Heat exchangers for Thermal energy storage: 2024 Update

PARKER FILTRATION AND ENERGY SOLUTIONS (FES)

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Heatric

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CURRENT EXPERIENCE

HEATRIC'S INVOLVEMENT INTO ENERGY STORAGE CONCEPTS TO DATE

SELECTED COMMERCIAL / NEAR COMMERCIAL CONCEPTS

- CRYOGENIC STORAGE
- SCO2 HEAT PUMP
- SOLAR SCO2 STORAGE

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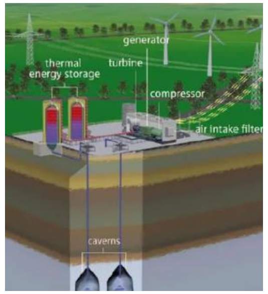
Thermal Energy Storage Enquiries Timeline

2009 - Present

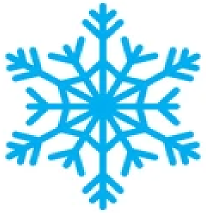
2011
FEED study for large scale CAES project in Germany



2013
Pre-FEED study for large scale Molten-Salt - sCO2 projects in the US

2019
Energy Storage is back thanks to the Duck-Curve

2021
First large scale commercial plant – Heat pump based on MAN ETES Energy storage

2009


Test units for the first Cryobattery Project in the UK (Highview Power)

2012

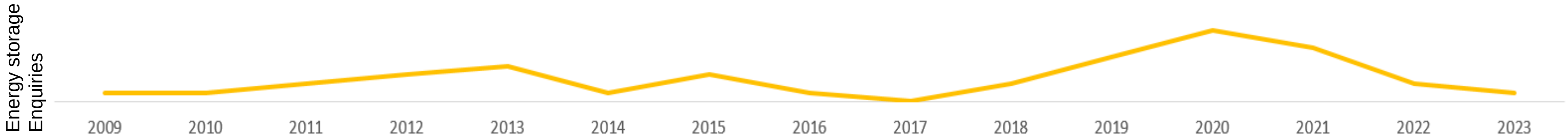

FID study for TEES system in Switzerland

2014


Demonstration units for the first Cryobattery Project in the UK (Highview Power)

2023


Several major projects in FEED – FID phase for 2023-24 build



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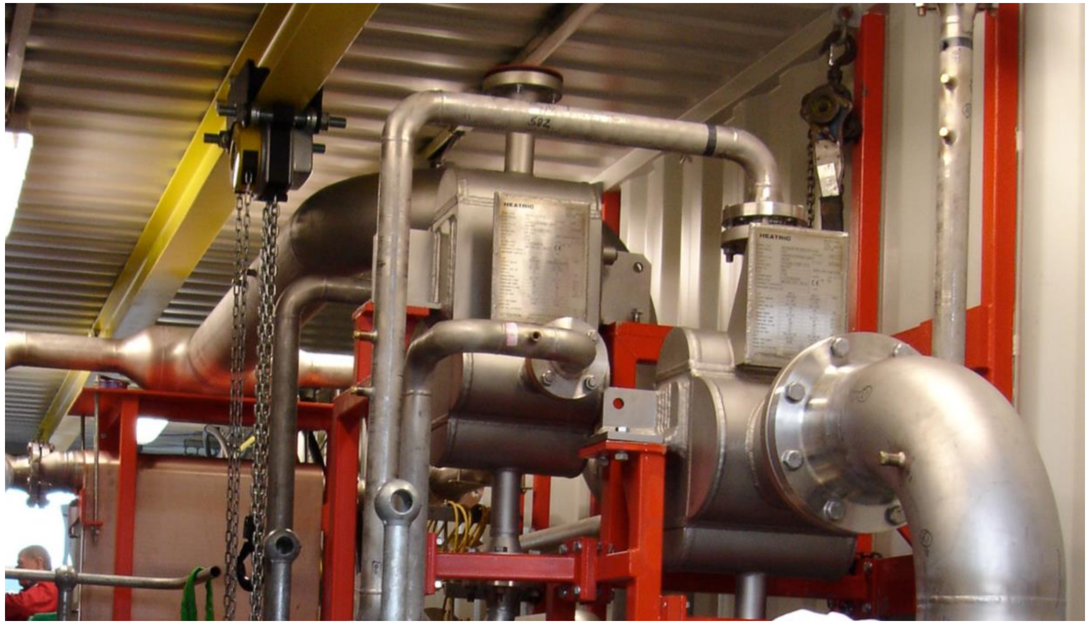
CRYOGENIC STORAGE – HIGHVIEW POWER

2009 – 2019: Proving and validating the Technology

2009 – 2013: Slough test site

- Proof of concept successful with operation until site closure 2013
- 3 exchangers supplied



Slough test site PCHEs

2014 – 2019: Bury Viridor Demonstration site

- Demonstration plant successfully operated until site closure 2019
- 2 exchangers supplied

Bury Demo site Evaporator and HX1 (front)

sCO2 HEAT PUMP – MAN ENERGY SOLUTIONS

Commercial reality (ETES District Heating)

MAN Energy Solutions

Esbjerg Plant:

- Construction started H1 2021
- 2x 25MWth Heat Pumps
- 25Mwth full sclae heat Pump successfully tested in Zurich Q2 2022
- Operation planned H2 2024

World first commercial plant for:

- sCO2 Heat Pump
- Core technology for ETES Energy Storage at scale
- Clean District Heating technology

