A national laboratory of the U.S. Department of Energy
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NREL National Renewable Energy Laboratory

Innovation for Our Energy Future

# Creating Baseload Wind Power Systems Using Advanced Compressed Air Energy Storage Concepts

## BACKGROUND/OVERVIEW

Greatly expanded use of wind energy has been proposed to reduce dependence on fossil and nuclear fuels for electricity generation. The large-scale deployment of wind energy is ultimately limited by its intermittent output and the remote location of high-value wind resources, particularly in the United States. Wind energy systems that combine wind turbine generation with energy storage and long-distance transmission may overcome these obstacles and provide a source of power that is functionally equivalent to a conventional baseload electric power plant. A "baseload wind" system can produce a stable, reliable output that can replace a conventional fossil or nuclear baseload plant, instead of merely supplementing its output. This type of system could provide a large fraction of a region's electricity demand, far beyond the 10-20% often suggested as an economic upper limit for conventional wind generation deployed without storage.

## THE BASELOAD WIND CONCEPT

The basic components of a baseload wind system, illustrated in **Figure 1**, include a large amount of wind generation, a large-scale energy storage system, and long-distance transmission.

Compressed air energy storage (CAES) is a hybrid generation/storage technology well-suited for use in the baseload wind concept. CAES systems, illustrated in **Figure 2**, are based on conventional gas turbine technology and use the elastic potential energy of

