# Energy Storage Technologies for Renewable Integration


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**" A vital element in mankind's quest for survival and progress"**

- 1st International Assembly on Energy Storage, Dubrovnik, Yugoslavia, 1979

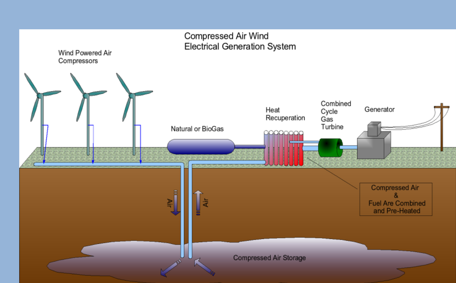

## Abstract:

The issue of intermittency is one of the biggest barriers to implementing large-scale renewable energy. The fact that wind and solar don't always produce enough electricity when we need it, and sometimes produce too much electricity when we don't need it is problematic. Furthermore, unpredicted gusts of wind or cloud cover can cause short-term instability in grids with high renewable energy penetration. To counteract this, large-scale energy storage technologies will need to be deployed. This project assesses a variety of available energy storage technologies and evaluates them based on their sustainability and effectiveness in enabling increased renewable penetration. Of these technologies, compressed air energy storage offers the most potential for renewable integration, Due to its large capacity and availability of potential sites for development in the U.S.


## Storage Technologies:

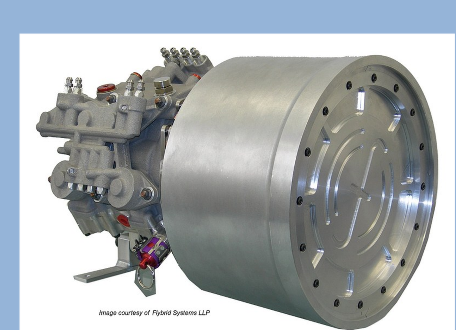
- **Pumped Hydro:** Charges by pumping water into an upper reservoir, discharges by releasing water to lower reservoir.

- **Compressed Air:** Charges by pumping pressurized air underground, discharges by releasing air.



- **Rechargeable Batteries:** Storage-scale batteries include redox flow, sodium-sulfur, lead-acid, and lithium-ion

- **Flywheels:** Energy is stored by accelerating a heavy wheel to a very fast speed, and is discharged by slowing it down



| | Pumped Hydro | Compressed Air | Redox Flow Batteries | Sodium Sulfur | Lead-Acid | Li-Ion | Flywheels |
|---|---|---|---|---|---|---|---|
| Capacity (MW) (approximate) | 2,500 | 500 | 5 | 10 | 10 | 1 | 1 |
| Cycle life (80% DoD) (approximate) | 30,000 | 20,000 | 4,000 | 4,500 | 700 | 7,000 | 35,000 |
| Round-trip efficiency | 85% | 70%* | 65% | 80% | 75% | 85% | 95% |
| Response Time | 0-10 minutes | 0-10 minutes | sub-second | sub-second | sub-second | sub-second | sub-second |
| | | | | | | | |
| Energy Arbitrage | Yes | Yes | Yes | Yes | Yes | Yes | No |
| Capacity Reserves | Yes | Yes | Yes | Yes | Yes | Yes | No |
| Power Quality | No | No | Yes | No | Yes | Yes | Yes |
| | | | | | | | |
| Present Worth ($/kw)* | $2,399.90 | $1,470.10 | $3,279.34 | $2,527.97 | $2,839.26 | $2,899.41 | $965.73* |

The ideal storage technology depends on the application. For power quality needs to balance out short term fluctuations in generation and demand, a fast-responding high-efficiency technology like a flywheel would be best. For balancing out load to from off-peak generation to peak demand, large-scale storage like pumped hydro and compressed air is best.

## Applications of Storage

- **Load-Leveling:** Store energy during off-peak hours to be released during peak hours, moving off-peak renewable generation to peak hours
- **Renewables Capacity Firming:** "Smoothes out" intermittent renewable energy by filling in gaps created by short-term cloud cover or changes in wind
- **Defer New Capacity:** Storage can operate like a natural gas-powered generation units, replacing the need for new fossil-fuel plants
- **Frequency Regulation and Voltage Support:** Fast-responding energy storage can smooth out short-term fluctuations in demand and supply keep the grid balanced

## Methods:

I did a literature review and conducted interviews with industry experts to obtain the necessary information. I then identified a set of criteria that would characterize the sustainability and renewable integration potential.

Notable criteria include:

- **Capacity:** The total available energy storage capability.
- **Response Time:** Speed at which a system can go from idle to full-discharge
- **Round-Trip Efficiency:** Amount of power put into a unit that is able to be withdrawn. For example a unit with 70% efficiency returns 7kWh for every 10kWh stored.
- **Recharge Rate:** rate at which power can be put into storage. A storage system might take 10 hours to deplete but 14 hours to recharge
- **Self-Discharge:** Energy discharge that occurs when the system is not being used, due to leakage and/or heat dissipation
- **Capital/Operating Costs:** Investment/operating costs on a per kW basis
- **Environmental Impact:** Some technologies like batteries potential use harmful chemicals, whereas technologies that utilize existing geological formations potentially can permanently change landscapes.

## Conclusions

Estimates for how high a penetration of intermittent energy the grid can handle without compromising stability range from 12-20%. Above this, energy storage is needed to smooth out the variable loads and maintain reliability. The ideal storage technology depends on the need and application. Compressed air currently offers the most cost effective option for large-scale energy management applications, necessary to integrate variable renewable energy. There are many potential geologic sites in the U.S. suitable for compressed air storage development, unlike pumped hydro. However, detailed geological studies and careful engineering must be carried out ahead of time to minimize negative environmental impacts. Large-scale storage deployment on the order of billions of dollars will be necessary to accommodate a grid characterized by renewable energy. A federal investment tax-credit would lower cost and spur investment. As natural gas prices increase and the cost of storage comes down relative to natural gas power plants, energy storage will become an economical option.