410 kWh off-grid energy storage

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By Kris De Decker, originally published by Low-Tech Magazine

Going off-grid? Think twice before you invest in a battery system. Compressed air energy storage is the sustainable and resilient alternative to batteries, with much longer life expectancy, lower life cycle costs, technical simplicity, and low maintenance. Designing a compressed air energy storage system that combines high efficiency with small storage size is not self-explanatory, but a growing number of researchers show that it can be done.

Compressed Air Energy Storage (CAES) is usually regarded as a form of large-scale energy storage, comparable to a pumped hydropower plant. Such a CAES plant compresses air and stores it in an underground cavern, recovering the energy by expanding (or decompressing) the air through a turbine, which runs a generator.

Unfortunately, large-scale CAES plants are very energy inefficient. Compressing and decompressing air introduces energy losses, resulting in an electric-to-electric efficiency of only 40-52%, compared to 70-85% for pumped hydropower plants, and 70-90% for chemical batteries.

The low efficiency is mainly since air heats up during compression. This waste heat, which holds a large share of the energy input, is dumped into the atmosphere. A related problem is that air cools down when it is decompressed, lowering electricity production and possibly freezing the water vapour in the air. To avoid this, large-scale CAES plants heat the air prior to expansion using natural gas fuel, which further deteriorates the system efficiency and makes renewable energy storage dependent on fossil fuels.

In the previous article, we outlined several ideas - inspired by historical systems - that could improve the efficiency of large-scale CAES plants. In this article, we focus on the small but growing number of engineers and researchers who think that the future is not in large-scale compressed air energy storage, but rather in small-scale or micro systems, using man-made, aboveground storage vessels instead of underground reservoirs. Such systems could be off-the-grid or grid-connected, either operating by themselves or alongside a battery system.

The main reason to investigate decentralised compressed air energy storage is the simple fact that such a system could be installed anywhere, just like chemical batteries. Large-scale CAES, on the other hand, is dependent on a suitable underground geology. Although there are more potential sites for large-scale CAES plants than for large-scale pumped hydropower plants, finding appropriate storage caverns is not as easy as was previously assumed. [1-2] [3]

Compared to chemical batteries, micro-CAES systems have some interesting advantages. Most importantly, a

distributed network of compressed air energy storage systems would be much more sustainable and environmentally friendly. Over their lifetimes, chemical batteries store only two to ten times the energy needed to manufacture them. [4] Small-scale CAES systems do much better than that, mainly because of their much longer lifespan.

Furthermore, they do not require rare or toxic materials, and the hardware is easily recyclable. In addition, decentralised compressed air energy storage doesn"t need high-tech production lines and can be manufactured, installed and maintained by local business, unlike an energy storage system based on chemical batteries. Finally, micro-CAES has no self-discharge, is tolerant of a wider range of environments, and promises to be cheaper than chemical batteries. [5]

Although the initial investment cost is estimated to be higher than that of a battery system (around $10,000 for a typical residential set-up), and although above-ground storage increases the costs in comparison to underground storage (the storage vessel is good for roughly half of the investment cost), a compressed air energy storage system offers an almost infinite number of charge and discharge cycles. Batteries, on the other hand, need to be replaced every few years, which makes them more expensive in the long run. [5,6]

However, decentralised CAES also faces important challenges. The first is the system efficiency, which is a problem in large- and small-scale systems alike, and the second is the size of the storage vessel, which is especially problematic for small-scale CAES systems.

Both issues make small-scale CAES systems unpractical. Sufficient space for a large storage vessel is not always available, while a low storage efficiency requires a larger solar PV or wind power plant to make up for that loss, raising the costs and lowering the sustainability of the system.