FME HighEFF

Centre for an Energy Efficient and Competitive Industry for the Future

Deliverable D3.3_2018.04

Thermal storage for improved energy efficiency in the industry

Delivery date: 2018-10-15

Organisation name of lead beneficiary for this deliverable:

SINTEF Energy Research

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Dissemination Level		
PU	Public	X
RE	Restricted to a group specified by the consortium	
INT	Internal (restricted to consortium partners only)	

Deliverable number:	D3.3_2018.04
ISBN number:	
Deliverable title:	Thermal storage for improved energy efficiency in the industry
Work package:	WP 3.3 Energy storage
Deliverable type:	Presentation
Lead participant:	SINTEF Energy Research

Quality Assurance, status of deliverable		
Action	Performed by	Date
Verified (WP leader)	Hanne Kauko	2018-10-15
Reviewed (RA leader)	Trond Andresen	2018-10-15
Approved (dependent on nature of deliverable)*)	Trond Andresen	2018-10-15

*) *The quality assurance and approval of HighEFF deliverables and publications have to follow the established procedure. The procedure can be found in the HighEFF eRoom in the folder "Administrative > Procedures".*

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Abstract

Various industries have a vast thermal energy demand in the form of steam, hot water or cooling. The production of steam and hot water is often based on utilization of fossil fuels, while cooling machines with high capacity may be required to cover peaks in cooling demand. At the same time, with increasing share of renewable energy sources in the power grid, industries may have access to green power with highly fluctuating prices. Moreover, there is a large potential for utilization of surplus heat from the industry.

This study presents three potential applications of thermal energy storage (TES) to improve energy efficiency and reduce emissions in the industry: (i) large-scale steam storage to be used in the Bayer process for production of alumina; (ii) cold TES for food industry; and (iii) hot water accumulator tank in a district heating (DH) system based on the use of industrial waste heat. Each application is being studied and developed under FME HighEFF, research centre for an energy efficient and competitive industry for the future.

The production of alumina from bauxite is based on the Bayer process, with a high demand for steam, traditionally produced by using fossil fuels. The use of fossil fuels could be replaced by electricity from fluctuating renewable sources, concentrated solar power (CSP), or high-temperature heat pumps utilizing industrial waste heat. In either case, large-scale steam storage able to deliver steam at high volume flow rates is required, currently not available commercially. For the present case, the process requirements are steam at 15 bar and a flow rate up to 1200 t/h. The desired storage capacity is up to 7800 MWh. Different storage alternatives, capable of meeting this requirement, will be discussed.

A large chicken slaughter house is under construction in Orkanger, Norway. The plant will have huge energy demand in the form of cooling and hot water, and access to renewable power from a nearby wind power plant. To be able to utilize green electricity from the fluctuating power market, a novel cold TES system with a storage capacity of 11 MWh utilizing CO2 as the heat transfer fluid will be installed, in addition to accumulator tanks for hot water. The TES system is estimated to reduce the peak power demand by 20 %.

Finally, the DH production in Mo i Rana, Norway, is based on waste heat recovery from off-gases of a nearby ferrosilicon production plant. Even if the amount of waste heat available exceeds the heat demand in Mo i Rana by far, costly peak heating sources are required to cover peak heating demands due to large fluctuations in both availability and demand of heat. By the use of thermal storage and optimal control, the use of costly peak heating sources may be reduced or even avoided. Initial simulation results from a dynamic model of the waste heat recovery system incorporating thermal storage with a capacity of 9 MWh and optimal control will be presented.

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Thermal storage for improved energy efficiency in the industry

Hanne Kauko, Håkon Selvnes, Brage R. Knudsen, Armin Hafner and Petter Nekså

10th KIFEE Symposium 5.-8.10.2018

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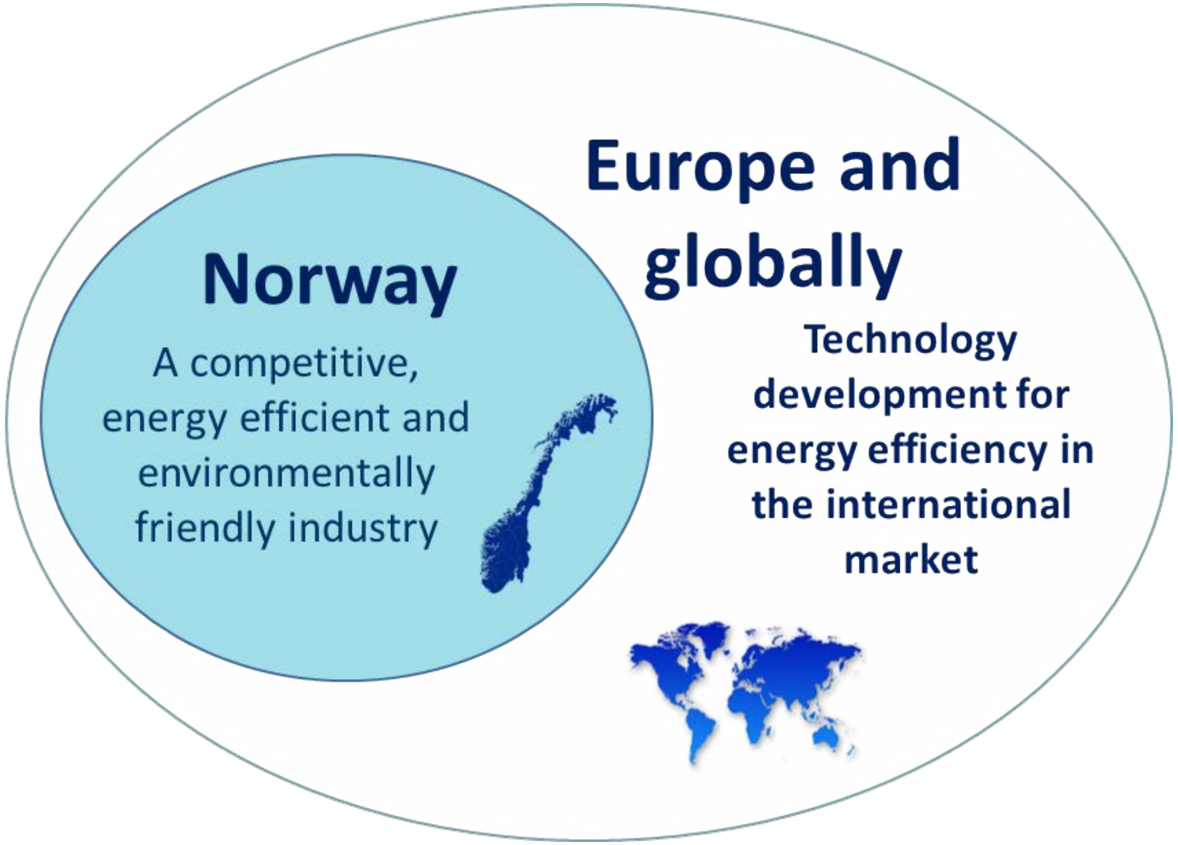
HighEFF Vision

Joint effort for creating a competitive, energy efficient and environmental friendly industry for the future



Europe and globally

Technology development for energy efficiency in the international market

Norway

A competitive, energy efficient and environmentally friendly industry

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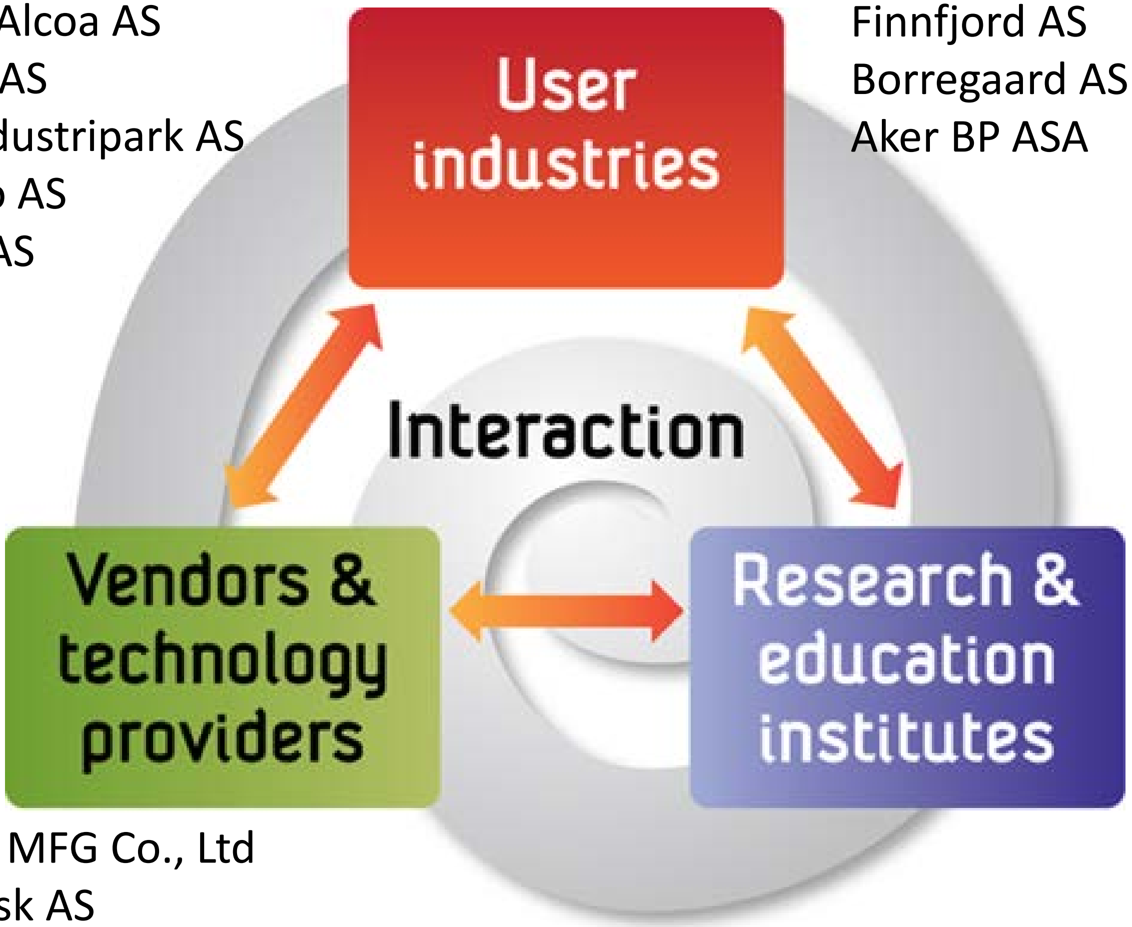

User industries

Interaction

Vendors & technology providers

Research & education institutes

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Hydro Aluminium AS
Rema 1000 i Norge AS
Eramet Norway AS
Norsk Alcoa AS
Elkem AS
Mo Industripark AS
Gassco AS
Orkla AS

Marine Harvest ASA
Glencore Nikkelverk ASA
TINE SA

Bulk Infrastructure AS
Glencore Manganese Norway AS
Vedde AS
Wacker Chemicals Norway AS
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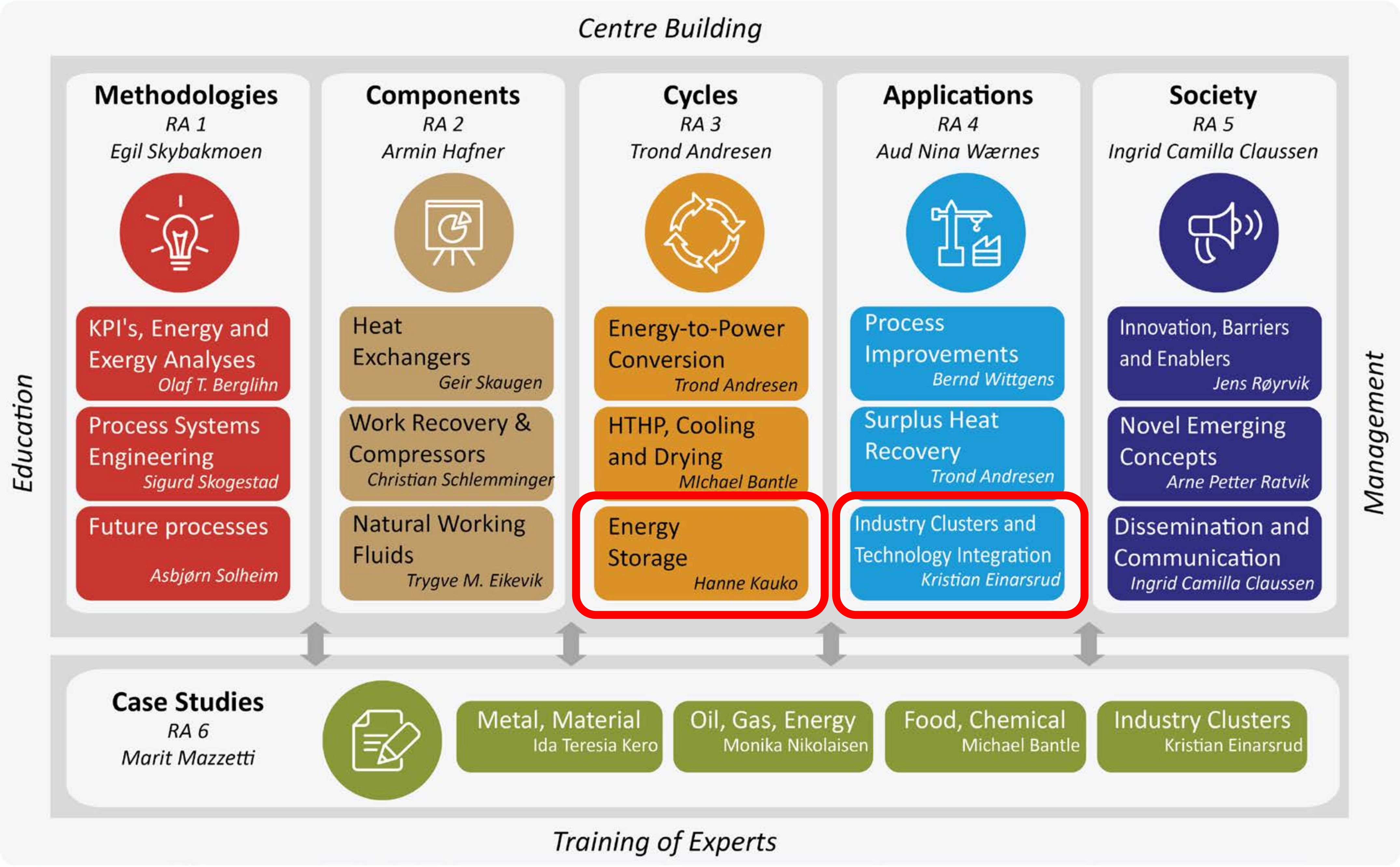

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- Process Systems Engineering — *Sigurd Skogestad*
- Future processes — *Asbjørn Solheim*

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- Work Recovery & Compressors — *Christian Schlemminger*
- Natural Working Fluids — *Trygve M. Eikevik*

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- Oil, Gas, Energy — Monika Nikolaisen
- Food, Chemical — Michael Bantle
- Industry Clusters — Kristian Einarsrud