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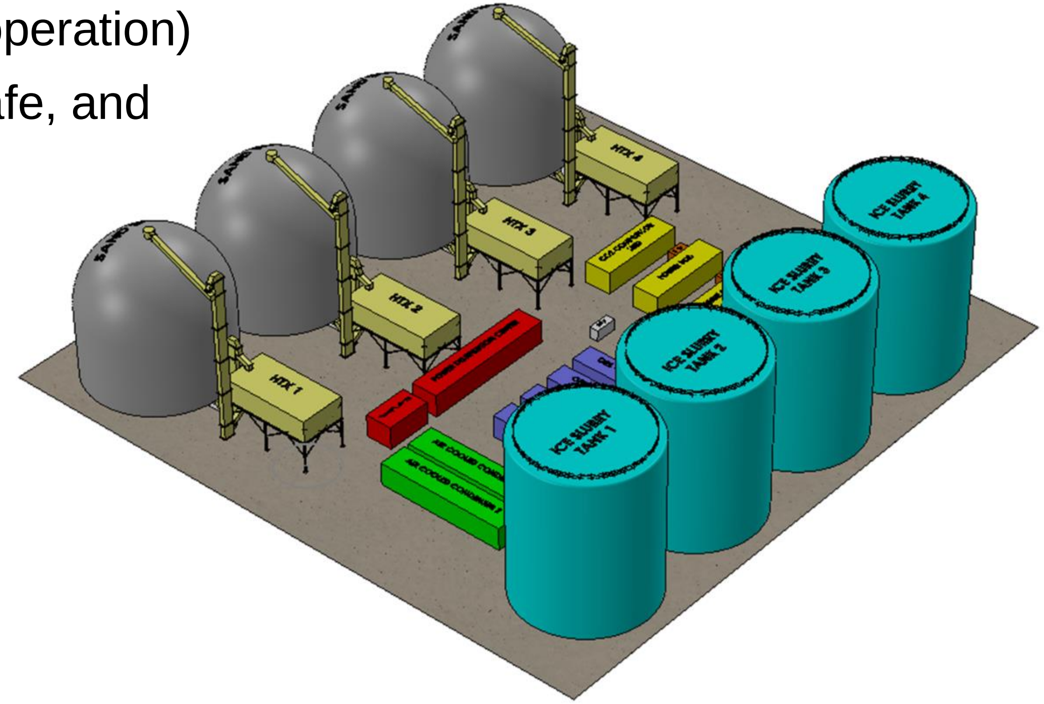
sCO2 SOLAR Storage – ECHOGEN POWER SYSTEMS

Building on the EPS 100 success

Key features:

- Long duration (>4-6 hours) energy storage
- Using already proven EPS 100 technology (>330 hours operation)
- Materials are low-cost, safe, and environmentally-benign
- Non-site specific



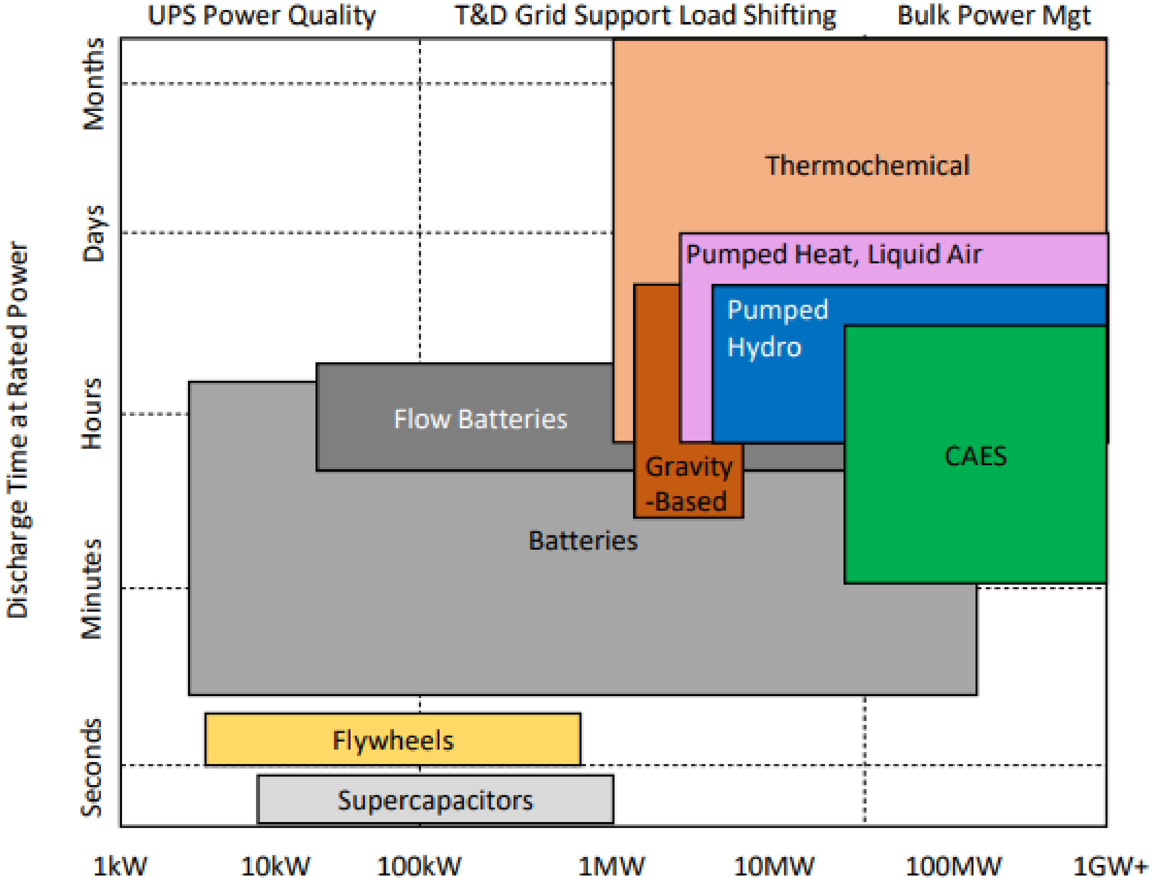
EPS 100 skid – 7-8 MWe

EPS 100 heat exchangers (2011)

HEATRIC's OVERALL ENERGY STORAGE VIEW TO DATE

Exciting opportunities but too many cycles to chose from?

- Investigation by ASME Turbo Expo Energy storage committee in 2022 found 85 different companies concepts of energy storage
- Quick introduction to various Energy Storage by Tim Alison during TMCES 2020 discussed 9 different concepts
- Most processes yet to be demonstrated / proven at scale although credit to Energy Dome, MAN ES, Highview Power and Echogen
- Pressure on OEM and supply chain to drive cost down, but needs investment to do so: difficult to decide who to back



Extract from "Thermal-Mechanical-Chemical Energy Storage Technology Overview" Tim Allison – TMCES 2020

Enabling Engineering Breakthroughs that Lead to a Better Tomorrow

HEAT EXCHANGERS FOR THERMAL ENERGY STORAGE

REQUIREMENTS

SIZING

REQUIREMENTS

The ideal heat exchanger … can it be done?

