AVANCERET ENERGILAGRING KONFERENCE

BOOK OF PRESENTATIONS

TEKNOLOGISK INSTITUT

TAASTRUP - 9. MARTS 2023

AVANCERET ENERGILAGRING KONFERENCE

VELKOMMEN

DAVID TVEIT & ANDERS CHRISTIAN SOLBERG JENSEN
TEKNOLOGISK INSTITUT

TAASTRUP - 9. MARTS 2023

AVANCERET ENERGILAGRING 2023

Konferencier:
Anders Christian Solberg Jensen, Teknologisk Institut

- 09.30: **Velkomst** v/David Tveit, Teknologisk Institut
- 09.40: **(Avanceret) Energilagring – hvorfor, hvor meget, hvordan?** v/Gunnar Rohde, Teknologisk Institut
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  - **Beton-laboratoriet** (divisionen for Byggeri og Anlæg), hvor du introduceres til de forskellige laboratoriefaciliteter og får et indblik i aktuelle aktiviteter.
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Seminar om Avanceret Energilagring

AVANCERET ENERGILAGRING KONFERENCE 2023

13. december 2012 kl. 12.00 – 16.30

Teknologisk Institut, Kongsvang alle 29, Aarhus, Konferencesalen.
Der startes med en sandwich og matchmaking

Det danske energisystem er unikt på grund af den store andel af vedvarende energi (VE) og en bredt distribueret elproduktion. Men med den langsigtede politiske målsætning om 100 % VE i energisystemet, hvor fossile energikilder kun vil blive anvendt i spidsbelastningssituationer og i nødstilfælde, bliver andelen af fluktuerende elproduktion meget udtalt.
Løsningen på denne udfordring er avancerede lagringsteknologier i forbindelse med intelligente distributionssystemer.

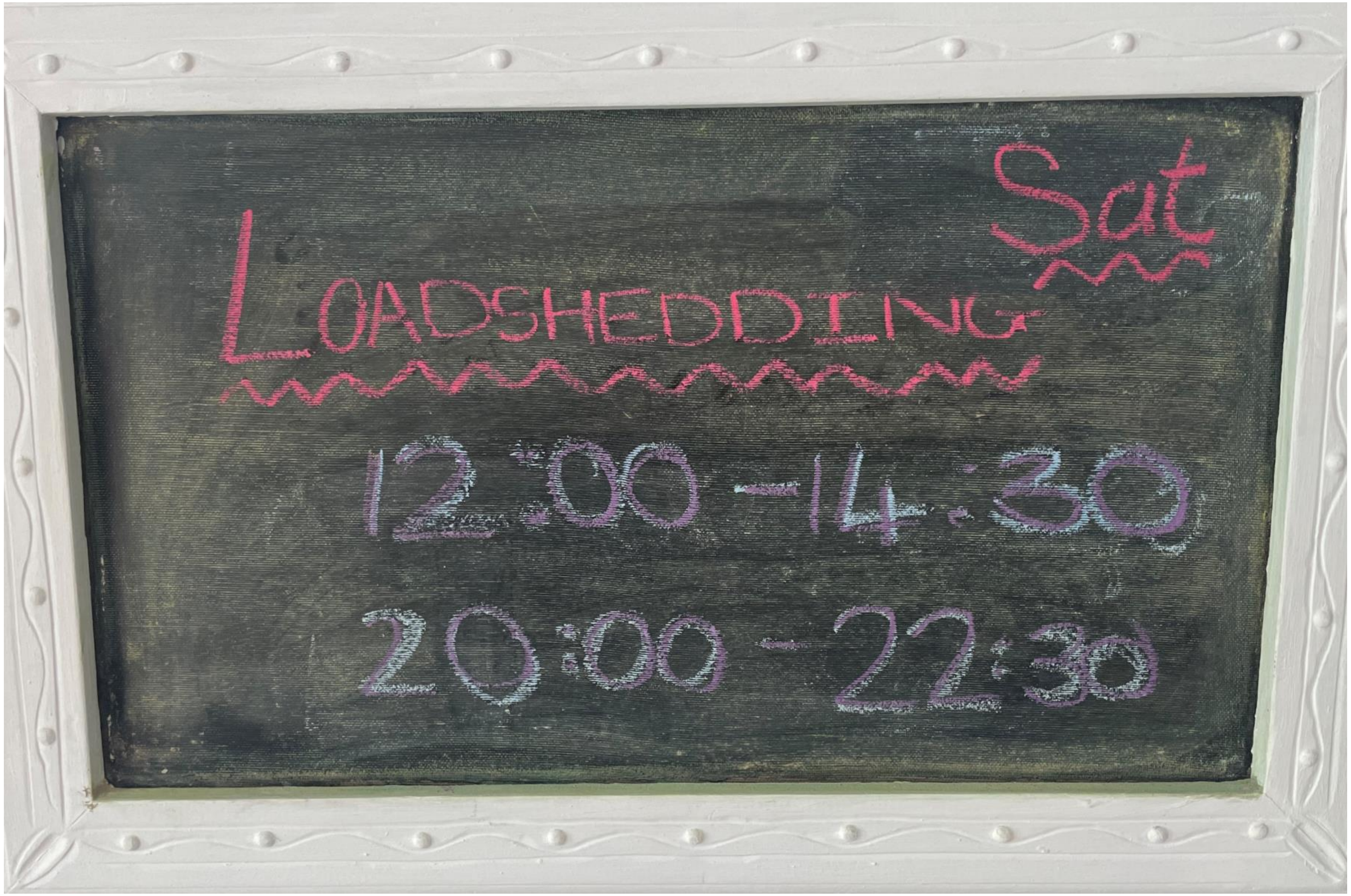
I dette seminar vil mange af de energilagringsløsninger der er mulige i dag, samt nye løsninger der er undervejs blive introduceret og belyst.

Program:

12.00 – 12.20 Sandwich og mulighed for matchmaking

12.20 – 12.30 Velkomst og introduktion, v/ teknologichef Frank Elefsen, Teknologisk Institut

12.30 – 12.50 Behov for regulering i fremtidens elsystem, v/ Anders Bavnhøj Hansen, energinet.dk


LOADSHEDDING
Sat
12:00 - 14:30
20:00 - 22:30

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Samarbejde om fremtidens behov

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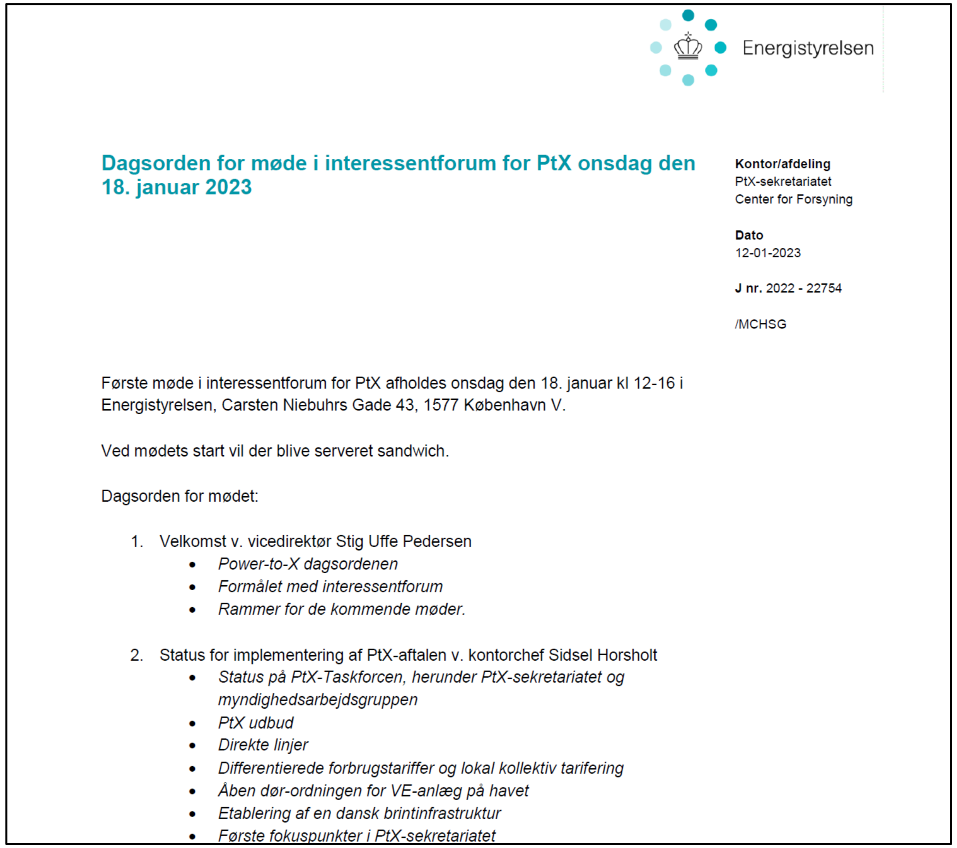


Energistyrelsen

Dagsorden for møde i interessentforum for PtX onsdag den 18. januar 2023

Kontor/afdeling
PtX-sekretariatet
Center for Forsyning

Dato
12-01-2023

J nr. 2022 - 22754

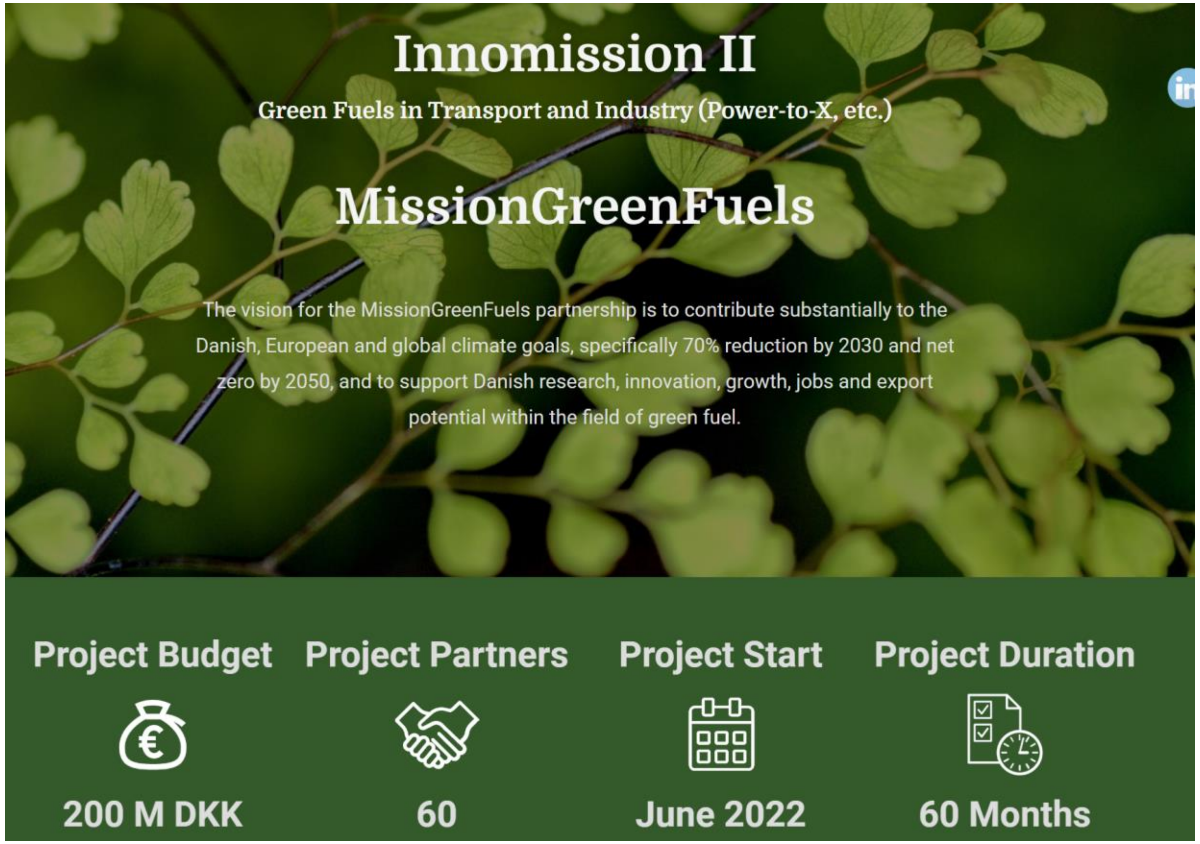
/MCHSG

Første møde i interessentforum for PtX afholdes onsdag den 18. januar kl 12-16 i Energistyrelsen, Carsten Niebuhrs Gade 43, 1577 København V.

Ved mødets start vil der blive serveret sandwich.

Dagsorden for mødet:

1. Velkomst v. vicedirektør Stig Uffe Pedersen
   - *Power-to-X dagsordenen*
   - *Formålet med interessentforum*
   - *Rammer for de kommende møder.*
2. Status for implementering af PtX-aftalen v. kontorchef Sidsel Horsholt
   - *Status på PtX-Taskforcen, herunder PtX-sekretariatet og myndighedsarbejdsgruppen*
   - *PtX udbud*
   - *Direkte linjer*
   - *Differentierede forbrugstariffer og lokal kollektiv tarifering*
   - *Åben dør-ordningen for VE-anlæg på havet*
   - *Etablering af en dansk brintinfrastruktur*
   - *Første fokuspunkter i PtX-sekretariatet*



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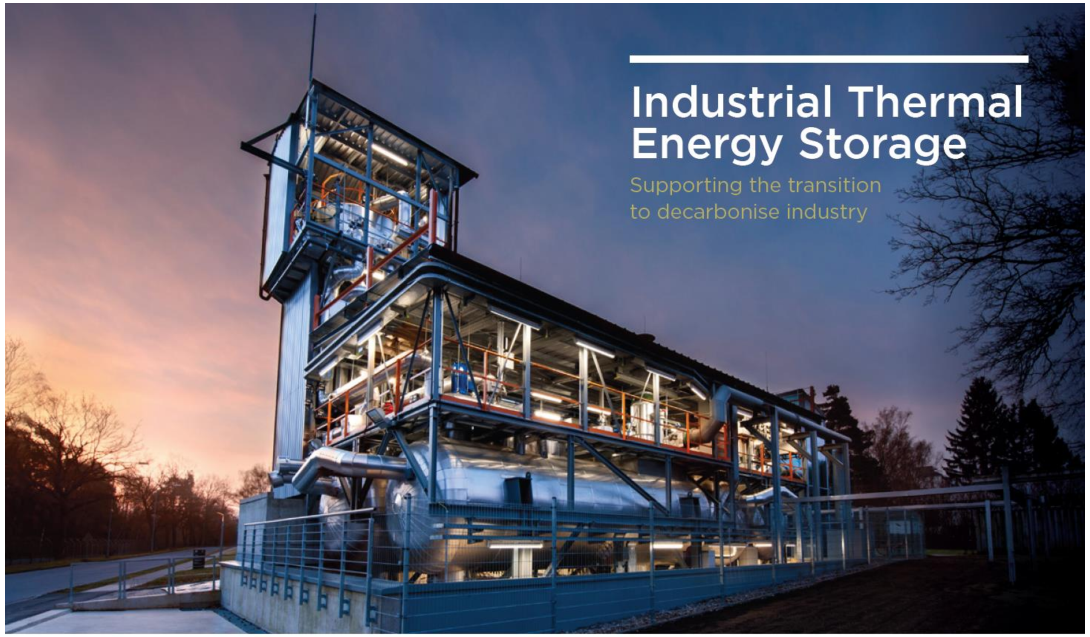

EERA
European Energy Research Alliance
Energy Efficiency in Industrial Processes

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DTU
UNIVERSITAT POLITÈCNICA DE VALÈNCIA
NTB Interstaatliche Hochschule für Technik Buchs
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(AVANCERET) ENERGILAGRING - HVORFOR, HVOR MEGET, HVORDAN?

GUNNAR ROHDE
TEKNOLOGISK INSTITUT

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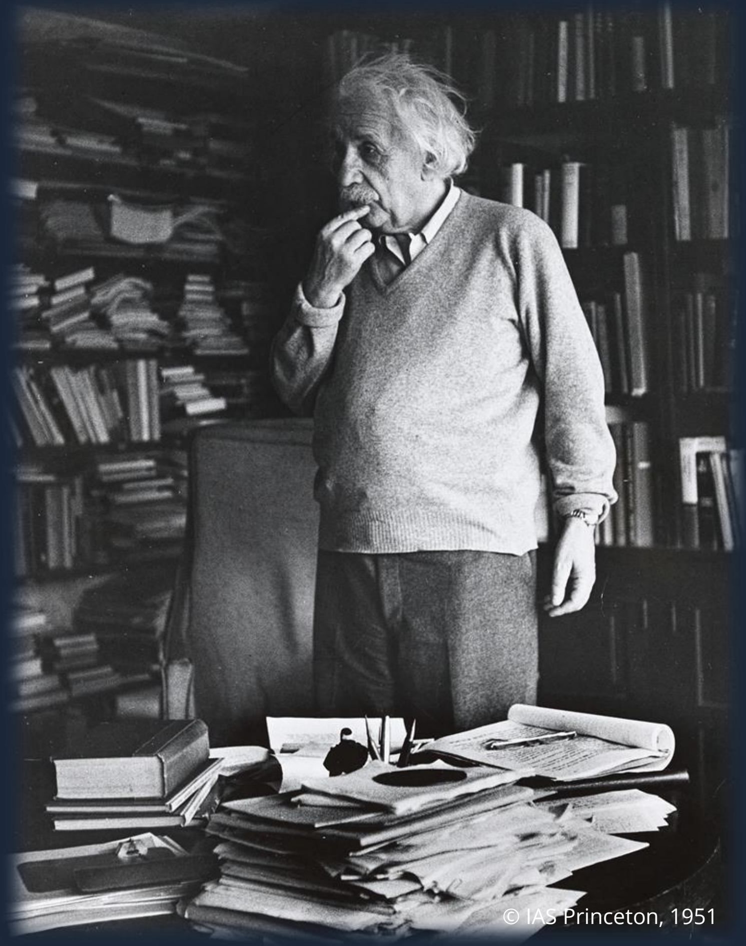
Gunnar Rohde | 09.03.2023

Agenda

- What makes energy storage advanced?
- Why energy storage shall be advanced?
- How (much) to advance energy storage?



Uddannelses- og Forskningsstyrelsen

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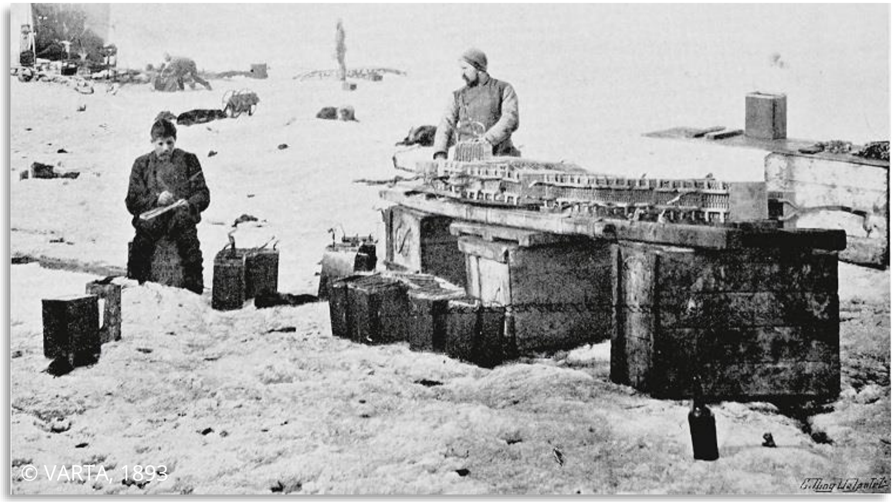
Energy storage is not a new thing

© Ruud, 1880


© NEL, 1927


© VARTA, 1893


© Schmid, 1899

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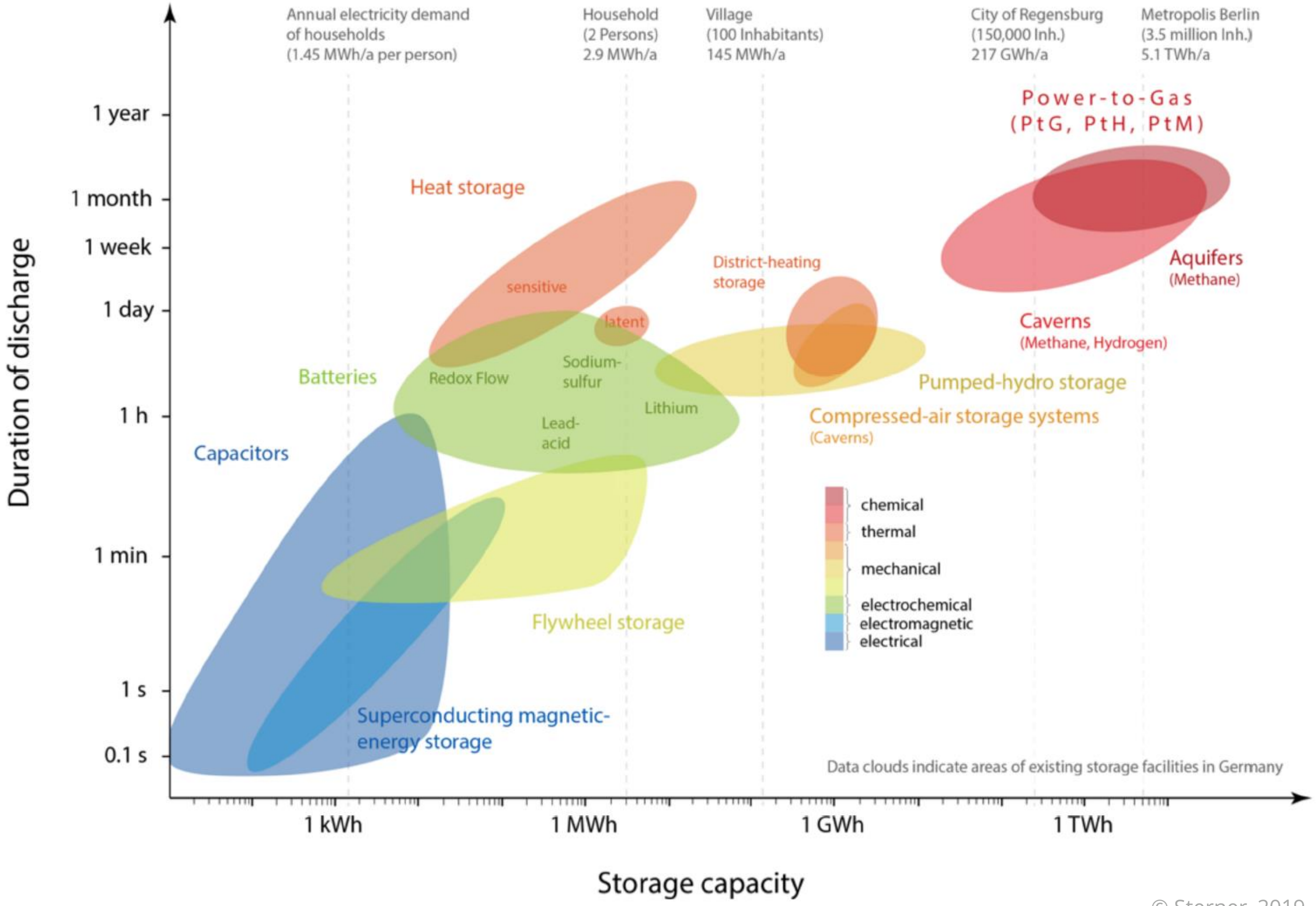
And it is still the same technologies



- A variety of energy storage technologies available
- All energy and power capacities are well represented
- Energy storage technologies complement and supplement each other

- *Only* ecological and economically efficient system integration missing

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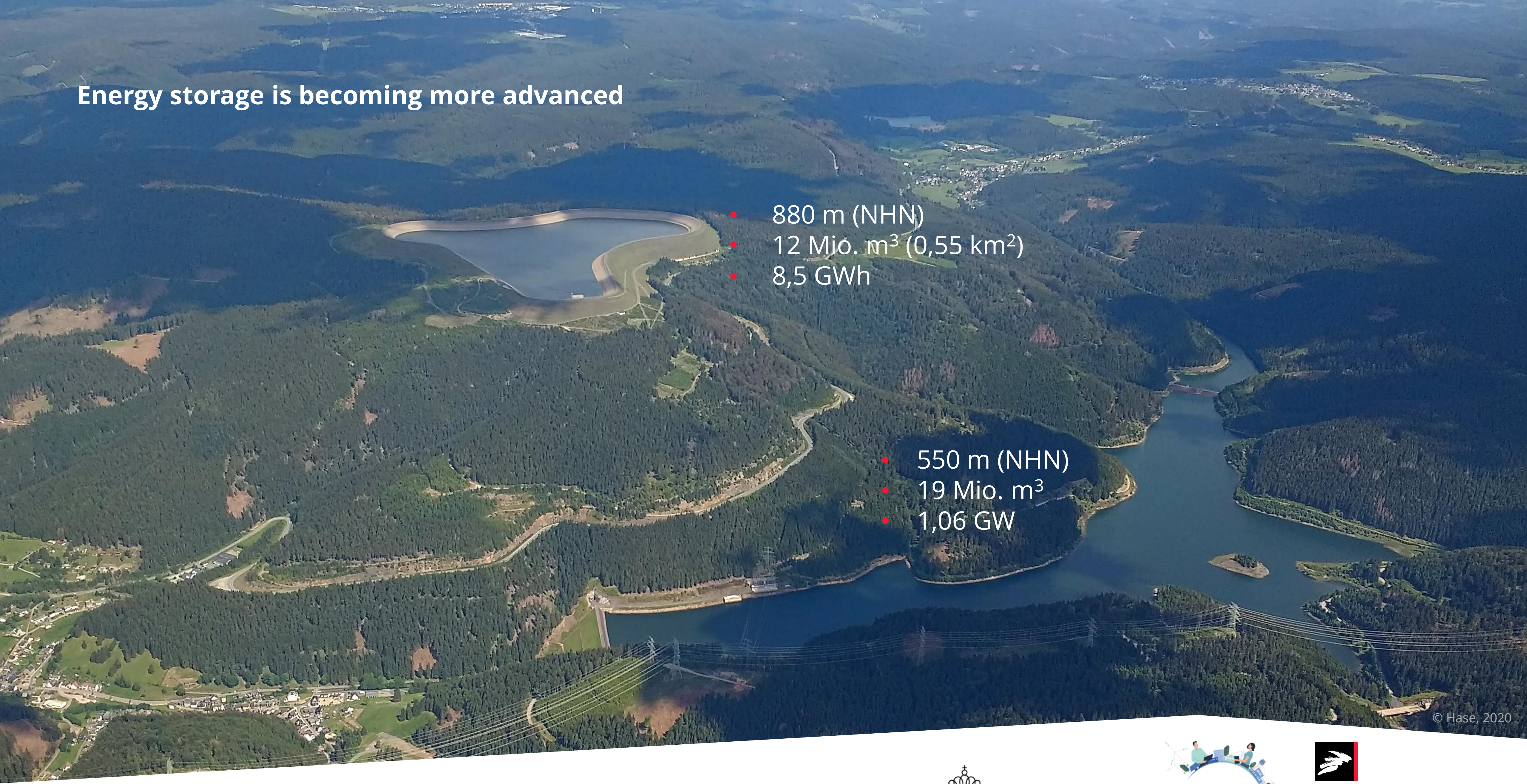
Energy storage is becoming more advanced



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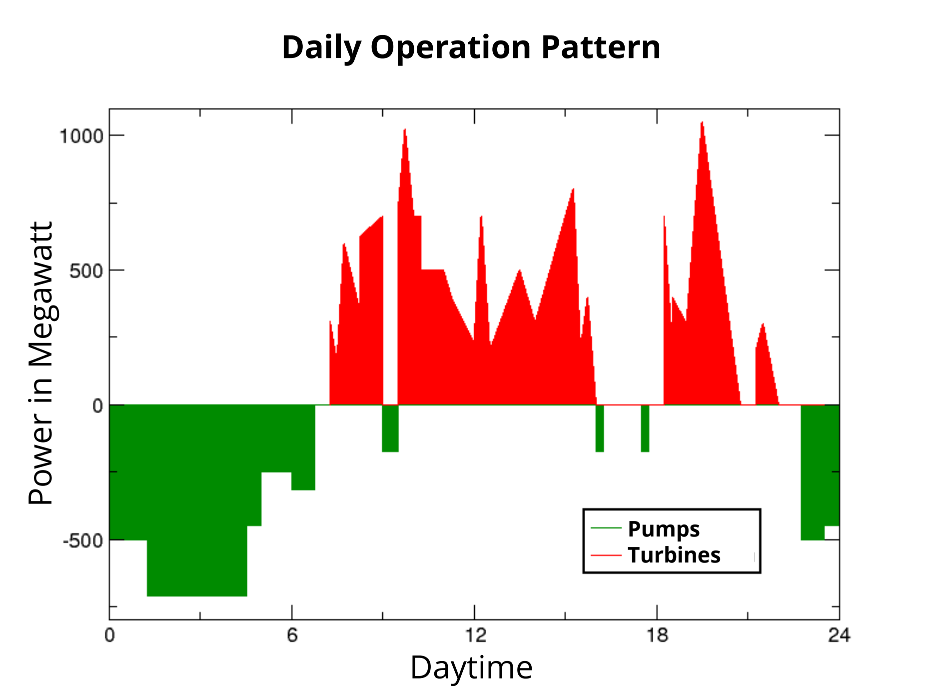
Classical pumped hydro power plant

- Independent pumps and turbines
- Pumps not adjustable (on/off)



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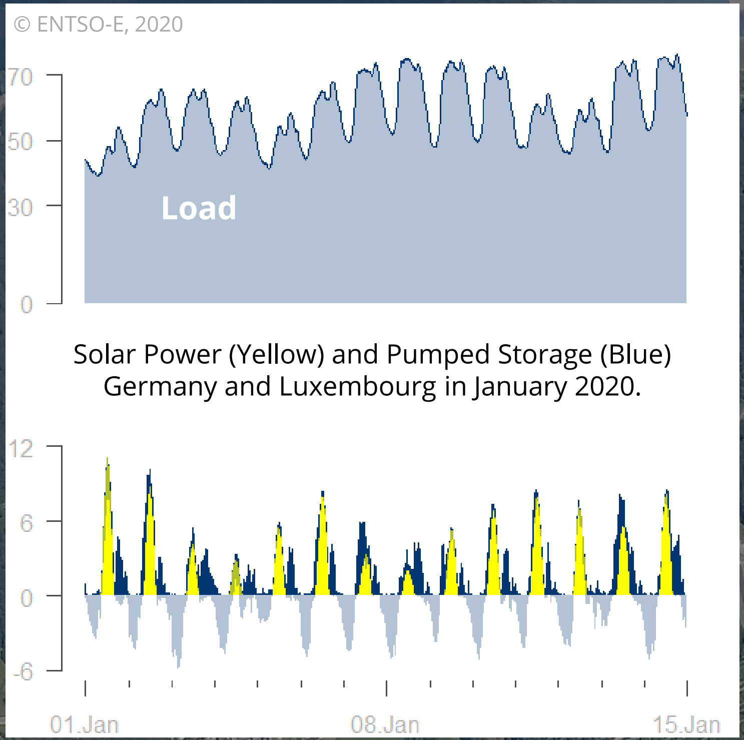
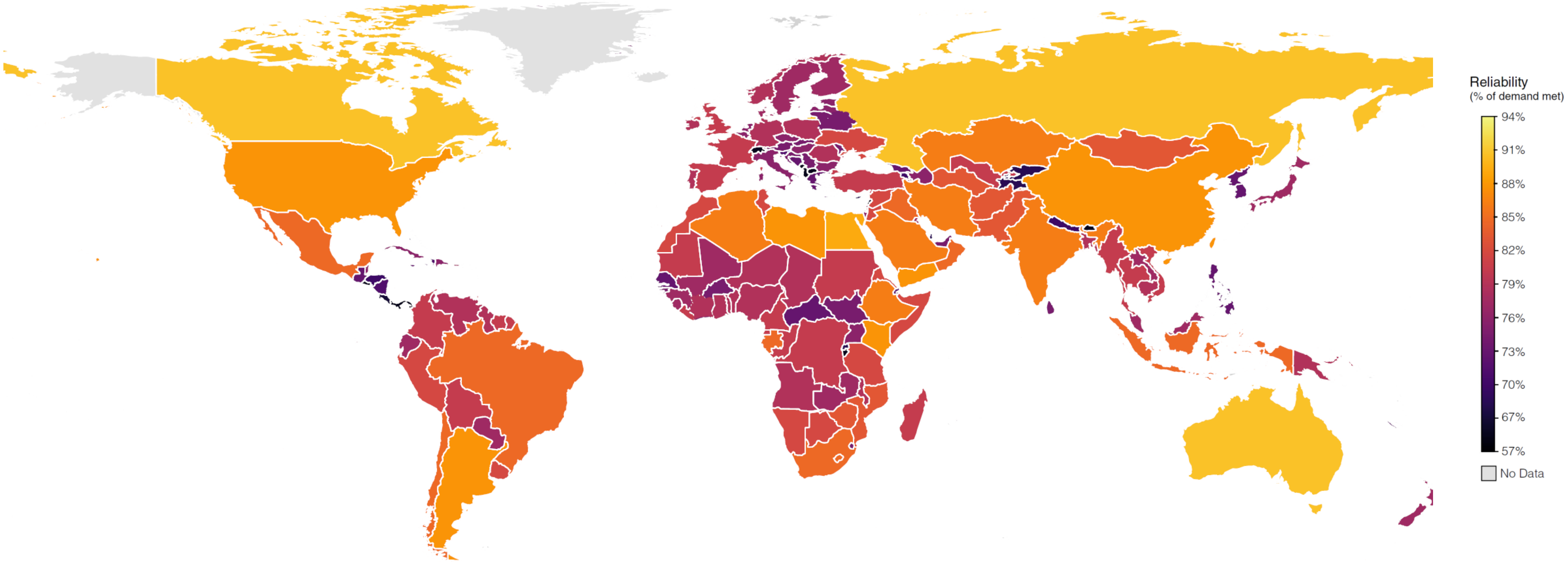
Advanced pumped hydro power plant

- Pumps and turbines fully coupled
- Pumps fully adjustable (2 of 4)



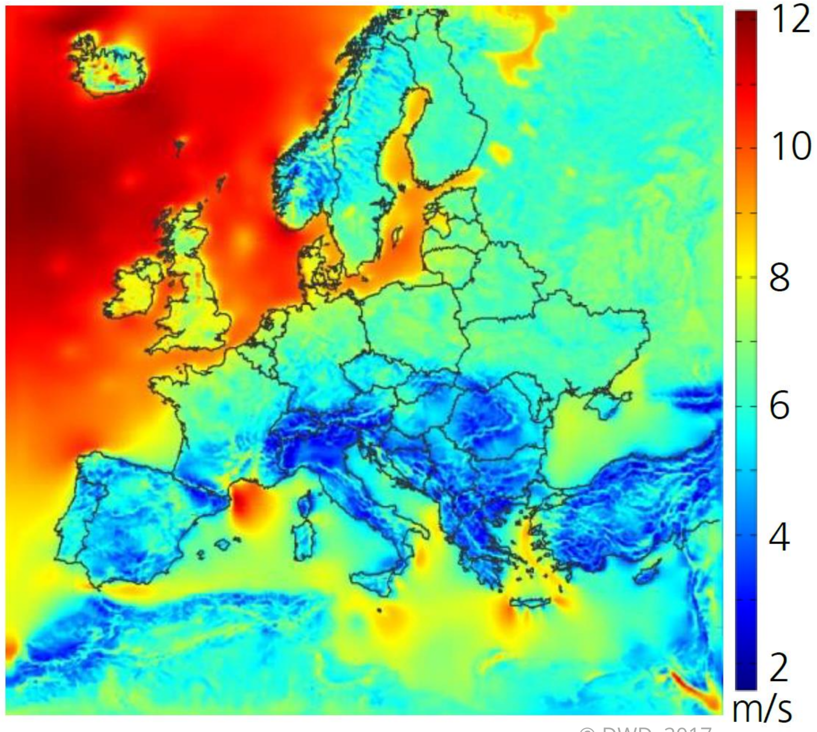
Solar Power (Yellow) and Pumped Storage (Blue)
Germany and Luxembourg in January 2020.

Reliability of solar and wind power recommends energy storage

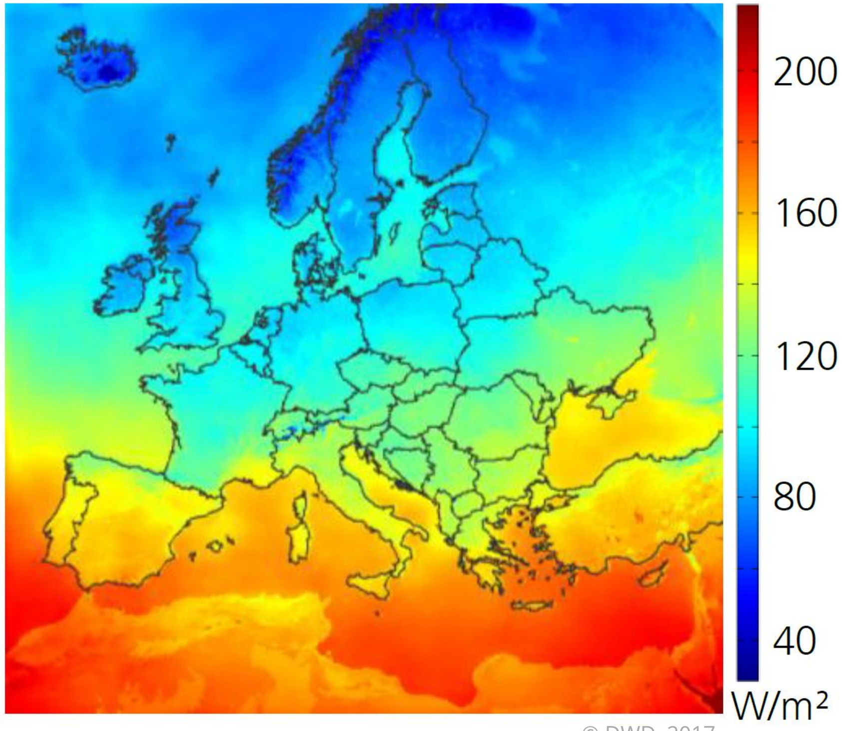


Solar and wind power in Europe is clearly inhomogeneous

Average Wind Speed 2007 - 2017



Average Solar Radiation 2007 - 2017



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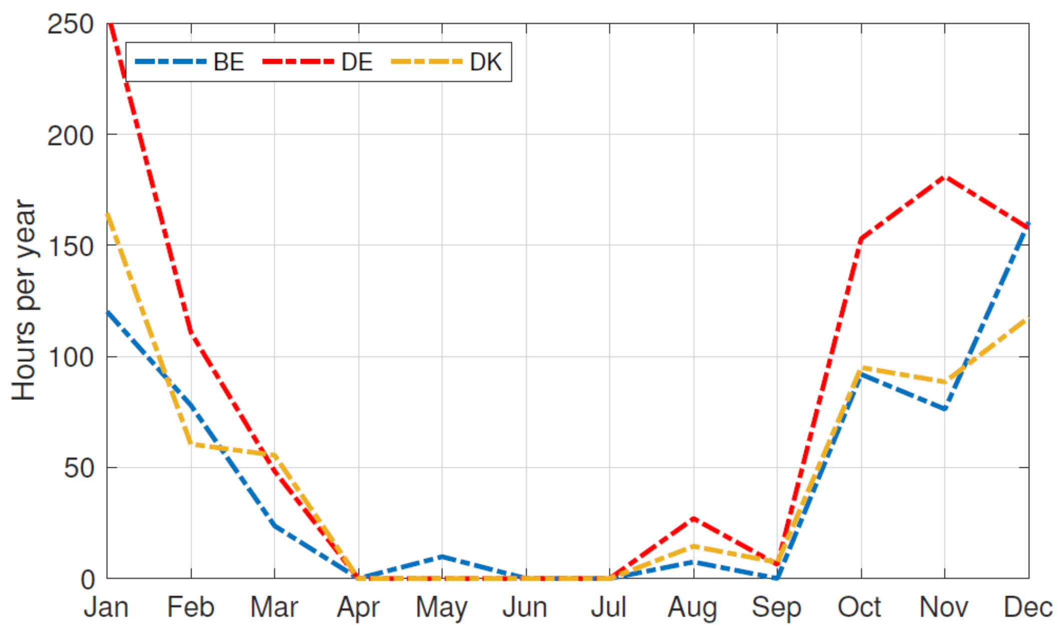
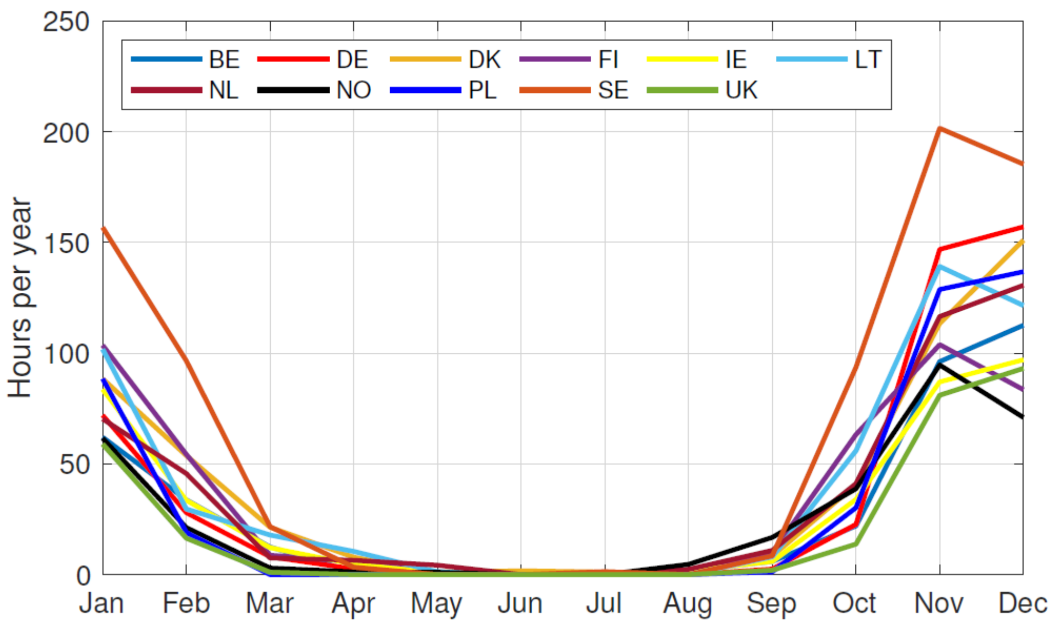
And at the end there is still the *Dunkelflaute*

ENTSO-E Data Average 2015 - 2018



Renewable.Ninja Simulation Average 2019 - 2039



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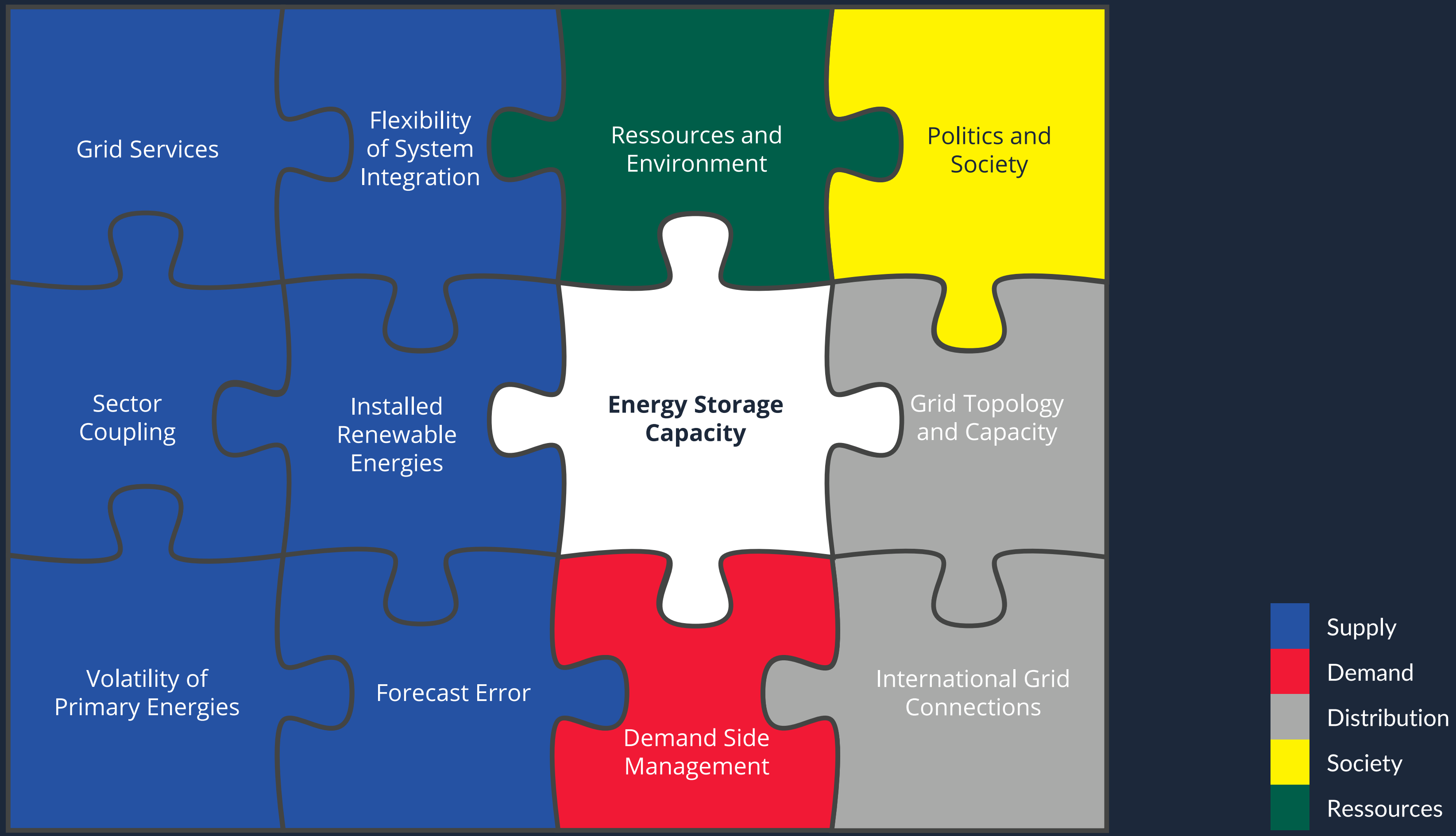
Advanced energy storage is a complex puzzle



