Energy Storage Analysis

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Project End Date: Project continuation and direction determined annually by DOE

Overall Objectives

- Formulate a benchmark framework for the evaluation of energy storage systems in grid applications.
- Contextualize hydrogen's potential role in energy storage applications.
- Analyze the techno-economic impact of hydrogen co-production.
- Use the above framework to communicate technology targets among stakeholders.

Fiscal Year (FY) 2019 Objectives

- Produce a simple test cycle for benchmarking energy storage systems.
- Evaluate hydrogen energy storage techno-economic performance in the landscape of on-the-market technology options.
- Examine the impact of using electrolyzer capital for producing merchant hydrogen in times when an energy storage system is full.
- Disseminate analysis outcomes and solicit stakeholder input on framework assumptions and technology targets.

Technical Barriers

This project addresses the following technical barriers from the Systems Analysis section of the Fuel Cell Technologies Office Multi-Year Research, Development, and Demonstration (MYRDD) Plan[1]:

- Stove-piped/Siloed Analytical Capability
- Inconsistent Data, Assumptions and Guidelines
- Unplanned Studies and Analysis.

Contribution to Achievement of DOE Milestones

This project will contribute to the achievement of the following DOE milestones from the Systems Analysis section of the Fuel Cell Technologies Office MYRDD Plan:

- Milestone 3.1: Annual update of Analysis Portfolio. (4Q, 2011 through 4Q, 2020)
- Milestone 3.3: Complete review of status and outlook of non-automotive fuel cell industry. (4Q, 2019)

FY 2019 Accomplishments

- Leveraged a simple framework for energy storage system evaluation to allow dialogue among stakeholders for assumptions and technology targets.
- Produced techno-economic analysis for long-duration (multi-day) energy storage using hydrogen.
- Benchmarked three general applications of hydrogen storage and outlined applicability relative to energy prices (energy storage, electrolysis only, energy storage with electrolysis co-production as a function of electricity, and hydrogen prices).

[1] https://www.energy.gov/eere/fuelcells/downloads/fuel-cell-technologies-office-multi-year-research-development-and-22

INTRODUCTION

Energy storage is becoming an essential part of the growth of renewable grid resources. This is due to the temporal variability of renewable power in different time scales. Power output can fluctuate on small scales from seconds to the large scales of seasons. Simultaneously, demand for power fluctuates on small scales to large scales. As electricity from renewable power is not dispatchable, a means of buffering supply and demand is needed to meet demand at all times without vastly over-building renewable generation resources.

Today buffering electric supply and demand is accomplished by using peaker plants, often running on natural gas due to their fast start-up time, low operating cost, and large turn-down characteristics. Such plants can remain operational for hours, days, and months as needed. Energy storage, such as pumped hydrogen, is used as a buffer, but its geographic limitations limit its growth potential to meet large renewable growth. Other means of storing energy have focused on small-time gaps between supply and demand–supercapacitors focus on sub-second time discrepancies, and batteries address few hours of storage. At the moment, no renewable options are available for storage durations of more than a few hours that can be installed agnostically of geography. In this study, we look at the potential role of hydrogen to address longer duration storage. Unlike other energy storage options, hydrogen systems have the ability to keep producing hydrogen once storage is full. We address the economic implications of such co-producing hydrogen as sensitivity to electricity and hydrogen prices.

APPROACH

This analysis uses a simple daily cycle of power production and storage recharging to approximate the diurnal operation of an energy storage system. Each day, energy storage is discharged at a 10MW rate for 4 hours and is recharged 8 hours at 11.6 MW (see Figure 1).