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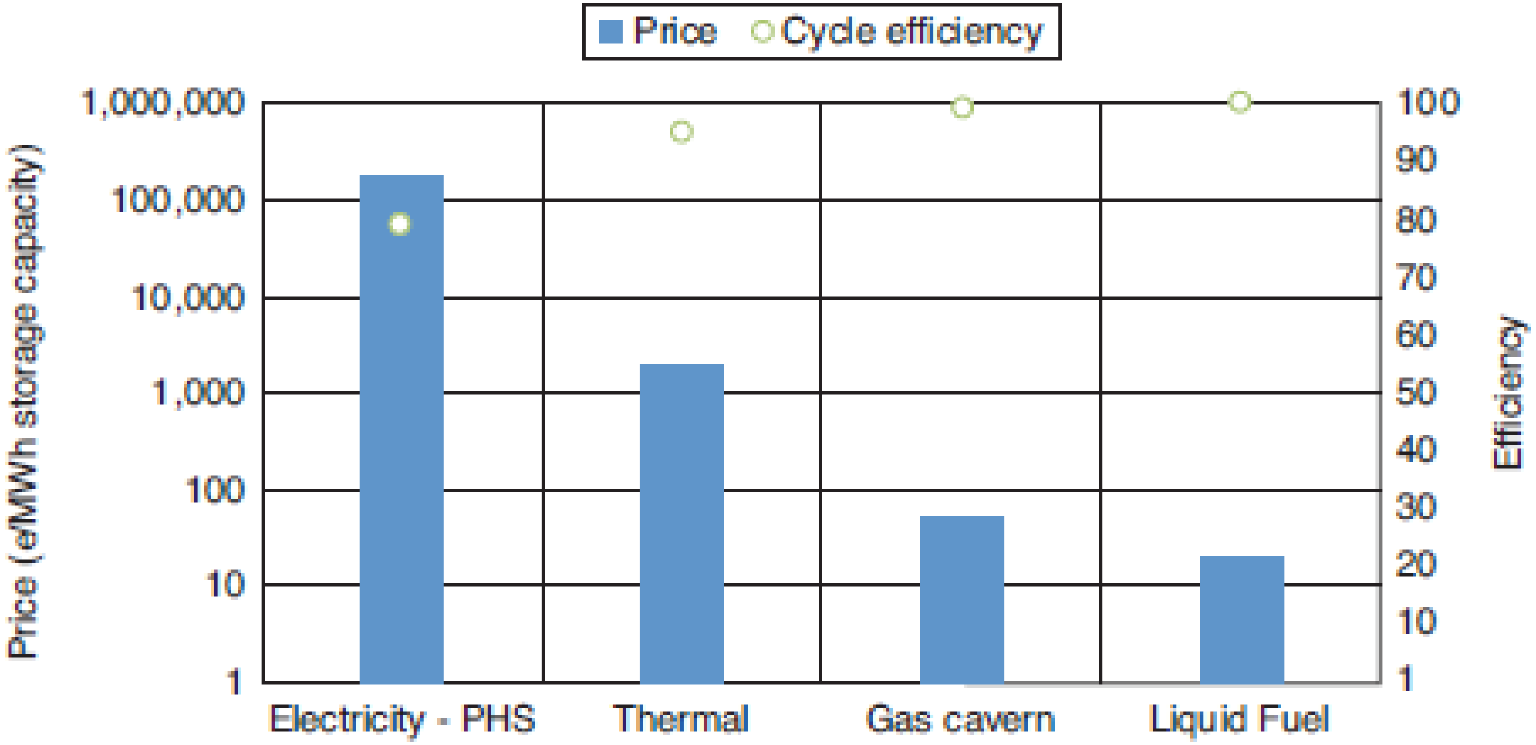
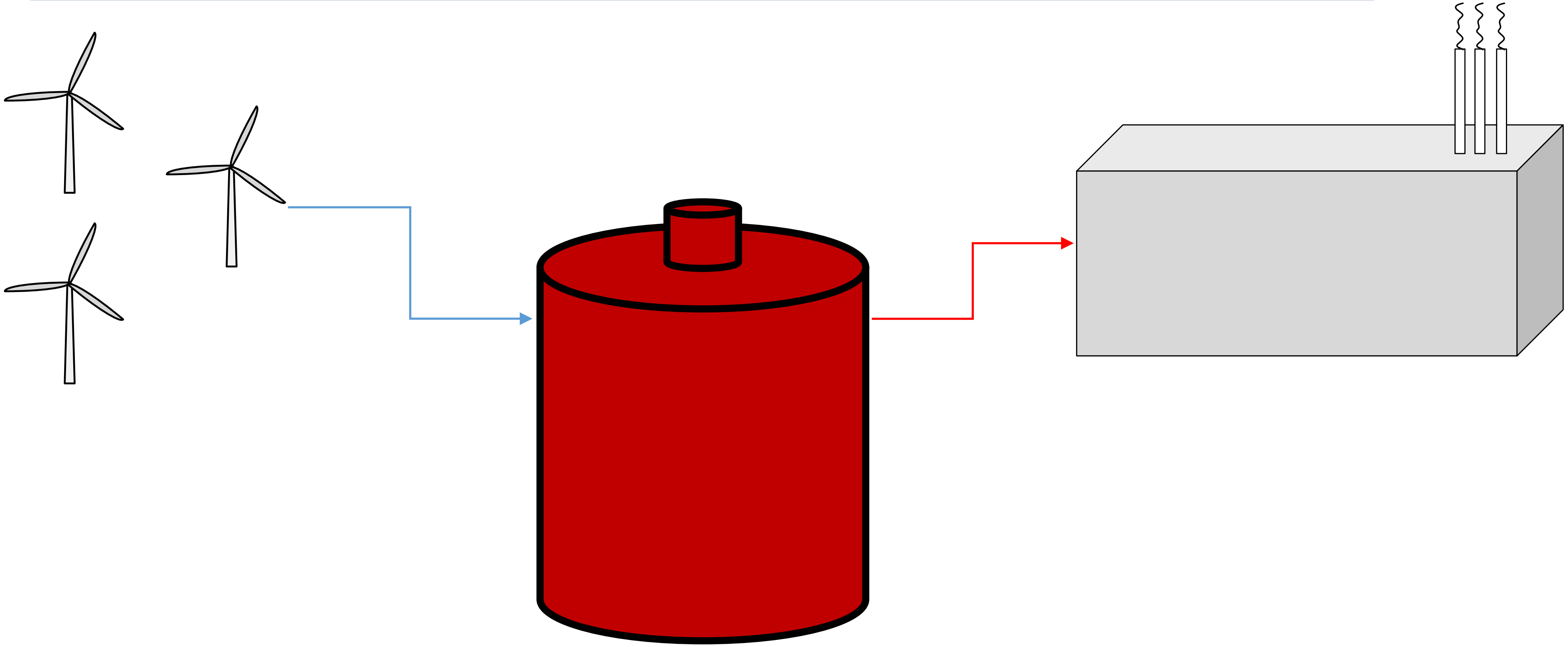
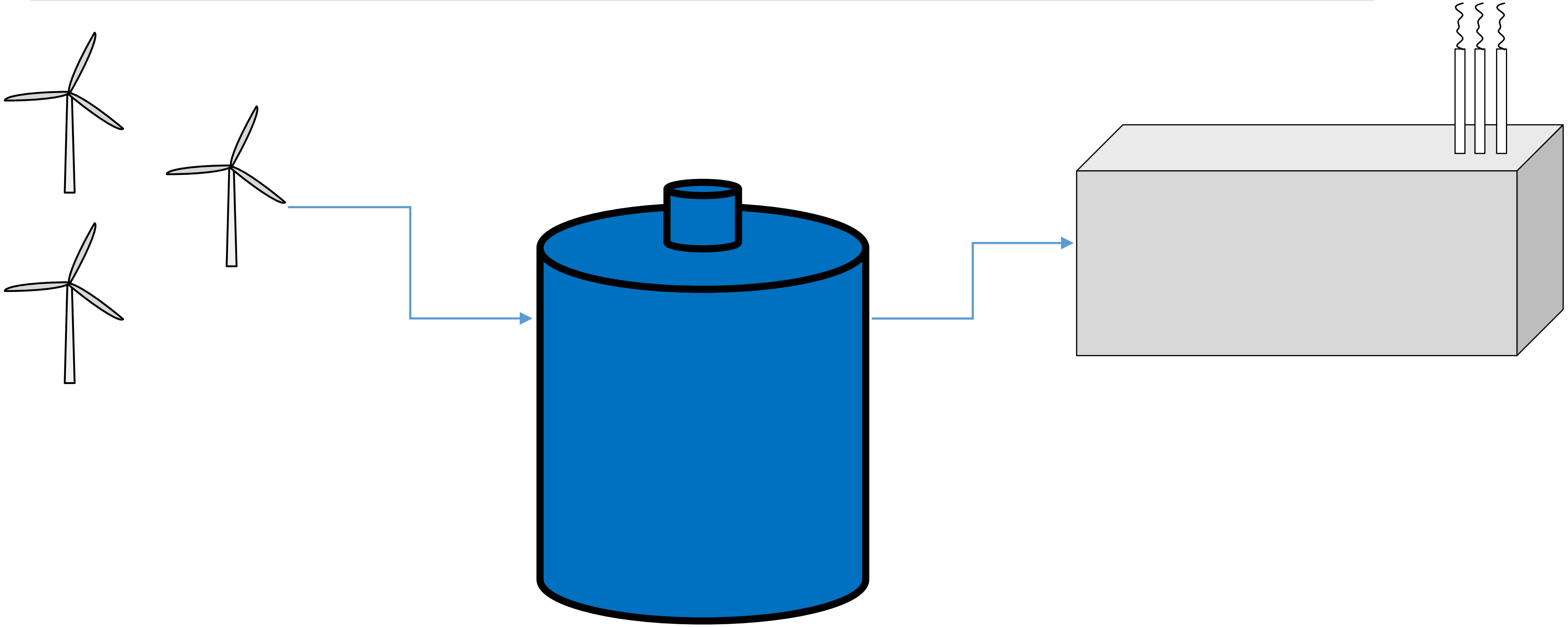


H. Lund, P. A. 0stergaard et al. Energy Storage and Smart Energy Systems. *International Journal of Sustainable Energy Planning and Management* Vol. 11 2016

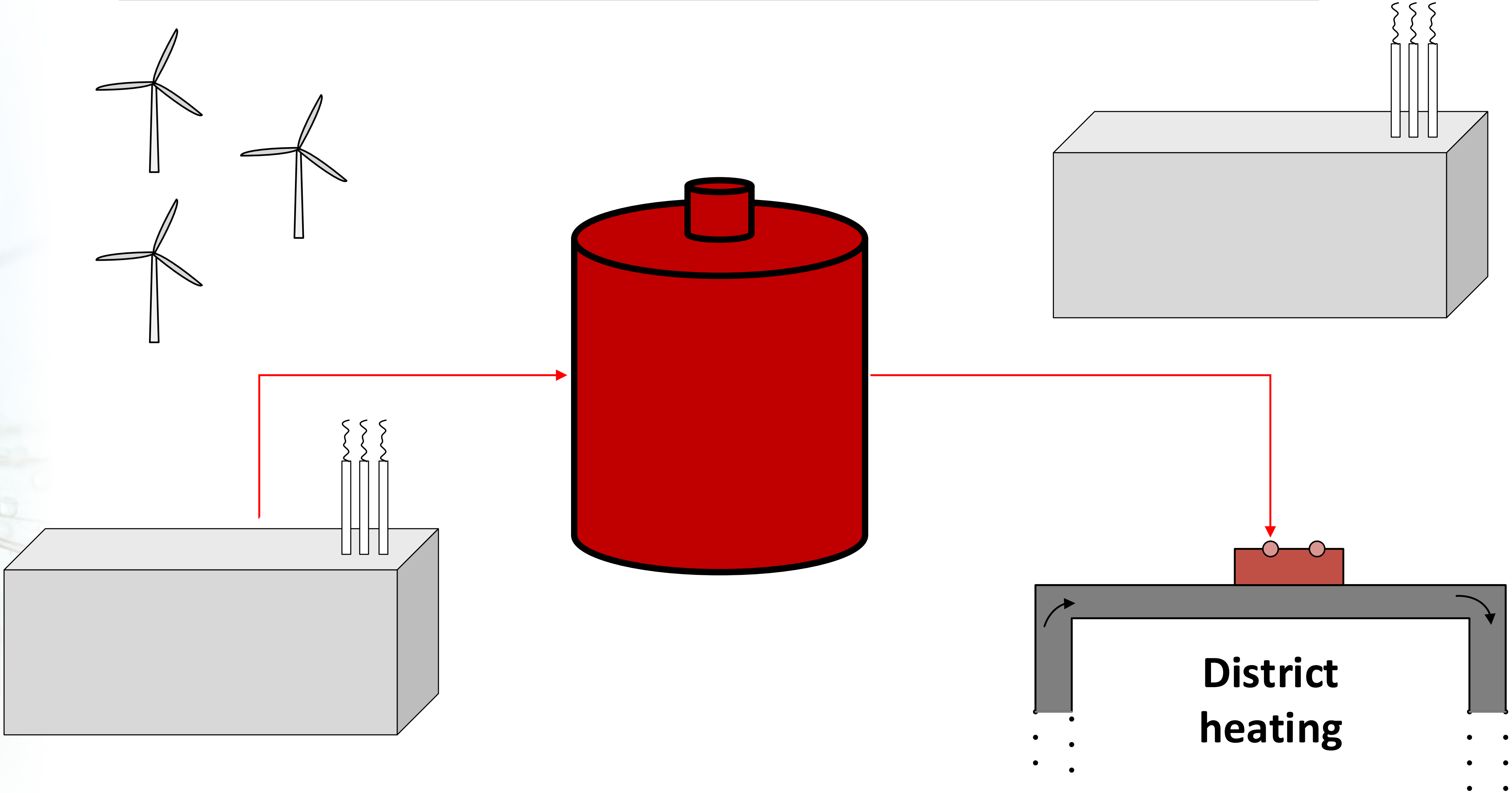
3 cases for application of TES in the industry



3 cases for application of TES in the industry



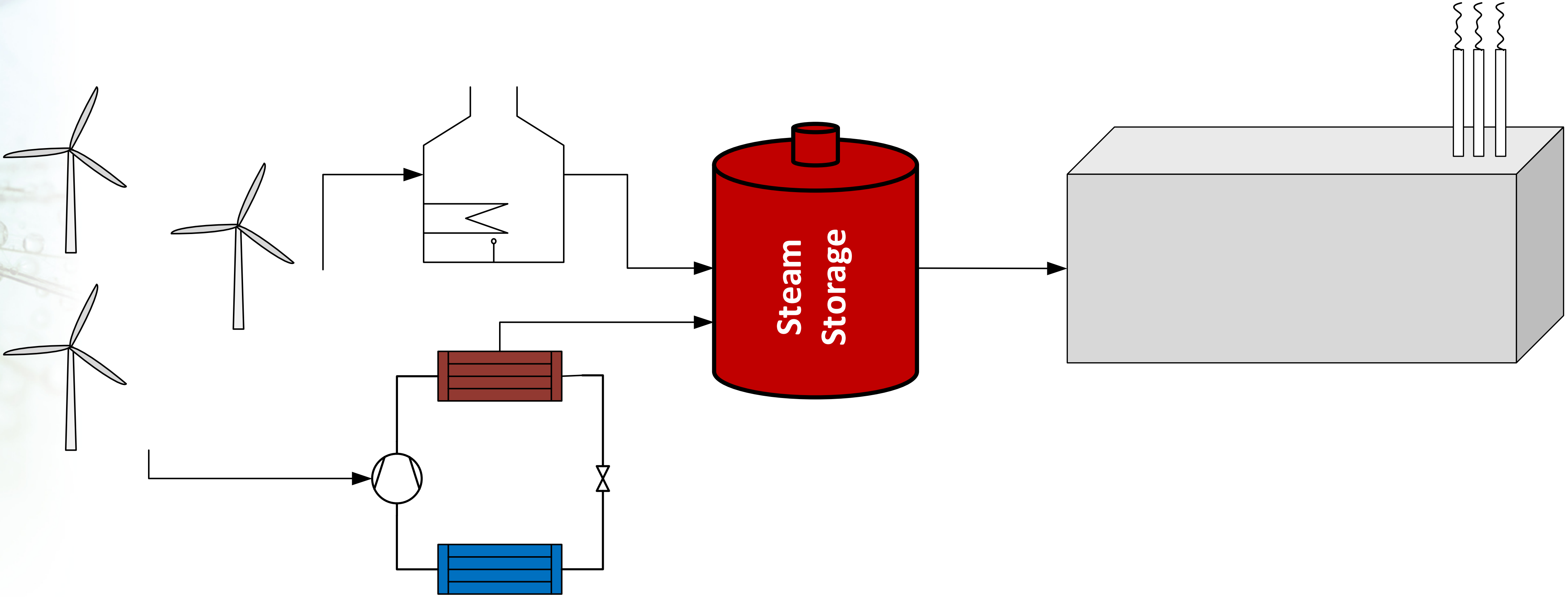
3 cases for application of TES in the industry



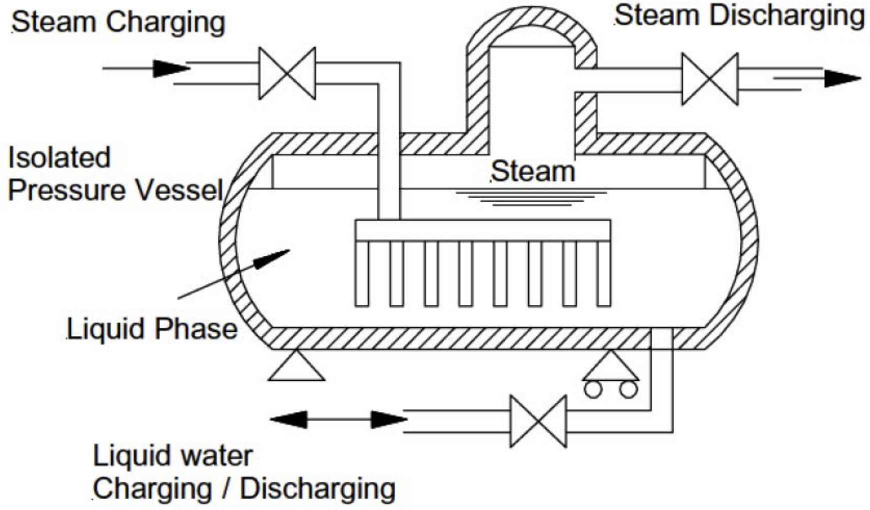
Case 1: Steam storage for the metal industry

Production of alumina from Bauxite through the Bayer process

- Steam demand up to 1000 t/h at 150 °C, 15 bar
- Green energy available from a fluctuating power market
- Large scale storage needed



Ruths Steam Storage



Sources: VDI, DLR, TU-Wien

Characteristics

Storage medium: Water, steal

Direct storage

Variable power to energy ratio

Storage density:

~ 40 kWh/m³ at 30 bars

~ 31 kWh/m³ at 100 bars

Costs: 4 €/tons of water, 6000 €/t steal

Pros

- Simple
- Commercially available
- Good for short time storage with high powers

Cons

- Low storage density at high pressures
- High costs of steal
- Not large scale storage and longer time scales

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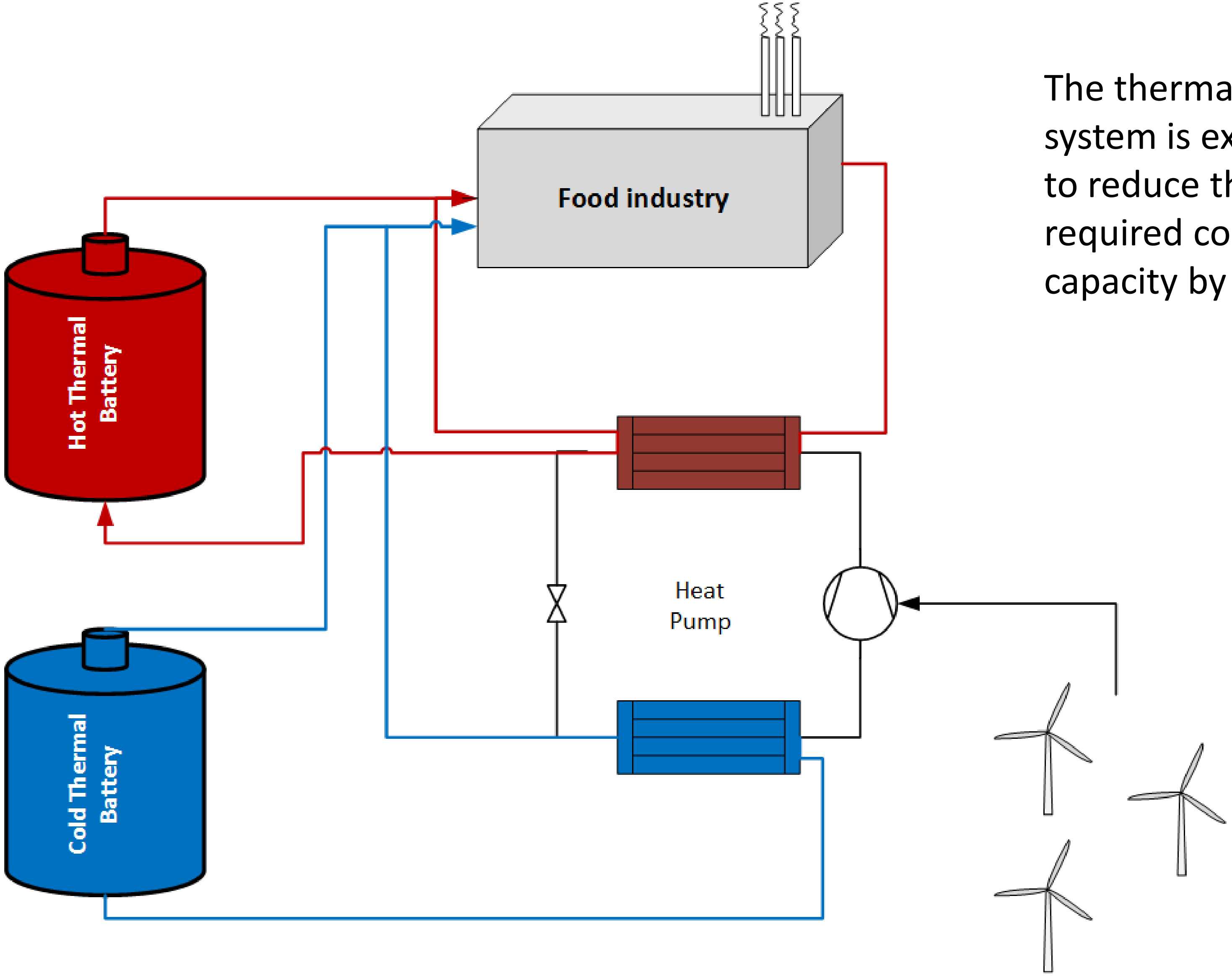
Case 2: Cold TES for the Food Industry



