NWE Electricity Supply Resource Technology Forum

Liquid Air Energy Storage (LAES)

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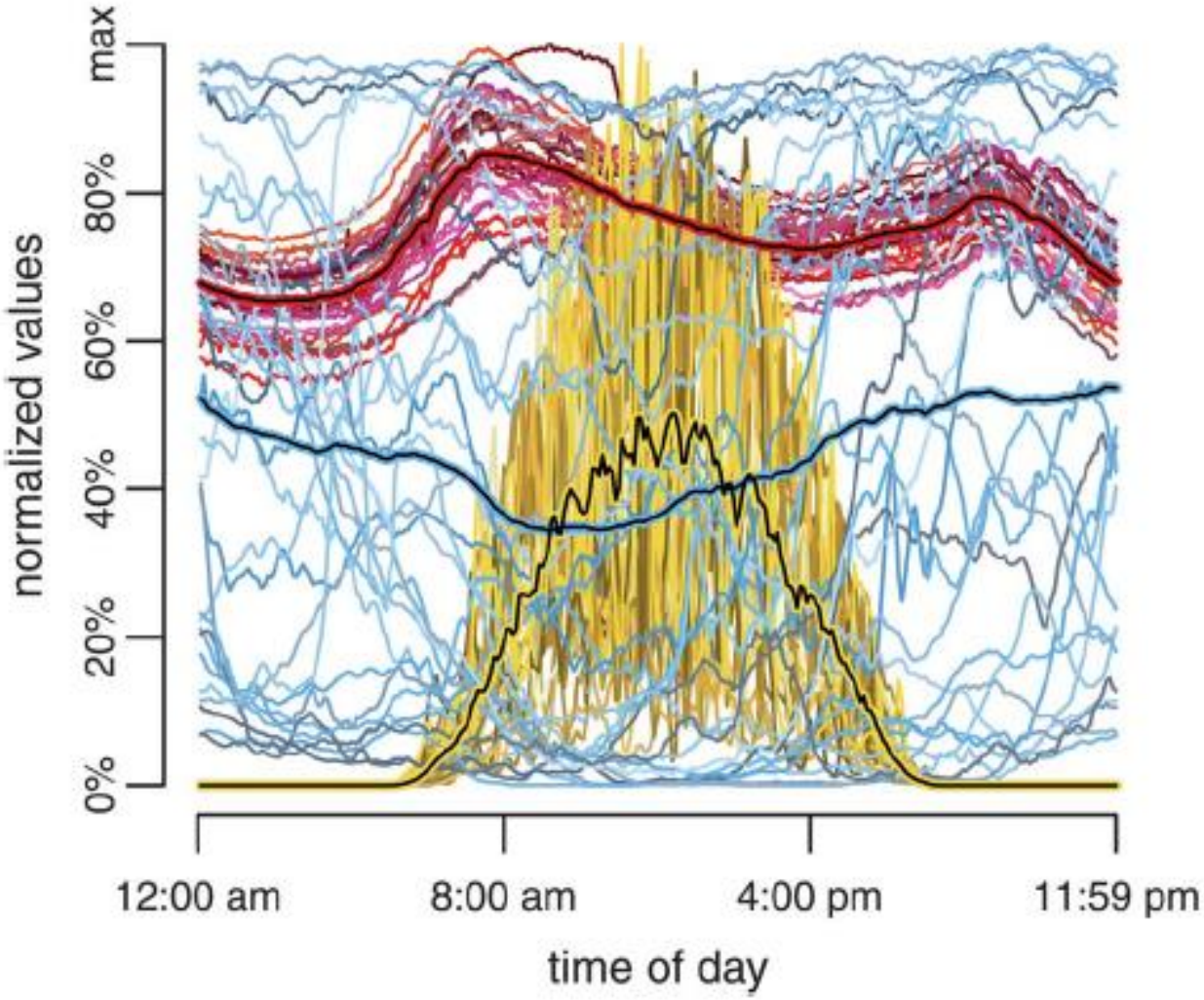
The REAL Problem – Intermittent RE, Wind & Solar PV

