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Office of ENERGY EFFICIENCY & RENEWABLE ENERGY

Water Electrolyzer Installations

Summary Report – September 2023

Hydrogen and Fuel Cell Technologies Office

U.S. Department of Energy

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Preface

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Acknowledgments

The Hydrogen and Fuel Cell Technologies Office (HFTO) acknowledges and thanks the National Renewable Energy Laboratory (NREL) for co-hosting this event. HFTO and NREL thank all speakers and panelists for sharing their valuable knowledge with the community. HFTO and NREL thank the organizing team for their effort in planning and executing the event, and the scribes for taking notes. HFTO and NREL also thank the participants of the meeting for their engagement in answering survey questions and for asking thoughtful questions of the speakers and panelists.

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List of Acronyms

AHJ	Authority having jurisdiction
ANL	Argonne National Laboratory
BIL	Bipartisan Infrastructure Law
DCPUD	Douglas County Public Utility District
DOE	Department of Energy
EERE	Office of Energy Efficiency and Renewable Energy
EPC	Engineering, Procurement, and Construction
FCEV	Fuel Cell Electric Vehicle
GREET	Greenhouse Gases, Regulated Emissions, and Energy Use in Transportation Model
HFTO	Hydrogen and Fuel Cell Technologies Office
ISO	International Organization for Standardization
NFPA	National Fire Protection Association
NREL	National Renewable Energy Laboratory
OEM	Original Equipment Manufacturer
SOEC	Solid oxide electrolysis cell
PEM	Proton exchange membrane
RD&D	Research, development, and demonstration
SMR	Steam methane reforming
TIC	Total installed capital cost
WCF	Water consumption factor

Executive Summary

With recent historic investment in clean energy technologies from the Bipartisan Infrastructure Law (BIL), the U.S. Department of Energy (DOE) is executing a strategy to reduce the cost of clean hydrogen produced via water electrolysis.[1] The BIL established a goal of reaching $2 per kilogram of hydrogen produced by 2026.[2] Achieving this goal will require significant cost reductions in electrolyzer equipment, increased energy efficiency, prolonged lifetime, low-cost electricity, and cost reductions in electrolyzer system installation.

The DOE Office of Energy Efficiency and Renewable Energy's (EERE) Hydrogen and Fuel Cell Technologies Office (HFTO) co-hosted an event with the National Renewable Energy Laboratory (NREL) on September 26-27, 2023, focused on water electrolyzer installations. The main goals of the event were to:

- Understand key challenges and cost drivers associated with installations of large-scale water electrolyzer systems
- Identify opportunities to reduce costs and streamline the water electrolyzer installation process
- Inform HFTO's research, development, and demonstration (RD&D) strategy for water electrolyzer installations

Over 450 people attended the event, highlighting the importance of this topic to the hydrogen community. The diverse audience represented a range of organizations including electrolyzer manufacturers; utilities; project developers; engineering, procurement, and construction (EPC) firms; national laboratories; universities; environmental justice organizations; and government (**Figure 1**). The audience also included a range of experience levels, with ~25% of attendees having some experience installing an electrolyzer and another ~25% who plan to be involved in the future (**Figure 2**).

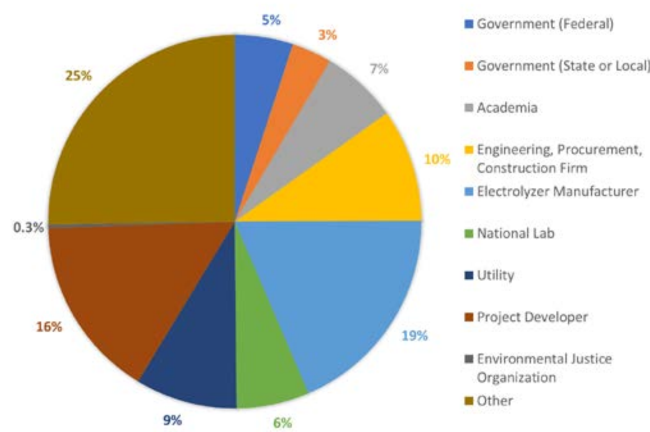

Figure 1. Attendance report by industry.

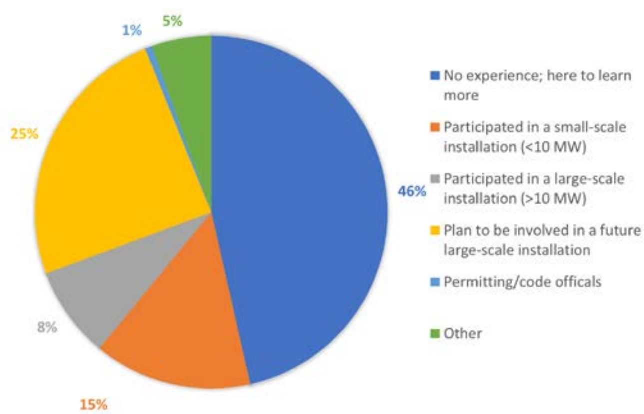

Figure 2. Attendance report by experience with electrolyzer installations.

Diversity was also reflected in the speakers and panelists, who brought unique perspectives from a range of industries including project developers, electrolyzer manufacturers, utilities, and national lab researchers. The first day of the event featured an electrolyzer installation case study, technical presentations on electricity and water demands, and two panels with representatives from project developers and electric utilities. The second day began with another case study, followed by technical presentations on safety, siting, codes/standards, and technoeconomic cost analysis. Each speaker was asked to focus on

[1] https://www.hydrogen.energy.gov/library/roadmaps-vision/clean-hydrogen-strategy-roadmap
[2] 42 U.S.C. § 16161d

understanding current challenges and highlighting opportunities for cost reductions and/or a more streamlined, time efficient process.

Currently, water electrolyzer projects take several years to execute, from project design through commissioning. Projects with <10 megawatt (MW) can take up to three years, while projects >10 MW can take five or more years. Project developers warned of long lead-times for equipment, not just for electrolyzer stacks, but for other components as well such as pumps, valves, and power electronic equipment. Delays in receiving equipment can cause delays in the overall project schedule. Careful consideration of all relevant codes and standards is also important during the design phase of a project to mitigate setbacks due to site re-location or site re-designs. Hiring qualified personnel (e.g., architects, code experts) that have experience with hydrogen projects can help to streamline the design phase, though personnel with such experience are in extremely high demand today. Another critical aspect that can cause significant delays to an electrolyzer installation project is obtaining required permits from local authorities having jurisdiction (AHJs). Early engagement with AHJs and community members to educate them about hydrogen and listen to their concerns was strongly encouraged by several speakers and panelists to streamline the permitting process.

Today, the total installed capital cost of a water electrolyzer is estimated to be ~2 times the capital cost of the equipment. With continued technology development and learning by installing many electrolyzers, a total installed cost of ~1.4 times the cost of equipment could be achievable. Of the total installed cost, ~15% is the cost of the electrolyzer stacks, ~35% is the cost of the other equipment, and ~50% is the cost of engineering and construction. Total installed capital costs will vary depending on location, project scope, electrolyzer stack type, and system design. Comparing results from different cost analyses is often challenging because of differences in system designs and assumptions – installing a water electrolyzer is rarely done without also installing other hydrogen infrastructure such as hydrogen storage and dispensing equipment. The variation in published capital costs could be indicative of real variation in costs today that are highly dependent on factors such as system design, location, and size.

Several opportunities to streamline the electrolyzer installation process were identified throughout the webinar, including communication with local communities, safety and risk analysis, workforce development, and siting. In general, information sharing between stakeholders early and often is critical to successful electrolyzer installations.

Early Communication with Local Communities: Community opposition to a hydrogen project can slow installation and even prevent projects from being realized. It is important to listen to communities' feedback and concerns about a project and try to address them early, especially those related to safety, noise, and impacts on local water supply. Seeking out community partners, such as economic development committees, that support the project can help to accelerate broader community acceptance. Early engagement with local fire departments, first responders, and AHJs is also important to streamline efforts. Government agencies can aid in these efforts by publishing educational materials that project developers can share with community groups, fire departments, first responders, and AHJs across the country. In addition, the federal government could work with state governments to ensure appropriate rules and regulations are in place for hydrogen projects.

Safety and Risk Analysis: Inadequate understanding of safety risks can lead to timely and costly site re-designs, or worse, a safety incident in the future. It is important to conduct appropriate hazard analyses at the correct stage within the project development timeline to ensure proper mitigation strategies are deployed. Government agencies are promoting hydrogen safety through the Hydrogen Safety Panel[3] and the Hydrogen Tools Portal[4] and in partnership with the Center for Hydrogen Safety.[5]

[3] https://h2tools.org/hsp
[4] https://h2tools.org/
[5] https://www.aiche.org/chs

Workforce Development: There is a need for more personnel with hydrogen experience in the design phase of the development process, including architects, code experts, and contractors. Training on the safe handling of hydrogen equipment is also critical. Government agencies could help to establish training programs or curriculum in partnership with local workforce development programs and AHJs.

Informed Siting and Site Design: For industries and firms interested in installing electrolyzers to produce green hydrogen, one of the first barriers to entry is understanding the types of electrolyzers and the scenarios for which each type is best suited. Government agencies could identify best use cases or reference system designs for different types of (and different mixes of) electrolyzer technologies in different scenarios. Additionally, government agencies can identify regions of the U.S. with renewable energy resources producing excess electricity to assist with siting new electrolyzer projects. Making such information publicly available to all interested stakeholders could help to accelerate deployments.

In addition, to the above opportunities to streamline the electrolyzer installation process, below are opportunities to further reduce installation costs:

- House electrolyzer stacks outside to eliminate the need for an expensive building
- Optimize equipment integration and build modular, factory installations (e.g., pre-assembled skids) to reduce overall system footprint and the amount of equipment that must be installed onsite
- Eliminate central water cooling to reduce system footprint and water usage
- Operate stacks at higher power density to minimize footprint
- Maximize installation size to leverage economies of scale

The information gathered during the webinar will inform HFTO's RD&D strategy to address high costs and process barriers to installing electrolyzers, with the aim of accelerating progress towards \$2/kg H_2 and mass deployment of electrolyzers.

