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HEAT EXCHANGERS FOR THERMAL ENERGY STORAGE: A SYSTEMIC APPROACH

HEATRIC

Renaud Le Pierres - Sales & Business Development Team

August 2022

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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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Heatric Thermal Energy Storage Enquiries Timeline

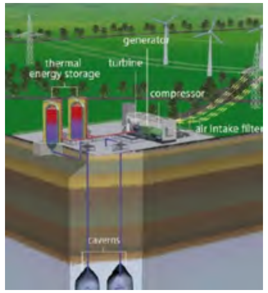
2009 - Present

2009

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

2011

FEED study for large scale CAES project in Germany



2012

FID study for TEES system in Switzerland

2013

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

2014

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

2019

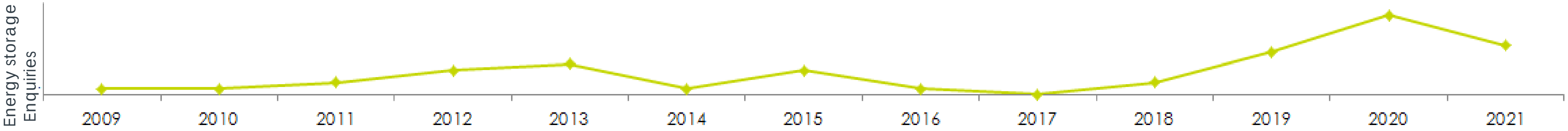
Energy Storage is back thanks to the Duck-Curve

2021

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

2022

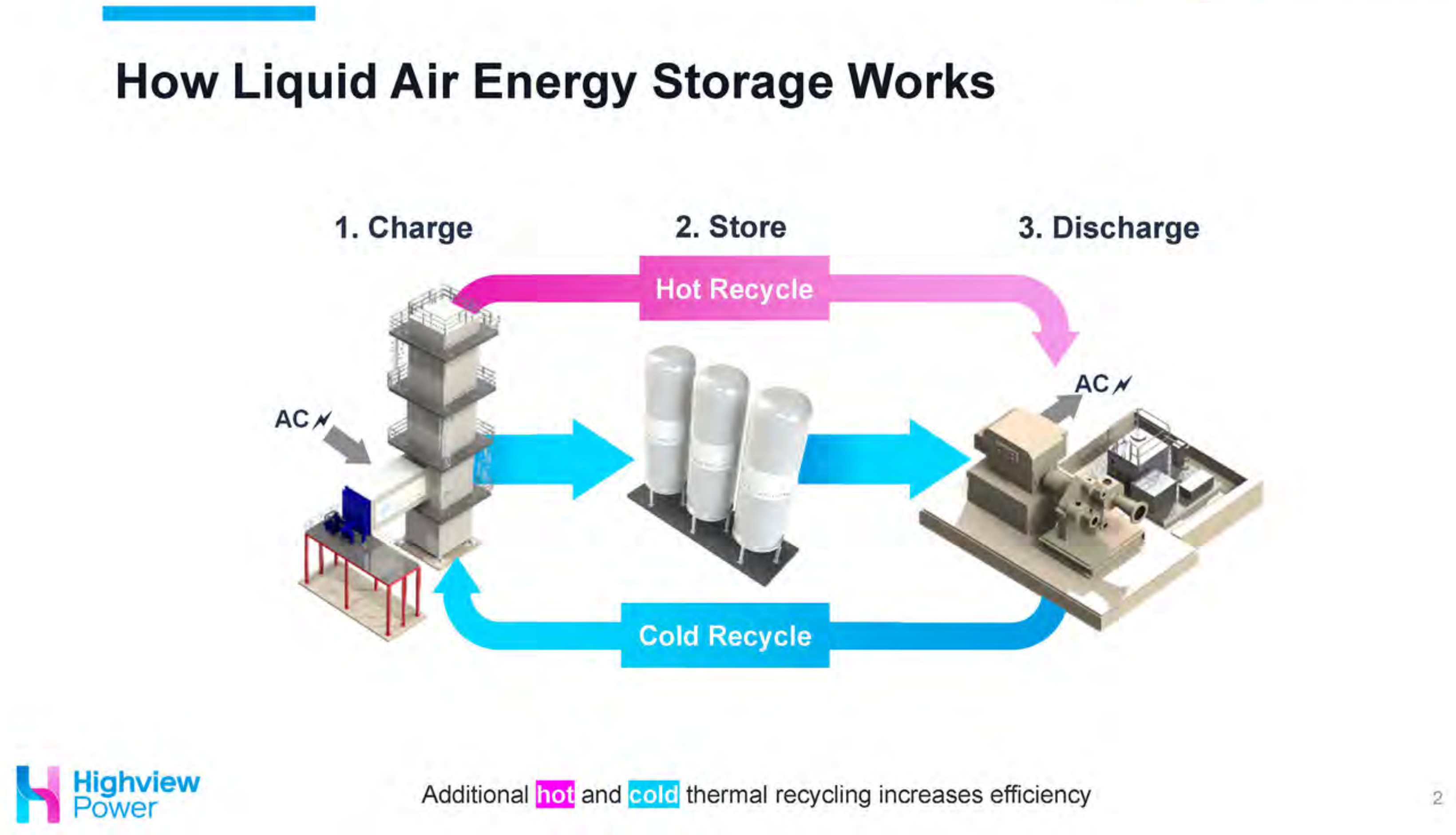
Several major projects in FEED – FID phase for 2023 build



CRYOGENIC STORAGE – HIGHVIEW POWER

Liquid Air Energy Storage (LAES)

LAES concept:

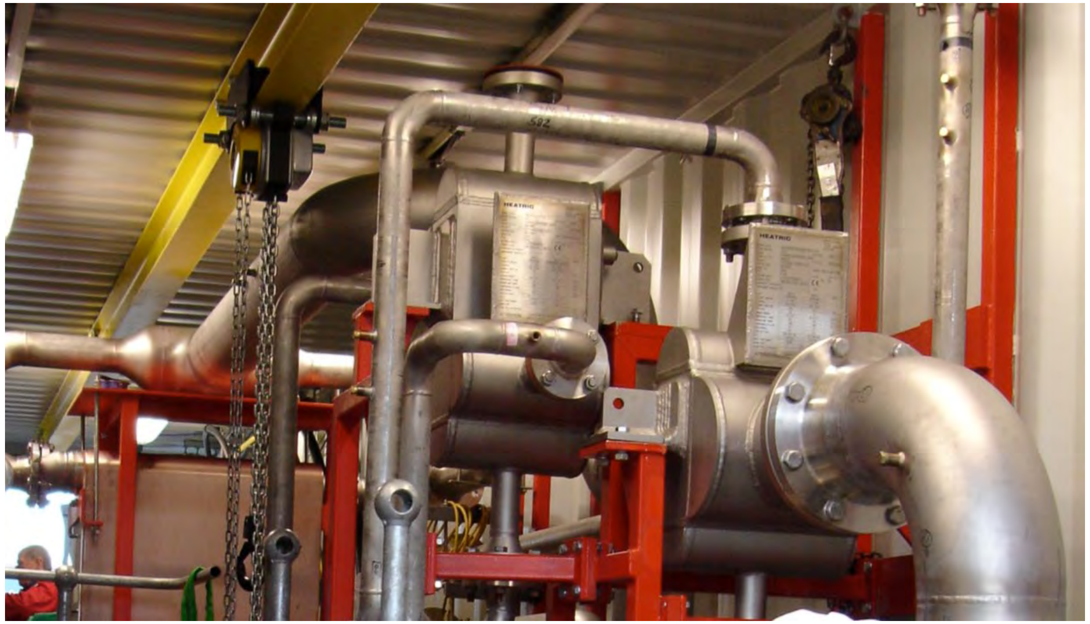


CRYOGENIC STORAGE – HIGHVIEW POWER

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

Electro Thermal Energy Storage (ETES)

