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HEAT EXCHANGERS FOR THERMAL ENERGY STORAGE: CHALLENGES AND MITIGATION

HEATRIC'S

FOOD FOR THOUGHT...

Tony Bowdery & Renaud Le Pierres - Business Development Team
August 2021

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APPETIZERS

- HEATRIC'S INVOLVEMENT WITH ENERGY STORAGE TO DATE

- SELECTED COMMERCIAL & NEAR COMMERCIAL CONCEPTS
    - CRYOGENIC STORAGE
    - sCO_2 HEAT PUMPS

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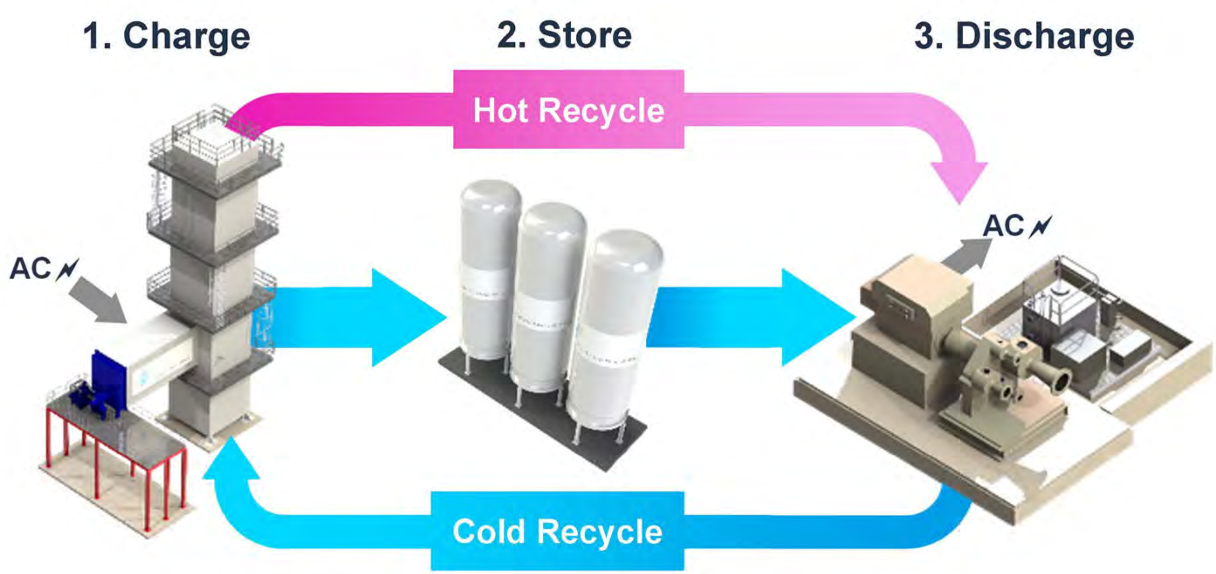
CRYOGENIC STORAGE – HIGHVIEW POWER

Liquid Air Energy Storage (LAES)