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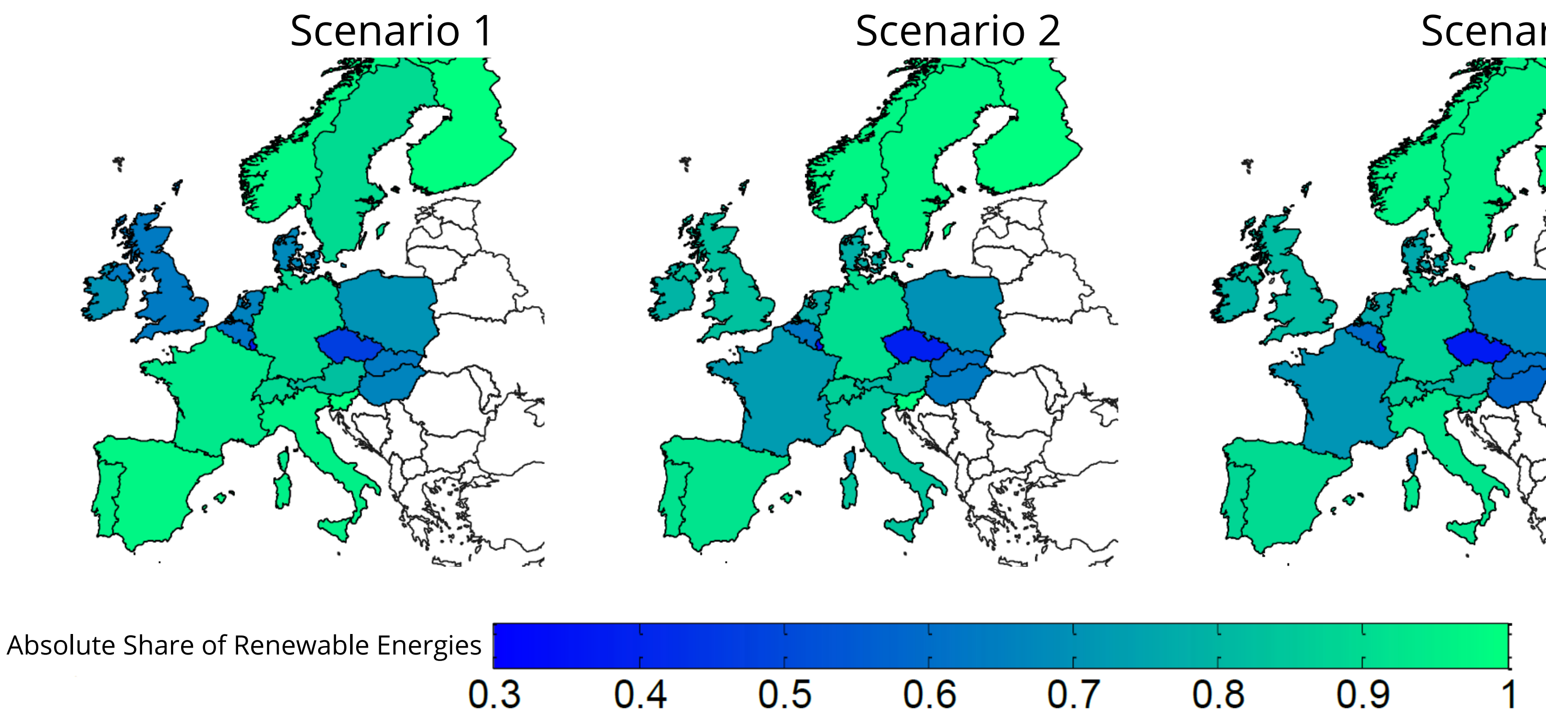
Many different development scenarios are possible



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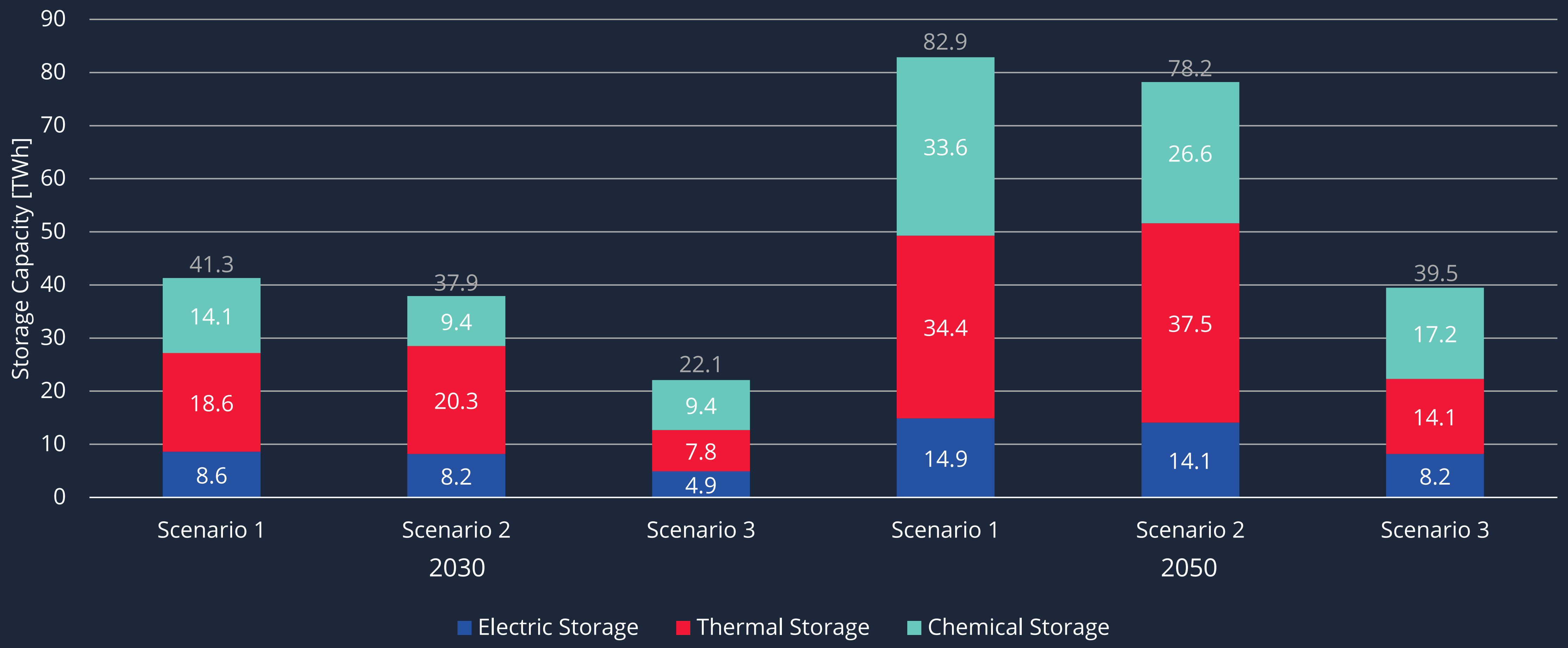
The specific demand for energy storage can be estimated



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Conclusion

- What makes energy storage advanced?
  - Advanced energy storage acts as an exergy prosumer in smart grids
  - Advanced energy storage reduced the environmental impact of renewable energies
- Why energy storage shall be advanced?
  - Smart grids with high share of renewable energies require temporal flexibility
  - Reliability of solar and wind power alone is not sufficient
- How (much) to advance energy storage?
  - Exergetic efficiency of renewable primary energies shall be maximised
  - 40 TWh advanced energy storage is a fair share for Denmark (2.5 PWh worldwide)

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Thanks! *Questions?*

Backup – If you want to see the numbers

Lithium Batteries

- Capacity: **kWh – MWh**
- Efficiency: **80 – 95 %**
- Cost: **250 – 500 €/kWh**

Pumped Hydro

- Capacity: **MWh – GWh**
- Efficiency: **75 – 85 %**
- Cost: **70 – 350 €/kWh**

Compressed/Liquified Air

- Capacity: **GWh – TWh**
- Efficiency: **40 – 70 %**
- Cost: **50 – 150 €/kWh**

Thermal Storage

- Capacity: **MWh – GWh**
- Efficiency: **30 – 60 %**
- Cost*: **2/10 – 50 €/kWh**

Power-to-Gas/Liquid

- Capacity: **GWh – TWh**
- Efficiency: **25 – 45 %**
- Cost: **5 – 25 €/kWh**

Flywheels

- Capacity: **kWh – MWh**
- Efficiency: **85 – 95 %**
- Cost: **150 – 250 €/kWh**

Supercapacitors

- Capacity: **Wh – MWh**
- Efficiency: **85 – 95 %**
- Cost: **< 50.000 €/kWh**

Worldwide Energy Storage Capacity

- Excl. pumped hydro: **34 GWh**
- Incl. pumped hydro: **2.2 TWh**
- Needed: **1 PWh**

Gravitational Storage

- Capacity: **MWh**
- Efficiency: **85 – 90 %**
- Cost: **150 – 250 €/kWh**

Carbon-Equivalent Footprint

- Energy Storage: **104 – 407 kg/MWh**
- Coal: **740 – 910 k/MWh**
- Natural Gas: **410 – 650 kg/MWh**
- Solar Power: **6 – 180 kg/MWh**
- Wind Power: **8 – 56 kg/MWh**

Energy Densities

- Gasoline: **13 kWh/kg**
- Natural Gas: **11 kWh/kg**
- Coal: **8 kWh/kg**
- Lithium Battery: **0.2 kWh/kg**
- Pumped Hydro: **0.003 kWh/kg** (@ 1 km)
- Nuclear Fission: **25 GWh/kg**
- Nuclear Fusion: **3.4 TWh/kg**
- Matter/Antimatter: **25 TWh/kg**

* Cost from 2 €/kWh as pure thermal storage and from 10 €/kWh when utilised as electric energy storage.

HØJTEMPERATURVARMEPUMPER - FØRSTE SKRIDT MOD DEMONSTRATION

WIEBKE BRIX MARKUSSEN
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HØJTEMPERATURVARMEPUMPER – FØRSTE SKRIDT MOD DEMONSTRATION

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9. MARTS 2023, TAASTRUP

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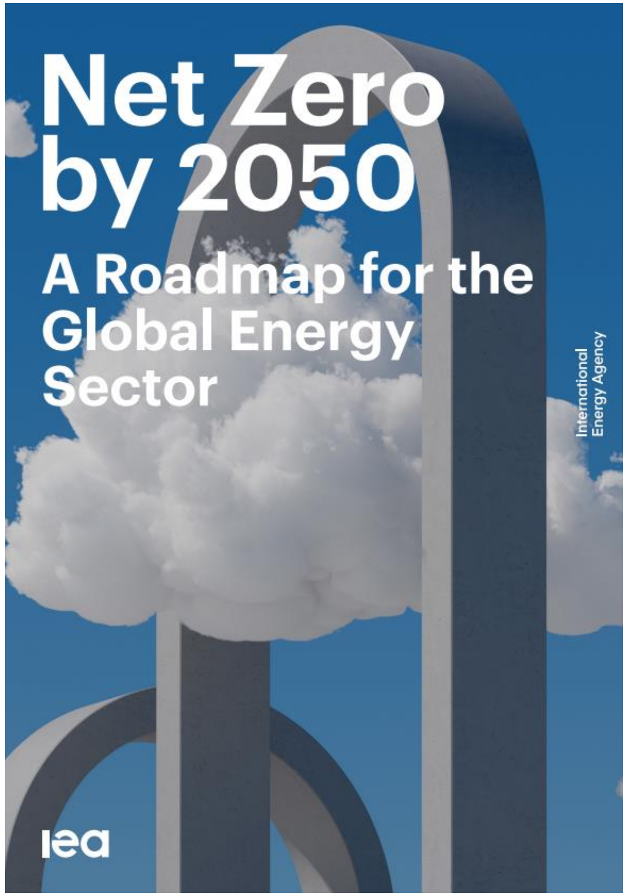
AGENDA

- Potentialer for høj-temperaturvarmepumper
- Varmepumper og termisk energilagring
- Igangværende demonstrationsprojekter ved TI
- IEA HPT Annex 58 on High Temperature Heat Pumps

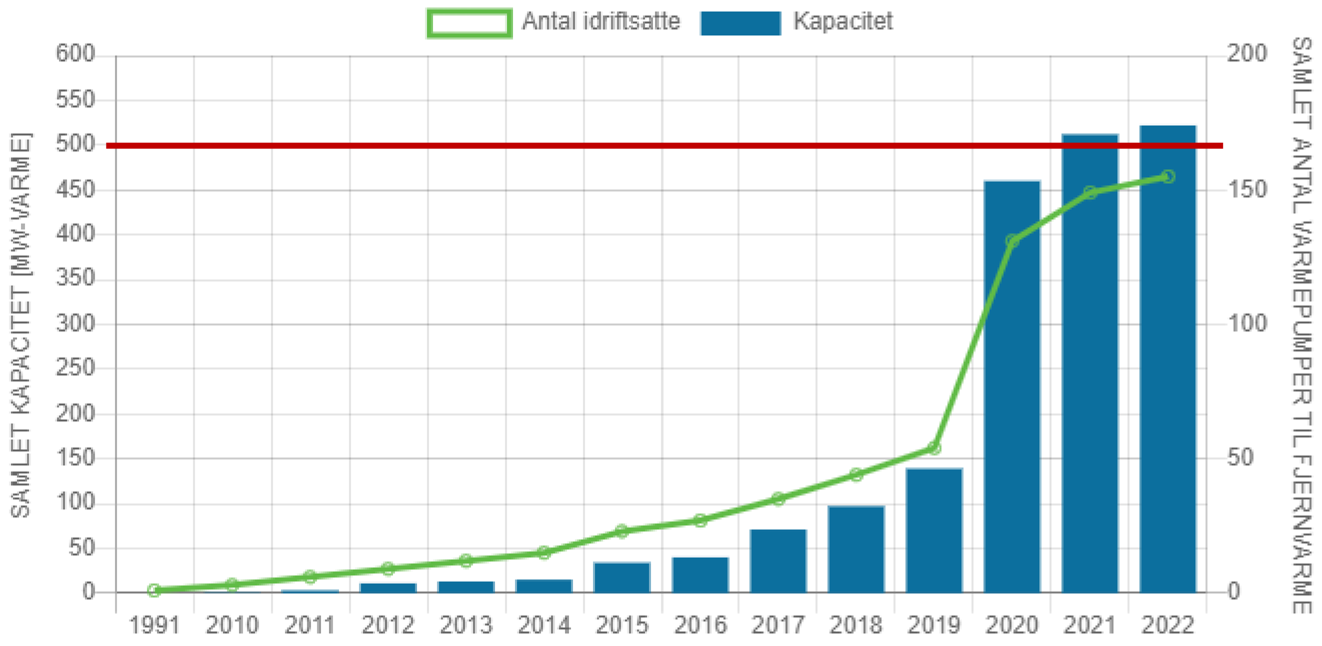
INTERNATIONAL ENERGY AGENCY - IEA



”Around 500 MW of heat pumps need to be installed every month over the next 30 years”

IEA (2021), Net Zero by 2050, IEA, Paris https://www.iea.org/reports/net-zero-by-2050, License: CC BY 4.0

STORE VARMEPUMPER I FJERNVARMEN I DK



Figur: https://varmepumpedata.dk/plants/

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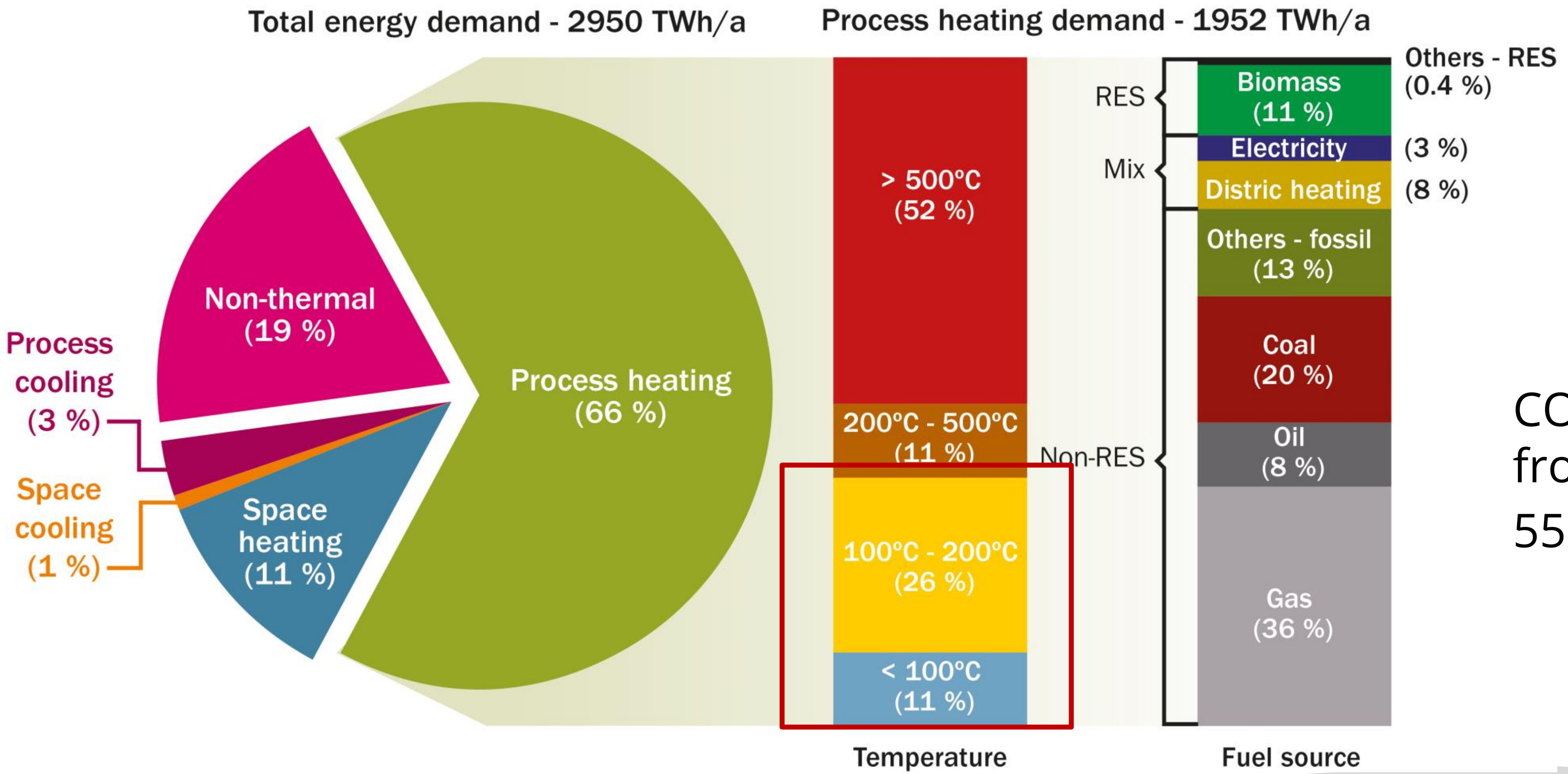
POTENTIAL FOR HTHPS – EU28



CO_2 emissions from Non-RES: 552 Mt/a

Figure based on Heat Roadmap Europe

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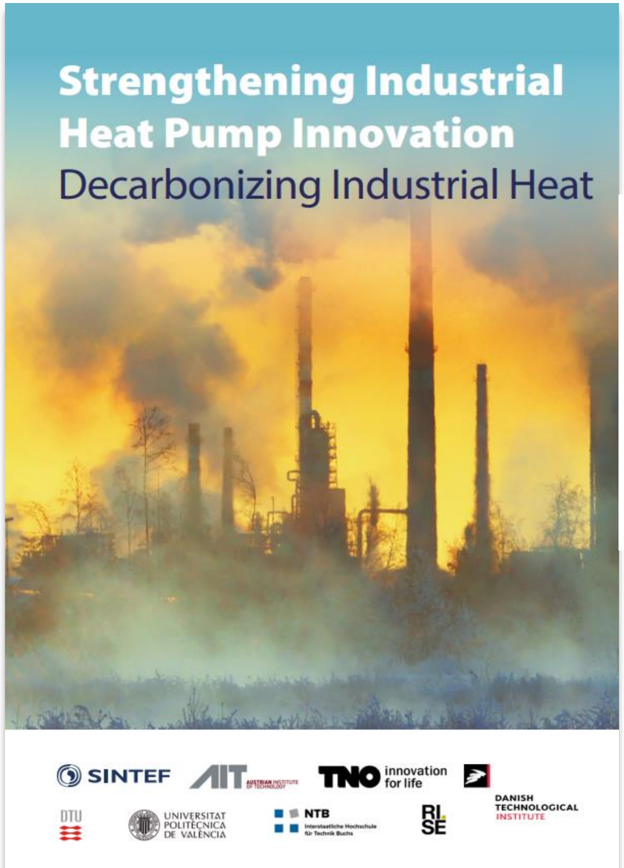
DECARBONIZING INDUSTRY



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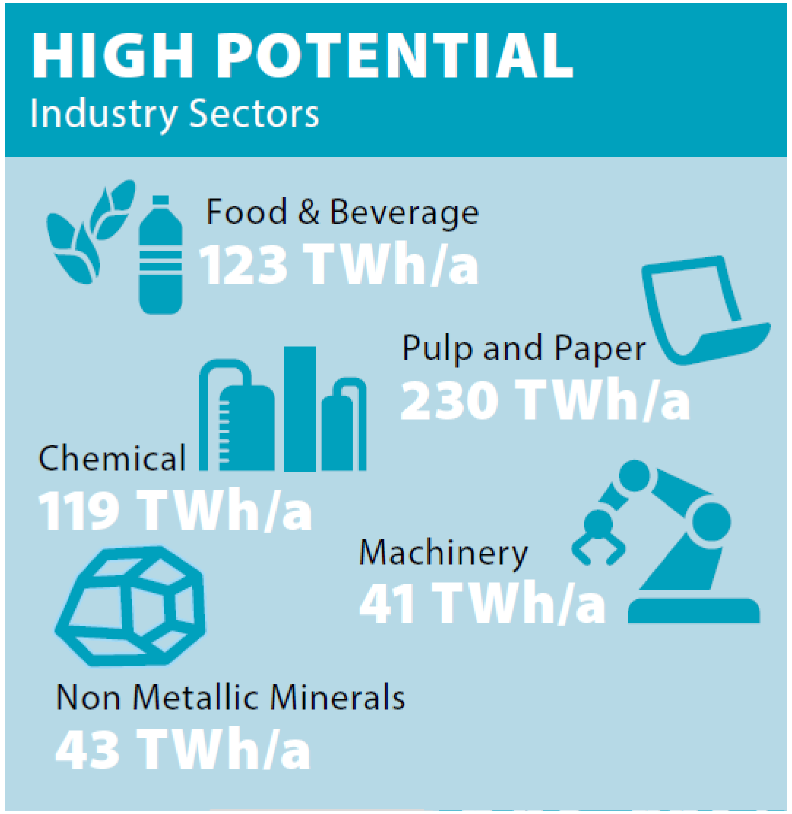
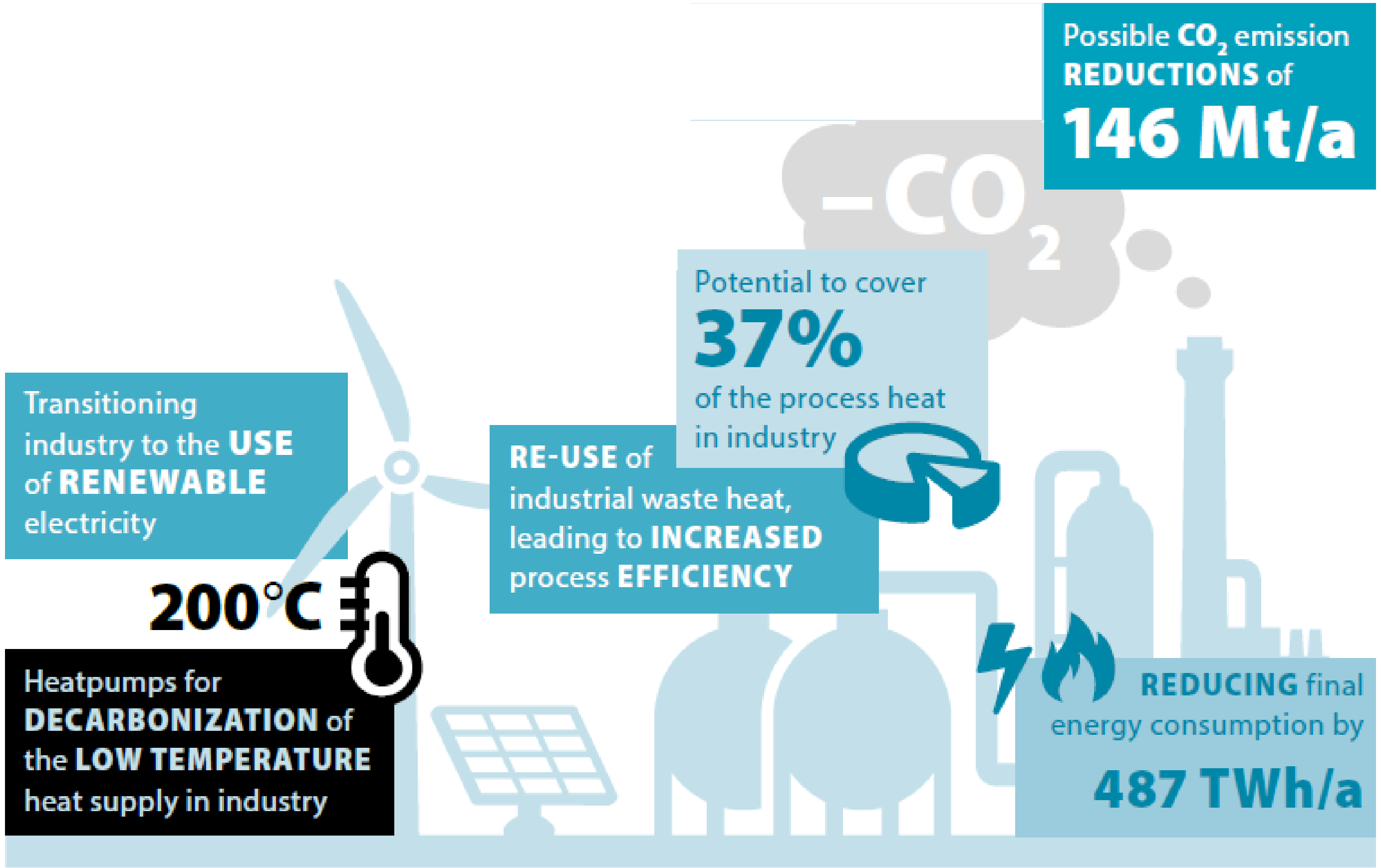
https://www.teknologisk.dk/white-paper-strengthening-industrial-heat-pump-innovation-decarbonizing-industrial-heat/43124

APPLICATION POTENTIALS





https://www.teknologisk.dk/white-paper-strengthening-industrial-heat-pump-innovation-decarbonizing-industrial-heat/43124

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HØJTEMPERATUR-VARMEPUMPER

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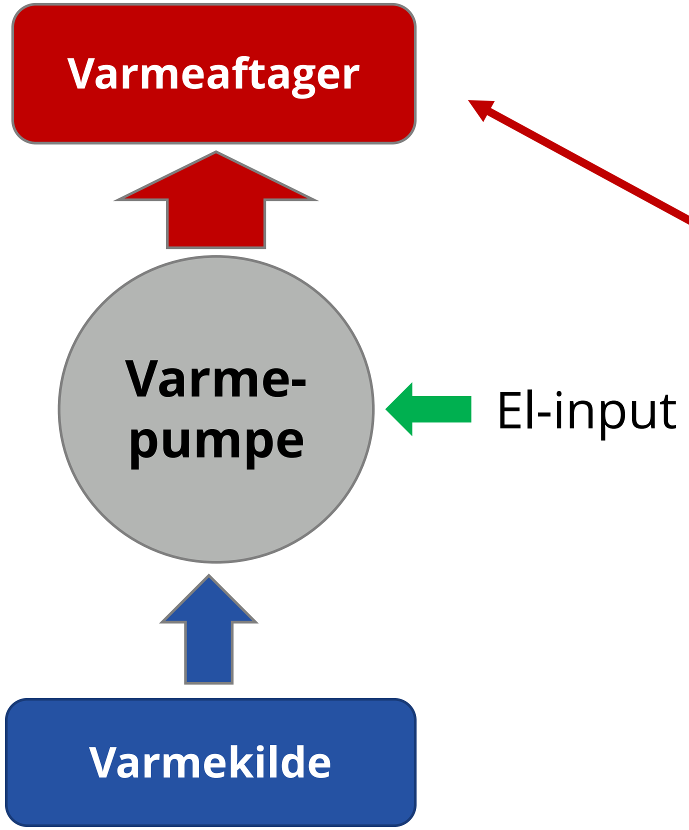
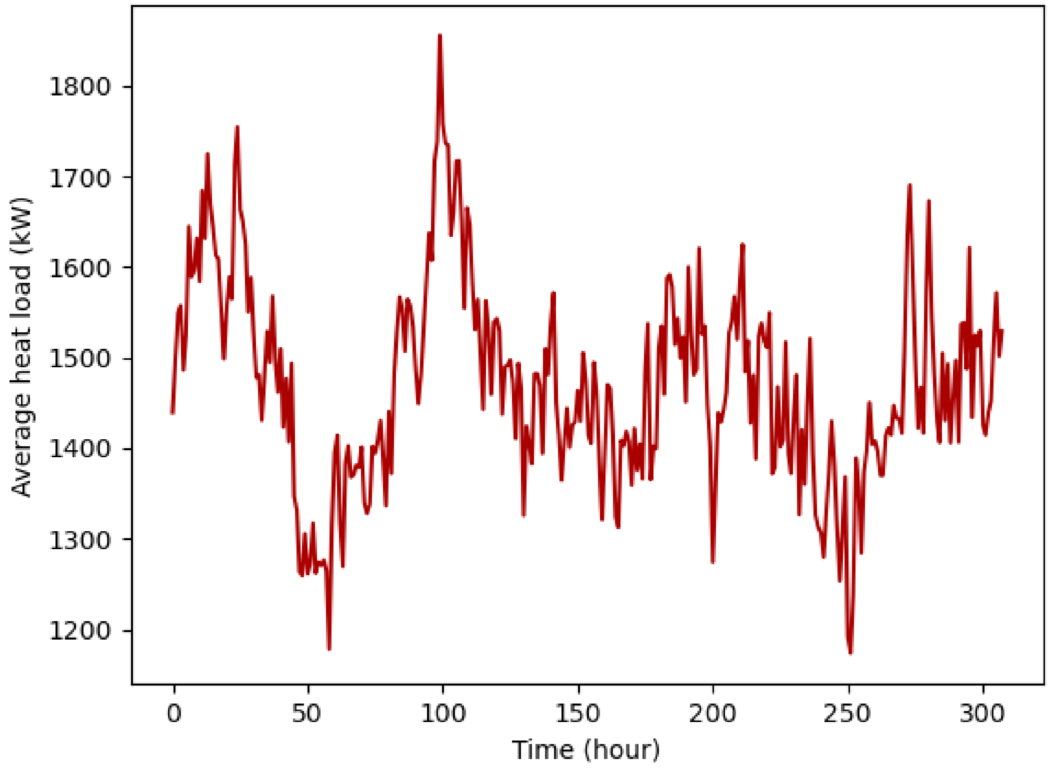
VARMEPUMPER I INDUSTRIEN



Eksempel: Varmebehov til industriel process



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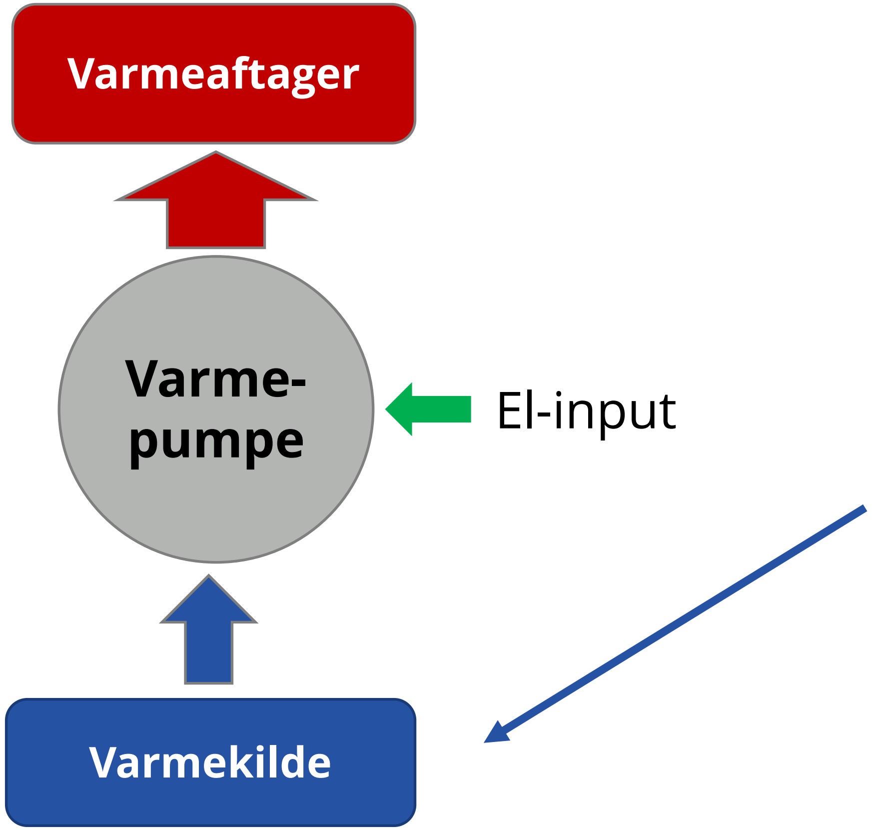
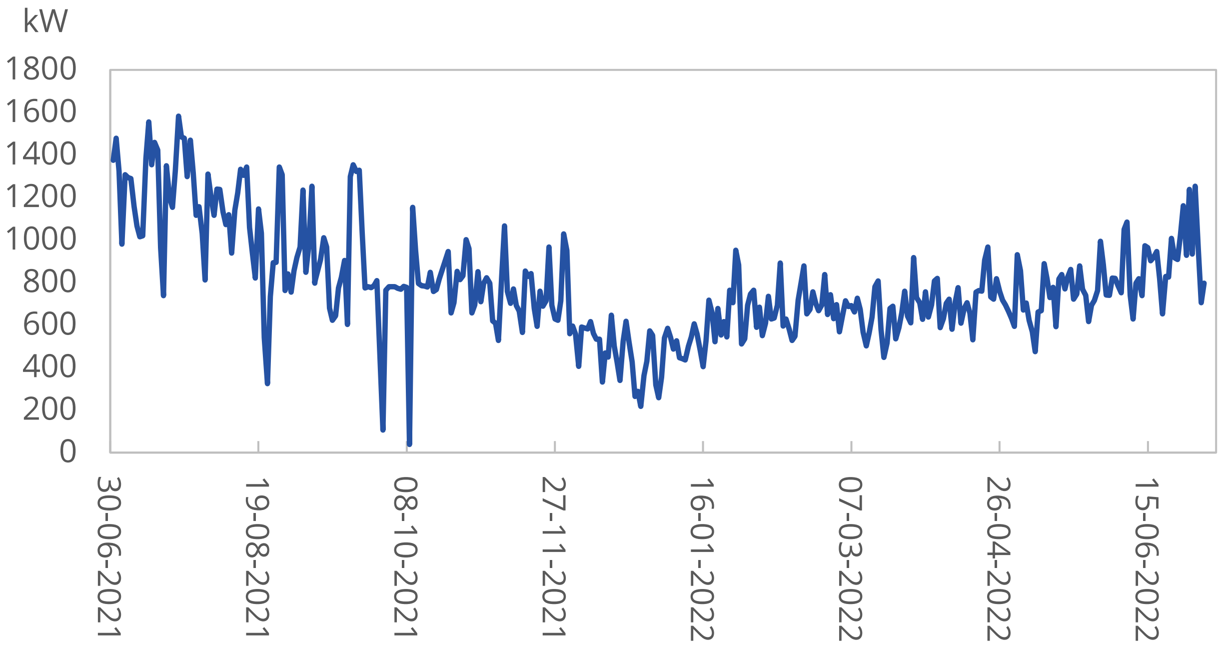
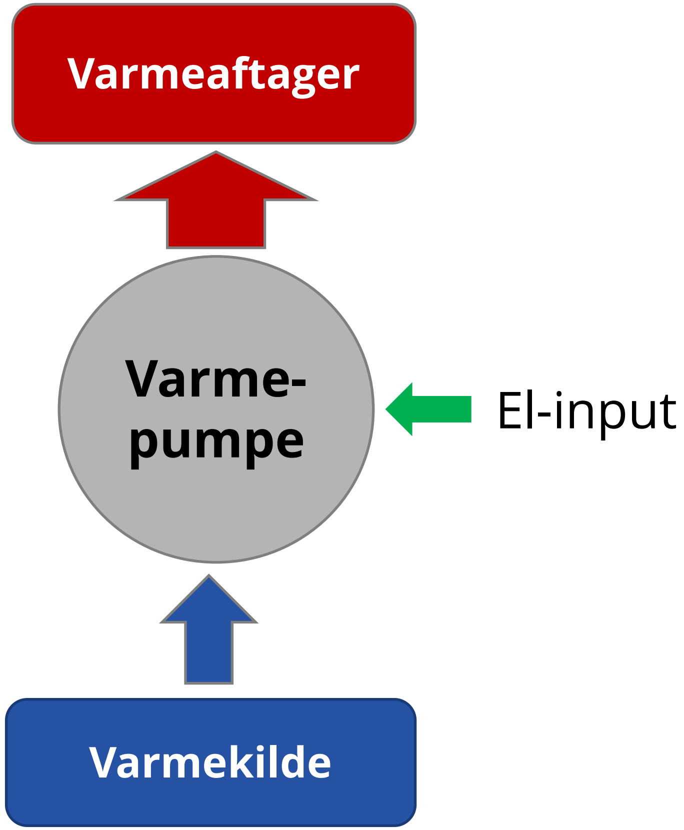
VARMEPUMPER INDUSTRIEN

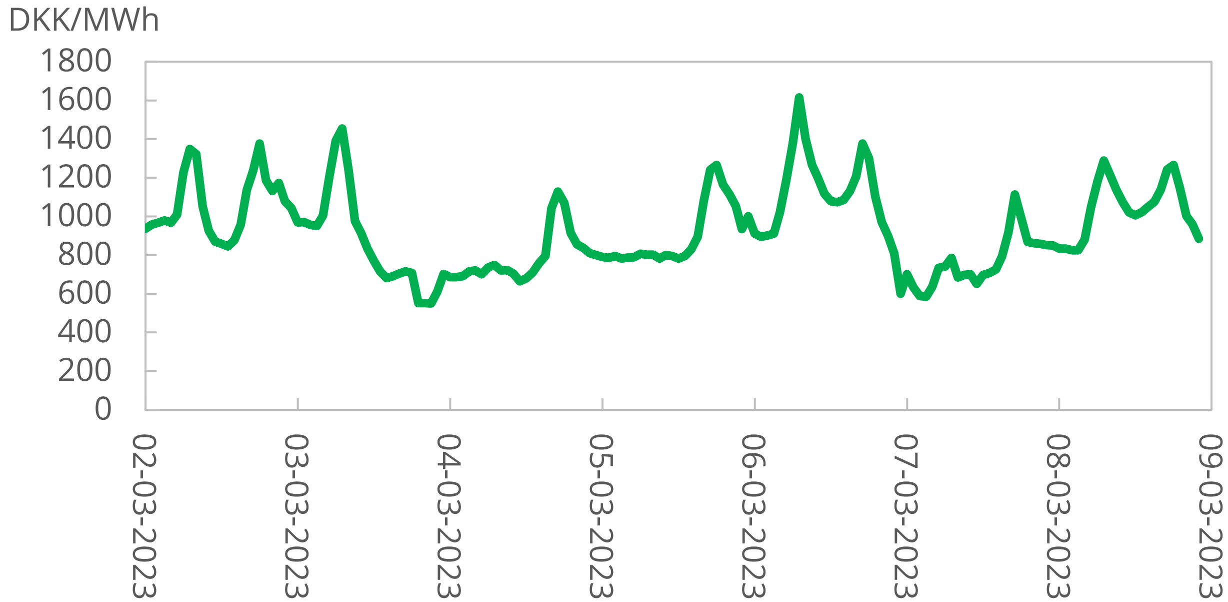


Eksempel:
Spildvarme fra køleanlæg



VARMEPUMPER I ET FLEKSIBELT ELMARKED





Nord-pool day ahead prices: www.nordpoolgroup.com

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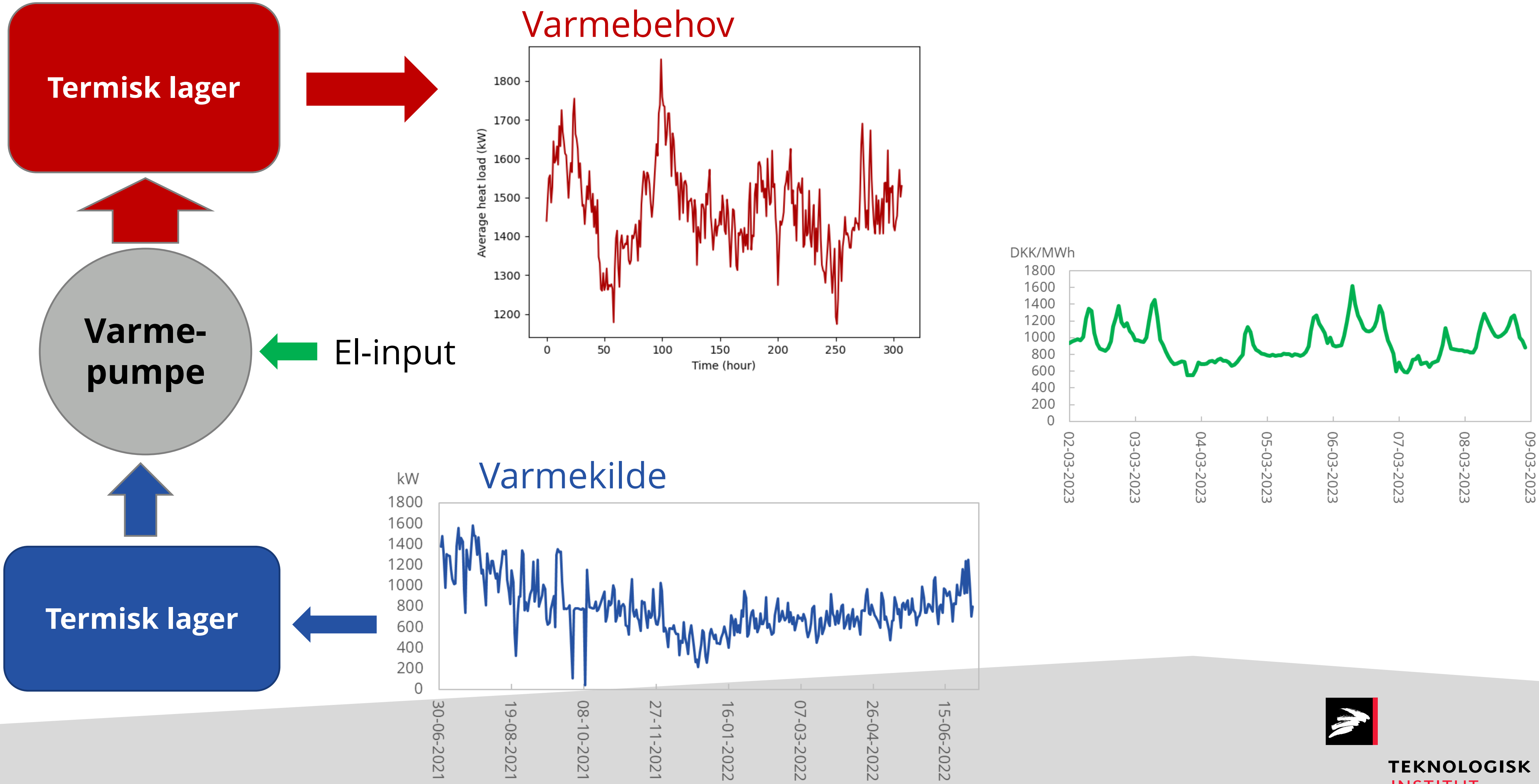
TERMISK LAGRING OG VARMEPUMPER



