As regions increase their dependence on intermittent sources of power generation, the value proposition of flexible technologies will increase to improve the utilization of these resources.

Considerations for leveraging flexible loads to decarbonize electricity and transportation*

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More regions of the world are looking to decarbonize electricity production using wind and solar power generation. This major transition from traditional power sources comes with a number of technological difficulties for grid operators and a myriad of political, economic, and technological options to correct these issues. Often, the root problem associated with renewable power generation is posed as one of generation intermittency. The current grid model is based on one where generation is continually altered to match the current demand of the end users, so naturally the focus trends toward what can be done to make the intermittent generation match the daily demand. This has led to a strong focus on developing new energy-storage systems to create systems which are capable of shifting energy at the scale that will be necessary to support grids with a high penetration of renewable resources.

Along with technological advancements in storage is the need to develop appropriate financial incentives and policies to encourage installation of technologies that will be most beneficial to the grid as a whole. For instance, at the operator level, energy-storage systems have gained a lot of interest for applications, such as frequency regulation, because of the potential for a high rate of return. However, other functions for which a battery system would be well suited at a technical level are not yet compensated in a way that encourages widespread interest. It is not enough for an appropriate technology to exist; financial mechanisms have to be in place to encourage investment in said technology. However, the intersection of policy, technology, and financial planning concerns can be very tricky to navigate.

This is true for end users as well. In acknowledgment of the fact that the intermittent generation problem can be posed more globally as a mismatch of supply and demand, many utilities are developing pricing structures to encourage end users to modify their demand to more appropriately match their generation capabilities. One method that is commonly viewed as a good option is time-of-use rate structures, which increase electricity costs during times when it is expensive or difficult to produce electricity in hopes of encouraging changes in demand to match generation.

End users then are faced with the question of how to modify their behavior or system to minimize their expenses, and again, the number of possibilities can be staggering. If loads could be shifted freely, they could simply move their demand to low-cost times of day. While this can be carried out with some loads, often the amount of load shifting that can be done is limited by non-economic factors (e.g., acceptable working hours, lighting needs, heating/cooling temperature limits, manufacturing throughput requirements). Barring the ability to freely shift demand, battery systems could be considered to shift the net demand from the grid, but the rate of return versus the installed cost would need to be sufficiently high to make the project worthwhile. Finding the right balance of system size and investment cost to potential savings is rarely a straightforward proposition, and minor details of their specific pricing structures can lead to major differences in financial valuation for any strategies being considered. Consequently, results can sometimes be surprising.

One example of how the interplay of technological and economic options can lead to unanticipated results is highlighted in a recent study on valuation of behind-the-meter hydrogen production. This work looked at a rather unique use case at the Natural Energy Laboratory of Hawai‘i Authority (NELHA) research park (see **Figure**). NELHA operates an ocean science and technology park at Keahole Point that supports economic diversity and sustainable development for the State of Hawai‘i. As part of this function, the research campus houses multiple enterprises serving a wide range of research needs. Among these, the campus will soon begin operation of a 250-kW hydrogen electrolysis facility that will be operated by the Hawai‘i Natural Energy Institute (HNEI). The hydrogen production and dispensing station is the brainchild of researchers at HNEI. The station will be used to evaluate the technical and financial performance of behind-the-meter electrolytic hydrogen production in addition to assessing the durability of the equipment. The station will also support a fleet of three hydrogen Fuel Cell Electric Buses (FCEBs) operated by the Hawai‘i Mass Transit Agency (MTA). The knowledge gained in this project will inform and "de-risk" the MTA on transitioning from a diesel bus fleet to a zero emissions FCEB fleet to meet Hawai‘i's clean transportation goals.

A previous study of this unique scenario showed that given the flexibility and scale of the electrolyzer relative to the rest of the research park's load, most all of the potential utility of an energy-storage device could be realized with the flexibility of the electrolyzer facility instead. With a standard flat rate electricity charge and monthly peak demand charges, the cost of

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electricity could be minimized by increasing the electrolyzer load at midday, when on-site solar generation at NELHA is high, and decreasing the load at other times of the day. This would minimize demand charges by removing any spikes in power that might lead to an excessive demand cost, while still producing the necessary amount of hydrogen; this highly flexible nature in hydrogen production facilities aligns demand with supply.