Concept: **How Liquid Air Energy Storage Works**



Additional hot and cold thermal recycling increases efficiency

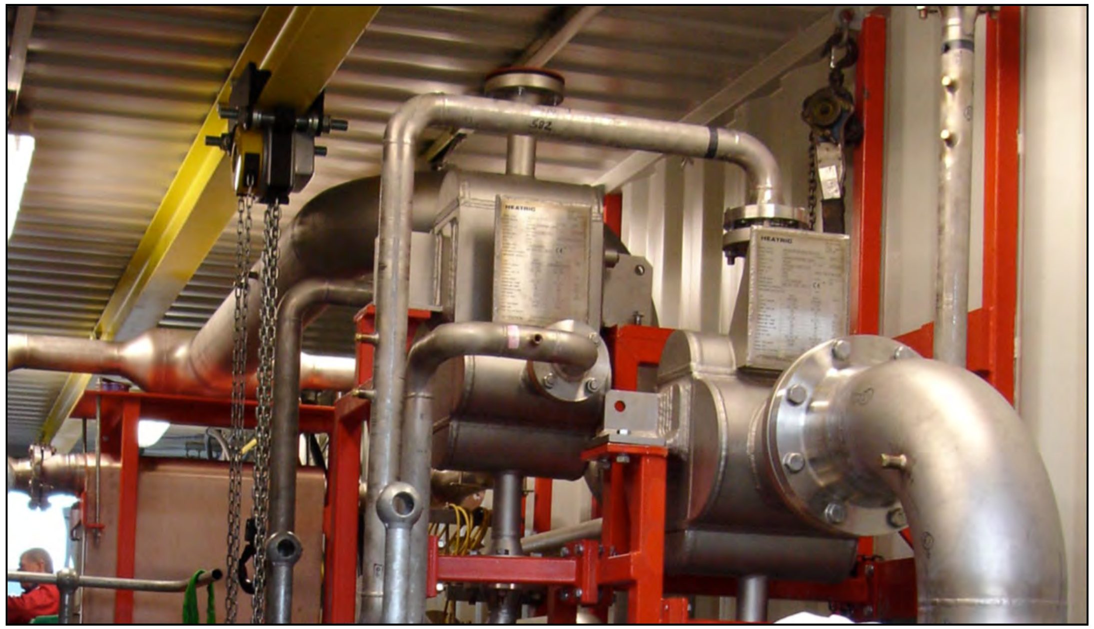
CRYOGENIC STORAGE – HIGHVIEW POWER

2009 – 2019: Proving and Validating the Technology

Highview Power®

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

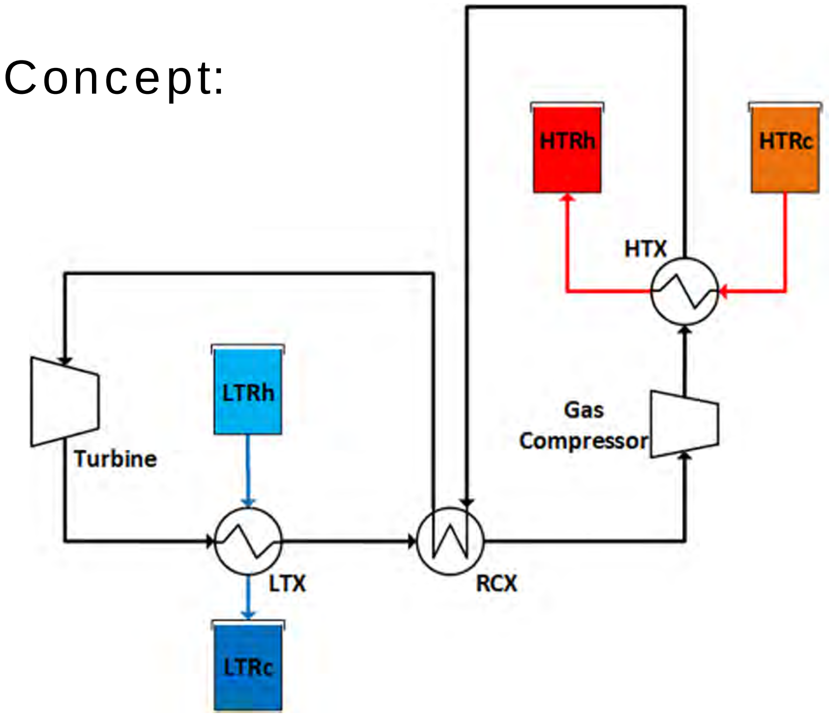
- Demonstration plant successfully operated until site closure 2019
- 2 exchangers supplied

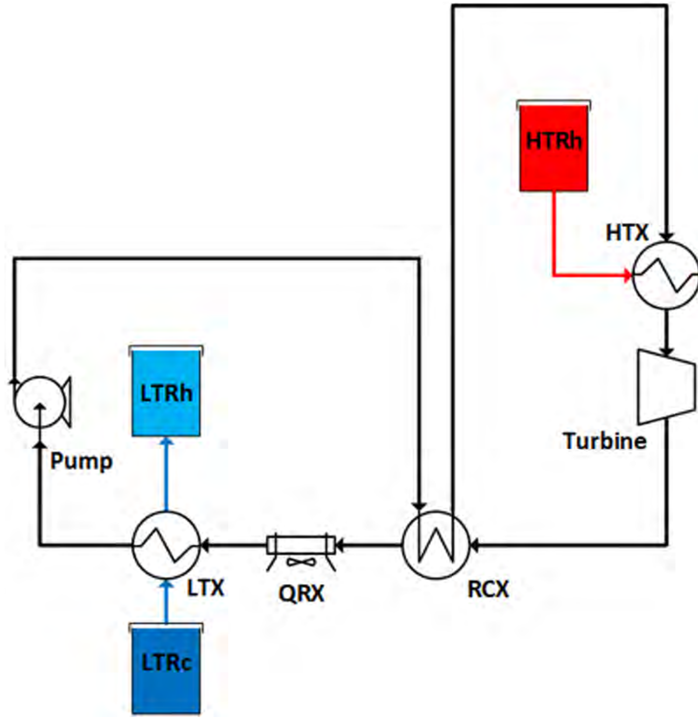
Bury demo site Evaporator and HX1 (front)

sCO_2 HEAT PUMP – ECHOGEN POWER SYSTEMS

Pumped Thermal Energy Storage

Concept:





Storage Charging Cycle (Heat pump)

- Electrical power from renewables is used to:
- Reduce the temperature of a Cold reservoir and
- Increase the temperature of a Hot reservoir
- Thermal energy then stored as both “heat” and “cold”

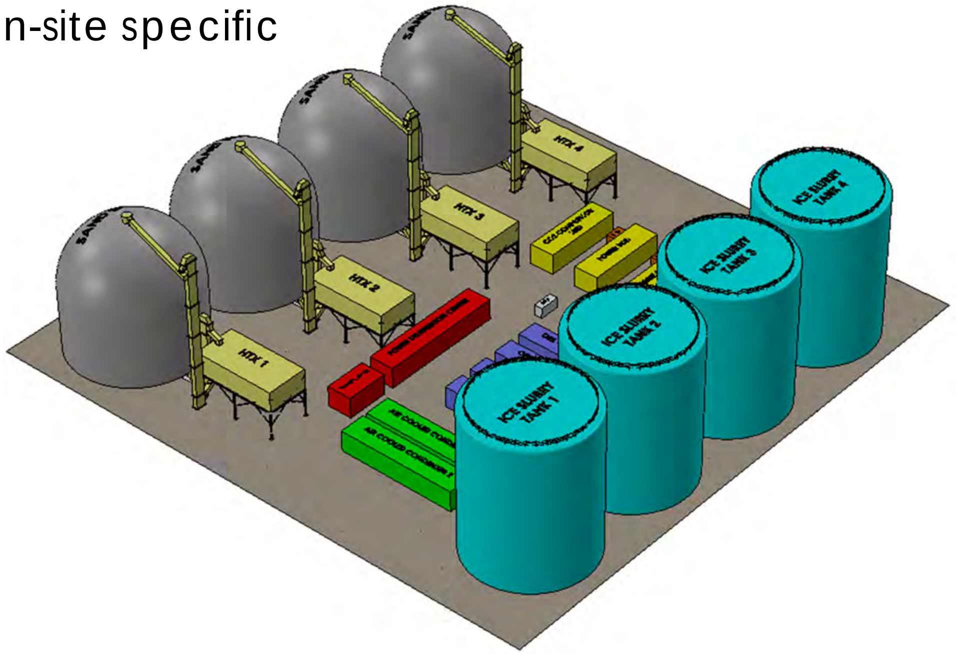
Power Generating Cycle (Heat engine)

