DOCKETED	
Docket Number:	19-IEPR-04
Project Title:	Transportation
TN #:	229133
Document Title:	Arndt Lutz Comments Power to Gas
Description:	N/A
Filer:	System
Organization:	Arndt Lutz
Submitter Role:	Public
Submission Date:	7/30/2019 7:14:26 AM
Docketed Date:	7/30/2019

Comment Received From: Arndt Lutz
Submitted On: 7/30/2019
Docket Number: 19-IEPR-04

Power to Gas

Nel is interested in Power to Gas projects in CA and has been working on such project opportunities for several years - a centralized in State electrolyser connected to wind and solar power projects to produce â€œgreenâ€ hydrogen. A recurring challenge for these projects is the guaranteed long term off-take of hydrogen; the transport and fuel industries have not been willing to enter into such long term agreements in the past. Due to a lack of such long term H2 off-take assistance from the CEC is critical to enable an in State project. A Power to Gas project could also demonstrate â€œenergy storageâ€ as well as grid balancing capabilities. For more benefits of such projects please see the DOE's 2018 white paper entitled "One-Way Energy Storage: H2@Scale"

Additional submitted attachment is included below.

One-Way Energy Storage: H2@Scale

"One-way" energy storage concepts (i.e. "power-to-gas") involve supplementing conventional energy storage by using energy to produce hydrogen, which can ultimately be supplied to diverse applications with high regional value propositions. The conversion of electricity to hydrogen via water electrolysis is approximately 70% efficient with potential for substantial improvement through further technological advances. [1] In such systems, hydrogen production technologies function as responsive load integrated with the grid or power generators, and supply both established and emerging markets for hydrogen; these markets include clean transportation (fuel cell vehicles), chemicals manufacturing (e.g. methanol and ammonia), petroleum refining, direct reduction of iron, and smaller consumers, such as glassmaking. While hydrogen is currently produced primarily from natural gas, an alternative is the use of electricity to produce hydrogen by splitting water. Electrolysis is one commercial water splitting technology that has been successfully demonstrated to be capable of fluctuating power intake within sub-seconds, meeting the performance requirements of responsive loads used for grid services. Water splitting technologies currently in research stages also include concepts that can utilize high-temperature heat, such that they could ultimately be integrated with thermal power generators.[1]

Potential benefits of one-way energy storage include:

- *Monetizing electricity that would otherwise be unprofitable to store.* The value of conventional energy storage in mitigating curtailment has been estimated to plateau at durations of 8 hours. [2,3] Power-to-gas concepts can be synergistic with conventional storage, allowing for electricity that would otherwise continue to be curtailed to be monetized. In the near-term, power-to-gas may be profitable when the hydrogen produced is sold for use in fuel cell vehicles. [4, 5] The profitability of these concepts can be enhanced if electrolyzers are reimbursed (e.g. through capacity payments) for participation in markets for grid services. [6]
    - Current costs of multi-megawatt electrolyzers are approximately $1,000/kW. At economies of scale and with additional technological advances, these costs are projected to decline to $400/kW. [7]
    - At average utility rates, the cost of electricity accounts for over 60% of the cost of electrolysis. [7] However, this percentage can drop significantly if electrolyzers are able to access low-cost electricity from resources that would otherwise be curtailed.

- *Reducing the footprint of energy storage.* In "power-to-gas" concepts, the technology used to draw power from the grid is independent of the technology used for energy storage. Electrolyzers draw power from the grid, and the hydrogen is ultimately stored mechanically at high volumes, such as in geologic formations, pipelines, or liquid dewars. Decoupling of power and energy technologies can reduce the footprint of energy storage. The volumetric energy density of pressurized (200 bar) hydrogen storage is approximately 600 watt-hours/liter, exceeding that of batteries and pumped hydro. [8]

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[1] For more information on high-temperature hydrogen production technologies, please see past proceedings from the U.S. Department of Energy's Office of Energy Efficiency and Renewable Energy's Fuel Cell Technologies Office's Annual Merit Review: https://www.annualmeritreview.energy.gov/

The U.S. currently has three salt caverns that store thousands of tonnes of hydrogen (hundreds of megawatt-hours, by lower heating value) underground, 1,600 miles of hydrogen pipeline, along with 9 liquefaction plants, the largest of which is in New York. Another possibility for hydrogen storage is the use of depleted oil and gas reservoirs, which are currently used for natural gas storage; use of such reservoirs would require engineering solutions to mitigate leakage and contamination of hydrogen. Figure 1 represents the quantities of hydrogen energy that could be stored underground in New York and Pennsylvania in existing reservoirs currently used to store natural gas.

