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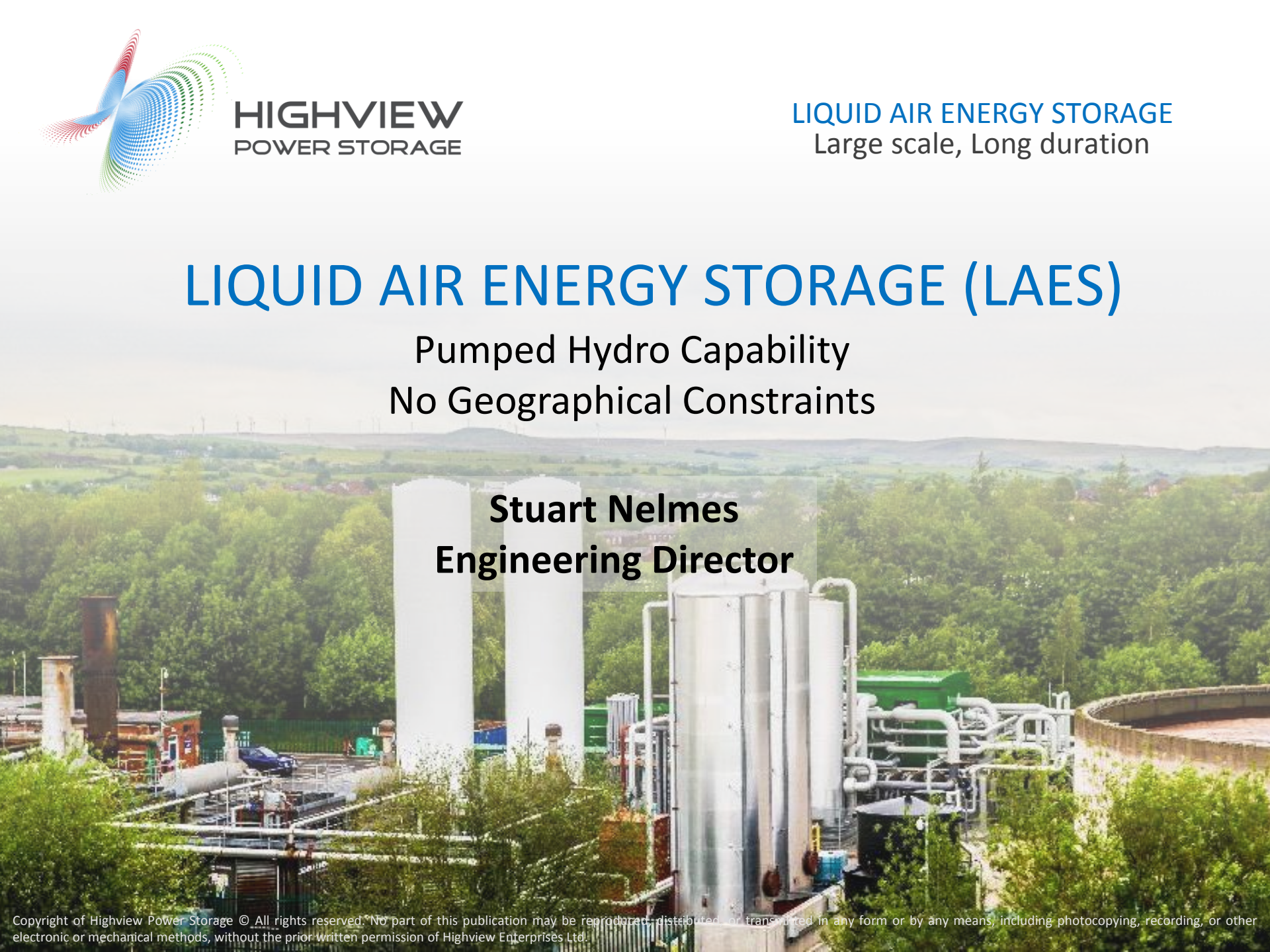
LIQUID AIR ENERGY STORAGE
Large scale, Long duration

LIQUID AIR ENERGY STORAGE (LAES)

Pumped Hydro Capability
No Geographical Constraints



Stuart Nelmes
Engineering Director

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Liquid Air Energy Storage (LAES)

is based on **proven components** from century-old industries

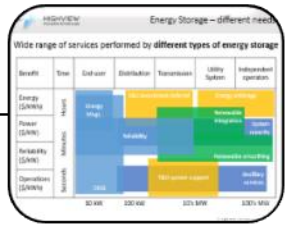
and offers a **low-cost** solution

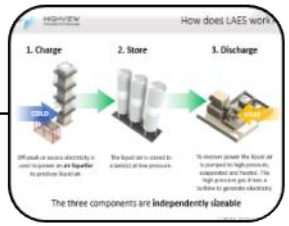
for **high-power, long-duration** energy storage

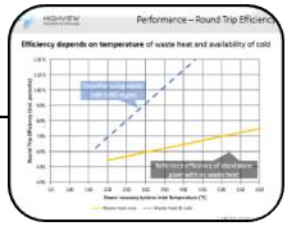
that can be built **anywhere**.

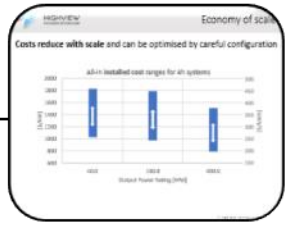
Agenda

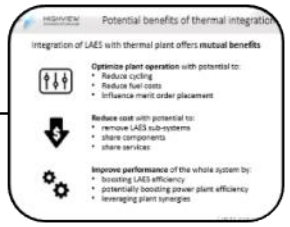
- Highview, a history
- LAES in the market
- Technology overview
- Performance characteristics
- Economics
- Thermal integration examples











Company Timeline

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2005

UNIVERSITY OF LEEDS

2008

The power recovery cycle demonstrated in lab-scale tests

2010

Installation of power recovery cycle in pilot plant

2011

Installation of complete pilot CryoEnergy Storage plant

2012

Highview signs co-operation agreement with the Messer group

MESSER Gases for Life

2013

Highview enters into a licence agreement with General Electric

2014

Highview and project partners, Viridor, awarded funding for a 5MW LAES demonstration project by the UK Government

Viridor Transforming waste™

2015

NAVFAC Naval Facilities Engineering Command

Multiple feasibility studies awarded, including an award from the U.S. Navy

Frost & Sullivan awards Highview with *Global Large-Scale Energy Storage Technology Innovation Award*

FROST & SULLIVAN

2016

Highview's grid scale High Grade Cold Store (HGCS) commissioned at the 5MW Pilsworth demonstration plant

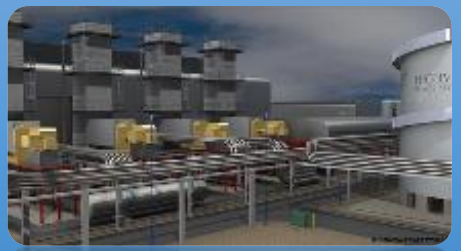
2017

Highview expanding into the US with new office in New York, a key market for LAES

acre

Future

The new conceptual GigaPlant 200MW/1.2GWh



350 kW / 2.5 MWh Pilot

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5MW / 15 MWh Demonstrator

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Energy Storage – different needs

