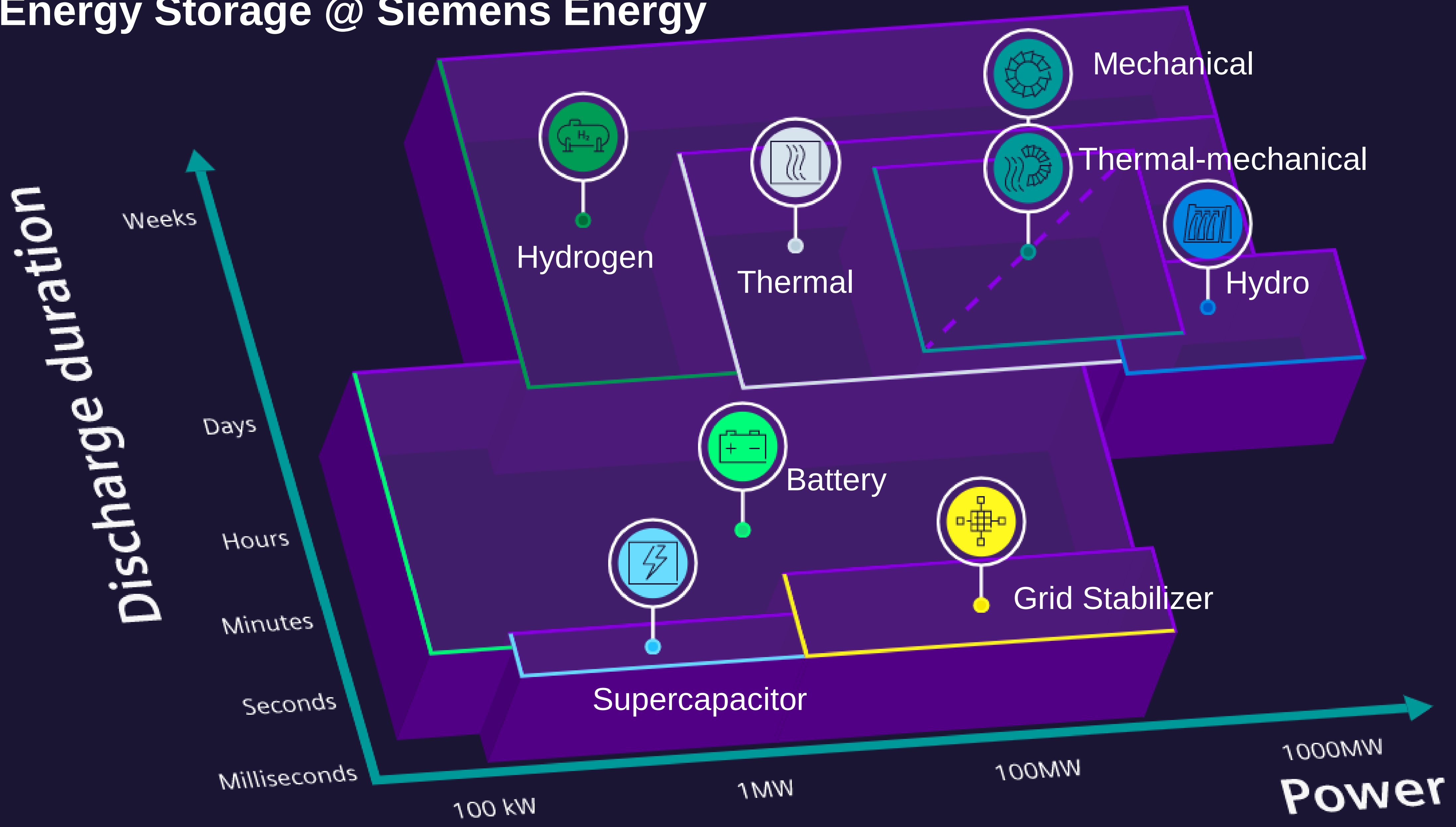
Compressed Air Energy Storage (CAES)

3rd Thermal-Mechanical-Chemical Energy Storage Workshop

August 2021

Energy Storage @ Siemens Energy



https://www.siemens-energy.com/global/en/offerings/storage-solutions.html

Compressed Air Energy Storage Introduction

Overview

- Improves utilization of renewable energy resources by **absorbing energy that might otherwise be curtailed**
- Increases grid capacity utilization, balancing, and reserve services
- **GW-hr energy storage** for supporting base load generators and load management
- Includes: Above ground systems, plant engineering, procurement, construction, installation, start-up services, long term service support

Client Value Proposition

- **Long duration storage**
- Energy and ancillary services with low fuel consumption
- Excellent load-following capacity and **part-load efficiency**
- High ramp rates and fast start-up
- **Independent operation of compression and expansion**
- Significant plant scope available from single source

Cycle flexibility and long storage duration – key to grid scale energy storage offerings

APPLICATIONS

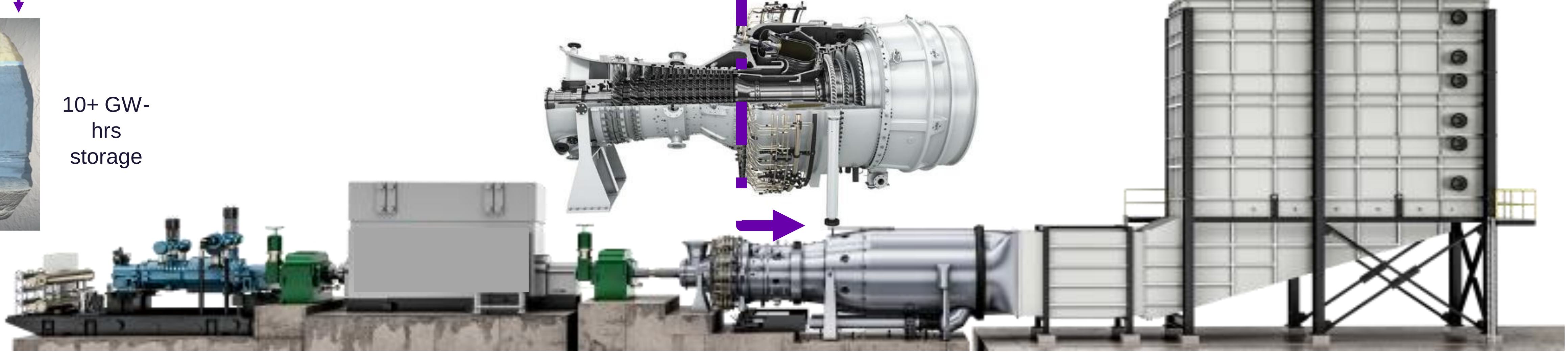
- Regulation & ancillary services
- Avoidance of renewable curtailment
- Transmission optimization

Compressed Air Energy Storage
Simple Concept - cut gas turbine into two pieces

Absorb and store excess energy

- Modular concept
- Significant Siemens OEM product scope
- Up to turnkey offering
- Performance, delivery and emission guarantees

10+ GW-hrs storage



Precise air flow management allows for wide operating range (16 – 160 MW)

“Air Battery” – Time Shift Load Absorbing Compressor from Power Generating Turbine

Compressed Air Energy Storage
Reference - McIntosh CAES Plant

Application: CAES
Country: USA
Commercial Operation Year: 1991
Client: PowerSouth Energy Cooperative

Scope of Supply

CAES

- Expander: 154.7 kg/s,110 MW
- Compressor: 89.5 kg/s, 49 MW
- Storage: Salt Dome @ 540,000 m^3
- Pressure Range: 45-75 bara

Siemens overall

- 2x W501F gas turbines
- 2x V84.2 gas turbines
- T3000 plant-wide control system
- Fuel gas booster compressors
- RG3 brushless excitation system
- D3000 vibration monitoring package
- D4 static excitation