- Stored thermal energy is converted back to electricity
- Using proven CO_2 power cycle
- Taking heat from the Hot reservoir
- “Cold” energy to improve heat engine performance

sCO_2 HEAT PUMP – ECHOGEN POWER SYSTEMS

Building on EPS-100 success

- Long duration energy storage(>4-6 hours)
- Using proven EPS-100 technology
- Low-cost, safe, environmentally-benign materials
- Sand or concrete for hot reservoir
- Ice slurry for cold reservoir
- Non-site specific



PCHEs for EPS-100 (2011)

EPS-100 skid (8 MWe)

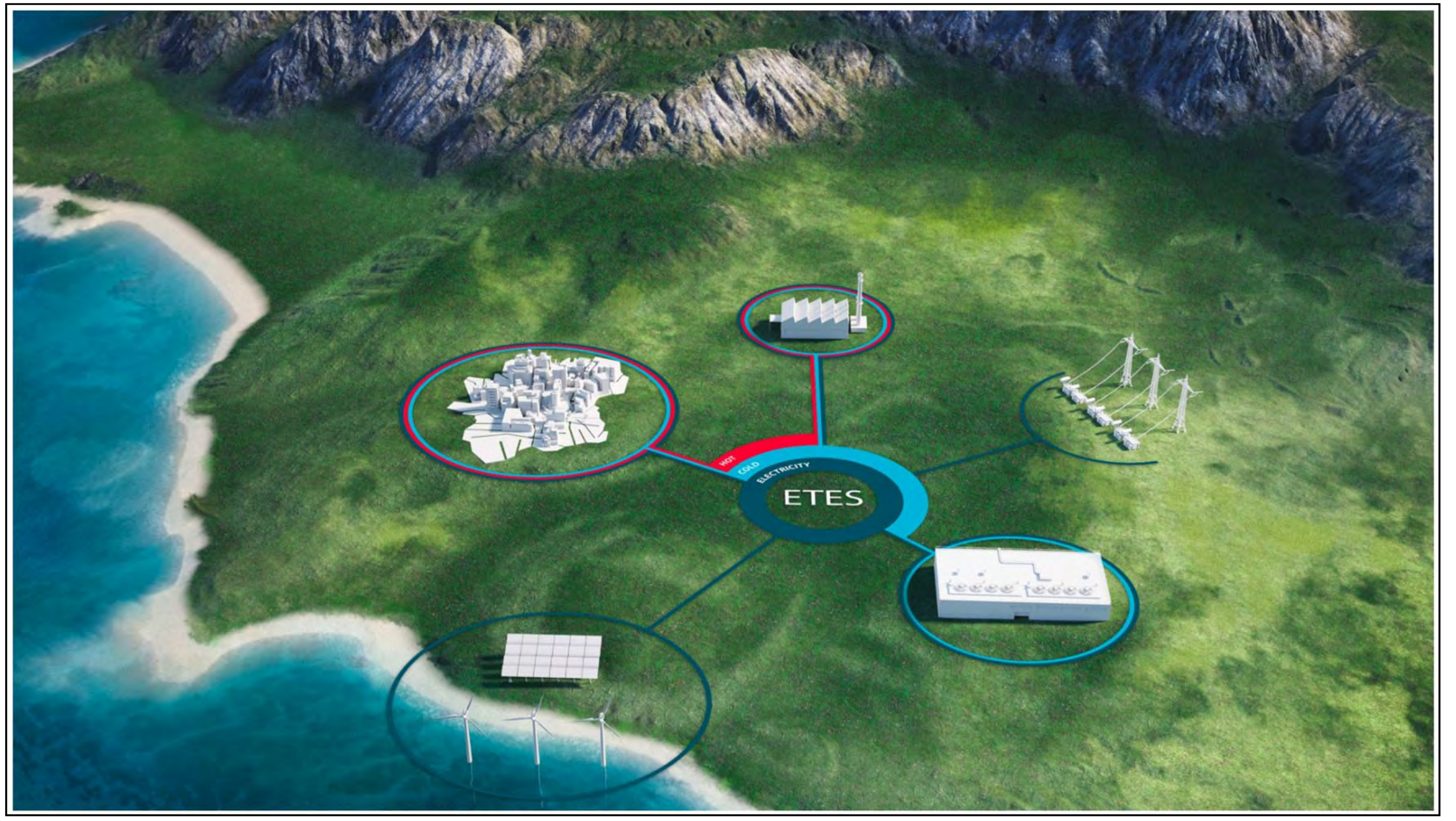
sCO_2 HEAT PUMP – MAN ENERGY SOLUTIONS

Electro Thermal Energy Storage (ETES)

MAN Energy Solutions

ETES concept – flexible solution:

- **ETES Heatpump:** High temperature, industrial-scale heat pump powered by renewable electricity (100% off-the-shelf components)
- **ETES Light:** ETES Heatpump plus thermal storage - hot &/or cold (100% off-the-shelf components)
- **ETES Tri-generation:** ETES Light plus re-electrification process to generate heat, cold and power in a single system (80% off-the-shelf components)



sCO_2 HEAT PUMP – MAN ENERGY SOLUTIONS

Commercial reality (ETES District Heating)

MAN Energy Solutions

Esbjerg Plant, Denmark:

- First commercial-scale ETES system
- Construction started H1 2021
- Operation planned H2 2022
- Clean district heating, 50 MW capacity
- Replacing coal-fired co-gen plant
- Power from local wind farms plus seawater as a heat source
- MAN HOFIM compressors / expanders
- Heatric PCHEs in the heat pump system
- Allowing thermal transfer between CO_2 loop and district heating network

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MAIN COURSES

- HEAT EXCHANGER REQUIREMENTS FOR THERMAL ENERGY STORAGE
- PCHE TECHNOLOGY OVERVIEW
- EXISTING SOLUTIONS AND DESIGN CHALLENGES

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HEAT EXCHANGERS FOR THERMAL ENERGY STORAGE

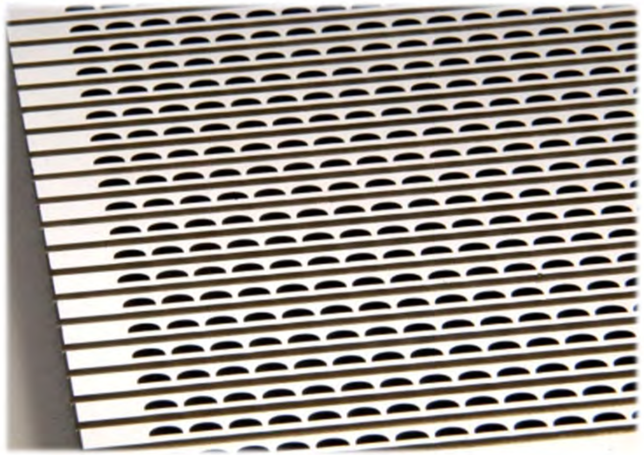
The ideal heat exchanger... What are the requirements?

- Big increase in exchanger enquiries for Long Duration, High Capacity energy storage (10's/100's MWhrs)
- Such exchangers require 1,000's m² of heat transfer area plus many (if not all) of the following:
  1. **High Performance** to minimise OPEX by increasing RTE (Round Trip Efficiency) / minimise losses
  2. **Compact & lightweight** to allow smallest plot / remote area / reduce installation cost
  3. **Fast Thermal Response** to minimise start-up time to operating temperature
  4. **Robust construction** to withstand repeated charge/discharge cycles and challenging process conditions (depending on the cycle and storage medium):
     - High pressures
     - High temperatures
     - Corrosion
  5. **Made in large size** to minimise the number of exchanger sections per module
  6. **Made in large quantities** to satisfy future high capacity project demands
  7. **Low cost** to reduce overall project CAPEX

Heatric PCHE Technology for Thermal Energy Storage

A unique combination of high efficiency, compact size and robust construction

Superior Performance

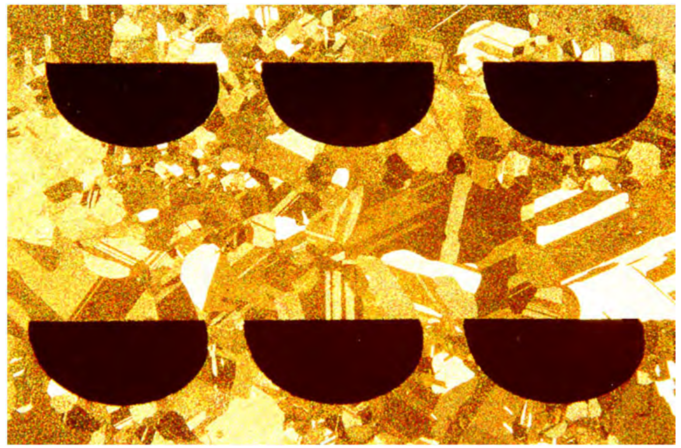


OPEX Savings

Bespoke PCHEs designs capable of:

- Close temperature approaches (>2°C)
- Very high thermal performance (sCO_2 recuperator 13.6 $MWth/m^3$)
- Extreme design pressures (>1,000 Bar)
- Widest range of temperatures (-196°C to 983°C)

Safe



Reduced Operational Risk

- Diffusion bonded, fully welded construction
- Allows full differential pressure between streams
- No catastrophic failure mode
- 30+ years track record of safe operation