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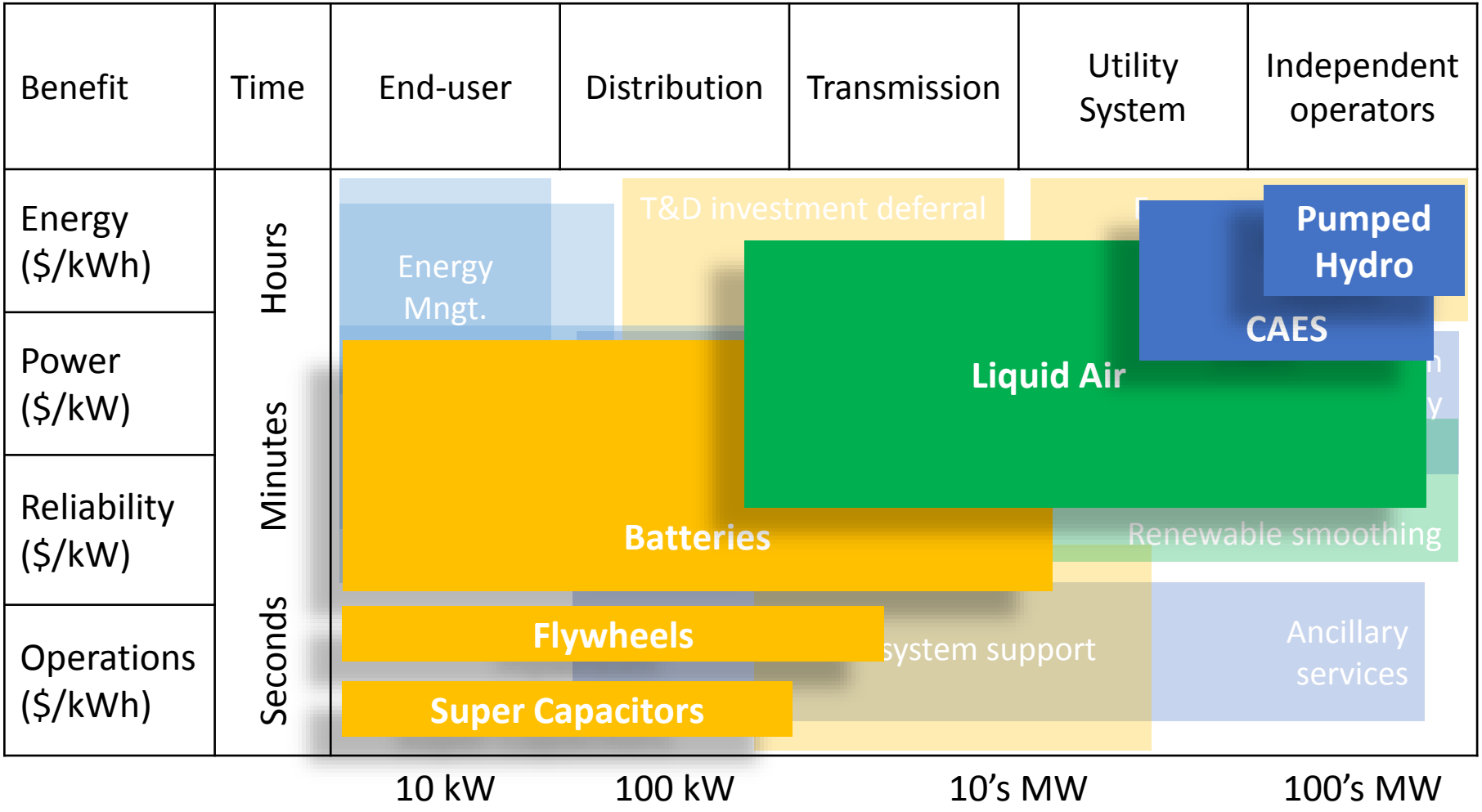
Wide range of services performed by **different types of energy storage**



Energy Storage – Main Technologies

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Wide range of services performed by **different types of energy storage**

Benefit	Time	End-user	Distribution	Transmission	Utility System	Independent operators
Energy ($/kWh)	Hours	Energy Mngt.	T&D investment deferral			
Power ($/kW)	Minutes	Batteries		Liquid Air	CAES	Pumped Hydro
Reliability ($/kW)						Renewable smoothing
Operations ($/kWh)	Seconds	Flywheels	system support			Ancillary services
		Super Capacitors				
		10 kW	100 kW		10's MW	100's MW

Why energy storage?

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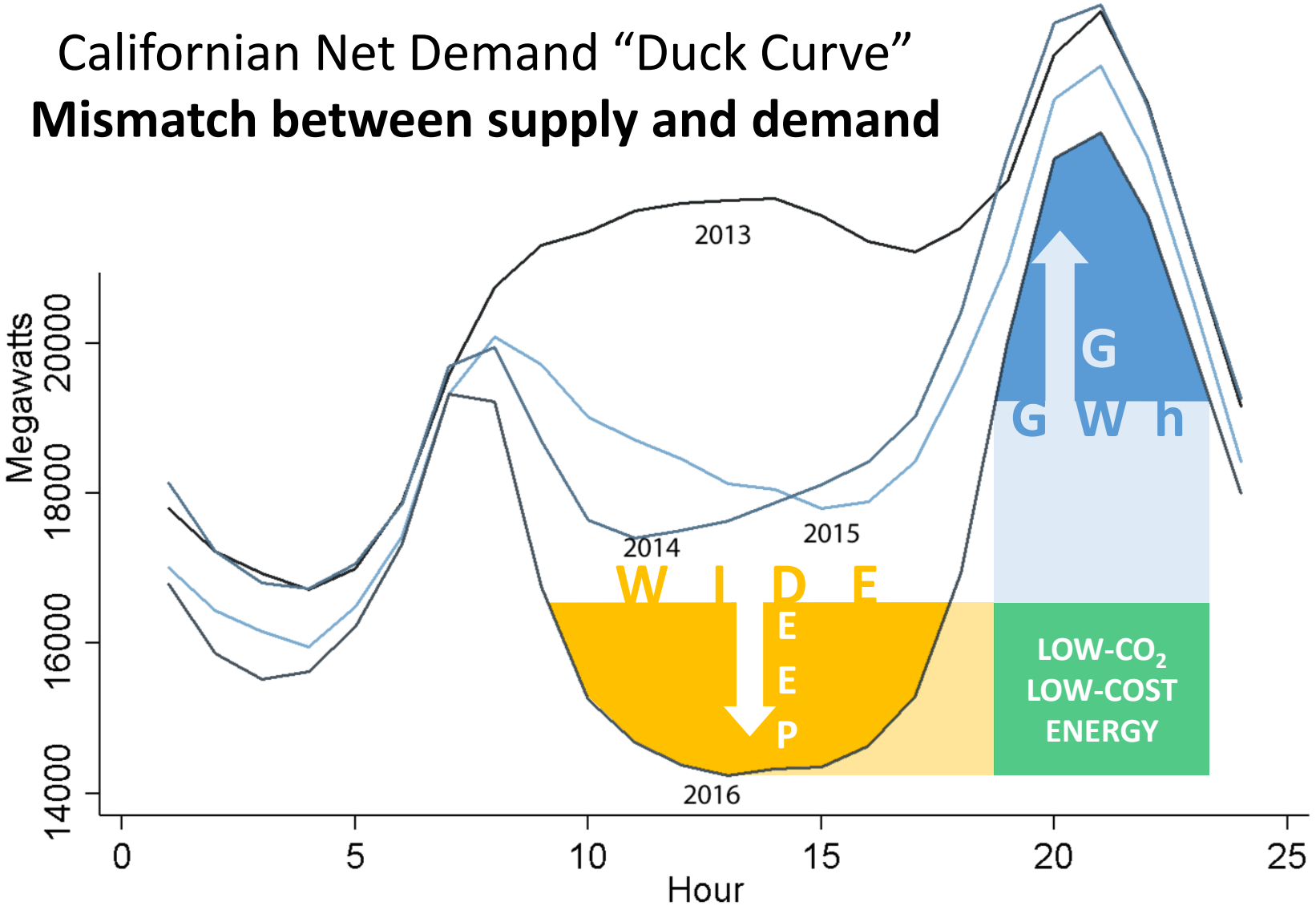
Californian Net Demand "Duck Curve"

Mismatch between supply and demand



Source: Adapted from http://reneweconomy.com.au/californias-duck-curve-has-arrived-earlier-than-expected-36106/

How does LAES work?

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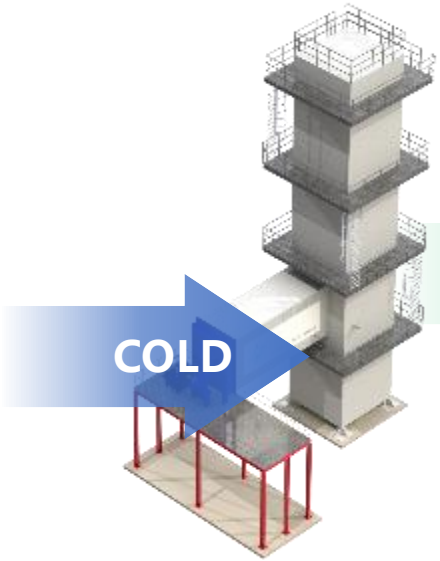
1. Charge

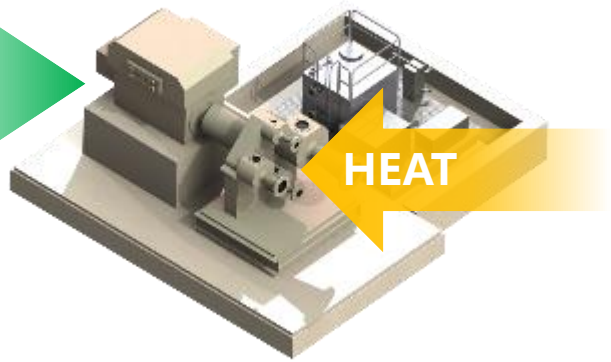


Off-peak or excess electricity is used to power an **air liquefier** to produce liquid air.

2. Store

The liquid air is stored in a tank(s) at low pressure.

3. Discharge



To recover power the liquid air is pumped to high pressure, evaporated and heated. The high pressure gas drives a turbine to generate electricity.