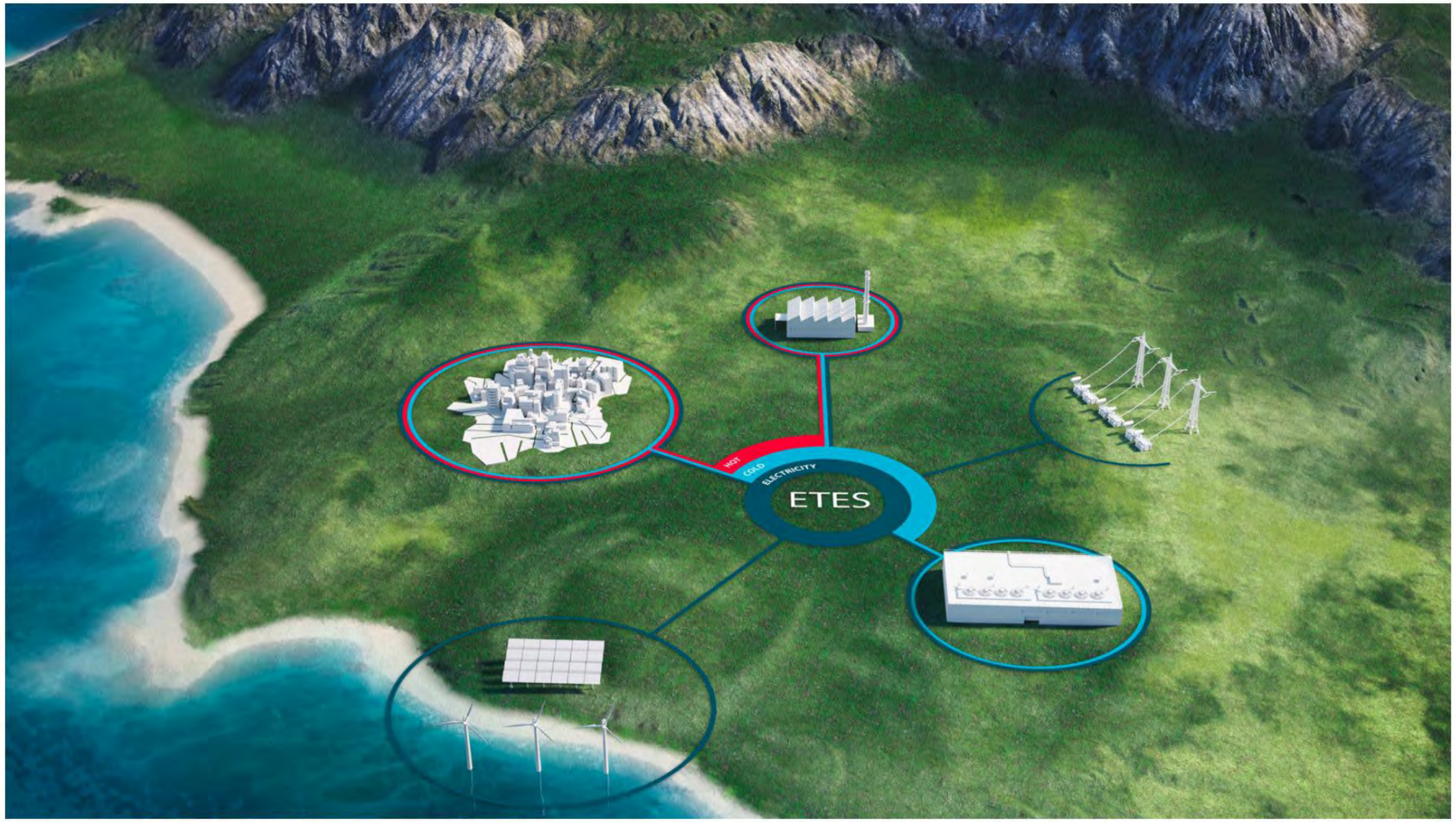
MAN Energy Solutions

ETES concept – flexible solution:

- ETES base: Utility-scale storage solution with 80% off the shelf components to make renewables baseload capable.

- ETES add: Upgrade fossil fuel power plant to hybrid power plant with additional revenue streams.

- ETES switch: Conversion of fossil fuel power plant to storage plant to provide second-life for power plant infrastructure.



sCO2 HEAT PUMP – MAN ENERGY SOLUTIONS

Commercial reality (ETES District Heating)

MAN Energy Solutions

Esbjerg Plant:

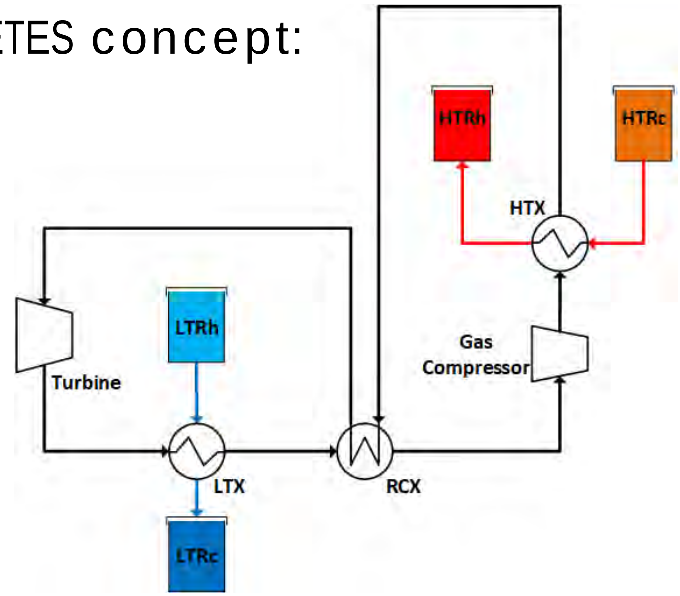
- Construction started H1 2021
- 2x 25MWth Heat Pumps
- 1st 25Mwth heat Pump successfully tested in Zurich Q2 2022 – 2nd in testing
- Operation planned H1 2023
- World first commercial plant for:
    - sCO2 Heat Pump
    - Core technology for ETES Energy Storage at scale
    - Clean District Heating technology

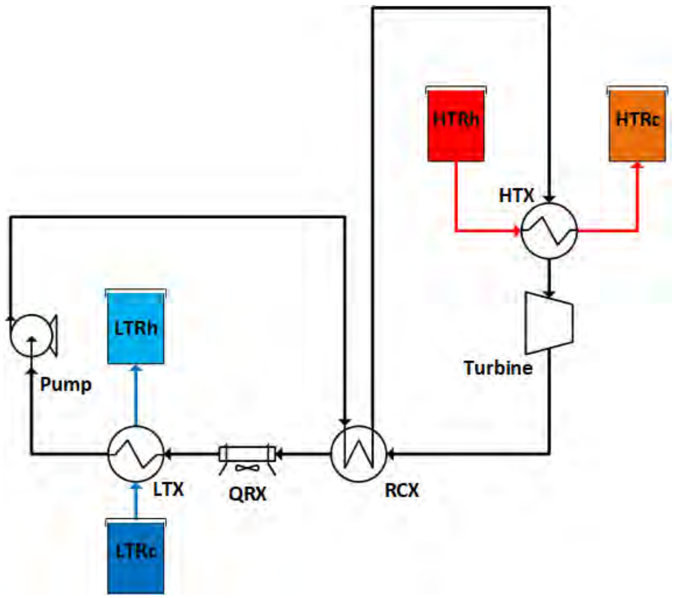
sCO2 SOLAR Storage – ECHOGEN POWER SYSTEMS

Electro Energy Storage (ETES)

ECHOGEN power systems

ETES concept:





Charging cycle

- Heat pump cycle
- Uses electrical power to move heat from a cold reservoir to a hot reservoir
- Creates stored energy as both "heat" and "cold"

Generating cycle

- Heat engine cycle
- Uses heat stored in hot reservoir to generate electrical power
- "Cold" energy improves performance of heat engine

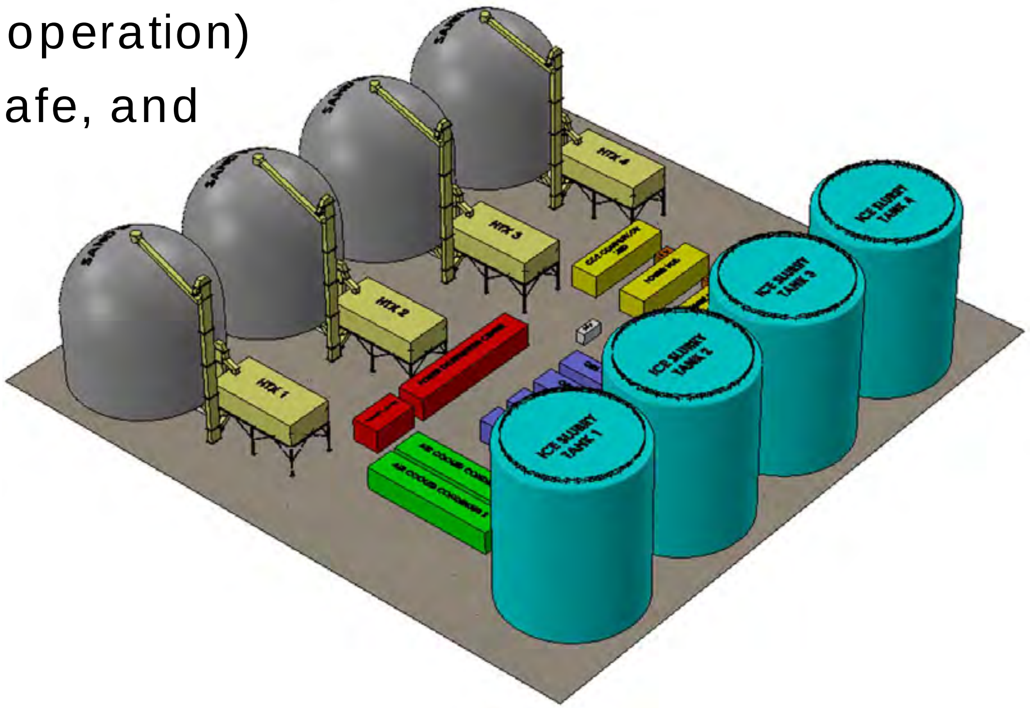
sCO2 SOLAR Storage – ECHOGEN POWER SYSTEMS

Building on the EPS 100 success

ECHOGEN power systems

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)

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MAINS

REQUIREMENTS

EXISTING SOLUTIONS?

SUPPLY CHAIN

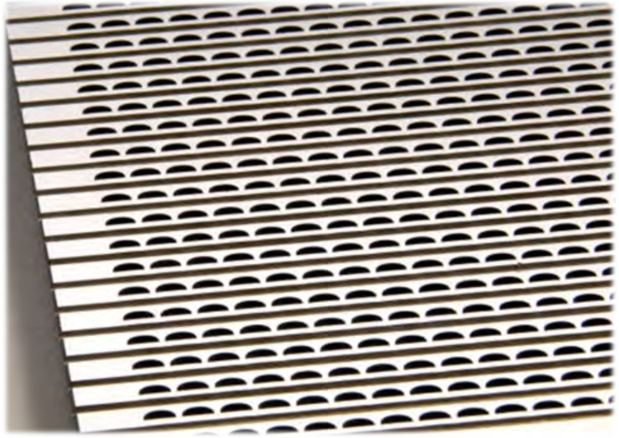
DEVELOPMENT NEEDS

Renaud Le Pierres - Sales & Business Development Team
August 2022

PCHEs Benefits for Energy Storage

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

Superior Performance

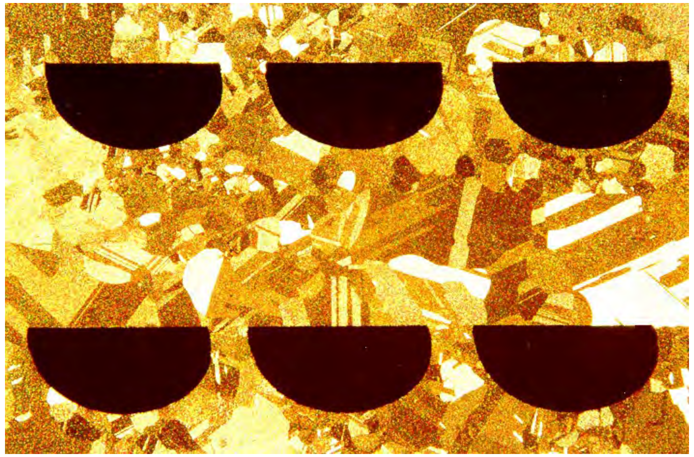


OPEX saving across wide range of processes

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

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
    5. Made in large size / quantities / modularised
    6. Cheap to reduce overall CAPEX

EXISTING SOLUTIONS?

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)

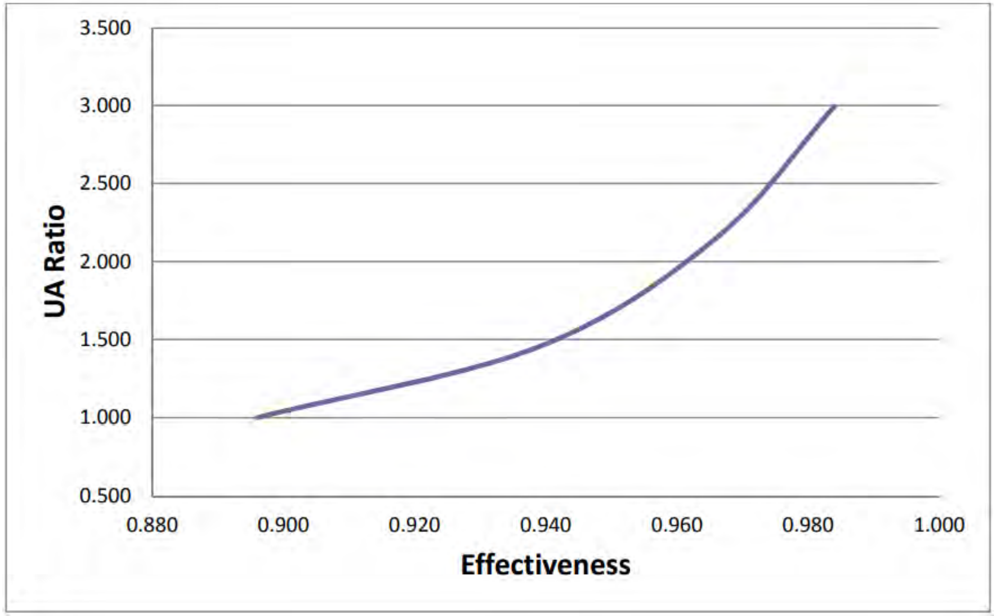
$$Effectiveness = 1 - \frac{\Delta T_{approach}^{*}}{T_{hot\ in} - T_{cold\ in}}$$