- There has been an increase in customers asking us for Long Duration (10/100's MWhrs) energy storage heat exchangers.
- Such exchangers, which easily require 1,000s m² of heat transfer, are required to deliver many if not all of the following:

1. High Performance to maximise OPEX by increasing RTE (Round Trip Efficiency) / minimise losses*
2. Compact and light to facilitate integration into tight space / remote area / reduce installation cost
3. Fast Thermal Response to minimise start-up time to optimal operating conditions
4. Robust, but depending on cycles and / or storage medium:
   - high pressures
   - high temperatures
   - Corrosion
   - Aperture size / pressure drop
5. Made in large size / quantities / modularised
6. Cheap to reduce overall CAPEX

HIGH EFFECTIVENES IMPACT

High Performance to maximise OPEX by increasing RTE (Round Trip Efficiency) / minimise losses

How to facilitate highest level of RTE from an exchanger point of view:

- Ensure highest effectiveness / closer temperature approach feasible (cost vs. performance)

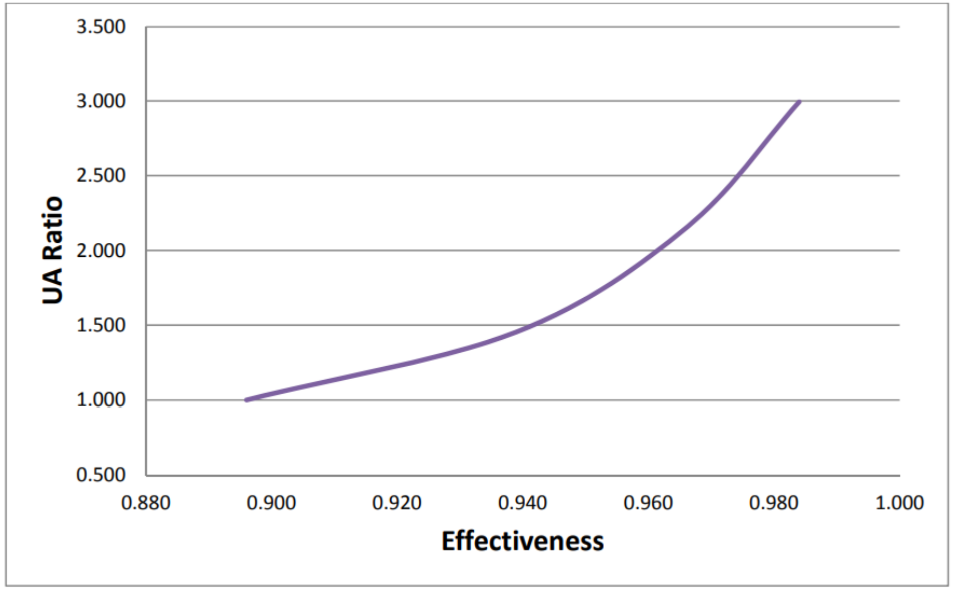
$$Effectiveness = 1 - \frac{\Delta T_{approach}^{*}}{T_{hot\ in} - T_{cold\ in}}$$

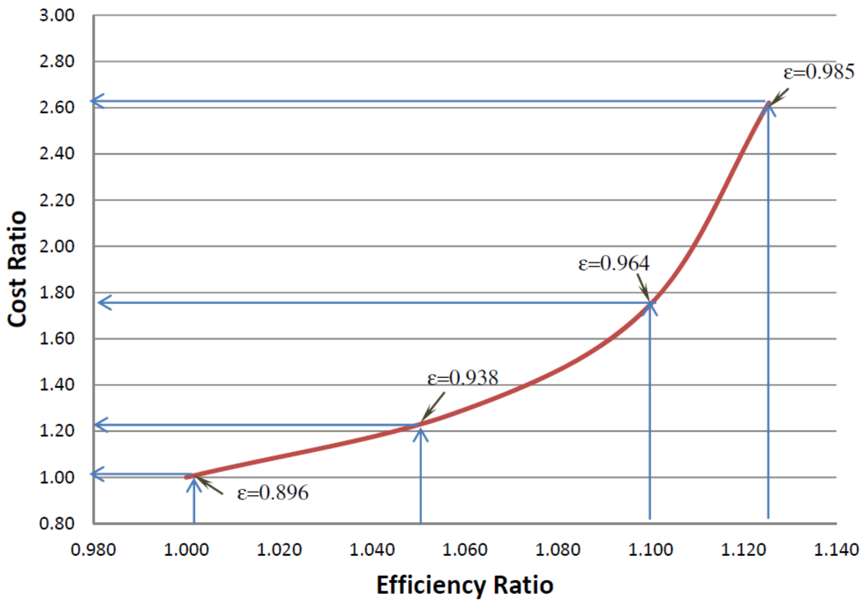
$$^{*}\Delta T_{approach} = Min[(T_{hot\ in} - T_{cold\ out}), (T_{hot\ out} - T_{cold\ in})]$$

UA where:

U = Overall heat transfer coefficient

A is heat transfer area





CHARGE / DISCHARGE IMPACT

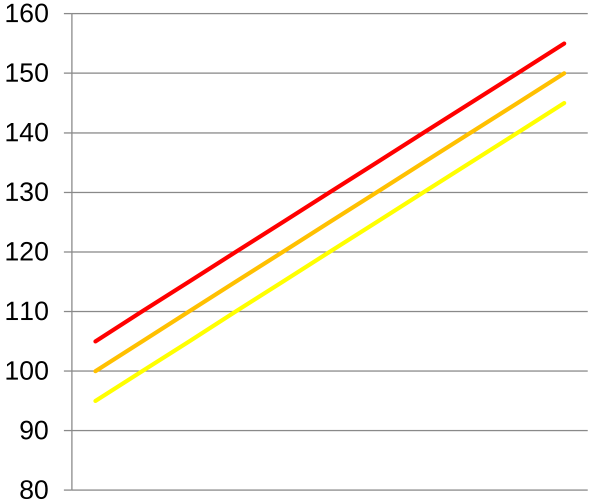
High Performance to maximise OPEX by increasing RTE (Round Trip Efficiency) / minimise losses

How to facilitate highest level of RTE from an exchanger point of view:

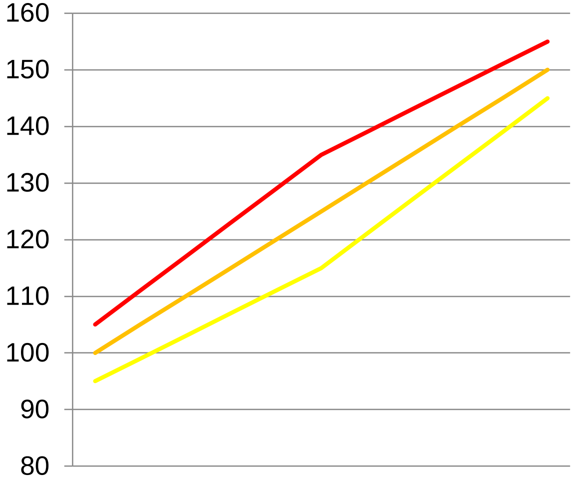
- Check reciprocity of the cycle (excessive losses between charge and discharge for given approach / underperformance due to process conditions)

Surface area requirement may drastically vary between charging and discharging if using the same heat exchanger for both cycles to reduce CAPEX