Project Background

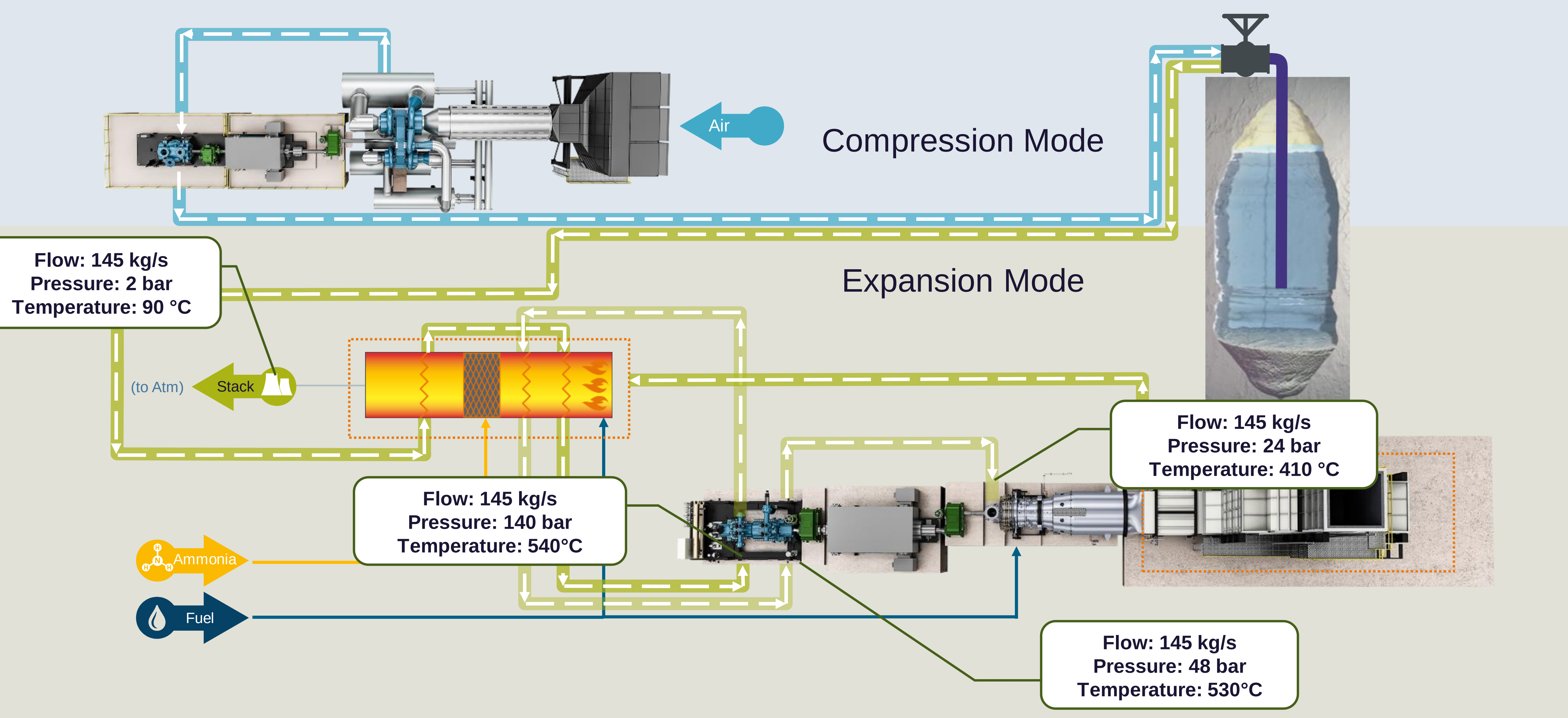
- PowerSouth had issues meeting electricity demands during peak usage periods
- Operating smoothly, economically and reliably for nearly 30 years
- Plant reliability rate now at 98.9%

Client Benefit

- Quick start capability during critical power outages
- Cost-effective power and a strong backup resource
- Operate their base-load plants more efficiently
- Control of entire plant from a single interface

Note: Refer to EPRI Report TR-101751 V1&V2 for extensive documentation concerning the McIntosh CAES Project

Compressed Air Energy Storage
Cycle Schematic – Simultaneous Operating Modes



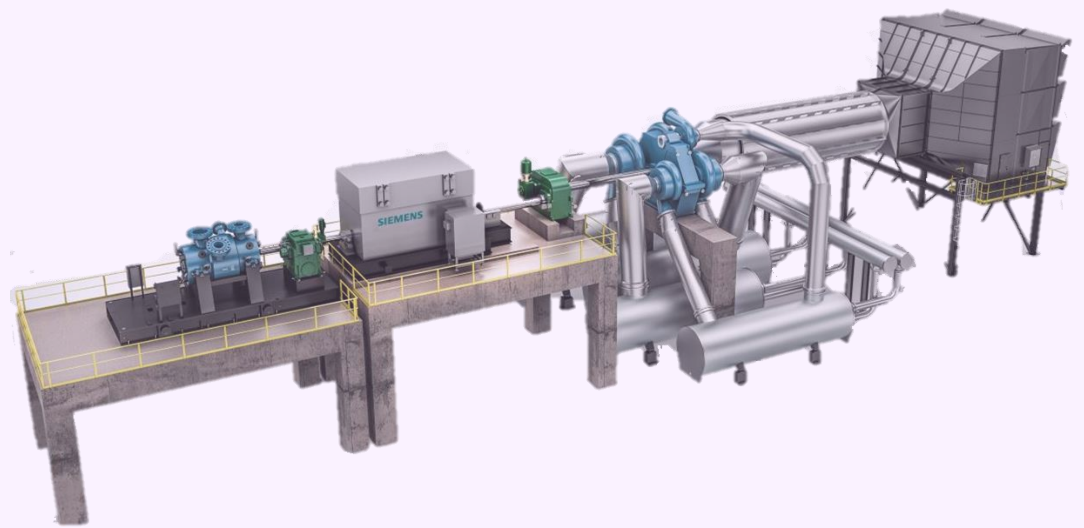
Compressed Air Energy Storage
Grid Scale Interruptible, Controllable Load Absorption

- Six-stage Integrally Geared LP Compressor
- Two-stage Inline Type HP Compressor
- Double-ended Drive 2-pole Electric Motor
- Water-cooled heat exchangers
- Up to 125 MW
- 30% turndown & 30% ramp rate per minute
- 4 minutes from offline to full load
- Interruptible demand response

