Liquid Air Energy Storage (LAES)

Technology Development & Deployment and its role in renewable-dominated energy systems

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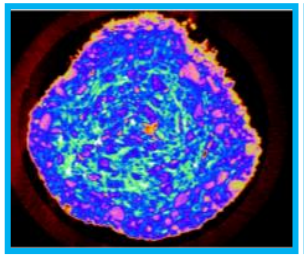
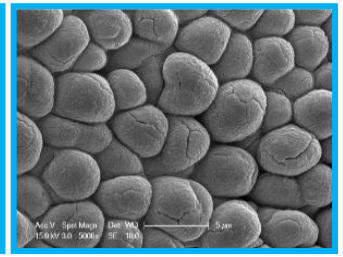
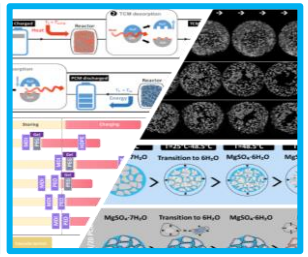




Contents

- Medium (MDES) and Long (LDES) Duration Energy Storage
  - Why MDES & LDES?
  - How do MDES & LDES fit?
  - What are MDES & LDES size and opportunities?
- Liquid Air Energy Storage (LAES) – an example of MDES
- Concluding remarks

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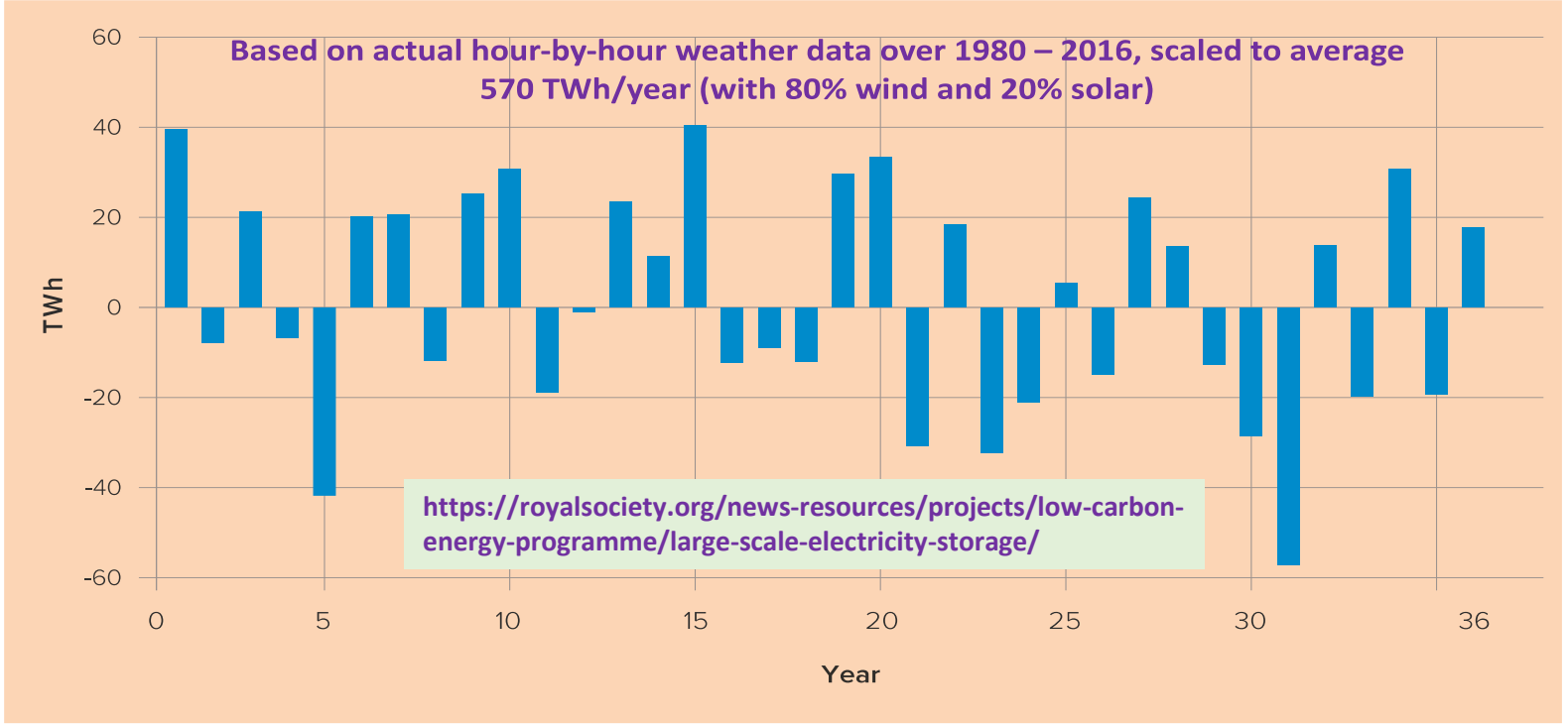
Why MDES and LDES?

A UK Royal Society Study - Large Scale Electricity Storage (2023)



Demonstration of storage needs at different durations - to address demand- supply mismatches at different length (time) scales

