Hierarchical Structures for Isothermal Compression / Expansion for Energy Storage

Lead Investigators

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Background and Unmet Need

In industry, compressed air is so widely used that it is often regarded as the fourth utility after electricity, natural gas and water. Compressed air energy storage (CAES) typically uses power from renewable energy (i.e., wind, solar) to compress air, and to generate electricity through a turbine when needed, as a way of (i) mitigating the intermittency of renewable energy sources, and of (ii) matching power supply and demand, which are time dependent.

Further, when storage demand is more than five hours, CAES is viewed as an alternative to Li-ion batteries, which face raw material scarcity, supply chain security, and environmental concerns.

The global CAES market is large and poised to grow substantially by 2028. It was estimated at $2.9 Billion USD in the year 2020, and is projected to reach $10.3 Billion USD by 2026[1].

Compressed air is more expensive than electricity, natural gas, and water power when evaluated on a per unit energy delivered basis. Despite this strong demand for compressed air, there is a lack of efficient systems requiring low energy consumption and this lack drives costs higher all the while the demand increases. While economies of scale may benefit the CAES if employed long term and on a wide scale, the classical configuration of a CAES plant is exceptionally inefficient and only a few plants have been built worldwide.

Isothermal CAES (I-CAES) plants are preferred because there is no temperature change during the compression and expansion stages, which leads to much higher thermodynamic efficiency and therefore lower operating costs.

Opportunity

The investigators have found cost-effective isothermal compression and expansion of gaseous streams is achievable through vasculatures with lung-like gas flow paths embedded in phase change material (PCM) or thermochemical materials. Their design is highly scalable; a patent has been applied for.

In previous attempts to obtain isothermal compression / expansion, temperature increase and decrease was managed primarily by spraying liquids into the cylinder of a common piston machine during compression, or by compressing a pre-mixed foam. However, these designs are not scalable and increase the overall system cost.

The inventors project the cost of using their system will be substantially lower than current diabatic plants, because the multiple compressors and coolers of current diabatic plants will be replaced by a single isothermal compressor. The Lorente-Bejan invention features a scalable design, for all sizes of CAES plants, particularly for the basic compressor to a large power plant.

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1 "Isothermal- CAES." Energystorage.org, Energy Storage Association, https://energystorage.org/why-energy-storage/technologies/isothermal-caes/.

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Further, energy storage is critical to the use and implementation of renewable energies such as wind. Isothermal CAES provides the potential for green, efficient, resilient, and scalable energy storage that holds several advantages over current energy storage methods, such as eliminating the need for batteries that require limited rare earth elements. While the state of the art for I-CAES has remained virtually unchanged for 10 years, this invention will advance the technology forward and provide an advantage in an exploding market.

Unique Attributes

- Dendritic airflow architecture allows for more uniform and efficient air compression and expansion with lower power demands.
- Energy storage material linings consisting of phase change or thermochemical materials improve temperature control over existing I-CAES technologies. These materials allow the invention to offer a self-controlling and energy-regeneration solution compatible with sensors already present in many mechanical sensors.
- The invention will allow plant operators to control, to reduce, and to spread the sources of thermodynamic irreversibility, which if not controlled, are to blame for the temperature increase during compression.

Applications

Any industrial process, including those in the chemical, construction, manufacturing, and storage industries, that requires compressing / expanding gas.

Energy storage is critical to the use and implementation of renewable energies such as wind.

Stage of Development

Complete specifications have been developed and are available.

Intellectual Property

United States Patent Application Published June, 2023, as US 2023/0184447 A1.

Licensing and Collaboration Opportunity

Villanova and Duke are seeking a licensee or collaborators to commercialize the invention.

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