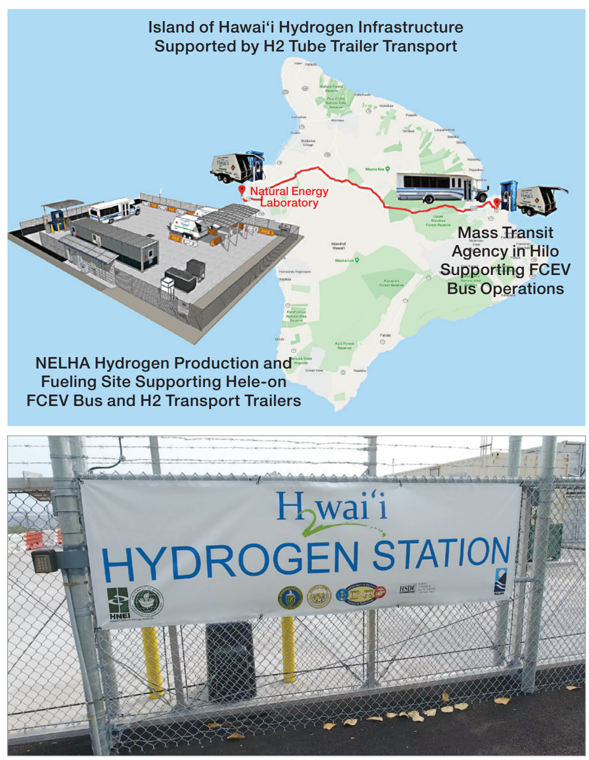
The question then became how to minimize the cost of hydrogen production in this scenario. Though the current electricity rate structure at NELHA uses flat electricity prices and demand charges, they have an option to switch to a time-of-use rate structure. The common assumption is that a time-of-use rate structure would benefit hydrogen production as the flexibility of the load makes it possible to shift production to low-cost times of day. A mixed-integer linear program of the scenario was modeled, including the changing efficiency of the hydrogen production plant at different power ranges, to simulate what the minimum production cost would be if the plant's load was optimally managed. Surprisingly, despite the common assumption that time-of-use pricing is good for load balancing technologies, it was found that the available time-of-use structure would actually increase the cost of production.

This is the result of the intersection of a number of minor technical- and policy-driven details that culminate in major impacts on the cost of production, even in an ideal case. The major factors that would lead to increased production costs are as follows:

1. The low-cost window is too short to produce the daily demand of hydrogen for the buses with the given system, so some production would need to be completed with more expensive electricity.
2. The demand charge does not have a time-of-use component, so limiting the production window increases demand charges for the month.
3. Limiting the production window requires high power operation, which lowers the plant efficiency and increases the amount of electricity that is necessary for production.
4. The available time-of-use rate structure still includes a large, flat \$/kWh energy cost recovery charge that represents a large portion of the bill.

A change in any one of these factors could completely change the value proposition of pairing the electrolyzer with the research campus load and significantly change the cost of hydrogen production. If the demand for hydrogen was lower, less production would need to occur at the low-efficiency, high-power range of the system, and results could be very different. If the prices during the different time-of-use windows or the duration of the price windows changed, results could be very different. If the demand charges also operated on a time-of-use basis such that increasing demand during low \$/kWh windows did not increase \$/kW charges, results could be very different.

Further analysis of the HNEI fueling station included consideration of different plant scheduling methods and configurations, as well as the impact of increasing on-site solar generation. These additional considerations highlighted a few other key points for system planning going forward. First, increasing on-site solar production would be the best method to reduce the cost of hydrogen production, but the maximum power of the electrolyzer eventually limits the benefit of more solar generation. With enough solar installed, the output of the solar array would outpace the maximum facility power, which would lead to lost solar production. This also points to the importance of pairing hydrogen production with other loads to maximize the amount of solar generation that is utilized. The analysis showed that this is mutually beneficial for both the production facility and associated load, in this case the NELHA research campus, as the cost of electricity of the combined system would be less than that of two independently operated systems under the same rate structure.



Images showing the production and dispensing process and the Hawai'i Hydrogen Station. Credit: Hawai'i Natural Energy Institute.

All of this showcases the incredibly multifaceted process that system valuation of this kind can, and needs, to become. The characteristics of the technologies involved, the specifics of the rate structure, and the design of the overall system all have major implications on the benefits of any load-shifting technology, but most certainly for hydrogen production. As regions increase their dependence on intermittent sources of power generation, the value proposition of flexible technologies will increase to improve the utilization of these resources, but careful planning on many fronts will be necessary to ensure that these benefits are realized. HNEI's new hydrogen production station is a great look at how all these considerations can come together to make electrolytic hydrogen production a viable option as Hawai'i moves to decarbonize the electricity and transportation sectors. □