The three components are **independently sizeable**

LAES – Standalone Configuration

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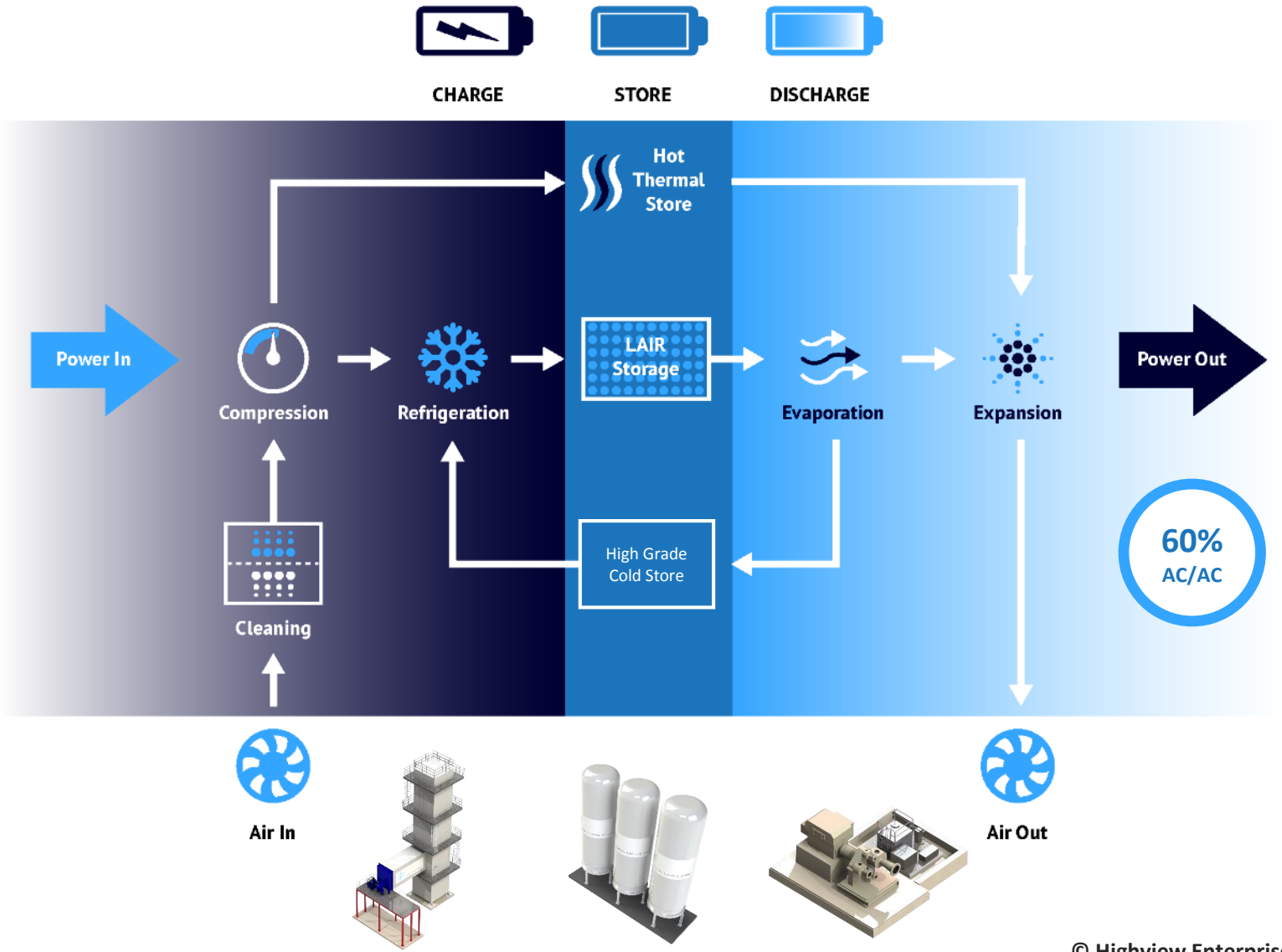

Environment

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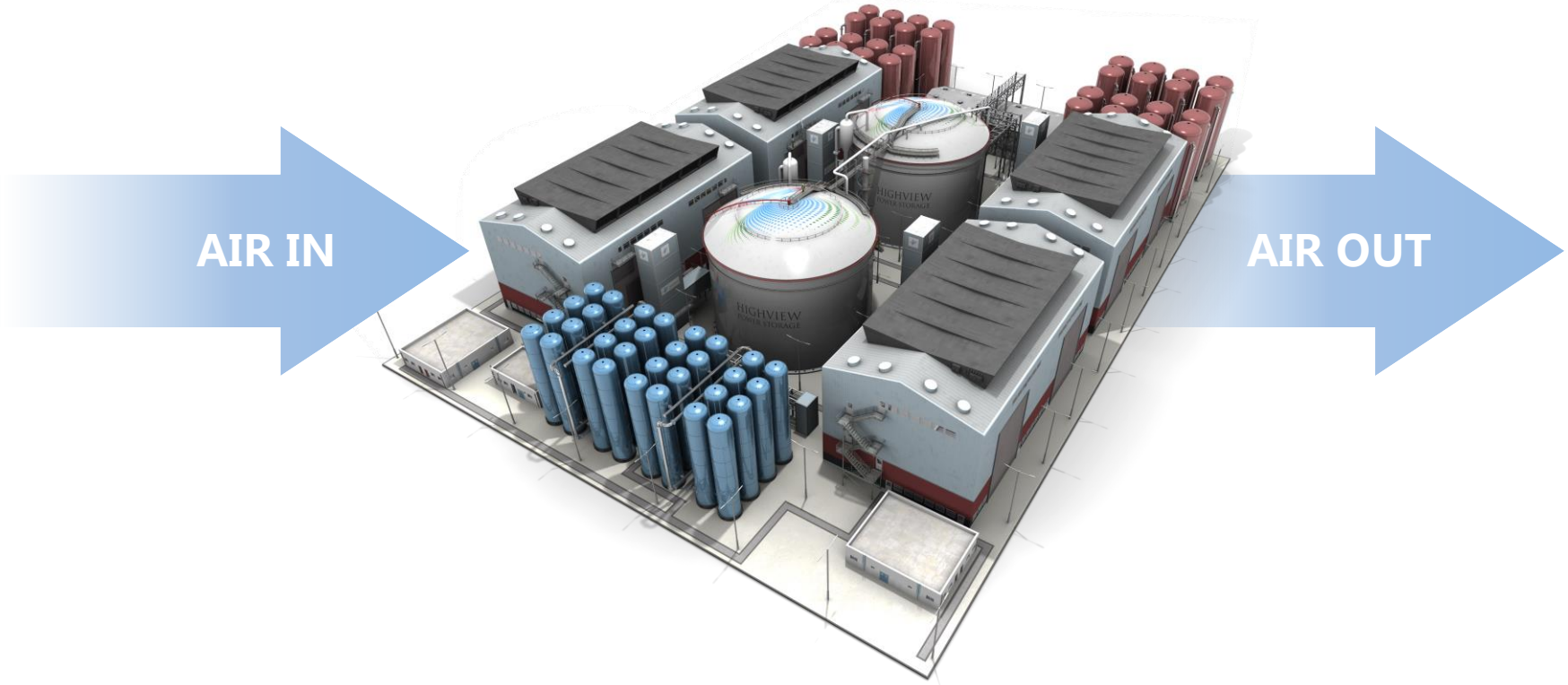
LAES cycle produces **zero emissions** and works with **benign materials**



Major Equipment Suppliers for LAES

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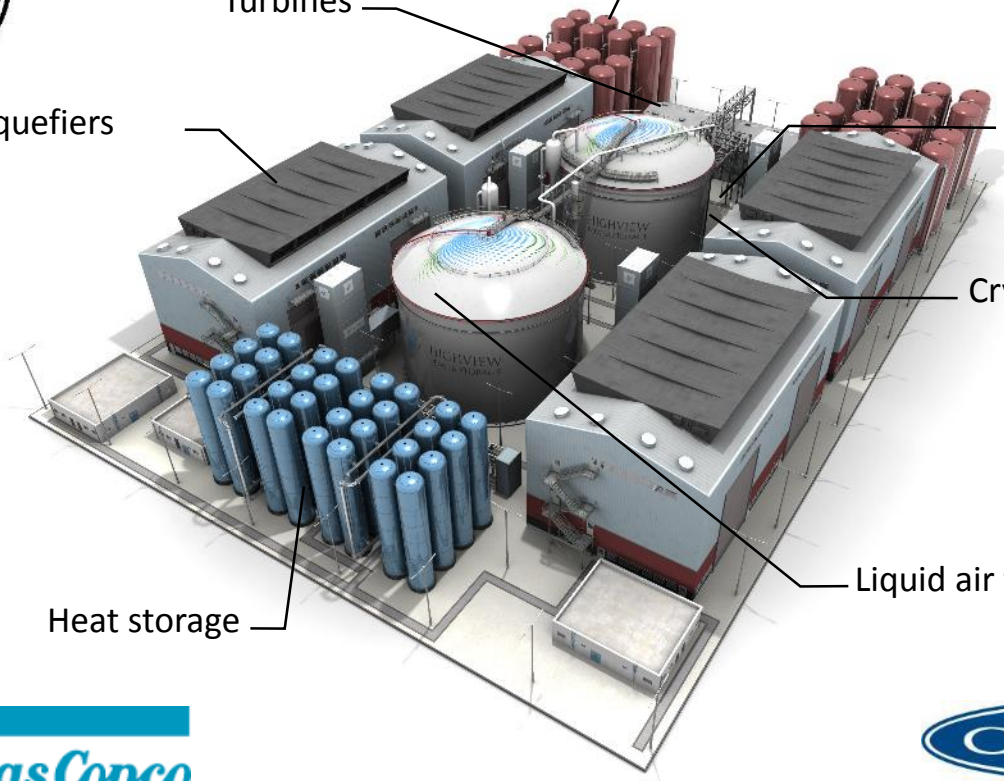
Leveraging an **established supply chain** through relationships developed through our projects



