at man så ikke behøvede nødvendigvis at stoppe driften, mens man i gang med at ombygge. Men man ligesom fortsætter med at bruge den ovn der kører lige nu og så moderniserer den anden, enten med med et storage eller mdet at elektrificere den så man ligesom har den bygnings proces i gang, mens man selvfølgelig stadigvæk kan fortsætte sine produktioner om Det er noget, du ser, at der vil kunne give mening. Men ligesom.

Jonas Bønsø 12:43
Det er bestemt. Det vil bestemt være en mulighed. Ja.

Jonas Bønsø 12:46
Og Det er vel også være en god. Det er en god test da ovnene er stort set identiske i opbygning så man i ro og mag eller hvad kan man sige, hvis man kunne bygge om på det ene mens den var ude af drift og man havde efterfølgende test havde held med det, så så kunne man jo gøre det samme. Når modparten så stille.

Jonas Bønsø 13:09
Og alle i de tilfælde på Hammershøj, der kan alle alle Vores produkter. Det kan brændes. i begge ovne.

Frederik Botin Carøe Villum 13:18
Okay, jamen Det var det. Så kommer vi over til fordi Vi er lidt nysgerrige omkring den organisatoriske proces eller opbygningen ude ved jer Sådan helt generelt fordi du nævnte det med. I har selvfølgelig været i gang med en planlægningsfase for VE anlæggene og en implementeringsfase, og jeg ved ikke om du bare kunne fortælle lidt om hvilke afdelinger der er involveret i de her projekter og hvilke personer i virksomheden der inddrages, om Der er en økonomichef om Det er en teknisk vejledning eller man søger sparring ved. Institutter eller Sådan lidt aktør analyse, indblik er det vi egentlig søger.

Jonas Bønsø 14:01
Ja skal jeg prøve nu er det Sådan en overordnet, nu tager vi os af det her ve projekt først. Det er meget dreven af, Vi har ejerledere i virksomheden der er 3 ejere, 2 brødre og deres nevø.

Jonas Bønsø 14:19
De 2 brødre er med i firmaet og driver firmaet. Den ene, han er administrerende direktør og den

anden er Innovations- og produktionsudviklingsdirektør. Ham refererer jeg til. Det her med et ve projekt, der har kørt meget. Usædvanlig meget oppe fra og ned, altså det er deres projekt, og nok også den trepart der ejer det, det er deres projekt. Og nok også set. Det er nok bare med økonomiske briller og og lidt mindre på. Teglværks briller hvis man må sige det Sådan uden at og Det er også den måde er det usædvanligt er, at Det er nok også en af de eneste projekter, der ligesom kører den vej. Ellers så er min chef, en af ejerlederne, ham Der er produktions og udviklingsdirektør.
Han har ligesom ansvar for den grønne omstilling og innovation og udviklingsprojekter, og det vil typisk være noget, som går via hans pipeline. Om Det er nogen, der får en god ide. om det er mig, Det kunne være posten, der putter noget ind i hans brevsprække, i hvert fald det, de går. Det går typisk via ham. Og så sidder jeg som projektchef og tager den initierende proces med at med at bearbejde de ting, der kommer ind, ligesom screene for hvad. Hvad tror vi på, hvad hænger sammen med det behov, Vi har, og den viden, Vi har omkring markedet. Udvikling, alt sammen ting. Og de ting der så ryger videre, det ryger så videre så videre til en analysefase. Og det vil typisk være en fase, som som det i sidder og laver nu. Hvor man enten selv nu er det kun mig i projektafdelingen. Jeg har også nogle at trække på både interne og eksterne aktører og sige Vi skal undersøge nogle ting for ligesom at prøve at kigge ind i er der noget. Er der en er der en business case her? Og hvis der så er det, så ryger den. Via Vores, Via Andreas vores produktionsdirektør. så vil han ligesom tage det med til bestyrelsen, altså store projekter især. Tage det med til bestyrelsen og ligesom få. Sætte nogle milepæle ind og så sige hvad er potentialet her? analysen siger at Der er potentielt en god business case. Næste step er måske at lave et forsøg eller lave en større analyse, alt efter hvor stort projektet nu er. Så hvis det fortsat ser positiv ud fra den fase. Så begynder man måske at kigge ind i nogle helt konkrete tilbud og.direkte For de forskellige leverandører og kigge ind i nogle planer for hvordan det passer ind i Vores organisation og produktionsplaner og Hvad der nu er af Interessenter og Sådan nogle ting på projektet.