Compact and Modular

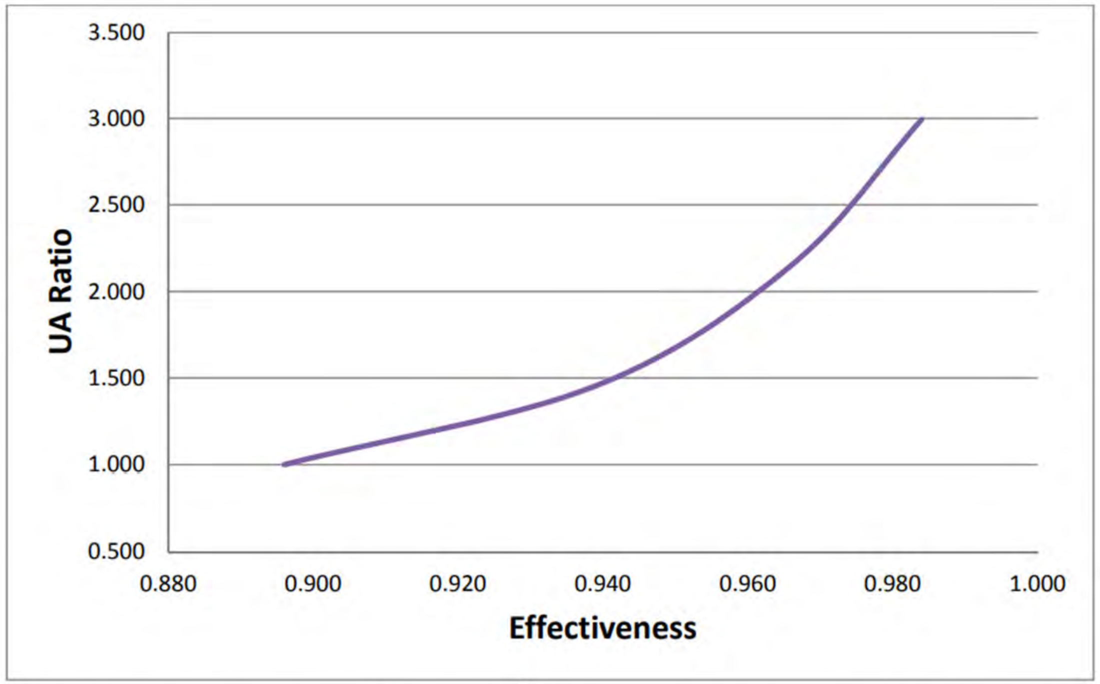
Installed Cost Savings

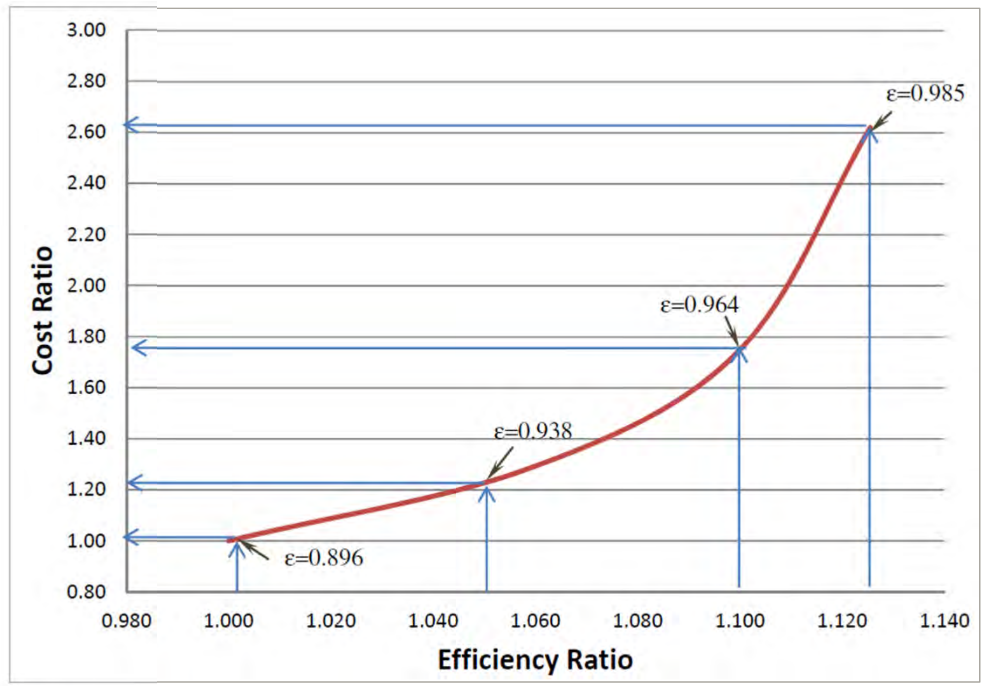
- Up to 85% smaller than Shell & Tubes
- Enables modularisation for ease of installation and transport to site
- Reduced footprint and foundations
- Reduced pipework and relief valves
- Lower mass and faster thermal response

EXISTING SOLUTIONS AND DESIGN CHALLENGES

High performance required - Impact of Effectiveness on heat exchanger size and cost

- Closer temperature approaches yield higher Effectiveness and improved Round Trip Efficiency (RTE)
- But at the expense of exchanger size and cost
- Size scales with UA (Q = UA ΔT where Q = duty; U = heat transfer coefficient; A = surface area requirement; ΔT = temperature difference)