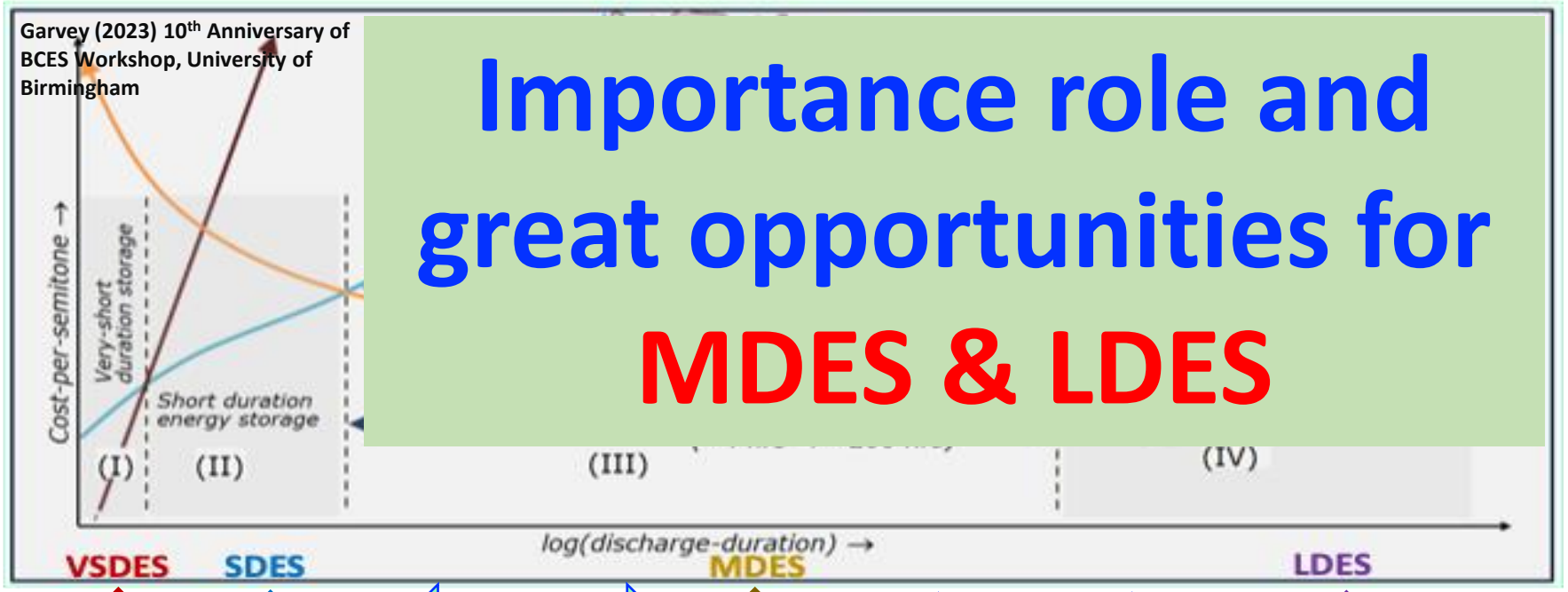
How do MDES and LDES fit?

VSDES for up to seconds
[e.g. supercapacitor, flywheel]
Very low $/MW (power)
Very high $/MWh (energy)

SDES for up to 2-4 hours
[e.g. Li-ion batteries]
Low $/MW (power)
High $/MWh (energy)

MDES for 4-200 hours
[e.g. Liquid air, compressed air, pumped hydro, thermal]
Low $/MW (power)
Low $/MWh (energy)

LDES for >200 hours
[e.g. Hydrogen, ammonia, methanol, thermochemical]
High $/MW (power)
Very low $/MWh (energy)



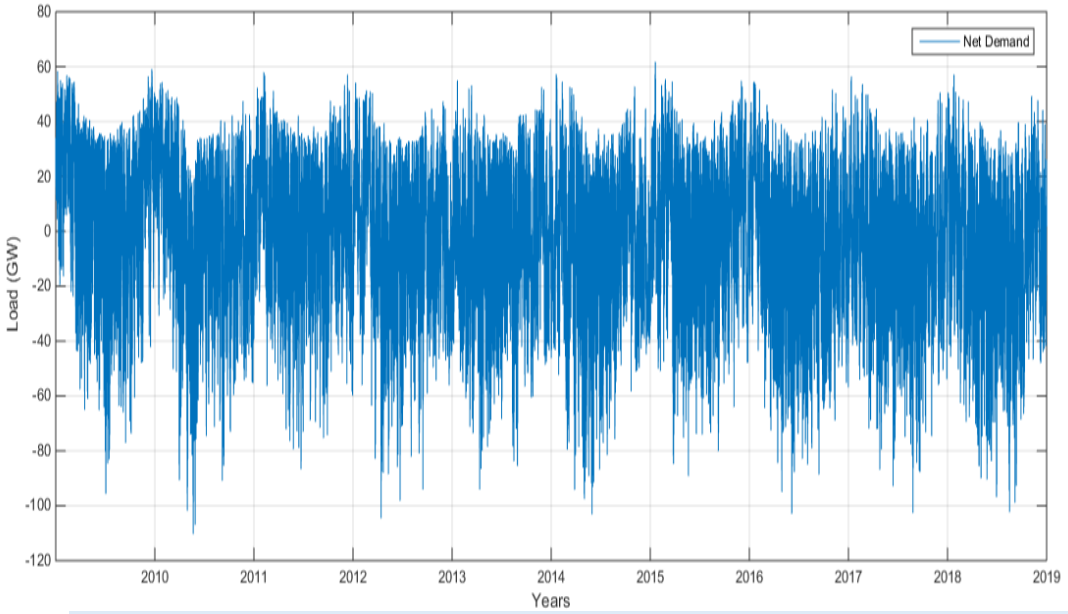
Importance role and great opportunities for MDES & LDES