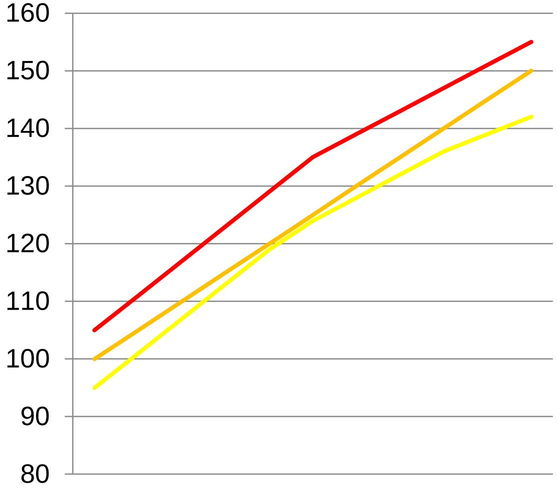
- / - charge
- / - discharge



10° RTE Loss in straight heat release with 5° approach



15° RTE Loss in non-straight heat release with 5° approach



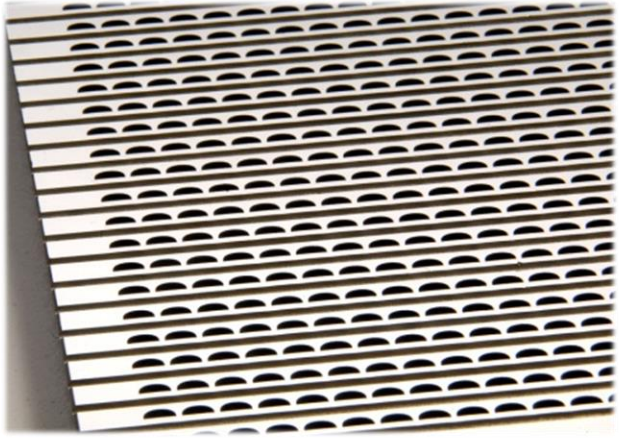
10° RTE Loss in non-straight heat release with 5° approach *

*note the large differences in temperature approaches in the 3rd case between charging and discharging and the implication on heat transfer area

PCHEs Benefits for Energy Storage

A unique combination for the aforementioned processes – but is it the solution to all cycles?

Superior Performance

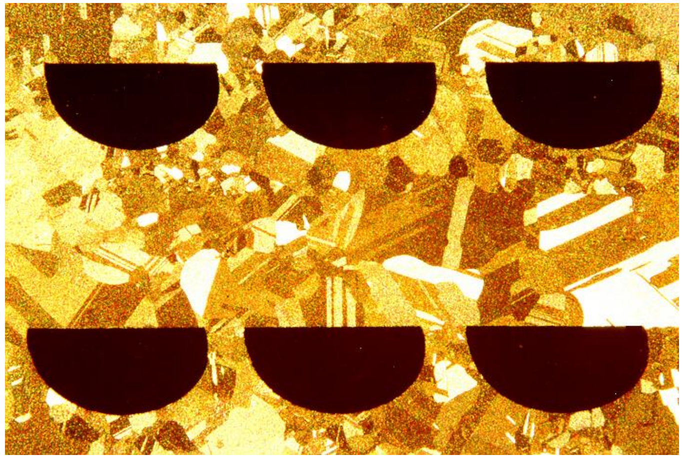


OPEX saving across wide range of processes

Heatric PCHEs are bespoke diffusion bonded compact heat exchangers providing:

- close temperature approaches (>2°C)
- very high thermal performance (i.e. 13.6MWth/m^3 sCO2 recuperator)
- high pressure capability (>1,000 Bar)
- widest range of temperatures (-196°C to 983°C)

Safe



Reduced operational risks

Using diffusion bonding with a fully welded construction, PCHEs:

- can operate at full differential pressure between streams
- are immune to flow induced vibrations and pressure fluctuations
- do not suffer from catastrophic failure mode
- have 30 years track record of safe operation and >3,000 exchangers supplied

Compact and Modular

Overall Project CAPEX saving

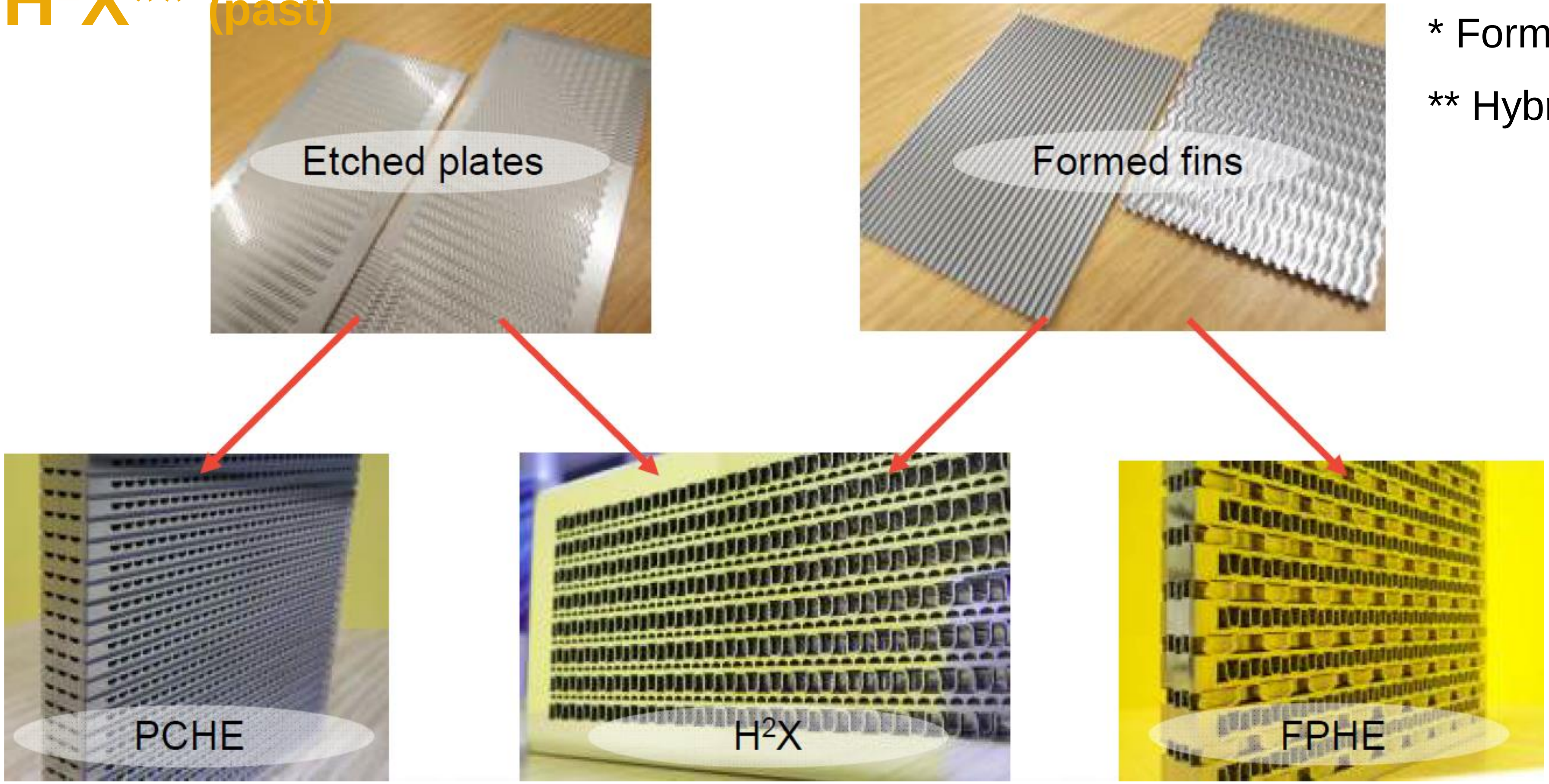
Heatric PCHEs are up to 85% smaller than Shell and Tube exchangers, offering:

- modularisation for ease of transport, on-site installation
- reduced foundation structure
- reduced pipework and safety valves
- retrofit capability in-lieu of S&T

Heatric products - Heatric PCHE (current), FPHE*, H²X** (past)

* Formed Plate Heat Exchanger

** Hybrid Heat Exchanger



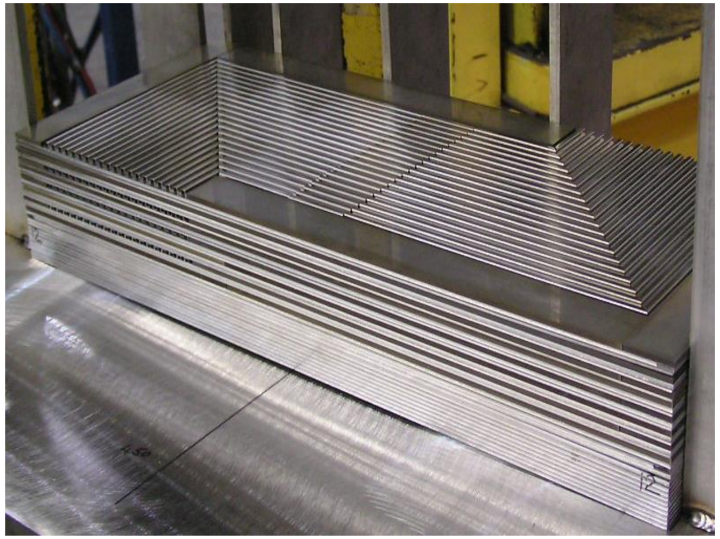
1980 2008 2006

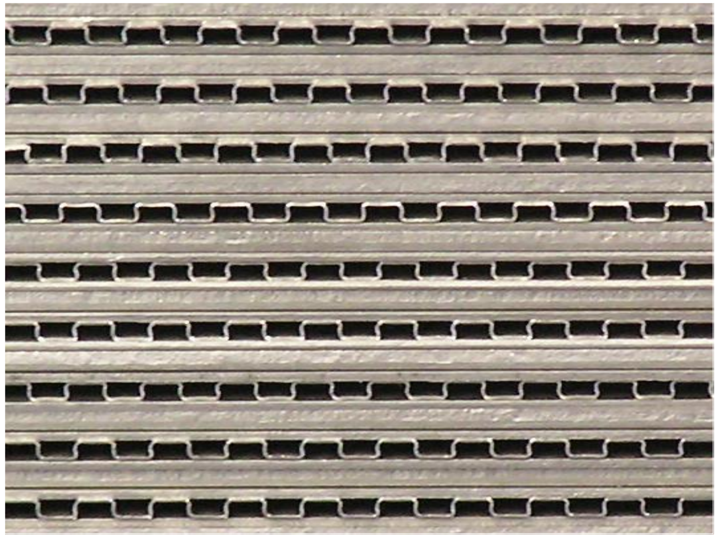
Etched channels vs. Fins

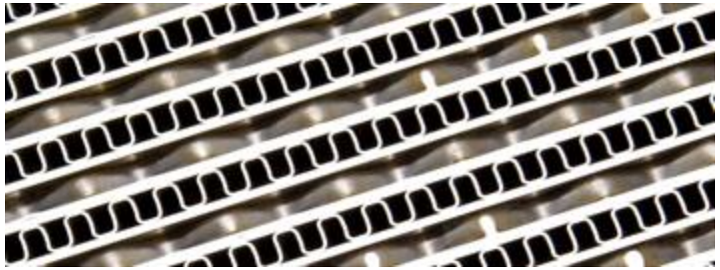
Photo chemically etched (PCHE)

- Etch depth – 0.5 to 1.2 mm*
- Can produce any type of flow paths
- All features in one operation
- Material etched thrown away
- Hard to etch materials may increase cost

*some sold PCHE used as small as 0.15mm and as large as 2.5mm etch depth







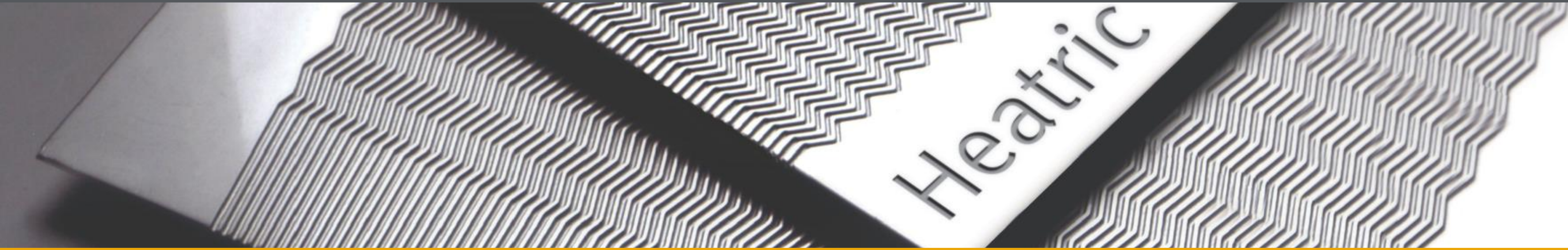
Formed (FPHE – H^2X)