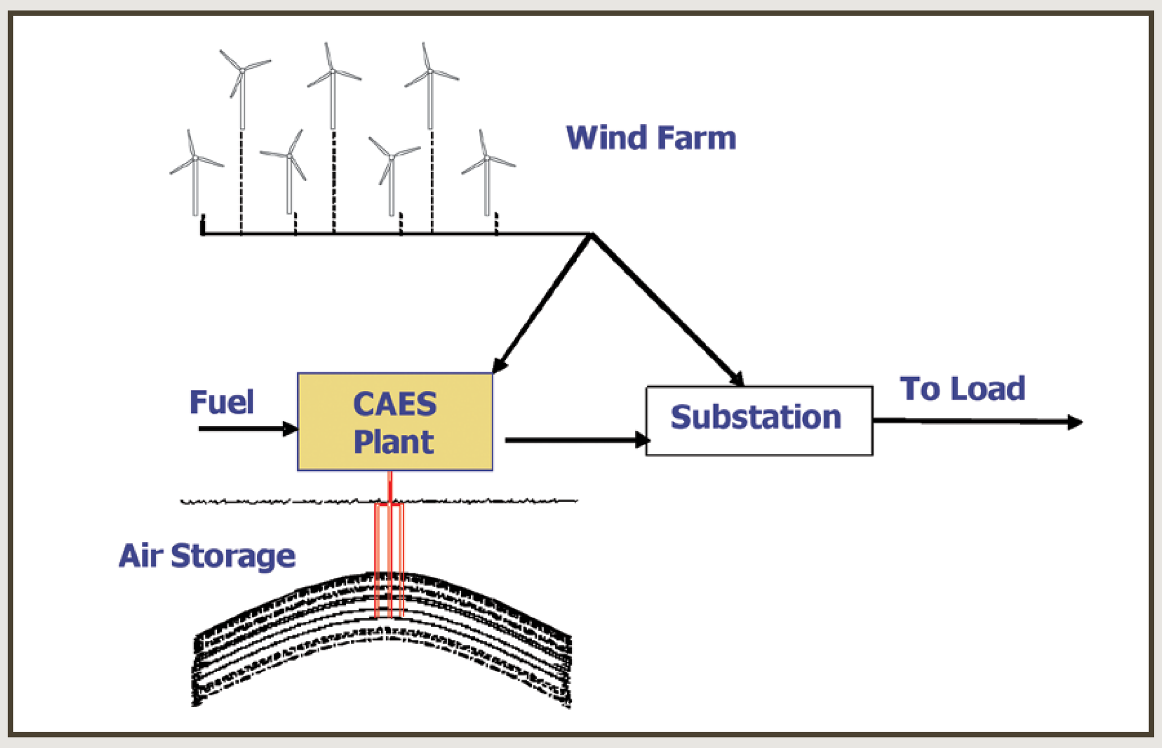


*Figure 1. Simplified Shematic of a Wind/CAES Power Plant*

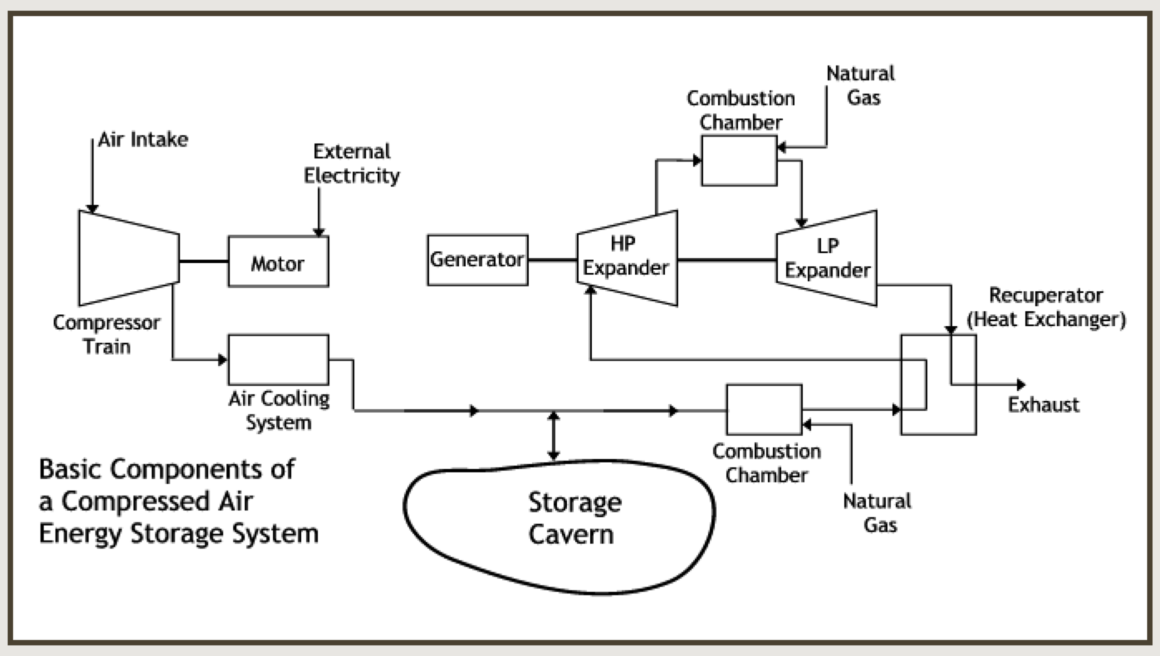


*Figure 2. Basic Components of a Compressed Air Energy Storage System*

compressed air. Energy is stored by compressing air in an airtight underground storage cavern. To extract the stored energy, compressed air is drawn from the storage vessel, heated, and then expanded through a high-pressure turbine that captures some of the energy in the compressed air. The air is then mixed with fuel and combusted, with the exhaust expanded through a low-pressure gas turbine. The turbines are connected to an electrical generator.

As part of a baseload wind system, CAES would be used to enable a nearly constant output by smoothing the

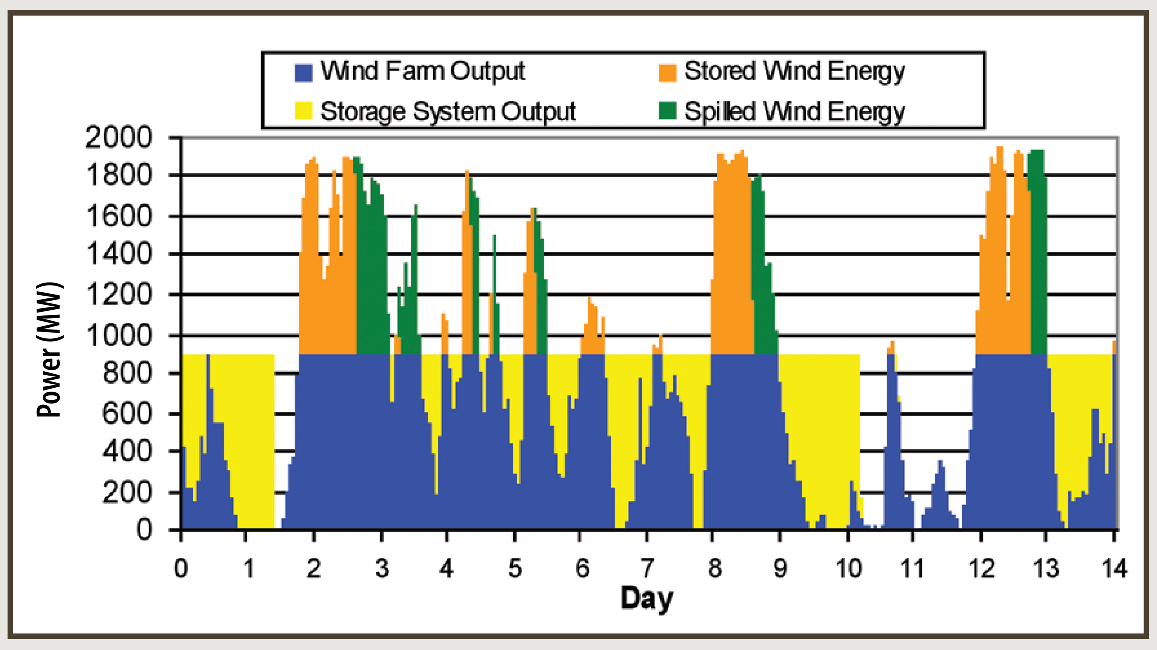


*Figure 3. Sample Baseload Wind Generator Output (Target Output = 900 MW)*

highly variable output from wind turbine generation. **Figure 3** illustrates how the combination of 2,000 MW of wind and 900 MW of CAES could be combined to produce a nearly constant 900 MW output. When operating at a high capacity factor (>75%), about 60-80% of the wind energy (averaged over a year) is placed directly onto the grid, while the remainder is stored (to be retrieved when the wind energy output falls below average) or "spilled" (due to limits of the storage cavern and transmission capacity).

## TECHNICAL AND ENVIRONMENTAL PERFORMANCE

The baseload wind power plant can achieve varying levels of performance in terms of expected capacity factor. Actual performance is dependent on optimizing the system component size and the tradeoff between high annual capacity factor and utilization of wind energy. **Figure 4** illustrates the energy flow through a baseload wind plant for a variety of possible scenarios.