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1 Introduction & Background

As part of the U.S. Department of Energy (DOE) Office of Energy Efficiency and Renewable Energy (EERE), the Hydrogen and Fuel Cell Technologies Office (HFTO) leads the DOE's Hydrogen Program.[6] HFTO specializes in advancing hydrogen and fuel cell technologies through applied research, development, and demonstration (RD&D). To inform RD&D priorities of hydrogen technologies, HFTO often convenes stakeholders from the research community, industry, government, and the general public.

On September 26-27, 2023, HFTO co-hosted, along with the National Renewable Energy Laboratory (NREL), the Electrolyzer Installation Webinar. This event was held virtually to allow for maximum public participation. The key objectives were to:

- Understand key challenges and cost drivers associated with installations of large-scale water electrolyzer systems
- Identify opportunities to reduce costs and streamline the water electrolyzer installation process
- Determine if and how those opportunities would benefit from federal government involvement

The event included presentations and perspectives from experienced industry professionals and national laboratory experts to gather a broad set of perspectives. A public audience was encouraged to submit live questions for the speakers and to participate in survey questions. The expert and audience input, documented in this report, will be used to guide HFTO's Production subprogram development. The agenda, presentations, and this report can be found at: https://www.energy.gov/eere/fuelcells/electrolyzer-installation-webinar

1.1 Key DOE Hydrogen Roadmaps, Programs, and Initiatives

Recently, the DOE Hydrogen Program released the *U.S. National Clean Hydrogen Strategy and Roadmap*, which outlines opportunities for clean hydrogen to contribute to national decarbonization goals across multiple sectors of the economy.[7] Hydrogen is a commonly used chemical feedstock in industrial processes today, such as ammonia production and oil refining. The *Strategy and Roadmap* reflects the H2@Scale vision (Figure 3), which shows that clean hydrogen can also be used in other emerging applications, such as transportation and steel refining, to achieve our national decarbonization goals. One of the three main strategies to realize this vision is to reduce the cost of clean hydrogen to grow existing and unlock new markets for clean hydrogen.

The *Strategy and Roadmap* is supported, in part, by the Clean Hydrogen Electrolysis Program, which was established in 2021 by the Bipartisan Infrastructure Law (BIL). The goal of this $1 billion program is to reduce the cost of clean hydrogen produced using electrolyzers to less than $2 per kilogram of hydrogen by 2026 through RD&D efforts.[8] Water electrolysis (the process of using electricity to convert water into hydrogen and oxygen gases) is a well-known technology for clean hydrogen production when utilizing renewable electricity. This program also supports the DOE's Hydrogen Energy Earthshot ("Hydrogen Shot") which aims to achieve $1 per kilogram of clean hydrogen produced by 2031.[9]

[6] https://www.hydrogen.energy.gov/
[7] https://www.hydrogen.energy.gov/library/roadmaps-vision/clean-hydrogen-strategy-roadmap
[8] 42 U.S.C. § 16161d
[9] https://www.energy.gov/eere/fuelcells/hydrogen-shot

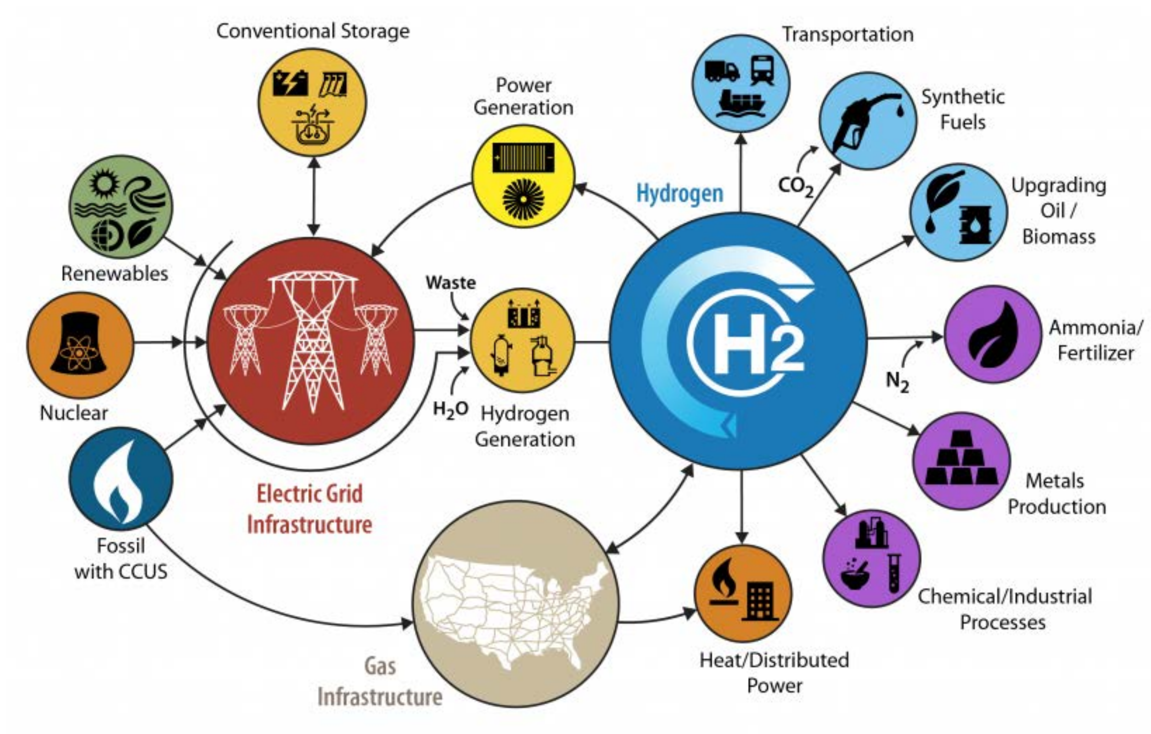


Figure 3. H2@Scale vision to enable decarbonization across multiple sectors of the economy.

1.2 Context: Ongoing HFTO Efforts for Water Electrolyzer Development

With funding from the Clean Hydrogen Electrolysis Program, HFTO is amplifying its investment in water electrolyzer technology development. HFTO has established and expanded several consortia (led by national laboratories) to help lead research and development (R&D) of water electrolyzer stacks and stack components. HFTO recently issued a funding opportunity to further accelerate electrolyzer R&D as well as manufacturing. In addition, HFTO has supported first-of-a-kind demonstrations of water electrolyzer stack and system technologies in novel applications, such as coupling a proton exchange membrane (PEM) electrolyzer with nuclear power at Nine Mile Point.[10] Development and demonstration of next-generation components and stacks are making impactful contributions towards cost goals; however, analysis has shown that the non-equipment costs to install an electrolyzer, including design, engineering, and construction costs, are a critical barrier to achieving \$2/kg H_2 by 2026.[11]

1.3 Installing Water Electrolyzers

While containerized 1-5 MW electrolyzer systems can result in more straightforward installations, installing a large-scale (~100 MW) water electrolyzer system requires a significant amount of engineering, planning, and construction. Site selection depends on access to available electric power, water, proximity to an off-taker or hydrogen consumption, and community acceptance. Installations can take years from planning to operation, subject to how quickly permits can be acquired, safety reviews can be completed, and equipment can be procured.

[10] https://www.energy.gov/ne/articles/nine-mile-point-begins-clean-hydrogen-production
[11] https://www.osti.gov/servlets/purl/2203367

The installation process requires coordination across many different groups. Water electrolyzer original equipment manufacturers (OEMs) can have different levels of involvement in the installation, from only providing the electrolyzer stacks and specifications to fully participating in the site design and construction. Project developers may be involved in the site design and planning. Engineering, procurement, and construction (EPC) firms may be contracted to build the site. Local utilities may be involved in building a new substation or transmission lines to provide the required electric power. Local authorities having jurisdiction (AHJs) and community groups are engaged in the siting and permitting process. Cooperation among these groups is critical to complete an installation.

2 Case Studies & Project Developers Panel

Both days began with a speaker experienced in installing water electrolyzers to provide an overview of the installation process. On day one, Len Anderson from the Douglas County Public Utility District in Washington first spoke about a project coupling a 5 MW electrolyzer with excess hydropower. On day two, Brenor Brophy from Plug Power presented his perspective on installing a 45 MW electrolyzer system in Georgia. Both speakers provided a perspective on lessons learned and opportunities to improve the installation process in the future.

Day one also featured a panel of project developers representing four different companies that have experience developing hydrogen projects. These panelists, listed in Table 1, brought a diverse set of experiences and perspectives about the biggest challenges for electrolyzer installations and opportunities for DOE and other government agencies to streamline and reduce the cost of installations. Detailed descriptions of each presentation and panel discussion are below.

Table 1. Expert speakers, affiliations, and presentation titles.

Presentation Title	Speaker Name	Speaker Affiliation
DCPUD Hydropower to Hydrogen Case Study	Len Anderson	Douglas County Public Utility District
Electrolyzer Deployment at Scale	Brenor Brophy	Plug Power
Panel: Project Developers	Marc Prasse	Sargent & Lundy
	Robert Beaumont	Constellation
	Anthony Borski	Nel Hydrogen
	Cameron Martin	Westinghouse

2.1 DCPUD Hydropower to Hydrogen Case Study

Len Anderson is a Senior Systems Distribution Engineer for Washington State's Douglas County Public Utility District (DCPUD). His experience includes 21 years of experience in electric power transmission and distribution, as well as 21 years of experience in the U.S. Navy Submarine Service as a Polaris & Trident Electronics Technician and Nuclear Propulsion Engineering Officer. At the time of the presentation, Anderson had spent three years implementing Douglas County's hydrogen generation project, which will utilize the district's Wells Hydroelectric Facility to produce two metric tons of hydrogen per day via electrolysis.

