ESIG
ENERGY SYSTEMS
INTEGRATION GROUP

ESIG REPORT

Assessing the Flexibility of Green Hydrogen in Power System Models

EXECUTIVE SUMMARY

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As decarbonization goals advance for both electric power systems and the broader economy, it is clear that the energy grid of the future will look vastly different from today's. Power systems will increasingly require different types of flexibility to balance supply and demand and maintain reliability as levels of wind and solar rise. Hydrogen production has the potential to provide such flexibility. ESIG's 2022 report *Increasing Electric Power System Flexibility: The Role of Industrial Electrification and Green Hydrogen Production* identified the need for green hydrogen production to be more deeply integrated into power system planning processes and the need for additional work to understand the implications of green hydrogen production for electricity system operations and market operations.

As a versatile energy carrier, hydrogen production via electrolysis is likely to be used across many sectors. Although providing flexibility services to the electric power sector may not be a hydrogen production facility's primary objective, there is substantial interest in understanding the ways that hydrogen can provide flexibility to the electric power system. Stand-alone hydrogenproduction that behaves as a flexible load is well suited for providing balancing and operating reserve–type services, whereas other services, like seasonal energy arbitrage, require the production of electricity through a fuel cell or combustion engine. Many studies suggest that, as the electricity system and broader economies decarbonize, hydrogen might be used to provide grid services instead of conventional dispatchable resources, such as coal-fired turbines, natural gas, and pumped hydro.

Potential grid services include:

- **Regulation:** To manage, on a second-to-second basis, uncertainty from forecast errors and generator responsiveness
- **Balancing (also known as ramping or load-following):** To manage variability and uncertainty within an hour and across hours
- **Operating reserve:** To manage contingencies or operational events—such as any combination of forced outages and periods of low wind or solar
- **Seasonal energy arbitrage:** To manage the mis-match of resource availability and load across seasons

This report explores the modeling needs and data requirements to integrate hydrogen into power system studies and evaluates the role of hydrogen production via electrolysis as a source of system flexibility. While other emerging technologies, such as coordinated charging of electric vehicles or stationary battery storage, may also provide similar flexibility, green hydrogen is of special interest due to its ability to store energy for use in many time frames (from seconds to seasons), its rapid response time, and its potential for large-scale deployment. The

See the full report: **Assessing the Flexibility of Green Hydrogen in Power System Models**

possibility of large centralized hydrogen production facilities is a key aspect of hydrogen's flexibility and predictability.

This report discusses several challenges and gaps in existing power system modeling tools and methods and is intended as a starting point for modelers evaluating the benefits and implications of using green hydrogen production to provide flexibility in their systems.

Four Main Technologies for Green Hydrogen Production

The components and processes of an electrolysis system affect the performance and costs of using green hydrogen production for flexibility. The four main types of electrolysis technologies are alkaline, polymer electrolyte membrane (PEM), solid oxide electrolysis cell (SOEC), and anion exchange membrane (AEM), and each has advantages and disadvantages in terms of cost and performance. Electrolysis systems that perform with higher operating ranges and faster response times are best suited for providing operational flexibility/ancillary services. Systems with higher efficiencies/capacity factors are better suited for providing longer-duration flexibility, such as seasonal storage.

Alkaline systems are the most mature technology and have the lowest capital costs and the longest life. While these characteristics are encouraging, alkaline electrolysis has drawbacks in terms of performance. Alkaline systems have a narrower operating range than other types. Further, it is best for them to operate continuously to reduce issues from short-circuiting or slow start-ups, making them potentially more suitable for continuous baseload rather than balancing services.

PEM systems are well suited for providing balancing services due to their faster ramp rates and start-up and shut-down times. Additionally, the costs and efficiencies of PEM electrolysis are expected to improve over the next decade, making it competitive with alkaline electrolysis.

Electrolysis systems with higher operating ranges and faster response times are better suited for providing operational flexibility, and systems with higher efficiencies/capacity factors are better suited for providing longer-duration flexibility, such as seasonal storage.

