

## XI.6 Emissions Analysis of Electricity Storage with Hydrogen

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### Introduction

The U.S. has wind resources to potentially produce large amounts of electricity each year. The U.S. also has significant resources of solar power, particularly in the southwestern regions of the country. These renewable sources of power are inherently intermittent and the supply of power from them cannot be controlled to match precisely the diurnal and regional demand. These renewable sources are typically curtailed when their supply becomes a large share of overall power supply, and they are supplemented with other fossil sources when their supply is less than the demand. Such intermittency imposes severe limitations on the potential large-scale utilization of renewable sources and the economics of their operation. Hydrogen has been proposed and examined in the U.S. and Europe as a potential energy storage medium to mitigate the intermittency of these renewable sources and to increase their utilization, especially with the expected large growth of these renewable sources to meet the renewable portfolio standards targets in the electric sector across the U.S. With hydrogen as a storage medium, when the incremental supply of renewable power exceeds the incremental demand, the excess power can be used to produce hydrogen for storage for later withdrawal during periods of peak power demand. Thus, hydrogen storage provides a buffer to match the supply and demand of electric power, and it could provide a significant reduction in energy use and greenhouse gas (GHG) emissions by reducing or eliminating the dependence on fossil sources that would otherwise serve the non-base (peak) load.

Argonne National Laboratory (ANL) examined the potential fuel cycle energy and emissions benefits of integrating hydrogen storage with renewable power generation. ANL also examined the fuel cycle energy use and emissions associated with alternative energy storage systems, including pumped hydro storage (PHS), compressed air energy storage (CAES), and vanadium-redox batteries (VRB). Figure 1 depicts these alternative energy storage systems for integration with grid electricity. The following sections present our approach to the above mentioned analysis, as well as the important stages, results, and key issues associated with the hydrogen use in energy storage applications.

### Approach

The fuel-cycle analysis of energy storage systems depends mainly on the round-trip efficiency of each alternative storage system. The round-trip efficiency is defined as the amount of electricity produced by the energy storage system per unit electric energy input to the storage system. Table 1 lists the round-trip efficiency for the different energy storage systems considered in this analysis.

### Fiscal Year (FY) 2011 Objectives

Conduct life-cycle analysis of hydrogen as energy storage for integration of large renewable generation sources into the electric grid.

### Technical Barriers

This project addresses the following technical barriers from the Systems Analysis section (4.5) of the Fuel Cell Technologies Program Multi-Year Research, Development and Demonstration Plan:

- (C) Inconsistent Data, Assumptions and Guidelines
- (D) Suite of Models and Tools
- (E) Unplanned Studies and Analysis

### Contribution to Achievement of DOE Systems Analysis Milestones

This project contributes to achievement of the following DOE milestone from the Systems Analysis section of the Fuel Cell Technologies Program Multi-Year Research, Development and Demonstration Plan:

- **Milestone 11:** Complete environmental analysis of the technology environmental impacts for the hydrogen scenarios and technology readiness. (2Q 2015)

### FY 2011 Accomplishments

- Conducted fuel cycle analysis of hydrogen storage and alternative energy storage options in various utility regions.