Wind BLUE

Solar Yellow

Demand Red

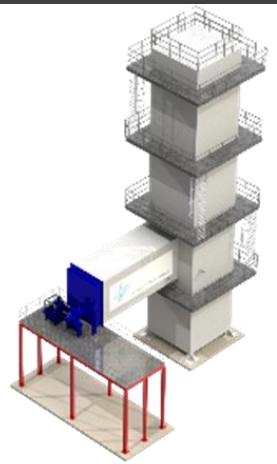
BPA
30 Days
April 2010



Liquid Air Energy Storage - LAES

Conventional Equipment Used in an Unconventional Manner

1. Charge



Off Peak or Curtailed RE produces Liquid Air.

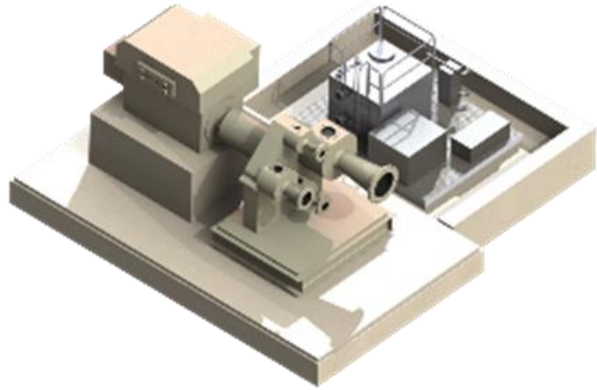