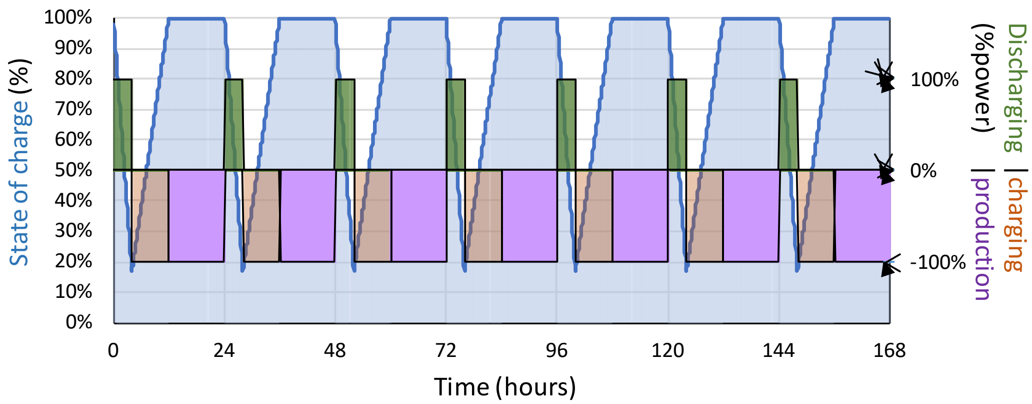

Figure 1: Simple daily cycle used for energy storage system operation with and without hydrogen co-production. This cycle approximates annual power generation, electricity use, hydrogen co-production and allows sizing of equipment for techno-economic analysis.

This operation approximates charging time while solar power is available, and discharges the energy in evenings when electricity demand usually exceeds solar production. By using such a simplified cycle, we can estimate equipment sizing, capital costs, and operating expenses. Furthermore, we are able to estimate the opportunity of using electrolyzers for supplemental hydrogen production when storage is full and benchmark it against a pure hydrogen production electrolysis system. Each modality of operation is then characterized in terms of internal rate of return. Systems yielding a better return on investment are assumed to be more desirable than systems with lower internal rates of return. Depending on the relative value of power production and hydrogen, some modalities of energy storage or hydrogen production would be more economical.

RESULTS

Enter body text. Enter body text. Our analysis used current technology targets for components relevant to three systems: energy storage only, energy storage with hydrogen co-production, and pure electrolysis (see Figure 2).

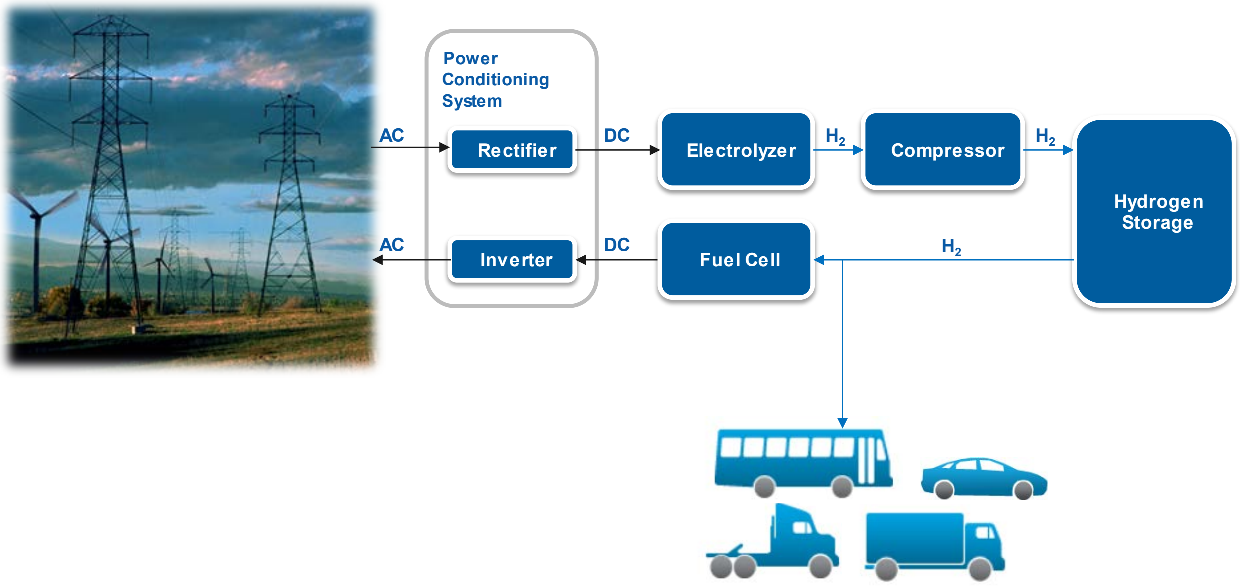

Figure 2: General system layout for energy storage analysis. In case of hydrogen production only via electrolysis, fuel cell and inverter are not included in required equipment.

