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Economics of Power to Gas

Additional submitted attachment is included below.

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ECONOMICS OF POWER-TO-GAS (P2G)[1]

Turns the Duck Curve problem into opportunity

As CAISO has pointed out with its famous Duck Curve, high variable renewable capacity in California risks over-generation, ramping challenges, curtailment, and slowing achievement of the state RPS. CAISO has stated that 350 out of 365 days of 2016 experienced some level of curtailment in the State. This was overall a tiny fraction of generation, but as California progresses from around 27% renewable electricity generation today to 50+%, there will be far greater risks of curtailment, balancing issues and negative pricing on renewable power, which must be addressed.

Surplus renewable electricity can lead to low and negative pricing, which present a potential opportunity to produce low cost renewable hydrogen that could be used or stored for later use. In other words, Power-to-Gas (P2G) has the potential to turn the problem of over-generation of renewables into opportunities because **low cost hydrogen production that allows more renewable electricity to be integrated economically into the grid and creates fuel for zero emissions vehicles and other industry products, as well as jobs and increased economic growth associated with P2G.**

More cost-effective and geographically efficient than Li-ion batteries at high capacity and more geographically flexible than pumped hydro and compressed air

All storage technologies are composed of 2 main components: a Power Conversion System (PCS) and an Energy Storage System (ESS) [source: Lazard]. P2G can use a designated hydrogen storage tank as its ESS or can leverage the existing, installed natural gas infrastructure to serve as the ESS. **When comparing capital costs in terms of the PCS only, P2G currently has significantly lower costs, in the range of $522-$1,000/kW[2,3], when compared to Li-Ion batteries, which are in the range of $1328-$2935/kW**.[4] Both of these ranges of cost are for widespread deployment of the technology (i.e., electrolyzers and Li-ion batteries). Note that the batteries can provide two-way power conversion, whereas the P2G case counts on existing equipment (e.g., NGCC plants) to produce the electricity in return.

When comparing installed cost in terms energy storage capacity, the discharge duration must be considered. Battery storage costs per kWh stored are constant, i.e., for each additional kWh of storage