- Fin height – 2, 3 and 4 mm
- Nearly no material wastage
- Can be made out of most materials
- One tool per fin geometry
- Need side and end bars, parting sheet
- More parts to make one sheet as fin pads small
- Jigsaw type construction

COST IMPACT

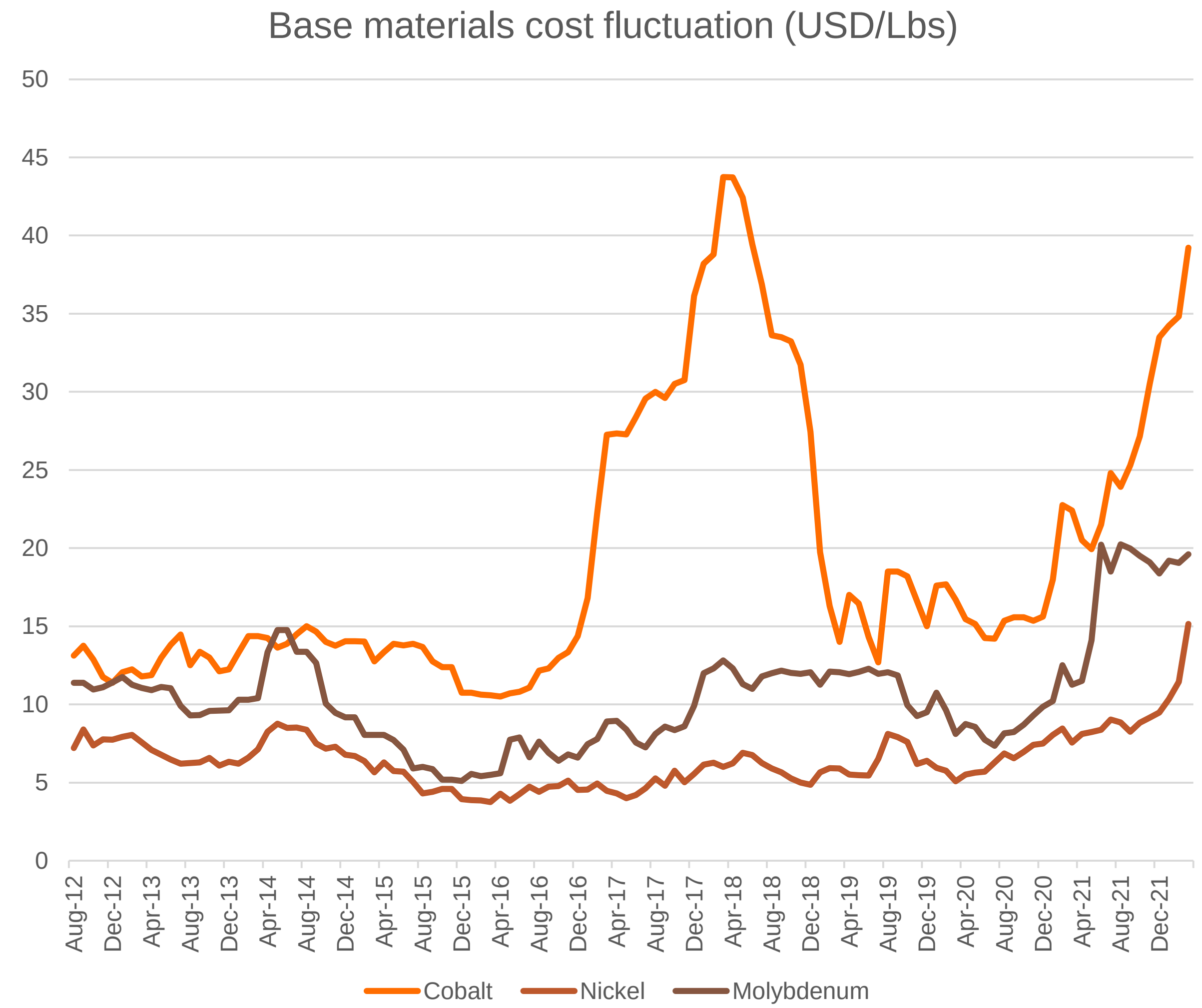
MATERIAL AND SUPPLY CHAIN

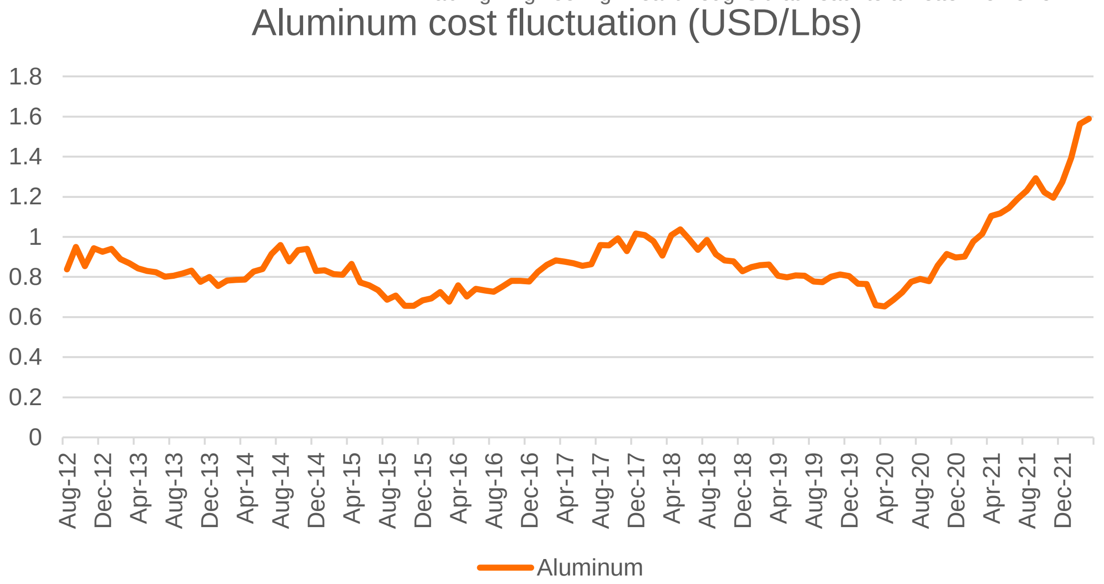
WHAT NEXT?