The thermal storage system is expected to reduce the required compressor capacity by **20 %.**

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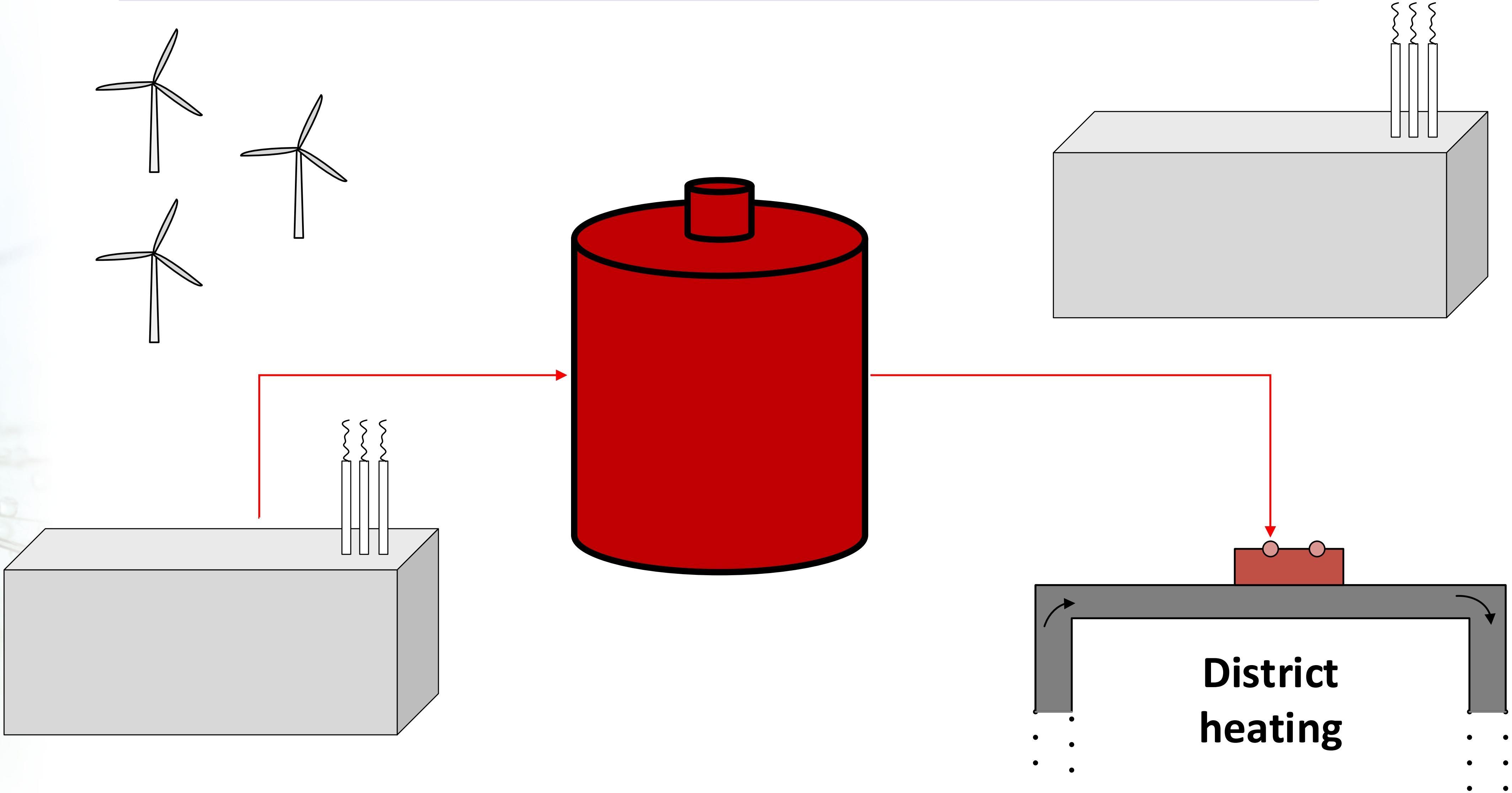
3 cases for application of TES in the industry



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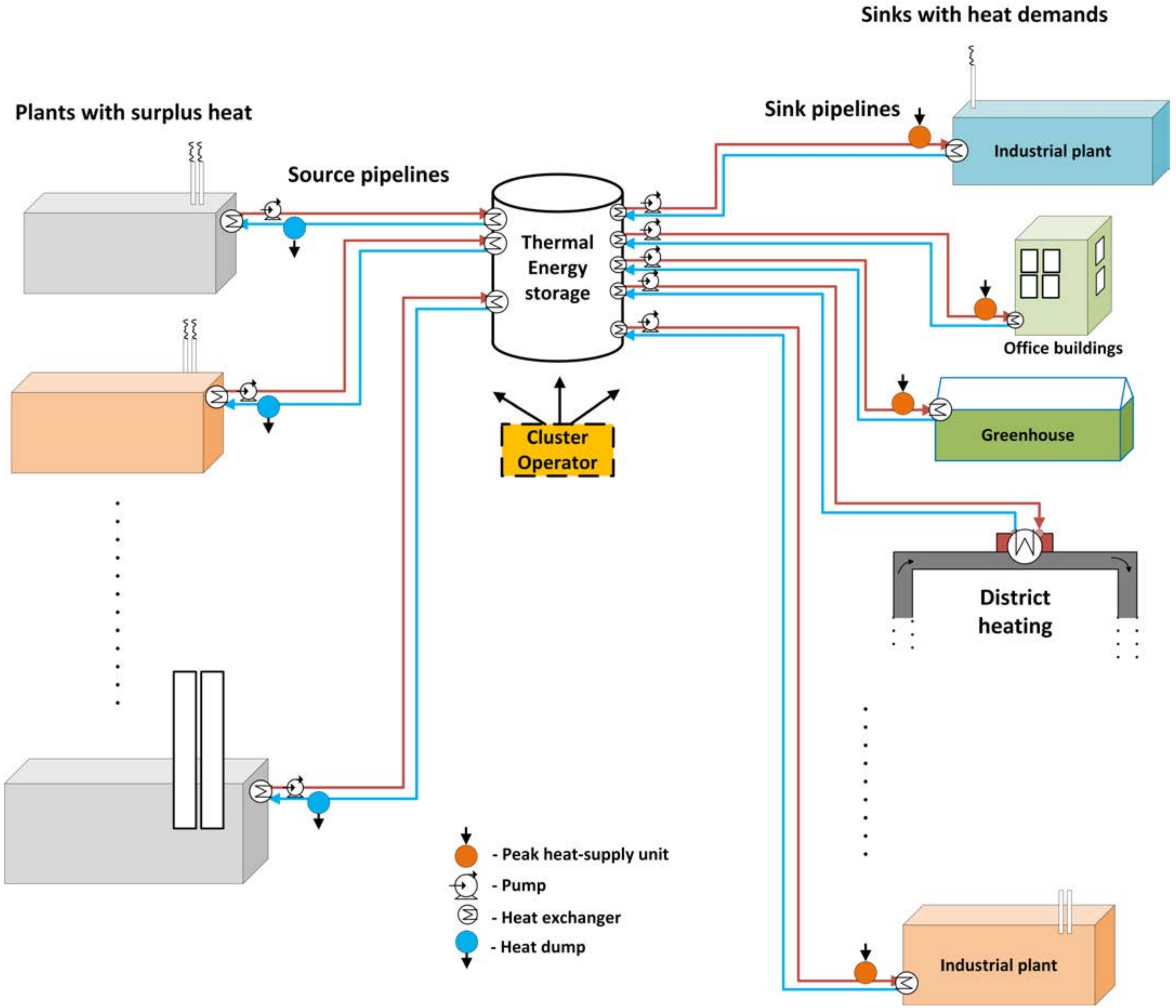
Case 3: TES + optimal control for industrial clusters



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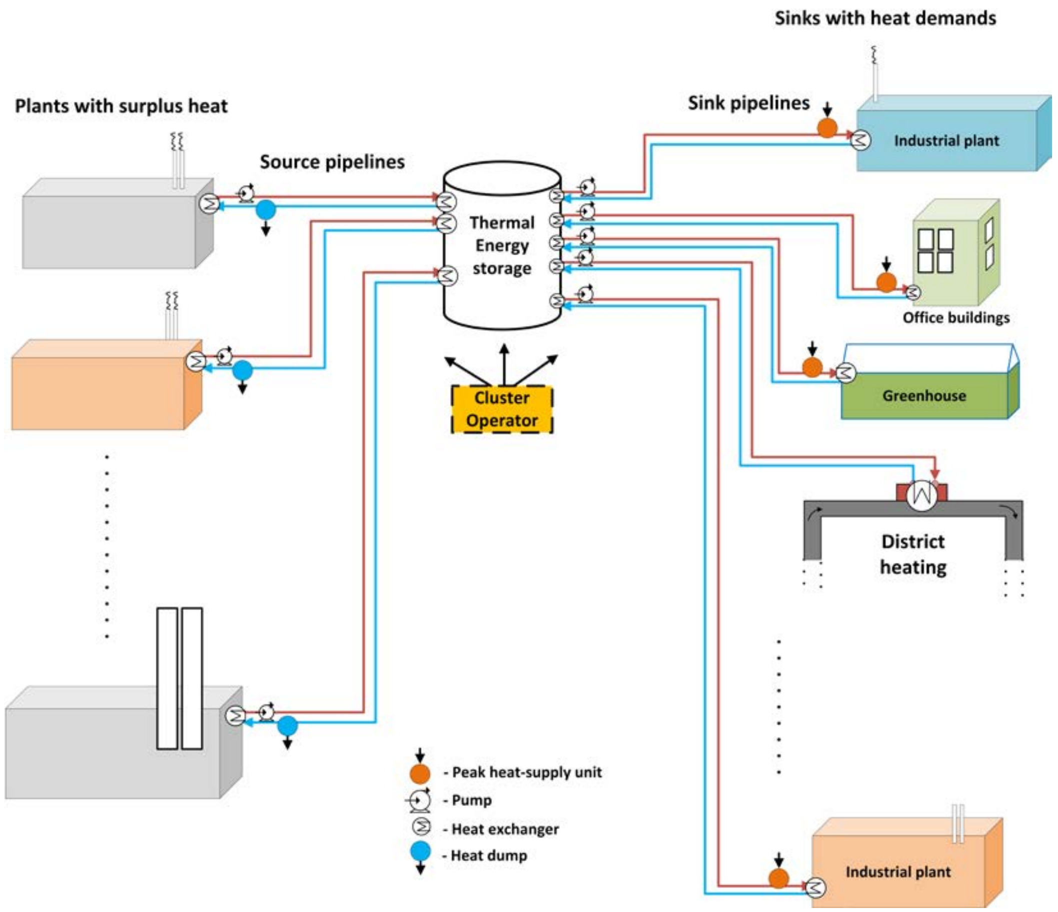
TES + optimal control for industrial clusters