Jonas Bønsø 17:16
Og så vil jeg typisk være tovholder på den.

Frederik Botin Carøe Villum 17:20
Okay det lyder lidt fordi at vi vi lagde mærke til. Jeg ved ikke om Det var om Det var dig der var med da vi var på tur på fabrikken, så var der en opslagstavle hvor der hvor der var en plan do check act model som Vi er blevet undervist i.

Jonas Bønsø 17:31
Ja Det kan man godt sige.

Jonas Bønsø 17:35
Jeg tror faktisk Jeg har et. Et billede af det, hvis de er interesseret.

Jonas Bønsø 17:42
Det er faktisk lidt mindre ting, vi arbejder rigtig meget med. Involvering af Vores medarbejdere. Ja i så høj grad som overhovedet muligt. Man kan sige Sådan på forskellige ting, det er dem som står med næsen nede i støvet. Det er dem der mange gange ved hvad Det er de kæmper med.

Jonas Bønsø 18:06
Men ja, Det er faktisk lidt det samme. Det kan man godt sige.

Frederik Botin Carøe Villum 18:10
men Det var Sådan lidt nu. Siger du involvering og nej. Ja lige præcis. Har du noget imod vi lige tager et?

..Screenshare being done..

Jonas Bønsø 18:37
Jeg er i gang med Sådan et et projekt omkring dataopsamling. Det er Sådan set det, man kan se her. Hvis det forrige uges produktion der. Vi måler oei. Det vil sige, vi kan ikke lige huske så tror 76 timer i en søjle her. Vi har maskiner er bemandet i 76 timer. Vi tabte 8 timer på ikke produktive tid. I form af pauser og opstart og nedlukning af maskiner, rengøring og møder. Er der en 50 timer tilbage, så har vi stillet om på maskinen i 6 timer. Og i de her kategorier. Og det vi så arbejder med nu er 62 timer til rådighed, og så har vi brugt nogle og 20 timer 28 timer på stop. Og Det er vi så arbejder med. Det er så at sige. Er der nogle af de her ting som går igen uge efter uge, som vi kan som vi kan angribe og så siger får elimineret? Det kommer man så med forbedringer i forhold i forhold til de ting.

Jonas Bønsø 19:37
Og så har vi så en forbedringstavle herovre. Nu er det så mig der står på den, men Vi har en der hedder besanding af vogne. Vi har en, hvor vi har en Manuel proces, hvor vi går ind og lægger sand på. Og så siger vi så hvad hvad hvad kan vi gøre her? kan vi få det automatiseret? Så laver vi en plan for.

Jonas Bønsø 19:51
Og så har vi så Det har vi så gjort, og så er vi ved at bygge den på i det tilfælde hvor billedet er taget her, og så vil vi typisk, når Vi er færdig med at bygge på, så vi så sige til operatøren nu får du nu får du en uge indtil vi står her igen næste gang til at checke af, virker det som det skal. Og så handler vi egentligt i forhold til hans feedback. Man kan sige, hvis han siger jamen det virker. Det virker fint nok, men hver gang den skal hver onsdag, når jeg starter op, så er der noget der en time eller whatever. Det er jo for pokker, det skal vi have gjort noget ved, så laver vi så igen en ny plan og så udføres hvor han får lov at tjekke det en gang til.

Jonas Bønsø 20:23 Og Det er helt på lavpraktisk. Det er nu helt. Det er typisk ikke investeringer, men det Det er opgaver og forbedringsforslag.

Jonas Bønsø 20:33
Ja man kan også køre på projekter altså vi sætter nogle milepæle ind,det går helt fra ide, hvor man ligesom checker den af og kører den igennem og har ligesom en screening proces hvor ikke at man ikke tager alle ideer op. Og så har vi en analysefase, hvor den som siger, Det kan også være en stopklods viser det sig at at Det er ikke et hold i den idé vi havde eller det. eller prisoverslaget vil få det alt for dyrt. Det kan aldrig nogensinde gå eller whatever det så måtte være, så var det tilbage til enten tegnebræt, eller så bliver det skrottet.

Frederik Botin Carøe Villum 21:04

Nu nævnte du også dermed også gerne vil involvere altså hele vejen hele vejen ned i igennem virksomheden også ligesom de her tavler, så har bruger i så også dem for eksempel til at at dem der går rundt ude i produktionsbåndet, de også kan komme med forslag eller hvordan.

Jonas Bønsø 21:21
Det er typisk dem der skriver på dem.