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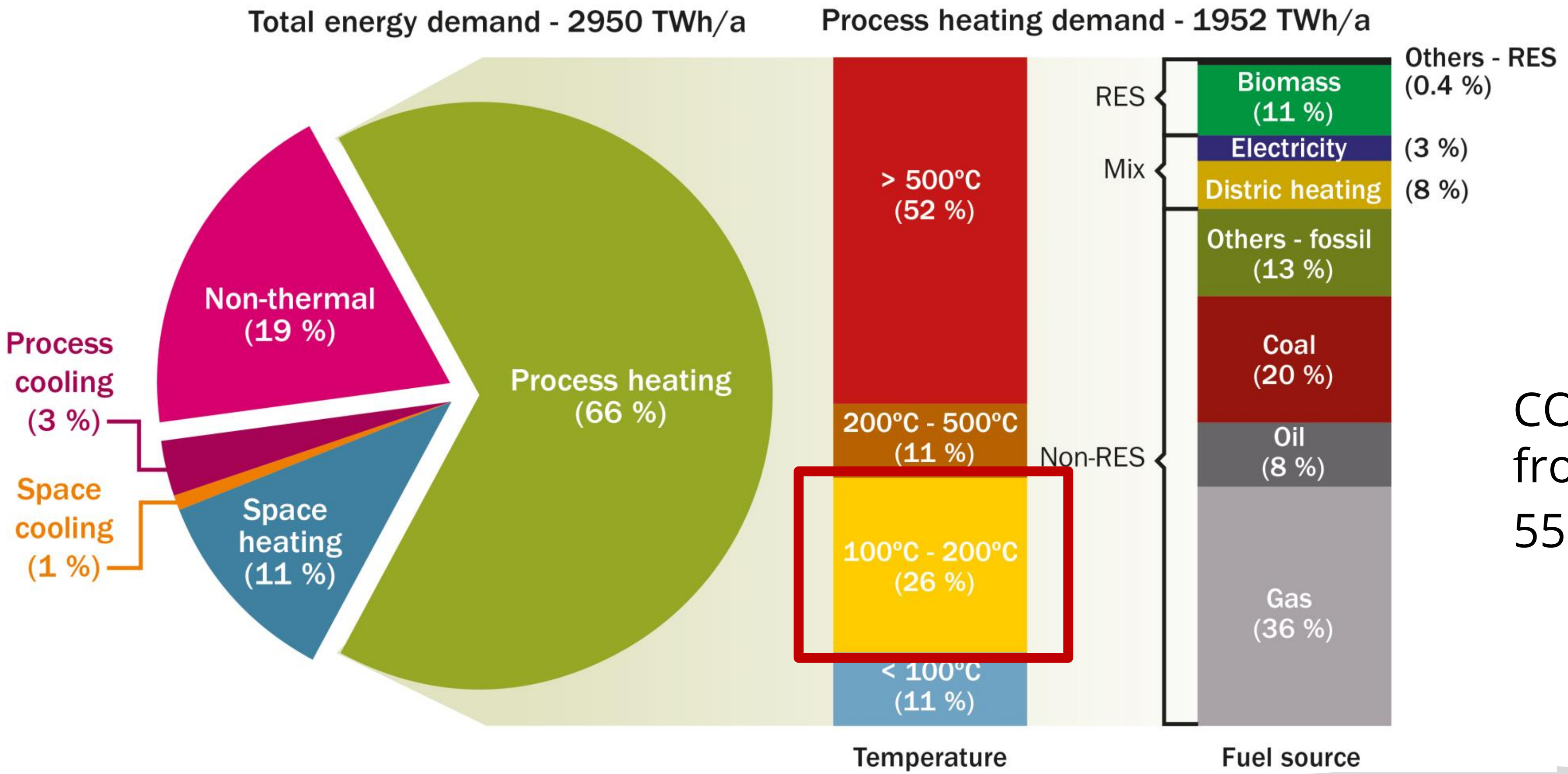
POTENTIAL FOR HTHPS – EU28



CO_2 emissions from Non-RES: 552 Mt/a

Figure based on [Heat Roadmap Europe]

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ET UDPLUK AF AKTUELLE PROJEKTER…

SuPrHeat

Motivation

- Focus on electrification of industry
- Increasing competitiveness of HTHPs
- Large heat demand between 100 °C and 200 °C

Objective

- To facilitate the electrification of industrial process heat supply at up to 200 °C
- To develop and demonstrate a technology portfolio with three prototypes (3 x 500 kW)

Scope

- Technologies: Steam compression, Hydrocarbons, CO_2.
- Integration and demonstration in dairy, slaughterhouse, brewery and others

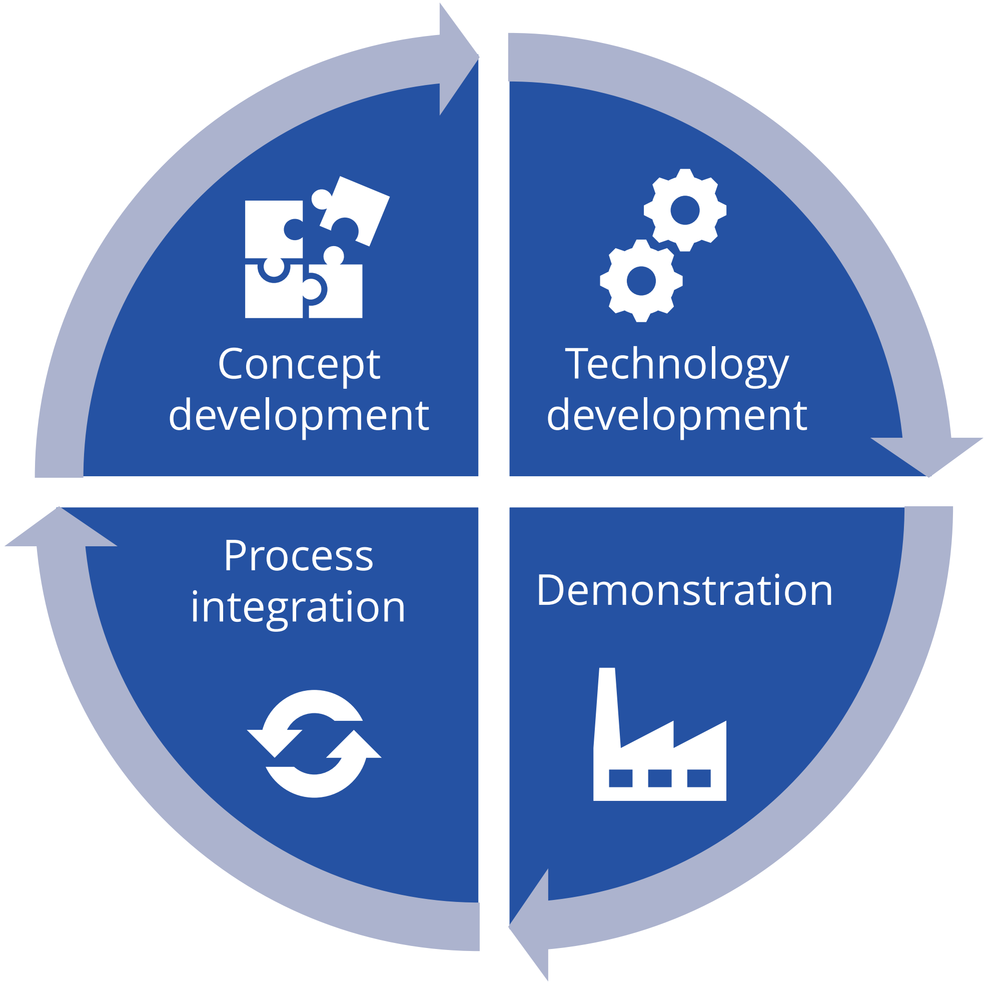
Project facts

- 09/2020 – 08/2024
- Budget: 61.3 mio. DKK
- 16 Partners
- http://suprheat.dk/

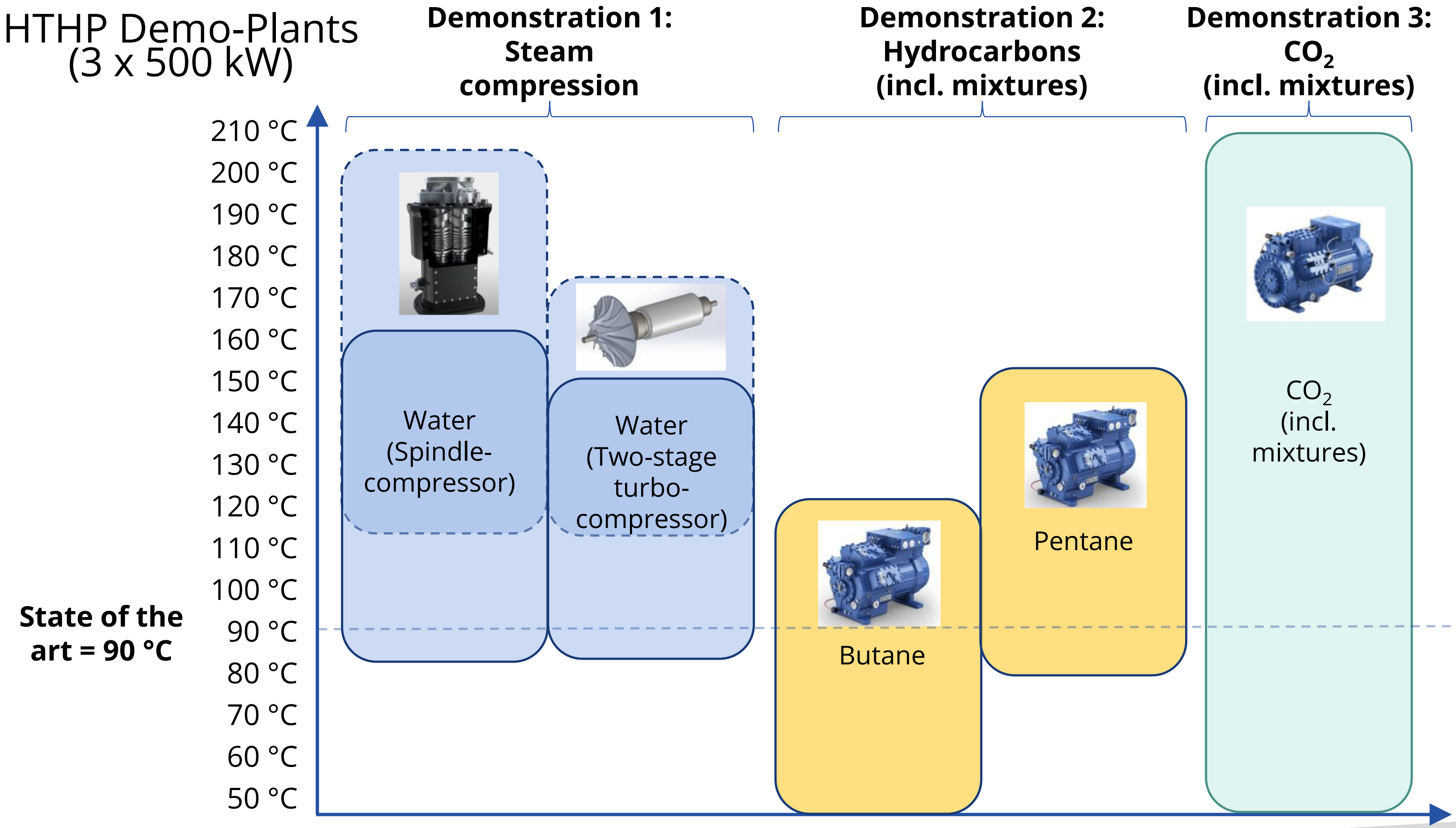
PARTNERS

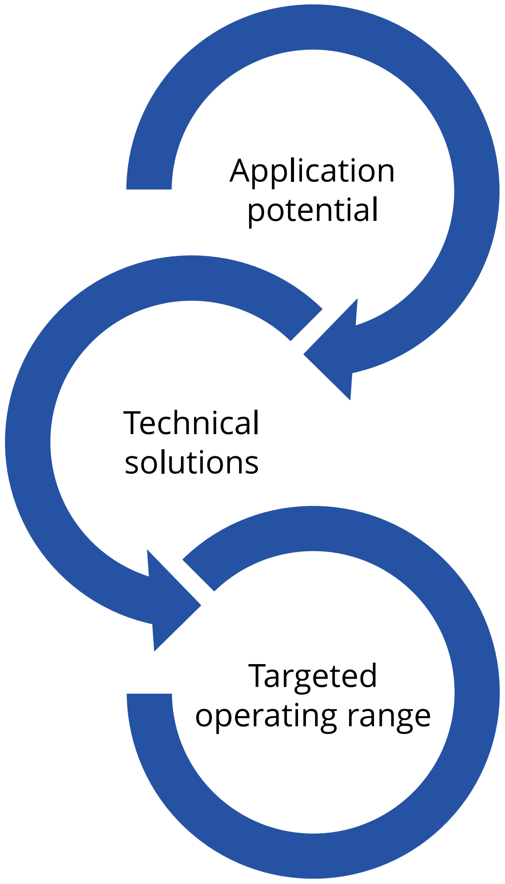
EUDP
The Energy Technology Development and Demonstration Programme
Arla
CHR HANSEN Improving food & health
CS TECHCOM ApS
spirax sarco First for Steam Solutions
GEA
FUCHS
Danish Crown
Royal Unibrew
SOFT & TEKNIK
BOCK colour the world of tomorrow
HAMBURG VACUUM
Viegand Maagøe
Alfa Laval
Danfoss
DTU
TEKNOLOGISK INSTITUT

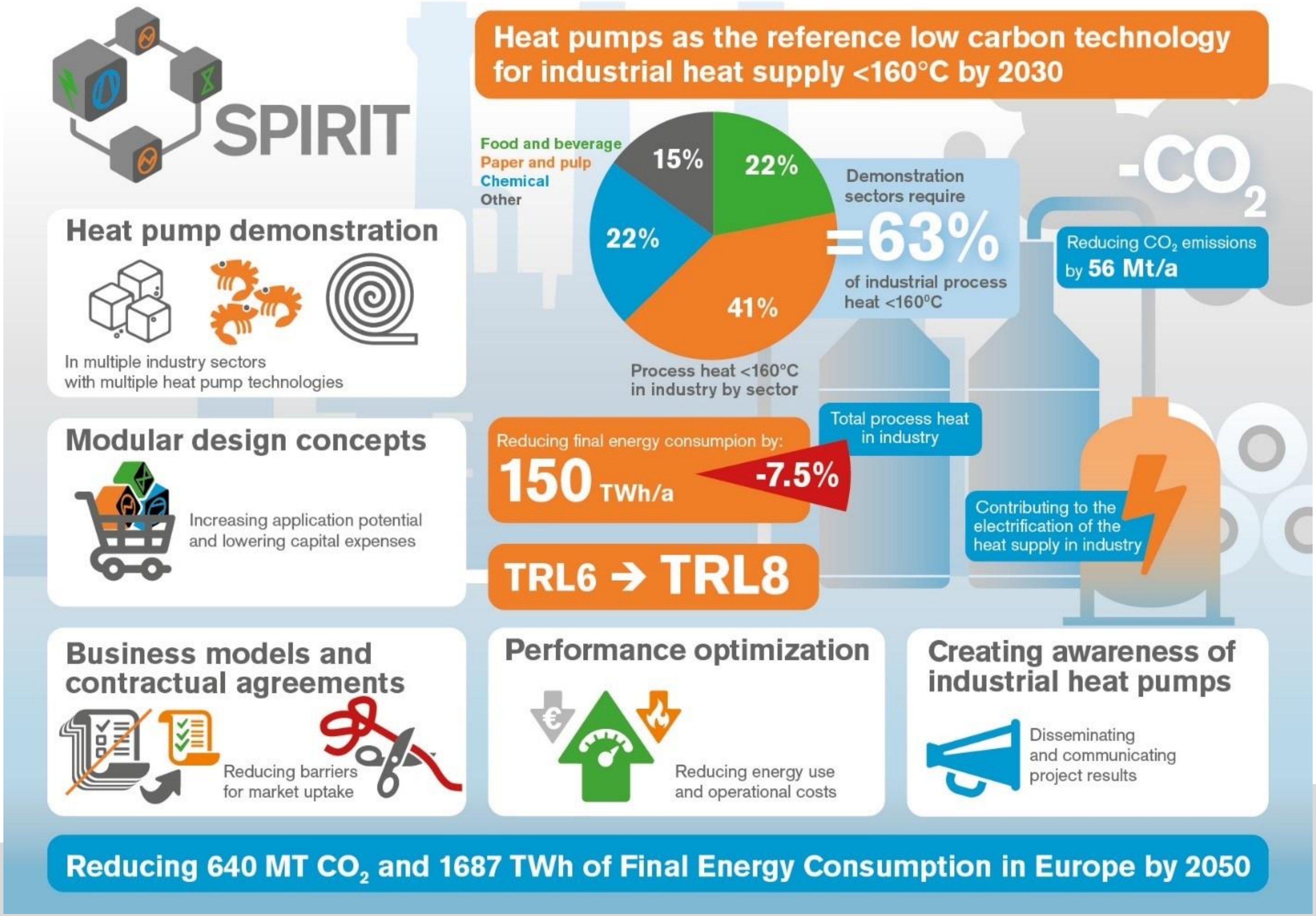
PROJECT OUTLINE



DEVELOPMENT TARGETS







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SPIRIT – PARTNER GROUP

SPIRIT

Coordinator: Simon Spoelstra

TNO innovation for life

End-User – Paper & Pulp

Smurfit Kappa

End-User – Food

Tienen-Tirlemont

STELLA POLARIS

Heat Pump Manufacturers

SPILLING Technologies

GEA engineering for a better world

MAYEKAWA MYCOM

RTO & Knowledge

DANISH TECHNOLOGICAL INSTITUTE

DLR

DTU Denmark Technical University

Simulation specialist

TLK ENERGY

Replication Case

TVP SOLAR

Non-Technical Barriers & Market Analysis

eurac research

SINLOC Sistema Iniziative Locali

Dissemination & Communication

ehpa european heat pump association

EUROHEAT & POWER

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IEA HPT ANNEX 58 ABOUT HTHP

- Heat pump technologies with supply temperatures above 100 °C
- Participants: **Denmark (Operating Agent),** Austria, Belgium, Canada, China, France, Japan, Germany, Netherlands, Norway, South Korea, Switzerland, US
- 01/2021 – 12/2023
- https://heatpumpingtechnologies.org/annex58/

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SUPPLIER TECHNOLOGY REVIEW

- Technology descriptions from 28 suppliers
- Key information includes:
  - Performance data
  - Capacity range
  - Max. temperatures
  - Working fluid
  - Compressor type
  - Spec. investment cost
  - TRL
  - Expected lifetime
  - Size & footprint


Annex 58 High-Temperature Heat Pumps

Screw compressor high-temperature heat pump

Rank®

Figure 1: Rank® HTHP and compressor

Summary of technology

Rank® is a worldwide recognized company in the design and manufacture of Organic Rankine Cycles for different capacities and applications. Now, Rank® is using this valuable experience in extreme conditions to develop high-temperature heat pumps (HTHP) that can produce renewable heat up to 160 °C.

New Rank® HTHP systems are based on a single-stage cycle with an internal heat exchanger (IHX). However, a two-stage cascade cycle with IHXs can be assembled for covering larger temperature lifts.

The compressor is electrically driven, is based on a screw technology with a frequency inverter to be adapted to the customer's actual operation. The compressor is based on direct drive, avoiding gears or pulleys, minimizing the maintenance, and increasing electrical efficiency. Moreover, magnetic coupling ensures tightness and a-voids the possibility of leakage.

Lubrication used for the proper operation of the compressor is polyolester oil (POE oil) of a specific viscosity, fully compatible with organic working fluids and able to work at high temperatures while keeping the optimum properties.

Annex 58 High-Temperature Heat Pumps

www.heatpumpingtechnologies.org/annex58/

Figure 2: Rank® modular solution

Our machines operate through an automatic, efficient managing system without human intervention. Real-time data transmission via the internet allows predictive maintenance by server data analysis, online supervision (PC, mobile phone, tablet, etc.), and remote configuration of working parameters.

Table 1: Performance for the single-stage cycle with IHX HTHP prototype (experimentally measured in lab, prototype, not fully optimized for specific purpose)

$T_{source,in}$ [°C]	$T_{source,out}$ [°C]	$T_{sink,out}$ [°C]	$COP_{heating}$ [-]
84	70	103	5.9
101	70	122	4.6
102	72	130	4.0
115	70	130	3.7
100	90	160	3.0
116	95	160	2.8

Table 2: Case study for production of thermal oil.

$T_{source,in}$ [°C]	$T_{source,out}$ [°C]	$T_{sink,out}$ [°C]	$T_{sink,out}$ [°C]	$COP_{heating}$ [-]
100	70	130	110	3.6
100	80	130	110	4.5

Project example

A perfect application for our HTHP systems is district heating networks (DHN).

DHN are present in urban and industrial environments where each user is connected and uses heat at a given temperature. Heat is distributed at a particular temperature, but users' needs can differ.

HTHPs present in the installations of each client can upgrade the heat at useful levels with a high COP (2.6 to 5.9), adapting the temperature glide of the heat sink.

HTHPs, which local renewable energy sources can power and promote decarbonization in industries connected to district heating networks, independently of the distribution temperature, avoiding the need for fossil fuel boilers.

FACTS ABOUT THE TECHNOLOGY

Heat supply capacity: 120 kW to 2000 kW

Temperature range: useful heat inlet 80 °C to 120 °C and outlet 100 °C to 160 °C / heat source inlet 60 °C to 100 °C and outlet 40 °C to 80 °C

Working fluid: adaptable to the application R245fa, R1336mzz(Z), R1233zd(E)

Compressor technology: Screw

Specific investment cost for installed system without integration: 200-400 € per kW, but it varies between temperature levels and applications

TRL level: TRL 7 – prototype demonstration

Expected lifetime: 20 years (with the possibility of hiring Service to extend lifetime and ensure the highest energy performance)

Size: weight 5.5 to 8 tons / surface requried 5.2 to 13 m² / height 2.2 to 2.5 m

Contact information

Rank ORC, s.l.

info@rank-orc.com / sales@rank-orc.com

+34 964 69 68 59

All information were provided by the supplier without third-party validation. The information was provided as an indicative basis and may be different in final installations depending on application specific parameters.

IEA Technology Collaboration Programme on Heat Pumping Technologies (HPT TCP)

Information in the technology description was provided by the technology suppliers without 3rd party validation
https://heatpumpingtechnologies.org/annex58/task1/

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SUPPLIER OVERVIEW

GEA Engineering for a better world.
enertime
Hybrid Energy HIGH TEMPERATURE HEAT PUMPS
enerin ENERGY ENGINEERING

EPCON Evaporation Technology AS
ecop
MAN Energy Solutions
Ohmia Industry

QPINCH
PILLER Blowers & Compressors
Weel & Sandvig ENERGY AND PROCESS INNOVATION
Fuji Electric

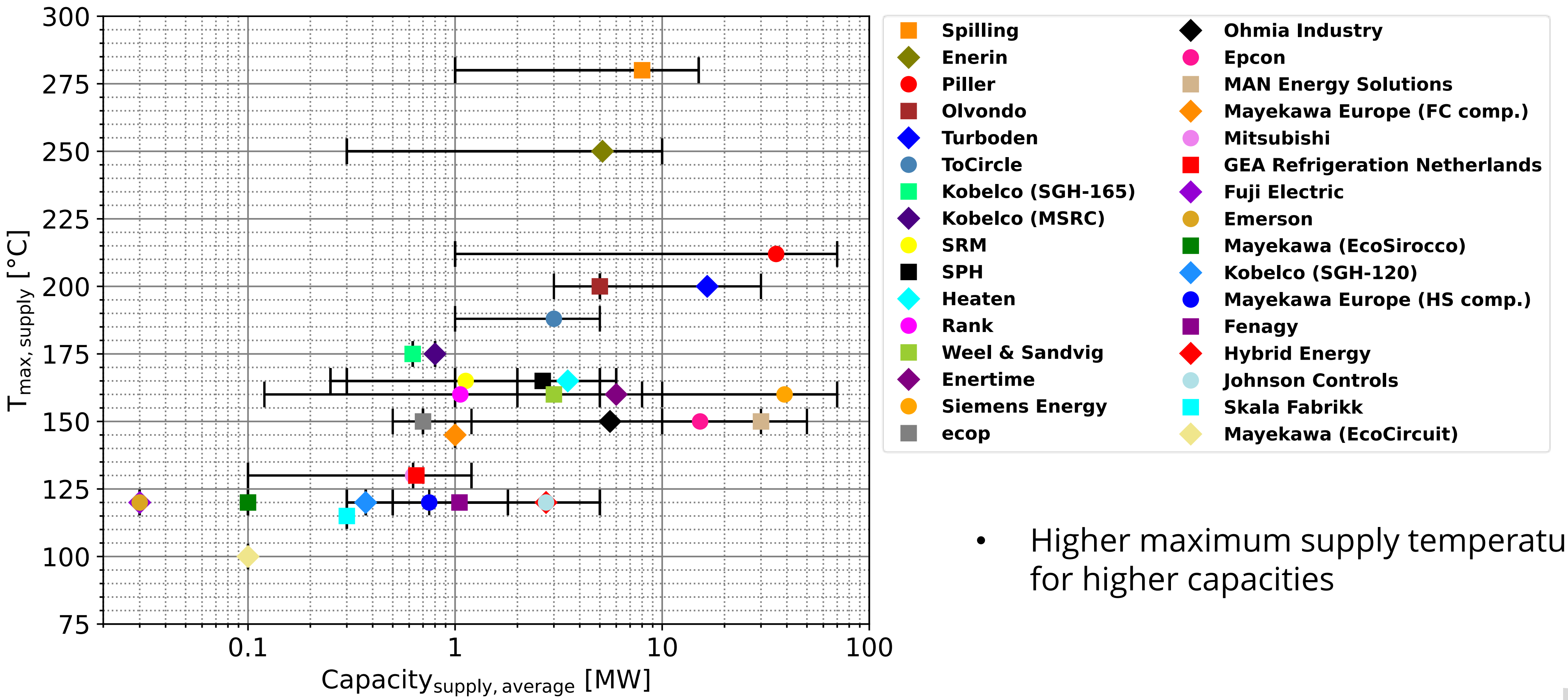
SPILLING Technologies
clean energy ahead TURBODEN
KOBELCO
MAYEKAWA MYCOM

Rank®
EMERSON.
SIEMENS energy
toCircle INDUSTRIES

SABROE Johnson Controls
:skala fabrikk
SRM
SPH Sustainable Process Heat

FENAGY FUTURE ENERGY SOLUTIONS
HEATEN
MITSUBISHI HEAVY INDUSTRIES THERMAL SYSTEMS
olvondo TECHNOLOGY

SUPPLY TEMPERATURE VS. CAPACITY

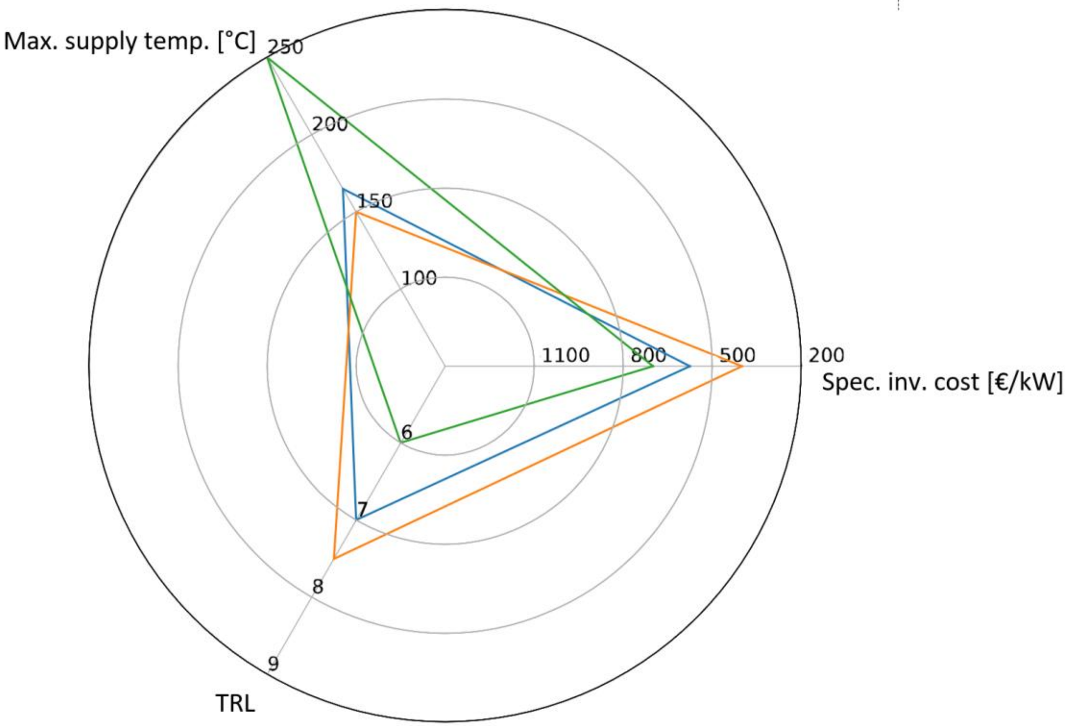


- Higher maximum supply temperatures for higher capacities

SUMMARY OF HTHP SUPPLIER REVIEW

- Task 1 report will elaborate on HTHP supplier review and give national HTHP market perspectives. To be published on Annex 58 homepage.
- Summary of Annex 58 HTHP technology review:

TRL level	4-9
Average specific cost	200 €/kW - 1500 €/kW
Capacity	0.03 MW - 70 MW
Max. supply temperature	100 °C - 280 °C
Availability	Geographical dependent, e.g. between Europe and Japan
Size of HTHP review	28 suppliers, 33 different technologies, and 83 performance use cases



3 examples of dependencies for HTHP technologies

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SYMPOSIUM ON HTHPS

High-Temperature
Heat Pump Symposium
Copenhagen 29.-30.3.2022

- HTHP Symposium (hthp-symposium.org)
- Focus on:
  - Potential and demand
  - Successful case studies
  - Available technologies
  - Developments and trends
- Good feedback and growing interest
- Presentations available as booklet:

DANISH TECHNOLOGICAL INSTITUTE

SINTEF

DTU


Langelinie Pavillonen, Copenhagen 2019


Langelinie Pavillonen, Copenhagen 2022


National Museeum, Copenhagen 2017

TAK FOR JERES OPMÆRKSOMHED

WIEBKE BRIX MARKUSSEN, WBM@TEKNOLOGISK.DK

TEKNOLOGISK INSTITUT

HELIAC ROCKSTORE
- 300 °C HEAT STORAGE

JAKOB JENSEN
HELIAC

TAASTRUP - 9. MARTS 2023

Heliac + RockStore

Concentrated Solar Thermal + 300°C Heat Storage

heliac

Bright and simple. Now and for the future.

Agenda

Om Heliac

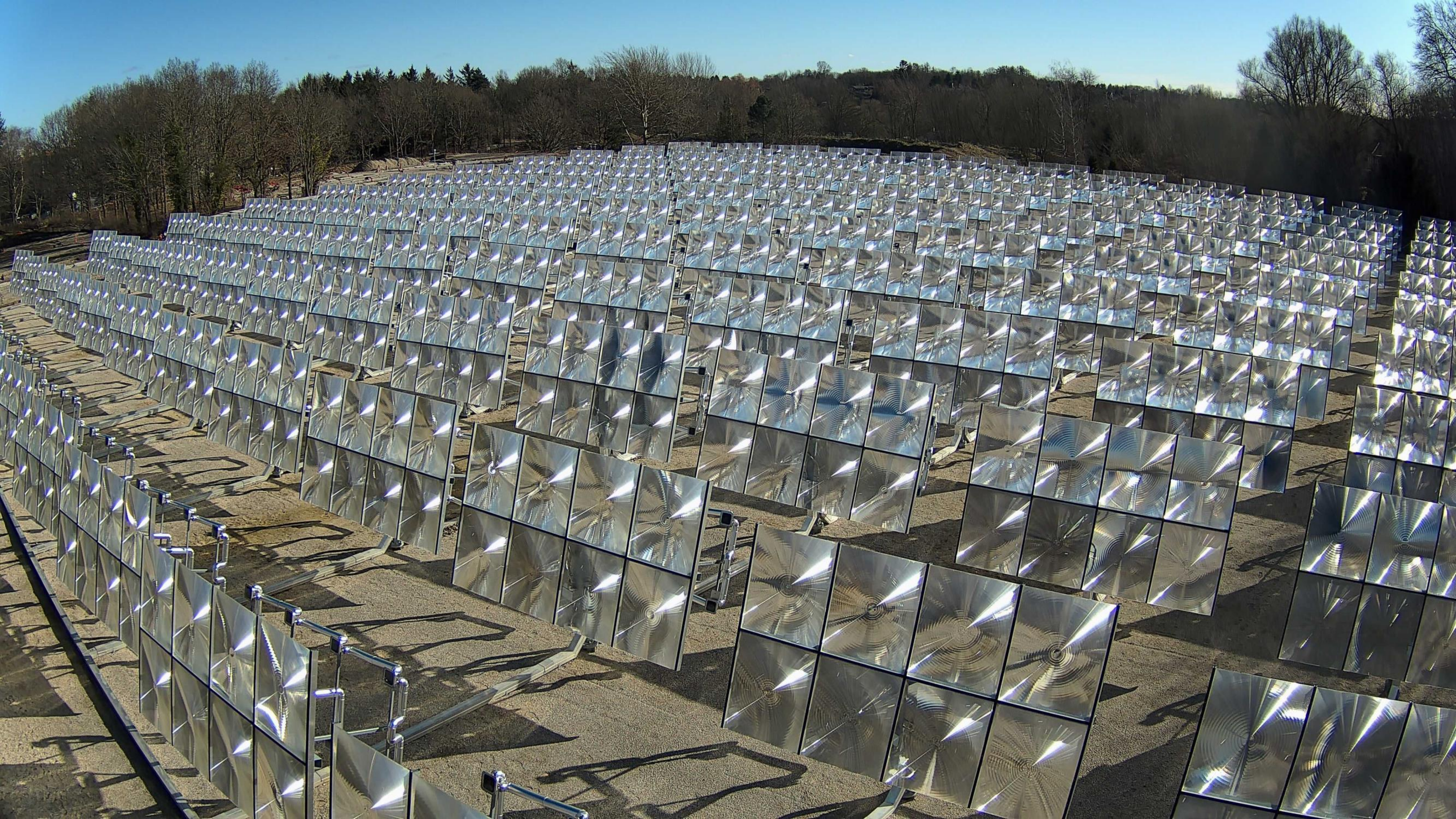
Hvorfor varme?

Hvorfor lager?

RockStore

Case

Et bump på vejen



Fokuseret sollys

Det globale energimix

VARME

51%

10,2%
Vedvarende energi

TRANSPORT

32%

Vedvarende energi

3,4%

POWER

17%

27,1%
Vedvarende energi

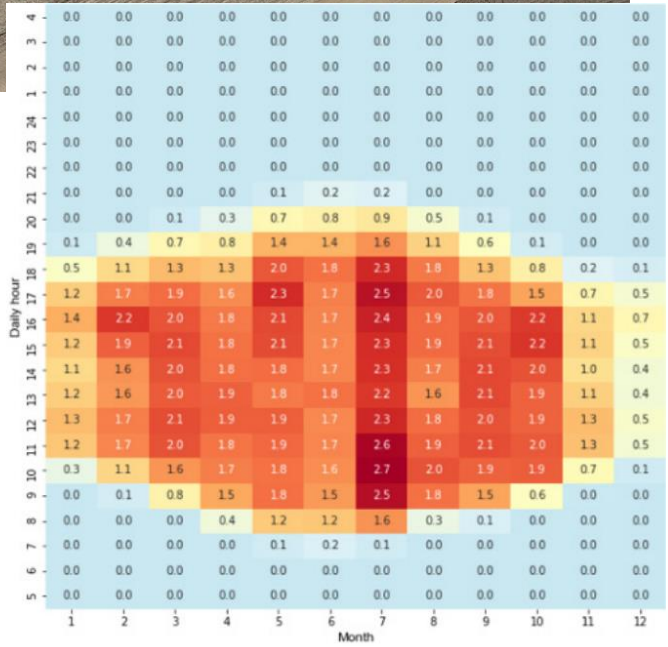
100^{0}C – 200^{0}C 1000 TWh	200^{0}C – 600^{0}C 500 TWh	>600^{0}C 800 TWh

EU Industrial Heat Consumption by Temperature Range

Case
- uden lager

Solfelt: 1.6 MW

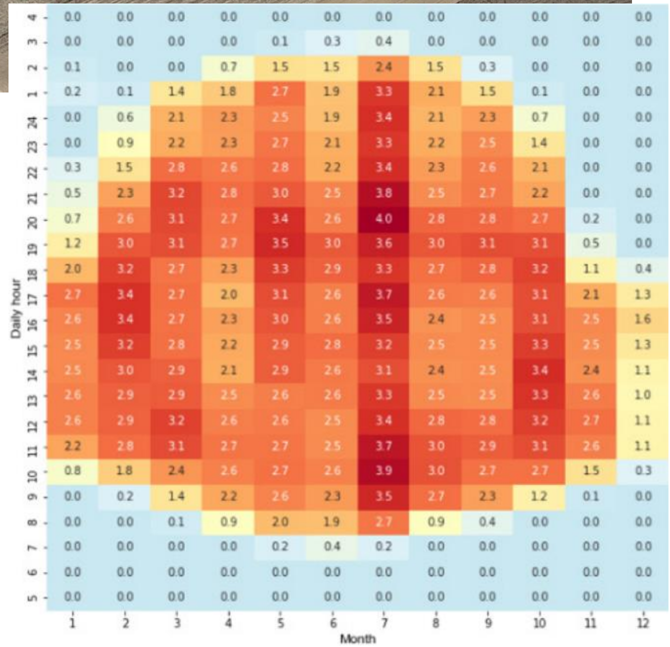
Lager: 0 MWh



Case
- med lager

Solfelt: 5 MW

Lager: 50 MWh



Business case for kunden:*

20 timers lager i Spanien

Dag/nat + weekend

	Uden lager	Med lager
Solvarme (MWh/år)	3.000	9.000
Naturgas (€/MWh)**	75	75
CO_2-besparelse (ton/år)	750	2.250
Solfraktion (%)	25	75
Solvarme (€/MWh)	35	40***
Energibesparelse (€/år):	120.000	315.000

** Inklusiv CO_2-skat, distribution & transmission, 90% kedeleffektivitet, lokal skat.Pris 8. marts 2023.

*** Ved 300 cykler/år + prisen på det energiinput, der lagres.

*NB: Alene ment som illustrerende poteniel case med stærkt afrundede tal, der i den virkelige verden afhænger af komponentpriser, solindstråling, renter, levetidsberegning, co2-skat, gaspriser, leverede & returnerede temperaturer samt kundens produktionsprofil.

heliac

RockStore

Patenteret løsning:
Lagring af energi i sten
op til 300°c

heliac

Proof of Concept

(2018-2019)

- 0.1 m^3
- 200 W
- 100°C – 250°C

SunCharge

(2019-2021)

- 15 m^3
- 1 MWh (120°C – 300°C)
- 36 kW opladning
- 1 MW afladning (dampproduktion)
- 120°C – 300°C

Co-funded by: EUDP Energiteknologisk udvikling og demonstration

heliac

RockStore

(2022-2024)

- 7 – 100+ m^3
- 0.5 – 10+ MWh
- 3 MW opladning
- 3 MW afladning (el + fjernvarme)
- 80°C – 275°C

Co-funded by: EUDP Energiteknologisk udvikling og demonstration

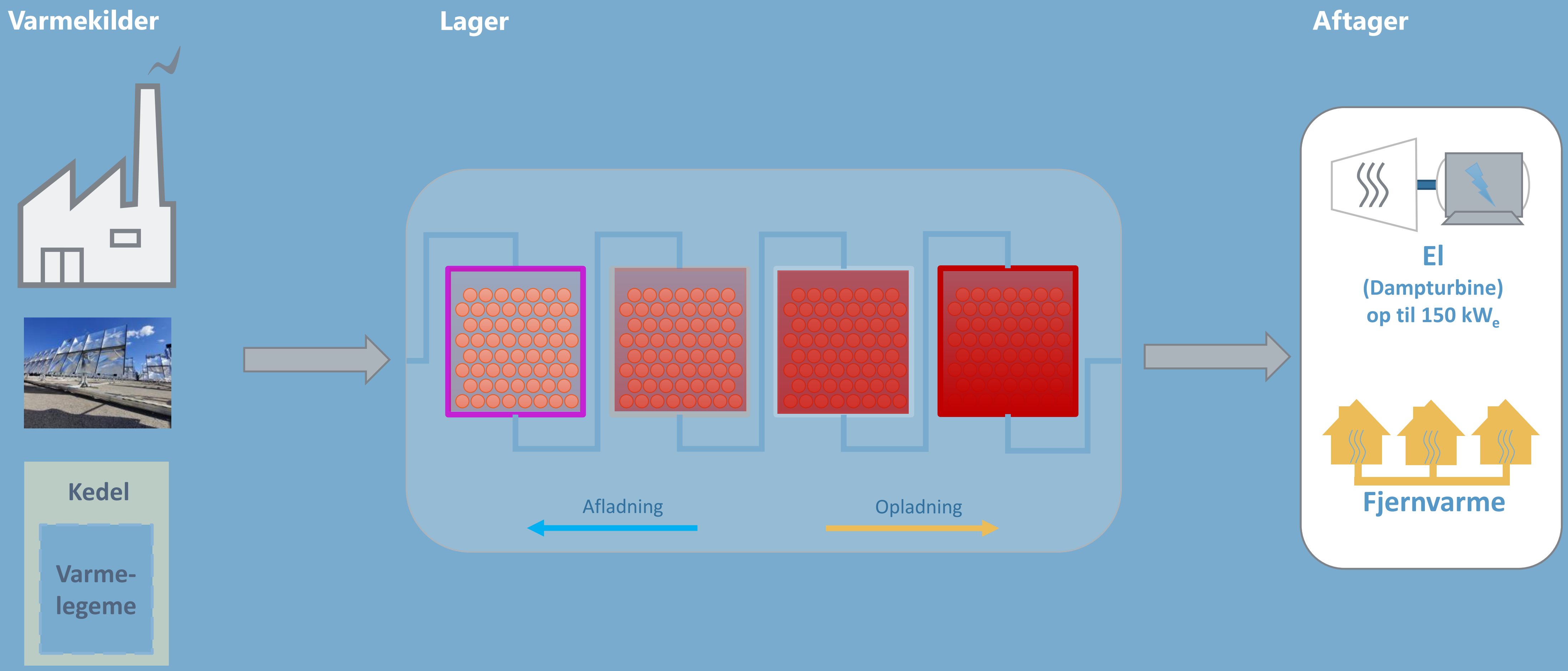
Fuldskala

(2025 –)

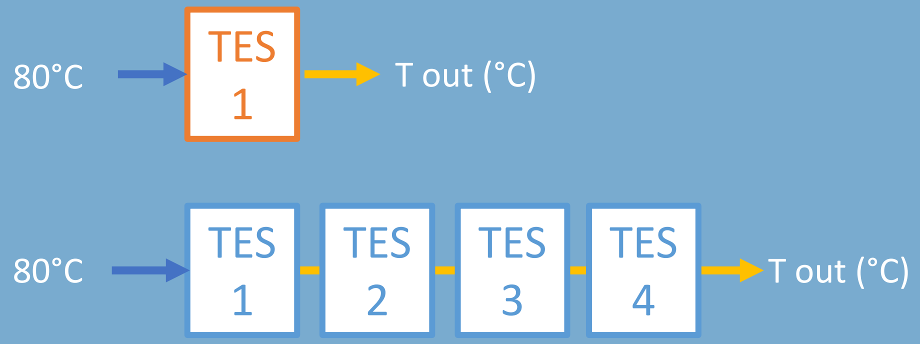
- 3,000+ m^3
- 300+ MWh
- 30 MW opladning
- 10 MW afladning
- 80°C – 300°C