Heatric

MAN

CRYOSTAR

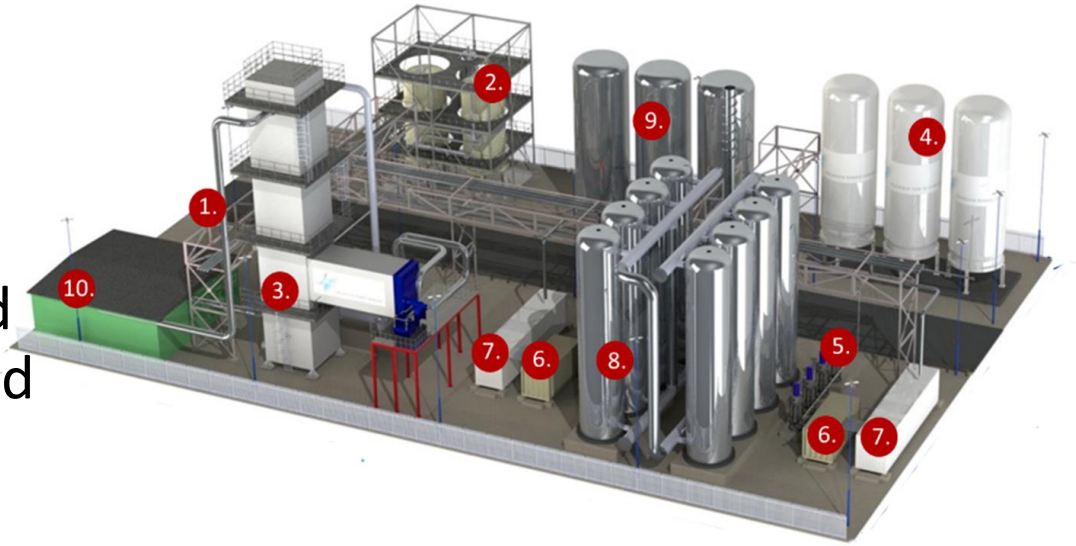
Atlas Copco

CHART
Innovation. Experience. Performance.

Layout

Adaptable layout to work within your footprint and height constraints

- Indicative footprints for 6h systems:
  - 20 MW: 0.5 acres
  - 200 MW: 4 acres
- Layout can be configured to the available space and shape of the plot.
- Equipment can be selected according to height requirements (vertical/horizontal tanks)



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

LAES technology benefits

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A **highly customisable** storage solution offering **unique advantages**