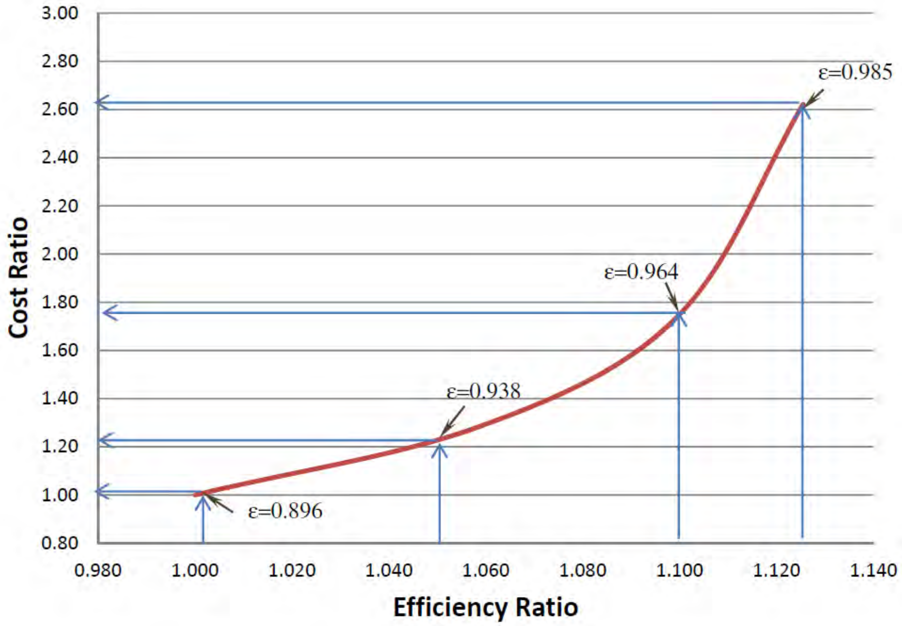
$$^{*}\Delta T_{approach} = Min[(T_{hot\ in} - T_{cold\ out}), (T_{hot\ out} - T_{cold\ in})]$$

UA is the amount of heat transfer area required where:

U = Overall heat transfer coefficient

A is heat transfer area





EXISTING SOLUTIONS?

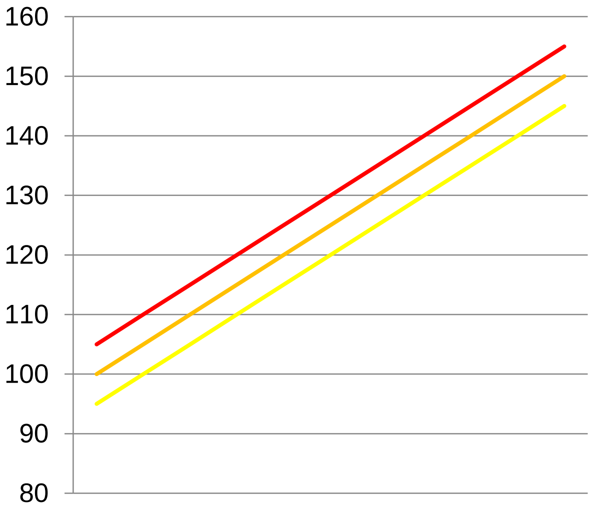
High Performance to maximise OPEX by increasing RTE (Round Trip Efficiency) / minimise losses

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

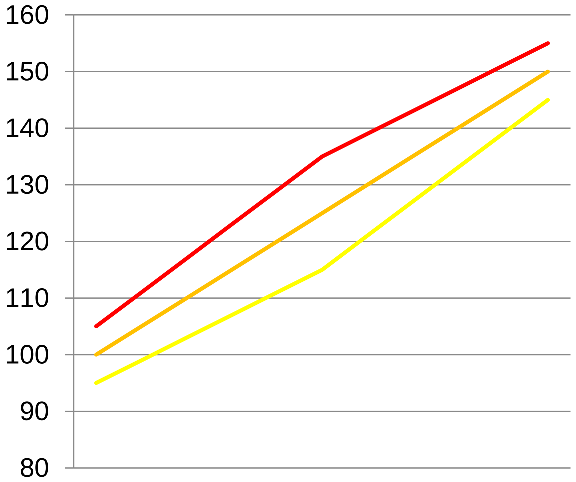
- Check reciprocity of the cycle (excessive losses between charge and discharge for given approach / underperformance due to process conditions)

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

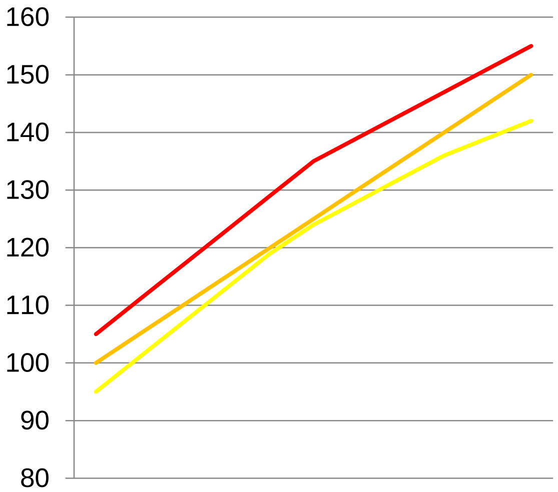
- / - charge
- / - discharge



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



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

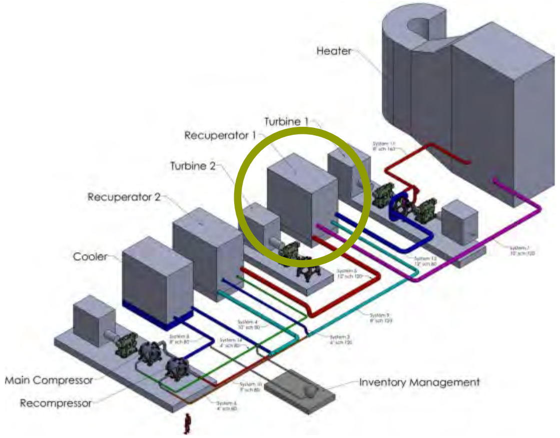


10° RTE Loss in non-straight heat release with 5° approach *

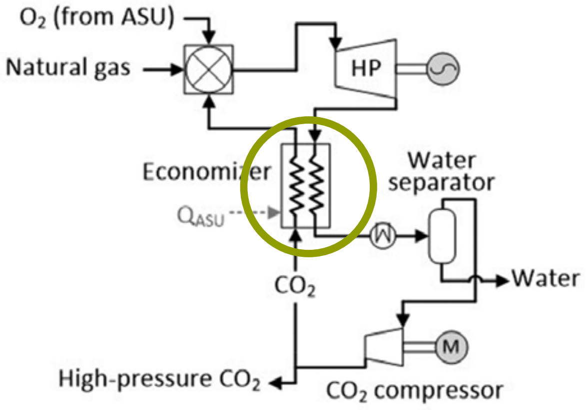
*note the large differences in temperature approaches in the 3rd case between charging and discharging and the implication on heat transfer area

EXISTING SOLUTIONS?

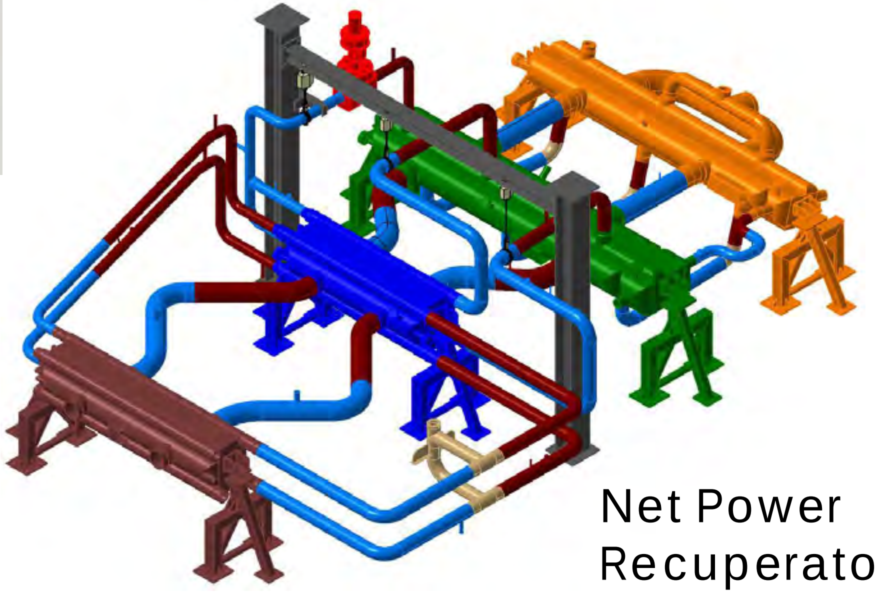
Heat exchangers are not always simple to design: the mechanical aspect