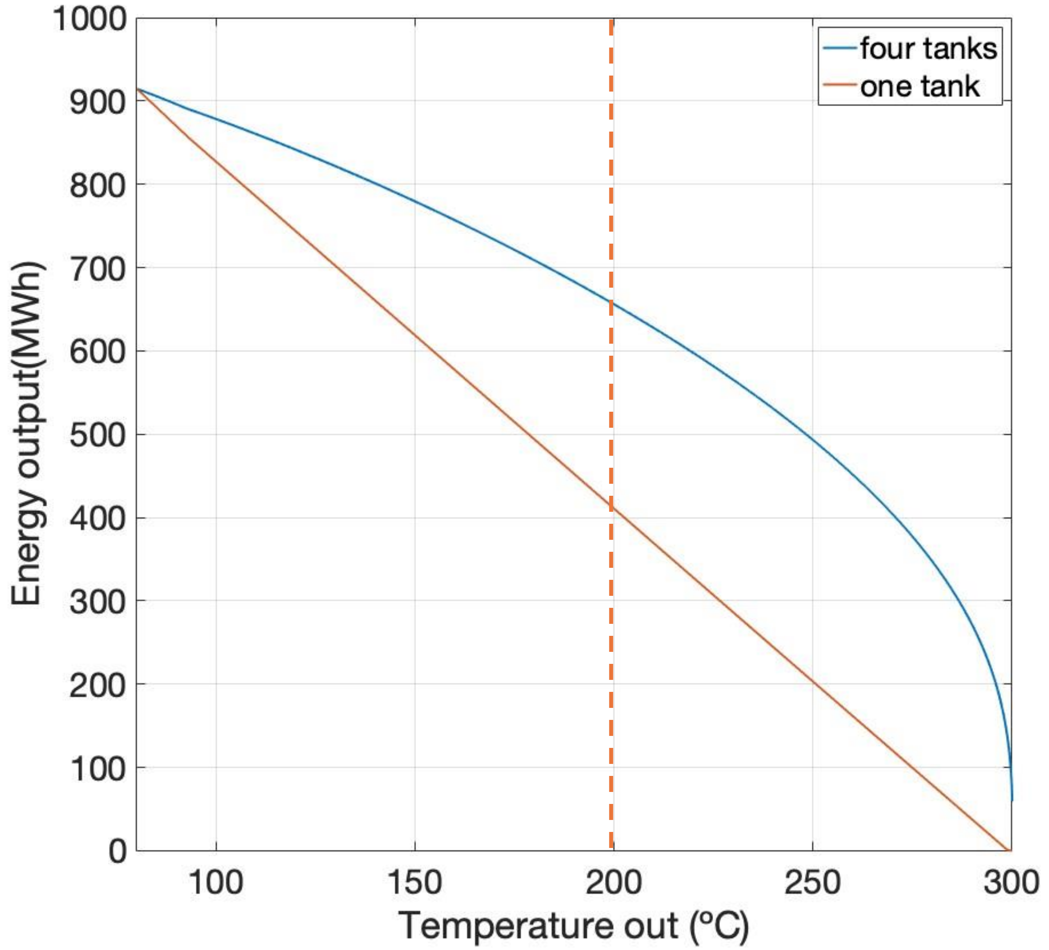
heliac

Systemdesign



Flere lagertanke = højere °C ud

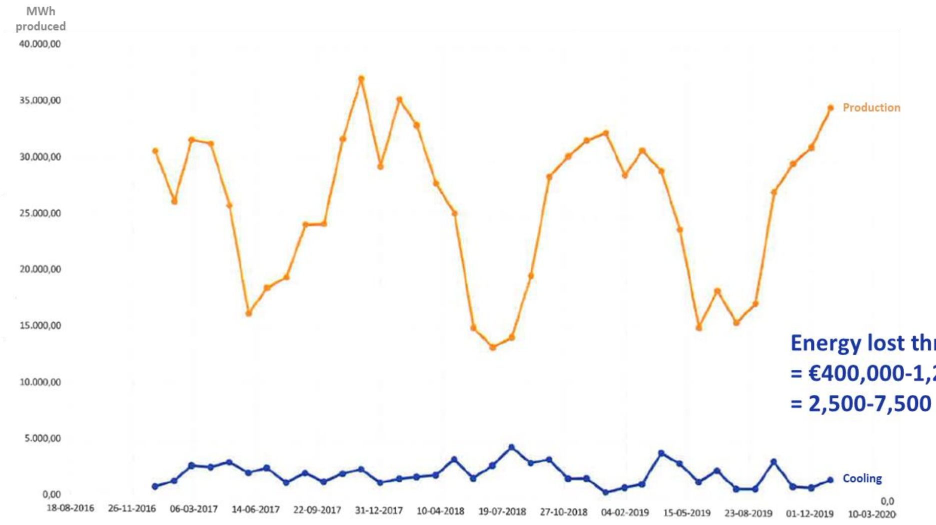





Case
Norfors

Besparelser

- **Naturgas:** 1,420 MWh/year
- **CO_2:** 22.1% - 289 tonnes
- **Spildvarme:** 24%



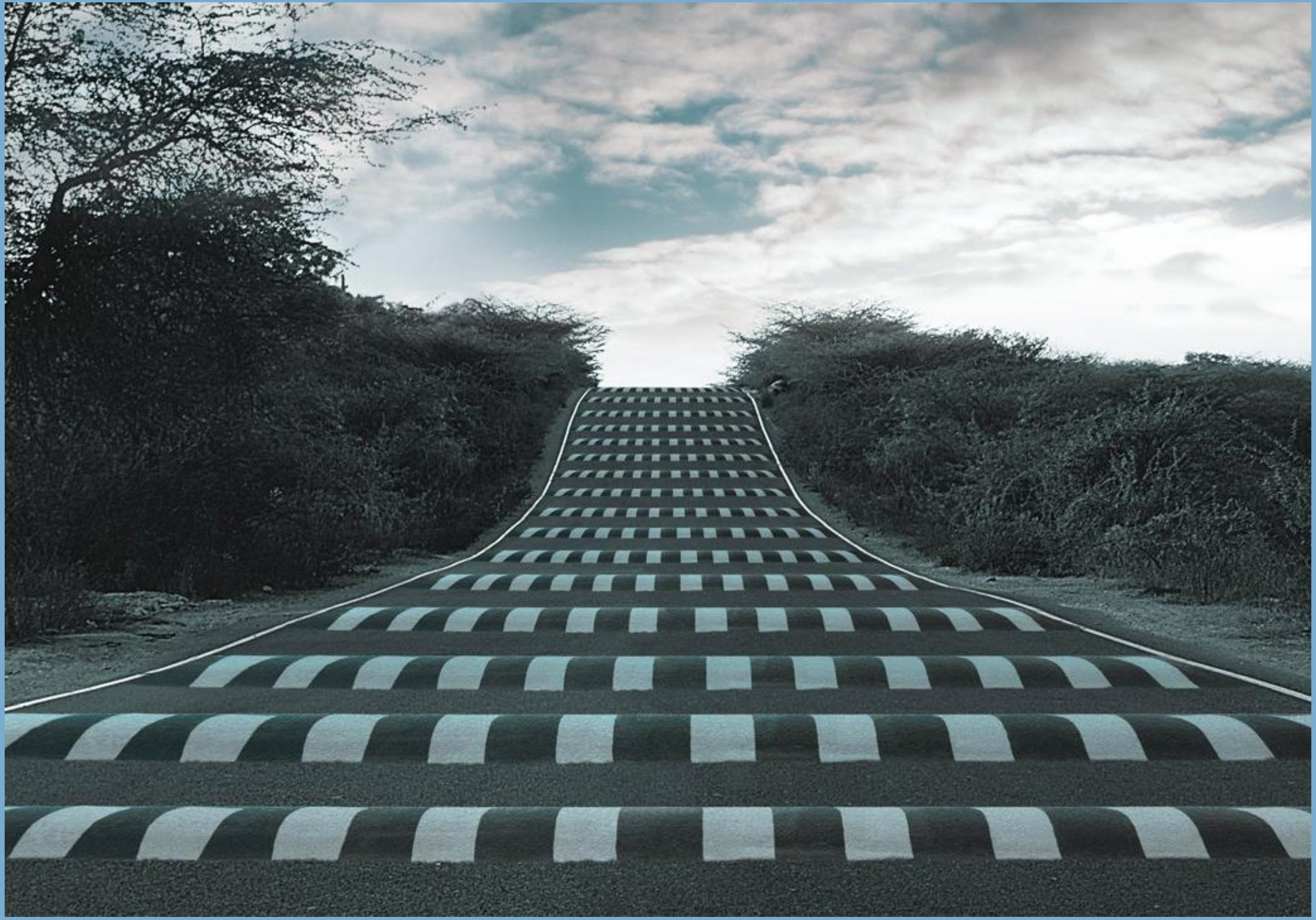
Energy lost through cooling: 4-10%
= €400,000-1,200,000/year
= 2,500-7,500 tCO_{2eq}

Funded by: EUDP Energiteknologisk udvikling og demonstration

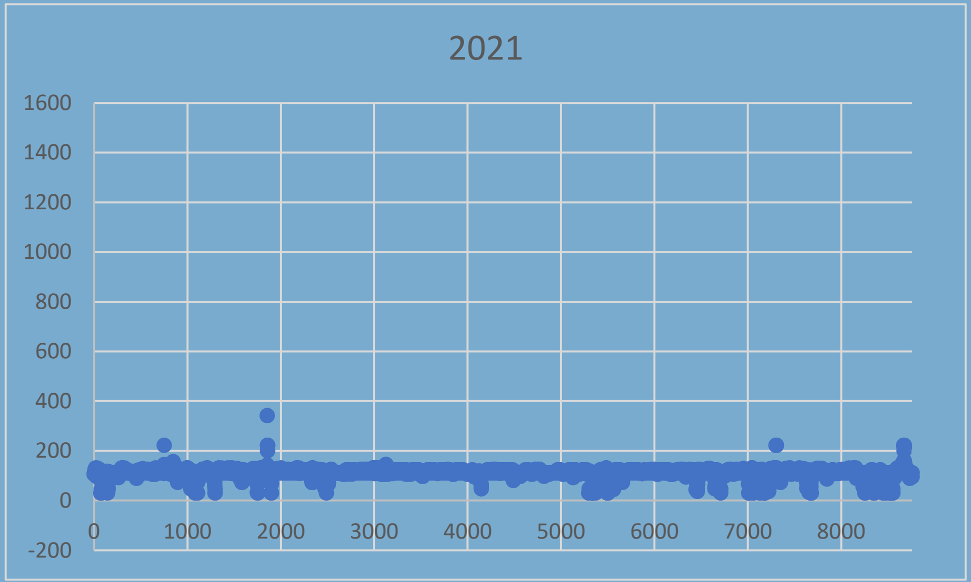
In partnership with:

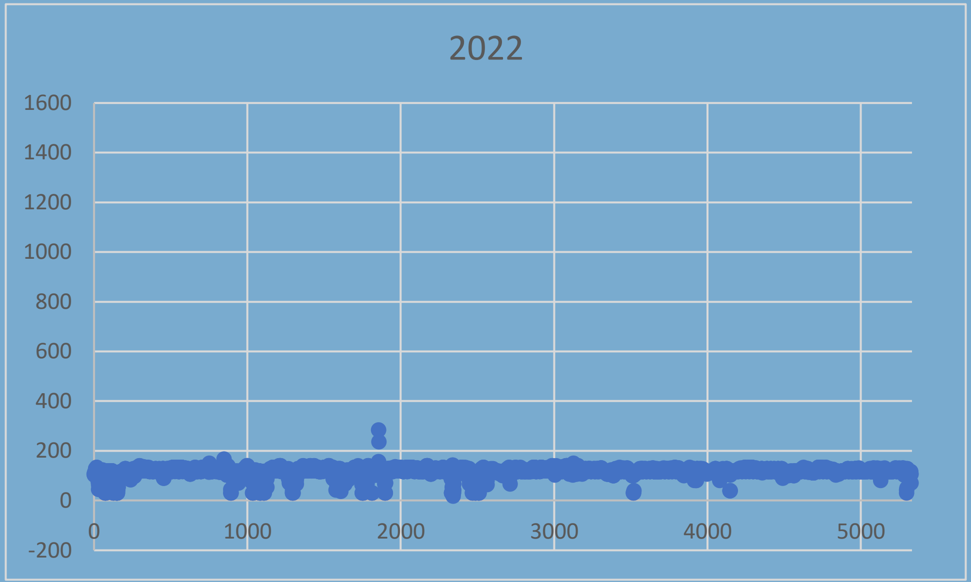
NORFORS, ALFA LAVAL, AALBORG CSP - Changing Energy, ROCKWOOL, Weel & Sandvig

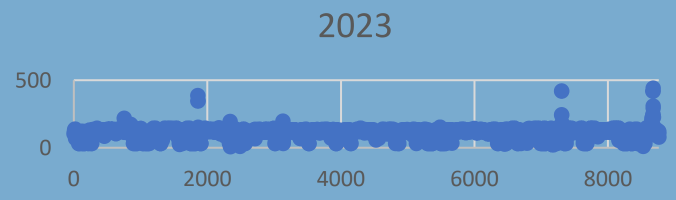
Baseret på data fra 2020-2021

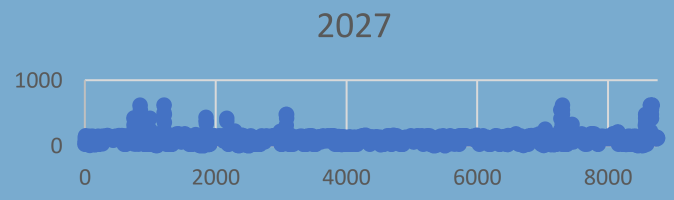


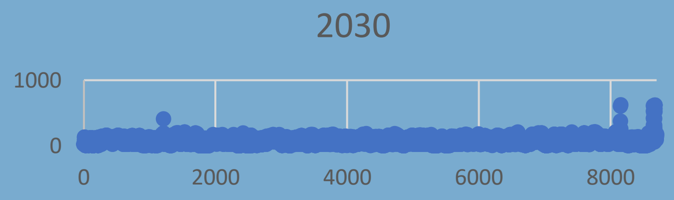
Energistyrelsens fremskrivninger



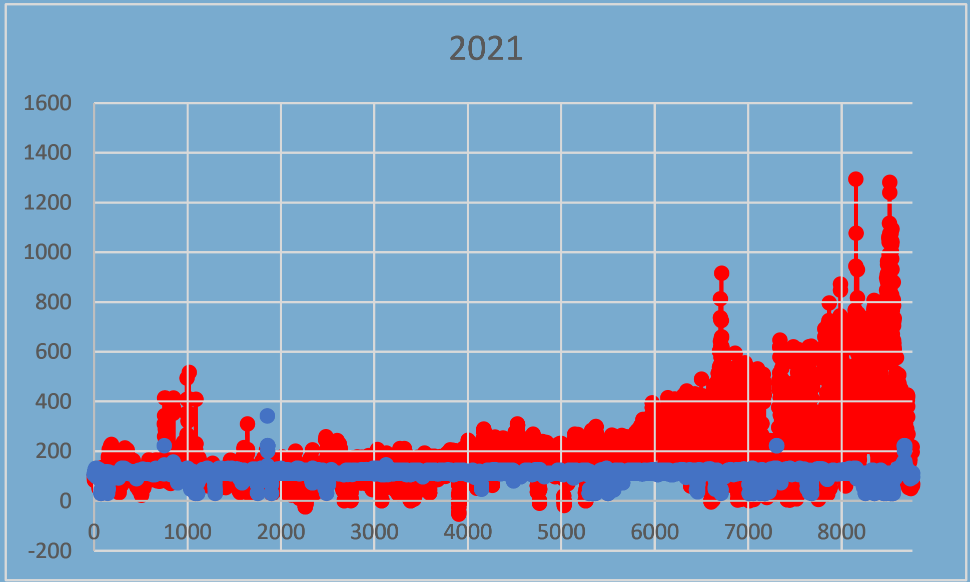


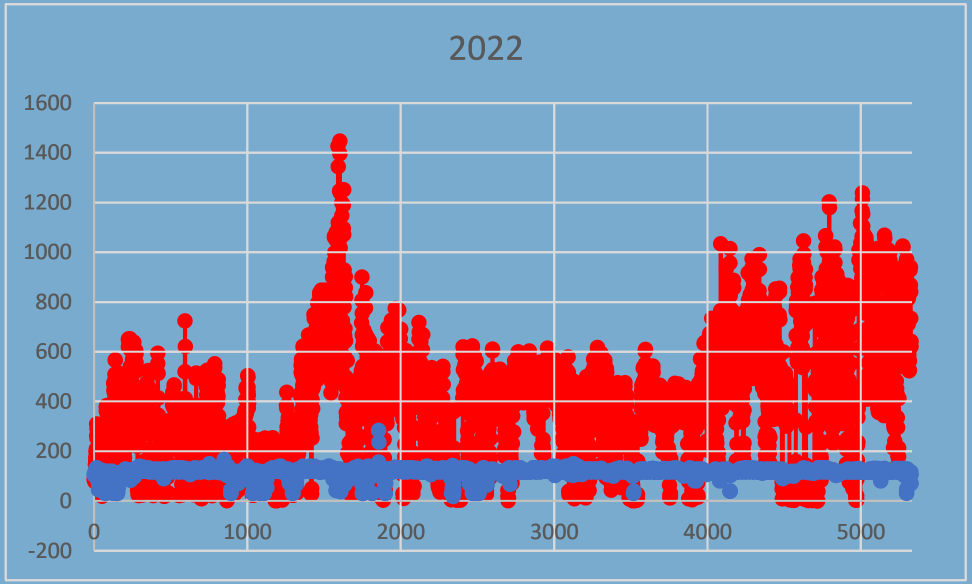


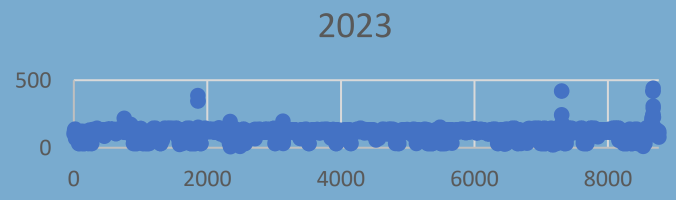


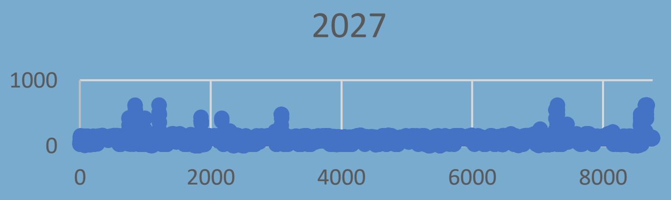


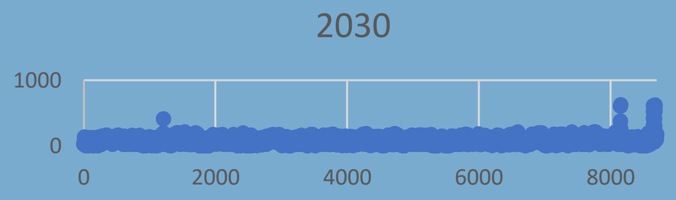
Fremskrivning vs virkelighed



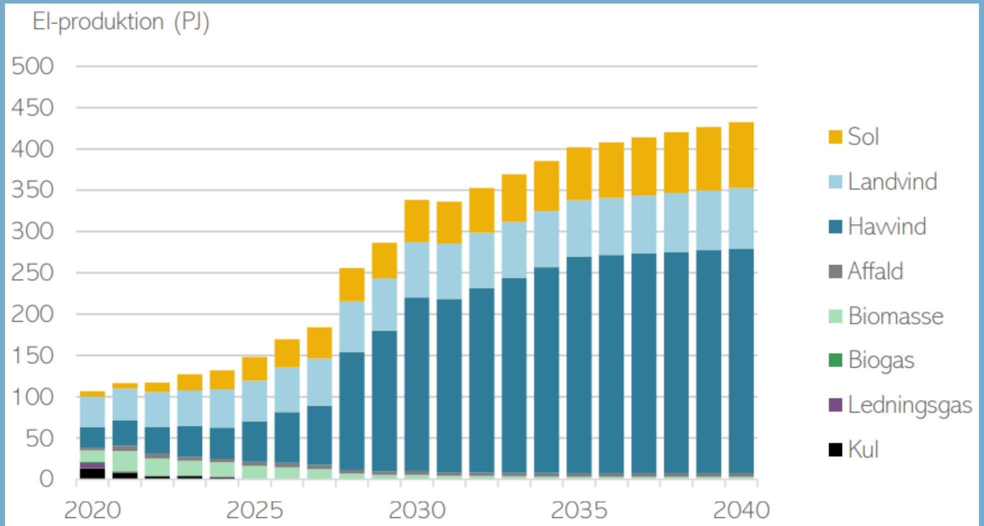


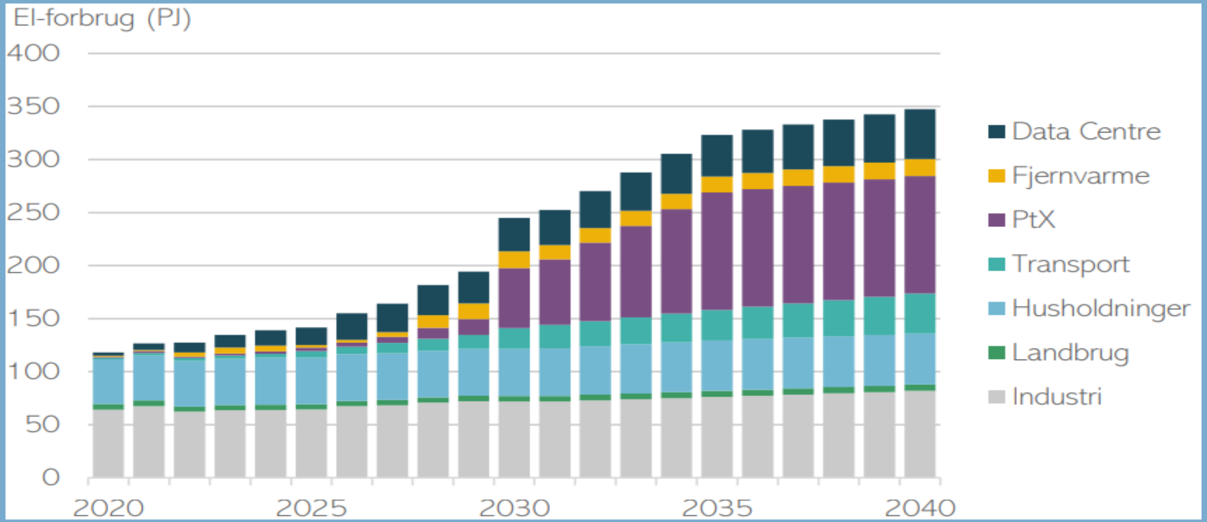




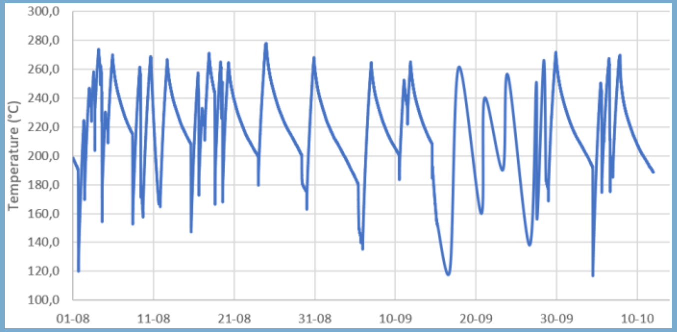


Produktion = Forbrug + 20%

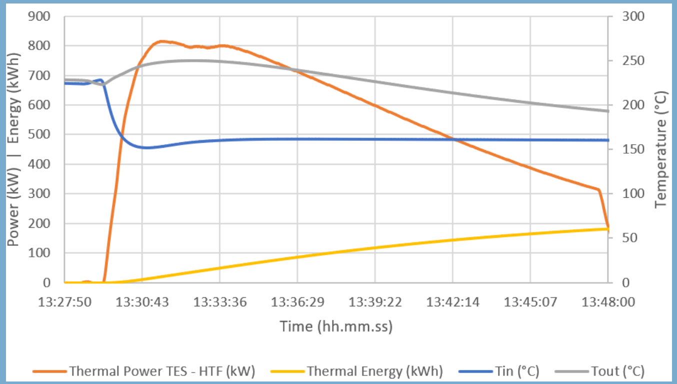




Damp fra lager



Op- og afladninger



Output - Dampproduktion

Q&A

Jakob Jensen

Chief Commercial Director

+45 22 48 08 02

jj@heliac.dk

www.heliac.dk

Bright and simple. Now and for the future.

AVANCERET
ENERGILAGRING
KONFERENCE

AC/DC - BACKUPSYSTEMET TIL OFFSHORE VINDMØLLER, DER SKAL KUNNE ALT

HENRIK DALSAGER
KK WIND SOLUTIONS A/S

TAASTRUP - 9. MARTS 2023

KK Wind Solutions®

AC/DC

backupsystemet til offshore vindmøller der skal kunne alt

We innovate to integrate®

Henrik Dalsager Christensen

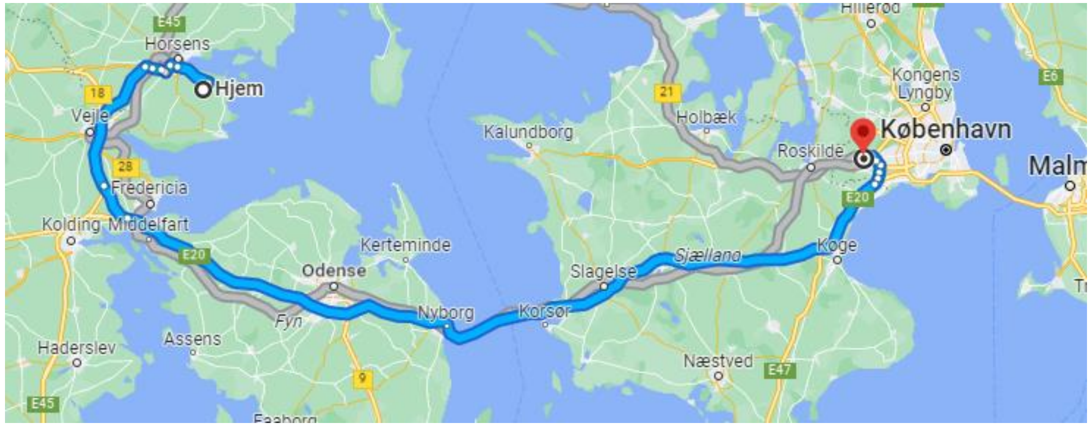
Lead Software Engineer, Energy Storage Systems

Henrik Dalsager

Lead Software Engineer, Energy Storage Systems

- Civ. Ing. / M.Sc. AIS. (Autnomous Intelligent Systems) @ AAU, 2010. (sådan noget med hvordan man styrer ting og sager, gerne fra software)
- B.Sc EE @AAU 2008 (svagstrømsingeniør)
- mobile robotics i ca. 5 år
- Har lavet varmepumper i ca. 4 år
- KK energilagring siden 2019.

- Dejlig kone
- 2 børn (3 & 6) år
- Er altid midt i et byggeprojekt



KK Wind Solutions **at a glance**

A leading global electro-mechanical system supplier

Full scope partner
Development - Manufacturing - Service

Competitive **global footprint**

Trusted partner to leading OEM's & Utilities

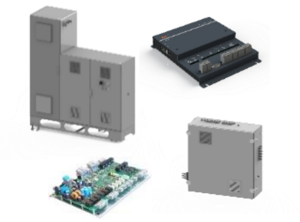
SIEMENS Gamesa RENEWABLE ENERGY · Vestas · GE Renewable Energy · Ørsted · e.on · 上海电气 SHANGHAI ELECTRIC · NORDEX · acciona Windpower · DOOSAN · UNISON · ENVISION · Meridian. · FRITZ SCHUR ENERGY · HYOSUNG · enel · NEXTera ENERGY · res · Pattern · VATTENFALL · CSIC · HydratechIndustries Wind Power

Sustainability at heart

KK Wind Solutions®

A strong product offering and integrated system supply

Advanced Control Systems



Power Conversion

Integrated System Supply

Monitoring and Prognostics Solutions

Power Backup

+35,000
More than 35,000 **wind turbines** are equipped with our solutions.

+65%
of the global **offshore capacity** is equipped with our solutions.

+1,500
Employees

+40
Years of experience
in electrical systems for wind turbines

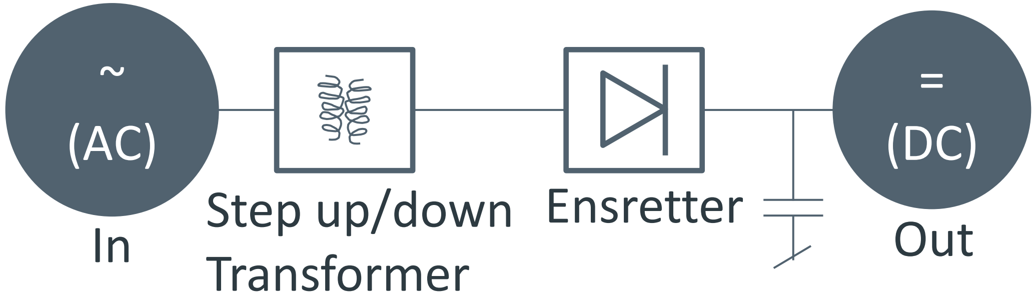
Strong long-term **ownership**

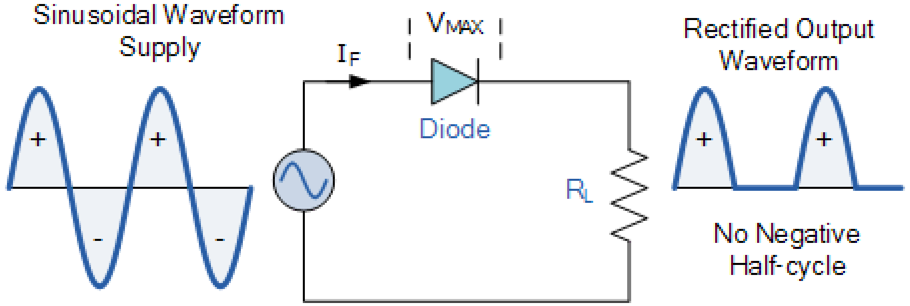
A.P.MØLLER

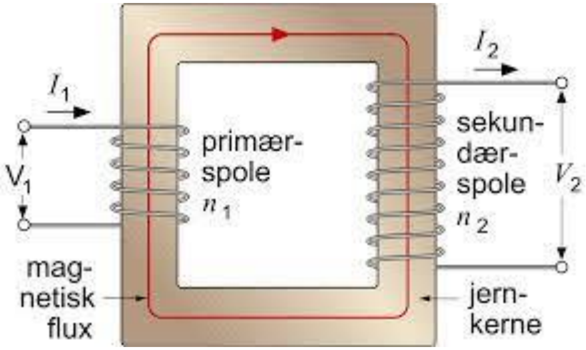
AC / DC – et par sekunder om teknik

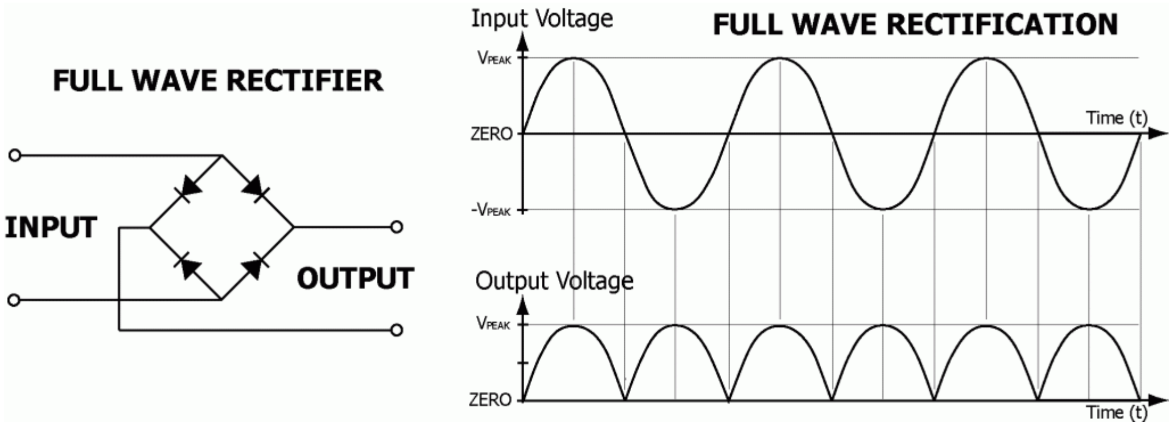
Power Converter Topologier

Teknologi der er ældre end mig..





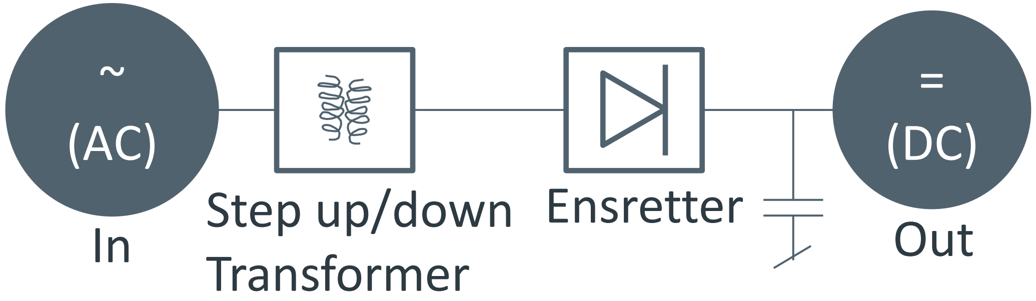


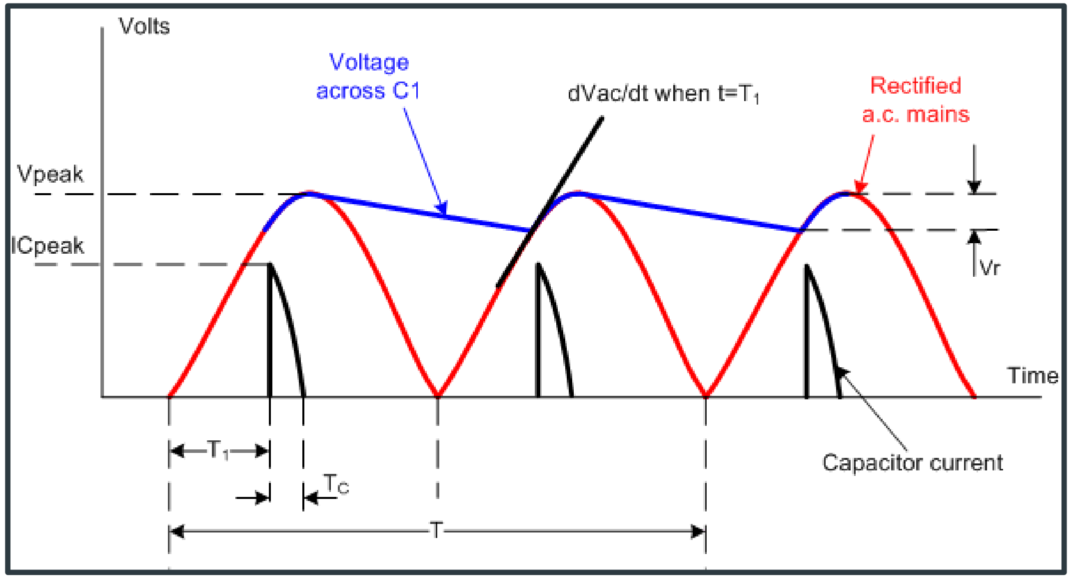


AC / DC – et par sekunder om teknik

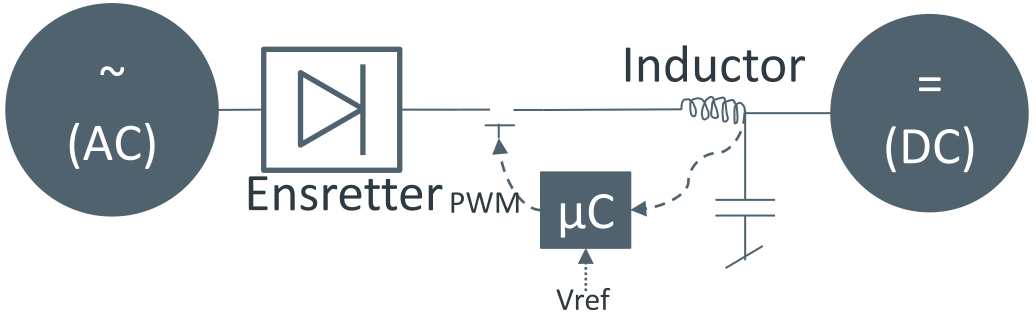
Power Converter Topologier

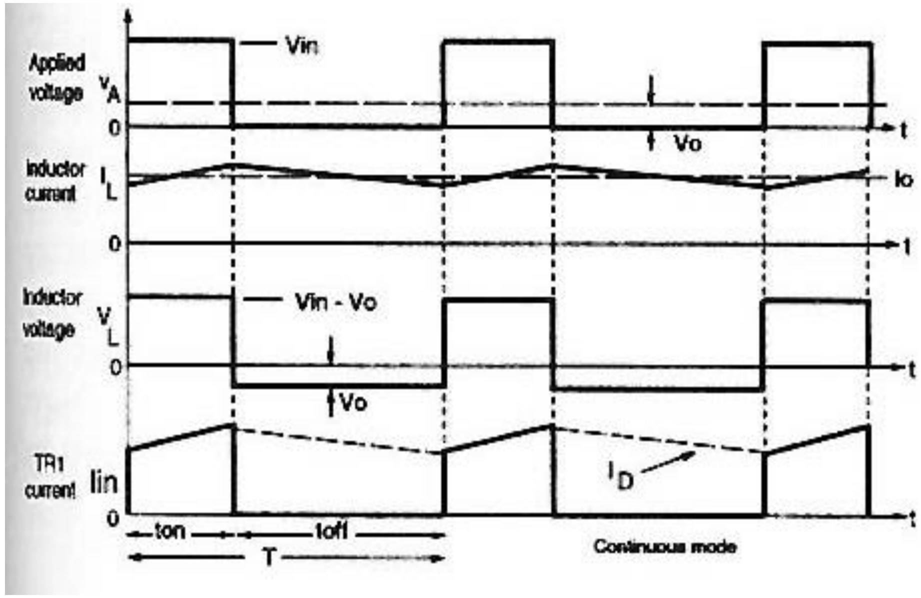
Teknologi der er ældre end mig





Teknologi der er ca. lige så gammel som mig..

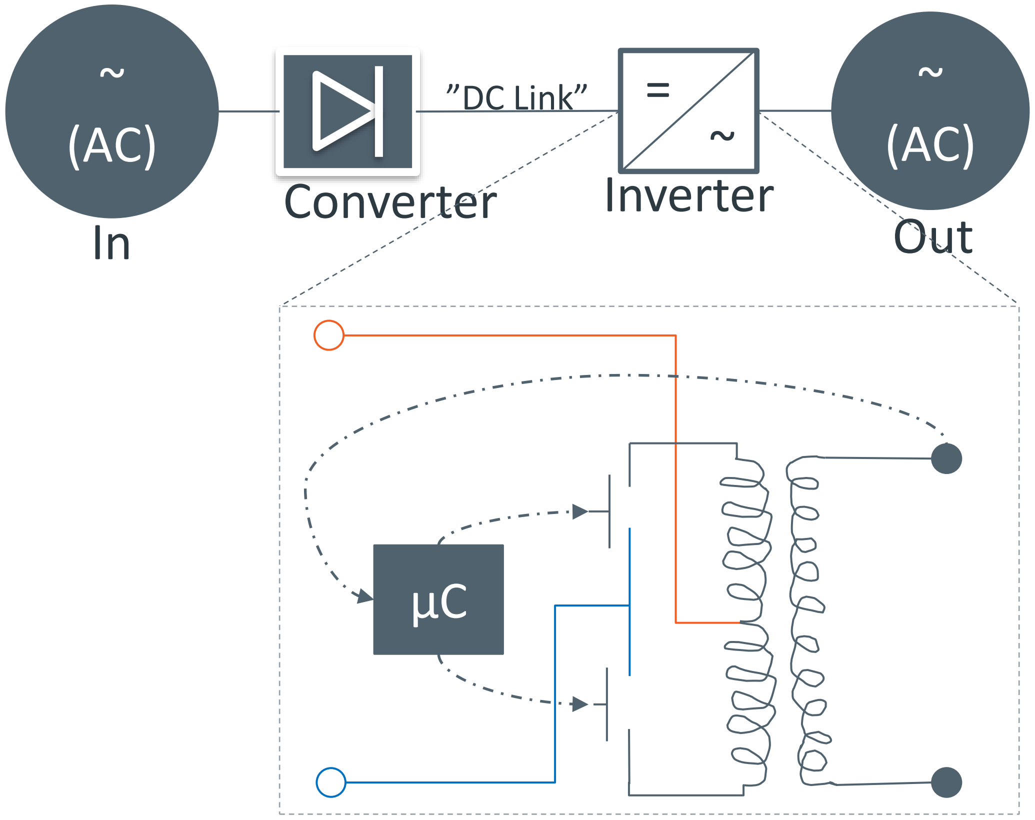


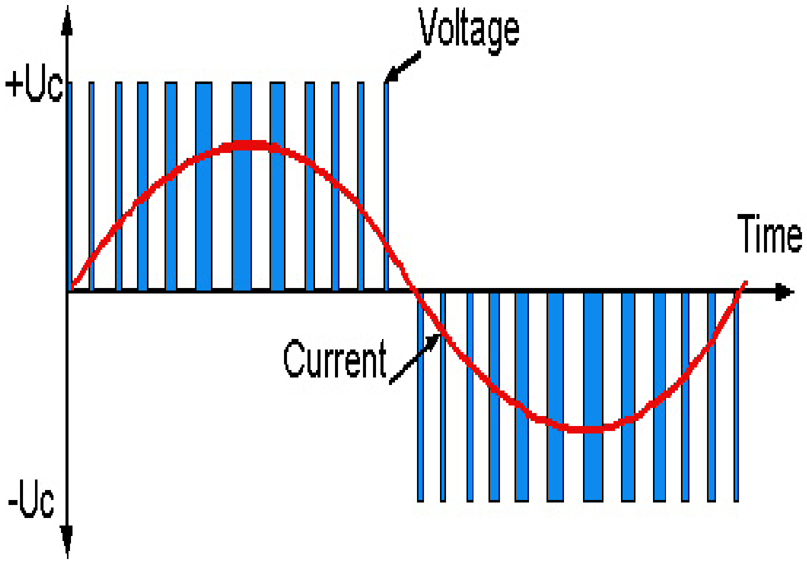


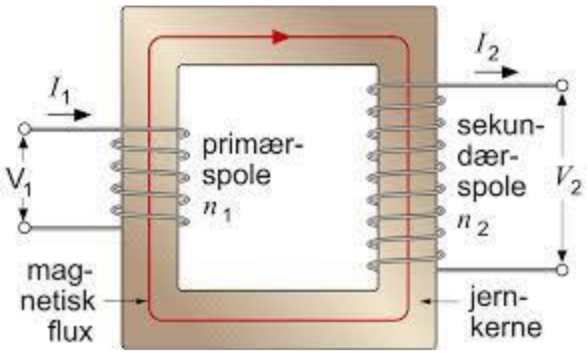
AC / DC / AC – et par sekunder om teknik

Power Converter Topologier

Klassisk AC / DC / AC struktur



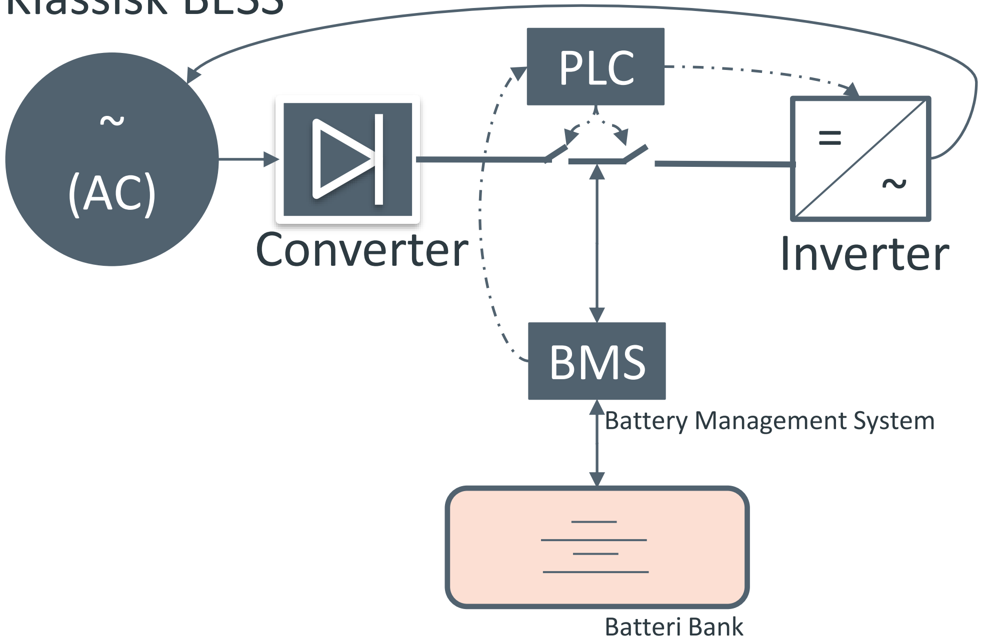




BESS

Battery Energy Storage Systems

Klassisk BESS



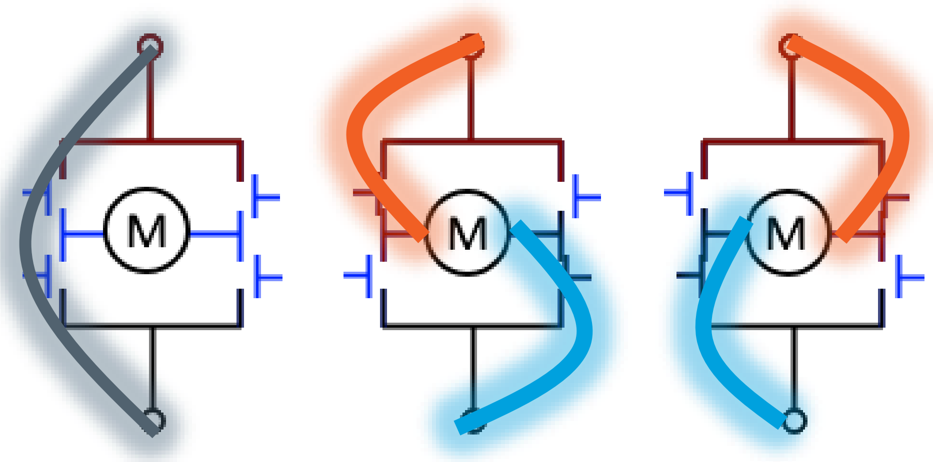
- Opladning, sker ved at indkoble converteren, og styre switch PWM, så strømmen ikke overstiger batteriernes tolerance, og så i øvrigt efter en effekt reference.
- Afladning sker ved at indkoble inverteren , og styre switch PWM, så strømmen ikke overstiger batteriernes tolerance, og så i øvrigt efter en effekt reference.
- DC Linket er brudt, da man gerne vil styre hvor strømmen løber hen, eller kommer fra.
- Batteribanken er typisk på >560V dc, da det svarer til passivt ensrettet 400V ac..

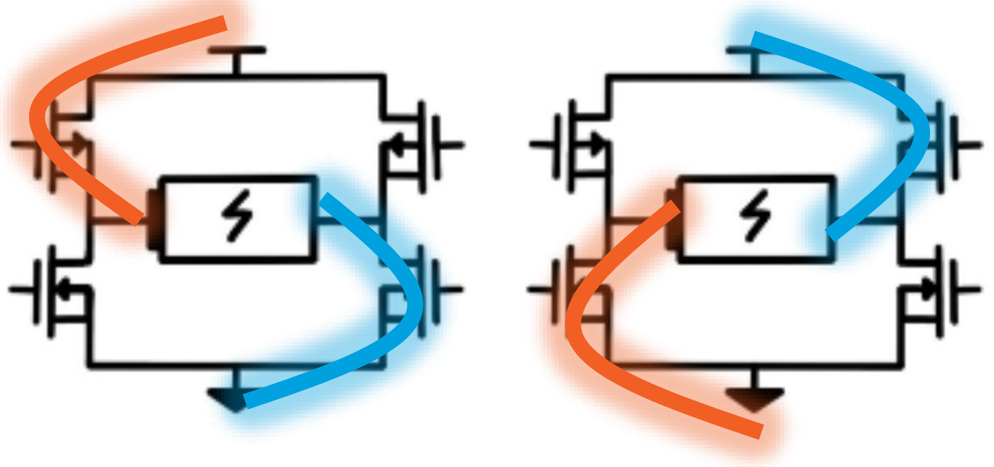
MultiCon Concept

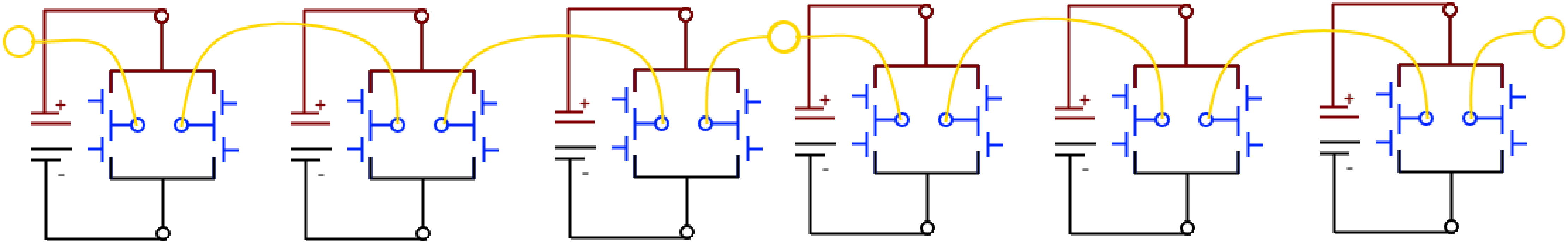
MultiCon : **Multi**level Power **Con**verter

Wind Solutions®

Lad os for et øjeblik tænke på et batteri som en motor..

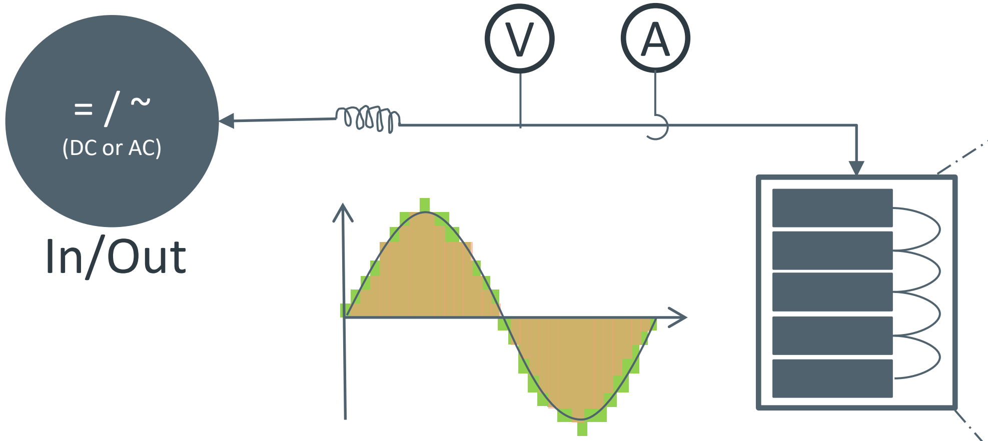


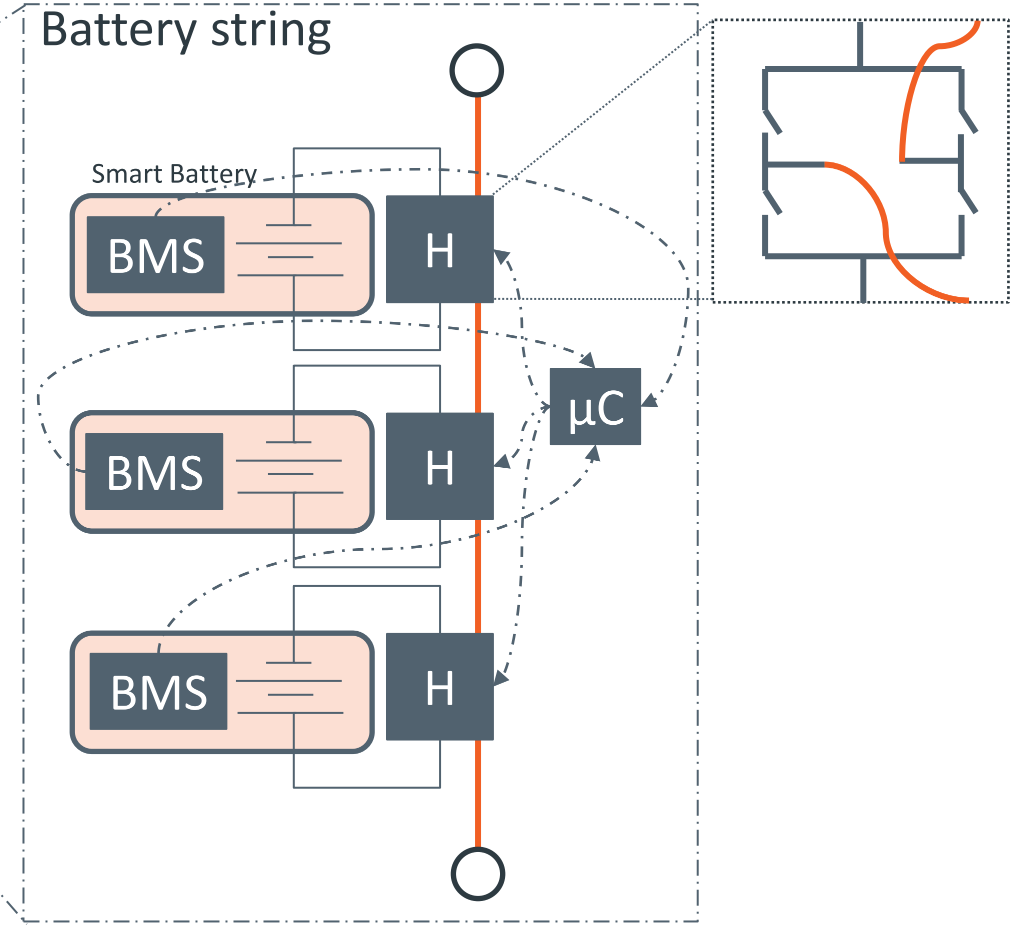




Multicon : **Multi**level Power **Conv**erter

MultiCon fortolket som Battery Energy Storage System

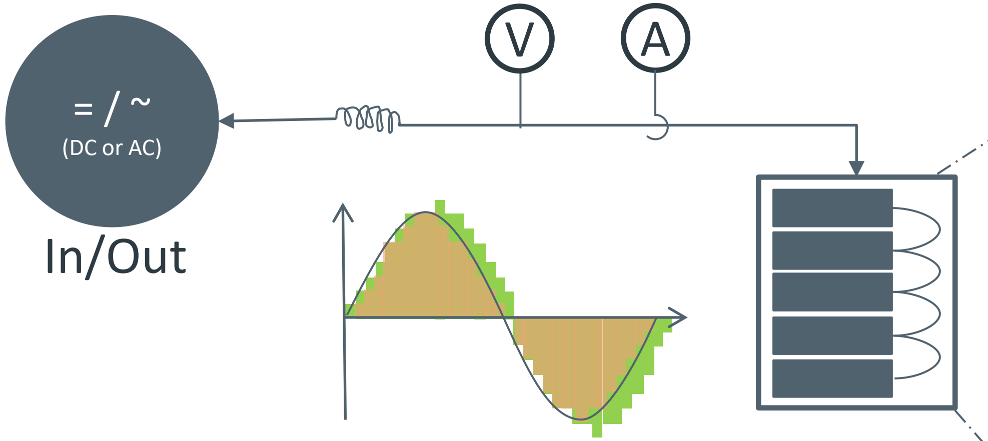


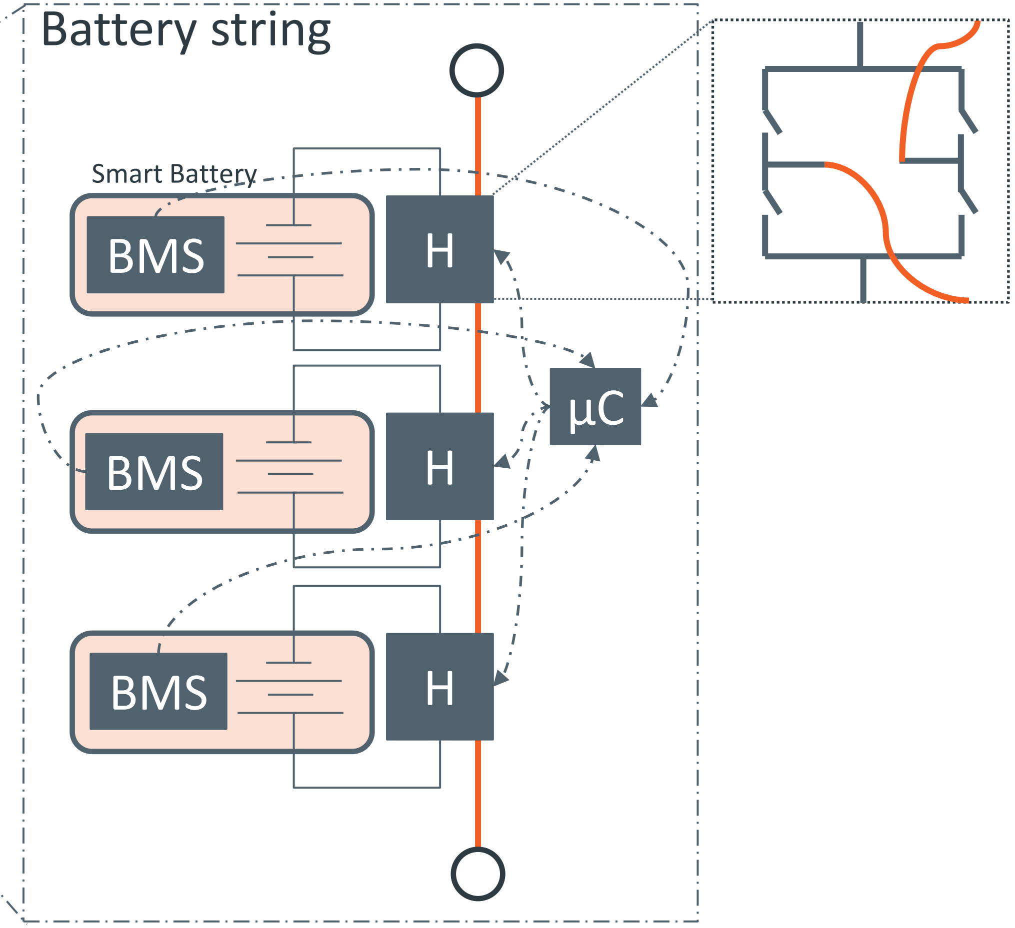


- Op/Afladning styres løbende, mange gange i løbet af en sinus, ved at ændre på hvilken spænding vi producerer.
- Det er software der definerer om vi styrer efter effekt, strøm, spænding..

Multicon : **Multi**level Power **Conv**erter

MultiCon fortolket som Battery Energy Storage System

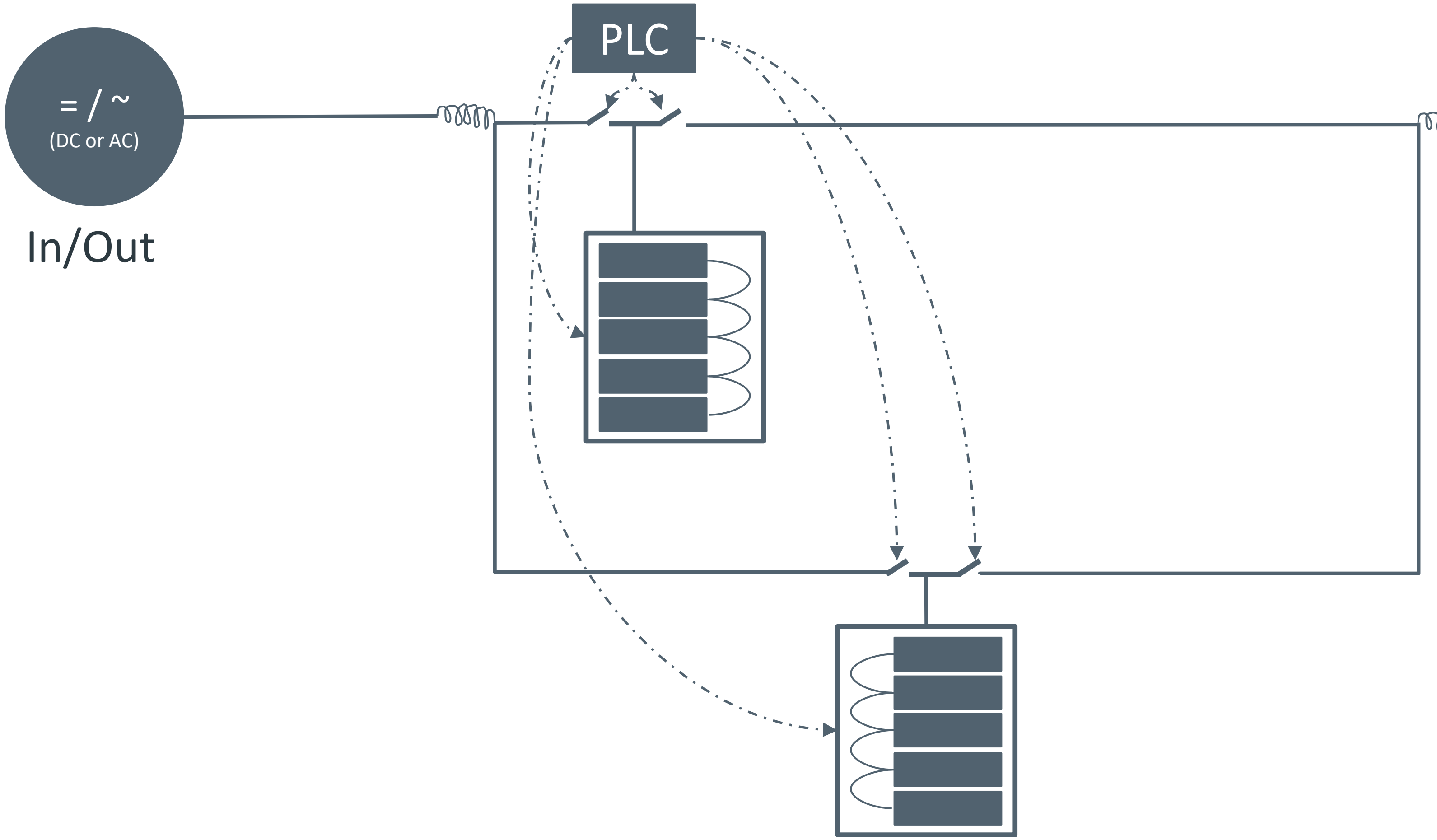




- Op/Afladning styres løbende, mange gange i løbet af en sinus, ved at ændre på hvilken spænding vi producerer.
- Det er software der definerer om vi styrer efter effekt, strøm, spænding..
- Eller evt. fasedrej

Multicon : **Multi**level Power **Conv**erter

Multicon fortolket som UPS, eller frekvensomformer.



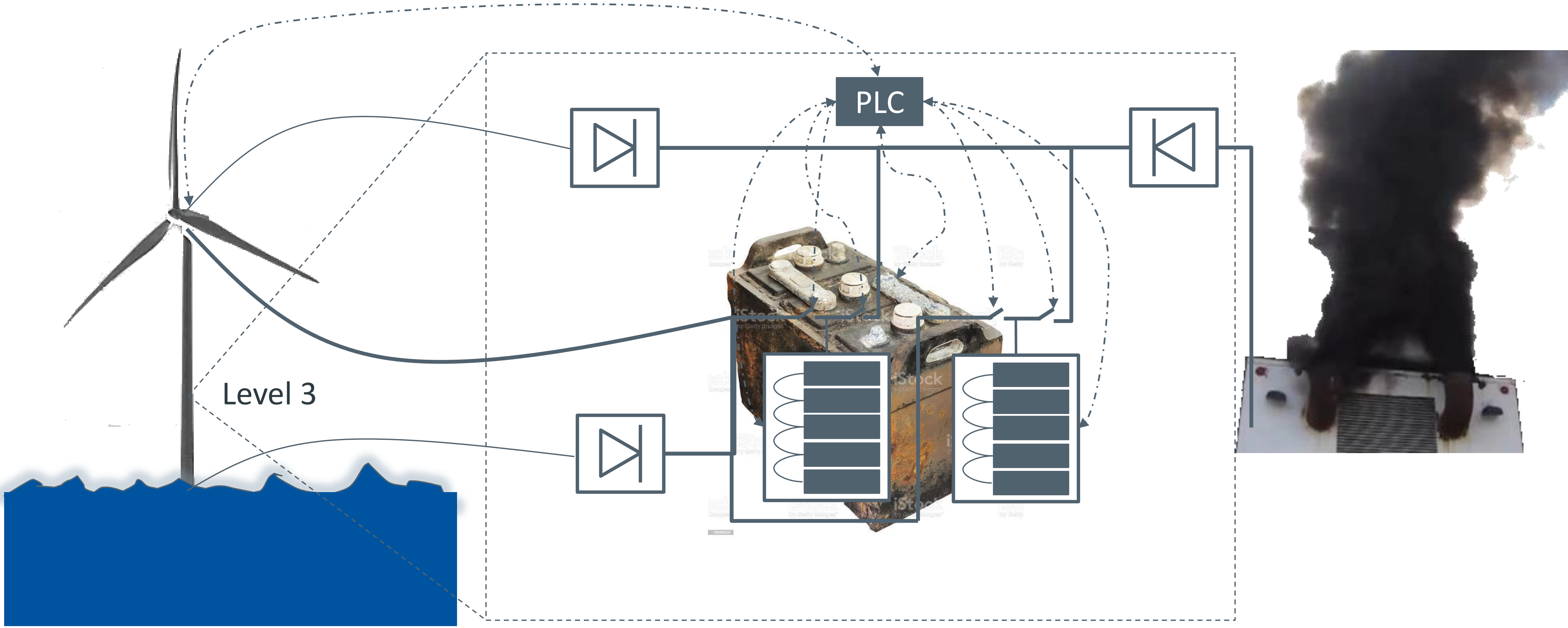
- 2 Strings er nok, hvis vi vil have en uafbrydelig forsyning.
- Den ene forsyner, mens den anden lader.
- Man kan lade fra et spændingsniveau / frekvens
- Man kan aflade på et spændingsniveau / frekvens.
- Synkronisering, når man bytter, sker inden indkobling.

MultiCon Produkter I marken (på havet)

OEM2 - APBS Type 1 (DC/DC UPS)

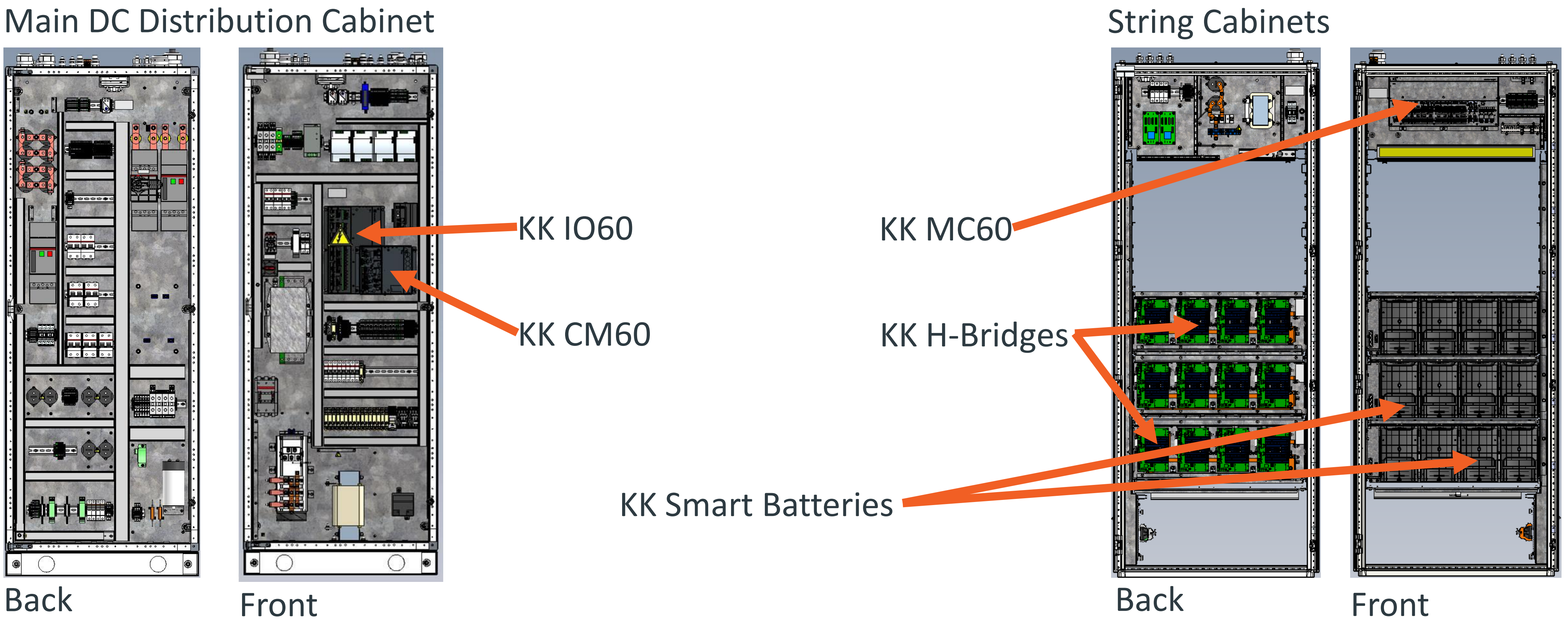
Wind Solutions®

"Idle power" backup system, lader fra ca 560 – 50Vdc, afleverer på ~400Vdc



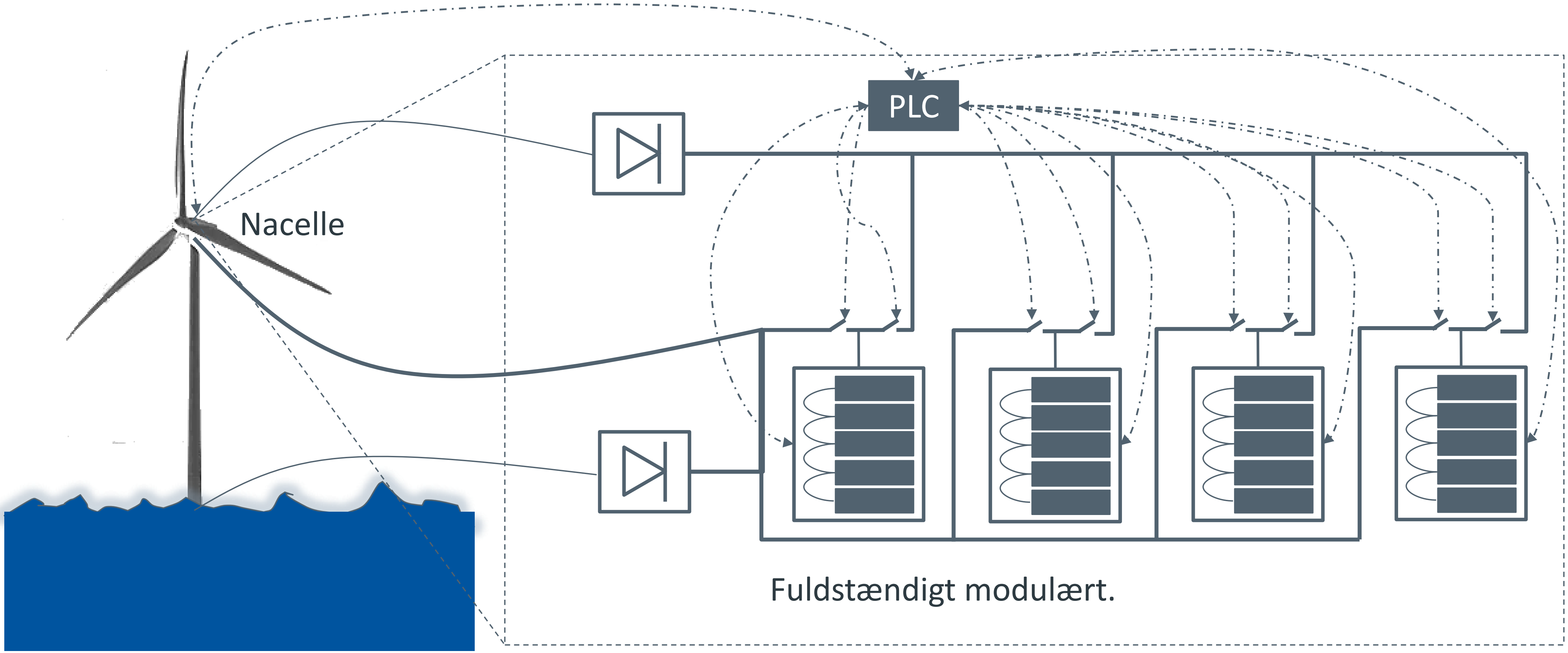
APBS Type 1 (First Sold System)

MVOW ”Idle power” backup system (VVUPS)



OEM2 APBS Type 2

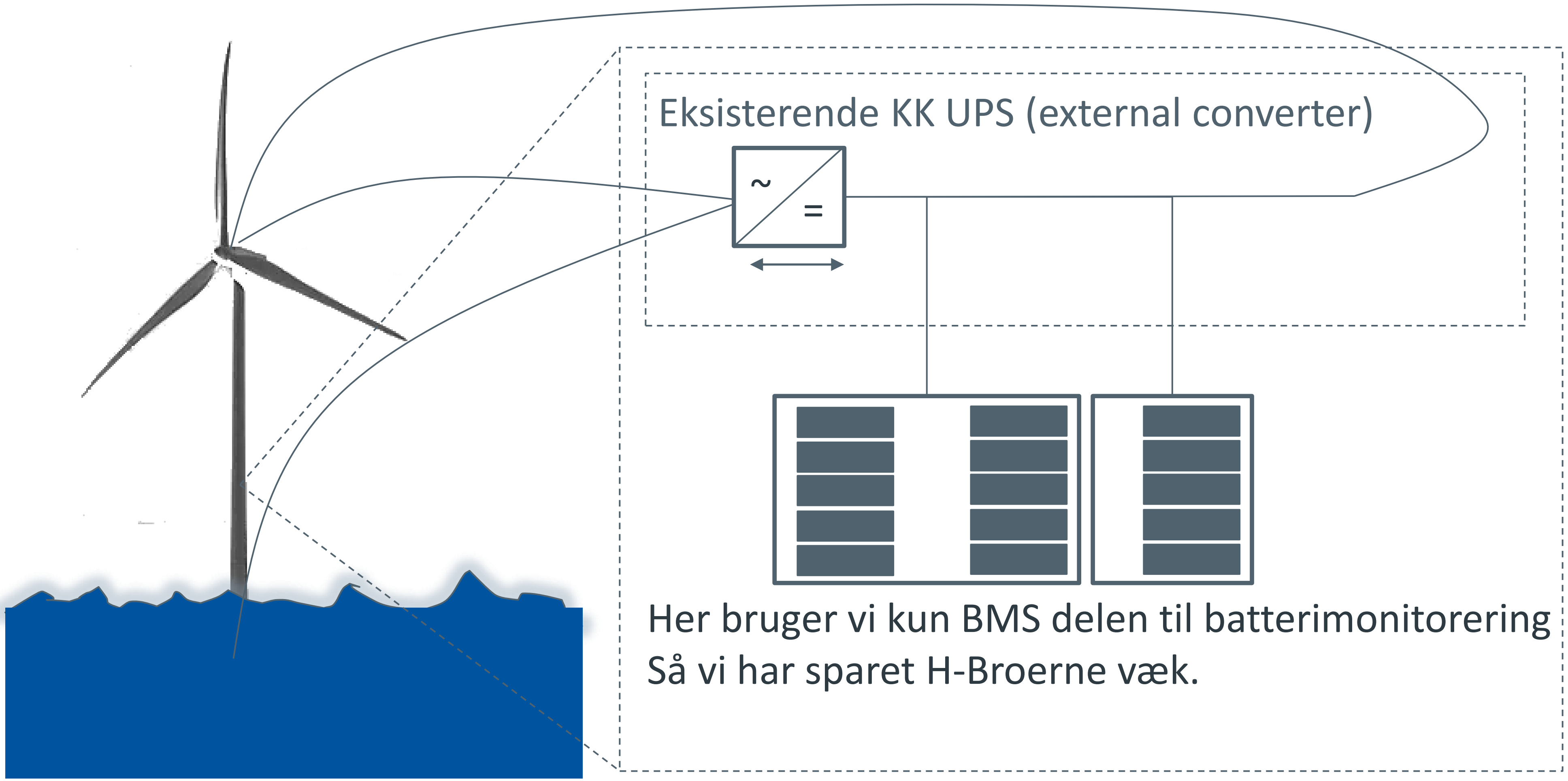
Vi snakker nu om 400V dc, ved 600A, kontinuert.



Fuldstændigt modulært.

OEM1 – Erstat blybatterier, for længere levetid.

Idle Power Backup System 125kVA

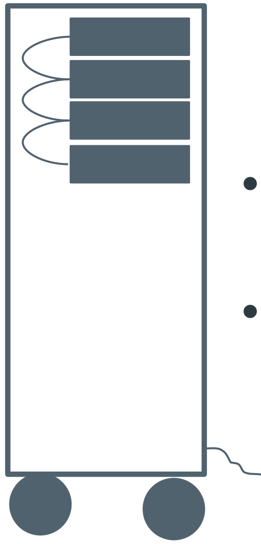


OEM3 AC Emergency Backup Power

Op/afladning fra 3 faset. Support for blackstart, dog med gapped backup.

LFP Charger

Storage facillity device for maintenance charging batteries



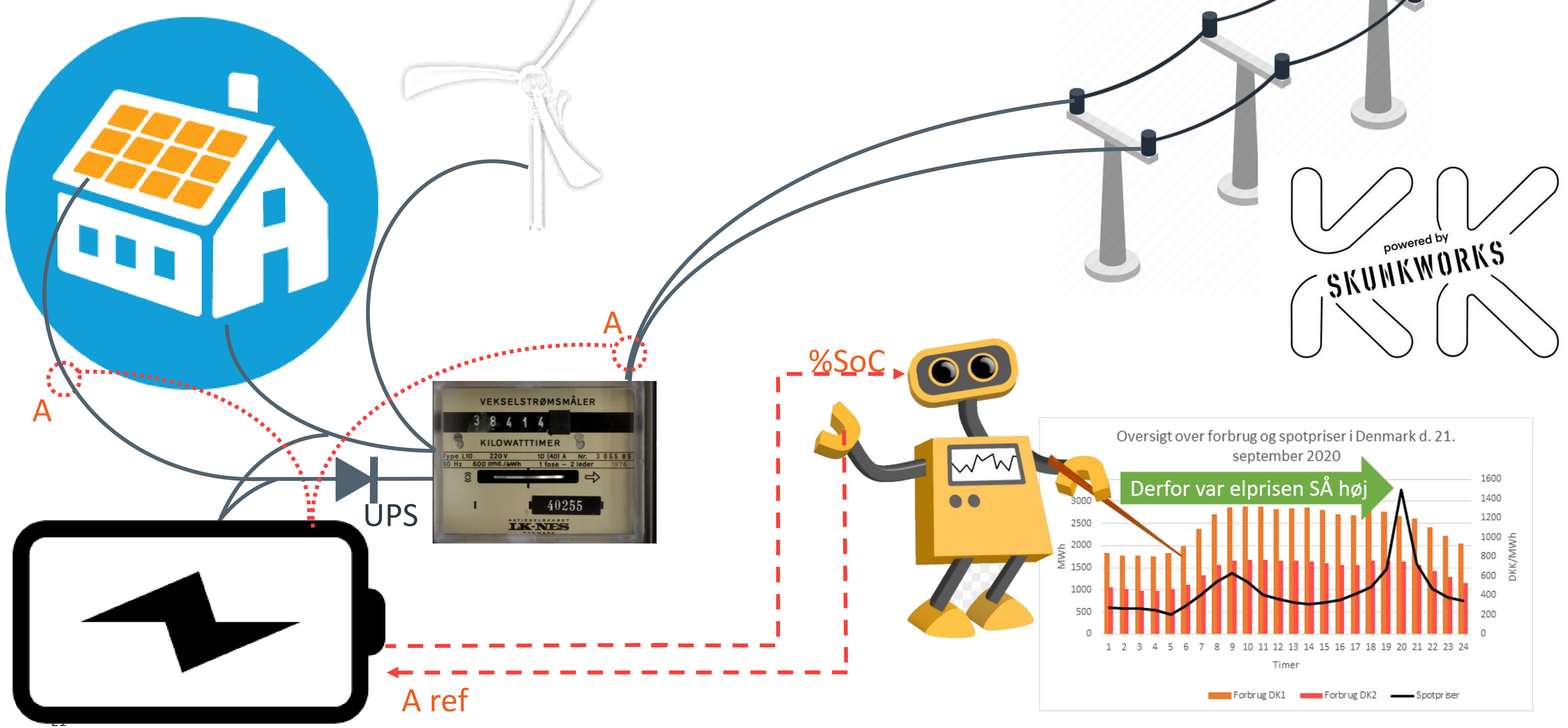
- 4 batterier (using 1:2 transformer)
  - eller 8 batterier, ingen transformer
- 1 phase @ 2kW
- Jeg har en med i dag…

Prototyper, eller, koncepter der måske aldrig bliver produkter, men som vi lærer noget af…

KK Wind Solutions®

Prototyper

Charging from solar (PV) inverter, delivering power via UPS, ensuring grid compliance



Prototyper

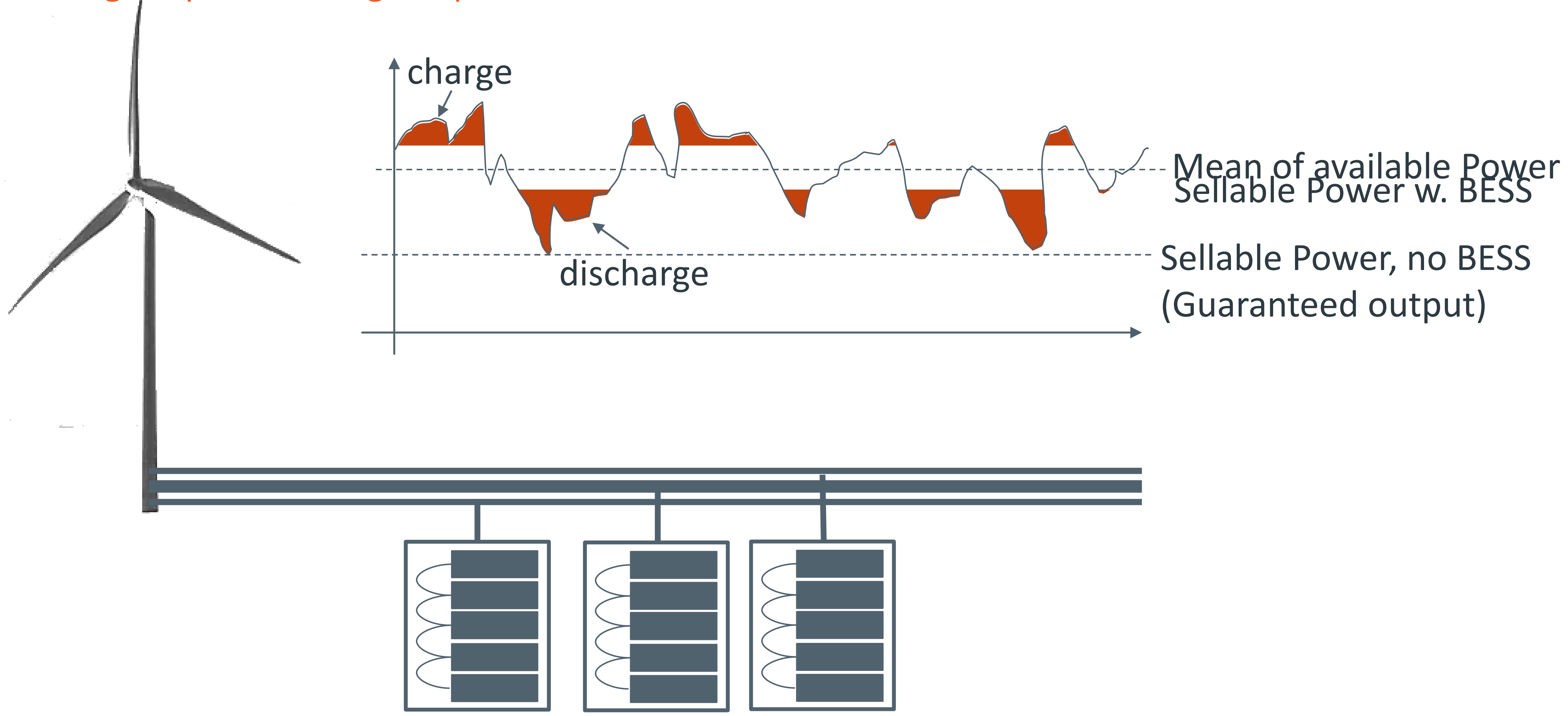
KK Wind Solutions®

Husstands installation.

powered by SKUNKWORKS

Prototyper

Peak shaving output tester ligenu på onshore turbine



Prototyper

Offline e.v. ladestation, solceller – 20fods container, type2 ladere.

Jeg svarer gerne på spørgsmål, eller vi kan "sparke dæk", hvis I gerne vil se teknologien I praksis.

Wind Solutions®

Thank you for your attention

We innovate to integrate®

ELEKTRISK KINETISK ENERGILAGRING - NYE MATERIALER, MERE ENERGI

MARTIN SPEIERMANN
WATTSUP POWER A/S

TAASTRUP - 9. MARTS 2023

WATTSUP POWER A/S

ELEKTRISK KINETISK ENERGILAGRING – NYE MATERIALER, MERE ENERGI

FLYWHEEL TECHNOLOGY

WHAT IS A FLYWHEEL?

W

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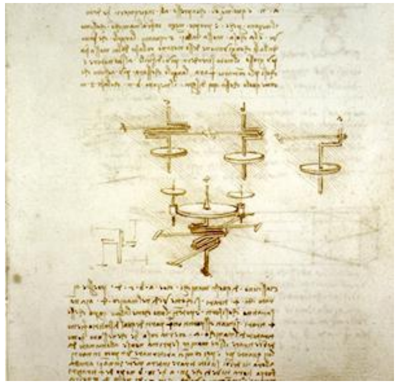
- A flywheel is a rotating mechanical device, which is used to store rotational or in technical terms kinetic energy. Flywheels have a significant moment of inertia and thus resist changes in rotational speed. The amount of energy stored in a flywheel is proportional to the square of its rotational speed. Energy is transferred to a flywheel by applying torque to it, thereby increasing its rotational speed, and consequently its stored energy. Conversely, a flywheel releases stored energy by applying torque to a mechanical load, thereby decreasing its rotational speed.

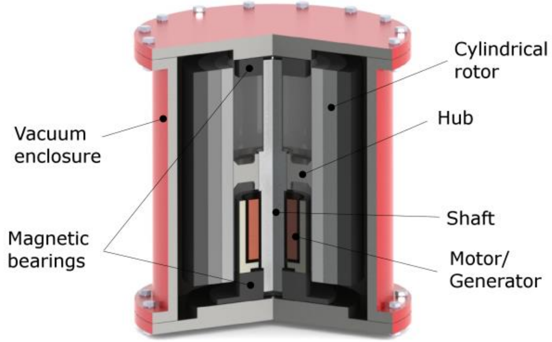
- On the right the flywheel technology development from the renaissance to today.