B. R. Knudsen, H. Kauko, T. Andresen (2018). An Optimal-Control Scheme for Coordinated Exchange of Time-Varying Surplus Heat in Industry Clusters. Under revision for *Journal of Cleaner Production*

Challenges

- Mismatch in availability vs. demand
- Surplus heat sources with different temperature levels
- Costly peak heating sources

Goals

- Maximize utilization of surplus heat with thermal energy storage (TES)
- Minimize use of peak heating sources
- Minimize heat dumping
- Predict fluctuations in demand and availability of heat

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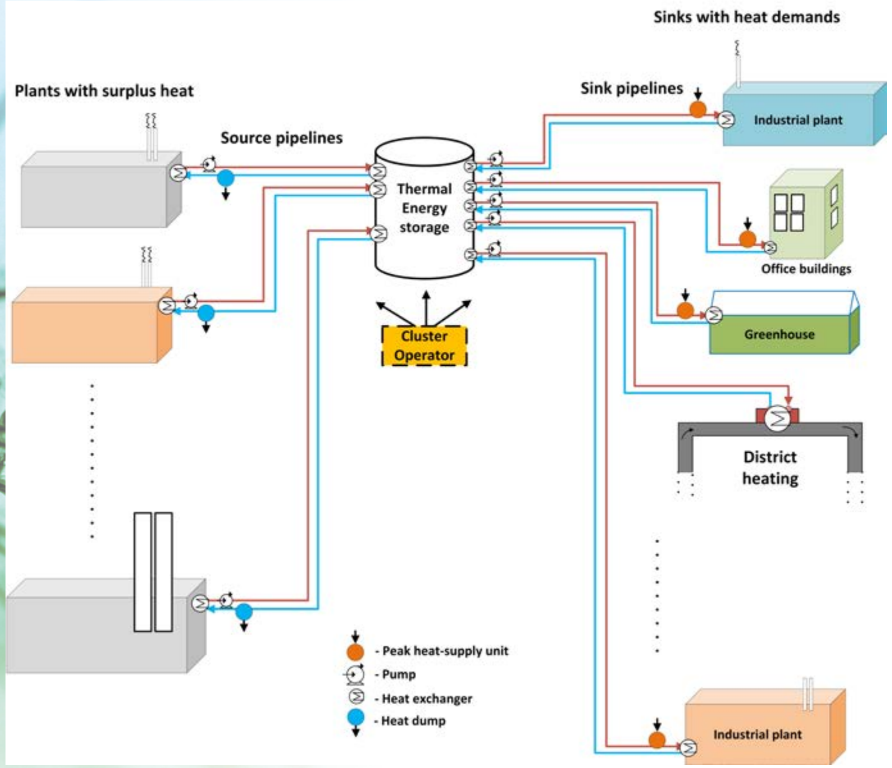
The optimization problem



Peak heating supply

Dumped surplus heat

Pump flow velocity

$$\min_{v^{\text{pump}},Q^{\text{peak}},Q^{\text{hd}}} \int_{t_0}^{t_f} \left(\sum_{j\in\mathcal{J}} Q_j^{\text{peak}}(t) + \gamma_1 \sum_{i\in\mathcal{I}} Q_i^{\text{hd}}(t)^2 + \gamma_2 \sum_{j\in\mathcal{J}} v_j^{\text{pump}}(t)^2 \right) \mathrm{d}t$$

Objective function

$$\text{s.t.} \quad \left| Q_j^{\text{del}}(t) - \bar{Q}_j^{\text{demand}}(t) \right| \leq \delta_j \bar{Q}_j^{\text{demand}}(t),$$

$$Q_j^{\text{del}}(t) := Q_j^{\text{TES,out}}(t) - Q_j^{\text{loss}}(t) + Q_j^{\text{peak}}(t),$$

Satisfaction of demand

$$0 \leq v_j^{\text{pump}}(t) \leq \bar{v}_j^{\text{pump}}$$

$$Q_j^{\text{peak}}(t) \geq 0,$$

$$Q_i^{\text{hd}}(t) \leq 0,$$

Bounds on control inputs

$$T^{\text{TES}}(t) \leq \bar{T}^{\text{TES,max}}$$

$$T_{j,p}^{\text{pipe-source}}(t) \leq \bar{T}_{c,i}^{\text{source}},$$

System constraints

Dynamic models of pipelines, HEXs and TES units

System unit models

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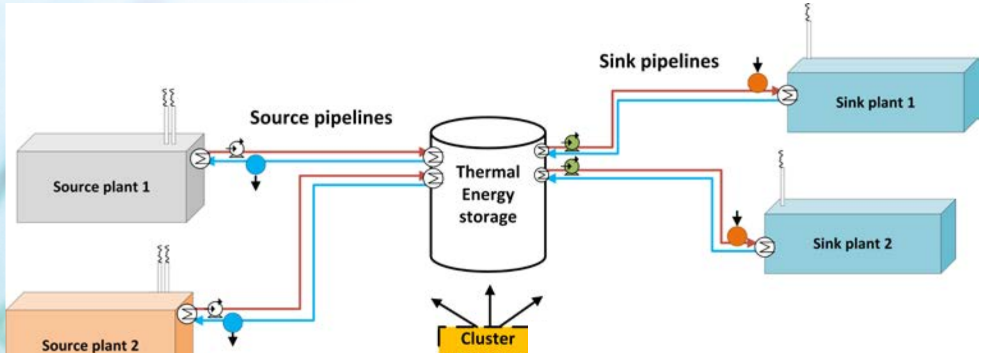
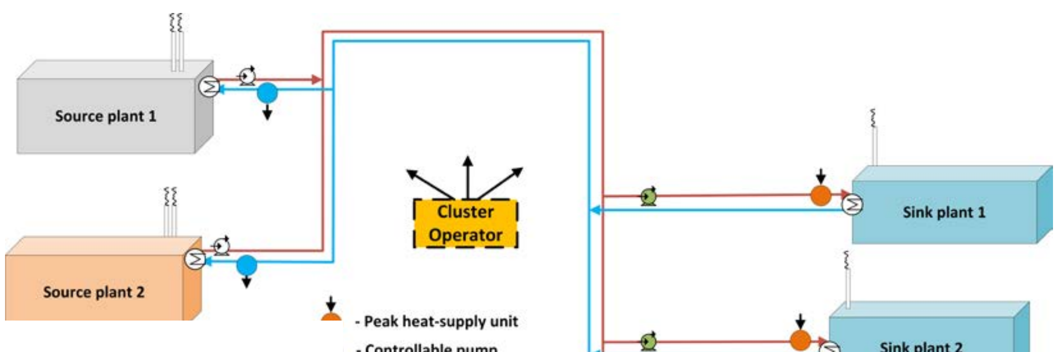
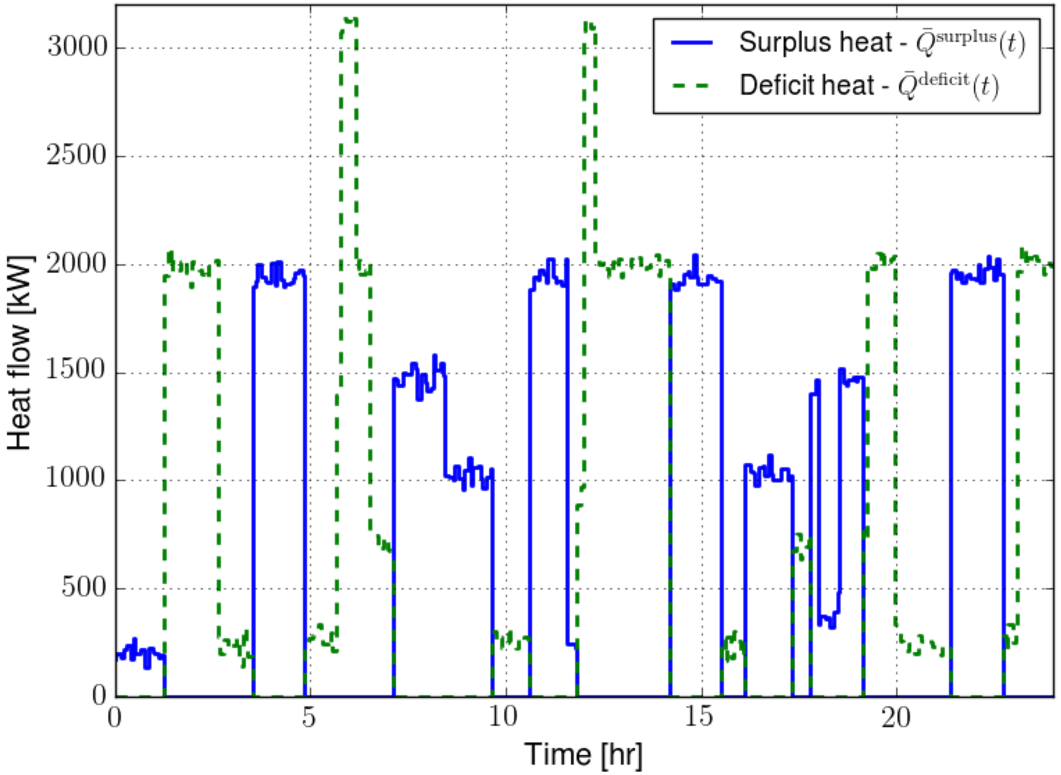
Implementation: Dymola (Modelica models), Jmodelica.org, Python and IPOPT – open source.