DATUM - over 1,200 installed

STC-GV - over 2,000 installed

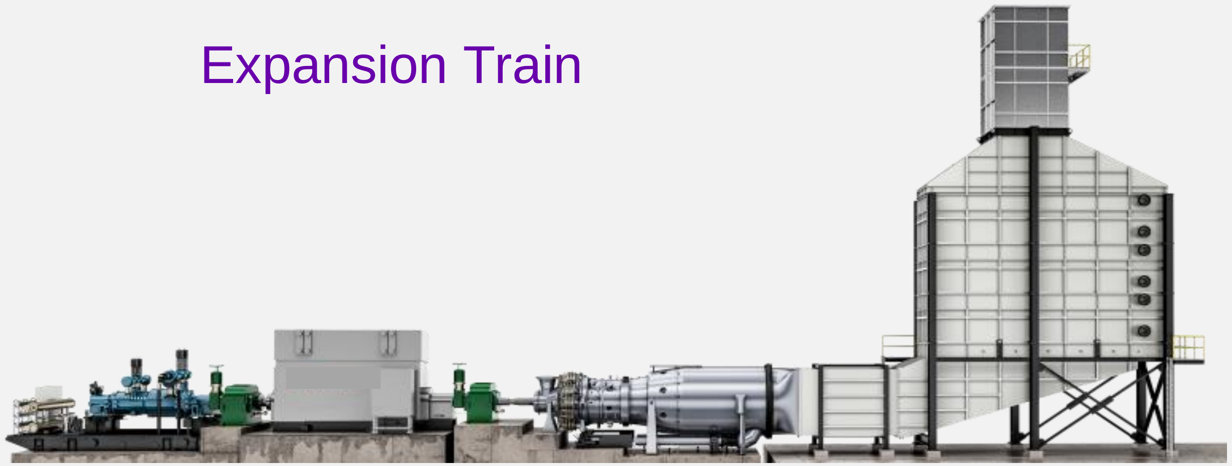
Compression Train



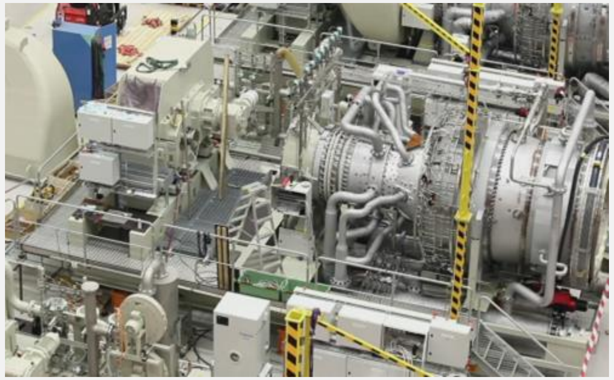
Efficient and Flexible Demand Response with GW-hrs of Energy Storage

Compressed Air Energy Storage
Equipment Configured to Operate as a “Super Peaker”

Expansion Train



SST-800 - over 130 installed



SGT-800 - over 350 installed

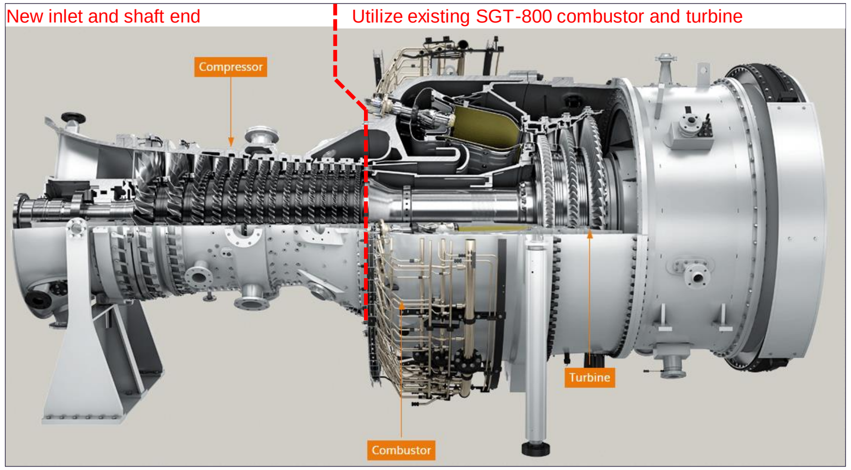
- 160MW and 140MW max design output
- Less 20MW min generation output.
- VHP and HP Expander derived from Siemens SST-800 steam turbine
- LP Expander with DLE combustion system derived from Siemens SGT-800 gas turbine
- Double-ended Drive 2-pole Electric Generator
- 20% ramp rate per minute
- Full generation in 10 minutes
- 90% effective recuperator with duct burner and Selective Catalytic Reduction system
- Up to 50% H2 co-firing; path to 100%