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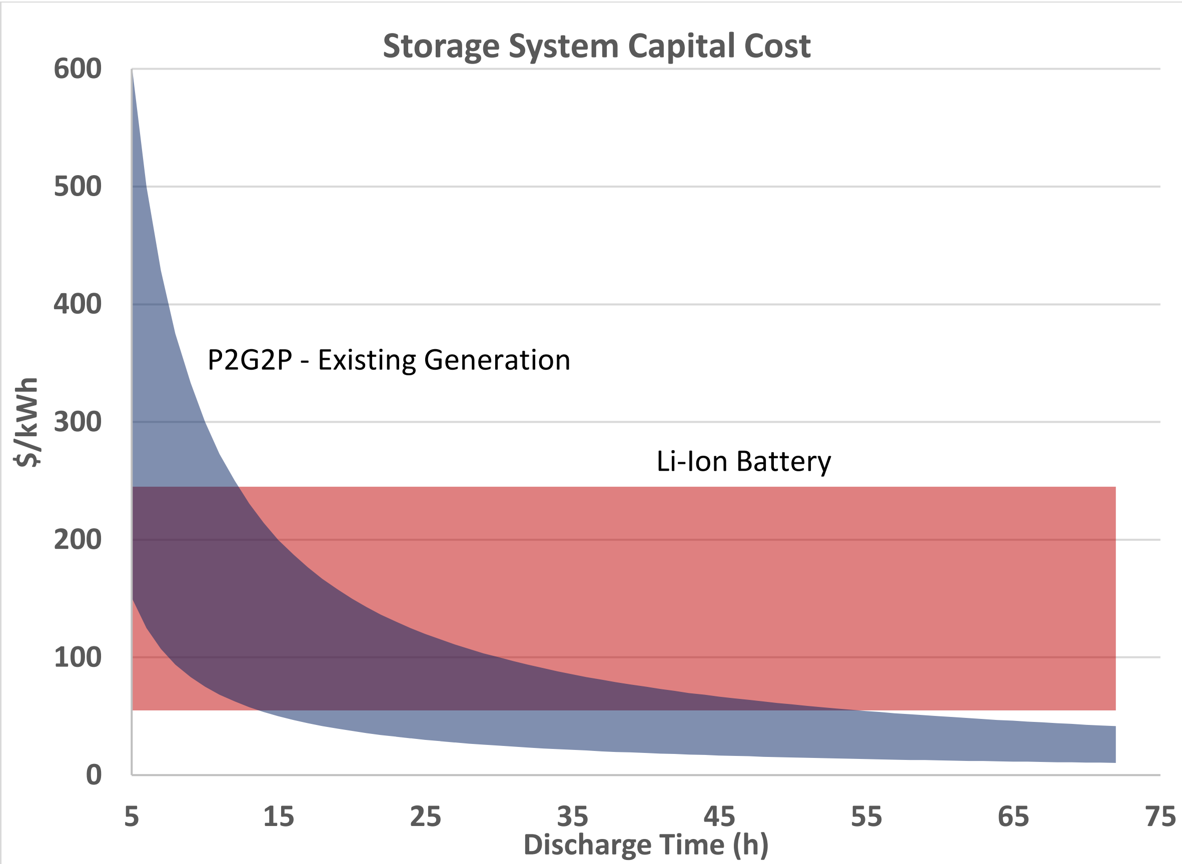
[1] Power-to-Gas is hydrogen produced using renewable electricity or methane made from combining that hydrogen with carbon dioxide.
[2] McKinsey & Company, "Commercialisation of Energy Storage in Europe," Fuel Cell and Hydrogen Joint Undertaking, European Commission, March, 2015.
[3] Nel ASA, Press Release / OSE-Filing, "Nel ASA enters into exclusive NOK 450 million industrial-scale power-to-gas framework agreement with H2V PRODUCT," Oslo, Norway, June 13, 2017.
[4] DOE/EPRI Electricity Storage Handbook in Collaboration with NRECA (SAND2015-1002)

capacity, an additional unit of storage must be added at a fixed capital cost. However, when P2G relies on the massive capacity of the installed natural gas grid to serve as the ESS, the installed storage cost per kWh of a P2G system decreases as the capacity increases. The figure below shows the capital cost[5] [6], adjusted for conversion losses, for a lithium-ion battery system and an electrolyzer system injecting hydrogen onto the gas grid for later use in an existing combined-cycle power plant for charging durations up to 72 hours. The latter electrolyzer case is dubbed Power-to-Gas-to-Power (P2G2P).



The cost ranges shown identify the relative potential for each of these technologies for reducing storage costs. **The chart shows that P2G2P could reach cost parity with a battery system with a storage duration of less than 5 hours. For storage duration of greater than about 50 hours, P2G2P is forecast to provide storage less expensively than batteries even when comparing current P2G2P costs to forecast future costs for batteries.**

A more accurate way to compare storage technologies, however, is to calculate levelized cost of storage (LCOS), i.e. the cost, over the life of the project, of storing a kWh of electricity and returning it to the electric grid for later use. While LCOS studies of battery technologies are common (see Lazard), few researchers have analyzed the LCOS of P2G in comparison to battery storage technologies. Researchers at UC Irvine are developing a model to make an accurate comparison. In order to maintain consistency across many energy production scenarios, the model does not consider the cost of the electricity used to

[5] U.S. Department of Energy, H2A Production Case Studies for Current (and Future) Central Hydrogen Production from Solid Oxide and PEM Electrolysis (Version 3.0)

[6] DOE/EPRI Electricity Storage Handbook in Collaboration with NRECA, Sandia National Laboratory, 2015.

charge the storage system. Under highly curtailed renewable scenarios, excess solar power can be obtained for very low prices.