DCPUD is interested in producing hydrogen from the hydropower resource during times of low electricity demand because starting and stopping a hydropower dam is expensive. Producing hydrogen via electrolysis will allow DCPUD to minimize spill from the dam and maximize efficiency. Hydrogen could also provide spinning reserves required by the grid.

DCPUD had to work through a variety of initial questions and decisions, including its authority to market hydrogen, what type of electrolyzer to use, and how to store the hydrogen. They also assessed the value of the hydrogen they could produce and their flexibility to curtail hydrogen production when power prices were high. Legislation was passed in 2019 that allowed DCPUD to produce and market hydrogen, and the utility district selected PEM electrolyzer technology because of its ability to respond quickly to changes in electricity availability, small footprint, and minimized waste streams.

The project's initial phase involves a 5 MW electrolyzer to produce two metric tons of hydrogen per day. In the future, the site could expand to 120 MW with 50 metric tons per day capacity. The hydrogen produced will be sold wholesale to industrial and transportation customers. The site includes hydrogen compression and hydrogen filling stations for tube trailer trucks.

Site specific challenges included National Fire Protection Association (NFPA) 2 requirements: hydrogen facilities cannot be sited directly under any electrical power lines, which was a constraint given the large number of power lines coming from the hydropower dam. They also encountered regulatory know-how hurdles because DCPUD's project was the first hydrogen project for the local AHJ. As a result, the AHJ considered the project from a worst-case scenario perspective and required some of the most restrictive measures.

Efforts to bridge these challenges included hiring an architect familiar with the AHJ and a hydrogen code expert. The availability of qualified expertise was a big challenge as these types of experts are in high demand. In addition, COVID compounded personnel challenges up and down the supply chain. Examples that Anderson provided included local construction companies unable to bid due to personnel shortages, as well the local concrete provider limiting amounts delivered to each customer due to material shortages. A lack of supply stretched even to data availability, with some manufacturers only wanting to address International Organization for Standardization (ISO) requirements instead of all the applicable standards. Noting the challenges of aligning personnel, materials, and information, Anderson highlighted the true value of securing a comprehensive EPC contractor with hydrogen expertise.

At the time of the presentation, Anderson noted important challenges that have reduced the value of this electrolyzer project. One challenge is that power price contracts have increased significantly, and this likely will curtail hydrogen production. While power was in the $20-25/MWh range a few years ago, such contracts are now up to $150/MWh. These prices favor selling electricity directly to a customer rather than using it to produce hydrogen (e.g., the hydrogen would be worth less compared to the generated power), thus reducing the incentive to produce hydrogen. At the time of presentation, it was still advantageous for DCPUD to utilize hydrogen as a spinning reserve, but there were not clear economic advantages beyond that.

2.2 Electrolyzer Deployment at Scale

Brenor Brophy is the acting Vice President of Project Development at Plug Power since December 2020. Prior to joining Plug Power, he worked at First Solar and Enki Technology, where he developed a deep knowledge of renewable energy project development and has transitioned this knowledge into developing large-scale hydrogen production projects. Brophy has a background in electrical engineering with a degree from the Waterford Institute of Technology.

Plug Power has become a global leader in supplying electrolyzers and hydrogen to end-users, covering the entire value chain along the way. They currently own and operate 200 hydrogen fueling sites for hydrogen fuel cell forklifts.

The presentation provided a case study of Plug Power's electrolyzer project in Camden County, Georgia. When complete, the project will include 45 MW of hydrogen production from PEM electrolyzers, leveraging knowledge and learnings from an initial 5 MW system. The project will also include hydrogen liquefaction to fill tanker trucks. At the time of the presentation, the 5 MW system was mechanically complete and the electrolyzer stacks were being commissioned.

Plug Power broke ground in August of 2021 for the smaller 5 MW project, completing it just one year later. The 40 MW expansion began thereafter and is expected to be finished by the end of 2023. Brophy noted that the supply chain delays have been minimized because Plug Power manufactures their own electrolyzer stacks. He also described how planning and logistics of this Georgia project were supported by local partners who were eager to bring the project to the area. This was important to streamline planning and permitting that otherwise could have caused delays.

Brophy included a high-level overview of electrolyzer project finances. He highlighted that the capital costs of most projects are too high for an acceptable rate of return at the target levelized cost of hydrogen. Current capital investments for electrolyzer projects are ~\$8-\$13 million/metric ton H_2 per day (TPD). To achieve a good rate of return and sell hydrogen at a price of \$5/kg (or \$2/kg with a production tax credit) would require a capital investment of less than \$6 million/TPD.

The cost breakdown shows that only ~15% of the capital cost is the electrolyzer stack. Overall, the equipment (procurement) represents ~52% of the capital cost and the other ~48% is construction and engineering. This breakdown is similar to that of an industrial chemical plant, whereas renewable energy projects (e.g., wind and solar projects) tend to be >70% equipment costs. When looking ahead, Brophy believes that the capital cost breakdown for green hydrogen production plants need to shift towards that of renewable energy projects to meet DOE hydrogen production cost targets. Opportunities to drive down the construction and engineering costs could include housing electrolyzer stacks outside (rather than inside buildings), optimizing equipment integration (e.g., system layouts, skids), and optimizing cooling (e.g., use of passive cooling, eliminating central water cooling).

2.3 Panel: Project Developers

Michael Hahn from HFTO moderated the Project Developers panel and introduced each of the four participants who were representing Sargent & Lundy, Nel Hydrogen, Westinghouse, and Constellation. Each speaker briefly presented their company's efforts in the hydrogen and electrolyzer space, including:

- Sargent & Lundy's 70 hydrogen projects ranging from 100s of kW to GW scale looking forward
- Nel Hydrogen's PEM platform sizes ranging from desktop to 100 MW facilities, as well as their efforts to scale up and drive down costs through manufacturing automation while looking to reduce dependency on rare earth elements
- Westinghouse's interest in enabling a hydrogen market utilizing nuclear power, providing significant optionality while competing directly with steam methane reforming technology
- Constellation's PEM electrolyzer demonstration project at Nine Mile Point Nuclear Plant

After the brief summaries of their respective company efforts, a series of questions were posed to the panel members, as summarized below.

Thoughts on why we are here today. What are the biggest challenges of installing electrolyzers?

The biggest challenges identified included permitting, costs, and timelines. Speakers highlighted that engaging permitting stakeholders and bringing their understanding up to the needed level involves significant time and effort, and that the same applies to suppliers. Also, there are significant costs embedded in local regulations, post-processing, and transport that are important to quantify and incorporate. Supply chain challenges also are having a significant impact on timelines that, while somewhat stabilizing, remains problematic. All these factors combine to make it difficult to deliver a finished product for the customer without delays.

What are some opportunities for DOE to help address challenges?

The panelists highlighted a variety of areas where DOE can be of assistance, including direct research investment, siting, hydrogen distribution, and project financing. For instance, in addition to basic research investment, one speaker noted DOE's value in working through best uses for mixes of electrolyzer technologies. Siting assistance is needed for identifying excess electricity within the grid and particularly useful renewable energy sources that best align with hydrogen project siting and different types of electrolyzer technologies. The panelists noted the need for leadership in hydrogen distribution, including how to stand-up an open pipeline network, and in assisting states to manage appropriate rules and regulations (e.g., safe distances). Funding assistance needs are diverse, including advancing risk analysis tools and bridging communication gaps and needs between lenders and project developers.

What were some lessons learned from previous projects?

For planning a project, understanding applicable regulations, knowing available planning tools, and hiring qualified personnel were key lessons learned. Having the right hydrogen contractor for the job, using the correct tools (e.g., Hydrogen Tools Portal) and regulations (e.g., NFPA), and clearly delineating responsibilities between the electrolyzer manufacturer and the EPC are vital. Building off such delineation, the appropriate management of time was noted as a key lesson, given the importance of including internal and external stakeholders, and conducting adequate hazard analysis at the correct stage within the project development timeline. Lastly, panelists noted key components of the buildout process that can be underestimated in terms of either cost or time include retrofits for behind-the-meter projects, generation of clean water for electrolysis and the management of the resulting waste brine, and commissioning.

How did you engage local communities? What feedback did you receive?

The panelists noted that community engagement and interests are diverse, with concerns revolving around the nature of hydrogen and oxygen gases generated, noise, and the potential impact on water and electricity supply. Key stakeholders to involve early in the process include local fire departments and first responders, as they will have requirements for risk mitigation that need to be incorporated into the project design. Discussion also highlighted how the inclusion of community and first responder stakeholders can reinforce broader community acceptance. This can provide reassurance to a community that emergency planning and resource interests have been addressed.

What is the time scale for building an electrolyzer project?

The panelists indicated that smaller demonstration projects (e.g., ~1 MW) can take up to three years, while larger 10-100 MW projects can take up to five years. Once an agreement is signed with a customer, it can take ~18 months for design and engineering and 6-12 months of lead time for equipment. Construction times are variable. Of note, the lead time for electrolyzer stacks is becoming more predictable and consistent, while the smaller components, such as pumps and valves, have become more challenging, impacting project schedules. The nuances of hydrogen projects, such as shifting to hydrogen regulated seals, must be factored into project schedules.

Can you provide any feedback regarding hydrogen contracts?

It was noted that the larger size of contracts can add to challenges. For instance, some developers are targeting >50 MW facilities - offtake and power supply agreements for those can take considerable time to negotiate and secure. Furthermore, with the growth in contract size, the applicability of the hydrogen production tax credit becomes a more important aspect to consider.

What are your thoughts on safety and what are some examples of components that need to be added to different projects?