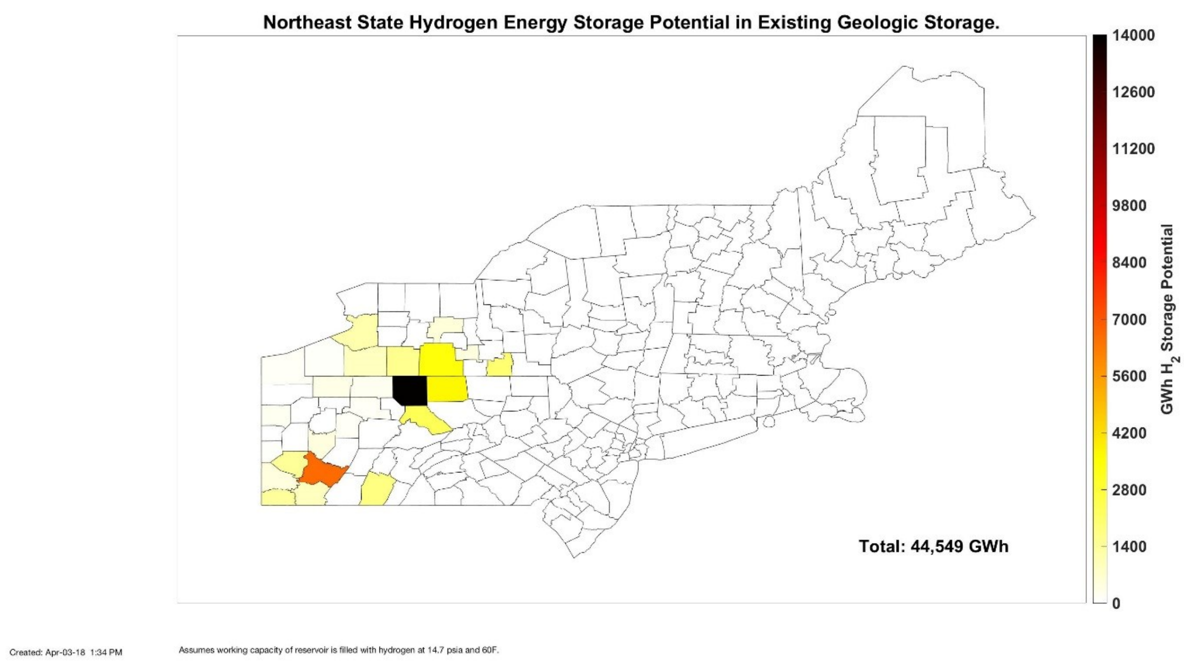

Figure 1 Potential for Hydrogen Energy Storage within existing geologic storage facilities in the Northeast. The map assumes that natural gas storage in these reservoirs is replaced with hydrogen, stored at 1 atm, 60 ˚F

- *Enhancing viability of nuclear power plants.* Emerging hydrogen production technologies, such as high-temperature electrolysis or thermochemical cycles, can utilize high-temperature heat (800°C-1000°C) for water splitting. Such technologies may have potential for close integration with current and next-generation nuclear power plants. In such hybrid systems, nuclear plants would supply heat to hydrogen production technologies when the use of heat for power generation is unprofitable. Hybrid systems may have a higher value proposition than the use of nuclear heat for electricity generation alone, and are currently being explored by utilities in the U.S.

- *Compatibility with two-way energy storage.* Hydrogen produced via power-to-gas concepts can also be utilized in power generation, to supply power back to the grid. Such concepts have value proposition when power generation is needed for timescales on the order of days. Hydrogen-based systems are expected to be more profitable than batteries at such time scales because their costs are significantly less sensitive to the volume of energy stored, particularly when existing large-scale infrastructure, such as caverns or pipelines, is utilized. Figure 2 compares the costs of battery-based systems with power-to-gas systems, assuming current costs as well as costs possible in the future, given R&D. While the round-trip efficiency of such systems is only 30-50% [9], they have a value proposition in the supply of long-duration backup power to support grid resiliency. Fuel cells are already used for backup power at facilities such as data centers, telecommunications towers, hospitals, and more. Their advantages in these applications include high reliability (99.7% availability), low maintenance costs, long lifetime, light weight, and low-noise, emission-free operation. [10,11,13]