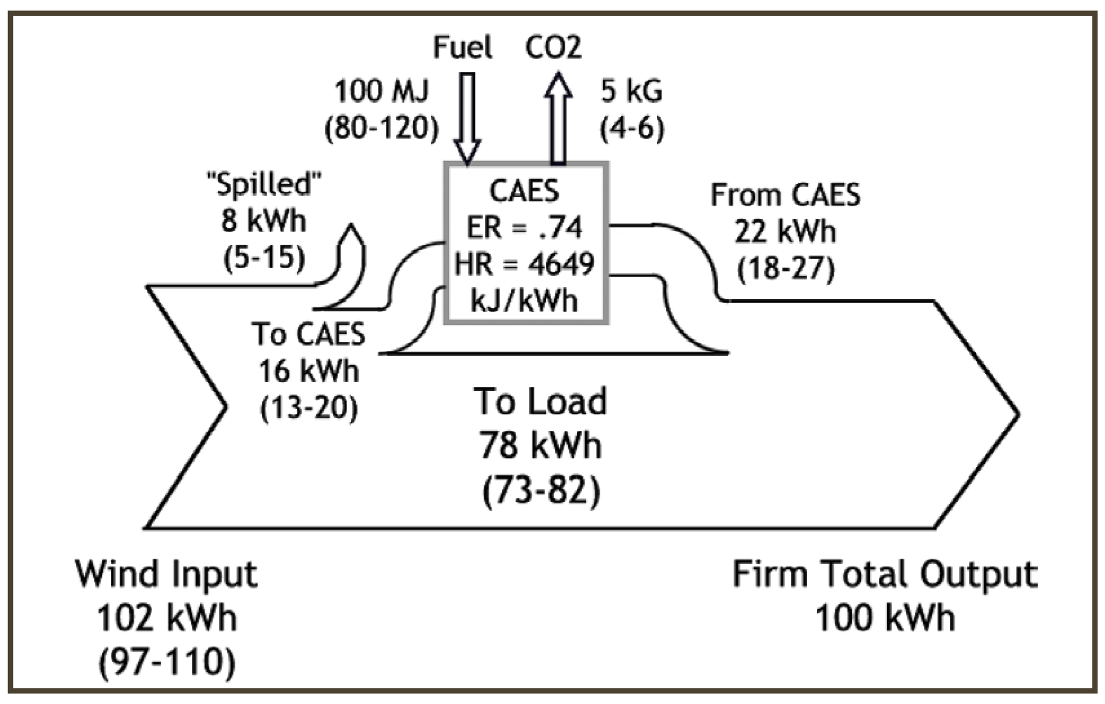


*Figure 4: Energy Flow through a Baseload Wind Power Plant*

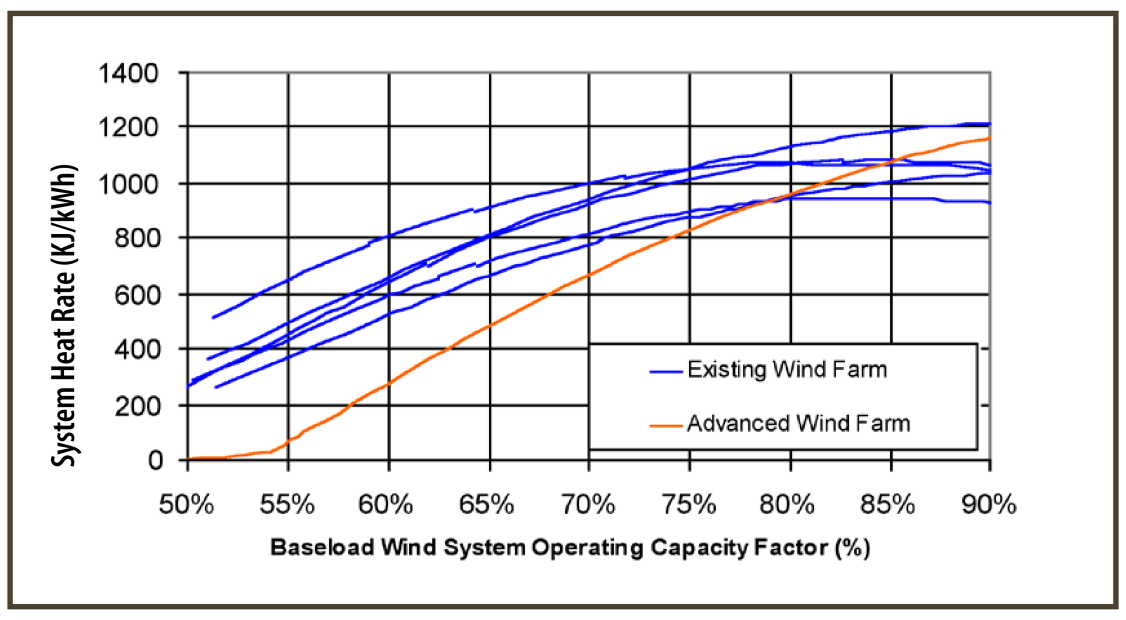


*Figure 5: Baseload Wind Plant Fuel Requirements*

The use of "conventional" CAES requires around 4,600 kJ of natural gas for each unit of energy stored by the CAES system. However, most wind energy does not need to be stored, so the effective "heat rate" of the entire baseload wind power plant is substantially less. **Figure 5** illustrates that a baseload wind plant operating at a high capacity factor will require around 1,000 kJ of fuel for each kWh placed onto the grid. Several cases are illustrated, using data from existing wind farms, and also simulations of advanced wind farms in higher quality wind resource regions. Use of natural gas fuel in the CAES system also leads to greenhouse emissions of about 40 to 80 g/kWh.

## ADVANCED WIND/CAES CONCEPTS

In addition to greenhouse gas emissions, the use of natural gas in CAES systems results in additional fuel price risk. Replacing natural gas with synfuel derived from local, more stable fuel sources is a possible alternative. One possible fuel source is gasified biomass, which eliminates the use of fossil fuels, virtually eliminating net $CO_2$ emissions from the system. In addition, by deriving energy completely from farm sources, this type of system may reduce some opposition to long distance transmission lines in rural areas, which may be an obstacle to large-scale wind deployment. Coal-derived syngas is another alternative in areas with existing coal mining infrastructure and where local economies are dependent in part on coal-extraction industries.

While the current penetration of wind energy is far too low to require energy storage, projected growth in the installed base of wind generation motivates thinking about scenarios of extremely large use of wind energy. Development of the "baseload" wind concept will require a greater understanding of the local geologic compatibility of air storage, and additional work will be required to examine the feasibility of advanced wind/CAES concepts described here.

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