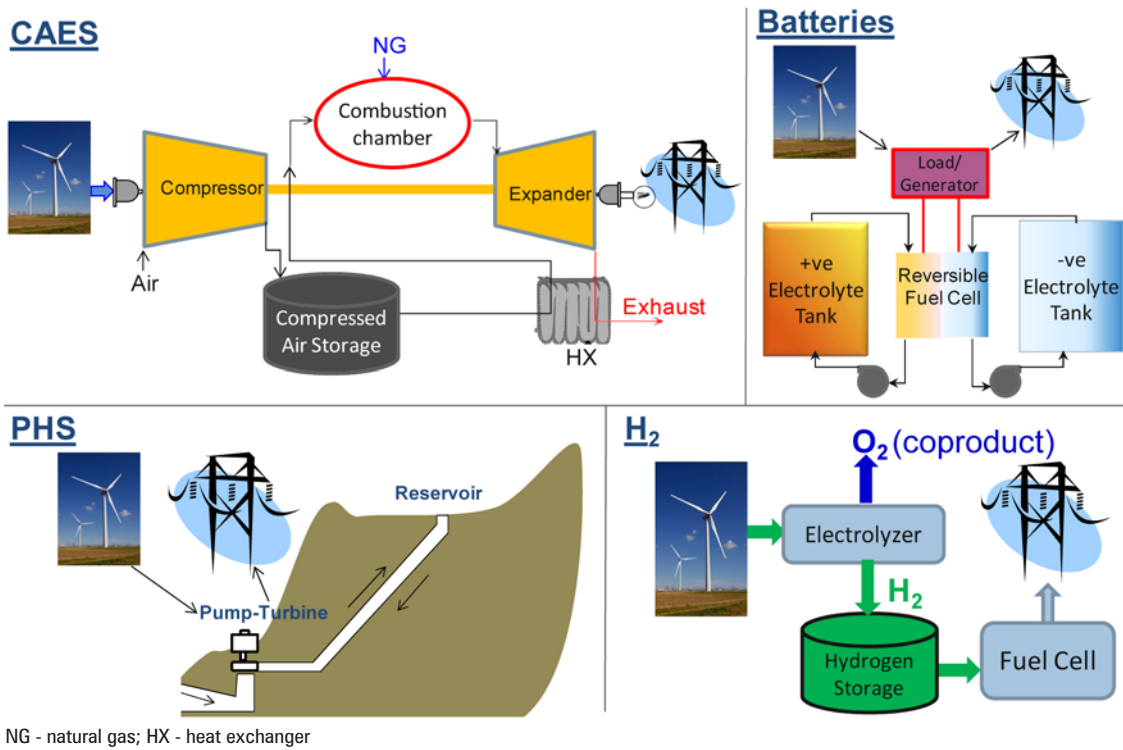


FIGURE 1. Alternative Energy Storage Systems

TABLE 1. Round-Trip Efficiency of Alternative Energy Storage Systems

Energy Storage System	Round-Trip Efficiency
Hydrogen	34%
Pumped hydro storage (PHS)	74%
Compressed air energy storage (CAES)	71%
Batteries	74%

This analysis assumes that the electricity produced from the energy storage system displaces the non-base load electricity (as provided in the eGrid database of the Environmental Protection Agency) for the different utility regions. The displacement of non-base load electricity provides an improved estimate over the displacement of fossil-based electricity generation when calculating the emission reduction benefits of clean energy projects. The electricity generation displaced by the electricity produced by the energy storage system are tracked upstream to their primary fuel sources for energy use and emissions calculations. The impact of “oxygen” as a co-product of hydrogen production via electrolysis is also included in this analysis.

**Results**

The fuel-cycle GHG emissions benefits per kWh of electricity produced by the energy storage systems are shown in Figure 2 for the states of California, Texas, New York, and

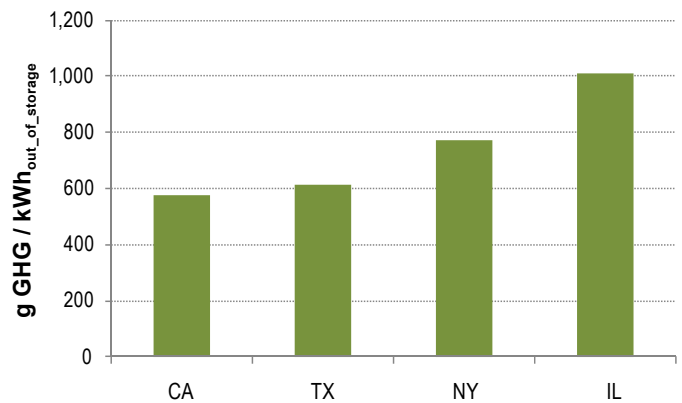
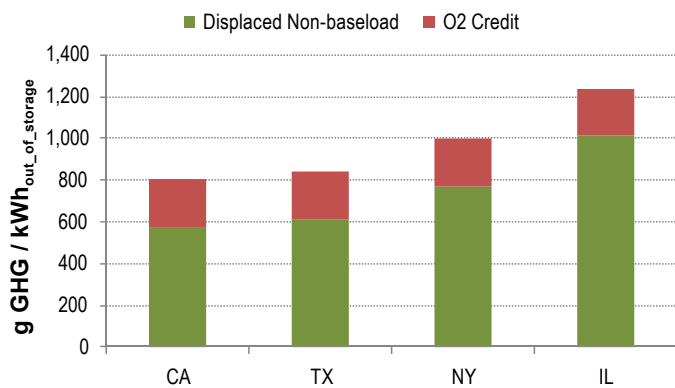
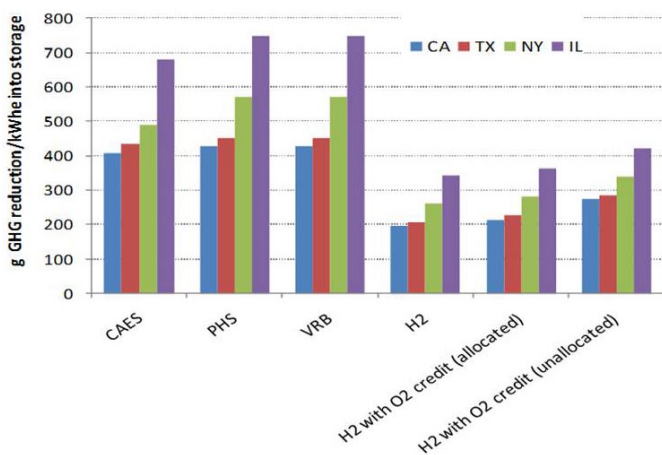