Grid electricity at 3.3¢/kWh was first converted from alternating current (AC) to direct current (DC) using a 98.4% average efficiency, 11.6MW rectifier. A proton exchange membrane electrolyzer (PEM) of 211 kg/h production capacity, was used with 54.3 kWh of DC power energy consumption for each kilogram of hydrogen produced. Product hydrogen was compressed into above-ground hydrogen storage tanks using 1.4 kWh of AC power. Next, 422 kg/h of hydrogen was withdrawn from storage into a 10MW fuel cell during power production, making 23 kWh of DC power for each kilogram of hydrogen. Power was converted to AC power via 98.6% efficient inverter. In the case of hydrogen co-production, the identical equipment was used, but when storage was full after each 8-hour recharge cycle, electrolyzer operation continued for an additional 12 hours. Product hydrogen take-off was not modeled explicitly but was valued on a per-kilogram basis by the techno-economic analysis. In the case of electrolysis-only operation, equipment was identical with the above description for the rectifier, electrolyzer, compressor, and storage. No fuel cell or inverter was used in electrolysis production mode.

Technology targets (see Table 1) were used to estimate capital and operating expenses for each system. Capital and operating expenses were analyzed using the H2FAST model [2] to arrive at the return on investment.

Table 1: Technology targets used in techno-economic analysis. Values have been thoroughly reviewed with industry and DOE stakeholders.

Subsystem	Technology Staus & Targets, all costs in 2016$	Current status
Rectifiers	Rectifier efficiency	98.4%
	Rectifier cost ($/kW AC)	$ 196
	Total installation cost factor (% of equipment capital)	57%
	System O&M (% of capital cost)	1.0%
Electrolyzers	Electrolyzer power use (kWh DC/kg)	54.3
	Electrolyzer cost ($/kW DC)	$ 737
	System life (years)	20
	Total installation cost factor (% of equipment capital)	57%
	System O&M (% of capital cost)	7.8%
Compressors	Power use (kWh AC/kg)	1.42
	Compressor cost factor A (equation form c=A*p^B; where p is power)	2290
	Compressor cost exponent B (equation form c=A*p^B; where p is power)	0.8225
	Cost factor for inclusion of oxygen compression	50%
	Total installation cost factor (% of equipment capital)	187%
	System O&M (% of capital cost)	4.0%
Storage	Terrestrial storage installed cost ($/kg)	1,168
	Terrestrial storage installed cost ($/kWh LHV)	35
	Terrestrial storage O&M (% of capital cost)	1.0%
	Cushion gas (%)	17.1%
Fuel cells	Fuel cell power production (kWh DC/kg)	20.0
	Fuel cell cost ($/kW DC)	507
	Total installation cost factor (% of equipment capital)	20%
	System O&M (% of capital cost)	6.0%
Inverters	Inverter efficiency (%)	98.6%
	Inverter cost ($/kW)	$ 384
	Total installation cost factor (% of equipment capital)	20%
	System O&M (% of capital cost)	1.0%
Feedstock	Electricity cost ($/kWh)	0.033

This analysis was repeated for a range of values for power production and the value of co-product hydrogen (see Figure 3). Valuation of product hydrogen was varied from $1/kg to $4/kg, and valuation of peak power was varied from 10¢/kWh to 40¢/kWh. In cases of high hydrogen price and low electricity price, the electrolysis-only system was found to yield the highest internal rate of return (ranging from 10% to 29%. In such systems, hydrogen value was more economical to produce due to its high price in comparison to the relatively low valued electricity. In cases of high electricity prices and low hydrogen prices, systems performing energy storage were most economical. Above ~23¢/kWh of peak power valuation internal rate of return was 10% to 28%. In a middle-range moderate hydrogen and electricity prices, hydrogen energy storage systems with hydrogen co-production yielded the highest rates of return. It is also notable that in cases of relatively low electricity value (e.g., 18¢/kWh), energy storage systems do not make economic sense due to their low internal rate of return. However, if such systems were operated in co-production mode and value of hydrogen of ~$2.8/kg can be obtained, economical performance of such systems can be realized at a 10% internal rate of return.

