An Elegant Design Makes Compressed Air a Contender for Grid-Scale Storage

The potential for the integration of large amounts of renewable energy sources with the electricity grid — as the smart-grid concept (pp. 25–50) proposes — will require large-scale storage devices. Batteries have proven to be effective and economical for short-duration, high-power grid applications, such as frequency regulation. However, the limited lifetime of batteries (5–10 yr) and the linear scaling of their cost with storage capacity hinders the use of batteries for sustained energy supply, which will likely be the bulk of the energy-storage market in the coming decade.

With lifetimes exceeding 20 years and small incremental costs for additional storage capacity, compressed-air energy storage (CAES) is a cost-effective alternative to chemical batteries for multi-hour storage applications.

In conventional CAES systems, multistage compressors with intercoolers pressurize air that is then pumped into underground geological formations for storage. When needed, the compressed air is released from the underground reservoir and heated through a recuperator, then mixed with natural gas and expanded in a turbine to generate electricity. One problem with this type of CAES system is finding a suitable underground site for storage, typically a salt cavern. The cancellations of two recent projects due to cavern constraints illustrate this issue. In addition, conventional CAES systems are only economical at large capacities (hundreds of MW), and their reliance on natural gas can be problematic in applications where natural gas is not readily available.

▲ SustainX operates a 1.5-MW ICAES prototype in Seabrook, NH. Image courtesy of SustainX.

SustainX, a venture-capital-backed spin-out of Dartmouth College's Thayer School of Engineering and a recipient of a National Science Foundation Small Business Innovation Research grant and a U.S. Dept. of Energy Smart Grid Demonstration grant, has developed a novel isothermal CAES (ICAES) technology that promises to eliminate the disadvantages of traditional CAES.

The company attributes the success of its technology to a key innovation: the mixing of air and water to create a foam. Instead of being discarded, the heat generated by the air compression is stored in the water portion of the foam for later use during expansion. This allows both the air compression and expansion to occur at near-constant temperatures without the need for an external energy source such as natural gas. Thermal efficiencies are high (>95%), and heat losses during standby periods are low.

The ICAES system mixes water with intake air to create lightweight foam at atmospheric pressure, compresses the foam in two stages, and stores the pressurized foam, either in rows of pipelines, similar to those used by the gas industry, or in a lined-rock cavern (LRC), which is a manufactured underground cavern lined with steel for storing high-pressure gas. Over time,

▲ Air and water mixed together to form a foam allows for rapid heat exchange. Image courtesy of SustainX.

the foam separates into two distinct phases of compressed air and water. During expansion, the air and water are remixed to form a dense foam, expanded through two stages, and then separated to recover the water.

Foam is a shear-thinning fluid whose properties can be tailored by changing the volume ratio of air to water, the morphology, and the flow velocity. SustainX has come up with the right combination of foam properties to meet heat-transfer and fluid-flow requirements, as well as the need for the foam to break up easily to allow an effective air-water separation following expansion.

The ICAES power modules come in two sizes (1.65 MW and 3.0 MW) and can be combined to create systems of about 10–15 MW. The use of an engineered LRC to store the air eliminates the geological siting constraints of salt caverns, because a majority of the earth's land mass is suitable for LRC construction. Because the power module and the LRC are separate, they can be sized independently to tailor the energy storage capacity to a particular application.

SustainX is currently operating a 1.5-MW commercial prototype at its headquarters in Seabrook, NH, and is finalizing agreements for initial commercial installations.

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