Jonas Bønsø 21:25
Og det Der er i det. Det er at vi kører hele tiden og kører i 2 hold, skifter nogle gange i treholdsskift. Så hvis man tavlen blev holdt i skiftet mellem daghold og aftenhold for at få så mange med som muligt. Men hvis du går om aftenen og har døjet med et eller andet, når man ikke har en leder eller en tekniker og kan få læsset det af på, så kan man skrive på de her grønne lapper i så på billedet, så skriver man egentlig bare sin initialer og så sin enten sin idé eller sit problemstilling.

Jonas Bønsø 21:53
Og så bliver det behandlet en gang om ugen på mødet, og Det kan være man siger, Det var da en forfærdelig idé. Jeg kan ikke lige se den det, og så fjerner man den igen.

Jonas Bønsø 22:02
Eller som man siger, Det var en god idé, men jeg kunne ikke ressourcer lige nu, så parkerer vi den. Men alle alle forslag der kommer op, bliver behandlet på det møde der. Inden inden de bliver i hvert fald fjernet eller sat i gang. Der er ikke nogen man må ikke. Man må ikke som leder gå ind og så sige ej for søren der her synes Jeg er dårligt. Den sniger jeg lige ud af bagdøren, de bliver behandlet på mødet. Man får en forklaring på, hvorfor bliver den lavet eller hvorfor bliver det ikke lavet?

Frederik Botin Carøe Villum 22:24
Så var vi nysgerrige omkring den samme boldgade som det her, lad os Sådan rent hypotetisk sige, at Sådan en elektrificeret løsning i form af storage eller en el kedel man stod til at sige. Det er faktisk en en business case der giver økonomisk mening, og man så nu overvejer at tage det videre i implementeringsfasen vil medarbejderne på fabrikken i form af en opslagstavle. Sådan bliver informeret omkring vi overvejer faktisk at skifte nogle af dele af produktionen ud kunne vi godt bruge måske nogle indspark? Eller vil der være en proces, hvor du i forbindelse med at driften ser lidt anderledes ud en involveringsproces, som netop som du nævner her kunne komme med nogle ting, og Det er vi utilfredse med. Eller hvad med? Hvad sker der med den her del af mit job eller eller lignende?

Frederik Botin Carøe Villum 23:09
Kunne det være noget, tror du det?

Jonas Bønsø 23:10
Ja det ville der komme, spørgsmålet er hvor langt henne i processen vi vil være før at man informerer det, langt størstedelen af Vores medarbejdere er jo ufaglærte operatører så Sådan noget som indspark til det rent tekniske. Ville blot være begrænset man vil nok tage. Vi har nogle procesoperatører der Sådan står på brændingen, som vil være rigtig gode og have med

i overvejelserne. Og så har vi også. Vi har på den her fabrikken her. Vores fabrikschef er jo uddannet ingeniør og vil helt sikkert. Bare i konceptet også kunne komme med mange indspark til hvordan det hænger sammen og eller have god sparring omkring. Der er nogle ting Vi skal tage højde for, og har vi husket det.

Jonas Bønsø 24:03
Så det ville nok være på flere niveauer, tror Jeg tror man vil starte. Starte lidt. Med overordnet tager vi nogle af de. mere teknisk stærke med, og så nok størstedelen Ville nok bare få det som information.

Jonas Bønsø 24:27
I og med at hvis man, hvis man nu forestiller sig at det bliver aktuelt, så vil det også være noget i at sige. Det er jo Det er jo en ret stor investering det her. Men hvis man hvis man melder det ud, så er det også. Det kan faktisk skabe noget tryghed for ens medarbejdere så sige vi. Vi tror vi tror på fremtiden. Vi tror på, at vi vil være foregangs fabrik på at producere mursten, og det må give det giver en tryghed, fordi så ved de også, at Det er ikke Sådan, at der planlagt, at alt skal flyttes til en anden fabrik i Randers tegl, eller så tror man på det. Det ville det signal vil man jo sende.

Frederik Botin Carøe Villum 24:55
I forbindelse med det lyder det jo rigtig godt synes jeg også fordi Det var det vi egentlig ved at være løbet igennem spørgsmålene. Vi har lige Sådan 5 minutter, tror jeg Vi har sat af, så måske lige nogle lidt få uddybende. Måske det der med at sætte et godt budskab og vi vi snakkede om det her med at at sætte nogle målsætninger, måske for at omstille processer eller vende sig væk fra naturgas, og Det var ikke måske lige på tegnebrættet lige nu. Ikke nogle bestemte tidshorisonter, men kunne du forestille sig at at en decideret plan for det her kunne være værd at få skrevet ned eller Sådan sige okay hvert fald inden 2050 eller inden 2040 eller lignende, så vil vi jo gerne af med. Lad os sige 50 % eller 30 % eller man kunne kunne det være at lave Sådan nogle løbende små målsætninger i forhold til lige så stille måske vende sig væk med.