Initial results from the model, using a capacity factor of 50%, or 12 hours of charging time per day, suggest an LCOS for batteries of 10-22 ¢/kWh compared to P2G of 11-40 ¢/kWh, depending upon the technologies and pathways considered. Under future systems cost and efficiency forecasts, the model suggests an LCOS of batteries of 5-15 ¢/kWh compared to P2G of 8-21 ¢/kWh. **P2G can be cost competitive with batteries and promises to serve an important role fulfilling the need for energy storage in California.**

Also it should be noted that P2G and P2G2P can store massive amounts of energy and can shift such energy over very long periods of time (e.g., seasonally, annually), which is difficult or impossible for Li-ion batteries.

Finally, P2G additionally has more continuous capacity in less space than Li-ion batteries. This is particularly important when there is a need to absorb continuous power generation or to provide time shifting of load over long periods. For example, a **1.2 MW** Li-ion battery installation in Quebec uses a **53 ft.** container and has a storage limit of only **1.2 MWh at a time**. By comparison, a **1.5 MW** capacity electrolyzer project in Hamburg uses a **40 ft**. container and can store up to **36 MWh /day,** as long as it is connected to the gas grid, and electricity generation to power the electrolyzer is continuous.

With regard to comparison to pumped hydro and compressed air energy storage (CAES) CEC Staff has acknowledged that pumped hydro and CAES are restricted in terms of project location due to their site-specific nature, and that best sites may not be within areas where they are needed. P2G, in contrast, has many options for siting because it so flexible – e.g., it can connect to the electric grid for large-scale storage, operate on a smaller scale at industrial facilities that use hydrogen, co-locate with a wind or solar farm to maximize their generation capacity and reduce the need for transmission upgrades, blend renewable gas into the vast existing gas system, or power one of the state's baseload gas plants. Recently a study conducted by McKinsey & Company found that converting renewable power into hydrogen by P2G followed by salt cavern hydrogen storage and use of combined cycle power plant conversion back to electricity (called Power-to-Power, P2P) was cheaper than pumped hydro storage. The findings showed that P2P with a round trip efficiency of 40% and capital costs of $1000/kW has a lower levelized cost of electricity than pumped hydro storage, the current lowest cost energy storage solution.[7]

NREL states: "Initial cost analysis indicates that hydrogen systems could be competitive with battery systems for energy storage and could be a viable alternative to pumped storage hydro and CAES at locations where these latter two technologies are not favorable."
http://www.nrel.gov/docs/fy16osti/64764.pdf

P2G is the only solution for terawatt-hour-scale, seasonal storage and to scale up renewable, carbon-free fuels for difficult transportation applications like long haul heavy-duty trucks, residential cooking, and aviation.

Among energy storage technologies, P2G is uniquely scalable to the terawatt-hour level. (See chart on p. 6 of this CHBC White Paper.)

[7] McKinsey & Company, "Commercialisation of Energy Storage in Europe," Fuel Cell and Hydrogen Joint Undertaking, European Commission, March, 2015.

According to a recent report from the European Association for Energy Storage, **P2G "is the <u>only</u> energy storage option available to store large amounts of energy seasonally and provide it on-demand to different sectors and applications."**

According to the German Federal Environment Agency, P2G and liquid **fuels derived from renewable hydrogen (PtL) are "needed to ensure a completely renewable energy supply for transport.** In particular, PtL can provide the liquid renewable fuels needed in aviation. (They) can also provide a renewable, GHG-neutral energy supply for shipping and long-distance road freight transport."

The results of CHBC analysis show that, based upon a range of input electricity prices of zero (free curtailed electricity) to $0.06/kWh (potential future off-peak rate), as well as upon expected progress on technology cost, hydrogen and methane can be produced at costs comparable to conventional vehicle fuel. This is without consideration of any renewable fuel premium, which could be in the range of $2 per gasoline gallon equivalent in the 2030 time frame.