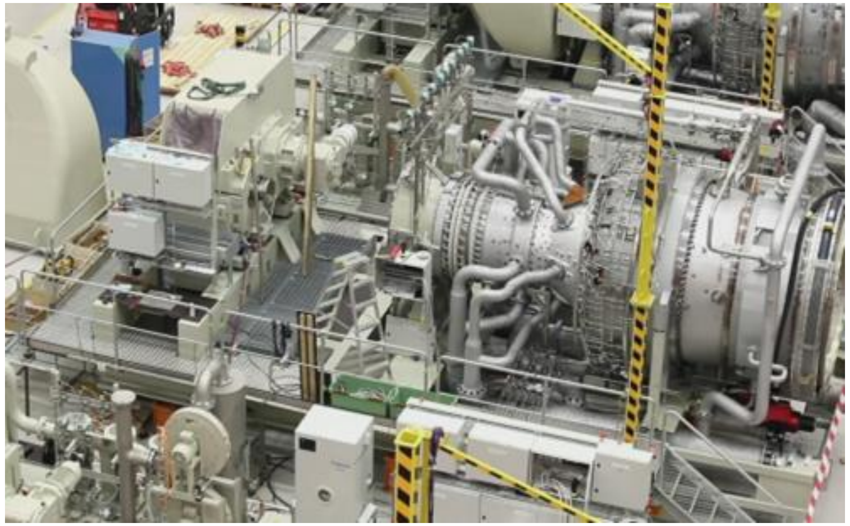
Unmatched Operating Range Provides Needed Flexibility to Balance Complicated Generation Mix

LP Expander derived from SGT-800 Gas Turbine (SXT-800)

Advantages of SXT-800 CAES Solution

- Large installed base and operating experience with the combustion and high-temperature turbine hardware
- State-of-the-art emissions achievable with DLE (no water injection)
- Performance improvement of the expander system due to higher turbine inlet temperature
- Smaller air piping for the same power output level leading to lower cost in the plant and potentially in the cavern and wellbore
- Experience of service personnel in installation, commissioning, and long-term maintenance of the SGT-800 hardware
- Significant size, experience, and capability of the SGT-800 core unit engineering teams to help solve any problems that may arise in the field





Compressed Air Energy Storage Expander Cycle Flexibility

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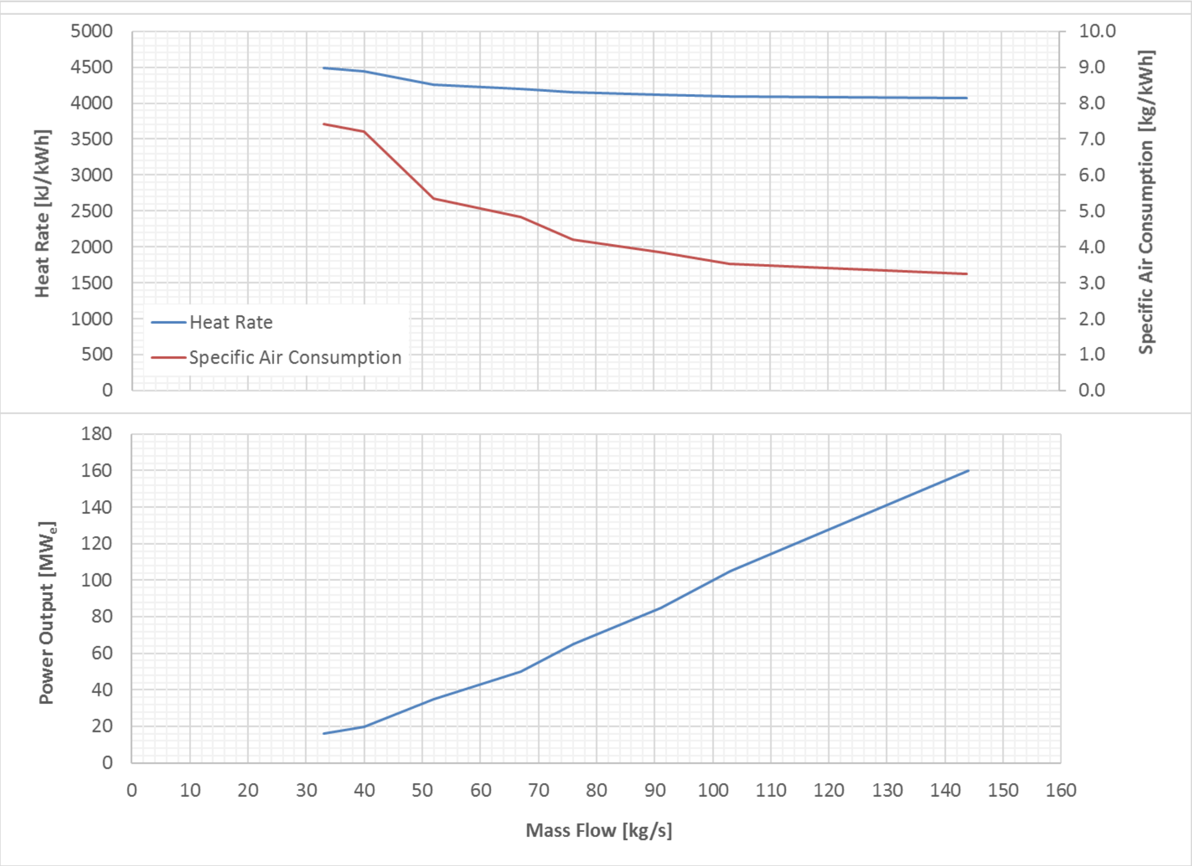

