Clean hydrogen edges toward competitiveness

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Clean hydrogen edges toward competitiveness

States and regions around the US are readying their bids to host centers for hydrogen production, distribution, and end uses.

The Biden administration's vision for wider adoption of hydrogen accelerated in June with the announcement of a $504 million loan to finance construction of an innovative carbon-emission-free hydrogen production and storage facility in Utah. Also in June, the Department of Energy detailed plans for spending $8 billion in public funding to create up to 10 regional hydrogen "hubs," which were called for in last year's bipartisan Infrastructure Investment and Jobs Act.

The loan to the Advanced Clean Energy Storage (ACES) project in Delta, Utah, will finance construction of what project officials say will be the world's largest green-hydrogen production and storage installation when completed in 2025. Green hydrogen is produced with no carbon dioxide emissions by water electrolysis powered with renewable sources. The Utah project's storage capacity of 5500 tons will be equivalent to that of all the nation's grid-scale battery-storage capacity projected for 2030, says Jigar Shah, director of DOE's Loan Programs Office.

The hydrogen will be stored at 69 bar or greater in caverns to be carved out in underground salt formations. It will be burned in combination with natural gas during periods of peak electricity demand in a new natural-gas-fired plant to be built by the electric utility Intermountain Power Agency. That power plant will generate electricity from turbines driven both by combustion of gases and with steam produced from the exhaust heat. To be fueled with a 30:70 mix of hydrogen and natural gas initially, the plant will be converted to all-hydrogen operation by 2045.

"Hydrogen has enormous potential for energy storage, as a transportation fuel, a source for 24/7 clean dispatchable power, and as a means for decarbonizing heavy industry," Energy secretary Jennifer Granholm told reporters on 8 June. "This loan will help reduce market risk and scale the hydrogen economy."

GREEN HYDROGEN will be produced and stored in salt caverns at the Advanced Clean Energy Storage site in Delta, Utah. The Department of Energy in June finalized a $504 million loan to the project, which will generate hydrogen from water using surplus renewable energy. The hydrogen will be stored in underground salt caverns and burned in combination with natural gas in an adjacent power plant to be built by 2025. In this rendering, the salt caverns are shown at the end of the injection pipes. The large gray-and-white-shaded areas depict salt formations.

Michael Ducker, the chief operating officer of ACES Delta and a senior vice president at Mitsubishi Power, one of the project partners, says the Utah plant's 220 MW of electrolyzers will nearly double the world's total installed capacity of 250 MW. