
DESTINATION 2050
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Current State and Advancements in Mechanical Energy Storage

Jeremy Shook - Principal Consultant, Strategic Advisory, Black & Veatch

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Agenda

- What is Mechanical Energy Storage?
- Overview of Mechanical Energy Storage Technologies
- Benefits of Mechanical Energy Storage
- What is Being Done to Advance Mechanical Energy Storage Deployment

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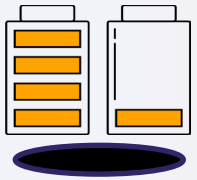
What Is Mechanical Energy Storage

Types of Energy Storage



Electrochemical
Electrochemical energy storage refers to batteries of different chemistries that store and release electricity.

Chemical
Chemical energy storage systems store electricity through the creation of chemical bonds.

Thermal
Thermal energy storage systems use electricity to create heat or cold which are stored to be used later.

Focus of Presentation

Mechanical
Mechanical energy stores potential energy for future use as electricity

Mechanical Energy Storage Technologies

- Pumped Storage Hydro (PSH)
- Compressed Air Energy Storage (CAES)
- Solid Mass Gravity Storage

Focus on Longer Duration (> 4 hours)

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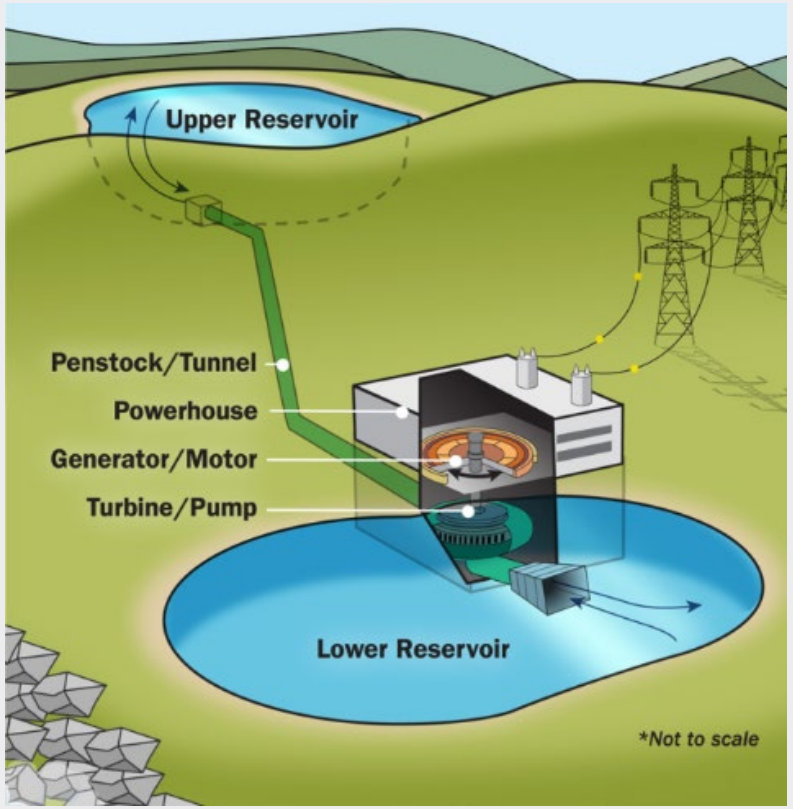
Overview of Mechanical Energy Storage Technologies

Pumped Storage Hydro

- A closed-loop gravity energy storage system that utilizes two water reservoirs at different elevations.
- Low-cost electricity is used to pump water from the lower water reservoir to the upper reservoir, charging the system.
- To discharge, water is released from the upper reservoir and spins a turbine to produce electricity. Water is then collected in the lower reservoir.
- To add hours of storage to the system you can increase volume of water in reservoirs without upgrading the power components.
- Types:
  - Open loop (river)
  - Closed loop (reservoir)



Pumped Storage Hydro (con't)

PROS

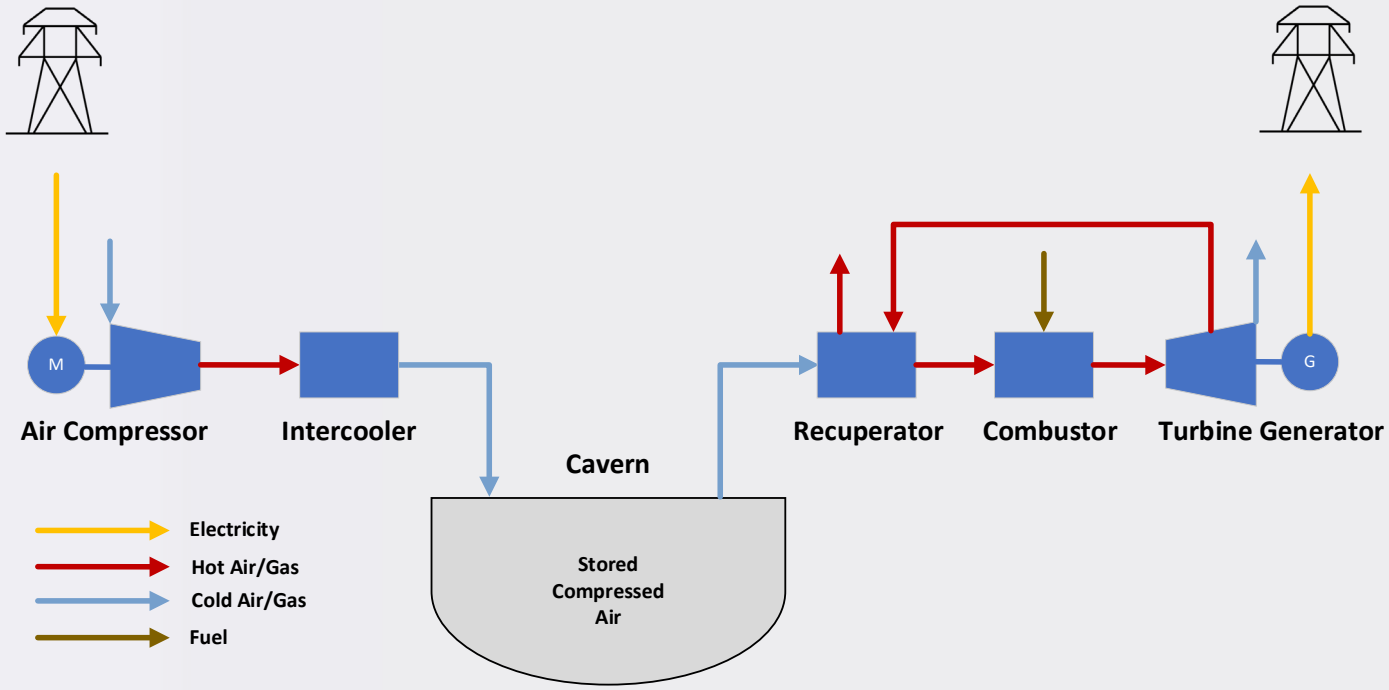
- Mature, reliable utility-scale energy storage technology.
- Low degradation leads to long project life.

CONS

- Requires specific geology for siting that provides significant elevation change between upper and lower reservoirs.
- Time required for permitting is significantly longer than other storage technologies, often extending project development timeline.

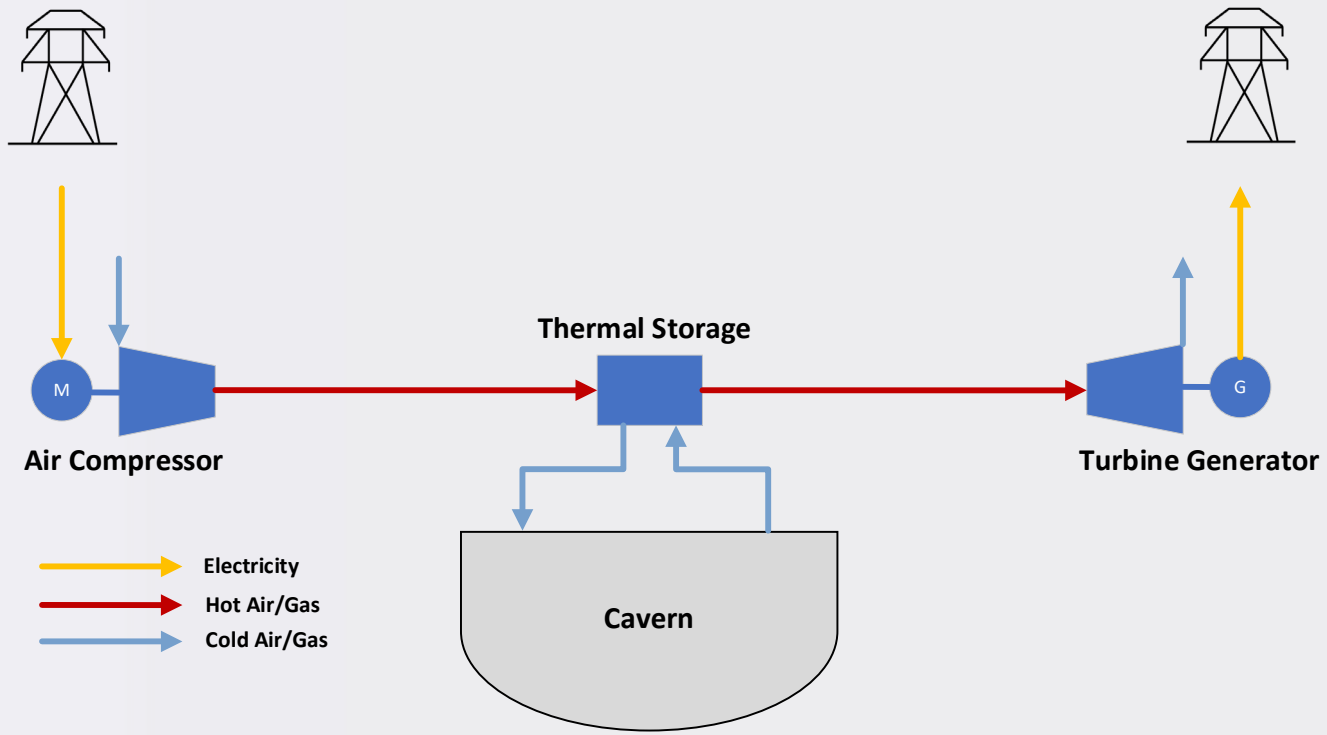
Diabatic CAES (D-CAES)

- Low-cost electricity is used to compress air.
- Compressed air is expanded in a turbine generator to produce electricity.
- Heat of compression is rejected to atmosphere.
- Compressed air is preheated with turbine extraction air and augmented with exhaust gases from a natural gas combustion.



Adiabatic CAES (A-CAES)

- Low-cost electricity is used to compress air
- Compressed air is expanded in a turbine generator to produce electricity.
- Heat of compression is stored in thermal storage medium.
- Compressed air is preheated with heat from thermal storage medium.



CAES (con't)

PROS

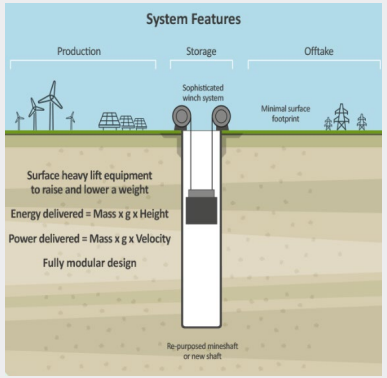
- Components are well-known in terms of their performance. Low technology risk.
- Levelized cost of storage is very low if the existing underground storage is available.