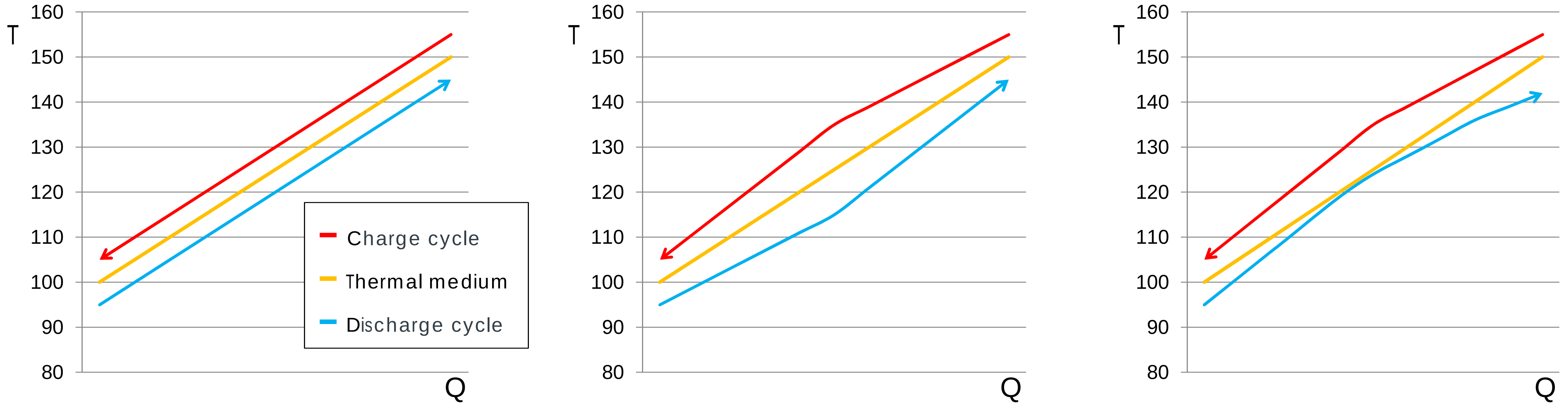
$$Effectiveness = 1 - \frac{\Delta T_{approach}^{*}}{T_{hot\ in} - T_{cold\ in}}$$

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

EXISTING SOLUTIONS AND DESIGN CHALLENGES

High performance required - Impact of Heat Curve on heat exchanger size and cost

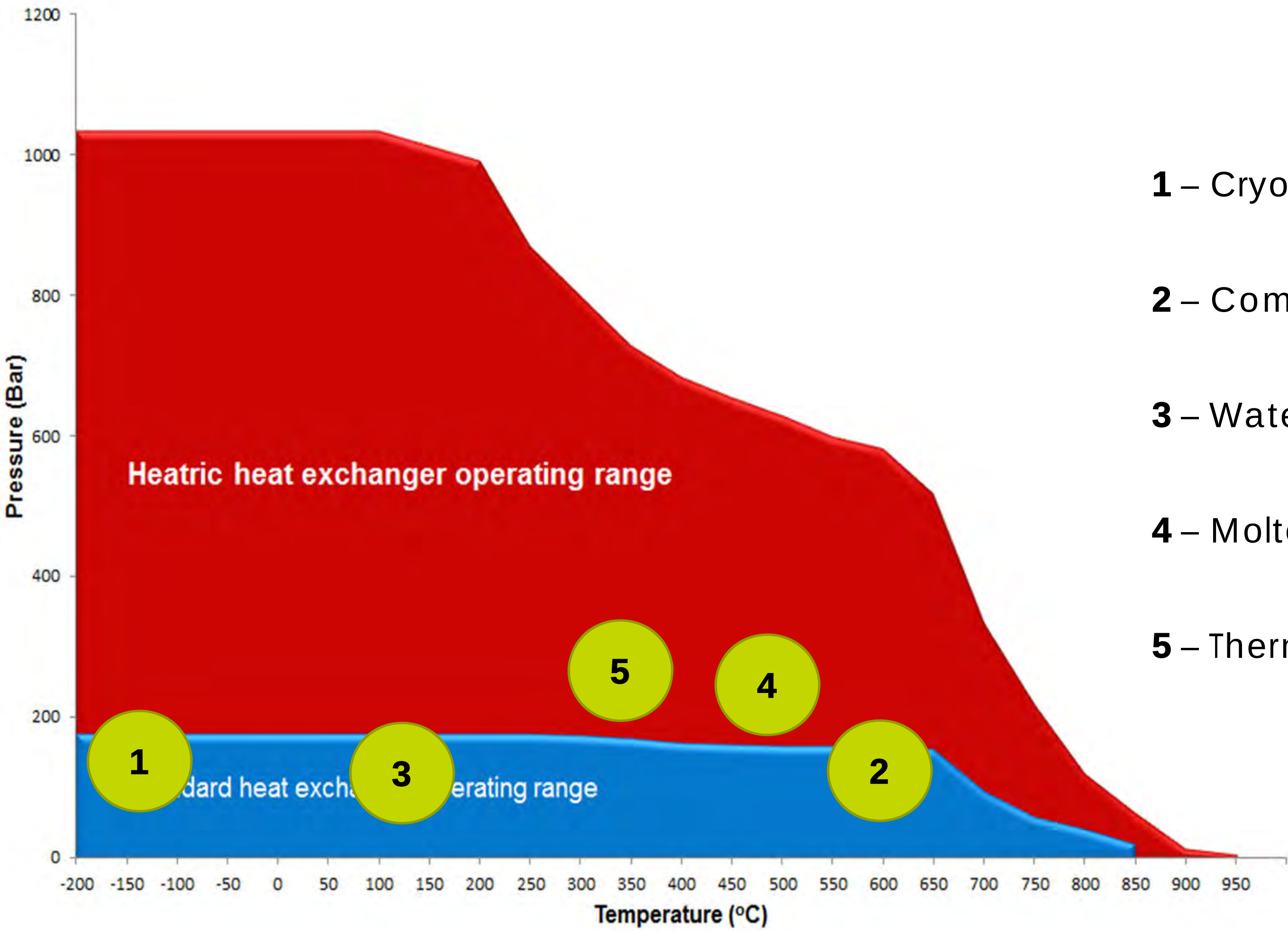
- Process design naturally has a big impact on heat exchanger size & cost
- Some power conversion fluids have non-linear properties (notably sCO_2)
- Important to check the reciprocity between charge and discharge cycles
- This can greatly vary the ΔT and area requirements for heat transfer between cycles
- And ultimately impact Round Trip Efficiency