Case study



V.S.





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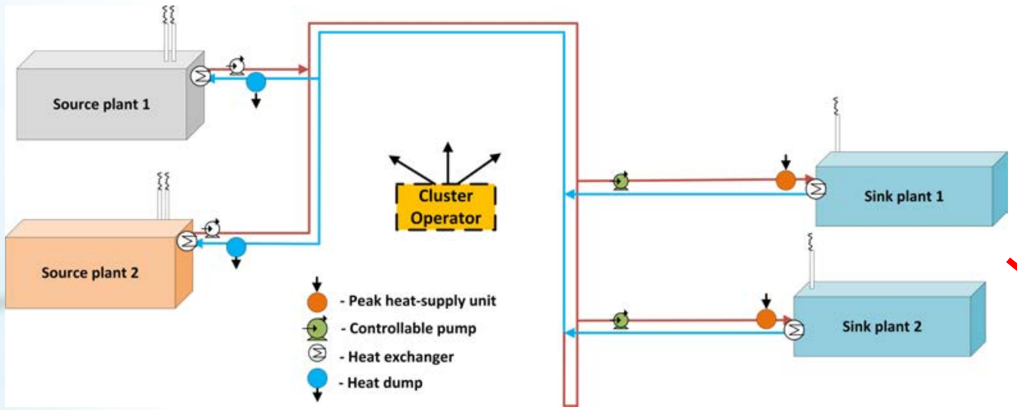
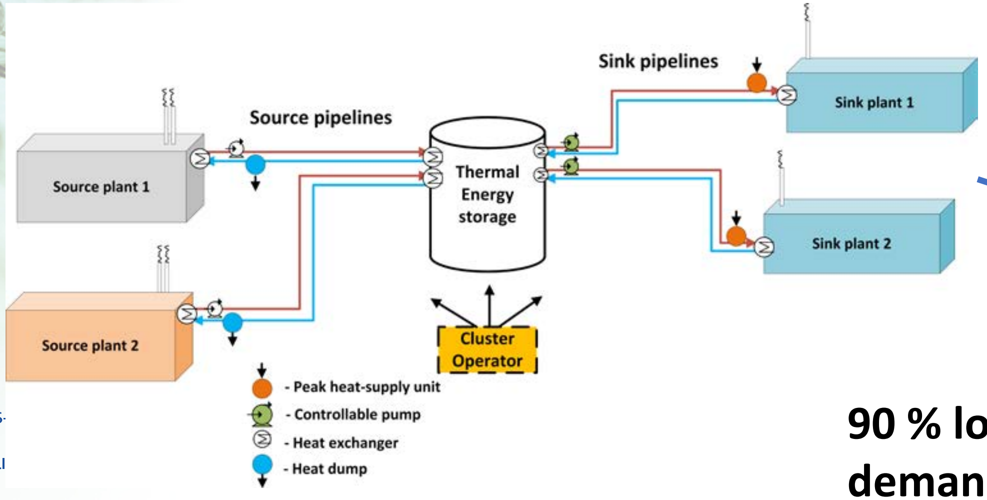
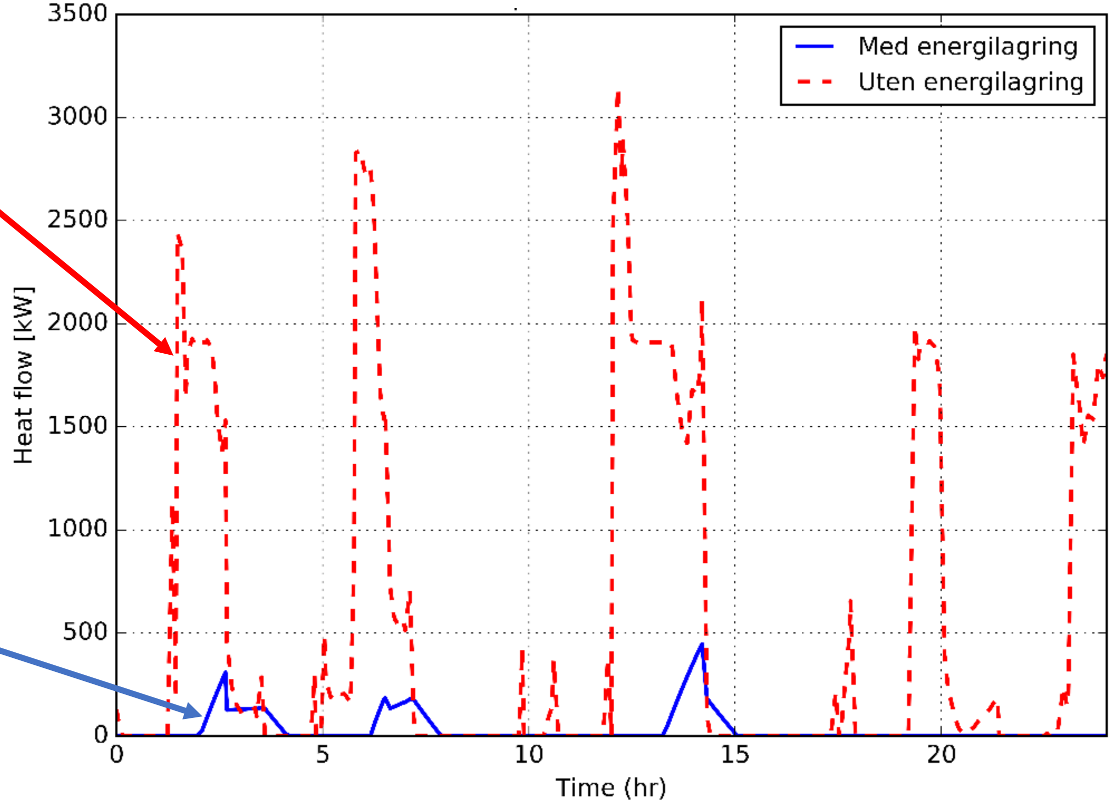
Results





Delivered peak heating over 24 hours



90 % lower peak heating demand when TES is applied.

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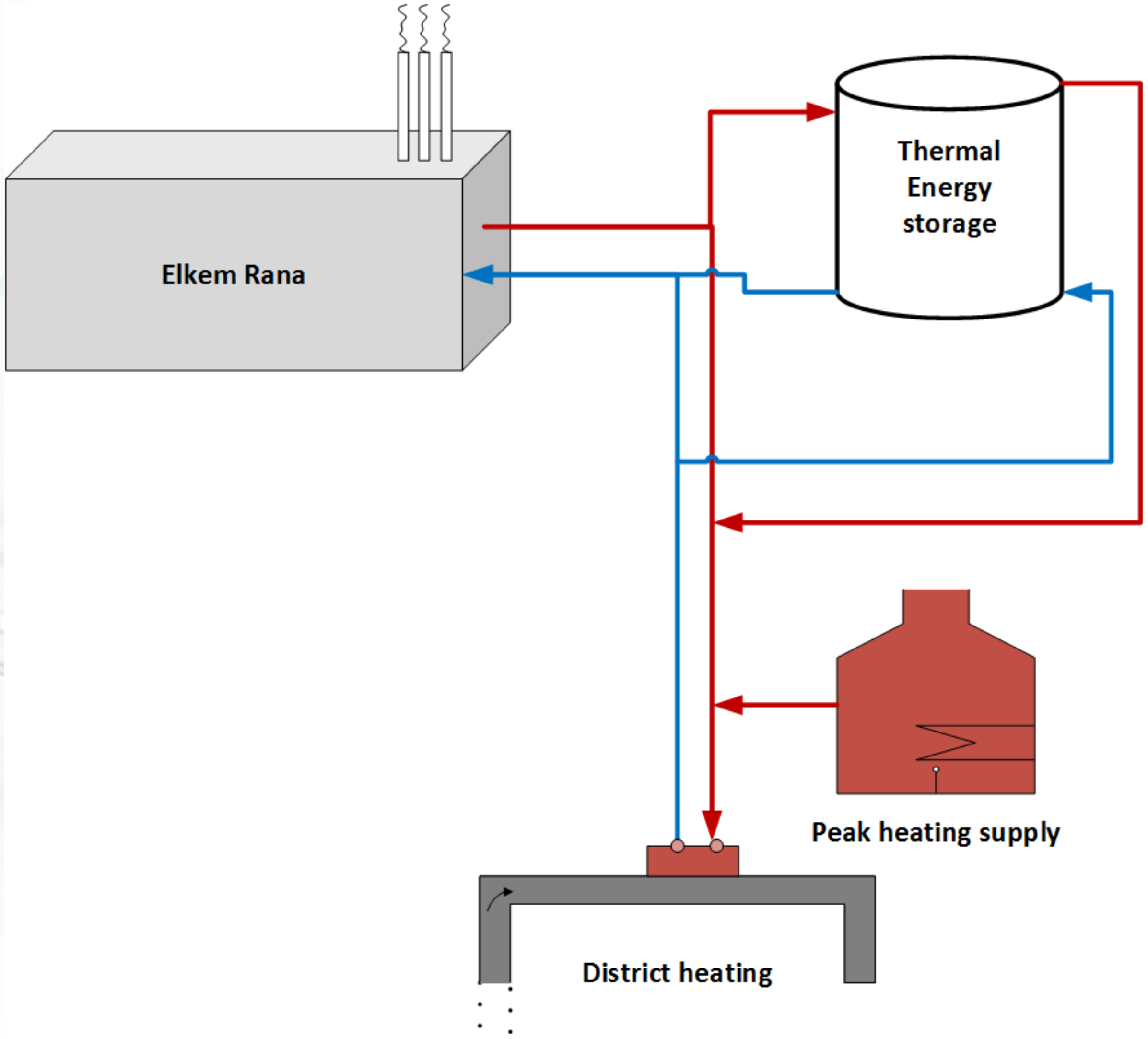
Potential for TES at Mo Industrial Park