Standard PCHE



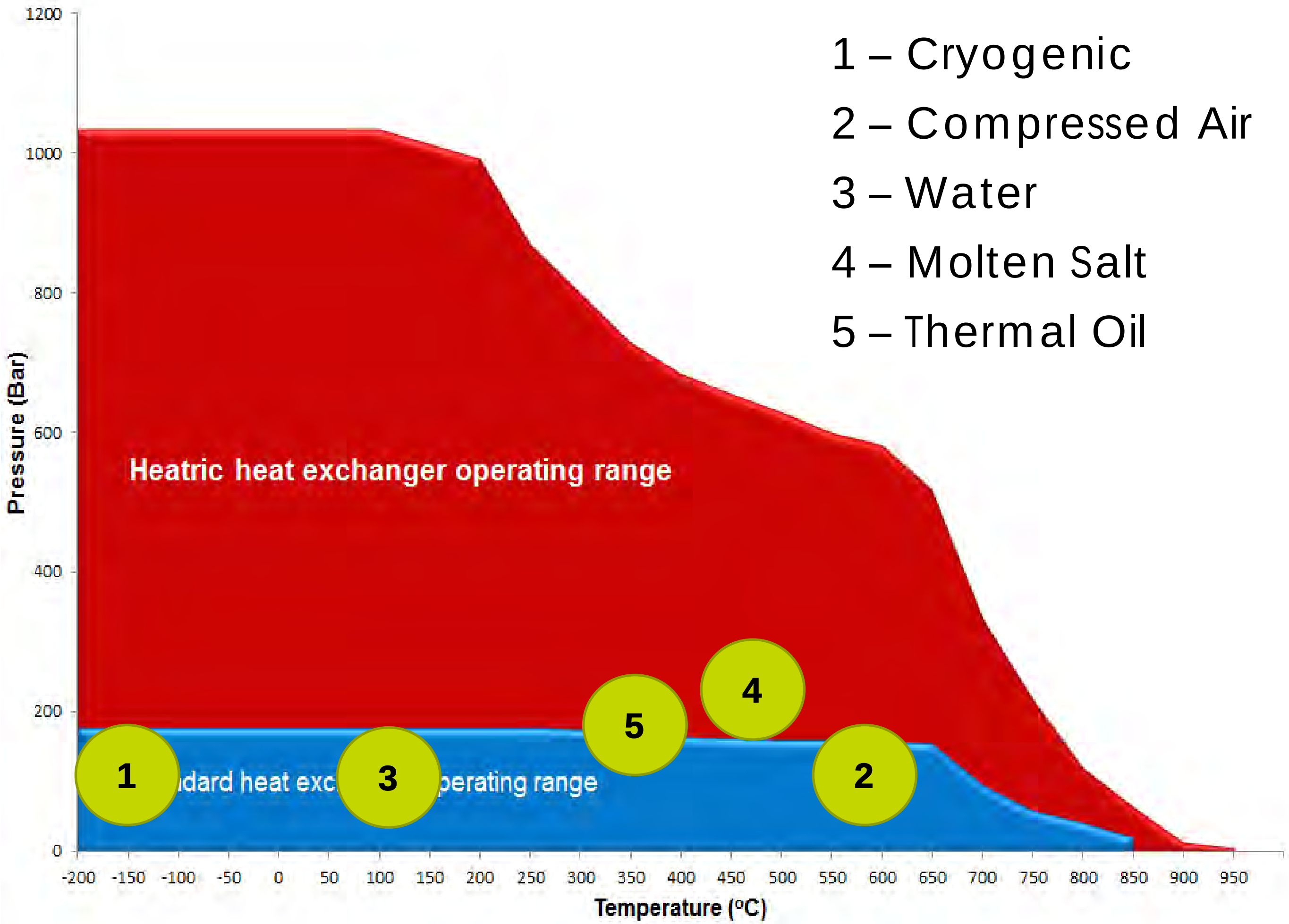
STEP High Temperature recuperator



Net Power Recuperator

EXISTING SOLUTIONS?

Robust, depending on cycles and / or storage medium – design range and material



1 – Cryogenic
2 – Compressed Air
3 – Water
4 – Molten Salt
5 – Thermal Oil

1 – SS316
2 – SS316
3 – SS316
4 – SS347
5 – SS316

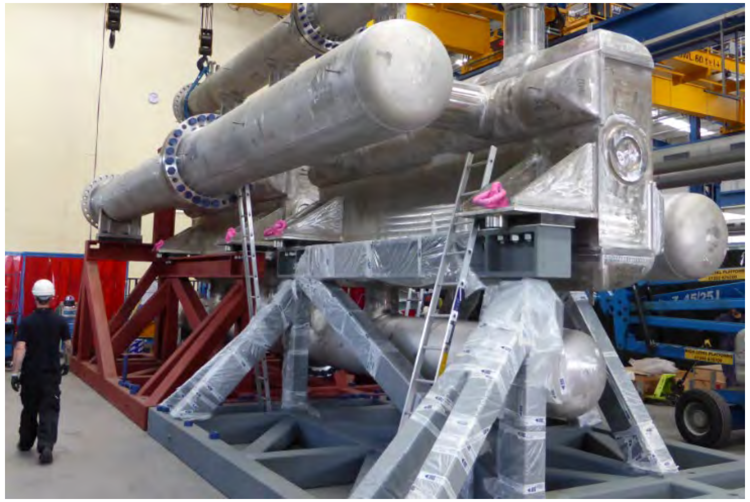
EXISTING SOLUTIONS?

Compact to facilitate integration into tight space / remote area / reduce installation cost
Fast Thermal Response to minimise start-up time to optimal operating conditions

Compact heat exchangers typically bring advantages both in terms of integration and in terms of cycle response compared to typical S&T exchangers:

- Reduced footprint making it easier to install in tight areas / retrofit (typically 3 to 4 times smaller)
- Lighter making it cheaper to transport / install and facilitating access to remote locations (typically 3 times lighter)
- Lower thermal mass facilitating faster response (as above)

However this point is especially important when considering the very large duties of such exchangers (10s MWth): compact does not mean small when requiring 1,000m² of heat transfer area.