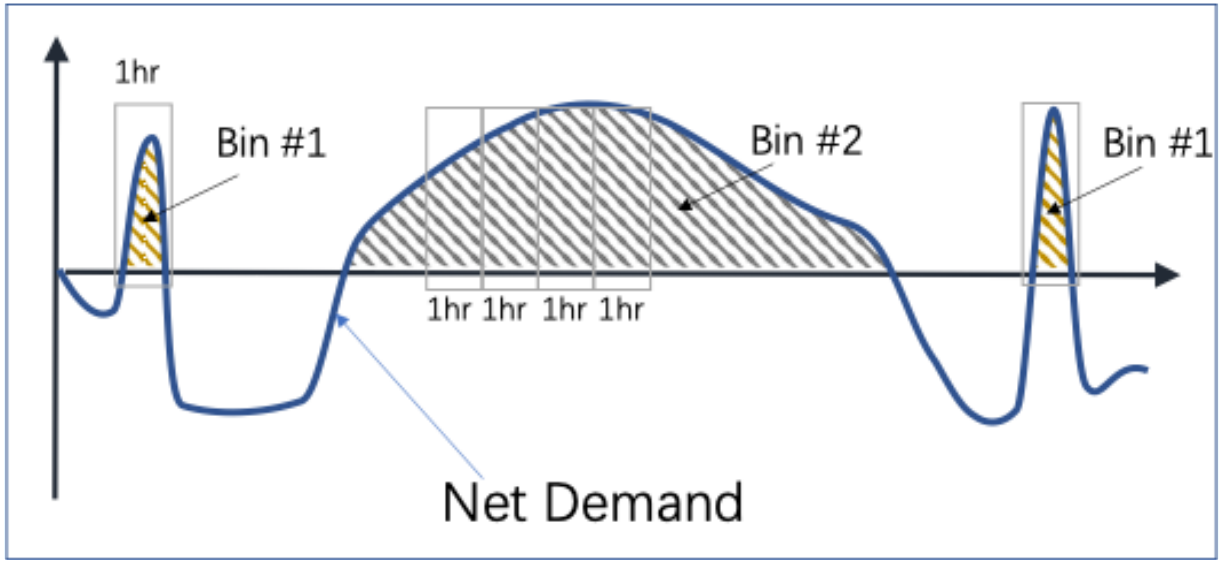
- **Power type - many cycles per day**
- **Fast cycle with small amount of energy**
- **Many viable business cases exist**

- **Energy type - 1-2 cycles per days**
- **Medium speed with large amount of energy**
- **Some viable business cases reported**

- **Energy type – 0.5-2 cycles per year**
- **Low speed with huge amount of energy**
- **Few viable business cases reported**

What are MDES & LDES size and opportunities?





Net supply-demand mismatch analyses for the UK using 10-year data – assuming 75% of generation from wind, 25% generation from PV and 10% over-capacity [adapted from Garvey (2024) Medium duration energy storage, IMechE London, January 2024]

- **VSDES** (e.g. flywheel and supercapacitors) & **SDES** (e.g Li-ion Batteries): <1% of the total of energy storage
- **MDES** (e.g. CAES and LAES; pumped hydro, thermal): ~92% of the total of energy storage
- **LDES** (e.g. hydrogen, thermochemical): ~7% of the total of energy storage

A huge opportunity for MDES

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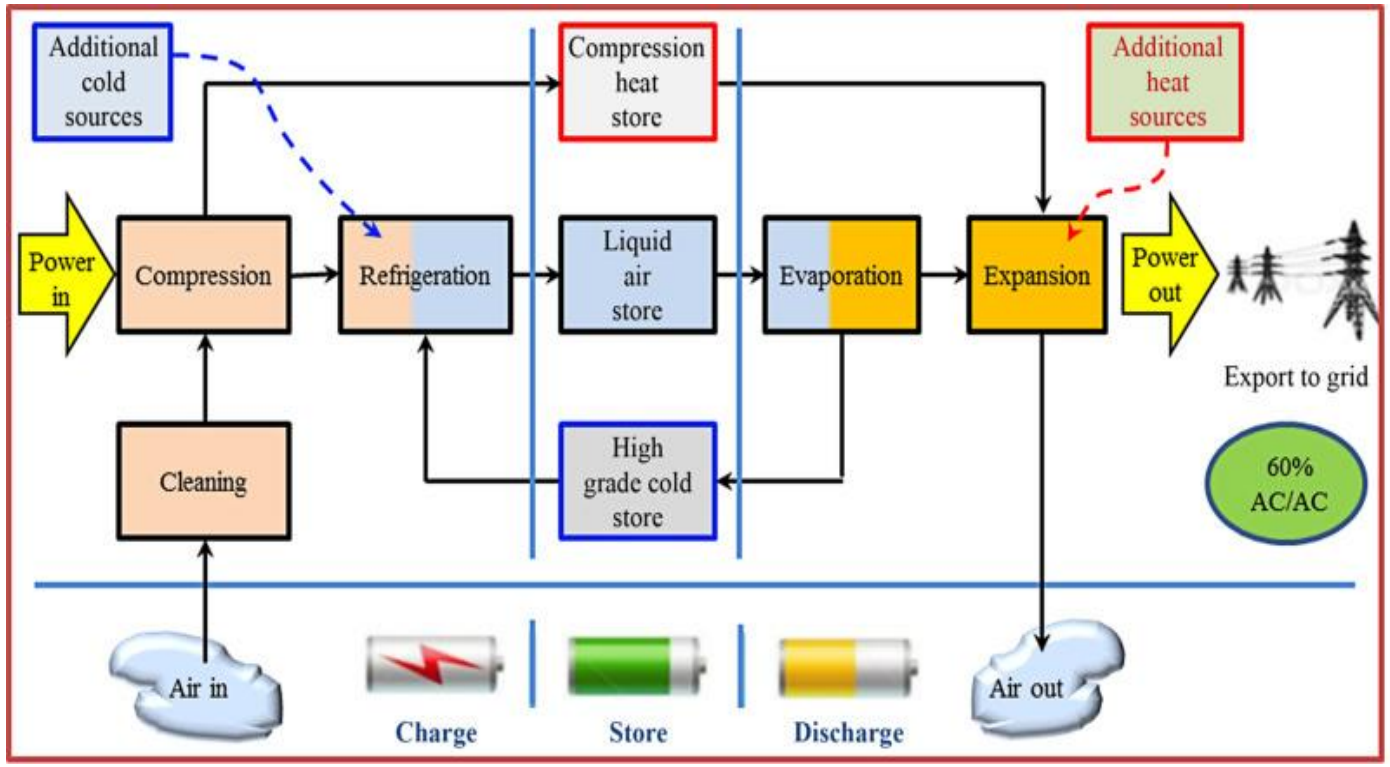
Liquid Air Energy Storage (LAES) – an example of MDES