Performance demonstrates wide operating range

Power	Heat Rate	System Flow	Fuel Usage*
MW	kJ/kWh	kg/s	kg/s
160	4067	144	3.9
105	4095	103	2.5
85	4120	91	2.1
65	4157	76	1.6
50	4199	67	1.2
35	4257	52	0.9
20	4440	40	0.5

*natural gas lower heating value

Near Flat Heat Rate, High Turndown, Rapid Regulation Response Allows An Unmatched Balancing Asset

Siemens Hydrogen Gas Turbines for our sustainable future
The mission is to burn 100% hydrogen

Gas turbine model		Power Output[1]	H_2 capabilities in vol. %
50Hz	SGT5-9000HL	593 MW	30
	SGT5-8000H	450 MW	30
	SGT5-4000F	329 MW	30
	SGT5-2000E	187 MW	30
60Hz	SGT6-9000HL	405 MW	30
	SGT6-8000H	310 MW	30
	SGT6-5000F	215 to 260 MW	30
	SGT6-2000E	117 MW	30
50Hz or 60Hz	SGT-A65	60 to 71/58 to 62 MW	15 / 100
	SGT-800	48 to 62 MW	50
	SGT-A45	41 to 44 MW	100
	SGT-750	40/34 to 41 MW	40
	SGT-700	33/34 MW	55
	SGT-A35	27 to 37/28 to 38 MW	15 / 100
	SGT-600	24/25 MW	60
	SGT-400	10 to 14/11 to 15 MW	10 / 65
	SGT-300	8/8 to 9 MW	30
	SGT-100	5/6 MW	30 / 65
	SGT-A05	4 to 6 MW	2 / 15

Values shown are indicative for new unit applications and depend on local conditions and requirements. Some operating restrictions/special hardware and package modifications may apply.

Higher H_2 contents to be discussed on a project specific basis

DLE burner | WLE burner | Diffusion burner with unabated NOx emissions

Heavy-duty gas turbines | Industrial gas turbines | Aeroderivative gas turbines

1 ISO, Base Load, Natural Gas; Version 3.4, July 2020

EU-Turbines Commitment to drive the transition towards a decarbonized Energy Mix

Hydrogen co-firing commitment from EU-Turbines

In January 2019, Siemens signed a **commitment on H_2 co-firing** in gas turbines at the #PowerTheEU summit

Today: Operation with **3 – 5% H_2** content
(→ already achieved for all new GT models)

2020: Operation with **20% H_2** content
(→ already achieved for most GT models)

2030: Commercial availability of turbines for **100% H_2**
(→ already achieved for AD-GTs, R&D and implementation plans in place to cover more GT models until 2030)

https://powertheeu.eu/

Siemens R&D activities to increase hydrogen capabilities

Siemens lately invested in in-house H_2 testing capabilities at Clean Energy Center in Berlin – Single burner tests at engine conditions

Engine Tests for SGT-600/700/800 running on H_2 in DLE (dry low emissions) combustion systems has resulted in sales release of 60/55/50 vol-H_2 respectively

Ongoing development to increase capabilities of our engines

Salt formations – North America

- Pressure holding capability is our main question. Can be sized to whatever client desires. Size equates to MW-hrs of storage.
- Rule of thumb is 0.8psi max cavern pressure per ft of depth to top of salt. So, 3200 ft to top of salt, then 2560 psi max holding pressure.
- Domal salt preferred over salt beds. Typically, domal can handle 160MW 3-stage. Salt beds at shallower depth, so 140MW 2-stage.
- Depleted gas fields – question of remaining entrained HCs.