- For online info please visit - http://www.youtube.com/watch?v=mz_7UF4KQpk

Leonardo *da Vinci* (1452-1519)



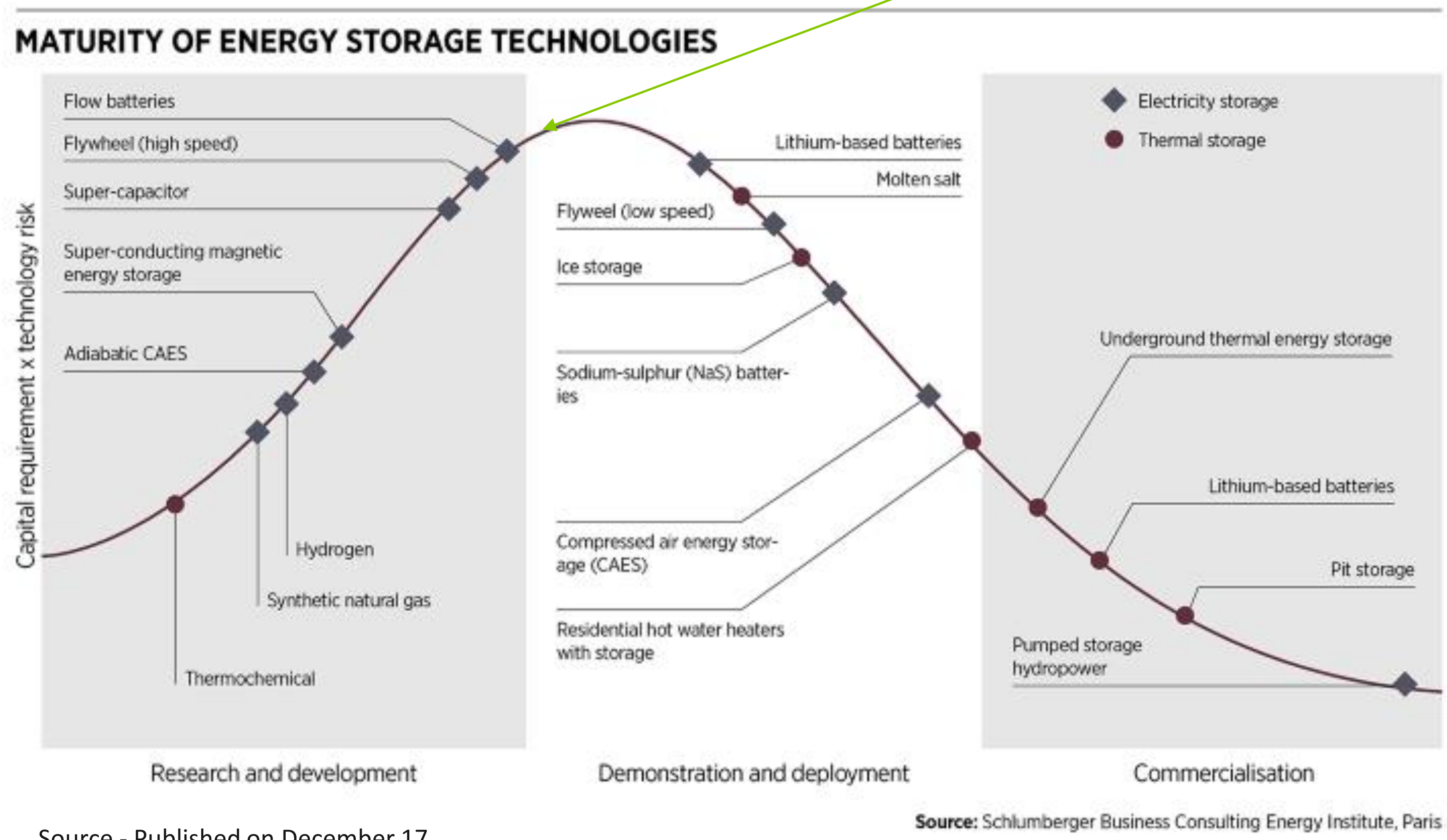
Technology anno 2015



WHERE IS THE TECHNOLOGY TODAY

WattsUp Power

WattsUp Power is passing this point at 150kWh

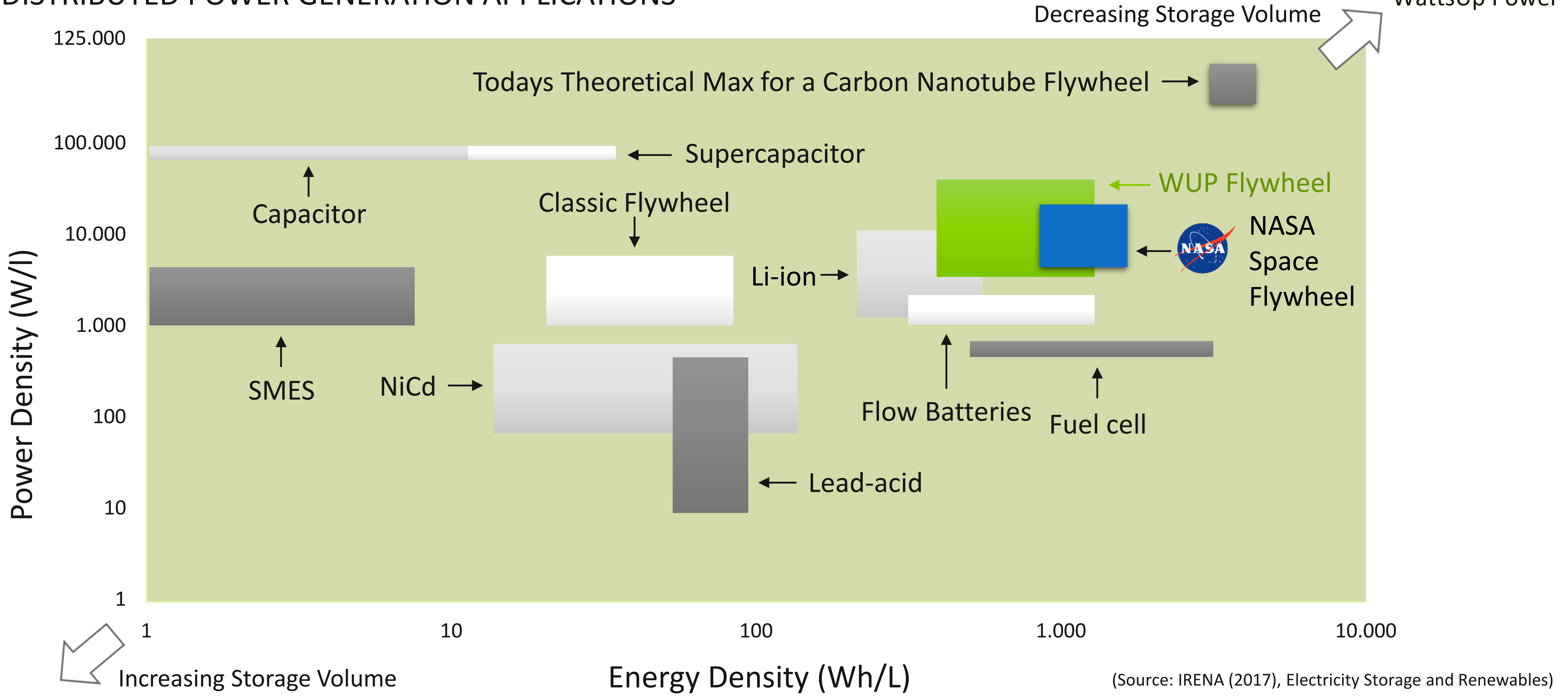


Source - Published on December 17, 2019 in What We're Reading - https://www.pathto100.org/a-new-twist-in-the-storage-story-as-battery-technology-improvements-are-evolving-much-faster-than-expected/

A COMPARISON OF POWER AND ENERGY DENSITY

THE WUP FLYWHEEL IS A SUPERIOR TECHNOLOGY AND WILL BE A MARKET LEADER WITHIN DISTRIBUTED POWER GENERATION APPLICATIONS

WattsUp Power



(Source: IRENA (2017), Electricity Storage and Renewables)

WHAT IS A FLYWHEEL?

HOW DOES IT WORK

W

WattsUp Power

- A flywheel is a mechanical energy storage which storages energy in a rotating mass. Energy stored called kinetic energy and is proportional with speed.
- NASA technology from the international space station 2009. WattsUp Power was very inspired. Enabled by new materials.
- 4 patent global families. Bearings, Cooling, Motor and Energy Storage System.
- Composite winding methods. Using a new type of Carbon Technology.

WATTSUP POWER’S FLYWHEEL

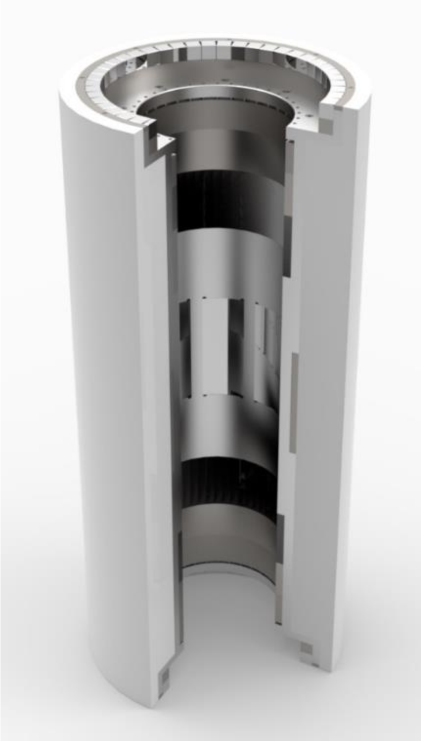
WHY ARE WE DIFFERENT

W

WattsUp Power

OUR ENERGY STORAGE PRODUCT OUTPERFORMS BOTH EXISTING BATTERY TECHNOLOGIES AND COMPETING FLYWHEEL TECHNOLOGIES!

- Exceptional low losses in patented magnetic array and motor/generator technology
- New carbon materials increasing energy storage and lower cost - >10x
- Kinetic Energy Generation - Proven Technology
- Long Performance Life – Durability
- Non-Hazardous or technology metals, ***scars materials***



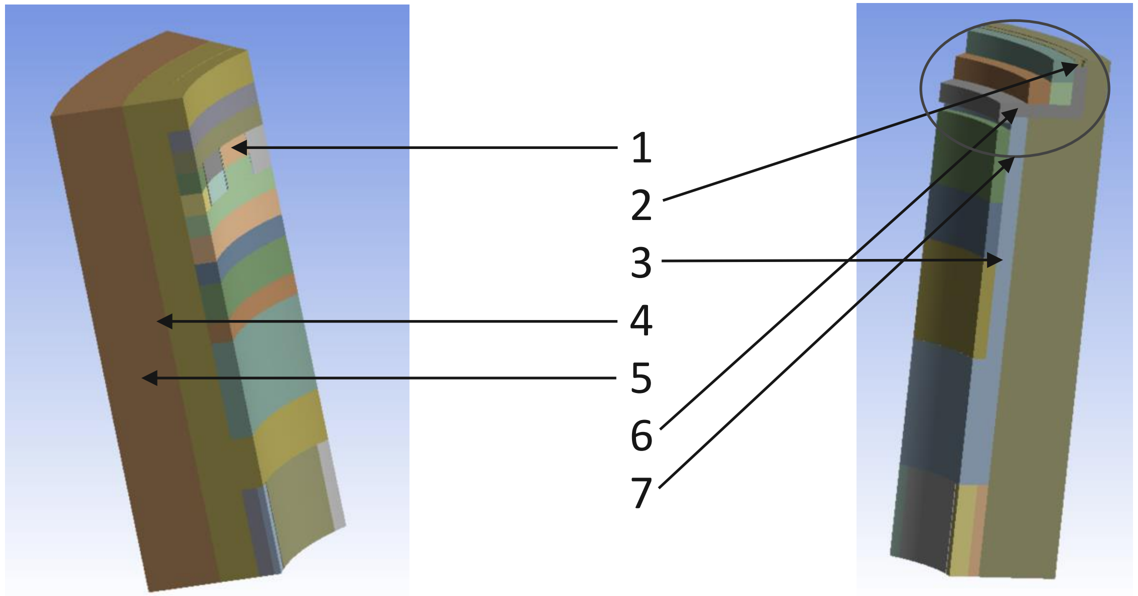
ROTOR

IMPROVEMENTS ON THE ROTOR TO REACH 37.500 RPM

WattsUp Power

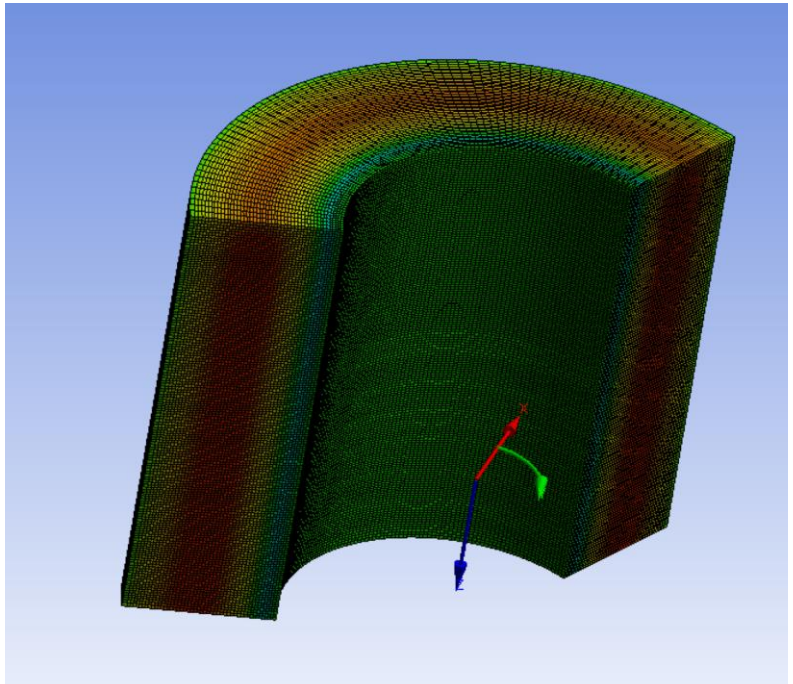
OVERVIEW OF IMPROVEMENTS

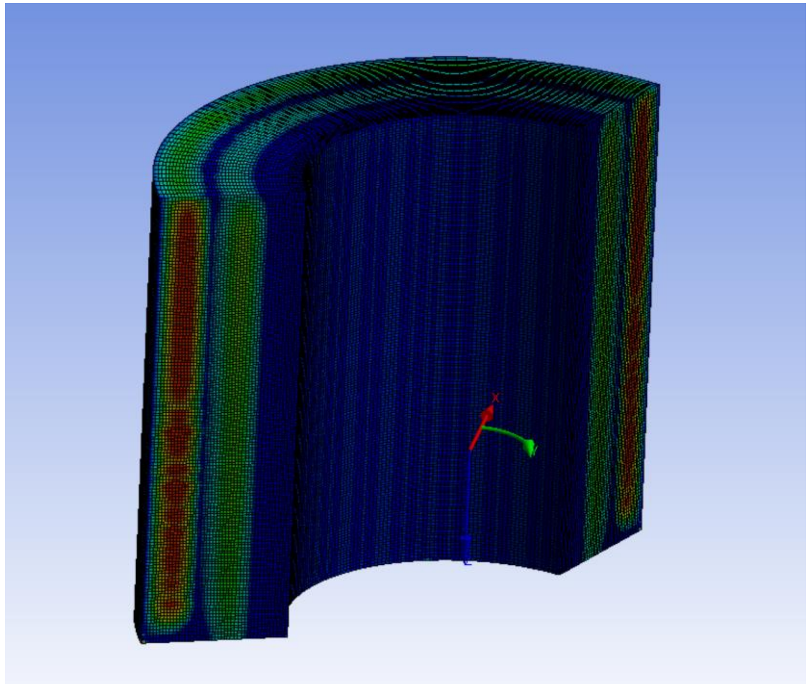
No	Detail	Deneb002	Deneb003/ Electra 001	Improvement Effect	Rating
1	PMB	Placement close to rim of the Rotor	Placed away from the Rim of the Rotor	Decrease of stresses in the ends of The Rotor	4
2	PMB holder holes	Holes in the PMB holder	Holes removed from PMB holder	Decrease of stresses in the PMB holder	3
3	Alu pipe	Used to keep parts in place inside GFRP cylinder winding	No Alu pipe parts shrink fitted into FRP instead	Stresses in Alu pipe removed assembly simplified	3
4	More FRP cylinders	The Rotor outer made of only one GFRP cylinder	At least+ 2 FRP cylinders to be shrink fitted	Decrease strain and stress in inner parts of the Rotor	4
5	Carbon	The design material limited to GFRP for outer Rotor	allowed to use both GRFP and CFRP	Possible to optimize the strength properties for max kWh out put	4
6	Balancing ring	Placement close to rim of the Rotor	Moved to the mid of the Rotor	Decrease of stress	3
7	Shape of the inner rotor	Stair inner shape of Rotor	Straight inner shape Rotor	Decrease of stress	5



FRP	Fiber reinforced plastic	
GFRP	Glass fiber reinforced plastic	
CFRP	Carbon fiber reinforced plastic	
Rating	1: low improvements	5: max high improvements

New ROTOR design and production method developed and approved and by 3. party to run 50.000 RPM and reach 500kWh
Design max. 75.000 RPM / 1M Wh





DESIGN SAFETY FACTOR (DSF)

NEW MATERIAL

Ordered before Christmas 2021.

WattsUp Power

COST	MATERIAL	32.500 RPM	37.500 RPM	DSF - SAFETY
$$$$	T1100	✓	✓	100%
$$$	T800S	✓	✓	50%
$$	T910	✓	✓	40%
$	T700S	✓	✓	25%
$	TODAY ADVANTEX 100%	✓	✓	0%

TODAY ADVANTEX
25.000 RPM

Weight: 750 kg // 165 lb
Height: 125 cm // 50 inch

100 kWh

150 kWh

250 kWh

WUP Recommendation - NOW

- TORAY - Brand
- +10 % Cost increase on Rotor.
- 250 kWh possible
- 3 Layer FW

WUP Recommendation – 500kWh

- TORAY - Brand
- 20% cost increase!
(Total 300.000 USD)
- 500 kWh possible
- 5 Layer FW
- Test Q4 2022
- Max. 75.000 RPM 1MWh

CODE NAME
NEED FOR SPEED

W

WattsUp Power

2GW PRODUCTION AND SALES - DK / NO / USA

TODAY	PILOT - APRIL 2022	PRODUCTION - JULY 2022	PILOT - OCTOBER 2022	PRODUCTION - JANUARY 2023
10.000 RPM 2021 Deneb 002	27.500 RPM 150 kWh Electra 001 37.500 RPM 70 kWh Deneb 003	Version 01 Max speed 27.500	37.500 RPM 250 kWh Electra 002	Version 01 Max speed 37.500 500 kWh Electra 750 kWh Electra

WATTSUP POWER FLYWHEEL OUTPERFORMS COMPETITORS

GLOBAL ENERGY STORAGE TECHNOLOGIES

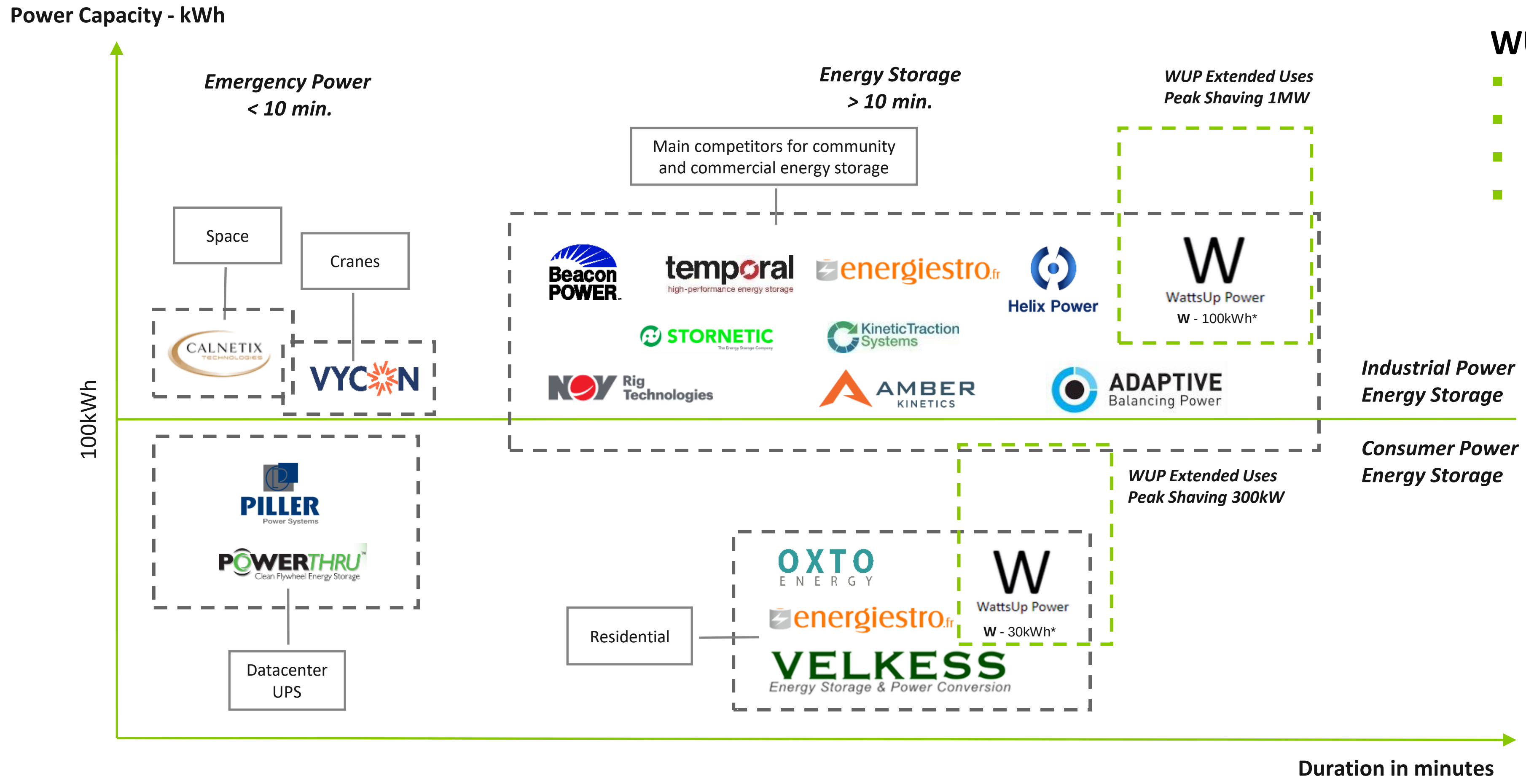
W
WattsUp Power

Technology	Transfer speed	Volume stored	Charging time	Life-time	Price
WATTSUP POWER FLYWHEELS	🟢	🟢	🟢	🟢	🟢
LITHIUM-ION BATTERIES	🔴	🟡	🔴	🔴	🟡
SUPER CAPACITORS	🟢	🔴	🟢	🟡	🔴
FLYWHEELS	🟢	🔴	🟢	🟡	🟡

COMPARISON TO OTHER FLYWHEEL PROVIDERS

GLOBAL FLYWHEEL TECHNOLOGIES

WattsUp Power



WUP'S STRENGTHS

- Permanent Patents designs
- Power x10 Vs. Energy
- Stability for Increased Speed
- Standard Integration Capability

EFFICIENCY COMPARISON BETWEEN MARKET AVAILABLE ESS

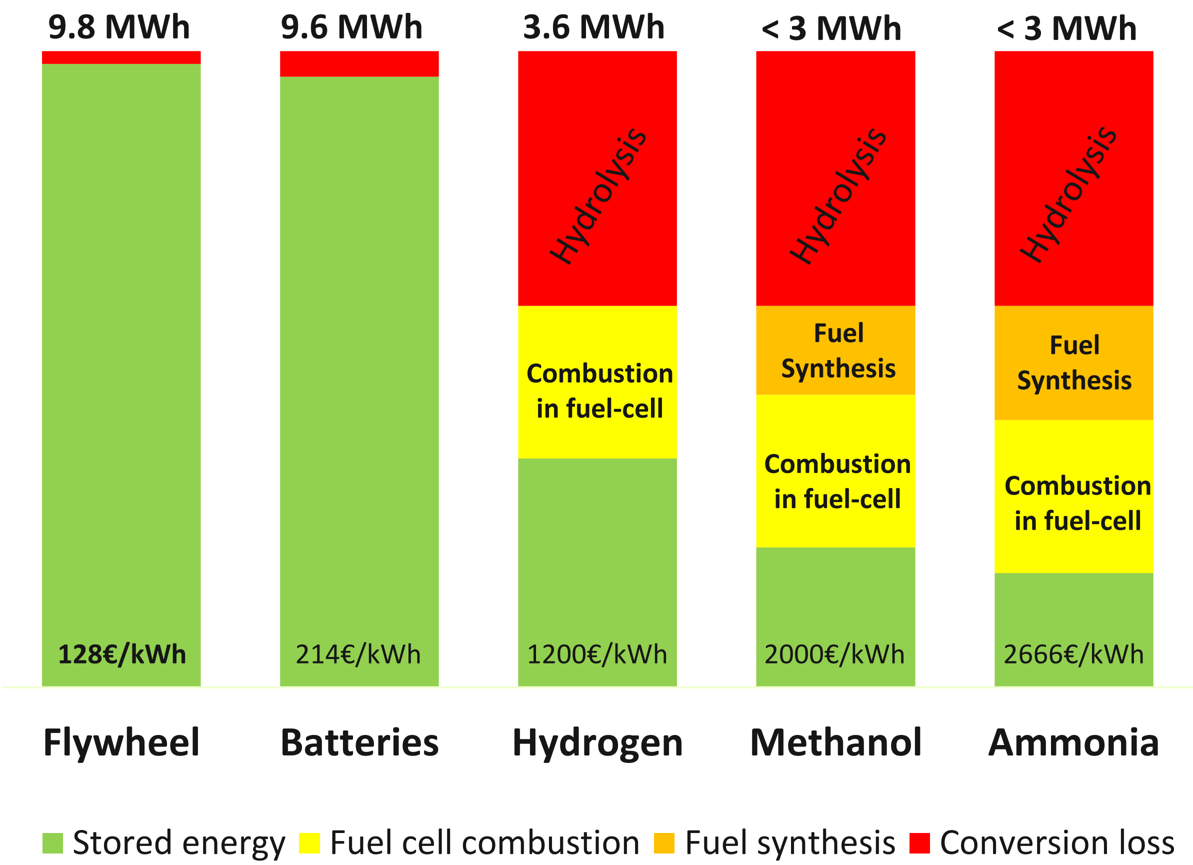
UTILITY SCALE ESS

WattsUp Power

10 MWH WIND FARM

Battery and **Flywheel Energy Storage Solutions**
Are more than +50% more efficient that hydrogen, methanol or Ammonia solutions

EFFECTIVE ENERGY STORED WITH 10 MWH GENERATED



Source paper publication 2021: www.transportenvironment.org

ONE PRODUCT – MANY SOLUTIONS

FOCUS AREAS – PROPOSED STRUCTURE AND PARTNERS

SOLUTIONS – MARKETS - REGIONS

W

WattsUp Power

WUP - Focus Areas

Maritime

EU | US

Areas
- Short-haul vessels
- SOV's
- Drilling
- Cruises
- Power Barge

Partner
- Spinning Energy – EU
- Edison Chouest – US

Railway

EU | US

Areas
- Peak-power
- Energy Management
- Ancillary Services

Partner
- TBD –Siemens / Alstom

Super Charging

EU | US

Areas
- Cars
- Ferries
- Busses
- Airplanes

- **Partner**
- Andel – EU
- Edison Chouest – US

Micro Grid //Grid Stabilization

EU | US

Areas
- Peak-power
- Energy Management
- Ancillary Service
- Load leveling
- Frequency Regulation
- Spinning Reserve

Partner
- Andel – Scandinavia EU
- Edison Chouest – US

Heavy Industry

EU | US

Areas
- Peak-power
- Energy Management
- Integration of local supply
- Ancillary Service

Partner
- DANIELI Group– EU
- TBD– US

Other areas of interest
- Mining
- Defense
- Space
- Deep Sea Mining
- Urban//Micro Grid

WUP – Risk Strategy

3- Key components + license
- Rotor
- Motor
- Bearing

JV Sales – Split (Concept)
- 50% WUP
- 20% Partners
- 20% Capital Investor
- 10% Employee

WattsUp Power is developing different business models, where local JV models is a possibility.

MARITIME – CASES

HYBRID –DIESEL / ELECTRIC, ALL ELECTRIC, WIND FARM SERVICE OPERATION VESSEL (SOV)

W

WattsUp Power

DENMARK AND NORDIC

Scandlines

MOLSLINJEN

TORGHATTEN

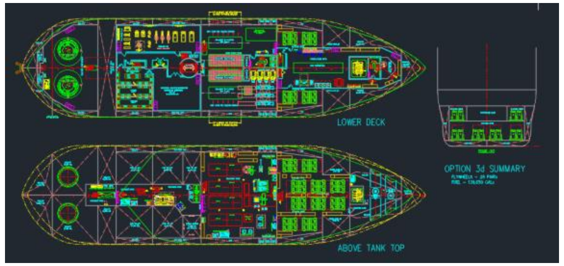
UNITED STATES

EVERSOURCE

Ørsted

Empire Wind

equinor



EDISON CHOUEST OFFSHORE

WUP's first SOV. Worlds first 100% Electric SOV

- 28 Par 250kWh flywheels, ***9 hours electrical operation***

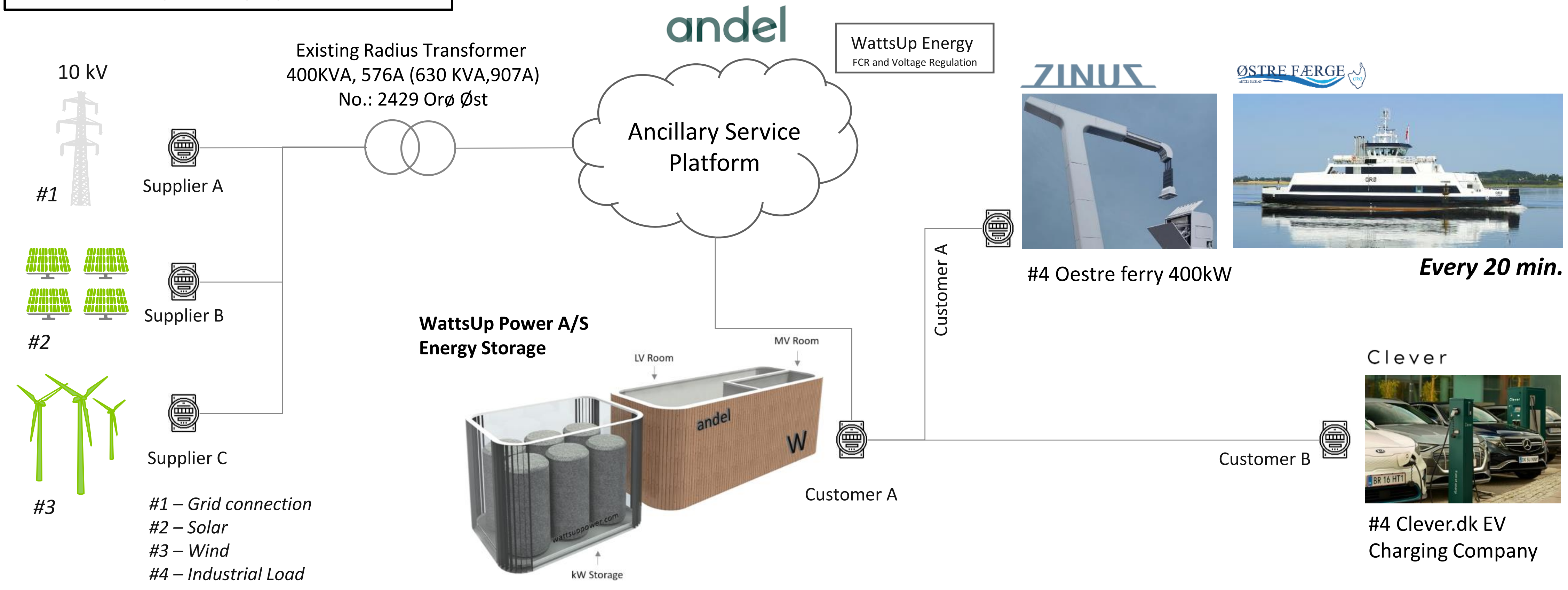
MICROGRID // SUPER CHARGING - CASE

THERE IS ONLY A 400KW TRANSFORMER ON THE ORØ ISLAND TODAY ***EXAMPLE OF CHARGING PROJECT***

W

WattsUp Power

WattsUp will operate the system 24 months from Q1 2023. With an Ancillary Service Platform develop for the purpose.



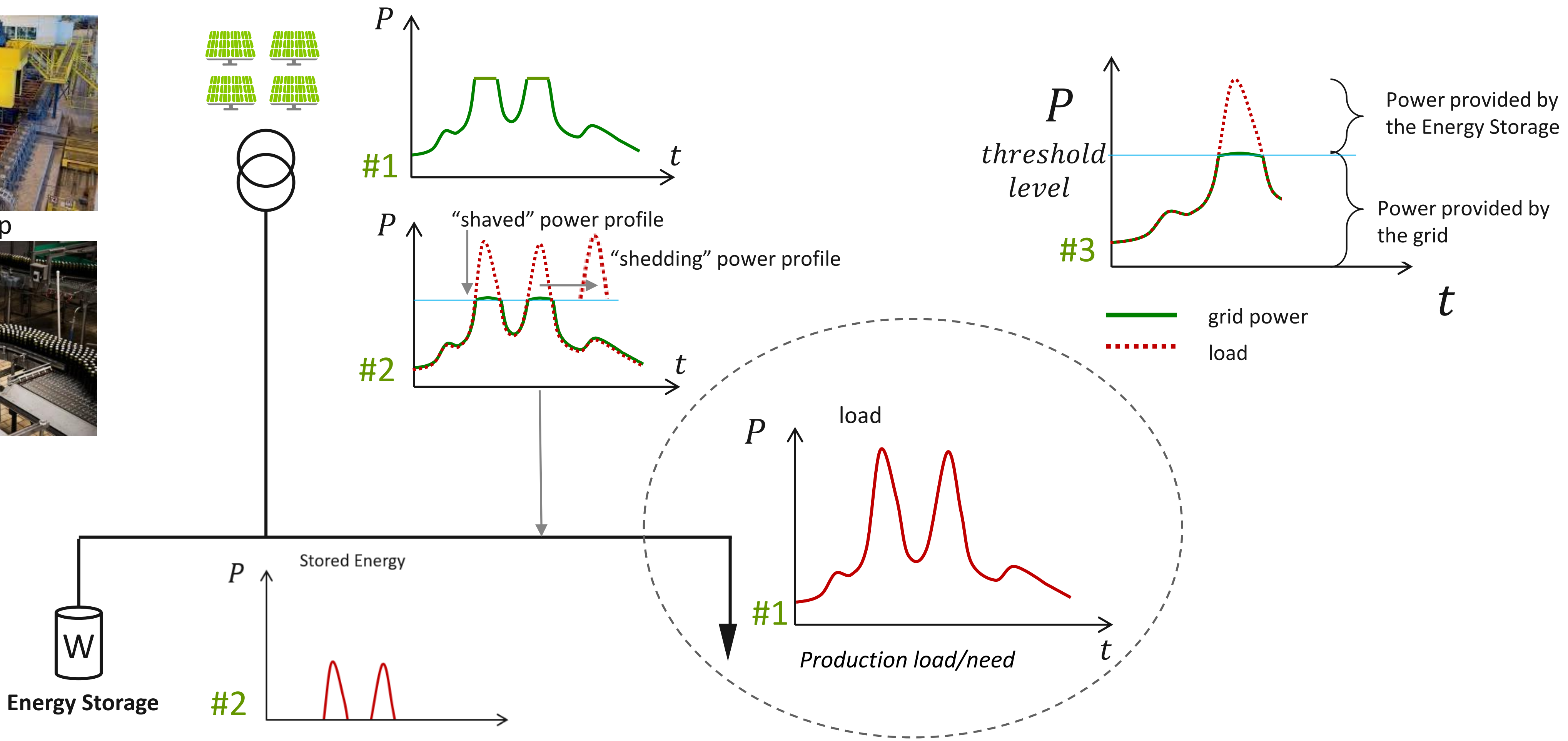
HEAVY INDUSTRY

ZERO EMISSION // CAPACITY REDUCTION - CASE

WattsUp Power

Ex. Danieli Group

Ex. Unibrew



CUSTOMERS PIPELINE

PRODUCTION CAPACITY TODAY – WE NEED TO EXPAND

WattsUp Power

PRODUCTION CAPACITY TODAY – ***100 UNITS***

Headquarter – USA - *Done*
- Sales & Marketing - ***Q1 - 2023***

Houston, Texas
- Research & Development
- Production – ***Q2 - 2023***

Mandeville, Louisiana

Headquarter – EUROPE - *Done*
- Sales & Marketing
- Research & Development - ***Done***
- Production - ***Done***

Copenhagen, Denmark

Production - EUROPE
- Production – ***Q4 2022***

Egersund, Norway

DELIVERED/ORDERED	2022	2023	2024
	4	20	**180**
		4	**28**
	2	58	**48**
		24	**48**
	4	144	**1032**
	2		
SUM	**12**	**250**	**1336**

Units value approx. 1,2 M DKK/unit. Pipeline development is dependent on capacity. Our goal is to have 16-weeks delivery time from January 2023.

HQ, R&D, SALES AND PRODUCTION

EXPAND TO GERMANY, SOUTHERN EUROPE AND ANZ

WattsUp Power

Headquarter - EUROPE
- Sales & Marketing
- Research & Development
- Production

Copenhagen, Denmark

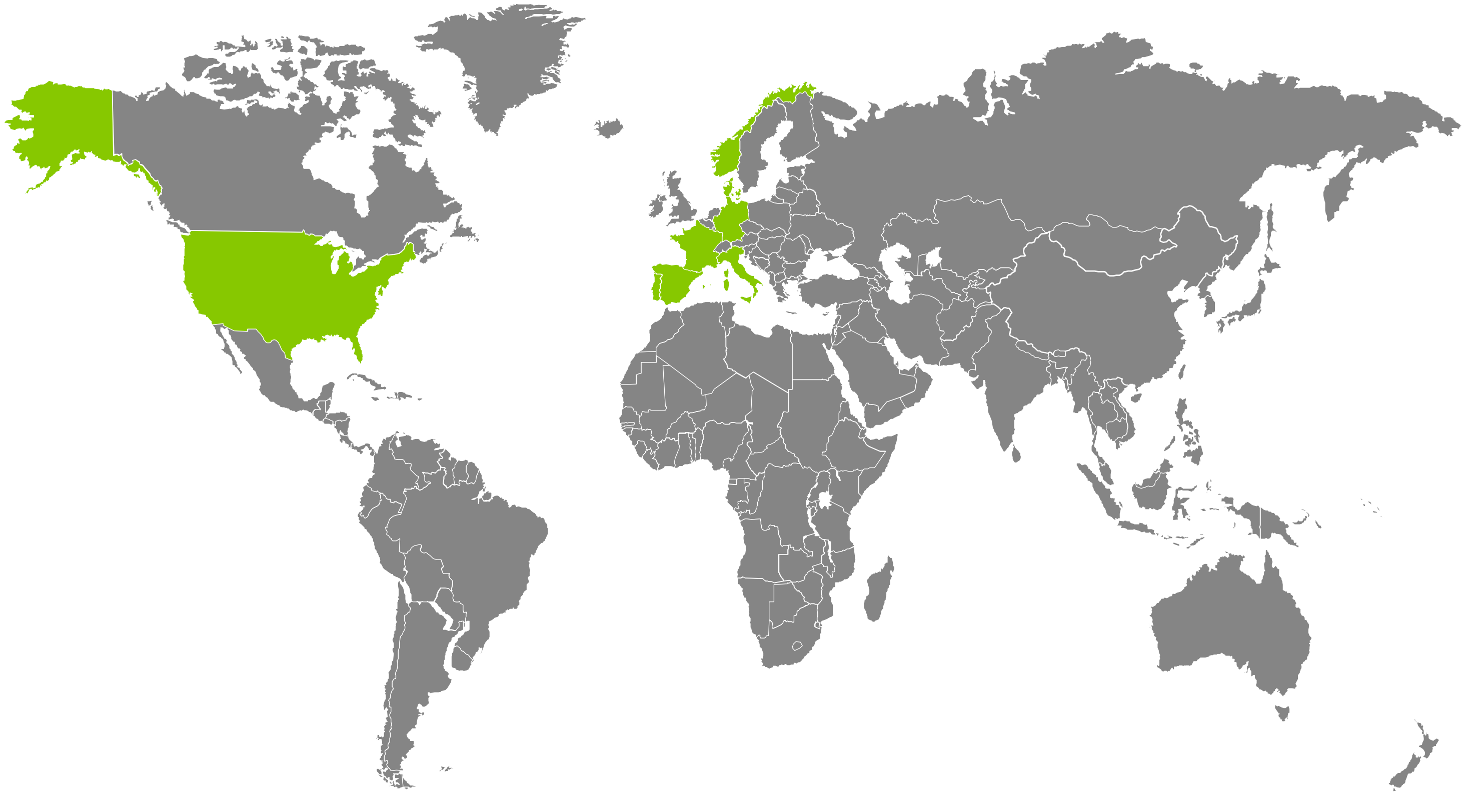
Headquarter - USA
- Sales & Marketing

Houston, Texas
- Production

Mandeville, Louisiana

Production - EUROPE
- Production

Egersund, Norway



Growth Focus Areas

Region Office - GERMANY
- Sales and Production

Region Office – SOUTHERN EUROPE (IT, ES, FR, PT) ITALY
- Sales and Production

EXPECTED IMPACT BY 2026

BUSINESS, SOCIETY AND ENVIRONMENTAL WITH GROWTH EQUITY

W

WattsUp Power

EXPECTED BY 2026

Euro 247M

NET SALES REVENUE

Euro 91M

YEARLY RESULT

2792

UNITS SOLD

413

DIRECT JOBS CREATED

ENVIROMENTAL IMPACT

A TOTAL REDUCTION BY 2026

CO2 298.862

(TON PER ANNO)

NOX 388.521

(TON PER ANNO)

“WattsUp Power is confident in our strategic plan and the long-term prospects for the energy storage market. We believe this investment will position us to further deliver on our growth initiatives, our environmental commitment, and our employees, customers, suppliers, partners and shareholders.”

THERMAL ENERGY STORAGE FOR PROCESS HEATING

KURT ENGELBRECHT
VIEGAND MAAGØE

TAASTRUP - 9. MARTS 2023

Thermal Energy Storage for Process Heating

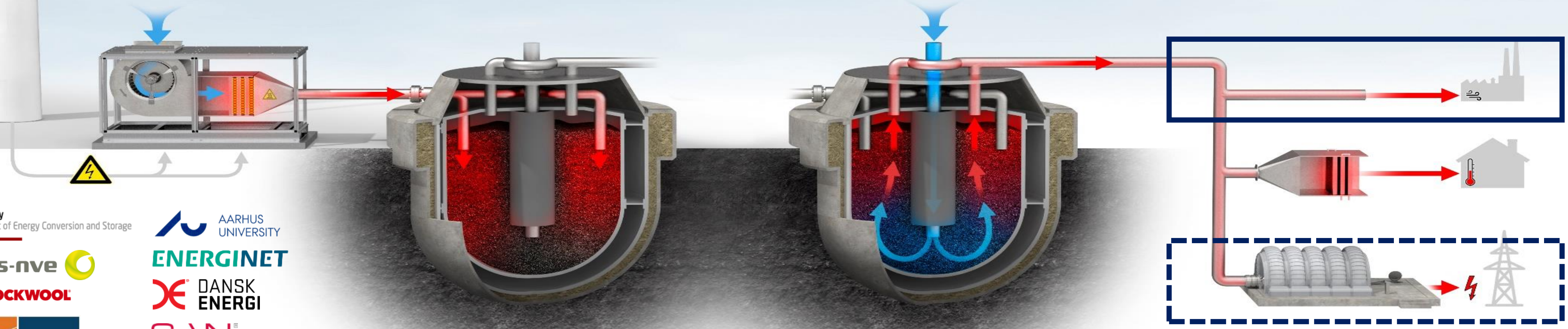
Energy Rocks

Cost- effective thermal energy storage for industrial heat at scale

Kurt Engelbrecht, Kai Knobloch, Yousif Muhammad

Department of Energy Conversion and Storage, Technical University of Denmark

Viegand Maagøe



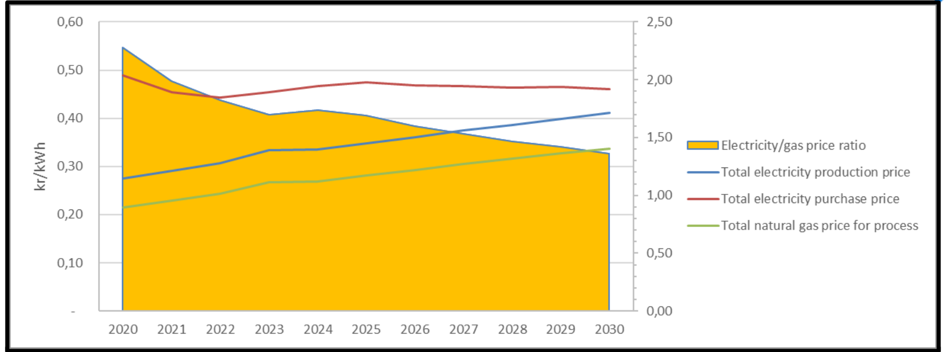
initial focus (TES > 600 °C)

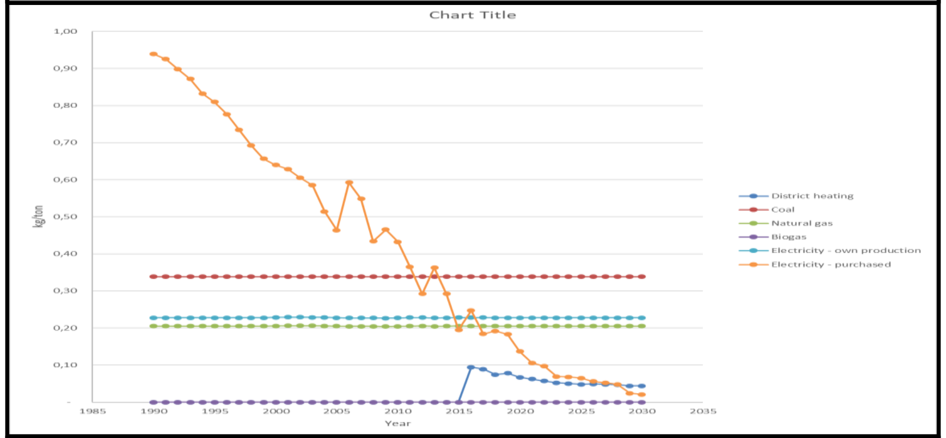
DTU Energy
Department of Energy Conversion and Storage
AARHUS UNIVERSITY
seas-nve
ENERGINET
ROCKWOOL
DANSK ENERGI
EUDP
Energiteknologisk udvikling og demonstration
SAN Electro Heat
GreenLab VILLUM FONDEN

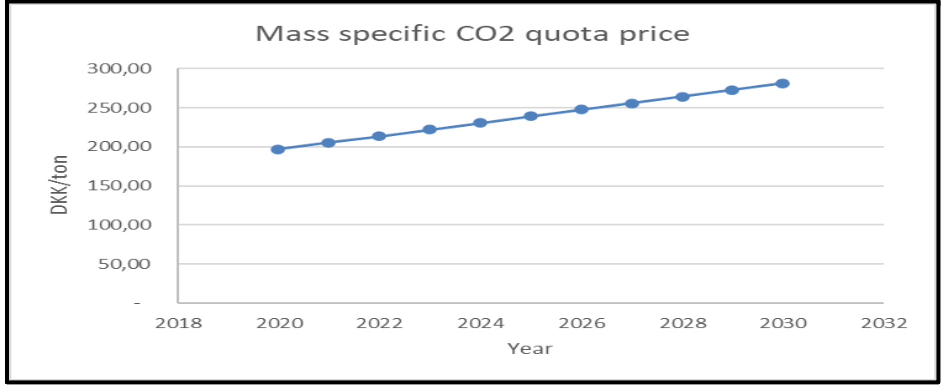
CP Kelco- Motivation for electrification– External：

- Electricity prices are expected to be relatively constant
- Natural gas prices are increasing
- Price ratio is decreasing
- Grid CO_2 factor for “fossil fuel” are constant
- Grid CO_2 factor for electricity from the grid is decreasing
- Carbon quota price are expected to increase (free quotas are phased out)
- Taxes and subsidy schemes are expected to reflect the national carbon strategy.