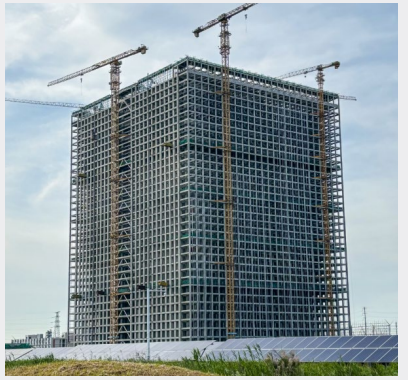
CONS

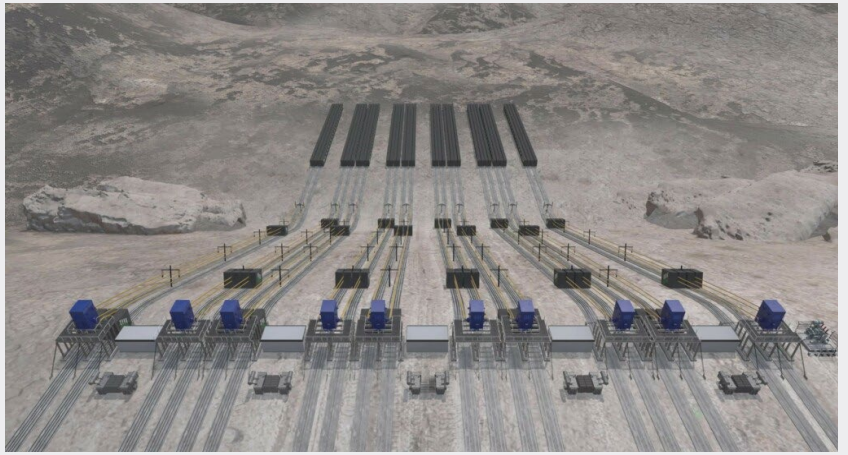
- Requires large storage volume for utility scale storage. Typically results in using a cavern which is limits suitable locations.
- Roundtrip efficiency is relatively low. A-CAES is looking to improve this.

Solid Mass Gravity Storage

- Low-cost electricity is used to lift an object, storing as potential energy to charge the system.
- Objects can be lifted and lowered above ground or below ground.
- To discharge, the object is allowed to fall and spin a turbine, converting the potential energy to electricity.
- Types
  - Below ground/shaft
  - Above ground structure
  - Slope







Solid Mass Gravity Storage (con't)

PROS

- Components are well-known in terms of their performance.
- Earth abundant materials are used in the system.

CONS

- Lower technology readiness level - currently at pilot validation stage
- Below ground and slope technologies are geology specific which limit site suitability.

[1]Energy Storage Grand Challenge Cost and Performance Assessment 2022, Pacific Northwest National Laboratory

[2]Black & Veatch assessment

Mechanical Energy Storage By The Numbers

Technology	Optimal Capacity (MW)	Optimal Duration (hrs)	Round Trip Efficiency (%)	Technology Readiness Level (TRL)	Estimate Cost of Storage ($/KWh)	Estimated Construction Duration (yrs)
Pumped Storage	1000's[2]	8-20[2]	80[1]	TRL 9[2]	60-500[1]	4-12[2]
Compressed Air Energy Storage	100's[2]	12-24[2]	Diabatic: 40-50[1,2] Adiabatic: 60-70[2]	Diabatic: TRL 9[2] Adiabatic: TRL 8[2]	Diabatic: 20-300[1] Adiabatic: Not available	2-8[2]
Solid Mass Gravity Storage	10's[2]	10-24[2]	80-90[1]	TRL 6-8[2]	120-1100[1]	3-5[2]

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Benefits of Mechanical Energy Storage

Benefits of Mechanical Energy Storage

- Renewables Integration
- Ease of Supply Chain
- Replace Peaker Plants
- Grid Stability
- Defer/Avoid T&D Upgrades
- Support for Black Start

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Advancing Mechanical Energy Storage Deployment