Industrial Gas Industry

2. Store

Liquid Air stored in tanks
# of Tanks = discharge duration

Industrial Gas & LNG Industries

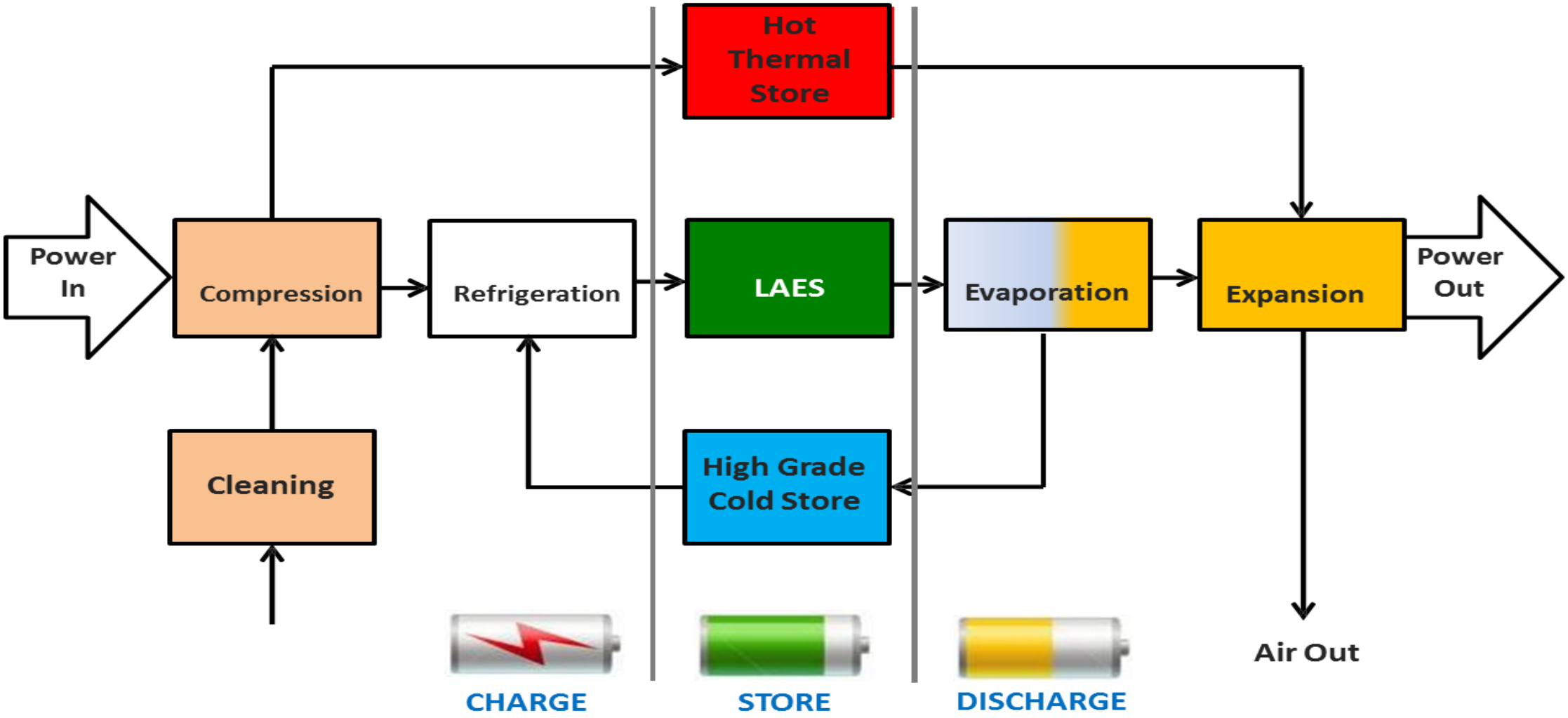
3. Discharge



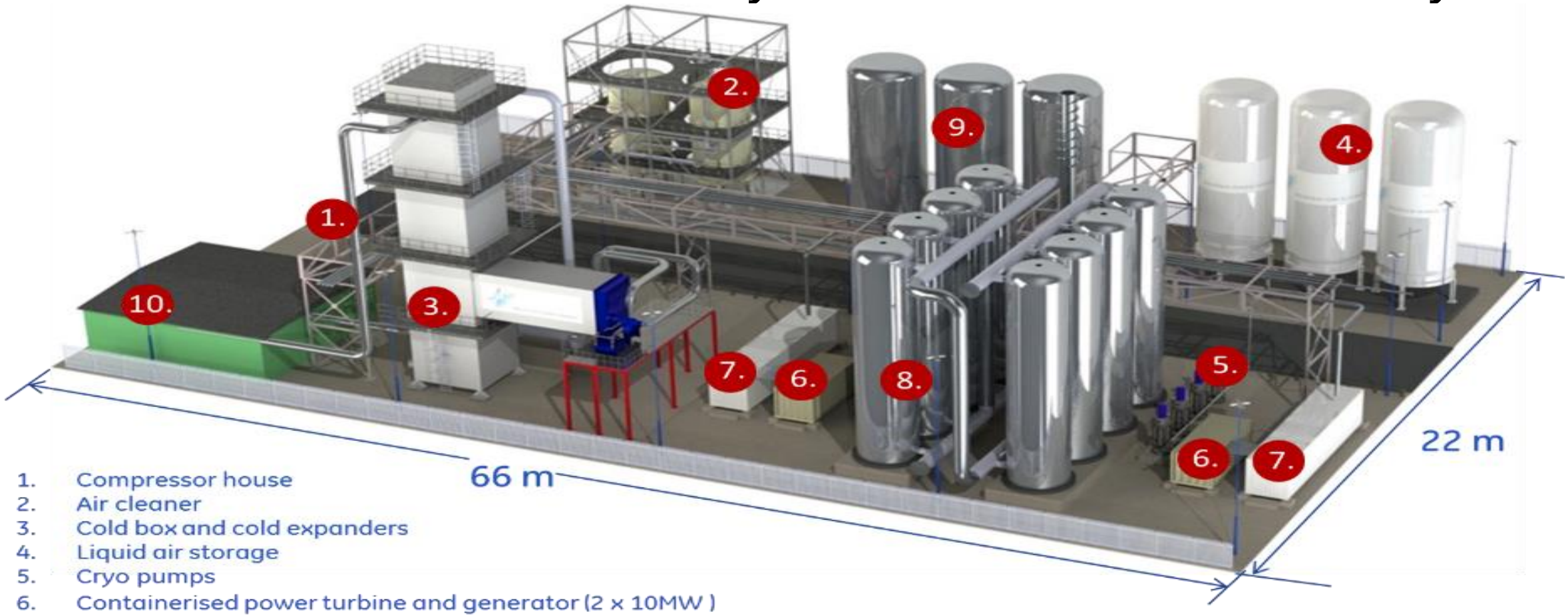
Pressurized Liquid Air is evaporated and heated to power the expansion turbine