Viegand Maagøe



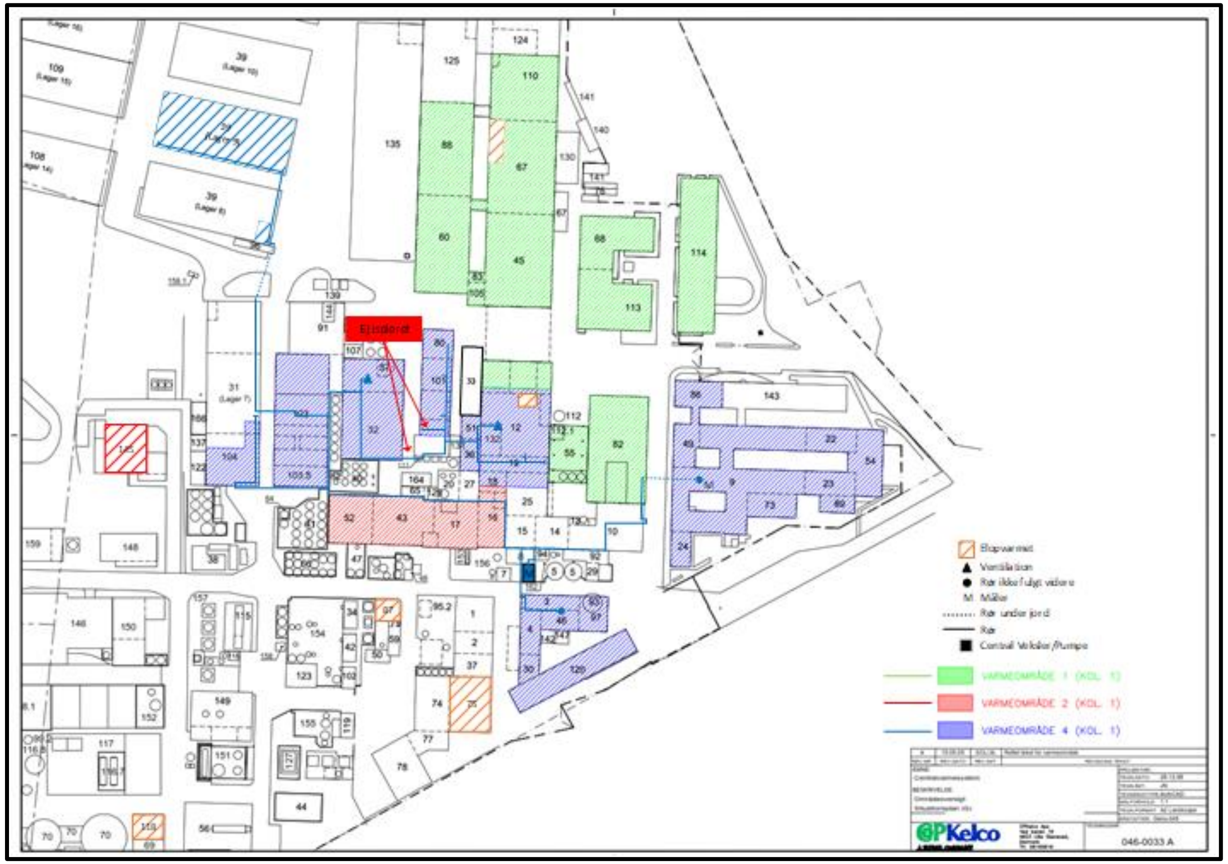




CP Kelco - Motivation for electrification - Internal

Viegand Maagøe

- Support capacity expansion
- Renew of process equipment
- Increasing flexibility
- Removing constraints
- Increase efficiency on process equipment => less waste heat
- Redesign production lines
- Introducing new equipment that support product quality



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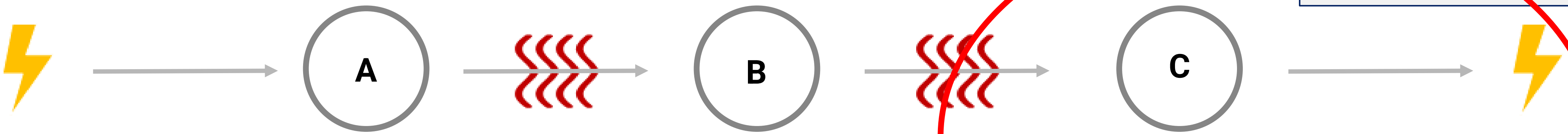
Initial focus: Power-to-Heat-to-Power *

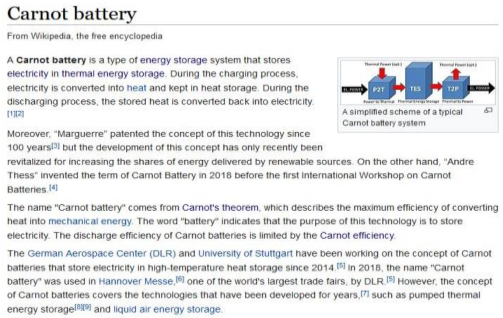
* classified as *Carnot Battery*

IEA Task 36



CONVERSION	STORAGE	CONVERSION
Resistive heating	Thermal Storage	Water-steam cycle

More about Carnot Batteries?



Carnot battery

From Wikipedia, the free encyclopedia

A **Carnot battery** is a type of energy storage system that stores electricity in thermal energy storage. During the charging process, electricity is converted into heat and kept in heat storage. During the discharging process, the stored heat is converted back into electricity. [1][2]

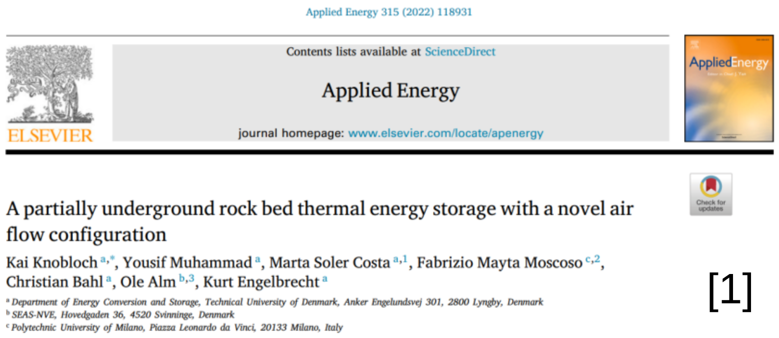
A simplified scheme of a typical Carnot battery system

Moreover, "Marguerre" patented the concept of this technology since 100 years[3] but the development of this concept has only recently been revitalized for increasing the shares of energy delivered by renewable sources. On the other hand, "Andre Thess" invented the term of Carnot Battery in 2018 before the first International Workshop on Carnot Batteries.[4]

The name "Carnot battery" comes from Carnot's theorem, which describes the maximum efficiency of converting heat into mechanical energy. The word "battery" indicates that the purpose of this technology is to store electricity. The discharge efficiency of Carnot batteries is limited by the Carnot efficiency.

The German Aerospace Center (DLR) and University of Stuttgart have been working on the concept of Carnot batteries that store electricity in high-temperature heat storage since 2014.[5] In 2018, the name "Carnot battery" was used in Hannover Messe,[6] one of the world's largest trade fairs, by DLR.[5] However, the concept of Carnot batteries covers the technologies that have been developed for years,[7] such as pumped thermal energy storage[8][9] and liquid air energy storage.

More about the rock bed itself?



Applied Energy 315 (2022) 118931

Contents lists available at ScienceDirect

Applied Energy

journal homepage: www.elsevier.com/locate/apenergy

A partially underground rock bed thermal energy storage with a novel air flow configuration

Kai Knobloch [a,*], Yousif Muhammad [a], Marta Soler Costa [a,1], Fabrizio Mayta Moscoso [c,2], Christian Bahl [a], Ole Alm [b,3], Kurt Engelbrecht [a]

[a] Department of Energy Conversion and Storage, Technical University of Denmark, Anker Engelundsvej 301, 2800 Lyngby, Denmark
[b] SEAS-NVE, Hovedgaden 36, 4520 Svinninge, Denmark
[c] Polytechnic University of Milano, Piazza Leonardo da Vinci, 20133 Milano, Italy

[1]

Contents lists available at ScienceDirect

Applied Thermal Engineering

journal homepage: www.elsevier.com/locate/ate

Research Paper

Degradation of a rock bed thermal energy storage system

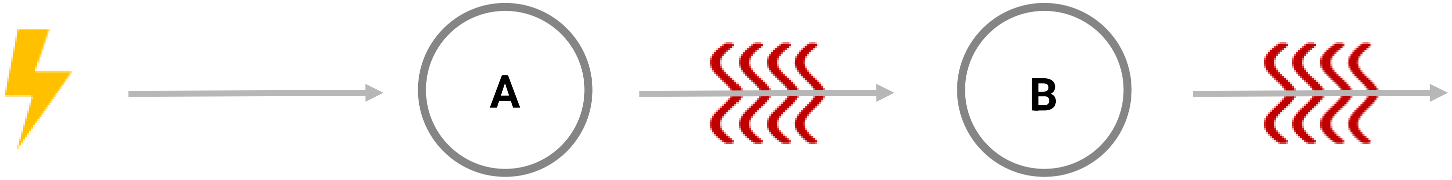
Kai Knobloch [a,*], Thomas Ulrich [b], Christian Bahl [a], Kurt Engelbrecht [a]

[a] Department of Energy Conversion and Storage, Technical University of Denmark, Anker Engelundsvej 301, 2800 Lyngby, Denmark
[b] Department for Geoscience, Aarhus University, Høegh Guldbergs Gade 2, 8000 Aarhus, Denmark

[2]

DTU

New focus: Power-to-Heat- …



CONVERSION

Resistive heating

STORAGE

Thermal Storage

Energy-intensive industries

such as

…

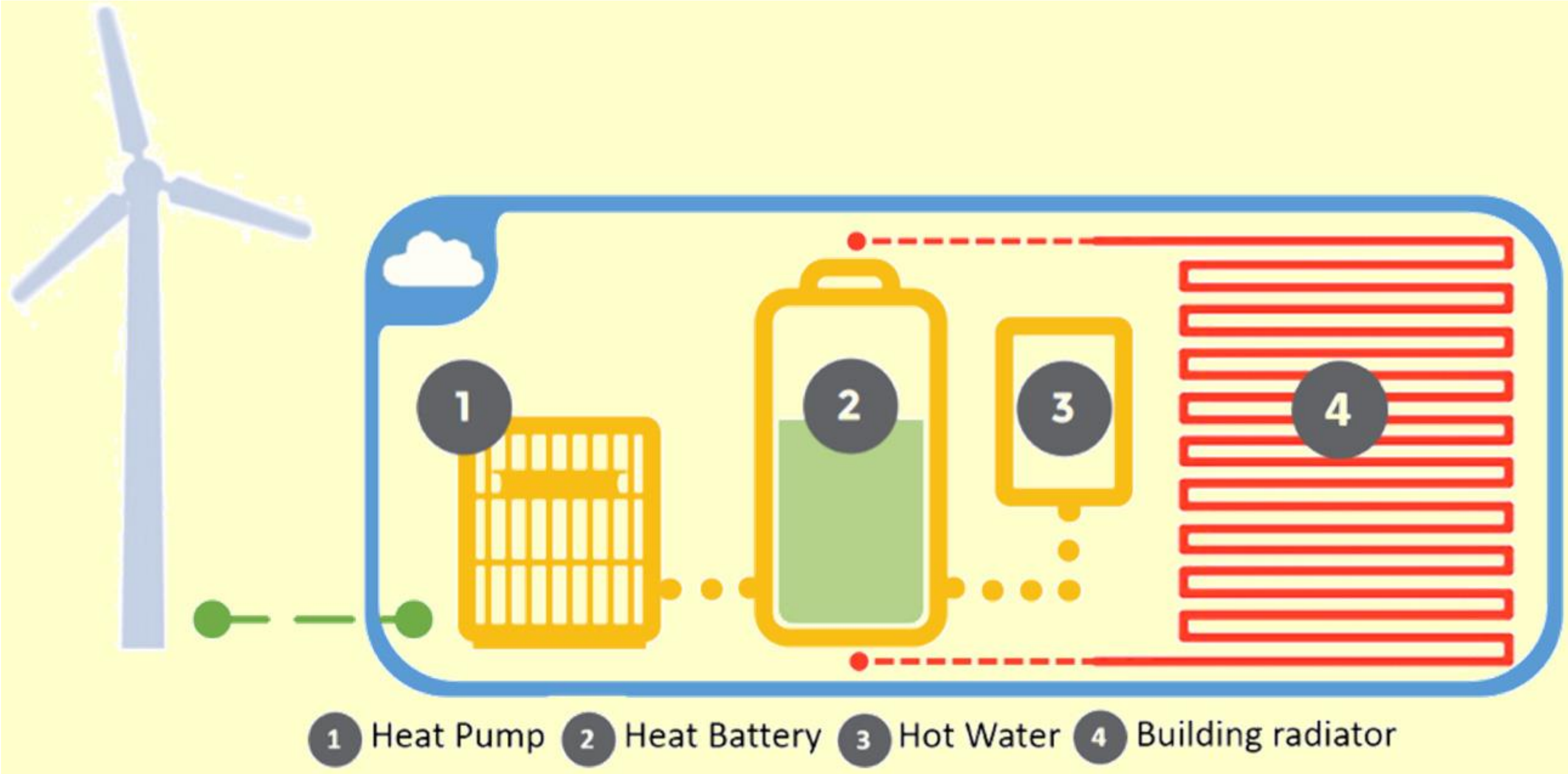
GreenLab VILLUM FONDEN

“Energy Rocks”

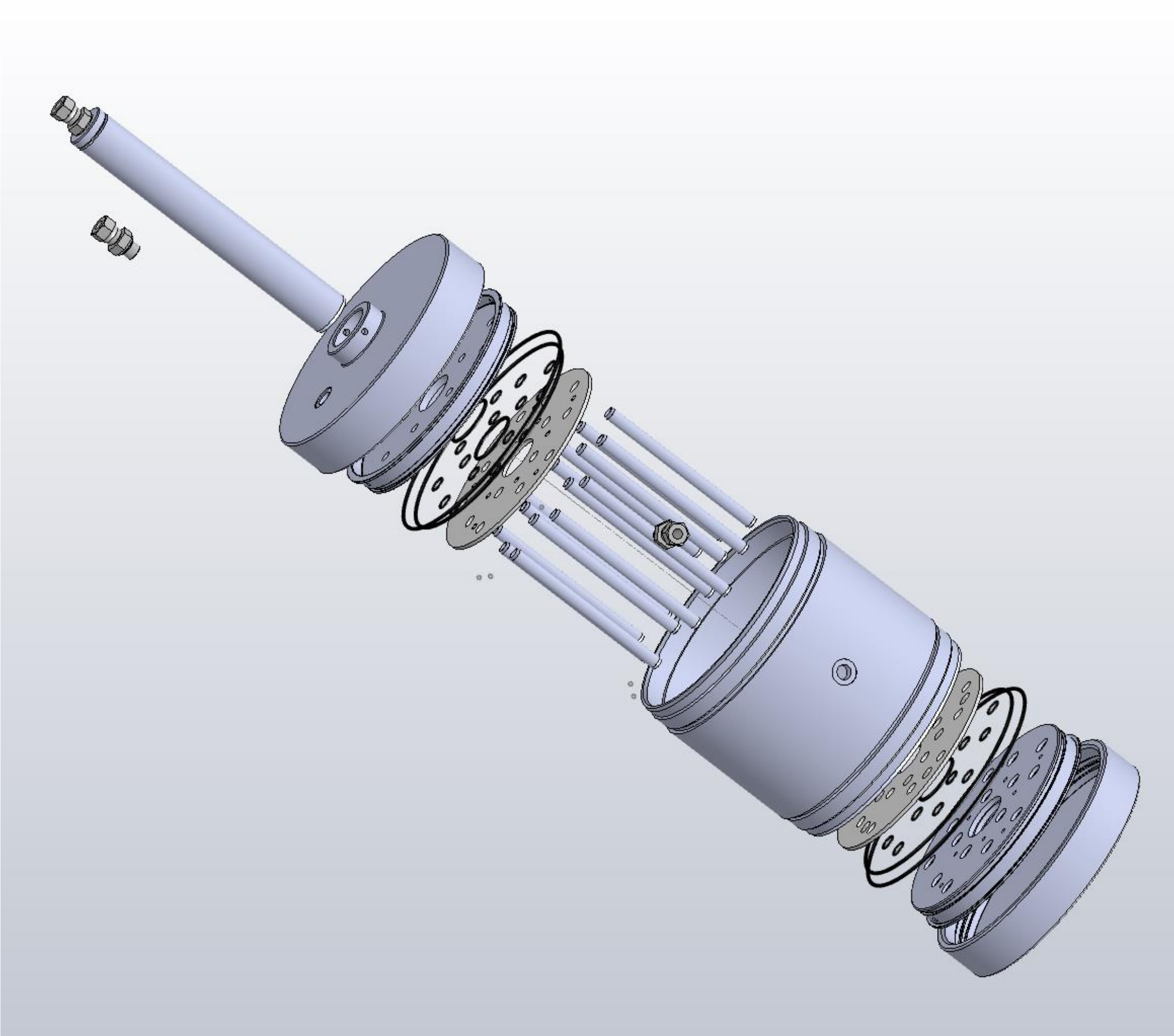
Design and size a cost- effective thermal energy storage for industrial heat at scale.

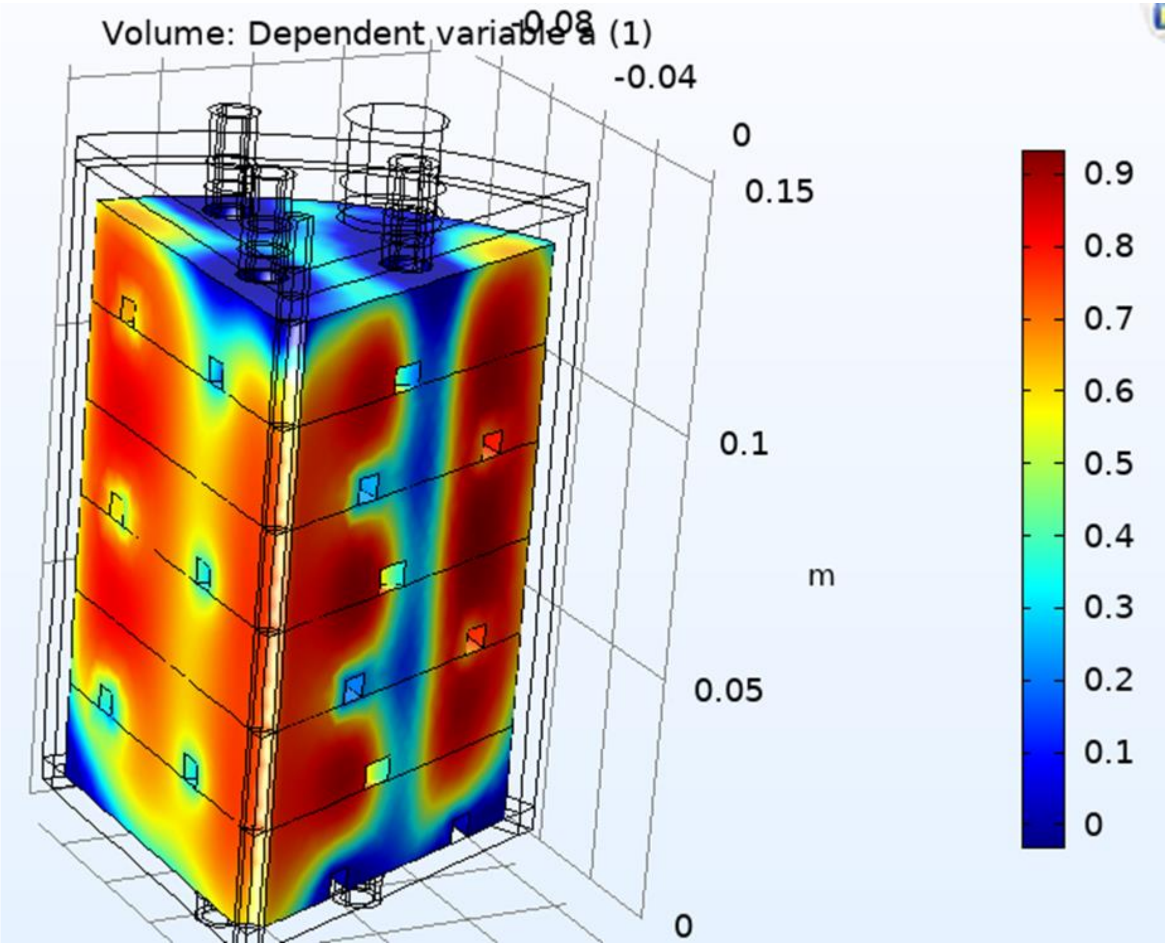
Thermochemical energy storage for seasonal heat storage

- Energy is stored by boiling ammonia out of $SrCl_2$ salt in the storage
  - This can be done on windy days by running the heat pump
- When heat is needed, ammonia is pumped back into the module to release heat
- Chemical storage allows for seasonal heat storage
- Work is funded by ELFORSK with industrial partner Sensible Energy



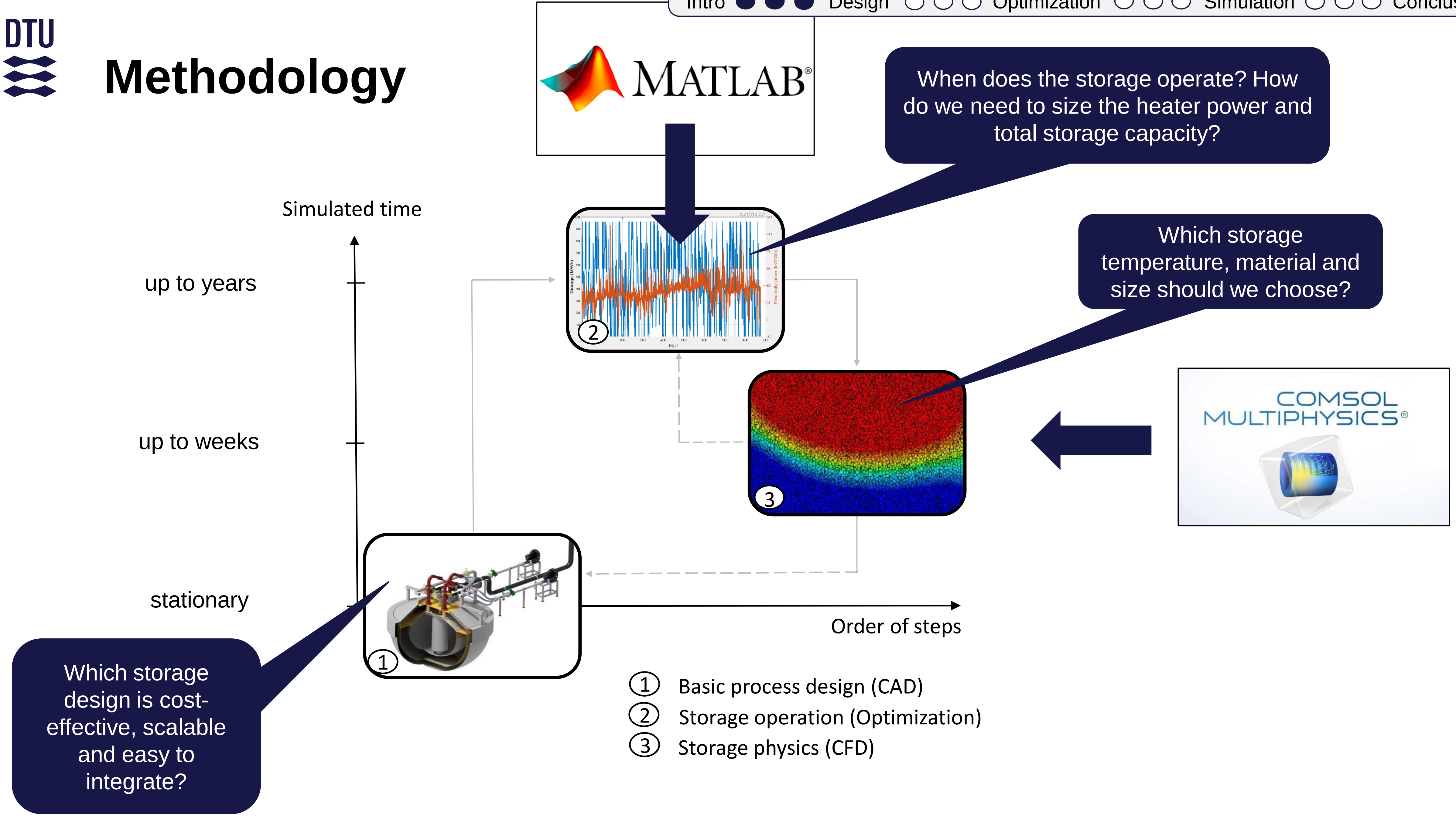
System design





DTU

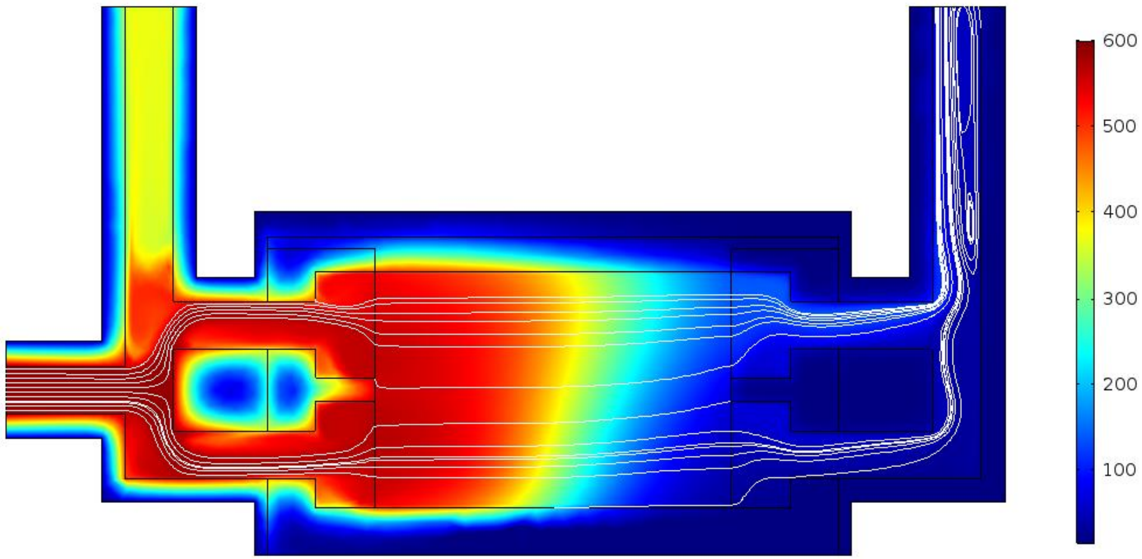
Methodology



① Basic process design (CAD)
② Storage operation (Optimization)
③ Storage physics (CFD)

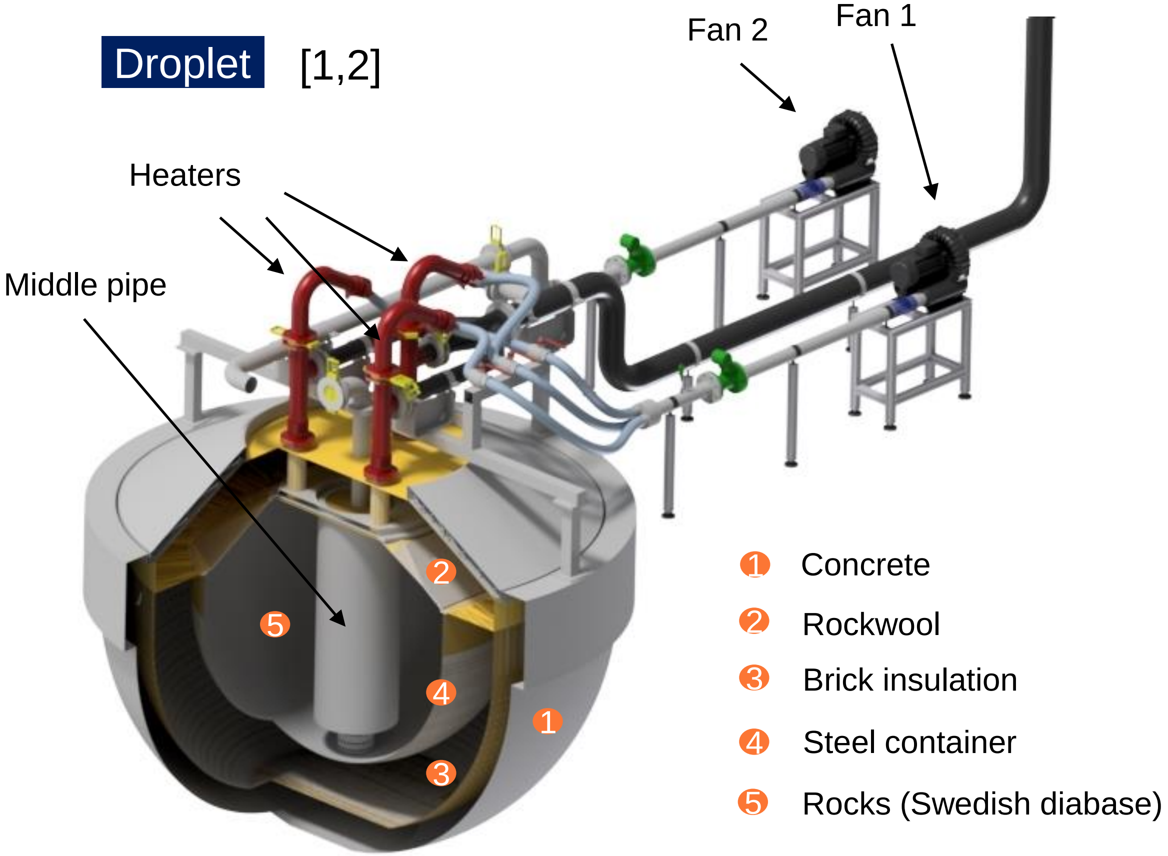
Rock Bed 1.0 and 2.0 at DTU Energy

Shoebox [6]



Temperature and air flow streamline after 6 h charge with *Re* = 12 and *NTU* = 56.

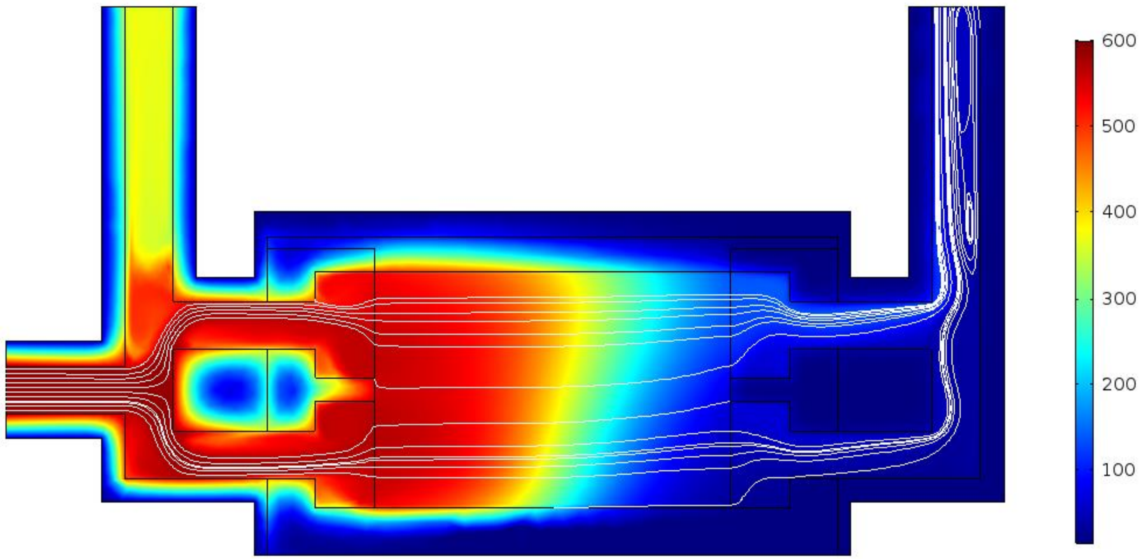
Droplet [1,2]



- two different rock sizes (8-11 mm and 16-22 mm)
- piping and heaters mounted on top of the storage
- middle pipe for flow reversal

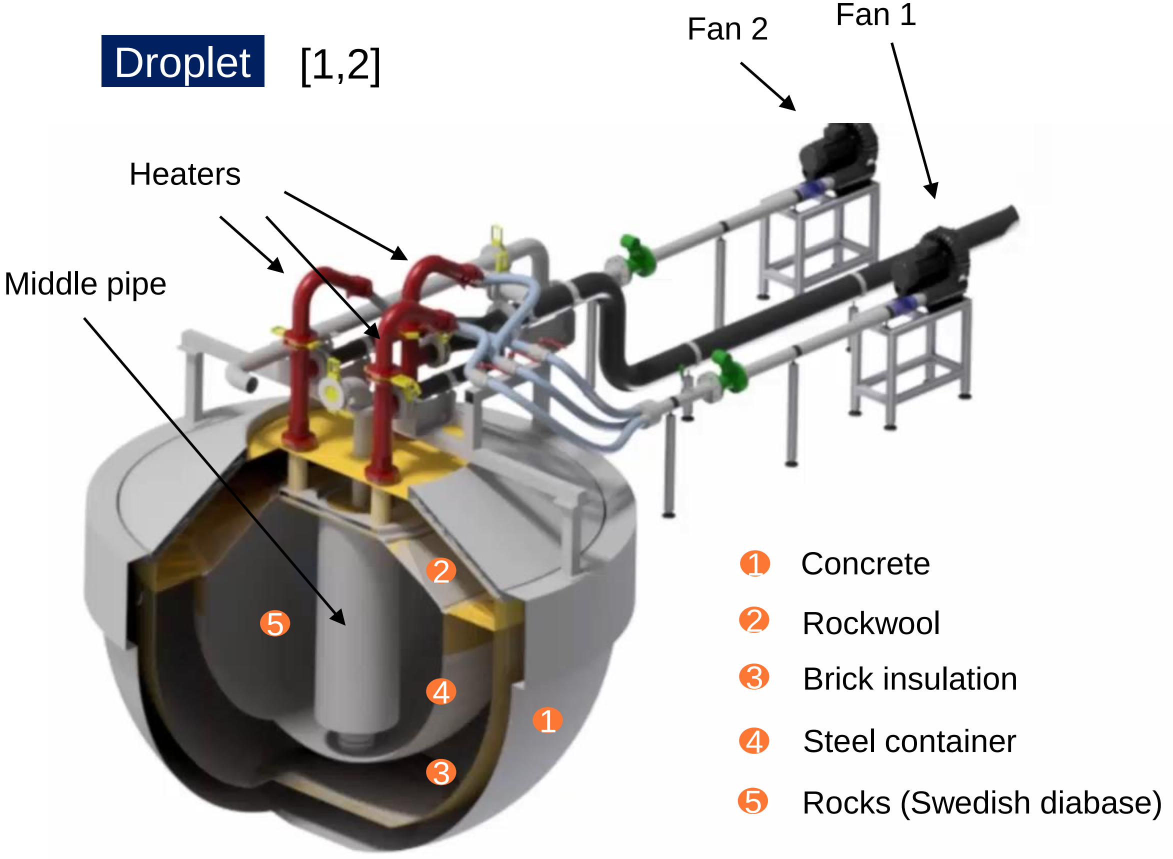
Rock Bed 1.0 and 2.0 at DTU Energy

Shoebox [6]



Temperature and air flow streamline after 6 h charge with *Re* = 12 and *NTU* = 56.

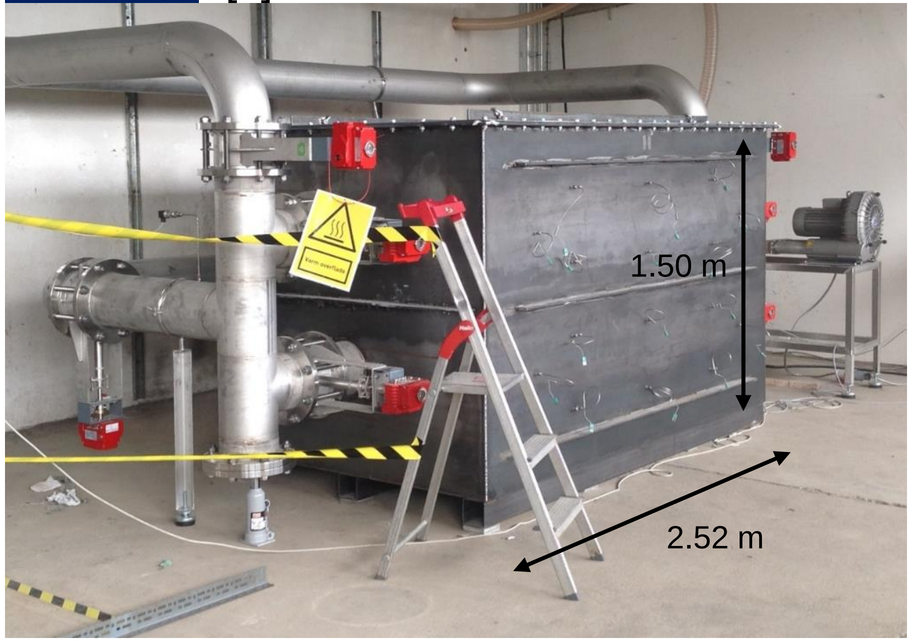
Droplet [1,2]



- two different rock sizes (8-11 mm and 16-22 mm)
- piping and heaters mounted on top of the storage
- middle pipe for flow reversal

Thermal energy storage (TES) pilot plants built at DTU Energy

Shoebox [6]



V_{pb} = 1.5 m^3

P_{ch} = 30 kW$_{el}$

T_{ch} = 600 °C

C_{th} = 450 kWh$_{th}$ (ΔT = 600 °C)

η_{RT} < 68.5 % (with one layer)

Droplet [1,2] 247 cycles, approx. 3500 h

V_{pb} = 3.2 m^3

P_{ch} = 45 kW$_{el}$

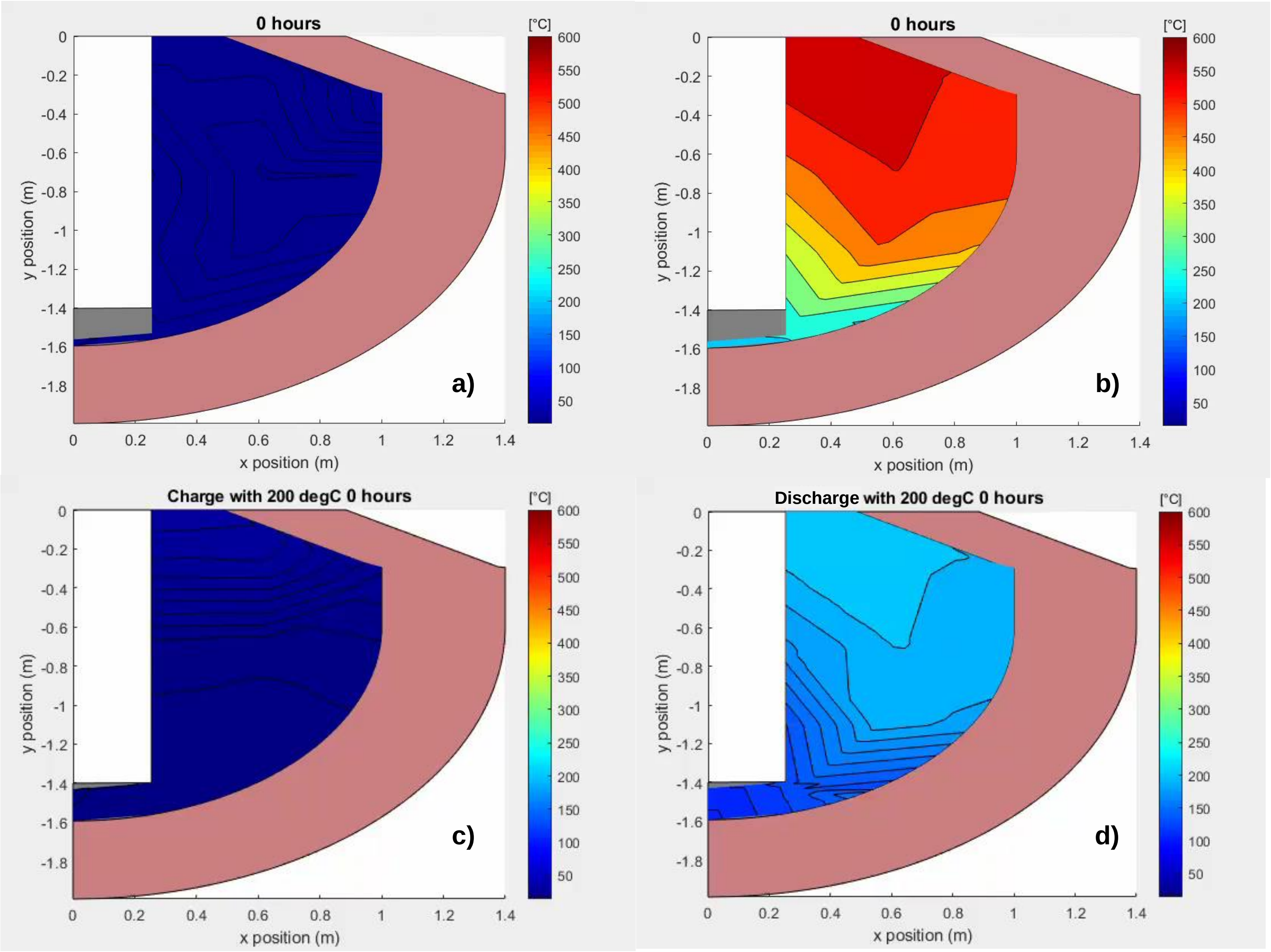
T_{ch} < 675 °C

C_{th} = 1000 kWh$_{th}$ (ΔT = 600 °C)

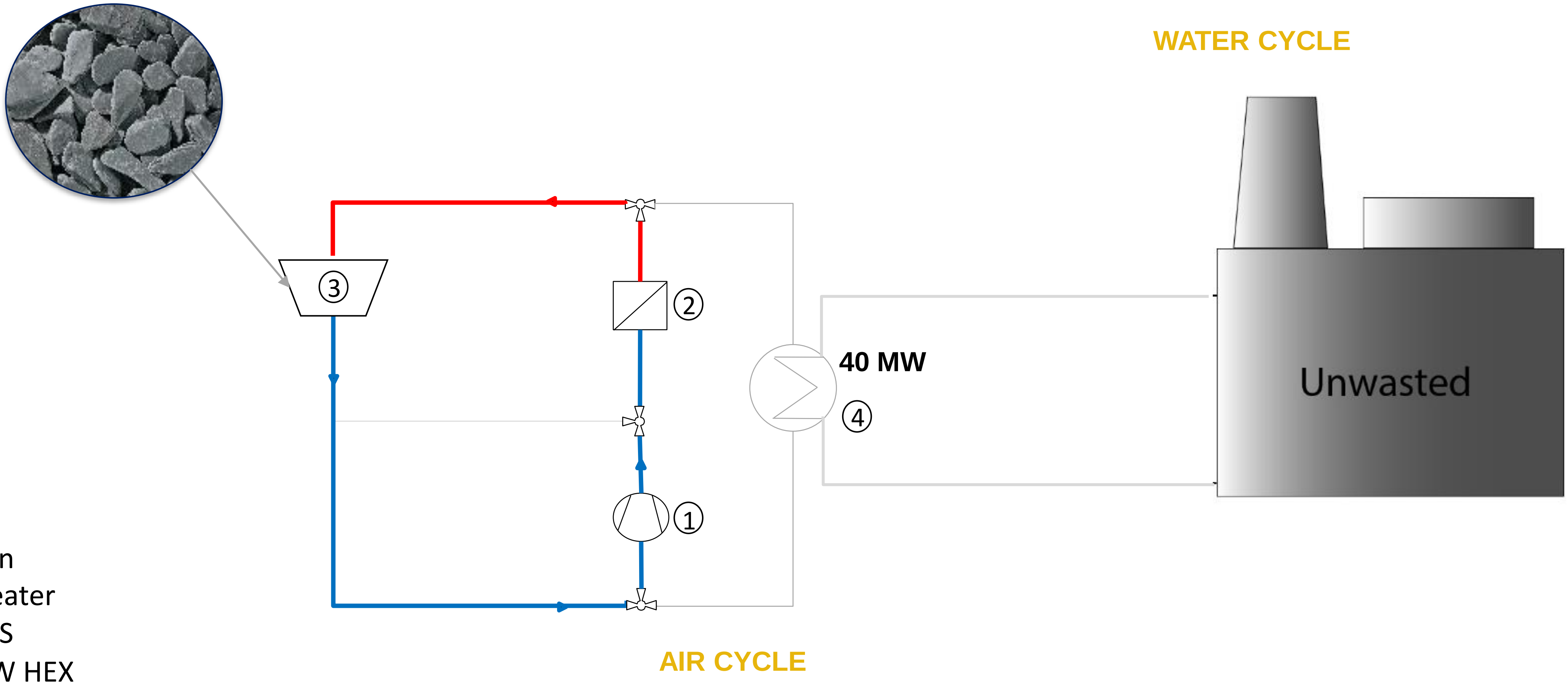
η_{RT} < 80.7 %

Temperature profile comparison (animation)

Figure 3 Reconstructed temperature during
a) 600 ℃/200 m^3/h charge,
b) followed by a 200 m^3/h discharge.
c) 200 ℃/200 m^3/h charge,
d) followed by a 200 m^3/h discharge.