Discussion covered a variety of safety issues, including setback distances, alarms, venting, and shutoff capabilities. In the case of the Nine Mile Point Nuclear Plant, the amount of hydrogen in the electrolyzer and its associated piping is small, so there was no minimum distance requirement between the electrolyzer and the nuclear reactor. However, blast risk did require 1500 ft of separation between the reactor and hydrogen storage. NFPA requirements and/or local emergency response authorities required a firewall, remote shutoff from inside the facility, and emergency shut-off capability from outside the facility perimeter. Such shutoffs also need to be tied to flame and other detectors. It was also noted that hydrogen venting must be separate from oxygen venting and sent to different locations. Lastly, insurance also drives certain safety evaluations and action, with the project evaluating lightning strikes and tornadoes, as well as installing more and safer access points to the system (e.g., installing a stair tower instead of depending on ladders).

How might on-grid vs. off-grid electrical connections impact electrolyzer operations and projects?

The electrolyzer technology itself is agnostic to power origination, but it is important to understand power generation limitations and capabilities when selecting a specific technology. Developers must consider the ability of the equipment to tolerate dynamic (e.g., on/off) operation, and should have appropriate back-up systems in place to ensure uninterrupted operation.

3 Water and Electric Utilities

As the two feedstocks for electrolytic hydrogen, the availability of water and electric power are crucial to the success of electrolyzer installation and operation. Brittany Westlake from the Electric Power Research Institute discussed the importance of electric utilities to the future of hydrogen and encouraged utilities to be partners that are consulted early in the installation process. In addition, a panel with representatives from utilities across the U.S. (see Table 2) discussed their interests in electrolytic hydrogen to decarbonize their power generation assets and the risks and challenges of integrating renewable energy resources with electrolyzers. To understand water requirements of electrolyzers, Amgad Elgowainy from Argonne National Laboratory shared research results on the consumption of water during electrolysis and highlighted a tool that can be used to understand water stress impacts on a region to address potential community concerns about water scarcity. Detailed descriptions of each presentation and panel discussion are below.

Table 2. Presentation titles and speakers for water and electric utility presentations and panels.

Presentation Title	Speaker Name	Speaker Affiliation
Electric Utility Perspective	Brittany Westlake	Electric Power Research Institute
Analysis of Water Consumption and Regional Water Stress Associated with Clean Hydrogen Production	Amgad Elgowainy	Argonne National Laboratory
Panel: Utilities	Steve Christensen	Xcel Energy
	Kristen Cooper	Duke Energy
	Greg Huynh	Los Angeles Department of Water and Power

3.1 Electric Utility Perspective

Brittany Westlake is a Senior Technical Lead at Electric Power Research Institute. She leads RD&D projects related to electrolytic hydrogen production, focused on technical and economic considerations for hydrogen production.

For electrolyzer vendors, siting requires consideration of electricity source, sustainable water source, the system footprint, and output/offtake. Coupling electrolyzers with renewable electricity sources complicates siting. Utilities must consider the schedule to build infrastructure, costs for existing customers and interconnection, system impacts, and grid reliability/power quality of the new load.

Westlake spoke to the challenges coupling electrolyzers to a renewable grid, but also highlighted the benefits (e.g., tax incentives) and opportunities that R&D could help advance. Electrolyzers can add flexibility to a renewable grid and can provide seasonal long-term energy storage if renewable profiles can be turned into operational profiles. Ramping impacts must be considered for electrolyzer capacity factor, system siting, and renewable utilization. There are opportunities for batteries to increase capacity factor and renewable utilization, reduce system ramping, and prevent clipping. If co-located, there are benefits and tradeoffs of a DC-coupled system operation. To research the impact of intermittent power loads on electrolyzers, Westlake suggests beginning at a high level and working down into the details. Scanning different renewable profiles provides an understanding of electrolyzer sizing and assessment of system durability. When comparing intermittent effects between various electrolyzer technologies, pairing production and end uses is valuable. Different electrolyzers have different specifications that are best suited for specific end uses. As a specific example, there is an opportunity to integrate large-scale electrolyzers with offshore wind resources, but more research is needed to understand how, when, and where this integration can occur.

Westlake encouraged project developers to talk to local utilities early in the process and consider them as project partners. She noted that it can take ~4 years to build new substations that connect renewable energy projects to the grid, and this is something for project developers to consider when designing electrolyzer projects. An example of the long timelines to get renewable energy projects in place is that procuring a transformer alone can take 2-3 years. Westlake also emphasized the importance of simple, clear communication with community stakeholders, local government approval boards, and regulators to speed up project timelines.

3.2 Analysis of Water Consumption and Regional Water Stress Associated with Clean Hydrogen Production

Amgad Elgowainy is a Senior Scientist and Distinguished Fellow at Argonne National Laboratory (ANL), leading the Electrification and Infrastructure Group. He has contributed to the development of the Greenhouse Gases, Regulated Emissions, and Energy Use in Transportation (GREET) model,[12] which provides an environmental lifecycle analysis, and has led the development of the hydrogen infrastructure technoeconomic suite of models, HDSAM.[13]

With the rollout of hydrogen economy government incentives, concerns arise for the potential water consumption associated with large-scale hydrogen production, especially in water-stressed regions.

To assess the water consumption associated with hydrogen production methods, the current predominant method of steam methane reforming (SMR) is considered the baseline. For this pathway, water is consumed as a feedstock and during natural gas processing. For electrolytic pathways, water is consumed as the feedstock, assuming the use of renewable electricity. Water consumption is defined as water withdrawal minus water rejection. For SMR, the total water consumption factor (WCF) is ~2.4 gal/kg H_2 without carbon capture and

[12] https://greet.anl.gov/
[13] https://hdsam.es.anl.gov/

sequestration (CCS) or ~2.9 gal/kg H_2 with CCS. For electrolysis, the WCF is ~4.1 gal/kg H_2 for centralized systems, and ~2.9 gal/kg H_2 for distributed systems (assuming deionized and reverse osmosis water treatment systems and a cooling tower). The difference in WCF between centralized and distributed systems is due to cooling losses. To put this in perspective, average at-home water use is 80-100 gal/person/day, so there is similar water consumption to produce 20 kg H_2/day as one person uses per day. Of note, upstream WCF is far lower for electrolysis using clean electricity (ranging from 0-0.4 gal/kWh) than for conventional natural gas and shale gas (0.25-3.90 gal/mm Btu).

While the GREET model is most renowned for tracking carbon intensity, it can also address water supply and demand by accounting for water consumption. ANL has used this tool to assess water consumption for PEM, solid oxide electrolysis cell (SOEC), and alkaline electrolyzers, accounting for water purification needs. Some parameters, such as water purification and cooling requirements, can be adjusted in the GREET model. ANL has shown that fuel cell electric vehicles (FCEVs) consume less net water than internal combustion engine vehicles.

However, water consumption and impacts are a regional issue. Depending on freshwater availability, even the same amount of water consumption may have a different water stress impact. ANL is developing the AWARE-US model that combines water consumption data with freshwater availability data at the county level to evaluate a water scarcity footprint.[14] This tool can be used by project developers to determine the impact on water resources of siting an electrolyzer in a particular county, which can also later be used to educate the local community on the expected impact on water supply. While the AWARE-US model only considers freshwater, there may be potential to treat brackish water and saline water for electrolyzers. Additionally, wastewater from the electrolyzer systems will be sent to treatment plants and then recycled in the region.

3.3 Panel: Utilities

This panel featured three speakers:

- Steve Christensen from Xcel Energy works on the commercialization of carbon-free electricity technology, net-zero gas, and transportation.
- Kristen Cooper is a lead engineer at Duke Energy working on generation technology and generation and transmission strategies.
- Greg Huynh works for the Los Angeles Department of Water & Power with a background in engineering and project management. Greg is currently working on decommissioning and converting a coal power plant into a new electrolytic hydrogen and natural gas-fueled generation facility with blends of 20-100% hydrogen, utilizing a nearby salt cavern as a hydrogen storage facility.

After the brief summaries of their respective company efforts, a series of questions were posed to the panel members, as summarized below.

1. *Are there any unique considerations that utilities must consider when developing hydrogen projects?*

   When developing hydrogen projects, utilities must consider the types and amount of renewable energy sources available and their access to transmission lines. Overall, location is an important consideration when siting hydrogen projects, considering not only the access to renewable power and transmission, but also other assets (e.g., underground hydrogen storage, hydrogen pipelines) that can be leveraged for the project. Utilities themselves are interested in developing hydrogen projects for power generation and load balancing, though there is significant risk to ratepayers because hydrogen is new

[14] https://www.anl.gov/argonne-scientific-publications/pub/143864

to the utility industry. One panelist found that permitting and educating the local government took more time than expected.

2. *How can reliability and affordability for ratepayers be met with these hydrogen projects?*

   For renewable power generation, utilities view hydrogen as key for load-balanced reliability. Using excess renewable electricity, utilities can produce hydrogen during times of low electricity demand and consume hydrogen to produce electricity when demand is high. In this way, hydrogen can be a long-duration energy storage solution and provide cost benefits to ratepayers. Hydrogen production may also mitigate electric transmission constraints, adding to reliability of the grid. In the near-term, government incentives like the hydrogen production tax credit are important for affordability.

3. *What considerations do you give to integrating electrolyzers with intermittent electricity sources? How do you account for intermittency in project design?*

   Disruptions to production and equipment damage are known risks associated with intermittency. These can be mitigated with quality control strategies that might include backup power systems (e.g., batteries) and regular maintenance outages. To forecast hydrogen production from a proposed system, it is important to consider the regional, seasonal, and diurnal behavior of renewable energy sources.

4. *How are you storing hydrogen, how much are you storing, and what are your end uses?*

   Storage mechanisms include the following: gaseous above-ground storage vessels, salt caverns, hard rock domes, subsurface compressed storage, and high-density metal hydrides. Hydrogen carriers such as ammonia and methanol are also being contemplated.