Mature components with lifetime of **30+ years**

Cost and revenue **improve with scale**

60% efficiency in standalone configuration

70%+ efficiency by utilizing **waste heat or cold**

Large-scale GW and GWh

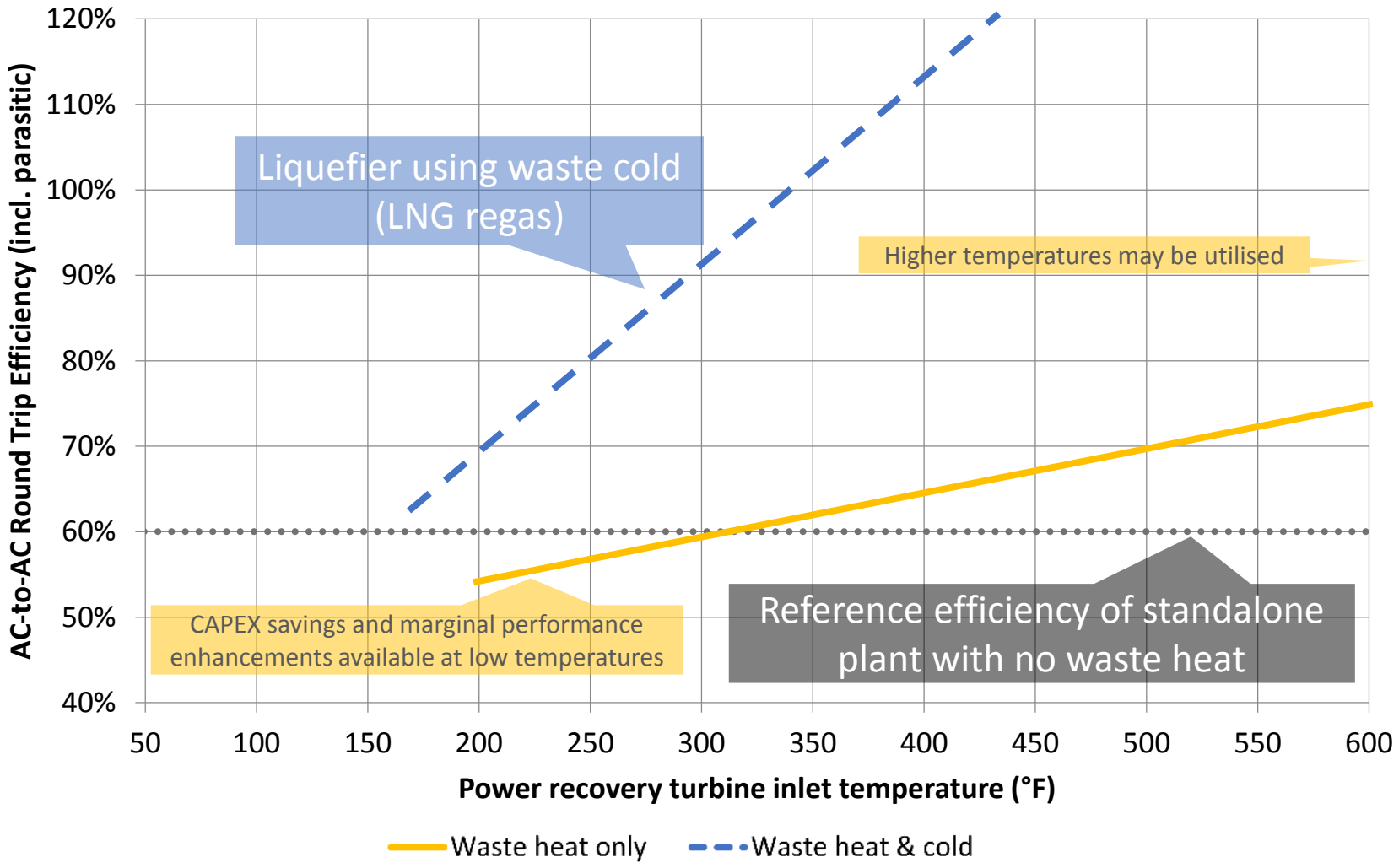
Can be **built anywhere**

Zero emissions and benign materials

Ready to deploy with an established supply chain

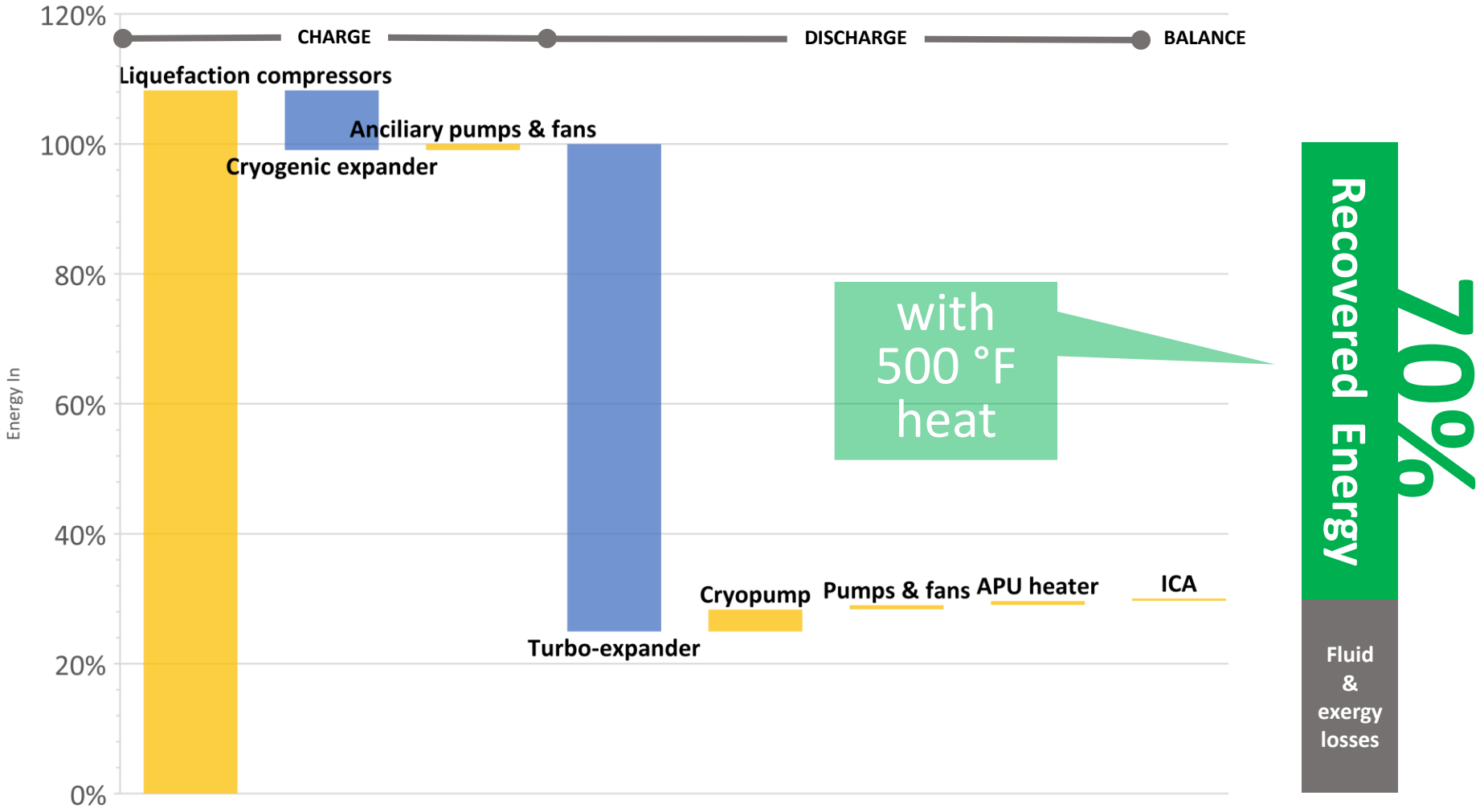
Performance – Round Trip Efficiency

Efficiency depends on temperature of waste heat and availability of cold and on scale



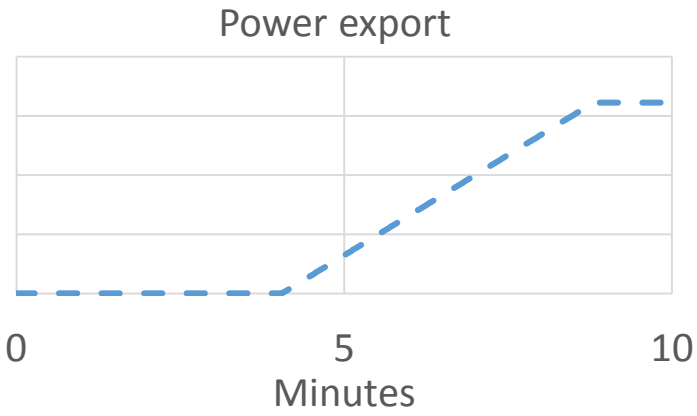
Ancillary loads and parasitic losses

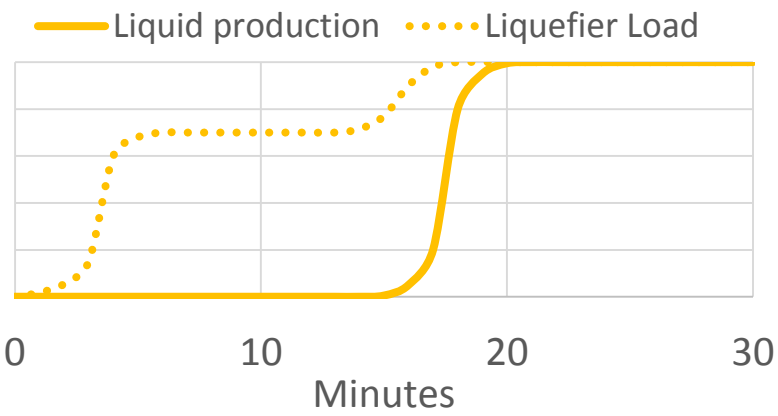
Highview's patented cycle maximizes recoverable energy



Performance – power recovery response

Capable of dispatch **faster than a classic peaking unit**



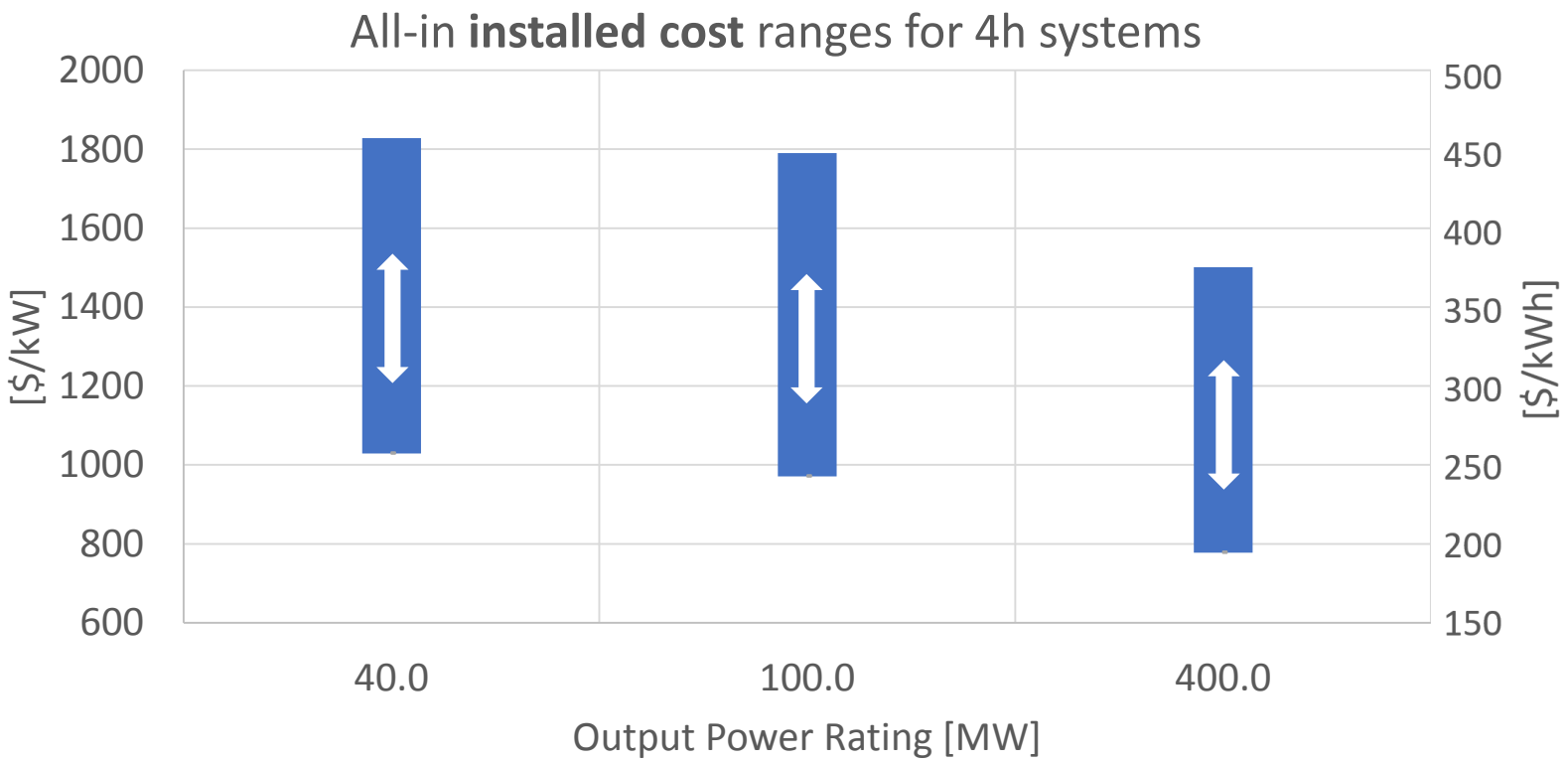


Mode of Operation	Time to export	Ramp rate
Standard	< 5 minutes	20% P_n / min
Spingen	< 30 seconds	5% P_n / sec

Mode of Operation	Time to load	Ramp rate	Time to liquid production
Standard	< 5 minutes	20% P_n / min	10 - 20 minutes from cold
Load bank	Instantaneous		10 - 20 minutes from cold