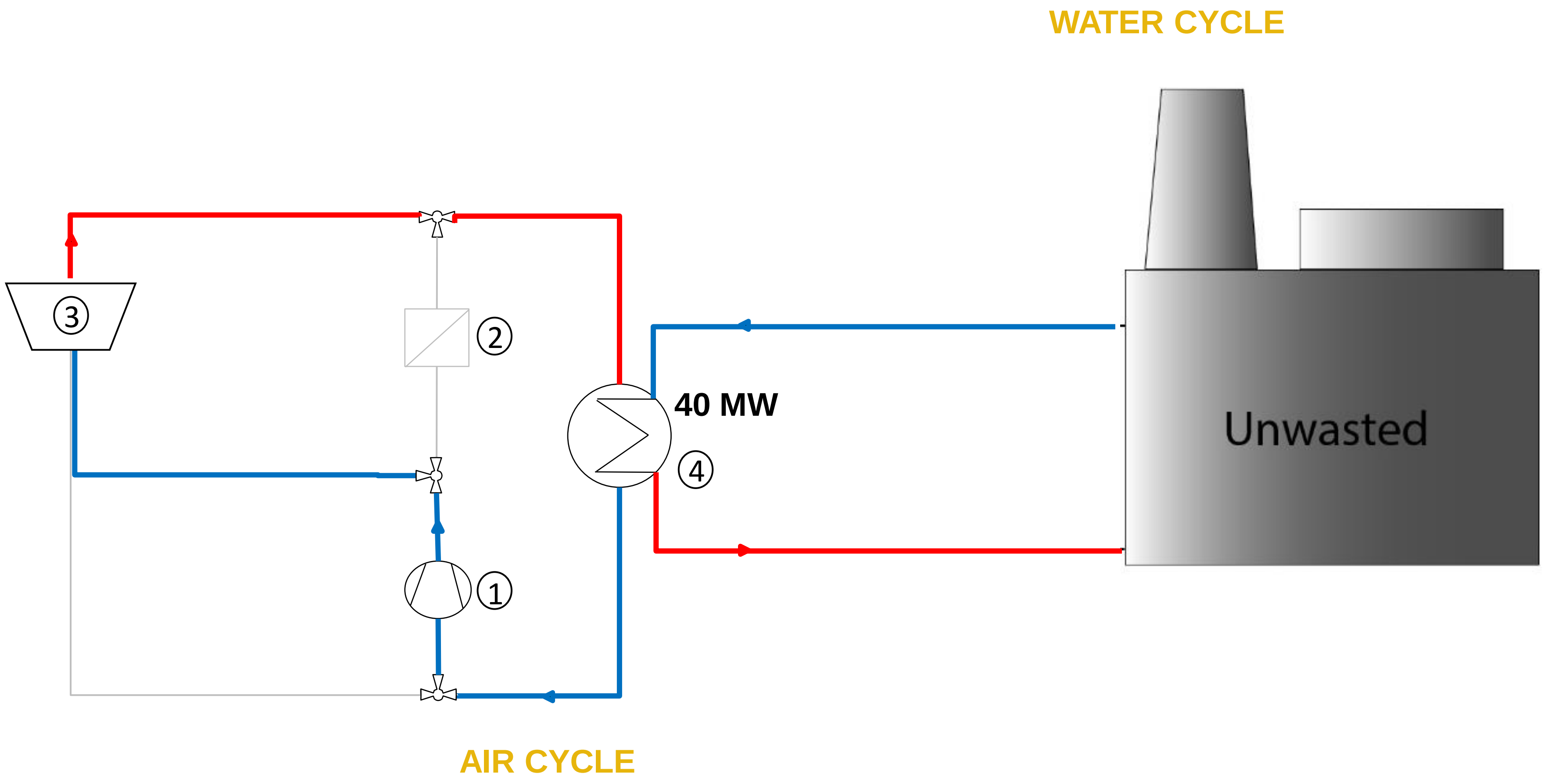


Integration @ GreenLab - charge



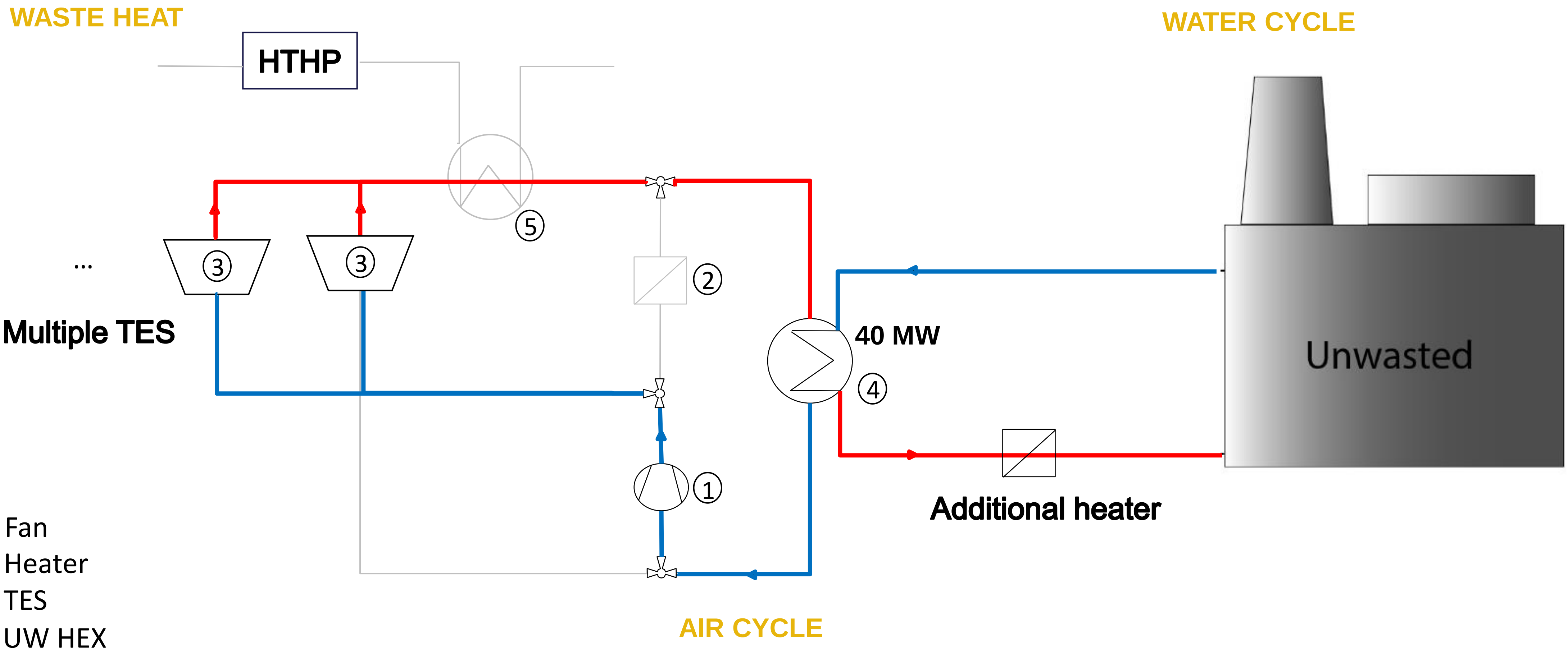
① Fan
② Heater
③ TES
④ UW HEX

Integration @ GreenLab - discharge



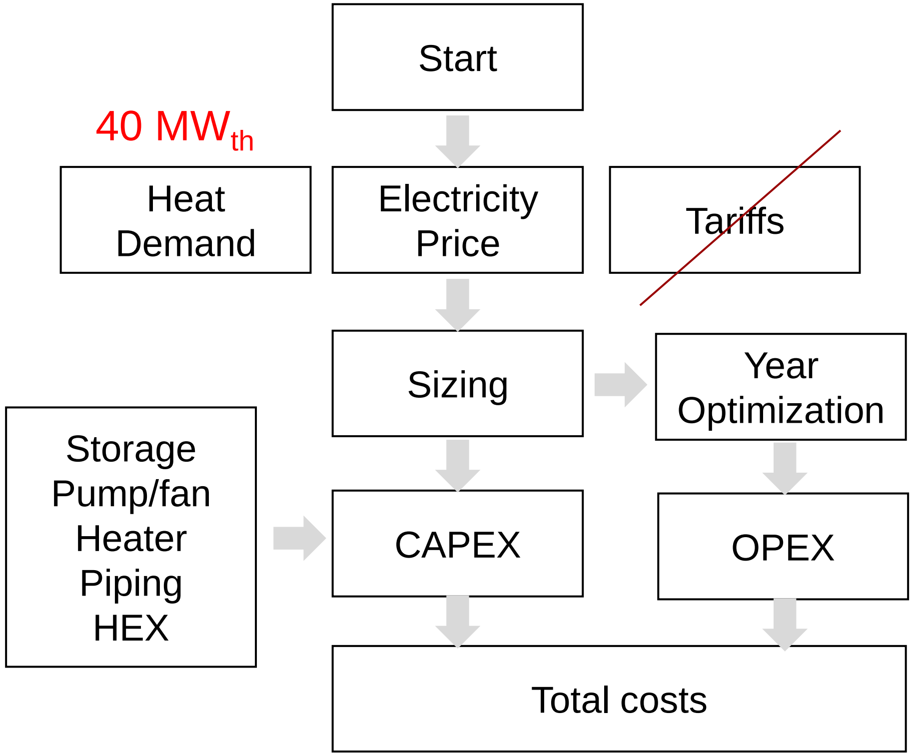
1 Fan
2 Heater
3 TES
4 UW HEX

Integration @ GreenLab - modifications



1 Fan
2 Heater
3 TES
4 UW HEX
5 Upgrade HEX

Economic storage optimization tool

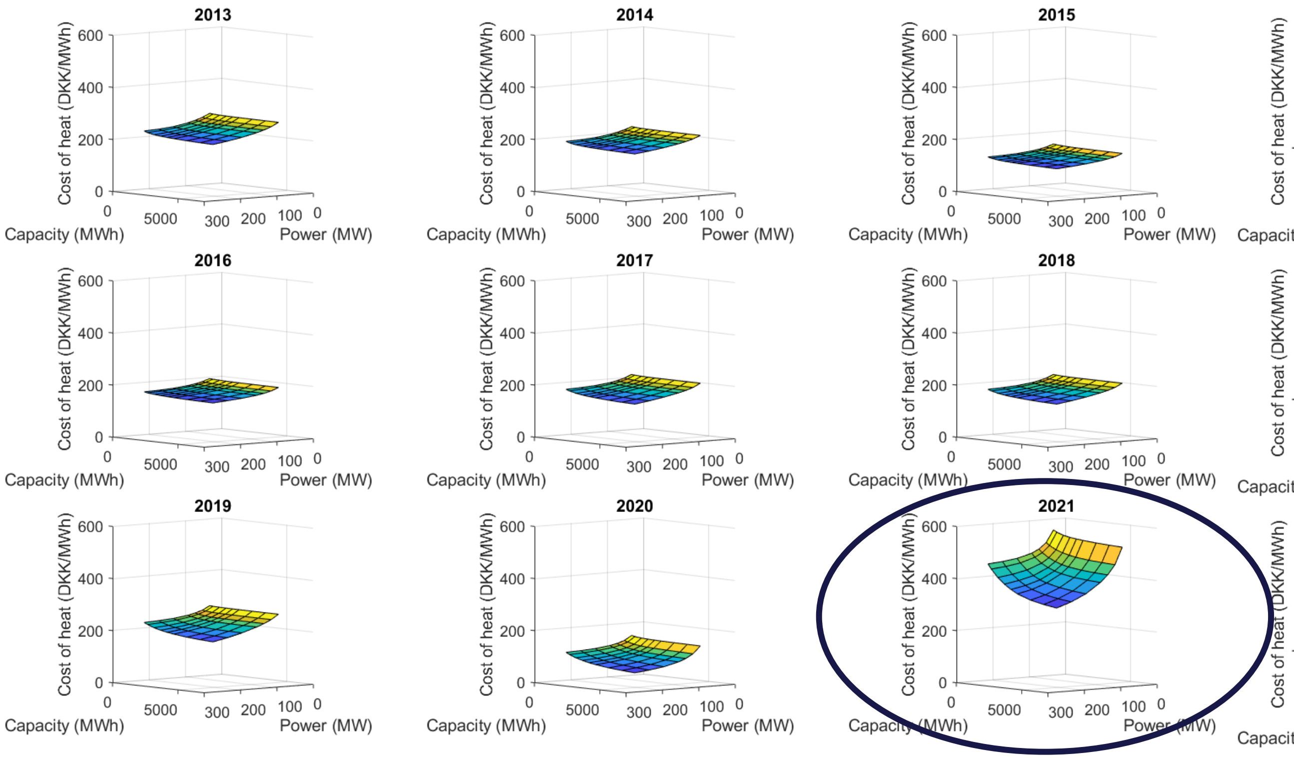


Theoretical analysis

P_{heater} = 60 … 240 MW ; $C_{storage}$ = 750 … 6000 MWh

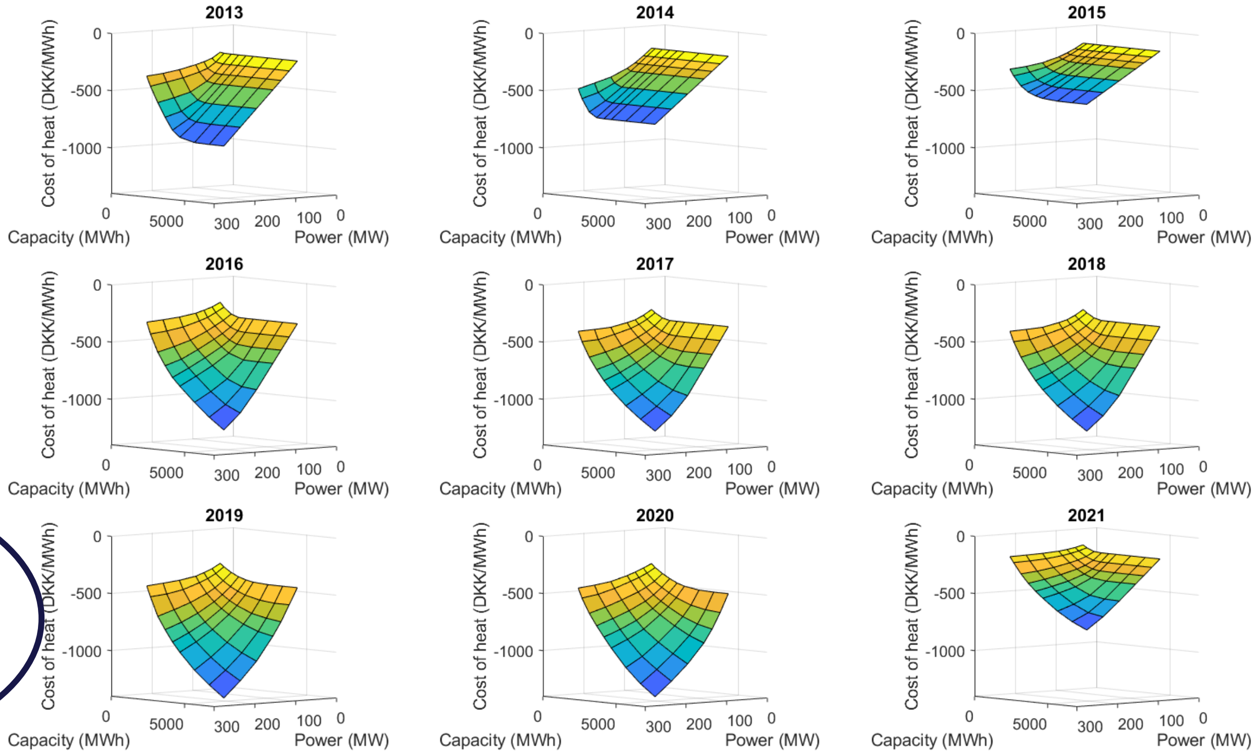
OPEX

P_{demand} = 40 MW



(for plausibility check)

P_{demand} = 0.01 MW

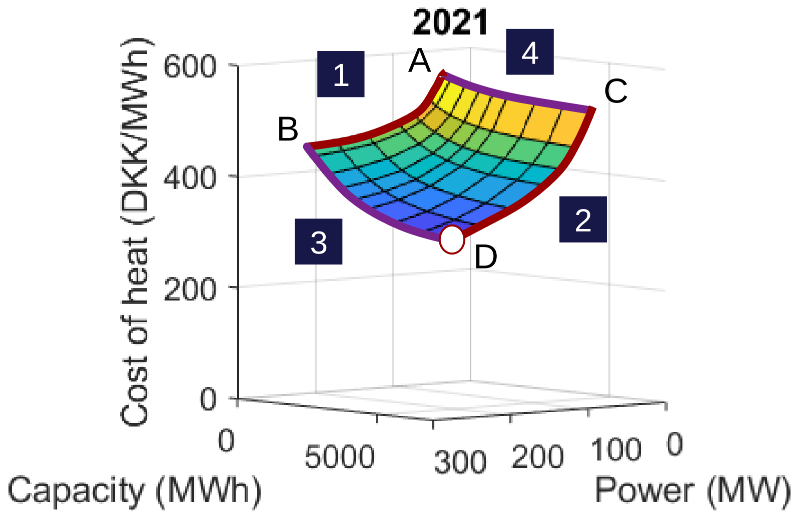


DTU

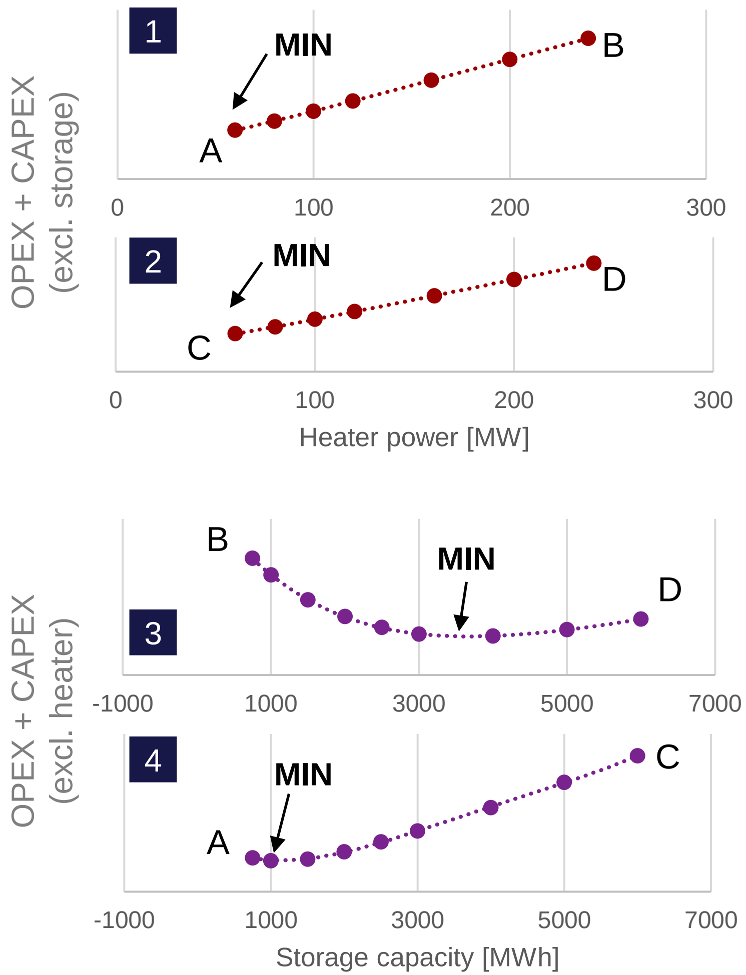
Theoretical analysis

P_{demand} = 40 MW ; P_{heater} = 60 … 240 MW ; $C_{storage}$ = 750 … 6000 MWh

OPEX → OPEX + CAPEX *



- ○ OPEX minimum
- Min. and max. capacity
- Min. and max. power



Increasing the power of the heater is so expensive that lowest costs are found for the lowest heater power of **60 MW**.

Increasing the storage capacity to 3500 MWh or **1000 MWh** leads to lowest costs overall. Case 4 is most interesting since it also has the lowest heater power.

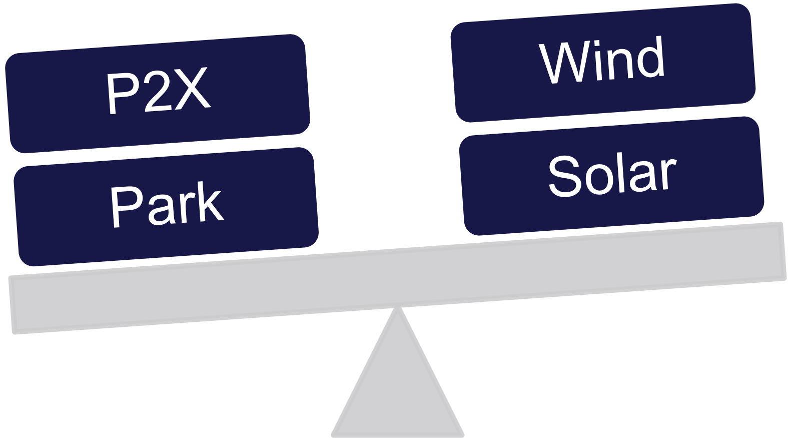
* calculated with 0.37 DKK/kWh_{th} and 312.5 DKK/MW_{el}

Practical analysis

Using data from GreenLab.

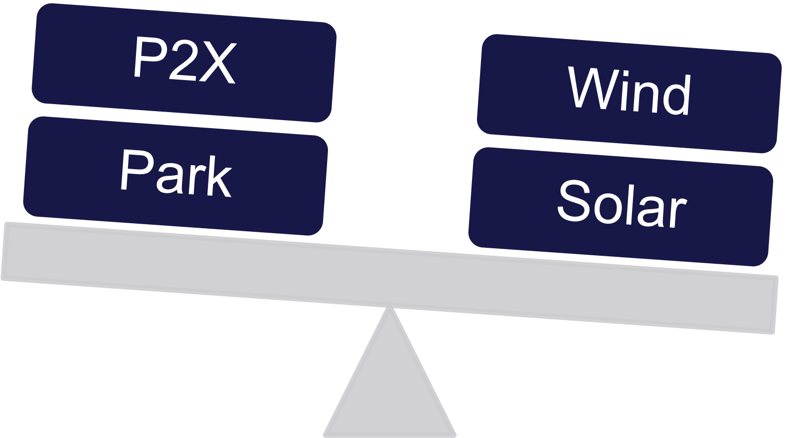
Consumption > Production

There is no energy left for Unwasted and/or TES.



Consumption < Production

There is energy left for Unwasted and/or TES.

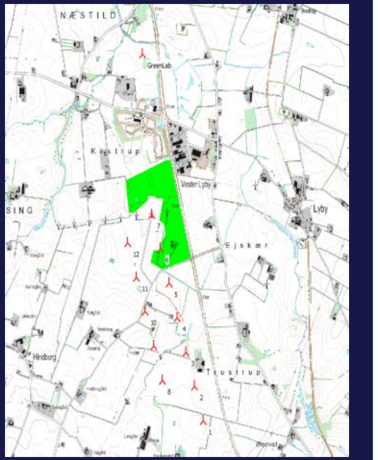


Order of priorities

Available power (MW)

Production from solar and wind

(approx. 53 MW_p and 30 MW_p)



12 MW for P2X

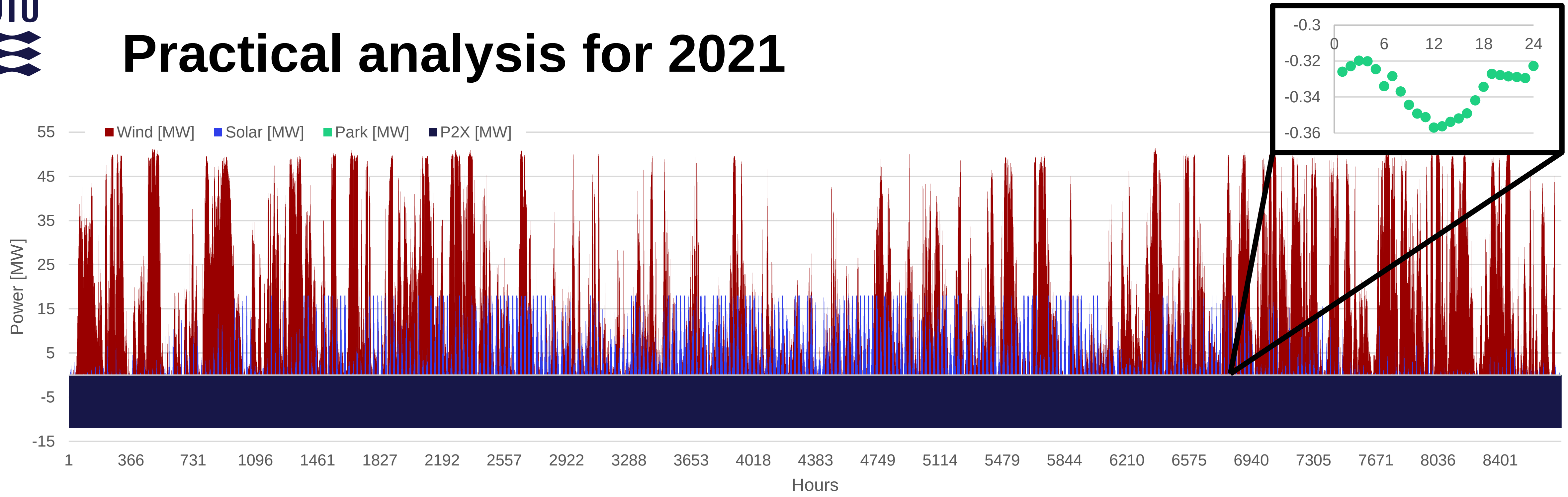
1

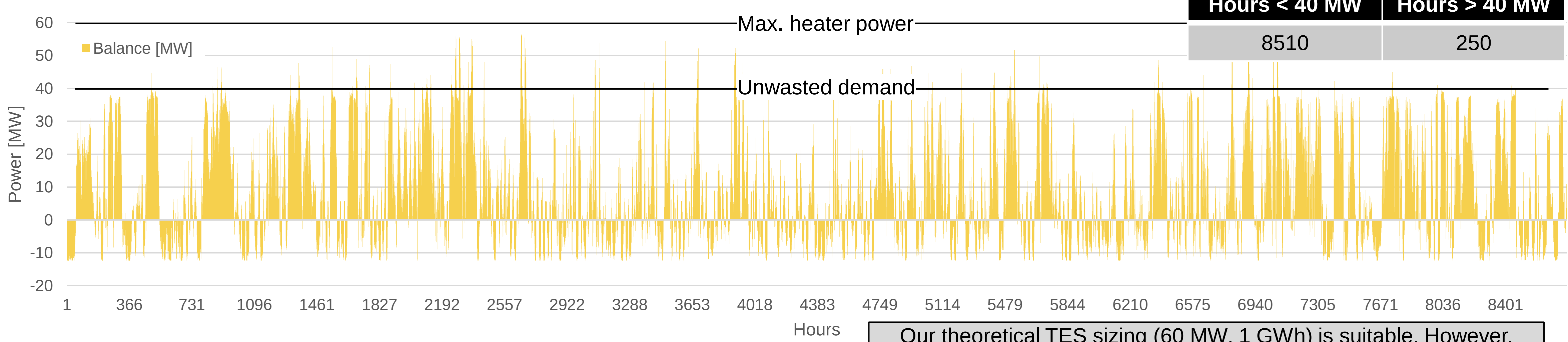
< 0.36 MW park consumption

2

left for Unwasted and/or thermal storage

Practical analysis for 2021





Hours < 40 MW	Hours > 40 MW
8510	250

Our theoretical TES sizing (60 MW, 1 GWh) is suitable. However, significant electricity import or production increase is needed.

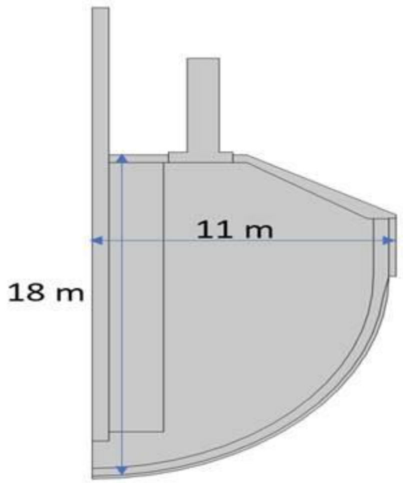
CFD: Storage temperature

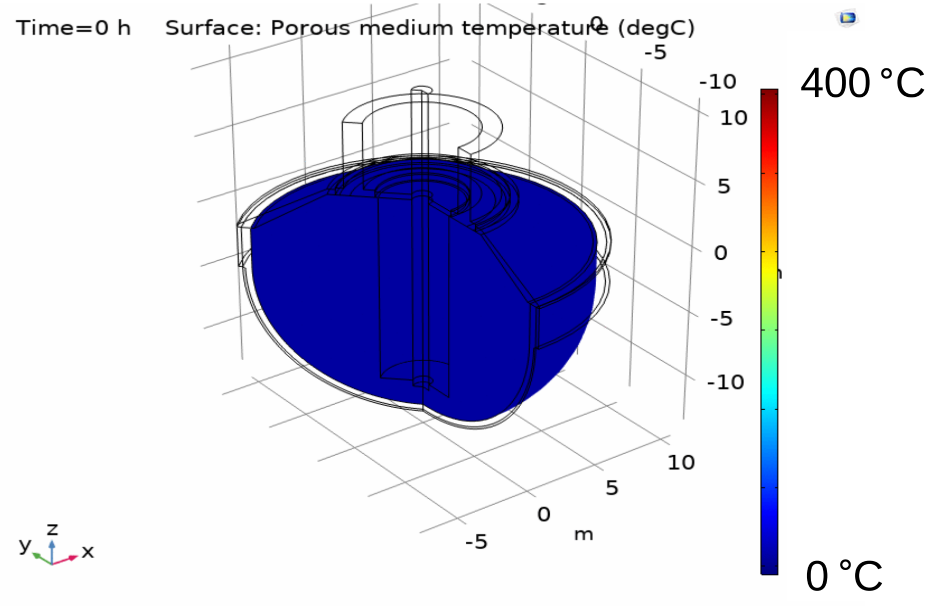
For a rock bed storage with 1 GWh total capacity.

high thermal losses

Storage temperature [°C]	Volume [m^3]
600	3201
400	4266
200	5686

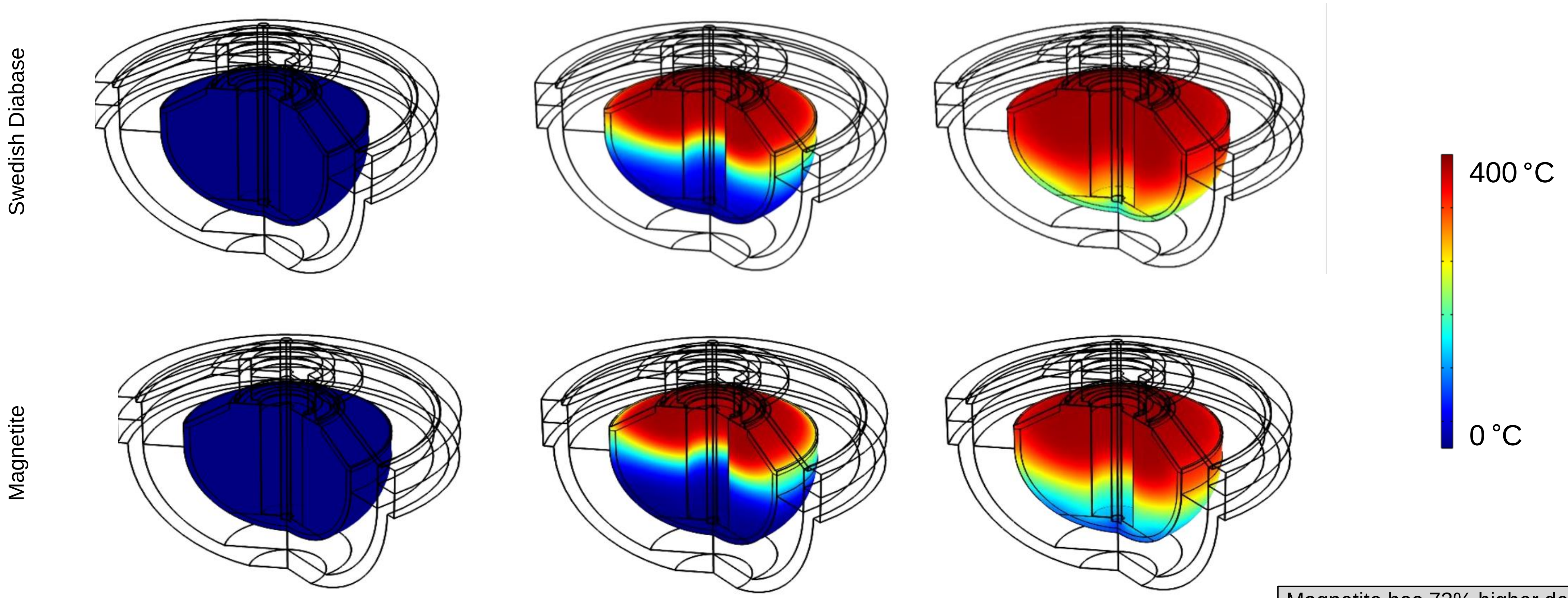
low energy density





CFD: Storage material

Comparison of two materials for an example charge process.

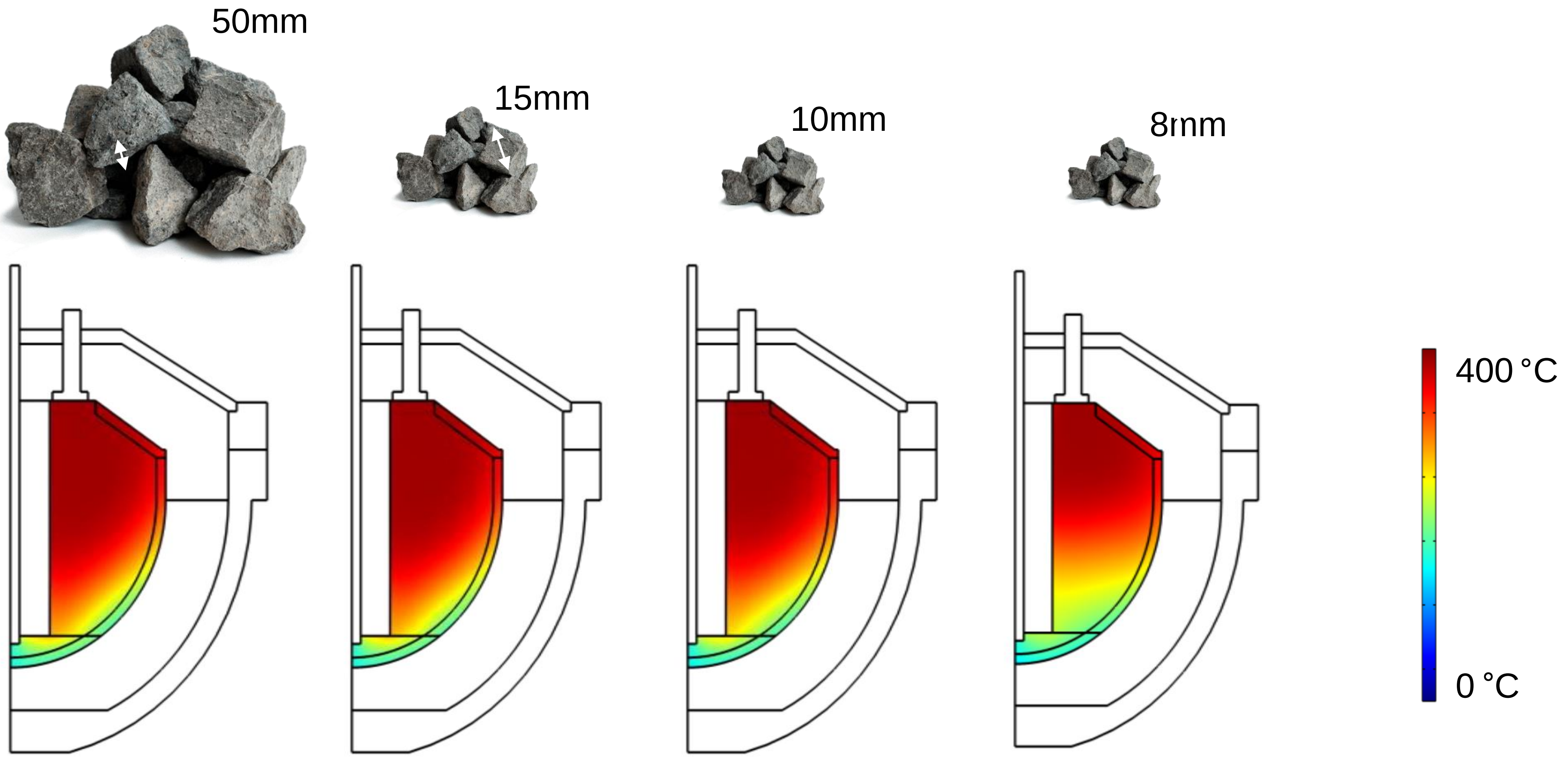


Magnetite has 73% higher density but costs twice as much and is ferromagnetic (spontaneous magnetization).

CFD: Particle size

Comparison of temperature distributions after 24h of charge for different particle sizes

Particle diameter [mm]	Energy Stored [%]	Outlet losses [%]
8	77.52	19.80
10	77.63	19.68
15	75.72	21.26
50	69.14	27.75



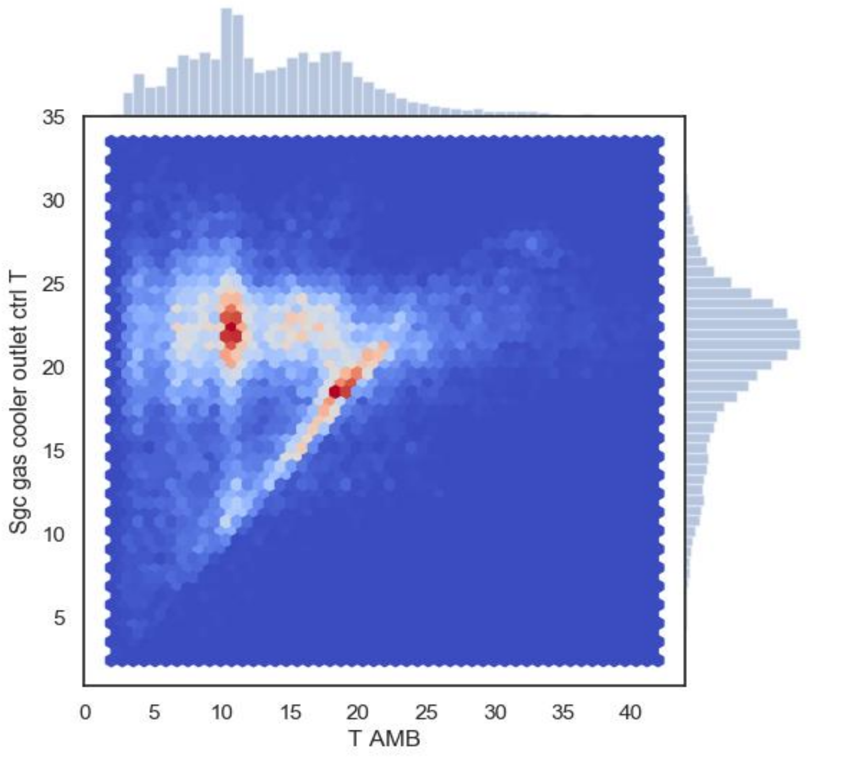
worse stratification but lower pressure drop

MLEEP (Machine learning til Energi- og Procesoptimering)

Viegand Maagøe

- Viegand Maagøe har efteråret 2022 startet R&D-projektet MLEEP støttet af ELFORSK, hvor machine learning-algoritmer skal demonstrere nye effektiviseringspotentialer i industrielle processer og forsyningsanlæg

- Projektet udføres med flere case-virksomheder:
  - Arla Foods
  - Viking Malt
  - Saint Gobain Gyproc
  - Avista Green
  - Ringsted Forsyning



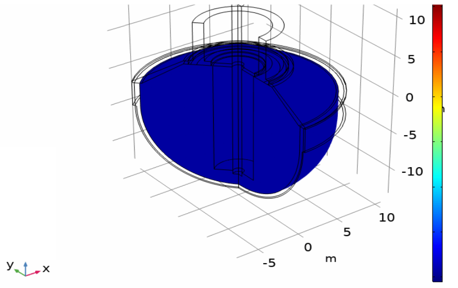
- Samarbejde med DTU, Biolean m.fl.

Conclusions

VILLUM FONDEN GreenLab

- Design and sizing of a thermal storage based on rocks for process heat supply of UnWasted at GLS
- The electrical air heater is a major system cost and may kill the economy of some projects
- For the GLS application a 25 h storage gave an economic optimum when the heater is treated as a sunken cost
- Thermal energy storage gives increased flexibility and reduced operating costs
  – Amounts will depend on fluctuations in electricity prices and hourly power consumption

1 GWh, 60 MW, 400°C, 4266 m^3
Swedish diabase Ø8-10mm



Thanks a lot to:

GreenLab VILLUM FONDEN

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