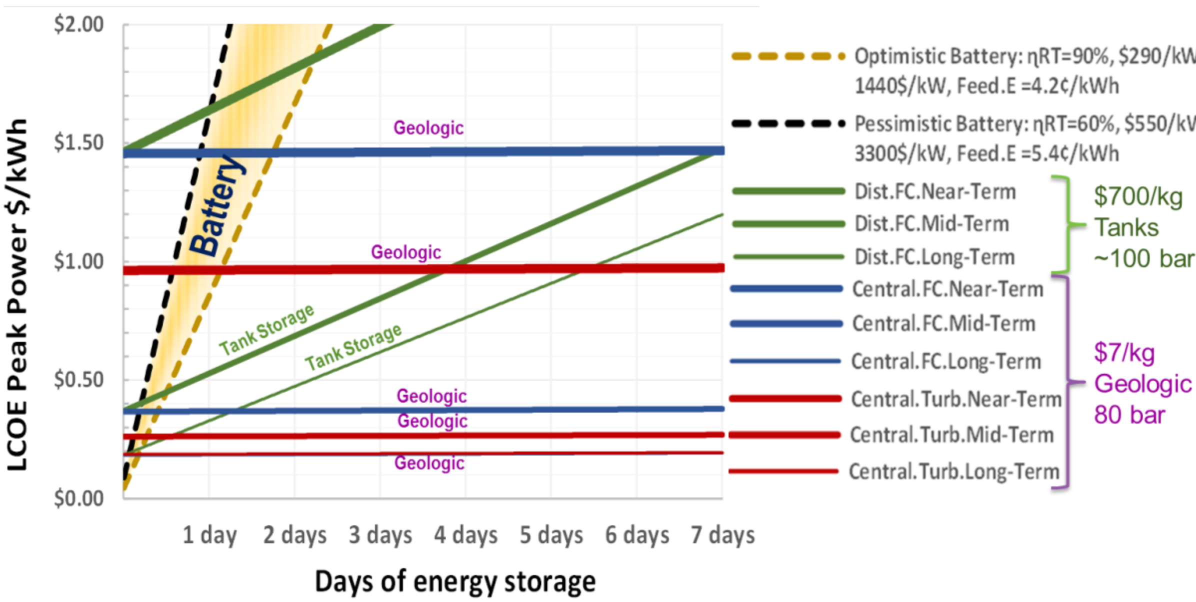

Figure 2 Comparison of the costs of batteries and fuel cells for energy storage and discharge Estimates are based on current costs, as well as potential future costs given R&D. [2] [12]

- *Enabling zero-emission transportation.* The use of hydrogen in fuel cells for light-, medium-, and heavy-duty vehicles is growing aggressively worldwide. Over 3,500 fuel cell vehicles have been sold or leased in the U.S. since their commercial introduction in 2015, and over 20 fuel cell buses are currently in operation in demonstrations. [15] By 2025, installation of over 200 hydrogen fueling stations is planned throughout the U.S., of which over 30 are already open for retail sale in California, and 12 are planned in the Northeast; four of these are expected to be located in New York. [14] Advantages of hydrogen and fuel cells in transportation include fast refueling times (5 minutes for light-duty vehicles), low life cycle emissions [16], as well as long driving ranges. Current light-duty fuel cell vehicles and buses exceed 250 miles in range. [15,17]

[2] In this study, near-term costs of electrolyzers were estimated at $2,000/kW, stationary fuel cells at $3,000/kW, and hydrogen combustion turbines at $783/kW. Mid-term costs of electrolyzers were assumed at $460/kW, stationary fuel cells at $677/kW, and hydrogen combustion turbines at $655/kW. Long-term costs of electrolyzers were assumed at $380/kW, stationary fuel cells at $434/kW, and combustion turbines at $655/kW.

Several demonstrations have already been launched worldwide regarding use of hydrogen in grid stability and energy storage applications. Noteworthy examples include:

- Integration of 6 megawatts of electrolysis with the electricity grid in Mainz, Germany to utilize excess wind energy. The hydrogen produced is subsequently blended into regional natural gas pipelines, or filled into tube trailers that supply fueling stations for vehicles.
- Integration of a 60-kilowatt electrolyzer with the electricity grid at the University of California, Irvine. The electrolyzer uses excess grid electricity to produce hydrogen that is then blended into natural gas in the University's natural gas piping. [18,19]

The U.S. Department of Energy's (DOE) H2@Scale initiative[3] is currently supporting early-stage research and development (R&D) to enable hydrogen as a wide-scale energy carrier that can provide cross-sector benefits, including energy storage, grid resiliency, and clean transportation. Recent activities have included the selection of 25 industry-led projects for partnership with the DOE's national laboratories to conduct research on hydrogen production, distribution, and integration with power generation. [20] Ongoing research led by the national laboratories includes early-stage R&D on advanced water splitting materials, platinum group metal-free catalysts for fuel cells, hydrogen storage materials, and durability of electrolyzers under simulated grid conditions, along with techno-economic analysis to establish the technical and economic potential of H2@Scale in the U.S. The safety of design, development, and use of hydrogen technologies is guided by industry codes and standards. The DOE maintains a portal known as H2Tools, hosting a wealth of information on codes and standards, best practices, as well as a database of lessons learned in work with hydrogen over the past several decades.[4] For information on the current costs and performance of hydrogen technologies, along with future targets, please see: https://www.energy.gov/eere/fuelcells/downloads/fuel-cell-technologies-office-multi-year-research-development-and-22

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[3] For more information, please see: https://www.energy.gov/eere/fuelcells/h2-scale
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