LEVELIZED COST OF RETURNED ENERGY (LCORE) ANALYSIS FOR COMPARING HYDROGEN END-USES & BATTERY STORAGE ECONOMICS

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Overview

As Renewable Portfolio Standards across the United States and around the world require increased amounts of retail electricity sales to be supplied from renewable generating technologies, the installed capacity of renewable generation must increase. Since this new renewable generation capacity comes predominantly from wind and solar, the amount of renewable generation at any given moment is controlled by time of day and weather conditions, including seasonal variations in energy availability. The intermittency of wind and solar generation can require increased quantities of flexible generation to provide high-speed ramping to keep the electric grid in balance. Given that this flexible generation is typically fueled with natural gas, the air emissions avoided by wind and solar generation can largely be offset by the increased emissions associated with the increased ramping requirements of natural gas-fired generation. Beyond simple variability, the amount of renewable generation can at times substantially exceed the capacity of the electric grid to accommodate it. This results in curtailment of renewable generation or, in deregulated wholesale energy markets, negative wholesale electricity prices. Otherwise-curtailed renewable generation can be put to beneficial use through the development of flexible, non-emitting alternative technologies that can replace emitting natural gas-fired generation to a greater or lesser extent. Such alternive technologies not only reduce the need for curtailment of renewable generation, but become increasingly important to maintain overall emissions reductions as renewable penetration increases.

Methods

A method for analyzing the levelized cost of conversion, storage, and return of input energy as an end product net of losses with a zero cost of input energy, termed the levelized cost of returned energy (LCORE), is introduced. Although the cost of input energy is generally an important cost element in such analyses, the increasing prevalence of surplus renewable electricity makes a zero-cost input energy case relevant if the input energy is assumed to be from otherwise-curtailed renewable generation. The methodology is uniformly applied across numerous different Use Cases for the purpose of comparing the net conversion and storage costs of various renewable electrolysis technologies and hydrogen end-uses with battery and flow-battery energy storage technologies. Each Use Case is defined by the equipment set used to produce the end product. The LCORE methodology is intended to support the comparison of technologies across a range of Use Cases, some of which return energy in forms other than electricity, such as vehicle fuel. The assumption of zero-cost input energy is identical for all Use Cases and allows the LCORE metric to be used to reflect solely the technology-specific levelized costs of converting, storing, and returning the input energy as a different product, either in form or in time.

The LCORE methodology accounts for capital costs, financing costs, operation and maintenance costs, energy efficiency of each step, technology lifetime, and replacement costs. The starting point for the economic calculations is a user-specified input vector of Exogenous Available MWh that represents the availability of otherwise-curtailed renewable generation. Multiple hydrogen-based Use Cases are defined, each of which uses the Exogenous Available MWh as the initial feedstock for an electrolyzer that produces hydrogen (and oxygen) by splitting water molecules using one of several possible electrolyzer technologies. A separate Use Case is defined for each hydrogen-based pathway depending on what happens to the hydrogen once it leaves the electrolyzer. For instance, the hydrogen produced can be injected into the natural gas distribution or transmission system either as hydrogen or after conversion to natural gas via methanation. Alternatively, the hydrogen can be delivered to a hydrogen fueling station to be dispensed as fuel for hydrogen fuel cell vehicles or used in a fuel cell to produce electricity to be returned to the grid during periods of high electricity prices In contrast to the hydrogen-based Use Cases, the battery energy storage Use Case uses the input vector of Exogenous Available MWh directly to charge a battery, with the battery discharging electricity back to the grid or directly to an onsite electric load at a later point in time.

Results

Results show that the most valuable use of the renewable hydrogen is as fuel for fuel cell electric vehicles, although the costs of the hydrogen fueling infrastructure are estimated to be high using the existing paradigm of trucking, compression, and dispensing (adding more than $7/kilogram to the price of hydrogen). Importantly, the analyses show that the range of costs for pathways that produce hydrogen by electrolysis from renewable generation and return it to the electric grid using the natural gas system to transport the hydrogen to an existing combined cycle plant to produce electricity have costs of $76–$210/MWh. These costs are directly competitive with battery energy storage pathways at $51–$150/MWh, but with the important distinction that hydrogen pathways also enable long-duration (e.g., seasonal) energy storage.

Conclusions

The LCORE metric is used consistently to assess the costs of various renewable electrolysis technologies and hydrogen end-uses together with battery and flow-battery energy storage technologies. The direct comparison on the consistent basis of the LCORE metric, which accounts for capital costs, financing costs, operation and maintenance costs, energy efficiency of each step, technology lifetime, and replacement costs, allows for an apples-to-apples comparison of the technologies. Unlike storage analyses that focus on temporal electricity price arbitrage, this method focuses on energy conversion, storage, and returned energy costs net of losses and is suitable for general comparison and for cases in which the marginal cost of input energy is zero. The LCORE analyses show that the range of costs for producing hydrogen by electrolysis from renewable generation and returning it to the electric grid using the natural gas system to transport the hydrogen and using an existing natural gas-fired power plant to produce the electricity has lifetime levelized costs that are directly competitive with those of battery energy storage. Results also show that the most valuable use of the renewable hydrogen is as hydrogen fuel for fuel cell electric vehicles, although the costs of the hydrogen fueling infrastructure are estimated to be high. No assumptions were made regarding future cost reductions in hydrogen fueling infrastructure, though such reductions could significantly improve the underlying economics of the associated pathways.