5. *What are some best practices/lessons learned to expedite the electric grid interconnection process?*

   The answer largely depends on scale, where larger systems require generation and transmission planning when assessing potential electrolyzer locations. One panelist noted that retiring coal plants have water rights and electricity rights, two key resources that could be redirected to hydrogen production facilities. It is also helpful for project developers to understand Federal Energy Regulatory Commission processes and to communicate early and often with the utilities.

6. *Do you see any opportunities for DOE or other agencies to bring down costs or speed up timelines when connecting electrolyzer projects to the grid?*

   Government agencies should continue to support demonstration projects that normalize hydrogen for the utility industry and reduce adoption risk. Defining hydrogen systems in a way that they can be easily repeatable (such as a system reference design) could also help to speed adoption. In addition, government agencies can continue to support automation of electrolyzer manufacturing processes to reduce lead times for electrolyzer stacks. Government could also fund objective, science-based research to help educate stakeholders that have questions and concerns about hydrogen safety. Beyond just the scope of hydrogen technologies, the U.S. government should continue to develop policies and processes that can accelerate the interconnection of new renewable energy projects to the electric grid.

7. *What has your utility done to engage with communities, and what feedback have you received?*

   Hydrogen can be complicated to explain to local community stakeholders. Continual engagement with both community leaders and the general public is important. The end use of hydrogen and the safety of hydrogen are common question topics. One panelist has found that it is important to address fears first (such as safety concerns) before discussing the more technical pieces of the project. An important aspect to communicate are the economic opportunities (e.g., job creation) that the hydrogen project can provide to the community.

4 Safety, Siting, Codes and Standards

Lack of attention to proper codes, standards, and safety protocols can result in significant schedule delays for electrolyzer siting and installation. The event featured three presenters on day two focused on these topics. Dani Murphy from WHA International, who also serves on the Hydrogen Safety Panel for the Center for Hydrogen Safety, highlighted the importance of safety features in electrolyzer systems to mitigate inherent risks related to hydrogen and oxygen generation. Brian Ehrhart from Sandia National Laboratories gave an overview of siting considerations for electrolyzer systems and encouraged holistic planning that includes other aspects of hydrogen infrastructure, such as hydrogen storage and fueling stations, that are often co-located with electrolyzers. Kevin Hartmann from NREL provided a comprehensive summary of codes and standards that are relevant for electrolyzer systems, and their impact on site design. Detailed descriptions of each presentation are below.

Table 3. Presentation titles and speakers for safety, siting, codes and standards presentations.

Presentation Title	Speaker Name	Speaker Affiliation
Hydrogen Safety for Large-Scale Electrolyzer Installations	Dani Murphy	WHA International
Siting Considerations for Electrolyzer Systems	Brian Ehrhart	Sandia National Laboratories
Electrolyzer Codes and Standards	Kevin Hartmann	National Renewable Energy Laboratory

4.1 Hydrogen Safety for Large-Scale Electrolyzer Installations

Dr. Danielle "Dani" Murphy is a senior mechanical engineer failure and hazard analyst, and hydrogen services lead for WHA International, Inc. Dr. Murphy earned her PhD in mechanical engineering from Colorado School of Mines where she worked in the research and design of microchannel reactors for solid-oxide fuel cell systems and previously worked at the National Renewable Energy Lab conducting hydrogen research. Among her most recent work, Murphy has been leading hydrogen safety discussions around the globe as a member of the Hydrogen Safety Panel and part of the Center for Hydrogen Safety.

Murphy emphasized that it is less expensive to be thorough with safety risk prevention and mitigation measures than it is to pay for the cost of an incident. Awareness and training are two of the most important factors of hydrogen safety for large-scale electrolyzer installations. Hydrogen is unique, and therefore operations, maintenance, and engineering personnel should receive specialized safety training.

Safety relies heavily on detection and fail-safe shut down capabilities to reduce risk. One inherent fail-safe shut down aspect of electrolyzer stacks is that when the current is removed, hydrogen and oxygen stop being generated. Other mitigation efforts include ventilation across unclassified equipment, classified electrical equipment used in the hydrogen compression and storage area, all unclassified equipment shuts off during an automatic system shut down, limited voltage and current to powered equipment, and proper bonding and grounding to reduce risk of electrostatic discharge ignition.

Leaks from the system are common, and mitigation strategies include limiting the number of joints and fittings to reduce leak points, regular maintenance and leak checks, leak and flame detection, and pressure and/or flow monitoring. In the case of mitigating fire or explosion risk, the following safety protocols should be followed: containment, leak detection, gas detection, fire detection, and fire/explosion protection. A fire or explosion is most likely to occur during start-up and end-of-life when there is the greatest risk for H_2 to cross the separator into the O_2 stream.

To maintain a fail-safe system, automatic isolation of storage vessels, automatic controlled venting of pressurized H_2 and O_2 gas volumes within the system (vessels and tubing), and ventilation remaining on is required. The system must have outdoor vent outlets that are free from ignition sources and meet both hydrogen and oxygen ventilation regulations.

4.2 Siting Considerations for Electrolyzer Systems

Dr. Brian Ehrhart is a chemical engineer at Sandia National Laboratories. He has a bachelor's degree in chemical engineering from Rensselaer Polytechnic Institute, and a master's and PhD in chemical engineering from the University of Colorado at Boulder. Since 2017, Brian has worked to support technical analyses for safety codes and standards for alternative fuels, particularly hydrogen. His current and past work focuses on assessing risk for hydrogen vehicles, rail, and infrastructure, and developing software codes for assessing various fire and thermal scenarios. He also serves on the Technical Committee for the NFPA 2 Hydrogen Technologies Code.

Siting considerations include location, as well as site design or system layout. Site design can be highly dependent on the codes, standards, and regulations that apply, which vary based on size of the electrolyzer (or planned hydrogen production rate), amount of hydrogen to be stored on site, and hydrogen dispensing station installation, if applicable. These aspects must be known to ensure proper siting and site design.

The siting of electrolyzers as part of a larger system requires considering inputs including water and power (AC electricity), electrolyzer stacks, hydrogen storage systems, compressors, chillers, and dispensers. Each of the components can be respectively broken down into size, footprint, and setback requirements. Broader considerations for site planning may include a review of fire code applicability (such as within NFPA 2), non-bulk versus bulk hydrogen storage, and indoor- vs. outdoor-housed electrolyzers. Even within a single system, there are several codes and standards that will apply depending on the design. Within a single code, there can also be references to additional regulations, codes, and standards that apply to different parts of the system.

Setback distances define a prescribed distance between a potentially hazardous system and different types of other systems, people, buildings, or materials. Risk-informed separation distance does not eliminate risk, rather it limits it to an acceptable level assuming that it is considered in addition to other necessary safety design features. Setback distances differ depending on the component being planned, with particular focus on oxygen storage, electrical classification, vent pipes from electrolyzers, and bulk gaseous hydrogen storage. The latter, for example, breaks down the setback distances into three groups: 1) general public, 2) people on site, and 3) fire spread prevention. Generally, distances to most areas of exposure can be reduced by blocking the line of sight with a fire rated wall.

Electrolyzer system footprints for hydrogen production systems vary significantly. For a large-scale hydrogen production system that includes ~10,000 kg of hydrogen stored above ground at 30 bar pressure, the majority of the ~1 acre footprint is covered by hydrogen storage tanks rather than electrolyzers. The footprint requirement varies widely and depends on the total hydrogen production and storage requirements. Possible routes to reduce system footprint can include an increase in hydrogen storage density (e.g., higher pressure gas or cryogenic storage) or using more vertically oriented above-ground storage options.

4.3 Electrolyzer Codes and Standards

Kevin Hartmann is a hydrogen and fuel cell infrastructure research engineer at the National Renewable Energy Laboratory. Kevin earned his bachelor's degree in mechanical engineering from the Colorado School of Mines in 2016 and began working in the lab in 2014 as an undergraduate intern on the hydrogen safety and sensor team before transitioning to his current position in 2017. Kevin's current research includes hydrogen dispenser component reliability, FCEV station optimization, hydrogen compression testing, large-scale hydrogen production, component failures, leak rate quantification, and hydrogen systems safety.

A *code* is a set of rules or guidance that experts recommend others follow and can be adopted into law. A *standard* is a detailed document outlining how to meet a code. Codes and standards are agreed upon best practices that are intended to promote safety. Many of these codes and standards are validated within a research environment such as the NREL Flatirons campus, which has a 1.25 MW electrolyzer, 1 MW fuel cell, a compressor, and 600 kg of hydrogen storage in addition to solar panels, wind turbines, and battery storage systems. The electronic components are connected to a controllable grid simulator, enabling researchers to study the integration of hydrogen equipment with renewable energy generation and battery storage. Generally, both international and national codes and standards are used for construction guidelines, such as fire and fuel gas codes.

There are numerous codes to reference when designing an electrolyzer project. In addition to national or international fire, building, and electrical codes, there are several hydrogen specific codes that may apply to a project depending on its location and scope: *NFPA 2* Hydrogen Technologies Code, *NFPA 55* Compressed Gases and Cryogenic Fluids, *CSA/ANSI B22734* Hydrogen Generators Using Water Electrolysis, and *CGA G-5* Hydrogen to name a few. Depending on the specific end use of the hydrogen, quality standards such as *SAE J2719, ISO 14687*, or *CGA 5.3* may apply. Additional codes that apply to subsystems including enclosures, hydrogen vent systems, piping systems, oxygen, and water and cooling should be considered as well.

Working closely with an AHJ is crucial for project success. AHJs are charged with enforcing building and fire codes according to their interpretation. Because hydrogen projects are not familiar to most AHJs, early engagement and education is key to the approval process. When possible, operators should select listed equipment (per *ISO 22734* or *CSA/ANSI B22734*) to potentially accelerate approval timelines.