Government Programs

ORGANIZATION	PROGRAM	SUMMARY
U.S. Department of Energy	Long Duration Energy Storage Portfolio	The LDES portfolio includes the following programs: • Long-Duration Energy Storage Demonstrations Program • DOE/DOD Long-Duration Energy Storage Joint Program • Long-Duration Energy Storage Pilot Program
California Energy Commission	Long Duration Energy Storage Program	Demonstration and deployment of non-lithium-ion long duration energy storage technologies across California.
NYSERDA	Energy Storage Program	The New York Public Service Commission approved the goal to 6,000 Megawatts of energy storage to be installed by 2030, and authorized funds for NYSERDA to support 200 Megawatts of new residential-scale solar, 1,500 Megawatts of new commercial and community-scale energy storage, and 3,000 Megawatts of new large-scale storage.

Selected Pilot Projects

COMPANY	LOCATION	PROJECT	TECHNOLOGY	CAPACITY (MW)	DURATION (HRS)
Absaroka Energy	Meagher, MT	Gordon Butte Project	Closed Loop Pumped Storage	400 MW	8.5
Hydrostor	Kern, CA	Willow Rock Energy Storage Center	Adiabatic Compressed Air Energy Storage	500 MW	8
Atlas Renewables /Energy Vault	Rudong, China	Gravity Energy Storage System	Solid Mass Gravity Storage	25 MW	4

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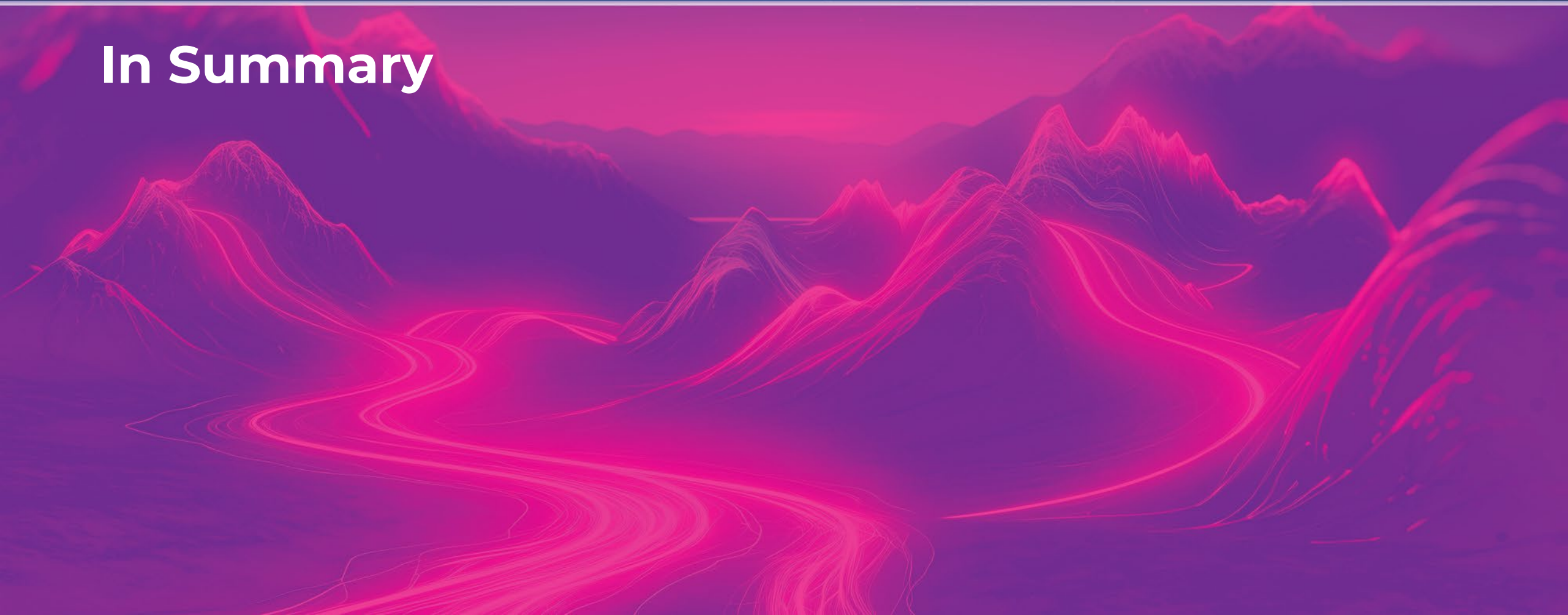
In Summary