Background:

- 85 GWh district heating (DH) annually
- 90 % of the DH from surplus heat from a FeSi plant
  - Remaining covered by peak heating boilers utilizing CO (9%) or electricity (1 %)
- Predictable peaks in the demand during the morning and afternoon

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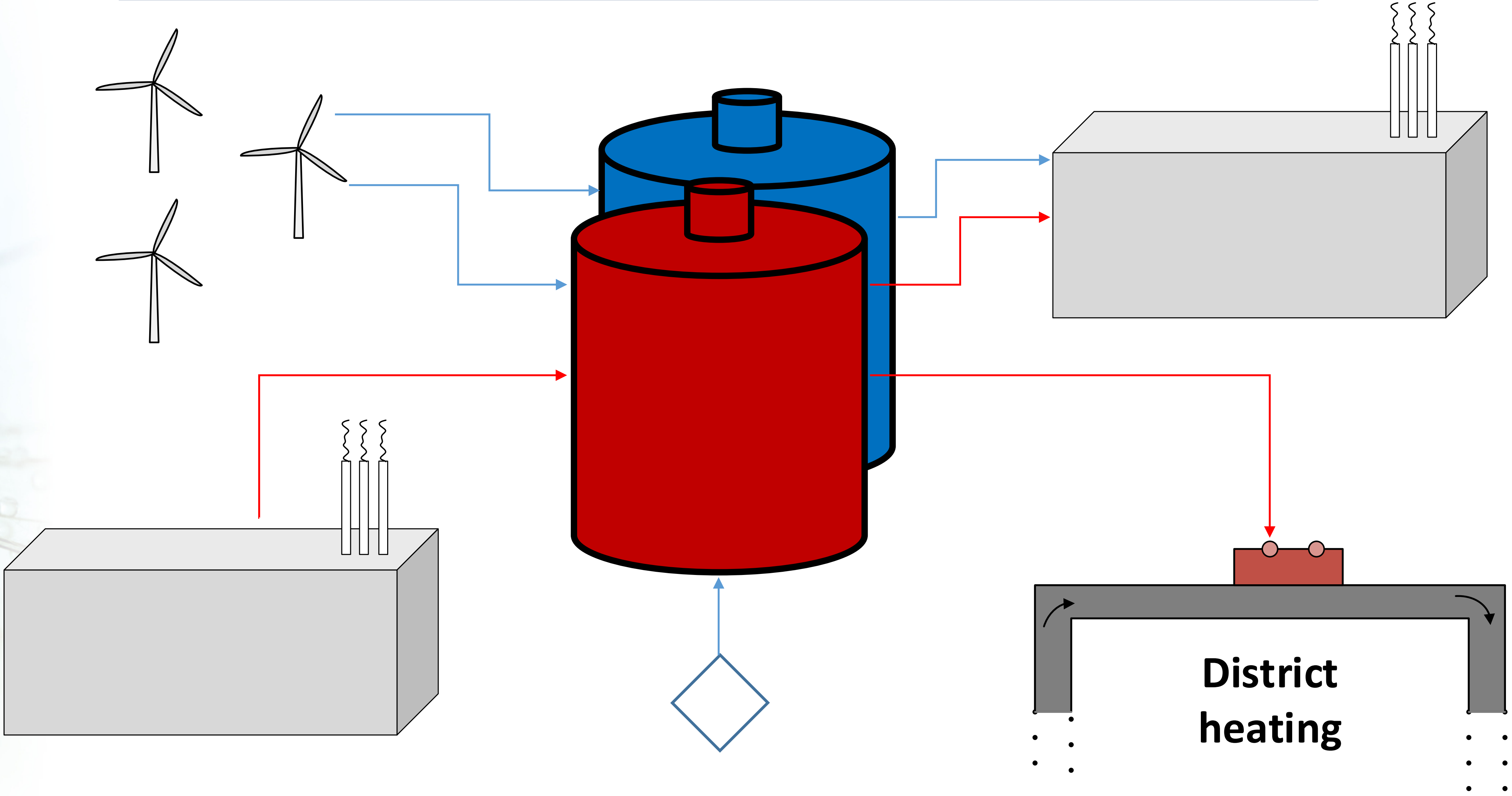
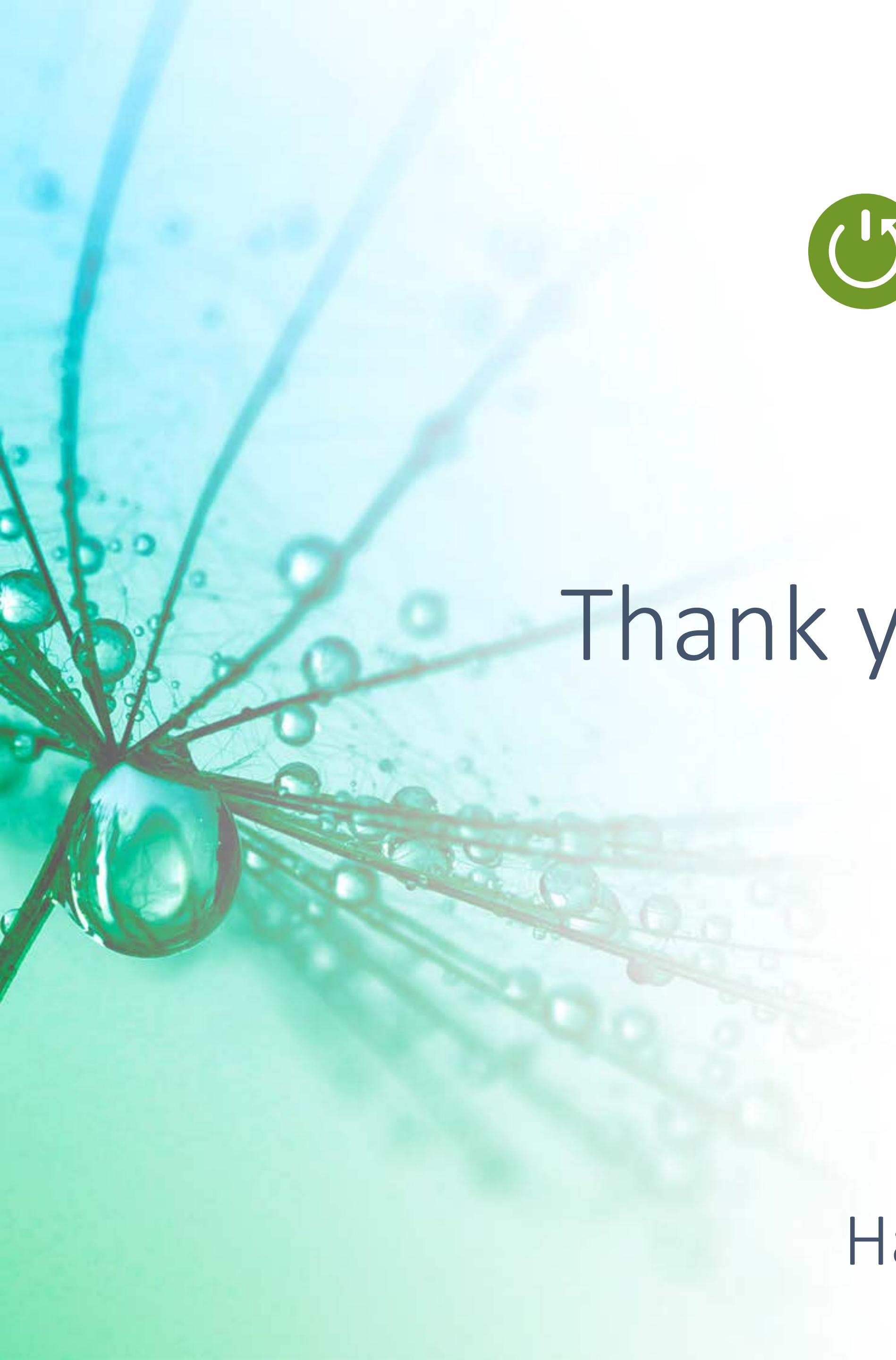
Summary and Conclusions





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Thank you for your attention.

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