The Principle

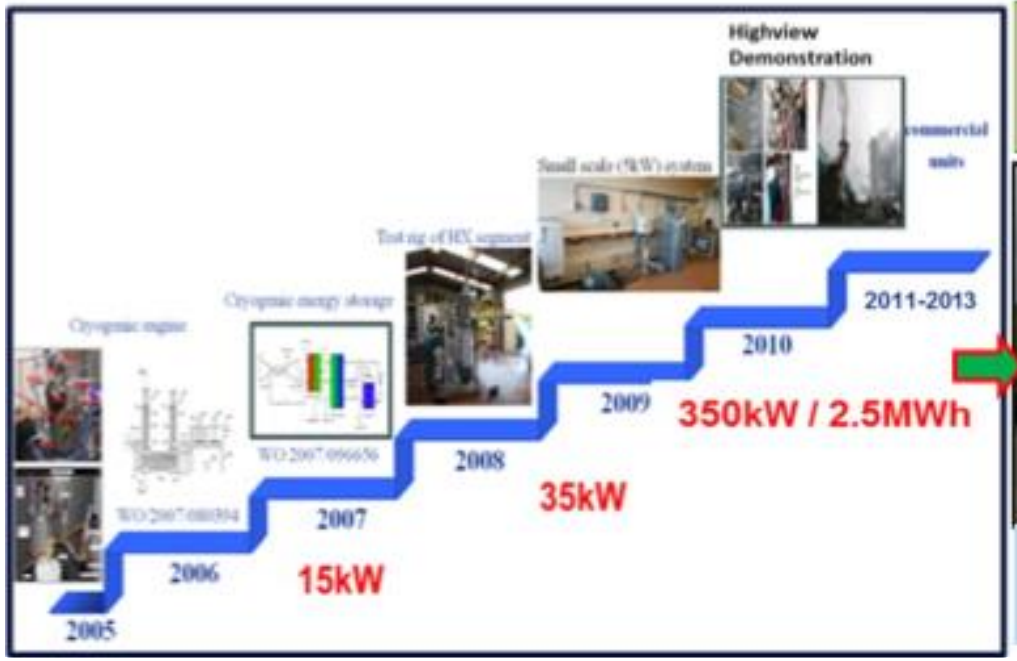


- **Materials flow** – Air in, air out
- **Energy flow** – Electricity in, electricity, heat and coolth out;
- **Energy store** – Liquid air (major), heat and cold (ancillary) with the heat from compression during charging and cold from waste cold recovery during discharging

Chen et al (2007) WO/2007/080394 – Major invention by my team then at University of Leeds over 2004-2006

Liquid Air Energy Storage (LAES) – an example of MDES

The Development History



Pre-commercial Demonstration

2015 - 2020
5MW/15MWh

First Commercial Plant

2020 - 2026
50MW/300MWh

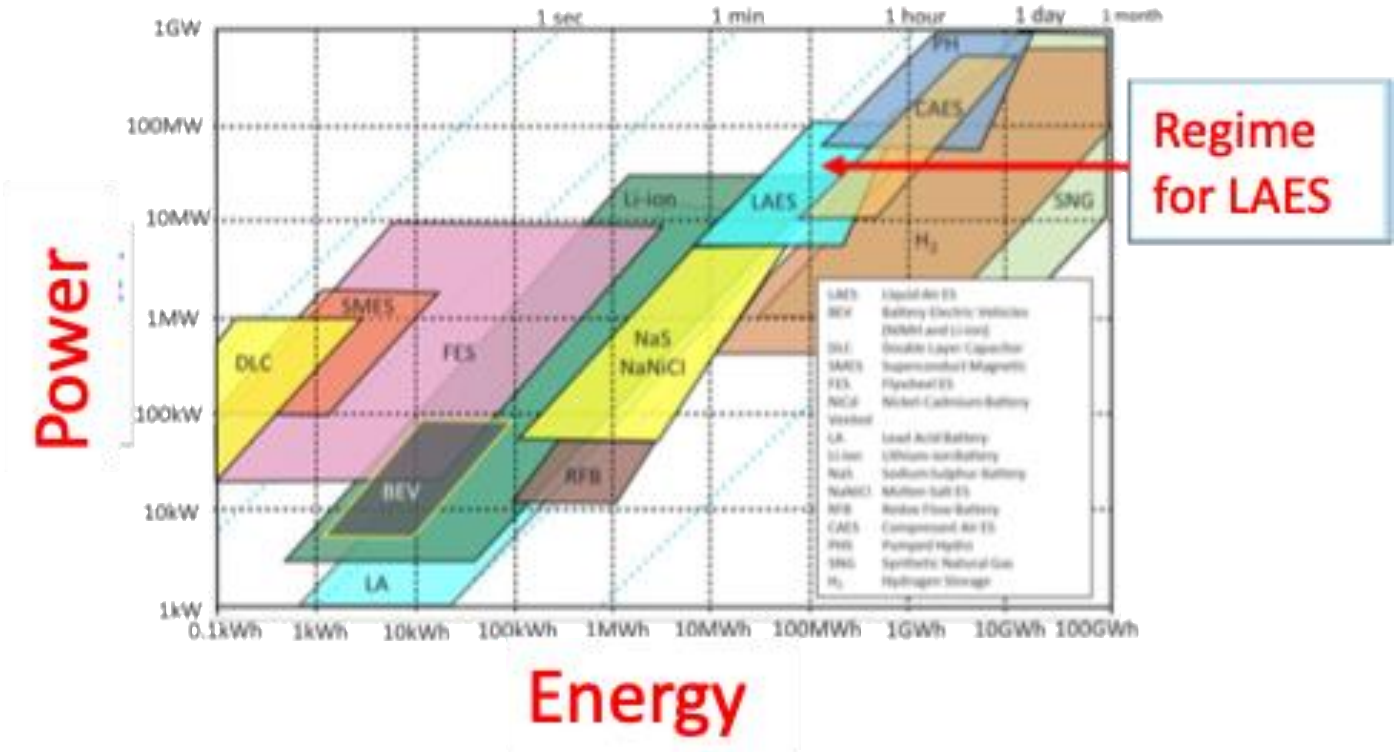
- Recent announcements by Highview to build 4x2.5GWh LAES plants by 2030
  - Manchester - 50MW/300MWh (2020 - 2026)
  - SHI Investment of USD$ 46 million (February 2020) and announcement of £300m investment led by UK Infrastructure Bank, Centrica & Partners (June 2024)