- Interchanger T/Q examples (same exchanger used for both charging and discharging cycles to minimize CAPEX)
- In the 3rd case, note the big differences in temperature approach for each cycle and the implication on area requirement for heat transfer

EXISTING SOLUTIONS AND DESIGN CHALLENGES

Robust construction vital to withstand challenging process and repeated charge/discharge cycles



1 – Cryogenic

2 – Compressed Air

3 – Water

4 – Molten Salt

5 – Thermal Oil

1 – SS316

2 – SS316

3 – SS316

4 – SS347

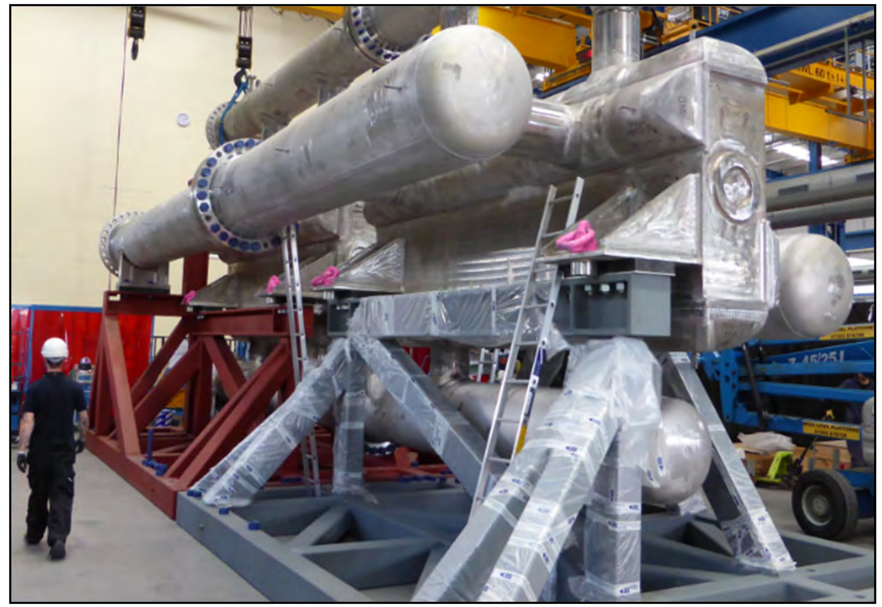
5 – SS316

EXISTING SOLUTIONS AND DESIGN CHALLENGES

Very large scale required but as low cost and compact as possible

Heatric

- Huge surface area requirements for long duration, high capacity energy storage (10's/100's MWhrs)
- Additional pressure drop can help reduce exchanger size & cost (at the expense of OPEX power demand)
- Designs are still often pushed into multiple exchanger sections in parallel
- Longer plates and cores help to minimise the number of sections / reduce piping requirements
- Smaller overall footprint
- Reduced installed cost



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DESSERT

- DEVELOPMENT NEEDS

- ENERGY STORAGE – HEATRIC VIEWPOINT

- WHAT NEXT?

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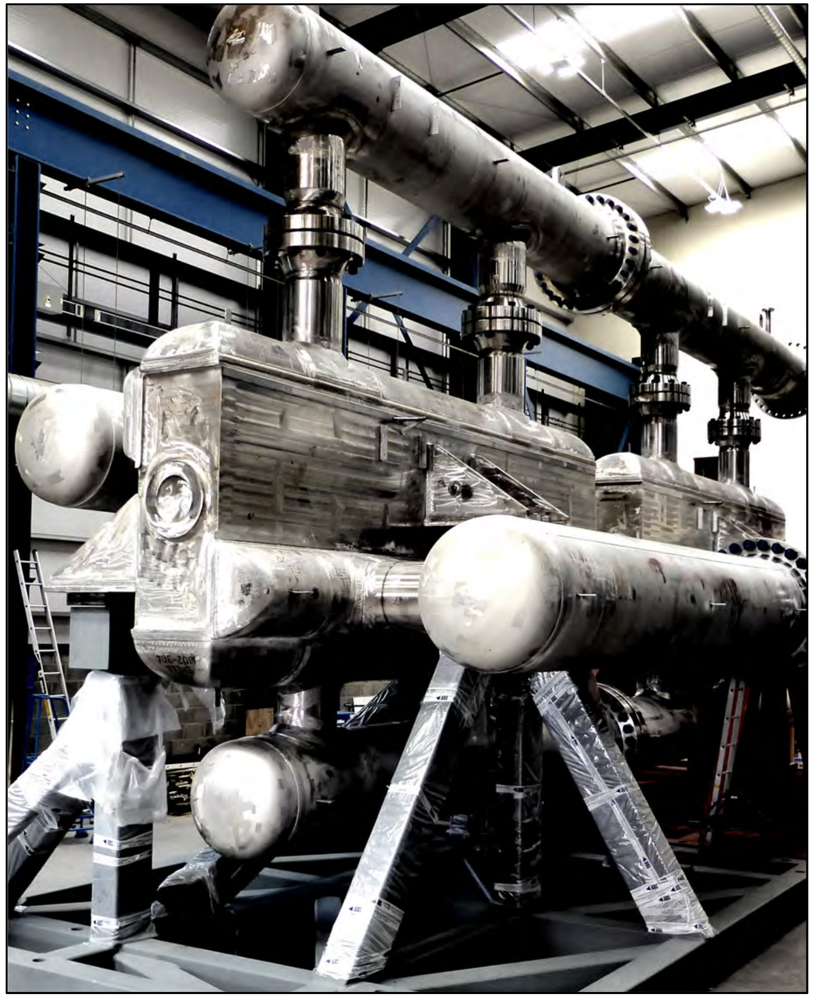
August 2021