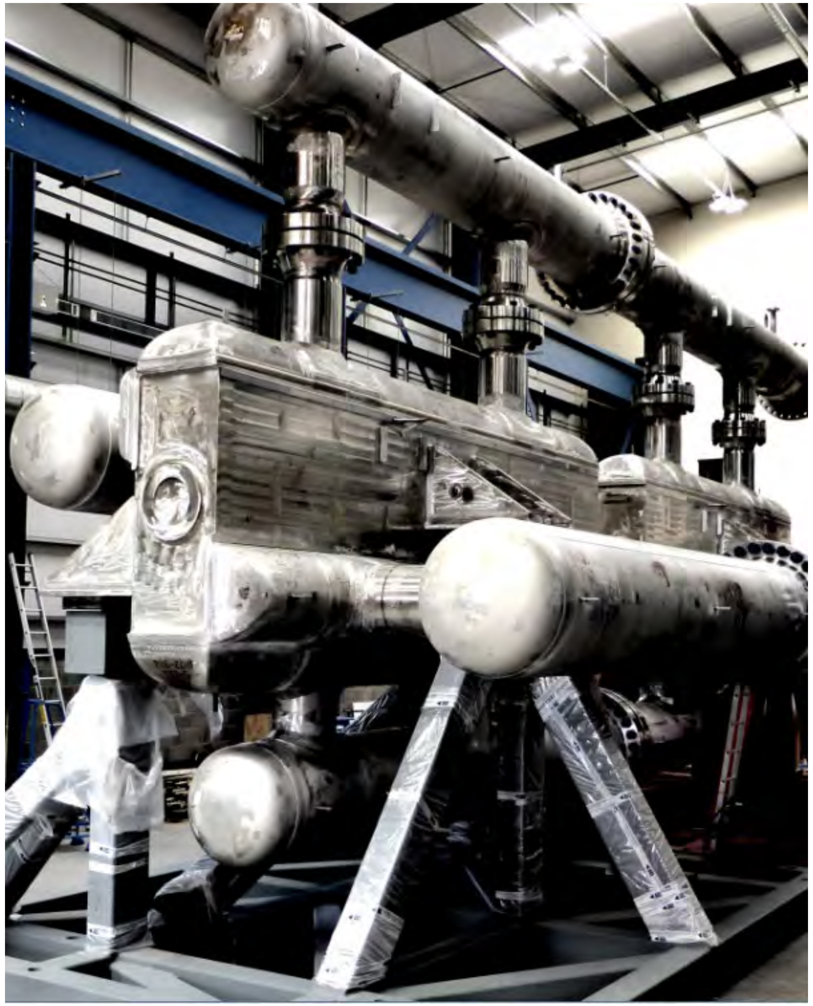


EXISTING SOLUTIONS?
Made in large size / quantities / modularised

Advantages of compact exchangers as described in previous slides are borne from the higher surface density per volume.

But even for compact exchangers long duration energy storage systems are requiring large duties which often exceed manufacturing capability in single units.

This can be addressed with optimising the design targeting individual duties to facilitate modular design



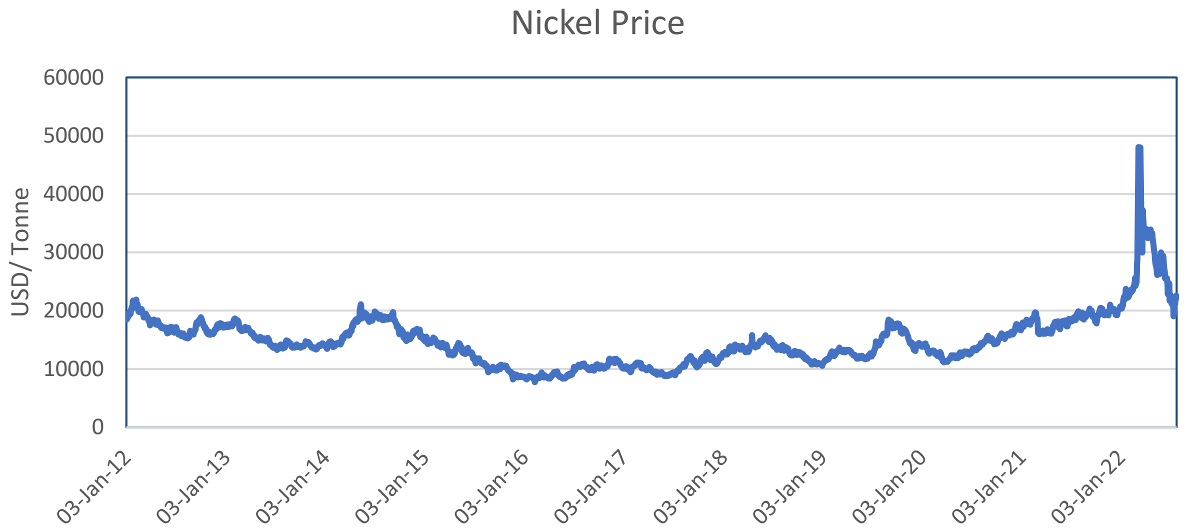
SUPPLY CHAIN

The reality and impact of costs (courtesy of PCC Metals Group)

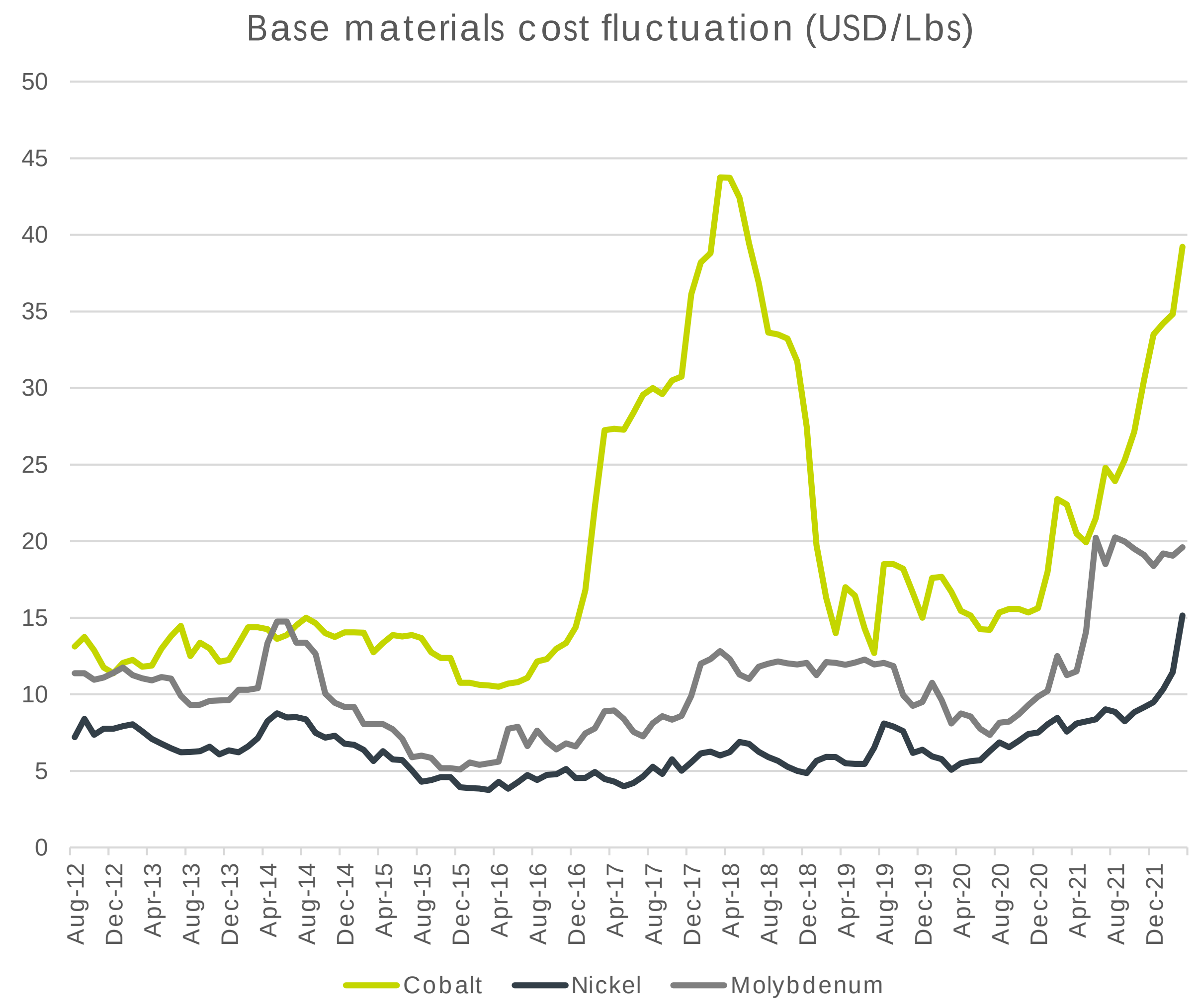
	Ni %	Mo %	Co %	Cost Ratio 2012-21	Cost Ratio 2022 1H	ASME Allowable Stress ratio (550C)	Cost Factor (550C)	ASME Allowable Stress Ratio (700C)	Cost Factor (700C)
316L	11	2	0	1	1	0.95	0.95	N/A	N/A
347	10	2	0	1.2	1.2	1.0	1.2	1.0	1.2
617	52	9	12	5	6	0.70	4.2	0.66	2.77
740H	50	0.5	20	5.5	7	0.36	2.52	0.24	0.60