Liquid Air Energy Storage (LAES) – an example of MDES

Some Snapshots

Liquid Air Energy Storage (LAES) – an example of MDES

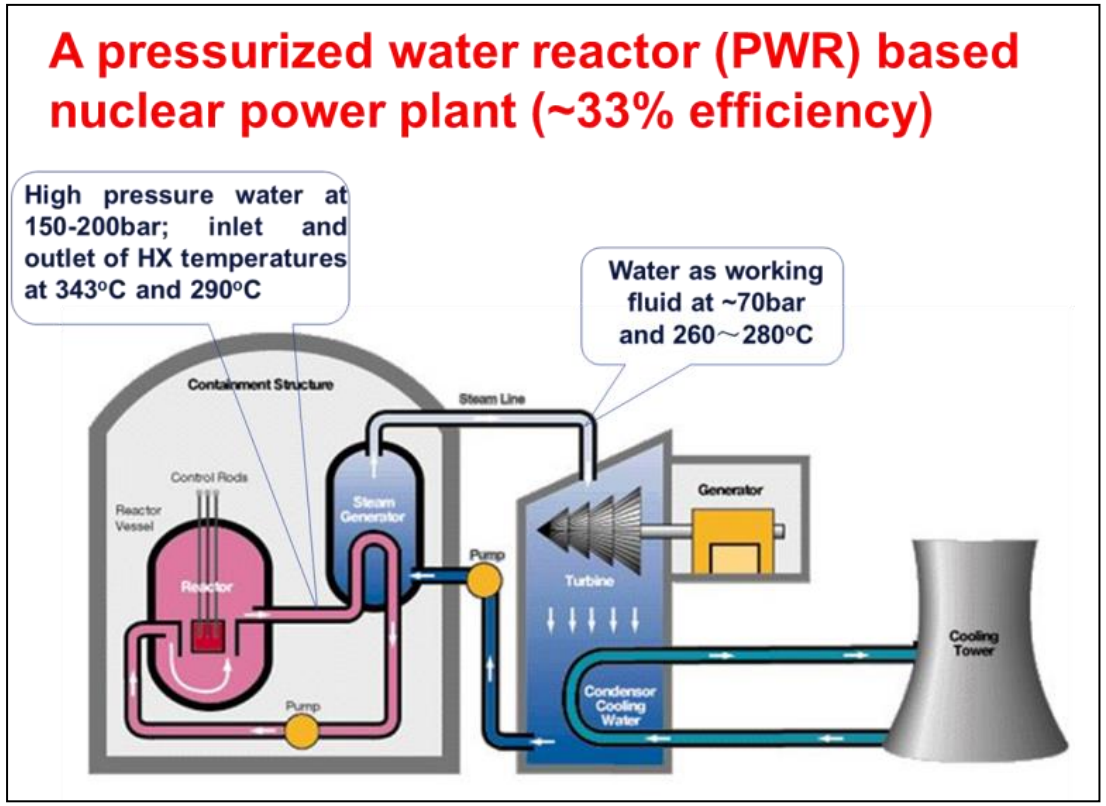
Large Grid-Scale Applications



- Large scale LAES technology suits mainly for energy related applications – round trip efficiency ~60%
- LAES can also be used for power related rapid response applications if run on e.g. Spin-Gen mode or integrated with batteries / flywheel / supercapacitors

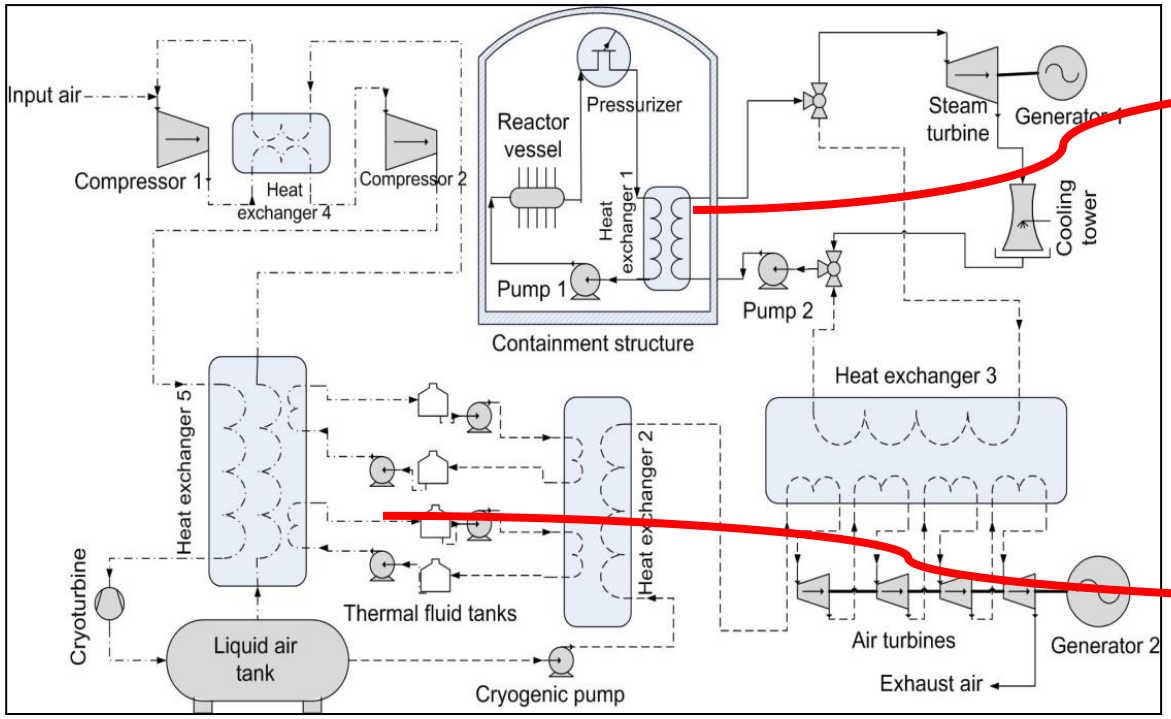
Liquid Air Energy Storage (LAES) – an example of MDES