DEVELOPMENT NEEDS

Compact heat exchangers provide many benefits to long term energy storage, but more is still needed…

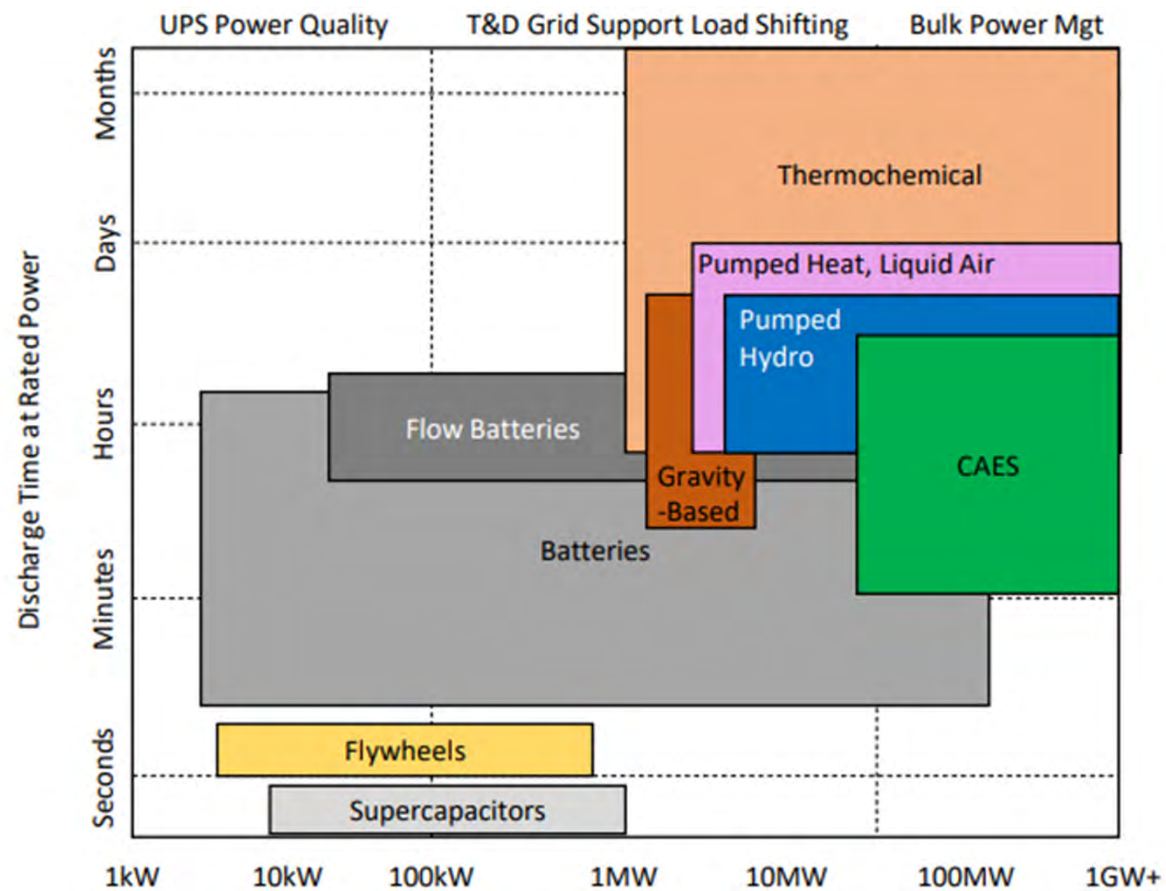
- Further increases in plate length will help with efficiency (but may require additional pressure drop)
- Greater core length to minimise number of sections and reduce piping and installed footprint
- Larger flow channels for certain thermal storage media like Molten Salt (blockage risk from impurities and solidification), but note that increased hydraulic diameter will reduce heat transfer coefficients and increase exchanger size
- Improved material & component supply chain for corrosion-resistant alloys (347, 617 & others)
- Lastly, when Energy Storage takes off as many expect, then lots more manufacturing capacity will be required!



ENERGY STORAGE – HEATRIC VIEWPOINT

Exciting opportunities but too many cycles?

- Original invite list for TMCES had nearly 300 different entities between universities, research institutes, government departments and industry
- 9 different energy storage concepts were discussed during TMCES 2020 introduction by Tim Alison
- Most processes are yet to be demonstrated and proven at scale
- Significant design resources are required to properly support and help optimise each cycle
- Pressure on OEM and supply chain to drive down cost, but investment required to do so
- Which systems will prove commercially viable?
- 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 to provide competitive materials in suitable product forms.

Standardisation

Process | Products
Performance

Standardization in Energy Storage cycles will lead to cheaper equipment and more cost-effective systems.
Potential for off-the-shelf with mass production and guaranteed performance based on proven suppliers.

Thermal Energy Storage

Modularisation

Flexibility | Footprint
Plant integration | Deployment

Modular approach allows off-site system construction for ease of installation in remote locations and reduced cost.
Flexible building-blocks for different capacity requirements.
Reduced engineering work and faster deployment.

Close Supplier Collaboration

Faster cycle optimisation
Better planning and deployment

Open, early collaboration is key to success.
Optimisation of cycle efficiencies running in parallel with component design for best OPEX/CAPEX balance.
Early discussion of plant layouts to minimise installed cost.

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