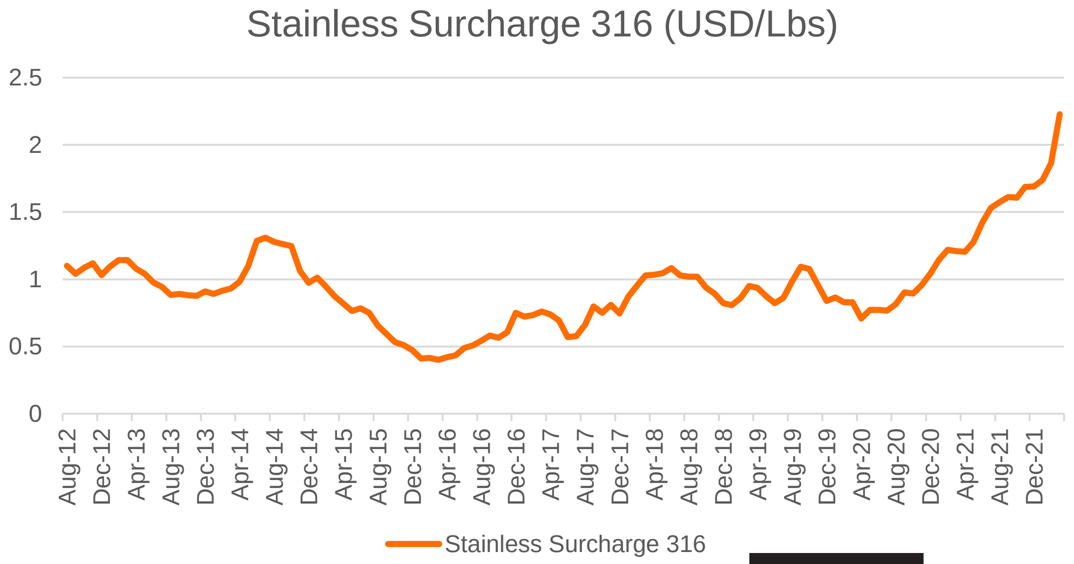


SUPPLY CHAIN

The reality and impact of costs







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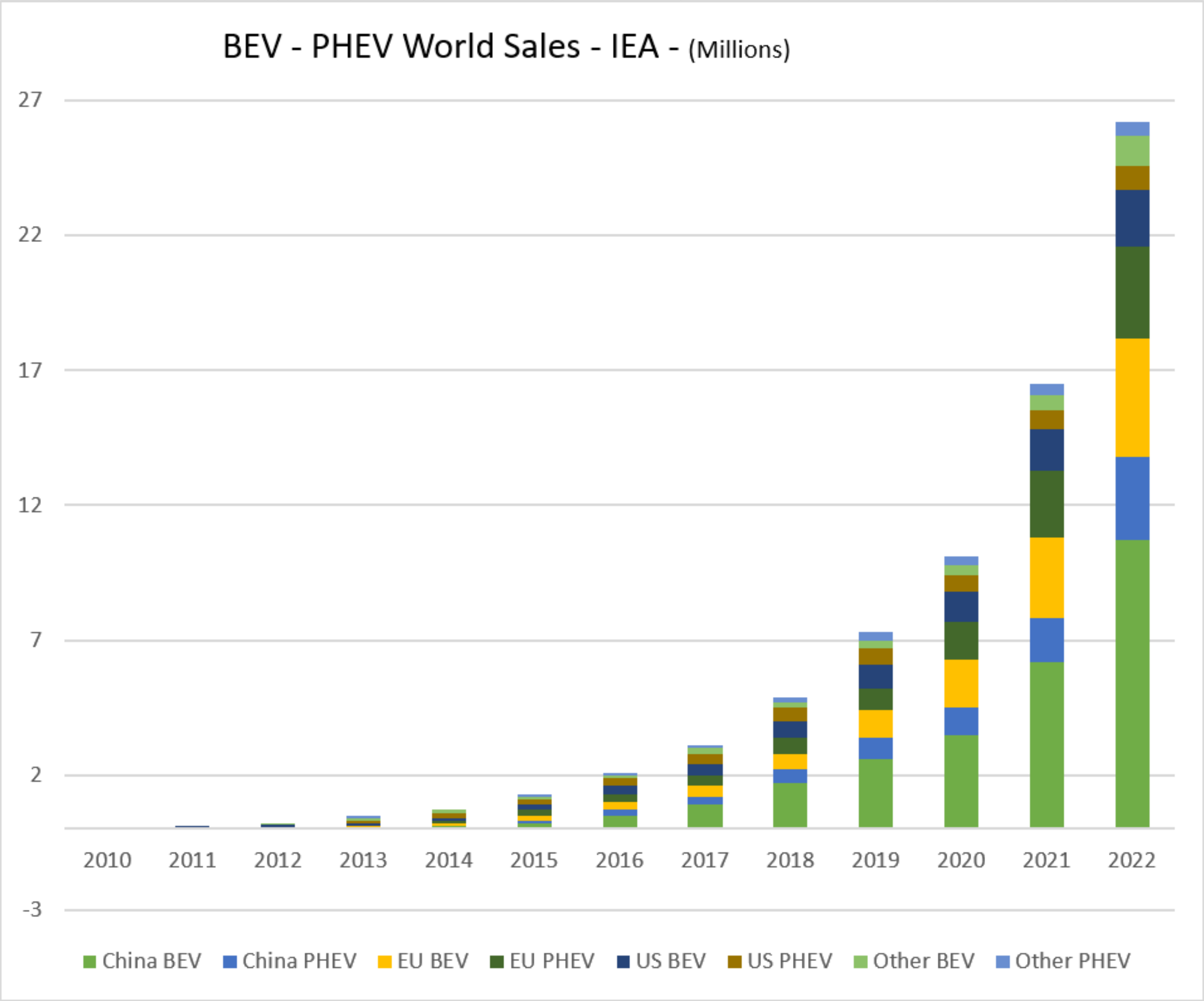
SUPPLY CHAIN