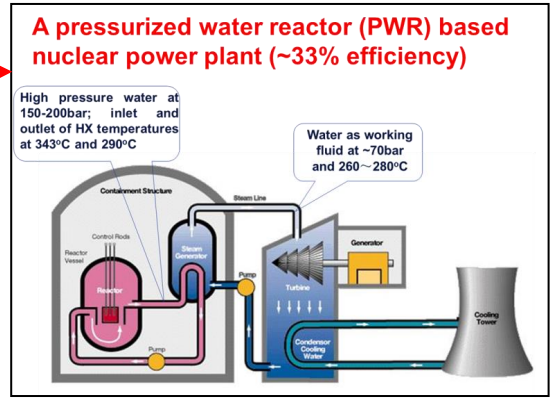
Large-Scale Applications - Integration with Nuclear Power Plant

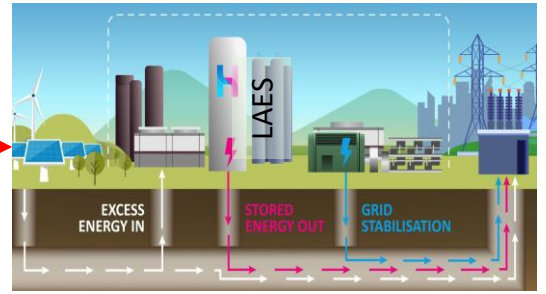


Liquid Air Energy Storage (LAES) – an example of MDES

Large-Scale Applications - Integration with Nuclear Power Plant







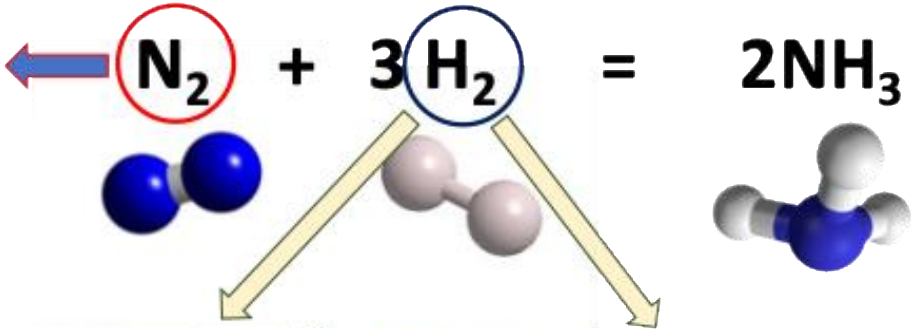
Peak shaving capacity up to 3 times higher; energy storage part of efficiency ~75%; CAPAX ~70% of pumped hydro and ~50% of batteries

Li et al. (2014) Applied Energy, 113, 1710-1716

An example of MDES – Liquid Air Energy Storage (LAES)

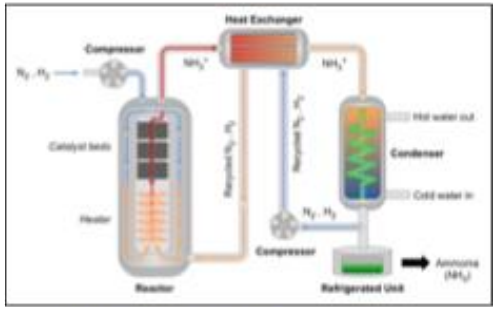
Application through sector-coupling - Ammonia synthesis