Economy of scale

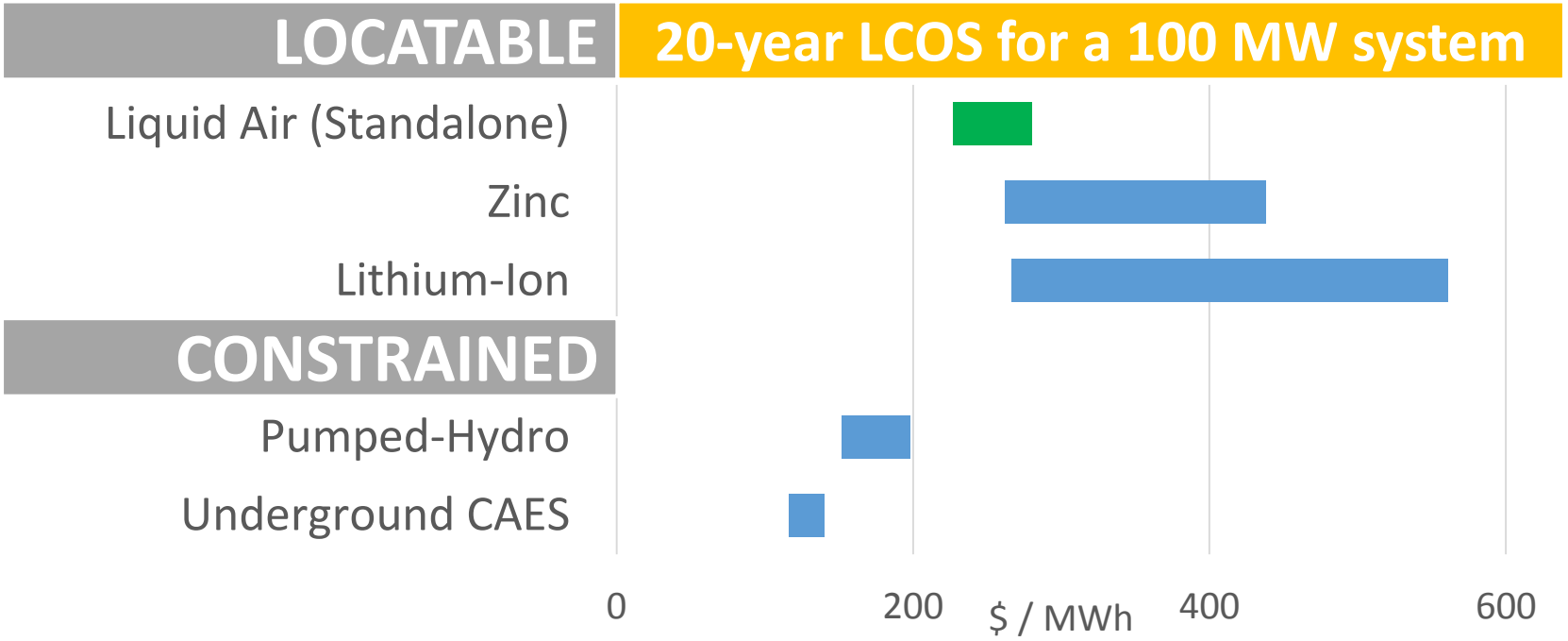
Costs reduce with scale and can be optimised by careful configuration



Lifetime cost

Lowest cost large-scale energy storage technology that can be **built anywhere**

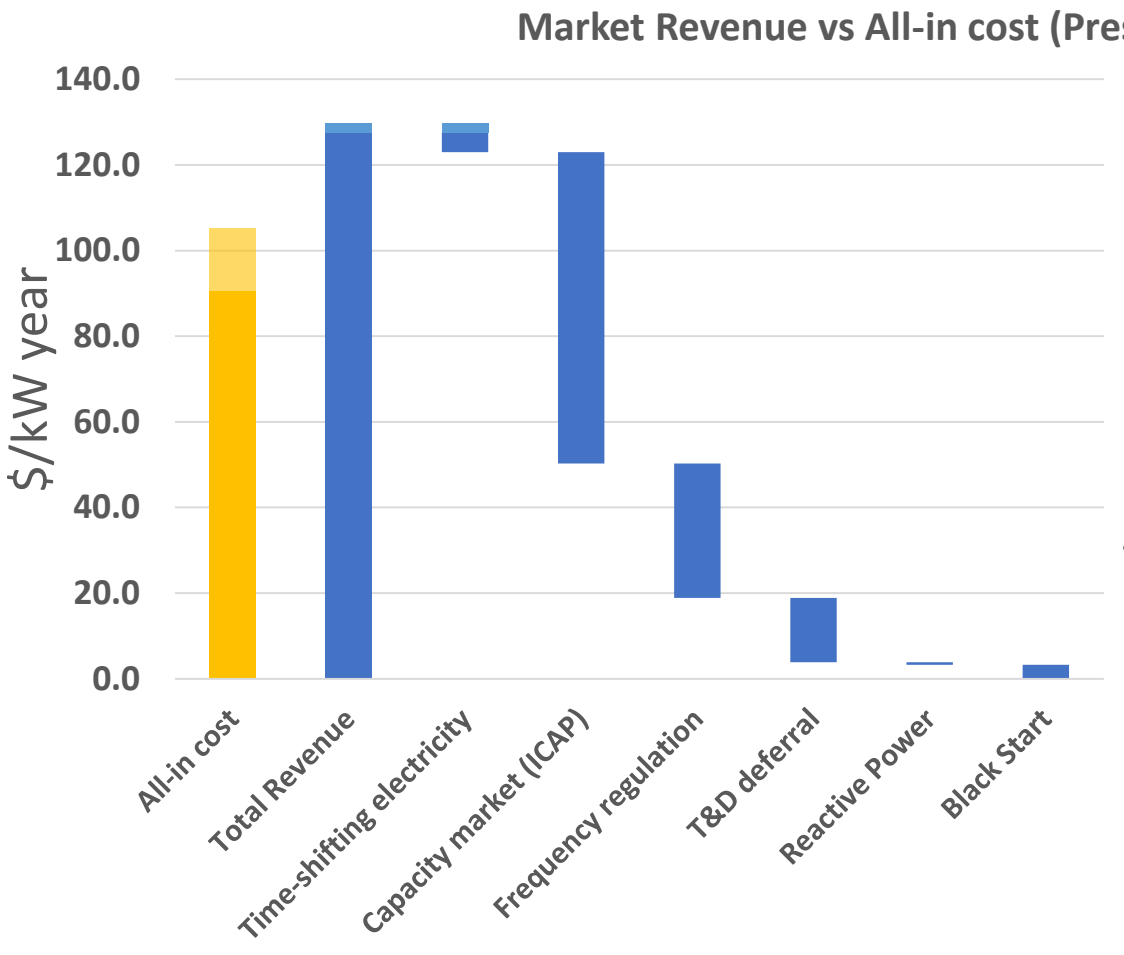
$$\text{Levelized Cost of Storage} = \frac{\sum_t \left(\left(CAPEX_t + O\&M_t + Replacement_t + Fuel_t \right) * (1+r)^{-t} \right)}{\sum_t \left(Electricity\ Generated_t * (1-r)^{-t} \right)}$$



SOURCE: Data from *Lazard LCOS 2.0* (*https://www.lazard.com/media/438042/lazard-levelized-cost-of-storage-v20.pdf*)

Revenue stacking

Positive returns add up by stacking sources of revenue



Further revenues available for thermally-integrated plant:

- **O&M savings** from reduced cycling
- **Reduced emissions**
- Potential **performance improvements** or **OPEX savings** through LAES process integration

Reserve capacity

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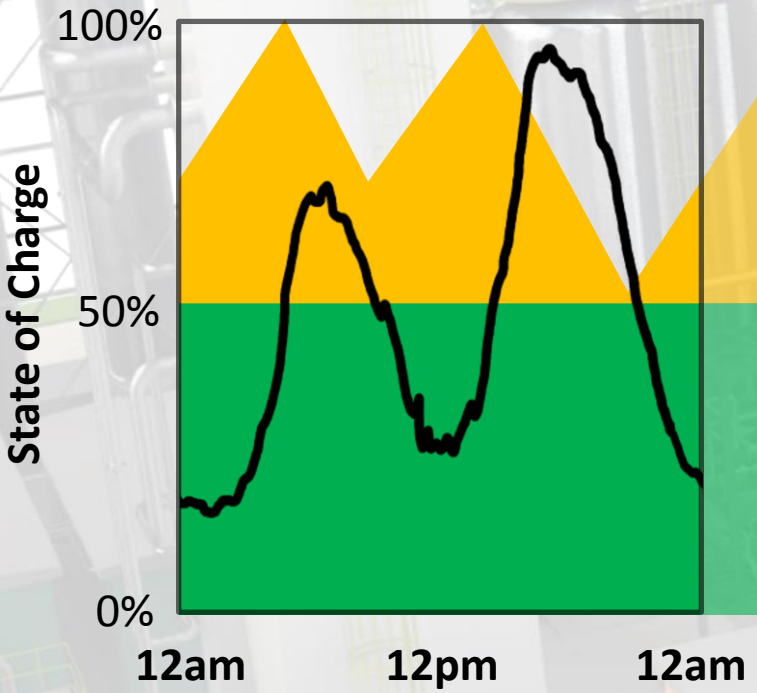
Low marginal cost of additional energy capacity

(as little as 20 $/kWh$_{CAPEX}$*)

Low-cost Reserve Capacity can be held for events such as black start or infrequent peak events to avoid T&D upgrades.