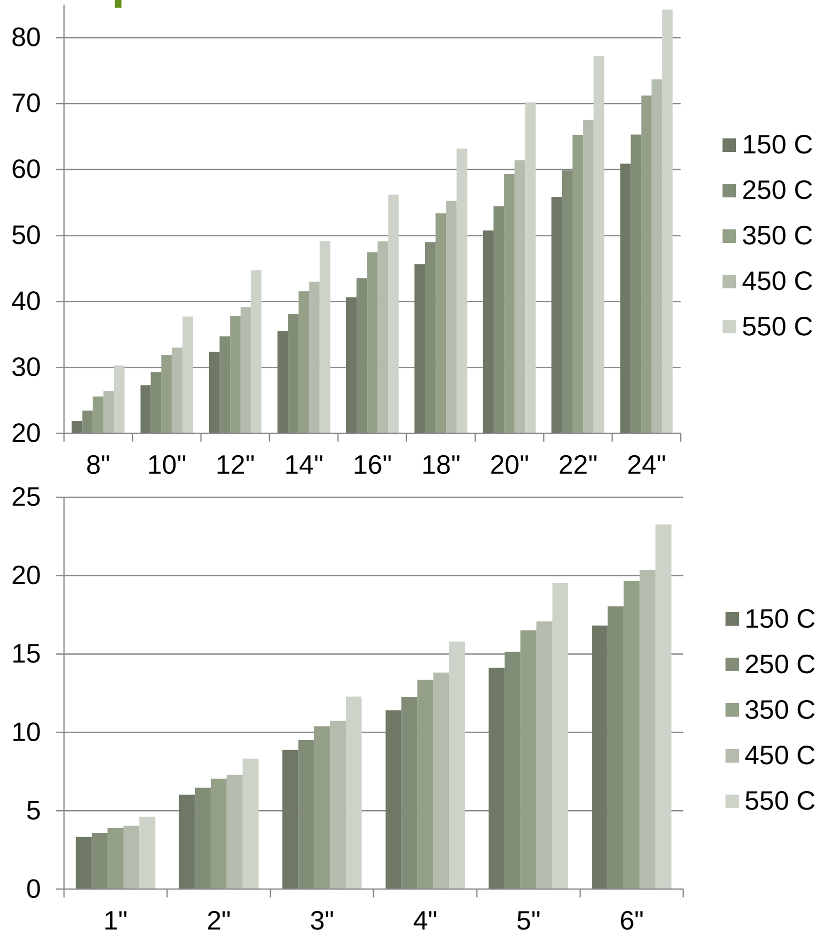
The reality and impact of costs



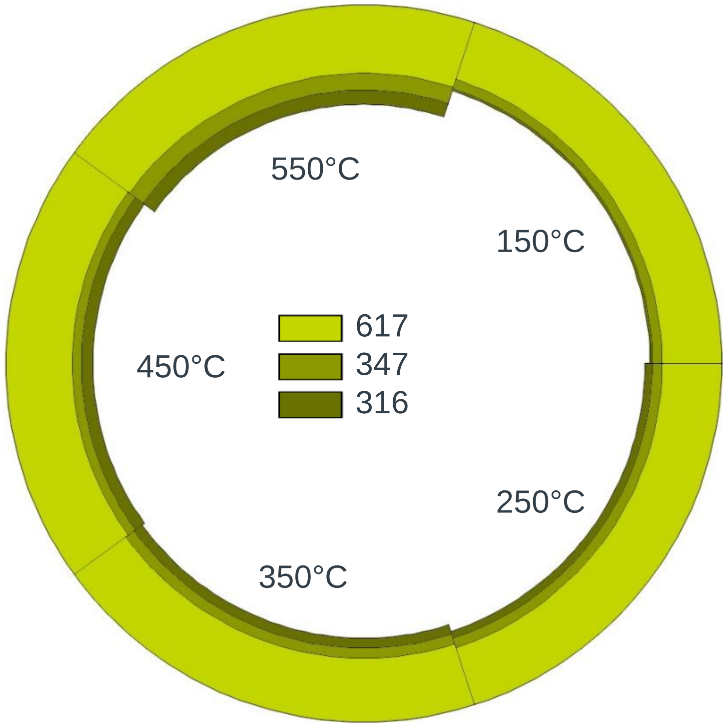
Mineral	Cell part	Average content in 66kWh battery [kg]	Content % of Total
Graphite	Anode	52	28,1 %
Aluminum	Cathode, case, current collectors	35	18,9 %
Nickel	Cathode	29	15,7 %
Copper	Current collectors	20	10,8 %
Steel	Case	20	10,8 %
Manganese	Cathode	10	5,4 %
Cobalt	Cathode	8	4,3 %
Lithium	Cathode	6	3,2 %
Iron	Cathode	5	2,7 %
Total		**185kg**	**100%**

SUPPLY CHAIN

Cheap to reduce overall CAPEX?

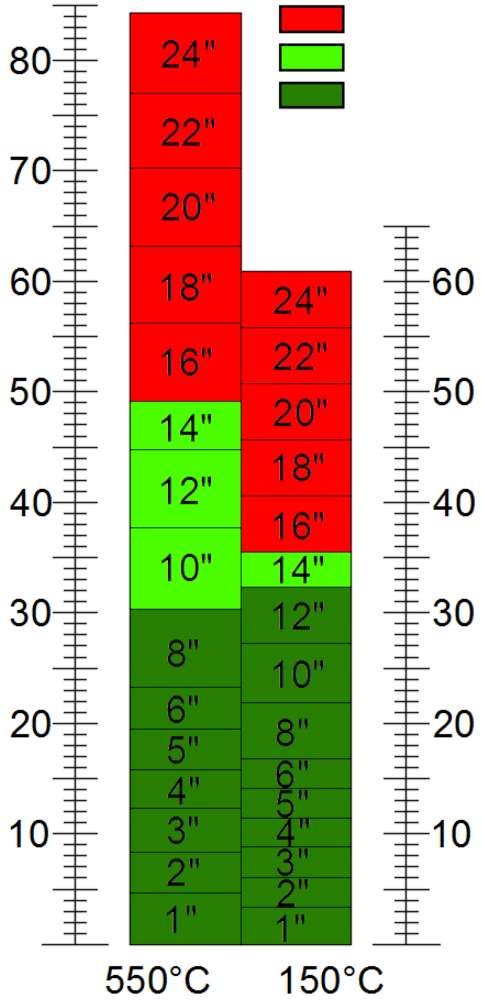


316 Pipe thicknesses vs. design temperature (250 Bar design pressure)



	150°C	250°C	350°C	450°C	550°C
316 vs 347	3%	9%	12%	13%	14%
316 vs 617	17%	22%	24%	23%	31%

316, 347, 617 Pipe thickness reduction vs. temperature (250 Bar pressure)



316 Pipe thickness vs. Std Pipe schedule (250 Bar pressure)

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What next?

How to ensure Energy Storage success

Supply Chain

Cost reduction
Product availability

Even in stainless steel, material price and product form availability can be a challenge; Supply chain must be engaged with to providing competitive materials in suitable product forms.

Standardisation

Process | Products
Performance

Standardization of the various Energy Storage processes where possible will lead to cheaper products, potential for off-the shelf with mass production and guaranteed performance based on proven existing supplies.

Thermal Energy Storage

Modularisation

Flexibility | Footprint
Plant integration| Deployment

Modularisation brings benefits in flexible designs with minimum changes, defined footprints facilitating plant integration and facilitation deployment even in remote area (i.e. containerized).

Close Collaboration with suppliers

Faster Cycle Optimisation
Better planning and deployment

As for any system design, trade-off between cycles efficiencies and components designs are necessary; to guarantee success collaboration at the earliest is needed.



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