Air Separation



Grey/Blue H_2 Production

GreenH_2 Production

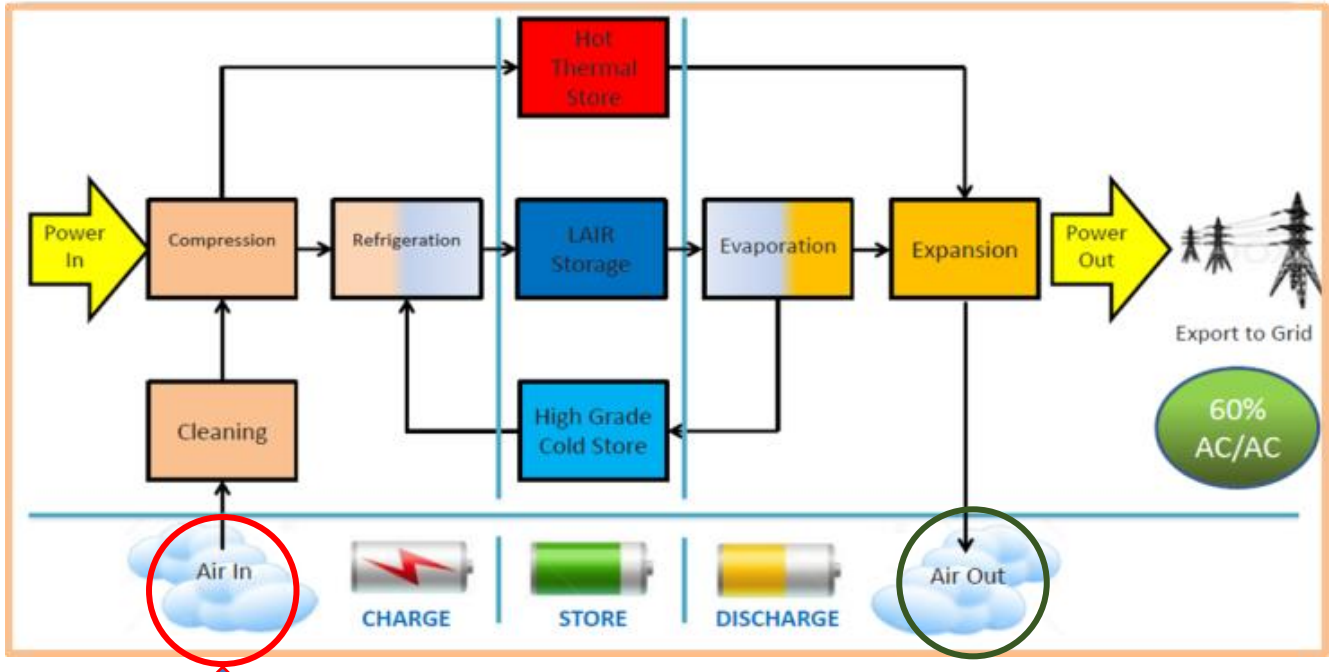


Ammonia Production Plant

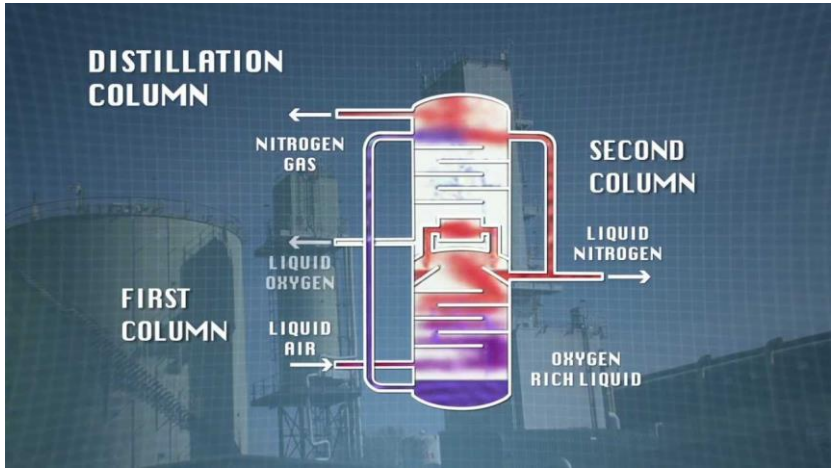
Synthesis of ammonia (hydrogen carrier): Haber-Bosch Process

An example of MDES – Liquid Air Energy Storage (LAES)

Application through sector-coupling - Ammonia synthesis



Integration



Air (N_2 + O_2) in

Clean Air (N_2 + O_2) out

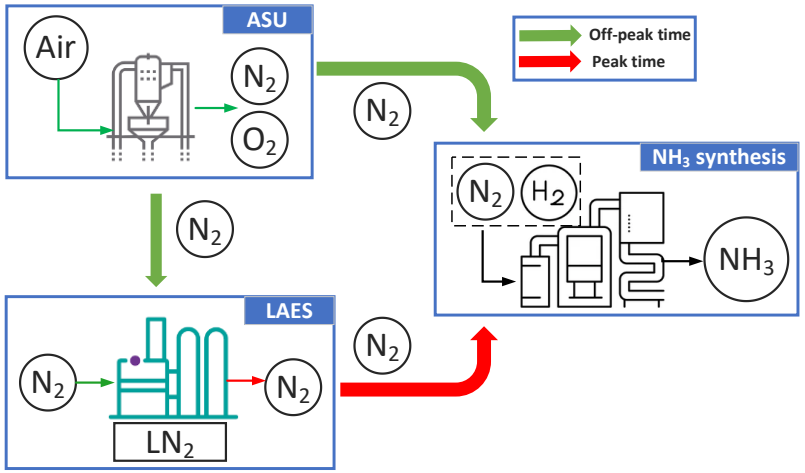
Clean N_2 out for supply to Haber-Bosch Process (NH_3)

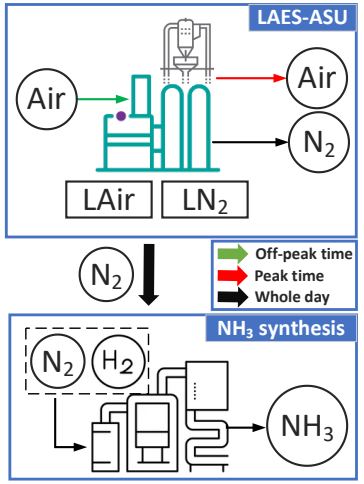
Clean O_2 out for other use

Typically, no distillation column included

An example of MDES – Liquid Air Energy Storage (LAES)

Application through sector-coupling - Ammonia synthesis





Design I - LAES working as a nitrogen buffer (less integrated)

- ***Off-peak time:*** ASU; LAES charge & Ammonia production
- ***Peak time:*** ***LAES*** discharge & Ammonia production

Design II - LAES for energy storage and air separation (highly integrated)

- ***Off-peak time:*** ASU; LAES charge & Ammonia production
- ***Peak time:*** ***LAES*** discharge & Ammonia production

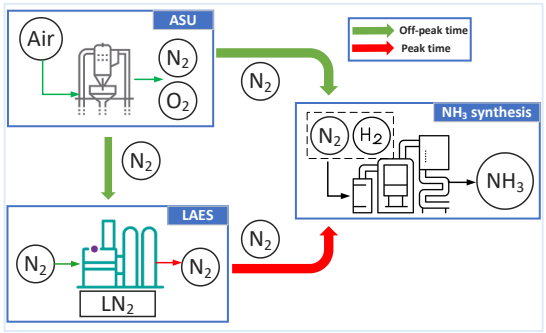
Turning PPT to Practice: First Step – Process Design