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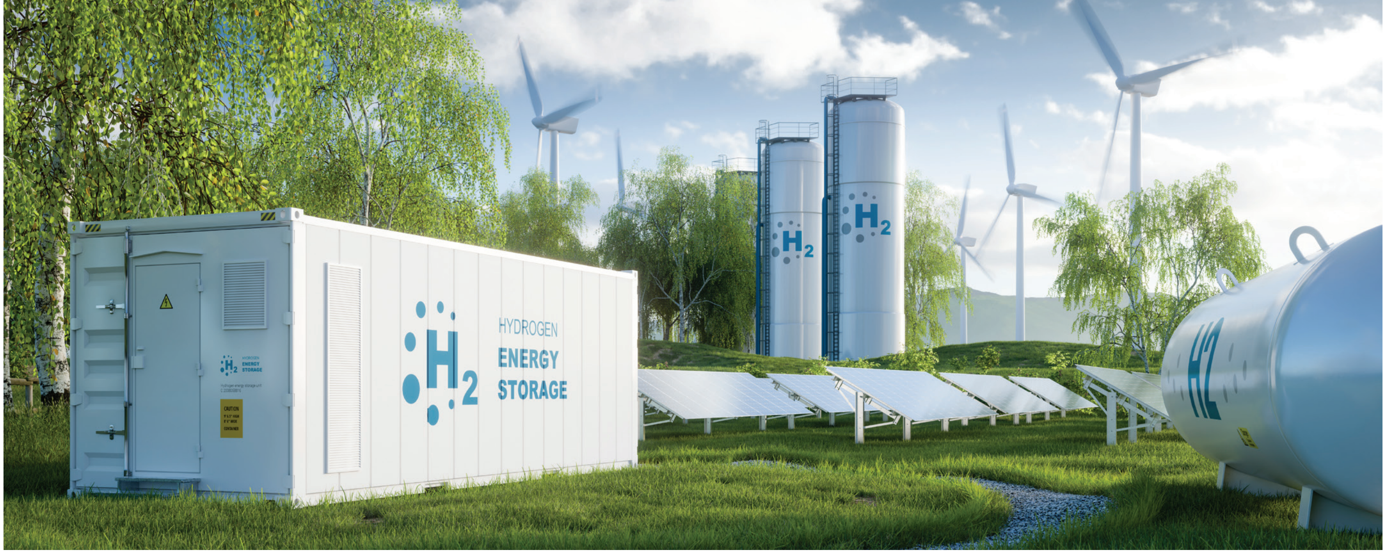
SOEC and AEM systems are the least mature technologies. While their costs and performance are less certain, they have the potential to provide flexibility benefits. Of note, SOEC systems of the future have the potential to operate across the widest load range (from -100% to 100%) by reversing their mode of operating and acting like a fuel cell.

Modeling the Flexibility of Hydrogen

Modeling the flexibility of hydrogen introduces new considerations beyond what power system models have typically incorporated. Modeling hydrogen's potential to provide grid flexibility is a complex effort: there are many options and permutations of potential electrolysis systems, operating regimes, and grid services to target. Modelers may consider the following questions to assist in selecting appropriate data inputs to incorporate:

- What grid services are needed in this geographical area?
- What tools are best suited for assessing these grid services?
- What time horizon is being studied?
- What operating regime and other end uses might a given hydrogen facility provide?
- What electrolysis system is best suited for providing the grid service(s) being studied?



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- What inputs are most critical for the grid service(s) being studied?
- How can the availability and uncertainties of supporting infrastructure be considered?
- How can the dynamics between hydrogen and electric power markets be considered?
- What data sources are available to develop modeling inputs?

Modeling hydrogen may require the use of multiple planning tools, such as capacity expansion, production cost, and multi-energy system models. It will be important to capture the technical characteristics and costs of different electrolysis technologies, the locational aspects of transmission and hydrogen networks, a range of assumptions around renewable energy sources and hydrogen prices, and the interactions between the electricity system and other sectors and markets. Modelers will need to incorporate and evaluate the benefits and implications of green hydrogen in their systems by using multiple planning tools, capturing the characteristics and behavior of electrolysis technologies and systems, sourcing high-resolution data, and considering different scenarios and sensitivities.

Moving Toward Best Practices

Given that hydrogen is still an emerging resource for power system applications, there is as yet limited consensus on best practices for modeling. However, organizations can continue to study the role of hydrogen in providing grid flexibility by developing initial models and can monitor improvements in the cost and performance of hydrogen to continually update their models. In parallel, ongoing research and software improvements may improve modeling techniques for future studies. And as the industry matures, knowledge and experience obtained from academia, other research institutions, software developers, hydrogen technology developers, and system modelers can be shared and used to move toward best practices. Several areas for further research and development can also be advanced, including improving the availability and quality of data for hydrogen production and demand, enhancing modeling capabilities and resolution to better represent hydrogen's potential role in providing flexibility to the system, and exploring the value streams and trade-offs of hydrogen production for different end uses and scenarios. Both the electric power sector and hydrogen facilities benefit from such exploration and collaboration around the use of hydrogen production facilities as a source of flexibility in power systems.

Assessing the Flexibility of Green Hydrogen in Power System Models by the Energy Systems Integration Group's Flexibility Task Force is available at https://www.esig.energy/green-hydrogen-in-power-system-models.

To learn more about the topics discussed here, please send an email to info@esig.energy.

The Energy Systems Integration Group is a nonprofit organization that marshals the expertise of the electricity industry's technical community to support grid transformation and energy systems integration and operation. https://www.esig.energy.