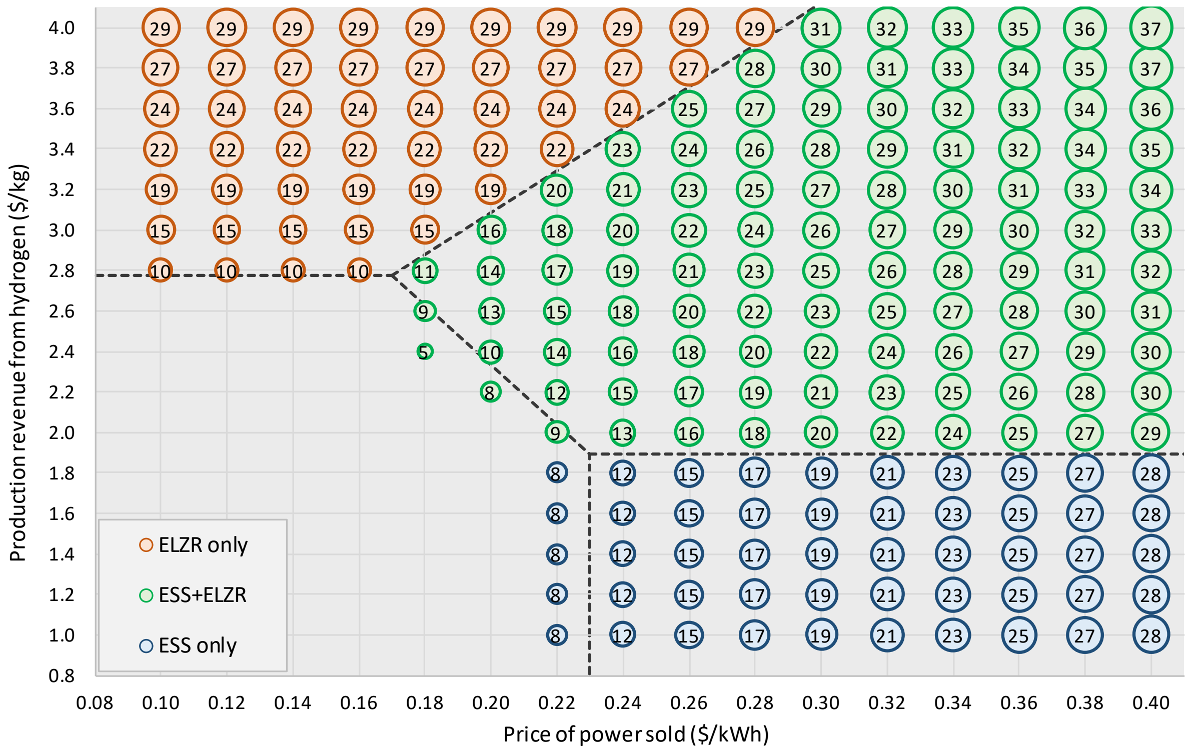

Figure 3: Internal rate of return (%) of best-performing systems for individual valuations of tge price of power sold (x-axis) and the value of co-product hydrogen (y-axis). Electrolysis only (ELZR only) is favored in cases of expensive hydrogen and cheap electricity. Energy storage systems (ESS only) are favored in cases of expensive electricity and cheap hydrogen. Energy storage systems with electrolysis co-production (ESS+ELZR) are favored in medium to high electricity and hydrogen price cases.

CONCLUSIONS AND UPCOMING ACTIVITIES

This analysis performed an economic evaluation of hydrogen energy storage systems in electron to electron storage, as well as hydrogen production and co-production. Depending on the market valuation of peak power and hydrogen molecules, one of three hydrogen systems would provide the best internal rate of return. In the case of expensive electricity and cheap hydrogen, an electron to electron system would be most economical. In the case of expensive hydrogen and cheap electricity, hydrogen production would be optimal. In the case of moderate to high electricity and hydrogen prices, an energy storage system with hydrogen co-production would provide better financial performance.

This analysis focuses on relatively short-duration storage of a few hours of power rating. Future activities will cover more extensive duration of storage, spanning days and weeks. Such application would help address the possible needs of higher renewables grids, as well as highlight the potential to provide renewable hydrogen for a variety of economic needs outlined in the H2@Scale [1] mission statement –ranging from transportation to fertilizers and metals production.

REFERENCES

1. Department of Energy, H2@Scale, retrieved on 10/2019 from: https://www.energy.gov/eere/fuelcells/h2scale
2. National Renewable Energy Laboratory, H2FAST model, retrieved 10/19 from: https://www.nrel.gov/hydrogen/h2fast.html