Compressed Air Energy Storage
Commercial Considerations

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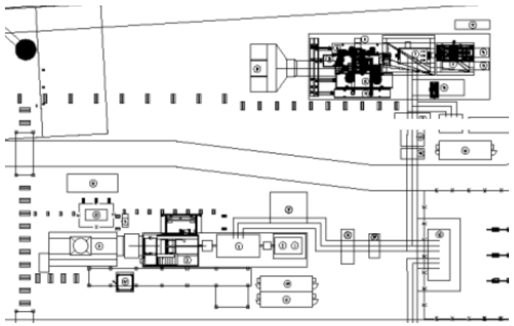
CAPEX equates to three (3) major components

- **Power Island** = [$400-600 / kW]
  - Numerous configurations w/ train quantities and compression sizing
- **Balance of Plant (BoP) / Engineering, Procurement & Construction (EPC)** = [$425-625 / kW]
  - Location, labor rates, building/site permitting, transmission interconnection, fuel pipeline, construction contingency
- **Reservoir** = [$50-150 / kW]
  - Salt cavern, aquifer, or hard rock mine
  - Greenfield vs. existing
  - Declines in $/kW-hr as cavern size increases

~5 acres per
1x compressor &
1x expander train plant



		Year 1	Year 2	Year 3
Not Siemens Scope	Cavern	Leach Plant & Cavern Creation		Installation & Commissioning
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	Trains	Equipment Build		

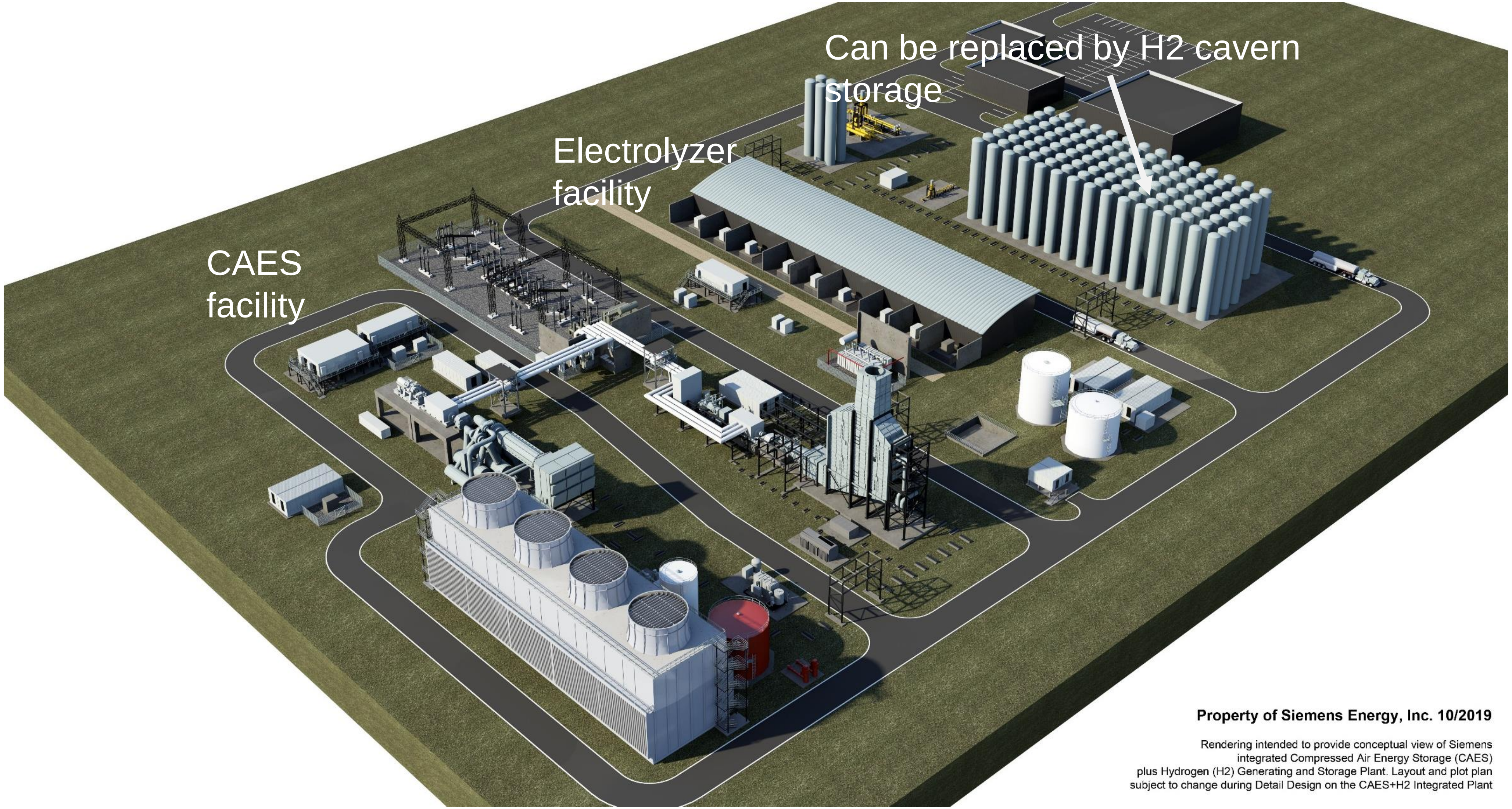
Compressed Air Energy Storage CAPEX Surface Plant Configurator