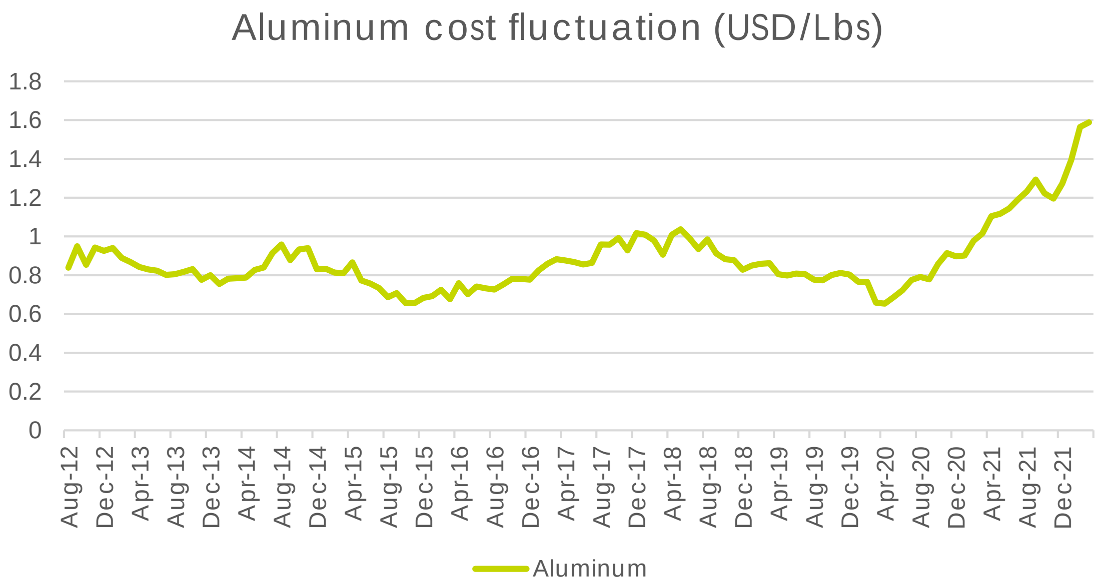
Nickel Historical average $14,100/T
Nickel Average price 2022 1H $28,500/T
Nickel Average price July 2022 $21,465/T

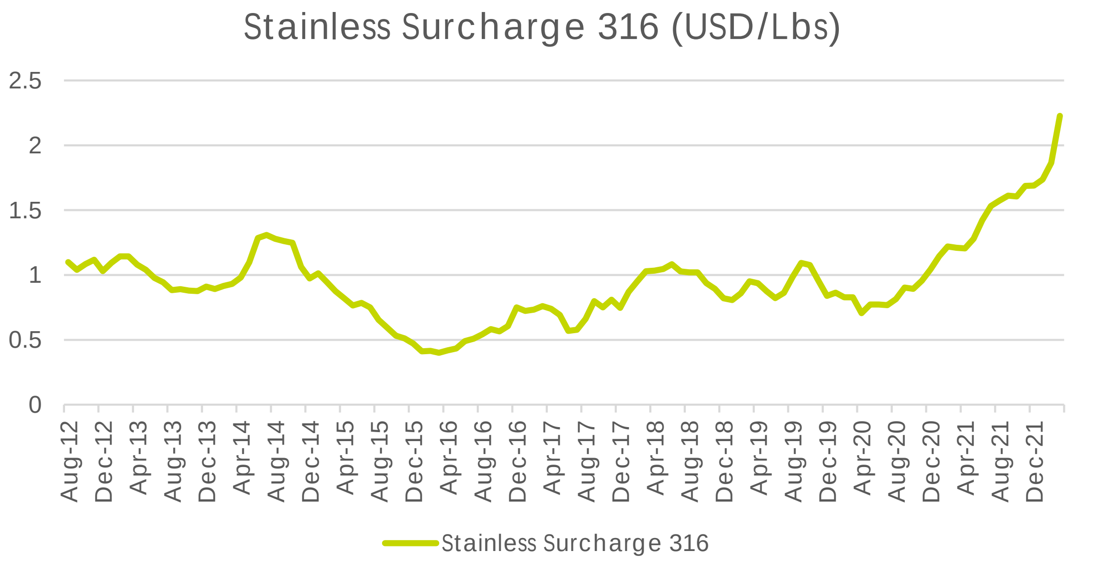
Quantity extras – Flat Products – Nickel alloys
2,000kgs – 20%
20,000kgs – 0%