Additionally, the **<u>only</u>** commercially available heavy-duty vehicle engine that meets CARB's strictest NOx standards runs on methane. Whereas, heavy-duty battery electric truck alternatives are years, if not decades away from commercialization, these "near zero emissions" engines can replace dirty diesel trucks today and help the most polluted regions in California meet state and federal air quality standards. The possible feedstocks for fueling these engines are fossil natural gas, biomethane from organic waste, or P2G.[8] Of these, **P2G is the only renewable, zero-carbon (or low carbon, if its mixed with natural gas) feedstock that can be made available at mass scale**. In addition, the recent pilots of heavy-duty fuel cell electric trucks by several manufacturers are building blocks for a medium-term zero-emission freight option fueled by hydrogen.

Studies in US and Germany suggest that P2G could help achieve deep greenhouse gas reductions more cost-effectively than an electrification-only pathway.

Fraunhofer ISE states: "To achieve Germany's national GHG reduction targets of 80-95% below 1990 levels by 2050, using P2G stored in the existing gas infrastructure **saves ~ 60 billion €** a year compared to alternatives."

E3 concludes that in meeting California's short and long term GHG reduction targets, if instead of an electrification only scenario, the state were to pursue a strategy combining electrification (especially for passenger vehicles), along with P2G – among other renewable gases - as a grid asset, it **could save up to about 10% in costs.**

The German Environment Agency states: "**The essential component in the transition to a society that is almost completely greenhouse gas-neutral is to convert the power which will be produced entirely from renewables into hydrogen, methane and long-chain hydrocarbons**."

Where P2G is in terms of commercial market development

[8] In this use case, P2G would refer to renewable hydrogen synthesized into methane.

P2G is in the early stages of commercialization, with more than 30 projects installed or in development in Europe, and 3 in North America, including a 2MW commercial facility procured by Ontario's transmission grid operator IESO and two demonstration projects in the US.

P2G is scalable from small to very large sizes. In the current phase of development, projects are being developed that are up to 100+ MW in size, for example, a series of 7 grid-injected hydrogen plants of approximately 100 MW each that are being installed in France. 10-20 MW sized projects are being developed. The European Union recently issued a bid for a 10+ MW P2G facility.

Germany's P2G Roadmap calls for at least 1 GW of P2G across the country by 2020/2025.

As with any energy technology that is new to the market, support is needed to make P2G economically competitive. Keys to economic success are:

- **Policy support**
  For example:
  1) *First and foremost making sure P2G remains part of the implementation of SB 1383,* in which the legislature explicitly directed the Energy Commission to look at "renewable gas" - that both houses of the legislature and the Governor's office understood at the time of the bill's passage to include agency consideration of electrolyzer-produced hydrogen.
  2) *Directing the CPUC to ensure P2G facilities are eligible for appropriate (wholesale or at least more aggressive retail rate structures) electricity rates*, as well as low T&D rates for fuel production and industrial process applications.
  3) *A renewable gas standard*, requiring state investor owned utilities to procure at least 5% renewable gas by 2030.
- **Appropriate electricity pricing**
  Electrolysis is a highly flexible load that can provide significant support for grid needs; however, in order to provide the full benefit, there needs to be an incentive structure to encourage that behavior. Current retail rates do not capitalize on the full flexibility of electrolysis systems. Access to wholesale markets and more aggressive retail rate structures would allow utilities and system operators to fully utilize electrolysis flexibility. Access to wholesale markets would allow electrolysis to produce hydrogen at times of low electricity prices. With $0/MWh surplus electricity, the cost of P2G transported on the gas grid and redelivered as fully dispatchable renewable electricity (via existing combined cycle or natural-gas-capable fuel cell generators). drops to **< $0.07/kWh net of conversion losses** (assuming 55% fuel-to-electricity efficiency). (See p. 9 of CHBC White Paper.) balancing
- **Support to enter new markets and maximize revenue opportunities**
  A broad set of revenue opportunities will be necessary to build a viable and sustained market for P2G – e.g. providing ancillary services, transportation fuels, electricity generation, building end uses, demand response.
- **Support for research and development**
  R&D for fuel cells brought down costs by 80% and can have a similar major impact on other hydrogen-based technologies.
- **High penetrations of renewable electricity generation**
  This will require multiple solutions, which, especially when penetrations become high enough to necessitate bulk seasonal storage, will include the P2G option because of its flexibility and scalability.