Jonas Bønsø 25:52
Ja både både ja og nej. Det er nok ikke mit svar alene der der afgør det, men mere det strategiske niveau men det der er i det. Det kan godt være Det er lidt politikersvar, men Det er Sådan lidt at at vi vi ikke store nok til at alene sætte så stort et præg på udviklingen af, hvad der kommer af grøn energi til opvarmning. Heller ikke teglværks branchen alene det. Det er nok nogle lidt større aktører der kommer til at gå forrest i det der. Stål, cement Som har du lidt flere midler og lidt flere ressourcer og lidt mere knowhow. Lidt mere power i den del, som som mere kan præge hvad retning udvikling kommer til at gå i, og Jeg tror for Vores vedkommende bliver det nok mere at at følge det og gøre klar på at adoptere de ting for teknologien vi kan være med i. Og stille om på de ting, hvor vi kan være med i den del. 2 år siden troede vi alle sammen skal brænde brint. Men vi kan ikke printe til en pris, hvor Der er nogen der køber mursten.

Jonas Bønsø 27:08
Vi kan ikke producere brint til nogen, der vil købe. Alligevel kan jeg forstå på det, men.

Jonas Bønsø 27:13
Tysk vil ikke engang have det alligevel. i hvert fald ikke hele. Så ja, Det er lidt svært at sige, og derfor vil gerne kunne være med til at sætte en målsætning omkring det, men Det er så usikkert Og Det er Sådan nogle forholdsvis store investeringer og vi Vi er ude og snakke i, så vi kommer ikke. Vi kommer ikke til at være foregang på det. Vi kommer til at følge det og vil gerne være med i en masse forsøg. Og dele en masse viden omkring det.

Frederik Botin Carøe Villum 27:42
Ja det giver også mening. Det er måske også det kommer lige lidt ligesom det med med Anders kom til os og sagde at det så er lidt samtaler med teknisk Institut omkring. Kunne det her være en løsning eller man snakker med ja nogle unuversiteter eller lignende omkring ja hvad hvad kunne fremtiden indeholde og det vil man kunne måske også forestille sig at at Sådan nogle sådanne aktører vil. Eller Det er måske lidt ledende spørgsmål, men kunne du kunne det være Sådan nogle der også vil blive inddraget i forbindelse med en omlægning?

Jonas Bønsø 28:09
Ja det kunne det godt være. Jeg mødte egentlig Anders via teknologisk Institut de havde et projext med sintex. Det har han sikkert fortalt om. Som har lavet det her varmelegeme. Og Det var lidt det der skete for os. Altså vi Jeg vil gerne være med og vil gerne dele viden og Sådan nogle ting, men det projekt Det sprang vi ud af igen, fordi det røg over i. Vi havde en ret stor egenbetaling for at Vi skal varme noget luft op og ser man rent el frem for biogas. Og biogas er regnet som co2 neutral og el regnes som co2 neutral, så den eneste gevinst vi kunne have på det. Det var lidt storytelling og så måske bare forskellen i prisen som er det der skulle betale den her investering hjem.

Jonas Bønsø 29:01
Og allerede der, der kommer det til at halte lidt. Det er så store investeringer vi skulle ud og investere i forsyningsanlæg og Sådan nogle ting i store størrelser på elsiden. Og så derfor. Vi vi kan ikke rulle det ud altså vi taler teglværks branchen er ikke stor nok til at bære Sådan en stor omkostning bagefter, hvor Der er måske nogle større aktører i Europa stål og cement måske. som bedre kan kan gabe over den største investering var med til at udvikle projekter.

Jonas Bønsø 29:40
Det er ikke fordi vi vil være med i det der, men vi kan ikke lige smide så mange penge i puljen.

Frederik Botin Carøe Villum 29:43
Nej nej, det giver det bedre mening at man så bare følger med i processen og selv se når der kommer noget der.

Jonas Bønsø 29:48
Ja vi kan levere knowhow, og vi kan mandetimer og vi kan levere ja ligesom jeg gjort til jer her Sådan set.