FIGURE 2. Fuel Cycle GHG Emissions Benefits of Energy Storage Systems in Different Regions (per kWh out of storage)

Illinois. Figure 2 reflects the GHG emissions saved in these regions by displacing the non-base load electricity generation units with energy produced from the storage of renewable electricity. Figure 3 shows the additional GHG savings due to the co-production of oxygen (O<sub>2</sub>) via electrolysis using the hydrogen energy storage system. The byproduct oxygen is a high value product with high purity (>99%) that is widely used in medical facilities, steel production, semiconductor production, wastewater treatment plants, etc. Significant amounts of oxygen are coproduced (8 kg<sub>O<sub>2</sub></sub> for each kg<sub>H<sub>2</sub></sub>) which can displace oxygen conventionally produced in



**FIGURE 3.** Fuel Cycle GHG Emissions Benefits of Hydrogen Energy Storage System in Different Regions (per kWh out of storage)



**FIGURE 4.** Fuel Cycle GHG Emissions Benefits of Alternative Energy Storage Systems in Different Regions (per kWh into storage)

air separation units where 0.7 kWh of electricity is used to produce 1 kg of O<sub>2</sub> (only 0.165 kWh/kg<sub>O<sub>2</sub></sub> if allocating electricity use by mass with N<sub>2</sub>). Figure 4 shows the GHG emissions benefits of the alternative energy storage systems in different regions per kWh into storage. The impact of the round-trip efficiency of the alternative energy storage systems is apparent in Figure 4, with greater GHG benefits for the storage systems associated with higher round-trip efficiency. The O<sub>2</sub> byproduct credit associated with the hydrogen storage system partially compensates for its low round-trip efficiency and improves its competitiveness with the other alternative storage systems.

## Conclusions and Future Directions

### Conclusions:

Using hydrogen for storage of electricity from renewable sources provides potential for significant reduction of GHG emissions by displacing electricity generation units that serve the non-base load in different utility regions. Energy storage systems achieve greater GHG emissions reduction when displacing more carbon intensive generation. However, the GHG emissions benefits of employing hydrogen energy storage systems are less than those associated with the alternative storage systems using CAES, PHS and batteries due to the low round-trip efficiency of the hydrogen pathway. The round-trip efficiency is crucial for life-cycle analysis of energy storage systems. Higher potential for GHG emissions reduction can be realized as the round-trip efficiency increases. The O<sub>2</sub> byproduct credit associated with hydrogen storage system improves its competitiveness with alternative storage systems. The emissions benefits of alternative energy storage systems should be evaluated in conjunction with other economical and technological aspects unique to each technology option.

### Future Directions:

Expand the system boundary to include the energy and emissions associated with the construction of the storage facilities in the life-cycle analysis of alternative energy storage systems.