Understanding all codes that apply to a project early during the design phase can mitigate costly redesigns later. To support implementation of the practices and procedures that will ensure safety in the handling and use of hydrogen per relevant codes and standards, DOE supports *H2tools.org* where you can find additional tools and resources, including the HyScan tool.

5 Cost Analysis

Understanding not only the cost of the electrolyzer system equipment, but also the cost to build and install these systems, is essential to meet the Hydrogen Shot target. Using a technoeconomic analysis approach, Yaset Acevedo from Strategic Analysis, Inc. presented results from a bottom-up project cost model for low-temperature electrolyzers, relying on equipment quotes and engineering cost principles based on technical specifications of equipment. Sam Sprik from NREL presented another approach to quantifying installation costs that consists of collecting real data from previous and ongoing electrolyzer installations. Detailed descriptions of each presentation are below.

Table 4. Presentation titles and speakers for cost analysis presentations.

Presentation Title	Speaker Name	Speaker Affiliation
Cost Analysis: Near Term and Future Projections of Installation Costs for Low Temperature Water Electrolysis	Yaset Acevedo	Strategic Analysis, Inc.
Electrolyzer Installation Costs: Data from Installed Systems	Sam Sprik	National Renewable Energy Laboratory

5.1 Cost Analysis: Near Term and Future Projections of Installation Costs for Low Temperature Water Electrolysis

Dr. Yaset Acevedo is a project engineer at Strategic Analysis, Inc., a Virginia-based consulting firm. Acevedo has several years of experience in process and technoeconomic modeling in the hydrogen, oil, and liquified natural gas sectors. He holds a PhD in chemical and biomolecular engineering from Cornell University and a master's degree in sustainable energy from University College Cork in Ireland. Strategic Analysis, Inc. has extensive experience developing bottom-up cost models for various hydrogen technologies. Analyzing the costs of electrolyzer installations is essential to identifying cost-cutting strategies.

Acevedo presented technoeconomic analysis results for installations of three types of electrolyzers: low-pressure (LP) alkaline, high-pressure (HP) alkaline, and PEM. Key assumptions about current density, voltage, pressure, efficiency, and hydrogen purity informed the development of each cost model. The analysis relied on a combination of reference data and engineering estimation methodologies to estimate total installed cost.

Cost calculations were primarily focused on capital costs including the uninstalled costs (manufactured cost + vendor mark-up), installation costs, and other indirect costs. Uninstalled costs include the electrolyzer stack itself, mechanical components (e.g., valves, piping, instrumentation), and electrical components (e.g., rectifier, wiring, distribution lines). Indirect costs include site preparation, construction overhead, engineering design, permitting, and contingency costs. The total installed capital cost (TIC) is thus the sum of the direct costs (uninstalled costs and installation costs) and the indirect costs.

For electrolyzer systems producing 50 metric tons H_2 per day, the analysis estimates the TIC to be \$164M, \$129M, and \$110M for LP alkaline, HP alkaline, and PEM electrolyzer types respectively using current technology and assuming n^{th}-of-a-kind installations (or ~\$1,300/kW (LP alkaline), ~\$1,100/kW (HP alkaline), and ~\$1,000/kW (PEM)).[15] As electrolyzer technology improves (e.g., higher current densities at the same efficiency) the TIC could reduce to \$112M (LP alkaline), \$88M (HP alkaline), and \$79M (PEM), largely driven by a progressive drop in the uninstalled capital cost (corresponding to ~\$1,100/kW (LP alkaline), ~\$900/kW (HP alkaline), and ~\$750/kW (PEM) assuming n^{th}-of-a-kind installations). Additionally, modest cost reductions are expected from greater efficiency in equipment and stack sizing as the scale of projects grows. The ratio of TIC to direct costs is ~2.0 for small and first-of-a-kind installations but are expected to approach ~1.4 for n^{th}-of-a-kind and large-scale installations.

Based on this analysis, Acevedo suggested various strategies to reduce the cost of electrolyzer installations. One possible strategy is to exploit economies of scale by maximizing installation size and stack manufacturing rates. A second strategy is to move towards more modularized systems and using factory installations (or skids) to reduce engineering design costs. A third strategy is to opt for higher stack power density whenever possible to minimize land and site preparation costs.

Acevedo also mentioned permitting as a significant driver of delays and uncertainty which can increase the cost of electrolyzer installations. In recent years, supply chain disruptions have led to long lead times for stacks and other equipment, with stacks requiring 1.5-2 years lead time, thus driving installation costs higher. The model does not account for these disruptions, meaning that real-world TIC is likely slightly higher than the model estimates.

5.2 Electrolyzer Installation Costs: Data from Installed Systems

Sam Sprik leads integration and safety research activities for the hydrogen production, power, and storage group in the Center for Integrated Mobility Sciences at NREL. A senior engineer proficient in analyzing large data sets, Sprik has extensive experience conducting technical evaluations of hydrogen fuel cell vehicles and

[15] In the time since the webinar and the publication of this report, DOE published aggregated total installed cost data for electrolyzer projects: https://www.hydrogen.energy.gov/docs/hydrogenprogramlibraries/pdfs/24002-summary-electrolyzer-cost-data.pdf

infrastructure in partnership with industry. Sprik started his NREL career in 1998, when he helped develop a widely used, user-friendly software tool to simulate advanced vehicle systems, primarily hybrid electric vehicles. Previously, Sprik worked at Chrysler Corporation in manufacturing statistical quality control. Sprik holds master's and bachelor's degrees in mechanical engineering from the University of Michigan and Calvin College, respectively.

Sprik presented a new study that he is conducting, in collaboration with Vivek Singh at NREL, to collect industry data on the capital costs of installed electrolysis systems. The objective of collecting and analyzing real-world costs is to compare to and inform DOE targets, identify areas that would benefit from government support, and suggest cost-reducing interventions. Data will be collected through a standardized template while ensuring the anonymization of information to protect the identities of participating firms and projects. Participants are asked to provide, at least amount, the total installed cost per MW (or per ton of hydrogen), though they are encouraged to provide cost based on different categories (e.g., safety, structural support, storage, design, site preparation, grid connection, financing, commissioning) which can then be analyzed statistically or visualized to gain additional insights.

The project is actively seeking more industry partners. Aggregating and sharing data does place additional costs on firms, but firms negotiating contracts with the DOE or another government agency can request a small allowance to defray the costs of data reporting. Additionally, firms that report data will gain access to highly valuable industry-wide aggregated data on the costs of electrolyzer installation. In the coming months, another project will begin to collect data on electrolyzer performance, maintenance needs, and operation costs.

Appendix A. Agenda

Day 1: Expert Presentations & Panels

(Q&A to follow each individual session)

11:00 AM	**Welcome, Context, & Overview of Webinar Goals** Speakers: Sunita Satyapal and Dave Peterson, DOE HFTO
11:30 AM	**Case Study on Electrolyzer Installations** Speakers: Len Anderson, Douglas County Public Utility District (WA)
12:00 PM	**Project Developers Panel** Marc Prasse, Sargent & Lundy (IL) Robert Beaumont, Constellation (NY) Anthony Borski, Nel Hydrogen (TX) Cameron Martin, Westinghouse (PA)
1:00 PM	**Break**
1:30 PM	**Electrical Utilities** Speaker: Brittany Westlake, EPRI (DC)
2:00 PM	**Water Utilities** Speaker: Amgad Elgowainy, Argonne National Laboratory (IL)
2:30 PM	**Utilities Panel** Steve Christensen, Xcel Energy (CO) Kristen Cooper, Duke Energy (FL) Greg Huynh, Los Angeles Department of Water and Power (CA)
3:30 PM	**Wrap-up and Adjourn**

Day 2: Expert Presentations & Panels

(Q&A to follow each individual session)

11:00 AM	**Welcome**
11:10 AM	**Case Study on Electrolyzer Installations** Speaker: Brenor Brophy, Plug Power (NY)
11:40 AM	**Safety** Speaker: Dani Murphy, WHA International (CO)
12:10 PM	**Siting** Speaker: Brian Ehrhart, Sandia National Laboratories (NM)
12:40 PM	**Standards** Speaker: Kevin Hartmann, National Renewable Energy Laboratory (CO)
1:10 PM	**Break**
1:40 PM	**Cost Analysis** Speakers: Yaset Acevedo, Strategic Analysis (VA) Sam Sprik, National Renewable Energy Laboratory (CO)
2:30 PM	**Closing Remarks and Adjourn**

Appendix B. List of Participant Affiliations

174 Power Global

300ppm GmbH

3M

ABB

Accelera Cummins

Acuicy

ADNOC

Aequatis LLC

AES

Air Liquide

Air Products

Airox Nigen Equipments Pvt Ltd

amadee & company

Amazon

Ambient Fuels

Amentum

American Gas Association

American Hydrogen Association

Analog Devices Inc

AP Ventures

Apex Clean Energy

Apricus Energy Partners

APS

APSA Consultants

Aqsorption Ltd

Arezza - Volt Logistics

Argonne National Laboratory

ARPA-E

Arup

AST

AT INDUSTRIES

Atec, Inc.

Atmus (former Cummins Filtration)

AUC

Audubon Engineering

Austin Power Engineering LLC

Avina Clean Hydrogen

Avium LLC

Bair Energy LLC

Baker Hughes

Baltimore Aircoil Company

Bambili energy

Beacon Energy LLC

Becht

Beezer

BET LEM STORES

Bosch

Boston Strategies International

BP

Brookhaven National Laboratory

C+UP

Cal Poly Pomona

California Energy Commission

California Public Utility Commission

Calvert Advisors, LLC

Catbird Consulting

Caterpillar Inc

CDTi

Cecilia Energy

CEERT

Central Queensland University

CEPCO RENEWABLES

Change Energy Services

CHARGE

Chevron

Circe Bioscience

City of Albuquerque

City of Fresno/Department of Transportation/Fresno Area Express

City of Riverside

Clearway Energy Group

CNH Industrial

Connecticut Department of Energy and Environmental Protection

Constellation Energy

Cratos Can Inc.