1x1 Power Train		**Amount ($MM USD)**
CAES Core Equipment		90
160MW Expansion train	$ 55	
105 MW Compression train*	$ 35	
Balance of Plant (BoP)		30
Construction		75
Subtotal - 1x1 Power Train		**195**
Each additional 1x1		
CAES Core Equipment		80
160 MW Expansion train	$ 50	
105 MW Compression train*	$ 30	
Balance of Plant (BoP)		25
Construction		65
Subtotal - additional 1x1		**170**

Notes:
- CAES core +/-10%
- BoP +/-15%
- Construction +/-20%
- BoP and Construction ~50/50% cost split between comp & exp
- 140MW equivalent is ~7.5% less cost for CAES Core and ~5% less cost for BoP and Construction.
- Typical cavern development range = $35 – 65 MM
- Each 1x1 = ~5 acres

* Assumes similar max mass flow for compression as expansion. Compression can be sized to lower or higher mass flow.

Energy (Storage) Transformation – CAES + H2



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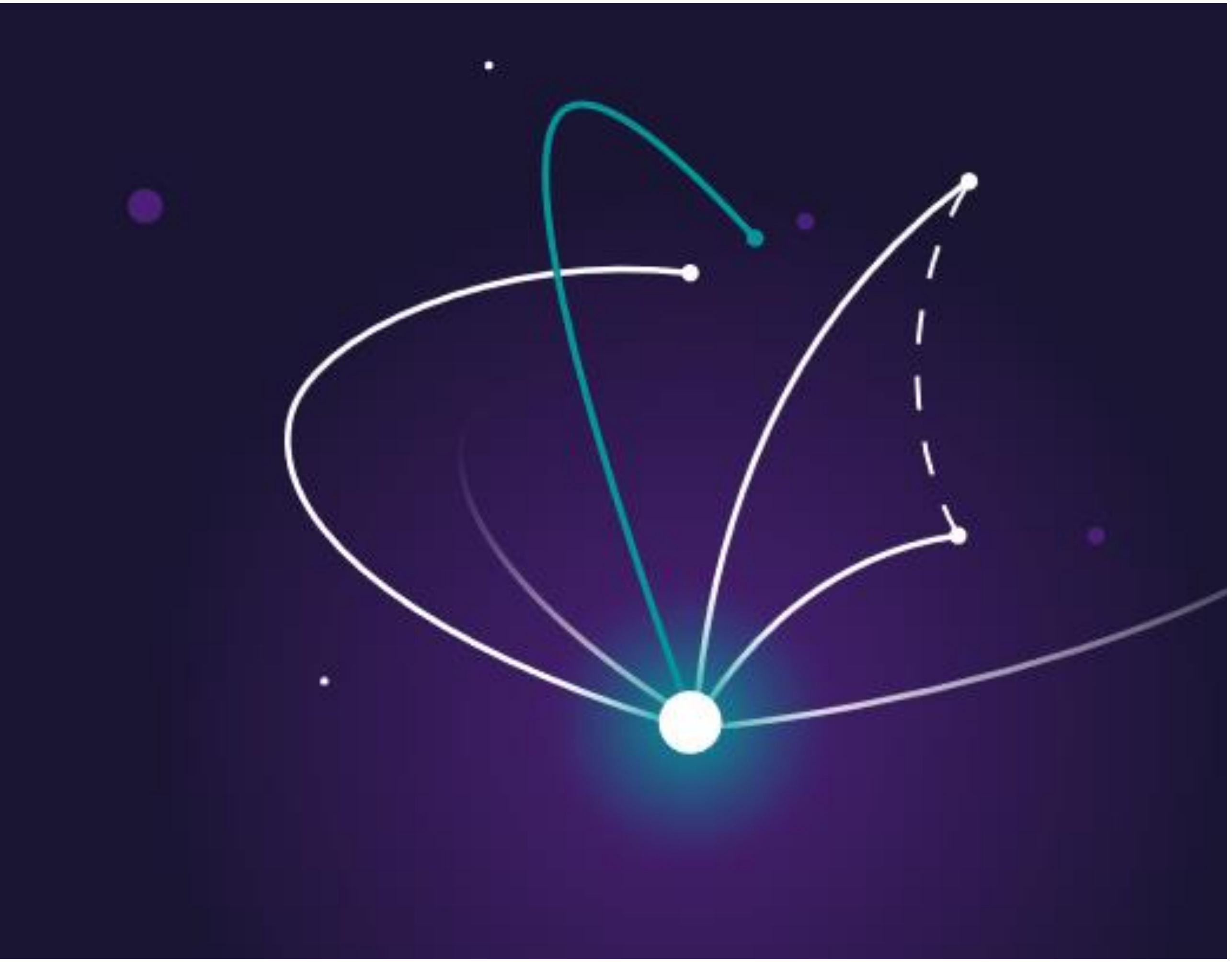

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