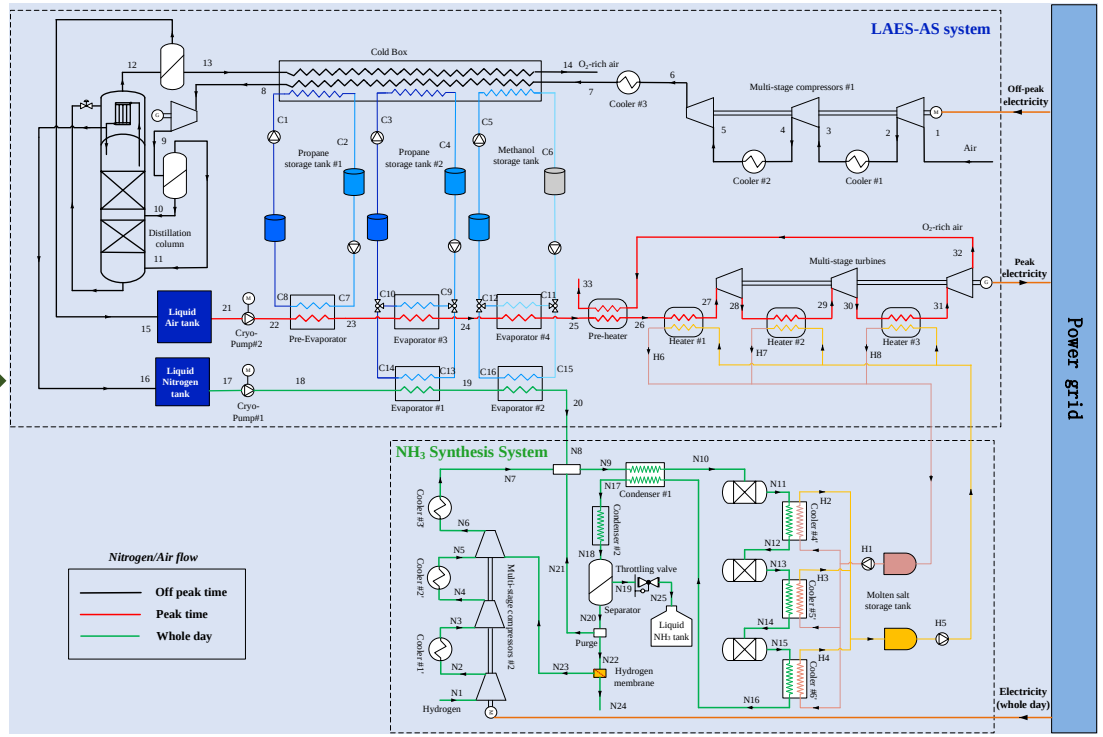
T. Zhang et al. (2024) Journal of Energy Storage, 112637

An example of MDES – Liquid Air Energy Storage (LAES)

Application through sector-coupling - Ammonia synthesis

Design I





Modelling & Optimisation

- ✓ ASU operation cost: ~40% ↓
- ✓ LAES initial investment cost: 11.3% ↓

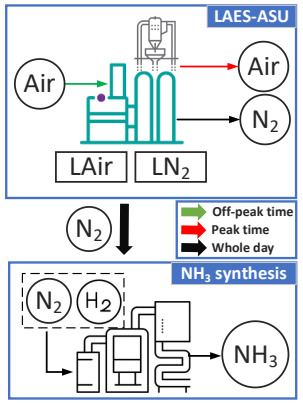
Turning PPT to Practice: Second Step – Optimization and Techno-economical Analyses

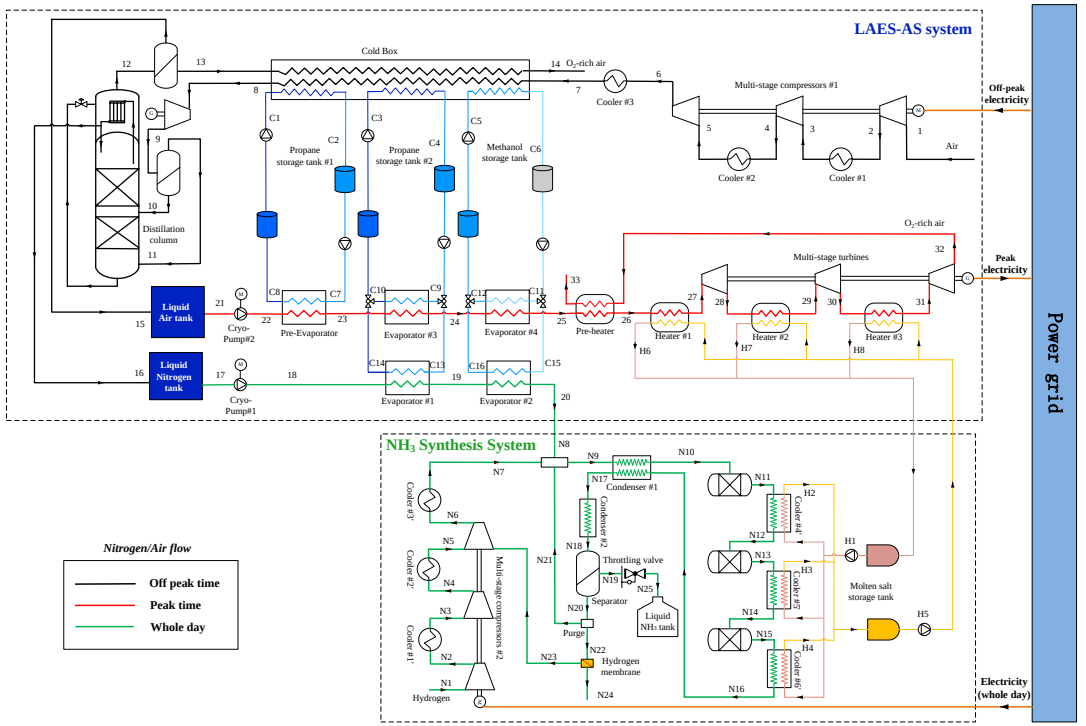
T. Zhang et al. (2024) Journal of Energy Storage, 112637

An example of MDES – Liquid Air Energy Storage (LAES)

Application through sector-coupling - Ammonia synthesis

Design II





Modelling & Optimisation

- ✓ Electricity consumption of NH_3 synthesis: **31.6%** ↓
- ✓ Power-Ammonia-Power efficiency: **13%** ↑

Turning PPT to Practice: Second Step – Optimization and Techno-economical Analyses

T. Zhang et al. (2024) Journal of Energy Storage, 112637

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Concluding remarks

- **Renewable-dominated net-zero energy transition needs energy storage at various durations**
- **Medium and long duration energy storage has a great role to play, with a huge projected future market (~90% in terms of energy, based on the UK data)**
- **LAES fits the Medium Duration Energy Storage category, and hence has a great opportunity in the future net-zero energy systems**
- **There are unique opportunities for the application of the LAES through sector-coupling**