Croft

Crowley

CRTSE

Cryoinfra

CSF Energy Group

CTO

Cummins Inc.

C-Z Marine Technology, LLC

Danskammer Energy

DEME

DENSO International America

DHS

DLZ Corporation

DNV Canada Ltd.

Dominion Energy

Dongyue Canada

Doosan

Douglas County PUD

Dupont Renewable Energy LLC

Dynapower Company, LLC

Earthfirst.community

ECL

EDP Renewables

Electric Hydrogen

Electron Transport Corporation

Emerson

EMLI

Enerflex

Energetics

Energy Information Administration

Energy Vault

Environmental Energy

Environmental Solutions

Envision Energy USA

EPRI

Equinor

ERM

ET Energies LLC

EvolOH, Inc

ExxonMobil

FCHEA

First Mode

First pro

Fluor

Fortescue

FPL

Fraunhofer IMWS

Fraunhofer Institute for Wind Energy Systems

Freelance

FuelCell Energy, Inc.

GCP Capital Partners LLC

GE Power

Gencell

GenH2

Georgetown University

Global Hydrogen Energy LLC

Great lakes Hydrogen LLC

Great Plains Analytic Services

GTA, Inc.

GTI Energy

Guidiville Rancheria of California

H2 Economics Canada

H2Technology

H2U Technologies

HIF Global

Hilti

Hitachi Energy USA

Hy Stor Energy

HyAxiom Inc

Hydrogeneconomy.org

Hydrogenics Corp.

Hyera Inc.

HyMAX LLC

HyTRIB

HyWatts Inc.

HyWin

Iberdrola

ICF

Idaho National Laboratory

IEEE

IFC

iHoriz Inc.

Illinois Tech

IMCO General Construction, Inc

IMEG

Imperial Oil

Infinium

Innovation & Engineering

Institute for Tribal Environmental Professionals

Intelligent Engineering and Energy Resources

International Desalination Consulting Associates LLC

International Iberian Nanotechnology Laboratory

International Trade Administration

IRD Fuel Cells, LLC

JA Paterson LLC

Jacobs Engineering Group

Jakson Green

JM Design Sdn. Bhd.

John Cockerill

Johnson Controls

Jones Family Solar Farm

Kawasaki Heavy Industries, Ltd.

KBR

KC Consulting

Kitsap Transit

KOBELCO

Kotzebue Electric association

Krest Engineering and Technologies Pvt. Ltd.

La Mancha Mills

Lawrence Berkeley National Laboratory

Lawrence Livermore National Laboratory

Lectrolyst

Lehigh University

Linde Inc

LMDesk LLC

Los Alamos National Laboratory

Los Angeles Department of Water and Power

Los Angeles Unified School District

LULAC

Lynntech, Inc.

Madden Engineering

MAH2

Marine Dolphin Enterprises

Mastercard

Mattiq

McDermott

MD - DPSCS

MERCHANTsi

Metropolitan Water District

Micro Hydrogen Inc

Ministerio Transporte y Obras Públicas

Mizuho Research & Technologies

MN Dept of Commerce

Morgan Lewis & Bockius LLP

NanoResearch Inc

NanoSonic Inc

National Grid

National Renewable Energy Laboratory

NAU

NEE

NEEA

Nel Hydrogen

New A.G.E. Inc.

New Fortress Energy

newtrace

Newtrace Pvt ltd

NextEra

Nexus PMG

NHDES

Nikola Motor Company

NJDEP

NNPCL/NNEL

North Dakota State University

Novaer Craft Engineering Solutions

Novo Hydrogen

Nuclear Energy Institute

Nulyzer

numberauto

Nuvera

NYSERDA

Obsidian Renewables

Oceti Sakowin Power Authority

OESC Group

Orange County Government

ORISE-DOE

Orsted

OXByEL Technologies

P2X Americas

Pacifico Energy Solutions LLC

Palo Alto Research Center

PANYNJ

Penn State University

Performance Manufacturing Center

Phillips 66

Phoenix Motorcars

Plug Power

Polykala Technologies LLC

Power to Hydrogen

PowerTech Engineering

Princeton University

Prodel

ProjectQRSargasso & SUNY Polytech Institute

ProjectQRSargasso, Inc.

PSEG Services Company

Public Electricity Production Energy Company (PRODEL EP)

Pulsenics

Ragonese Holdings LLC

Ramaco Carbon

RealEnergy

Recurrent Energy

Reliance Industries Ltd

Renewable Revolution

RenewCO2 Inc.

Repauno

RES

Rice University

Riggs Distler & Company

RIL

Robert BOSCH LLC

Robert L. Hershey, P.E.

Rockwell Automation

Sandia National Labs

SCELZA & MONTANO

Schaeffler Group USA Inc.

SD Mines

SDGE

SEG Greenpower

SEI Homes, LLC

Sempen

sescmg

Sharper Energy Technologies

Shell

Siemens Energy Inc.

Sizewell C

SKYRE

SLAC/SSRL

SMA Altenso GmbH

Smartex

SN Cosmo LLC

SoCalGas

Sogang University

Solar Hydrogen, Inc.

Solaredge

Solon Mfg

South Dakota School of Mines and Technology

Southern Company

SPC GRANT Ltd

Standby Systems, Inc.

STAUBLI CORPORATION

Sterling and Wilson

Strategic Analysis Inc.

Stroock & Stroock & Lavan

SwRI

Syzygy Plasmonics

Technology

TecTerra Consult

Telios Corporation

Tennessee Tech University

Terraform Industries

TES

Tetra Tech, Inc

Tetramer Technologies LLC

Teverra LLC

Texas A&M UNiversity

Texas state university

The City of Riverside

The DOH Associates

The Elder Geek LLC

The High Pressure Gas Safety Institute of Japan

The Leighty Foundation

The Ohio State University

Thermo King Corp

TJC

TMEIC

Toray

TotalEnergies

TravelCenters of America

TreadStone Technologies, Inc.