Key Takeaways

- PSH is a proven technology but is geographically limited with long project development timelines.
- D-CAES is proven technology but has low round trip efficiency, typically uses natural gas to augment performance, and is limited by use in salt caverns. A-CAES is attempting to improve on these shortcomings.
- Large scale solid mass gravity storage is a new technology that has the potential for more widespread usage than PSH or CAES. There is also the potential to scale and simplify systems to drive down costs.

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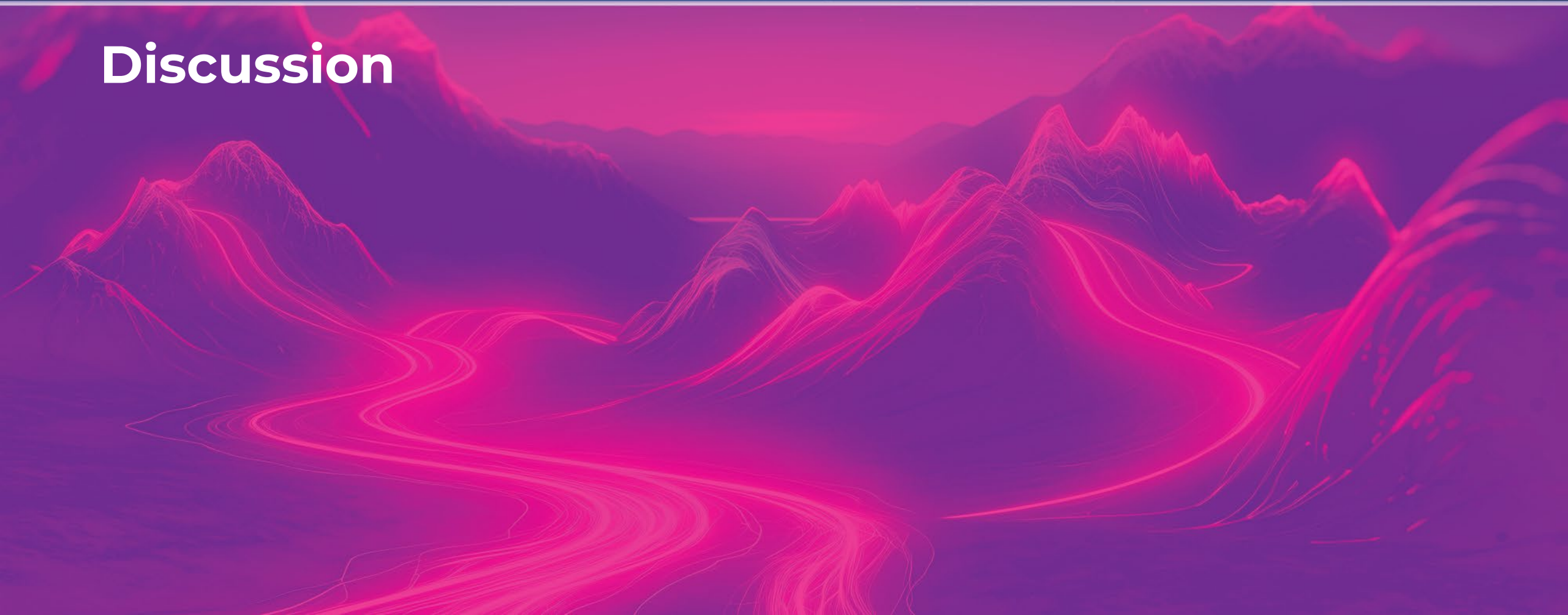
Discussion



Contact Information

Jeremy Shook
Principal Consultant
Shookj@bv.com
+1 704-450-8924