SUPPLY CHAIN
The reality and impact of costs

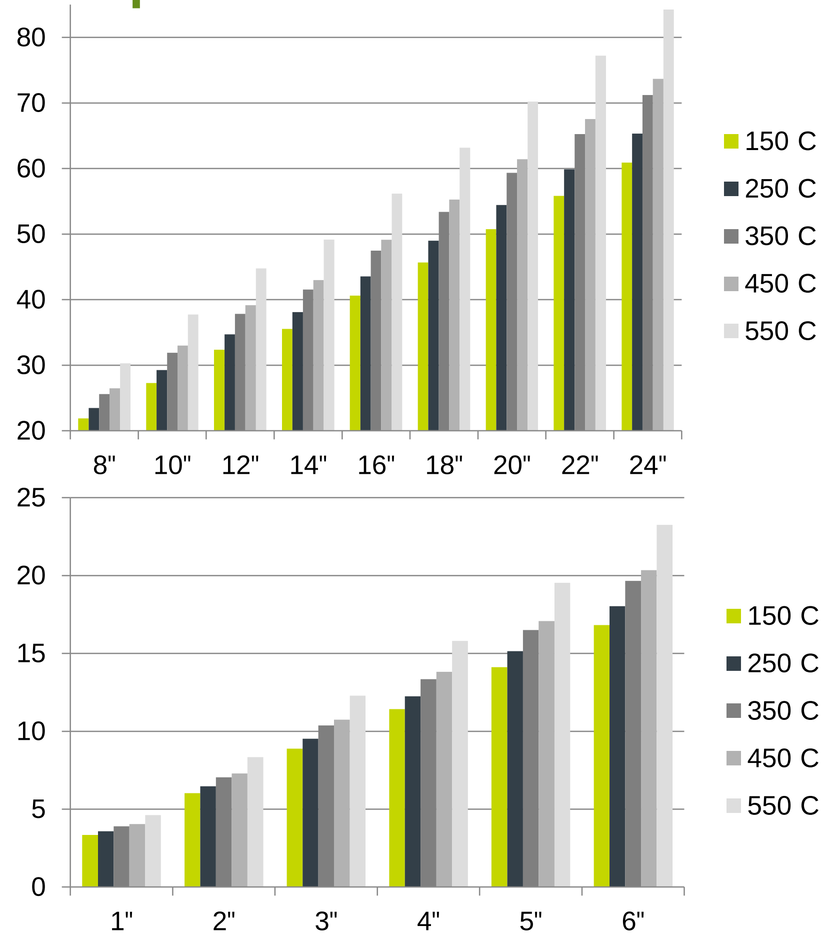




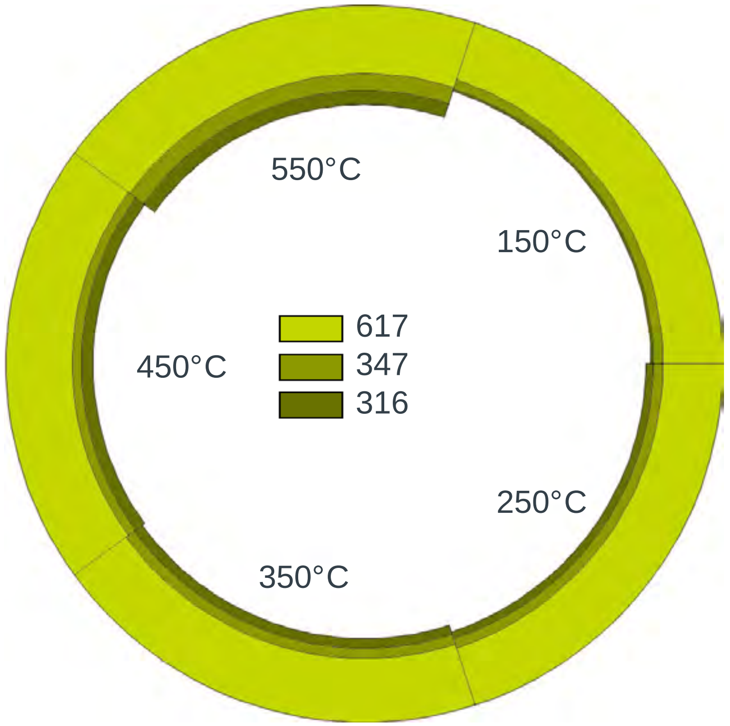


SUPPLY CHAIN

Cheap to reduce overall CAPEX?

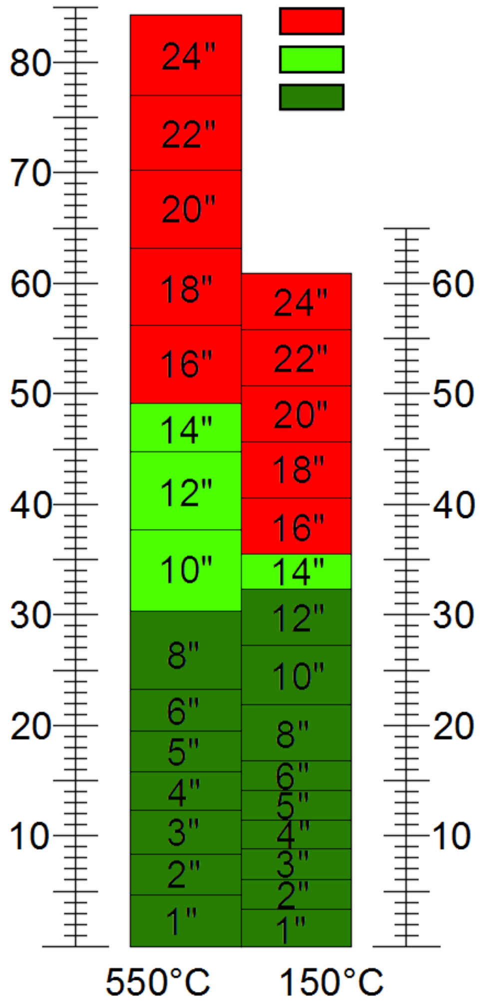


316 Pipe thicknesses vs. design temperature (250 Bar design pressure)



	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)

DEVELOPMENT NEED?

The ideal exchanger ...? Certainly more to do

In the same manner various energy storage systems answers various customers requirements, but as seen during last year TMCES not all of them, Compact heat exchangers provide many benefits to long term energy storage, but more is needed as far as PCHEs are about for the cycles more suited to such technology:

- Any corrosion allowance negates the benefits of compact exchangers and material of construction have a great impact on cost (supply chain engagement)

- Small channels have limitation when dealing with specific thermal storage medium (larger channel designs)

- Some system requires very large thermal duties thus larger compact exchangers than currently existing to reduce overly complex pipework to interconnect too many units adding (develop larger blocks)

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2022'S VIEW?

HEATRIC'S OVERALL ENERGY STORAGE VIEW TO DATE

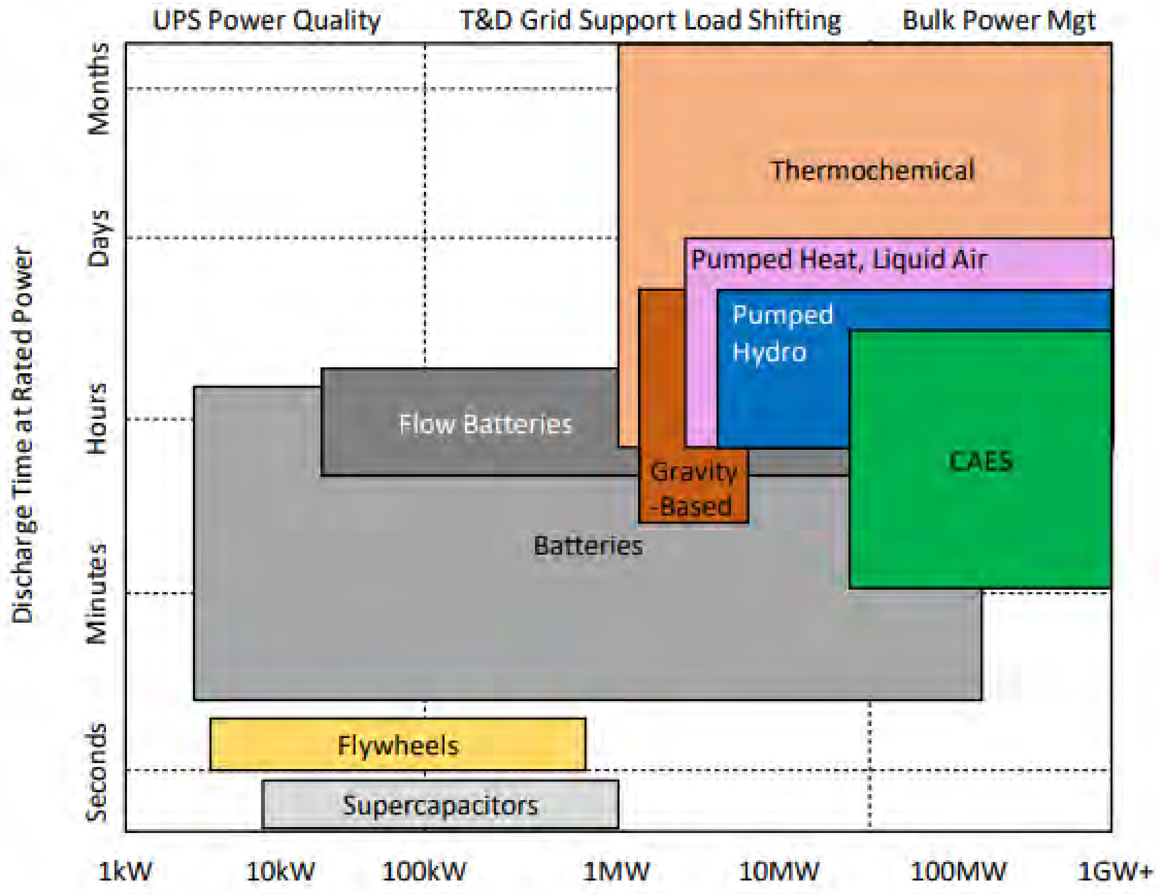
WHAT NEXT?

Tony Bowdery - Sales & Business Development Team
July 2020

HEATRIC's OVERALL ENERGY STORAGE VIEW TO DATE

Exciting opportunities but too many cycles to chose from?

- Latest investigation by ASME Turbo Expo Energy storage committee 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 and MAN ES
- 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

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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