TreasureBeam

Trelleborg

U.S. Commercial Service

U.S. Department of Commerce - ITA

U.S. Department of Energy – Hydrogen and Fuel Cell Technologies Office

U.S. Department of Energy - Idaho Operations Office

U.S. Department of Energy – Office of Clean Energy Demonstrations

U.S. Embassy, Luanda

U.S. Environmental Protection Agency

ÚJV Řež

UL Solutions

Unimi

Uniper Hydrogen GmbH

Universidad Tecnológica del Uruguay

University of Alberta

University of Calgary

University of California, Berkeley

University of Californica, Irvine

University of Central Florida

University of Connecticut

University of Delaware

University of Florida

University of Maryland

University of Mumbai

University of Oklahoma

University of Papua New Guinea

University of Pennsylvania

University of South Carolina

University of Tennessee

University of Texas at Dallas

University of Toledo

US Embassy in Guatemala City /Department of Commerce

USC

USCA

UTEC

Utility Transformation Consortia

VCA

Verbio North Americica

Verdagy

Verde Hydrogen

Verne

Vestas

Vishwakarma Institute Of Technology, Pune

Volkswagen

Volvo Group North America

Wasco County

Washington State University

Washington University in St. Louis

Weaver

Westinghouse Electric

WGL

Windsohy, LLC

Wishgard, LLC

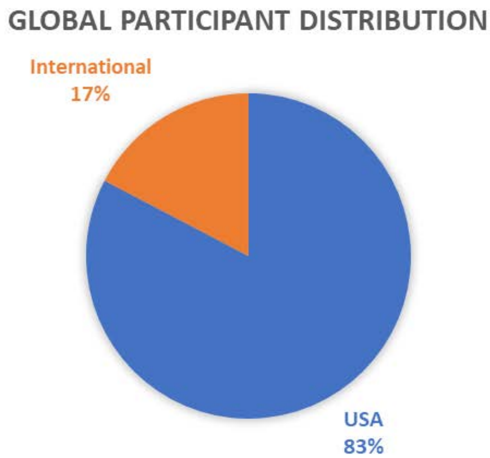
Xcel Energy

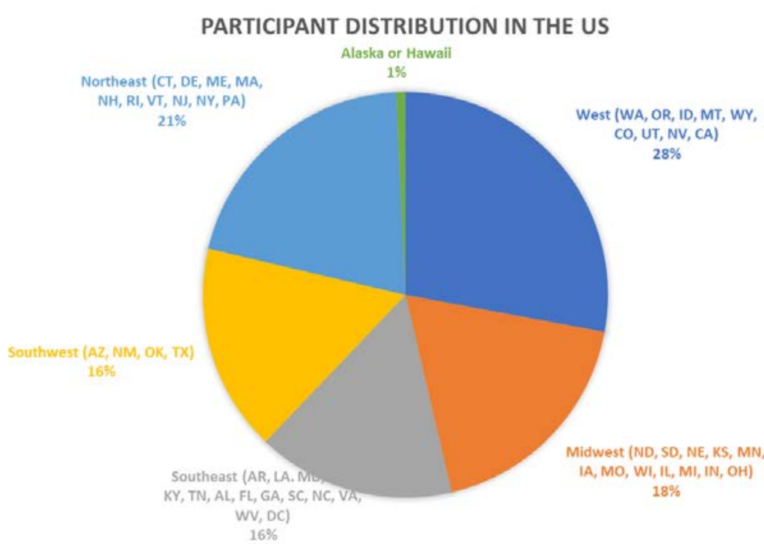
Yardarm Energy LLC

Zhero

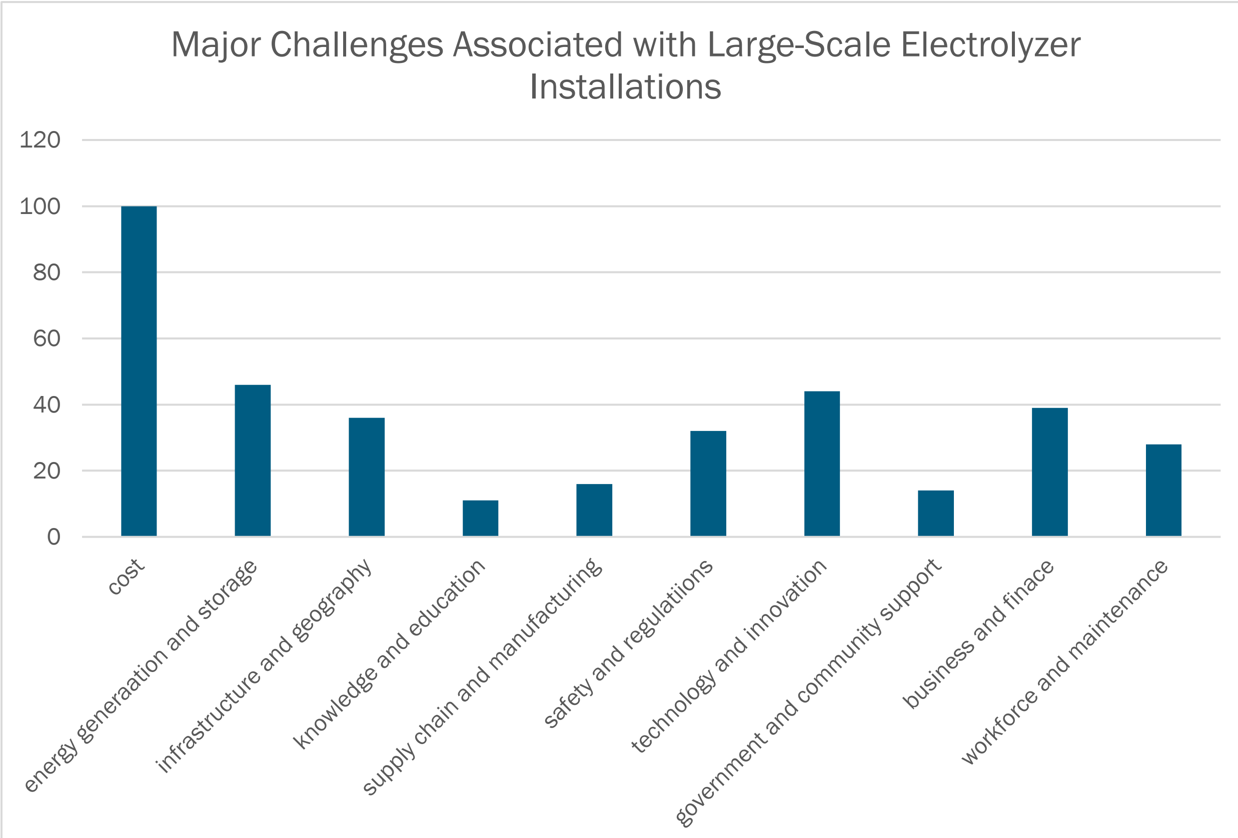
Appendix C. Audience Participation Results

Audience participation was encouraged throughout the event, in between speakers and panelists. Select results are below, including some additional information on participant demographics:

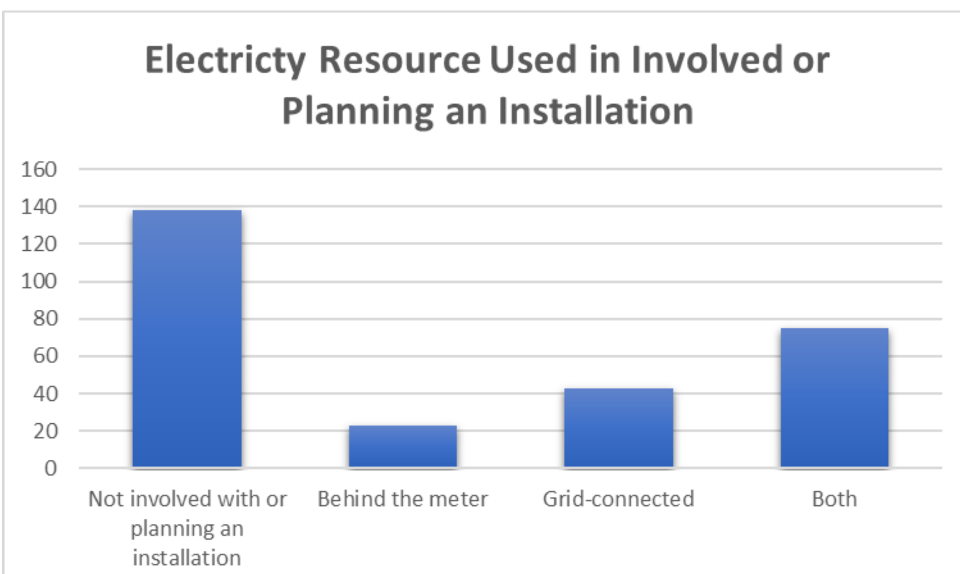




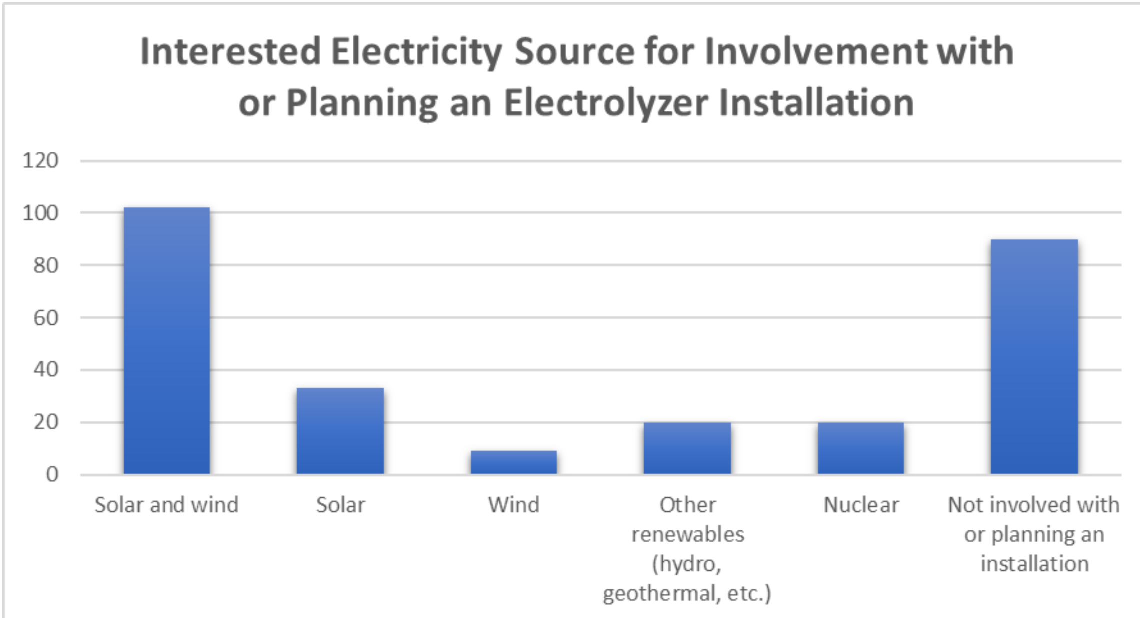
What do you see as the major challenges associated with large-scale electrolyzer installations?



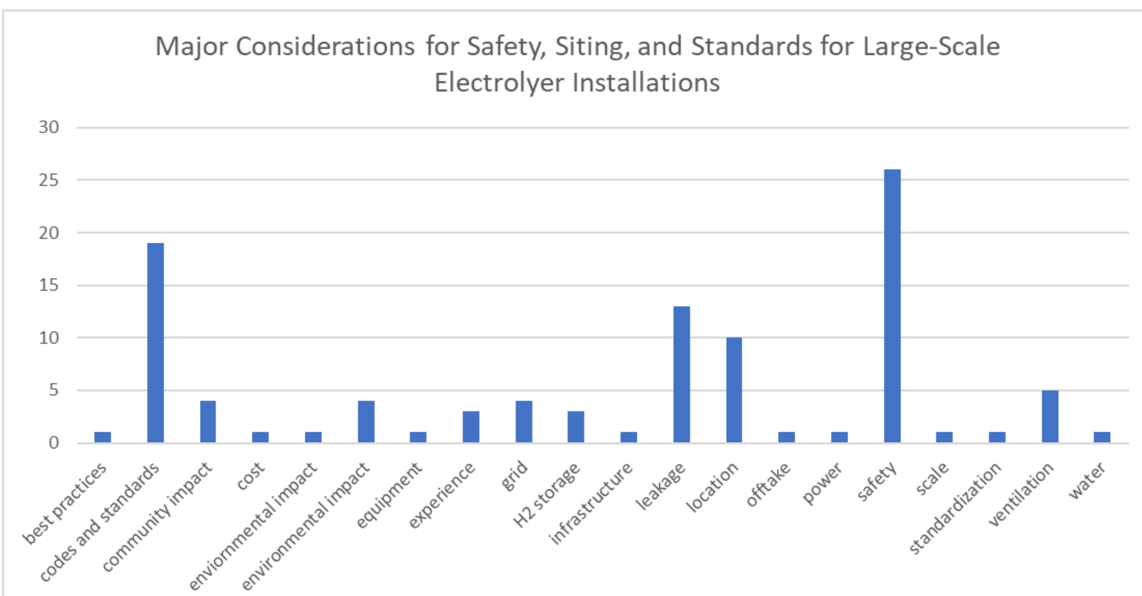
If you have been involved with or are planning an installation, is the electricity input primarily behind the meter, grid-connected, or both?



If you have been involved with or are planning an electrolyzer installation, what electricity resource are you most interested in using?



What are the major considerations for safety, siting, and standards for large-scale electrolyzer installations?



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