O&G Refineries Worldwide

Simplified LAES Cycle Diagram

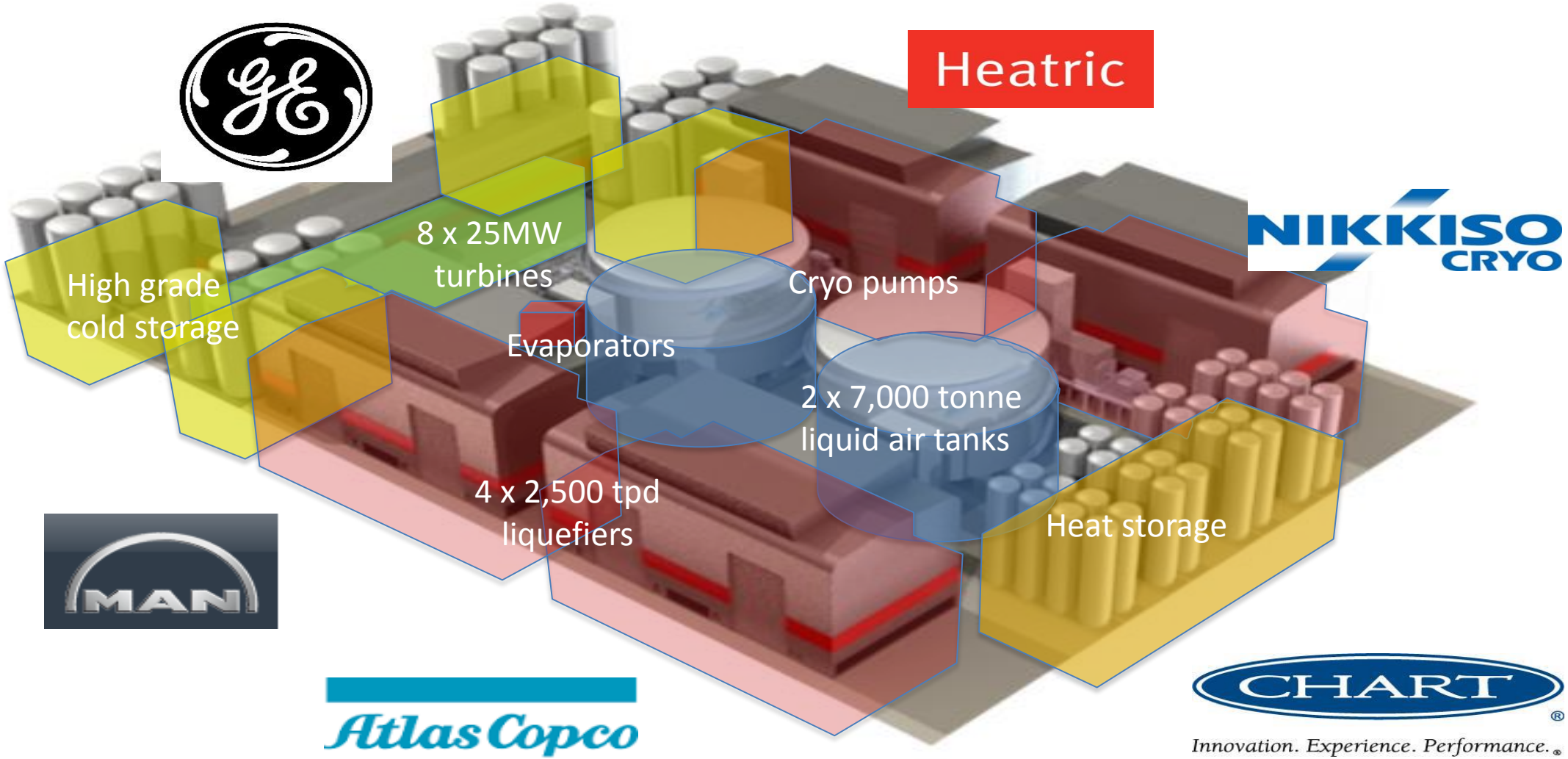


Indicative Layout for a 20MW/80MWh System



1. Compressor house
2. Air cleaner
3. Cold box and cold expanders
4. Liquid air storage
5. Cryo pumps
6. Containerised power turbine and generator (2 x 10MW)
7. Heat exchanger containers
8. High grade cold stores
9. Hot water storage
10. Electrical intake and switch-house