*as low as $20/kWh with heat available, as low as $40/kWh without.

Potential benefits of thermal integration

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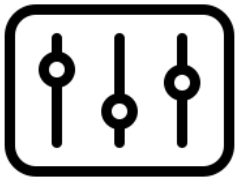
Integration of LAES with thermal plant offers **mutual benefits**

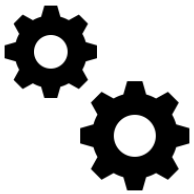


Optimise plant operation with potential to:

- Reduce cycling
- Reduce fuel costs
- Influence merit order placement

Reduce cost with potential to:

- remove LAES sub-systems
- share components
- share services



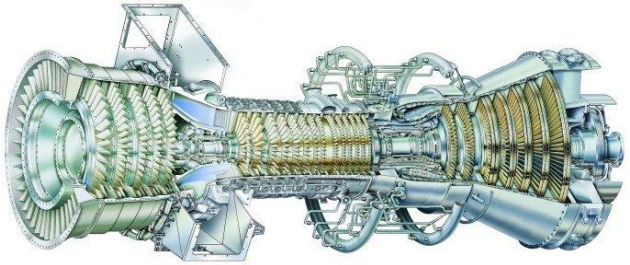
Improve performance of the whole system by:

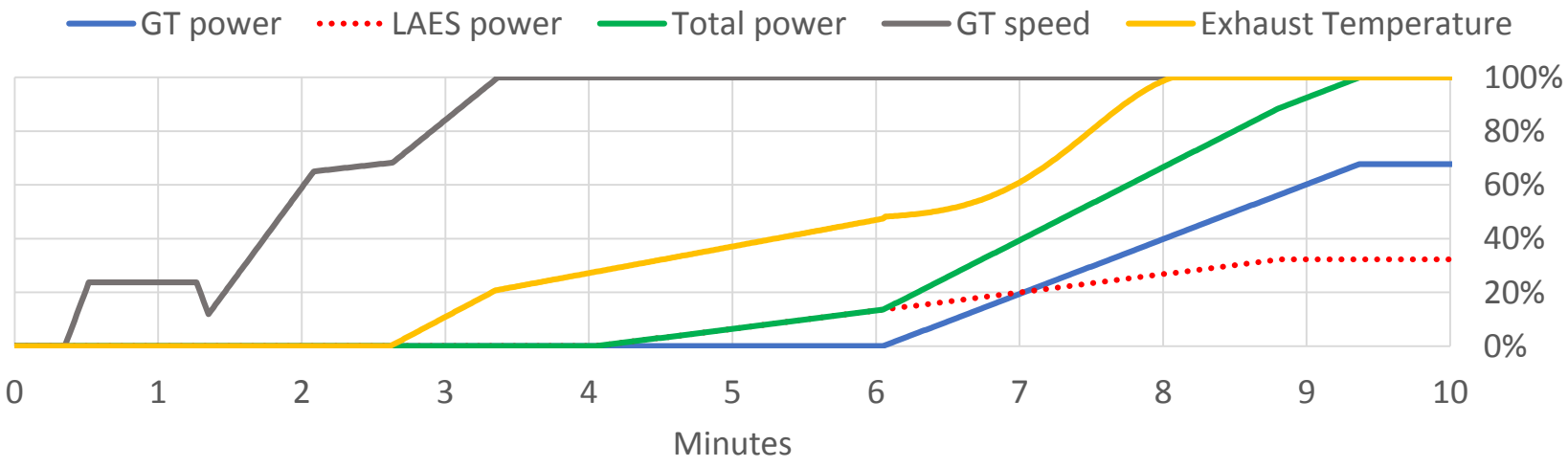
- boosting LAES efficiency
- potentially boosting power plant efficiency
- leveraging plant synergies

Example 1: Peaker plant

Improved Peaker offering: enhanced capacity and storage services

- 900 °F waste heat
- Up to 70% Round-Trip Efficiency
- Charge off peak / dispatch with the gas turbine
- Developed in collaboration with General Electric





Example 2: steam cycle

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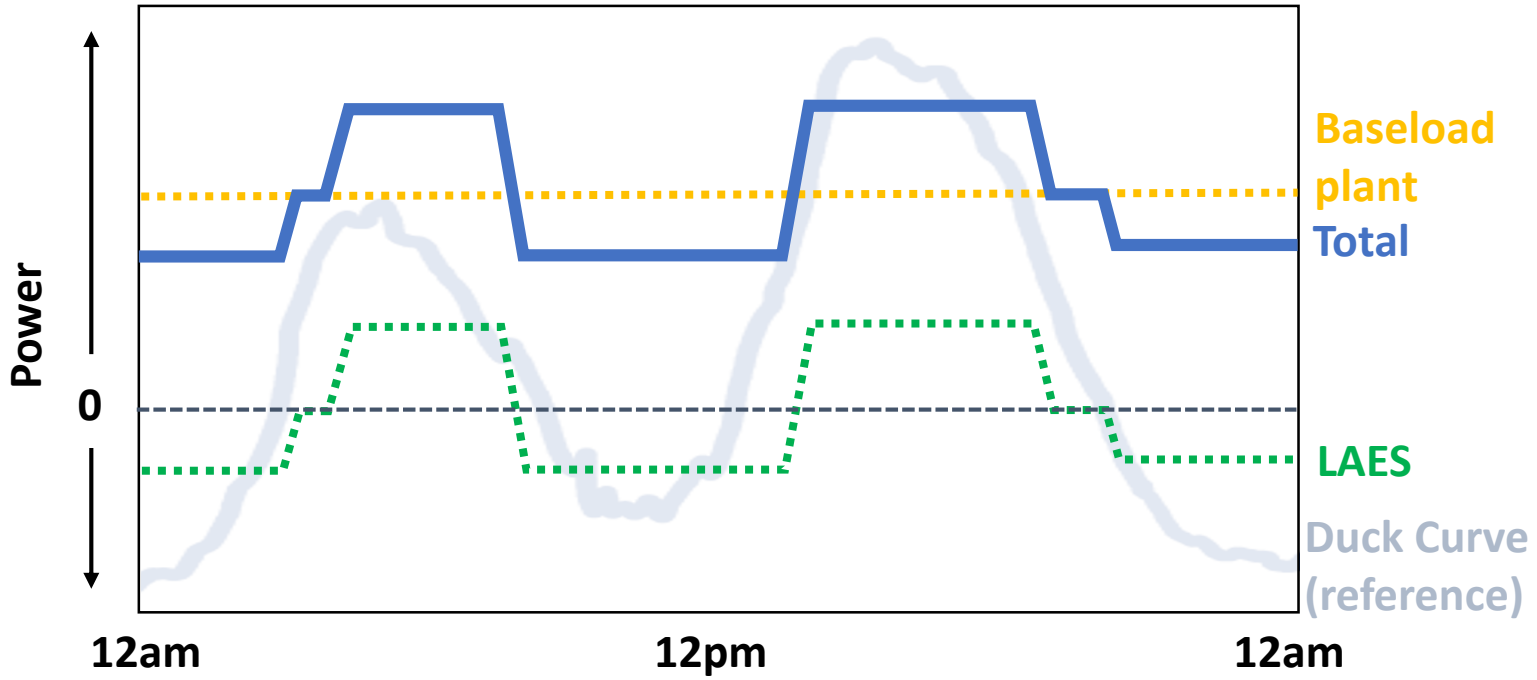
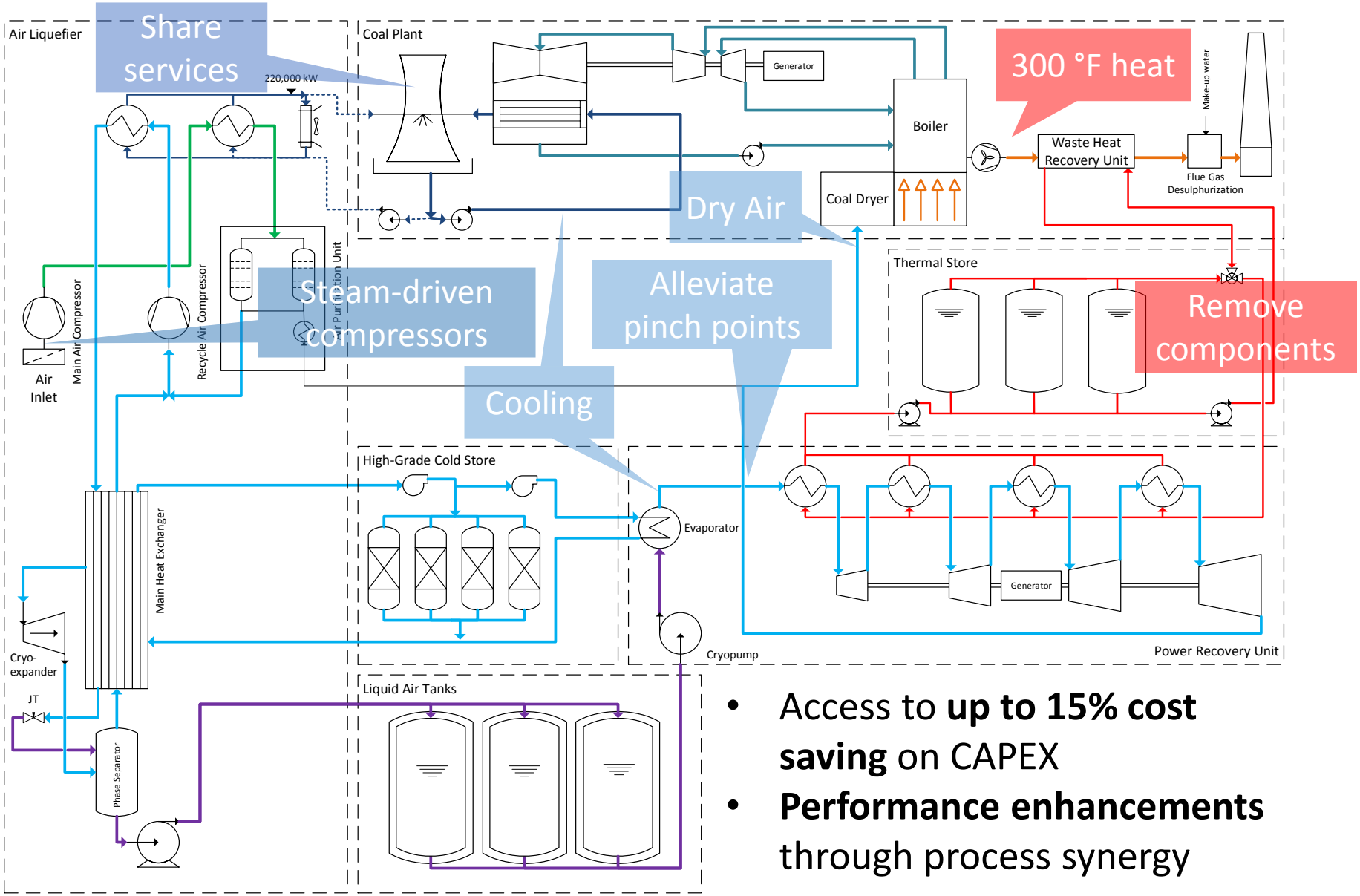
LAES with a baseload plant can be **a more flexible asset**