Major Equipment Suppliers for LAES



Integrated Energy Storage

State of the Art	• 5 MW, 15 MWH commercial demonstration unit at Pilsworth, N. Manchester in the UK, commissioning now, COD Feb 2018
Size, Scope and Penetration	• 10 – 200 MW • 40 MWH – 1.2 GWH • Firm wind, transmission deferral
How would you use it in MT?	• Working in MT for 2 years • Bid on Colstrip 1 & 2, repurposing • Tendered Hybrid Peaker to NWE – 67 MW firm, 4 hrs
What is the lead time?	• Today - Early units 18-22 months, NTP to COD • Near future - Modular 6-8 months, NTP to COD

Integrated Energy Storage

Specific Products?	• Energy & Capacity – Behaves just like a rotating machinery asset • Frequency Response – Combined with short term BESS (ramp hider) • Voltage Regulation and KVAR Support – Utility scale rotating generator • Spinning Reserve – Standalone using “SpinGen” technology • Resource Adequacy – Firms wind and solar, time shifts power delivery
Benefits to MT Customers?	• Remove intermittency from Wind • Time shift MT wind to winter & summer peaks
How would you use it in MT?	• Fully dispatchable even while charging • Operates just like a spinning asset • Can provide regulation up & down • Congestion relief and transmission deferral • Handle over-generation of solar PV based on number of interconnect requests in 2015-16

Integrated Energy Storage

Cost of Ancillary Services?	• These need to be modeled and vary between standalone LAES and Integrated Energy Storage systems (co-located with a gas peaker unit)
Fixed costs per MW-month	• These need to be modeled and depend on site specifics such as charging rate, discharge rate and hours of discharge at full load
Variable cost per MWH	• Generally run at 3 – 6 $/MWH depending on the configuration of the system as noted above. This includes 1.5% of capex per annum for O&M • High charging rates (MW/hr) have a significant impact.
Expected Life	• Based on standard equipment from the air separation and petroleum industries, we expect 30 years of useful life. Major maintenance is at 20 years with minor overhauls every 8 years. Lots of operating data to confirm long term performance and O&M costs.

Integrated Energy Storage

Estimated reliability/availability?	• Based on significant historical data on the key components, we estimate 18 days per year off line to perform maintenance which implies 95% availability. Again, years of operational data exists on all major components.
Estimated capacity factor? What determines hourly capacity factor?	• Based on significant historical data, we estimate the capacity factor to be 98%. • Hourly capacity factor is dependent upon the charging rate, duration of charging and duration of discharge and includes liquid air storage tank volume reserves.
Is there a daily, monthly, seasonal or yearly shape to output?	• The most common benefit of LAES systems is to time shift RE from when it is generated to when it is needed. The charging cycle has a shape based on the source of power but the discharge can be shaped to meet a customer's needs.

Benefit Summary – NorthWestern Energy

- NWE's wind RE from 8% of nameplate capacity to 35%
- Delivers wind RE on demand, no curtailment
- Effective NHR
  - 8500 Btu/kWh typical Peaker
  - 3400 Btu/kWh Hybrid

✓ **60% reduction in gas consumption**

YES WE CAN!

But only with utility scale storage

How do you do that?

Highview/ MADA/ GE/ SNCL Hybrid Peaker with LAES				
Heat Rate Model:	MWH	Weighting	Component HR, HHV Btu/kWh	Implied HR combined system
Total MWH Generated	195,700	100%		3,404
Total MWH Generated from LM6000	69,900	36%	8,500	
Total MWH Generated from gas firing of PRU	6,000	3%	12,000	
Total MWH Generated from LAES - direct bypass or stored wind energy	119,800	61%		

BESS Rapid Response + LM6000 & LAES Ramp Rates