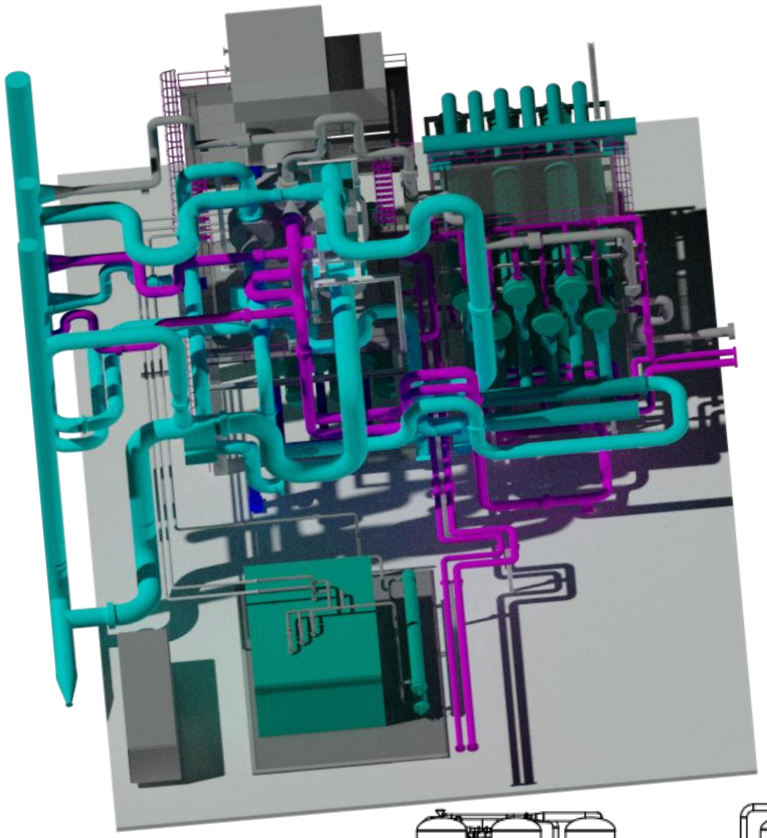


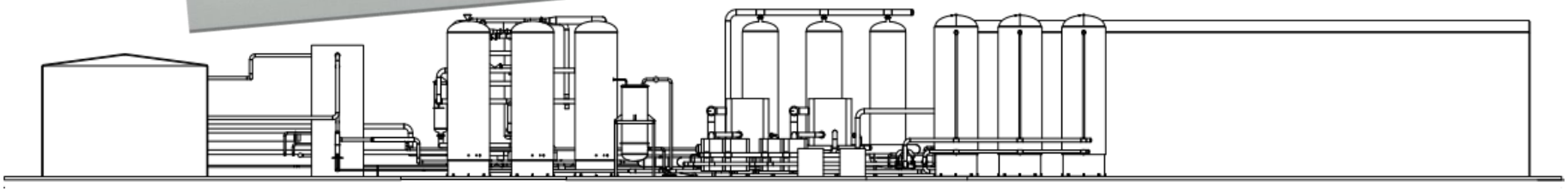
Example 2: steam cycle



- Access to **up to 15% cost saving** on CAPEX
- **Performance enhancements** through process synergy

Next generation LAES (Hybridisation)





Enhanced LAES system utilising ultra capacitor and flywheel technologies

Demonstration project currently in construction phase will be operational summer 2018

The benefits include;

- Near instantaneous import response
- Near instantaneous export response
- Reduced main turbine start-up

Contact Us

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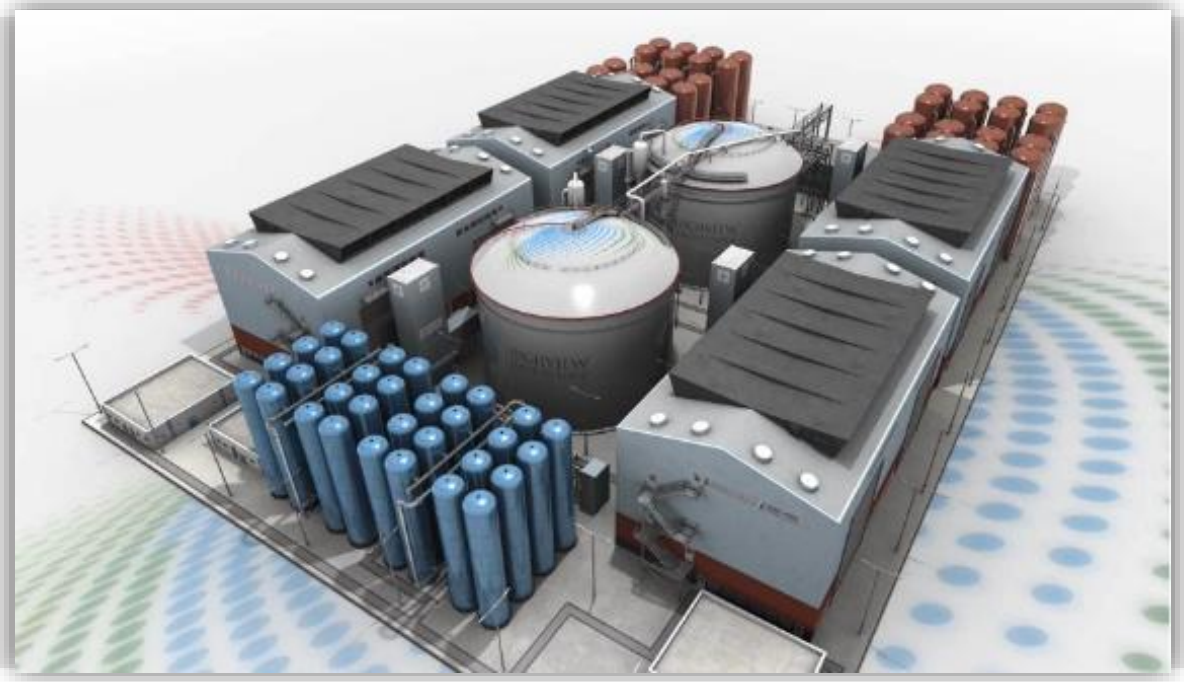

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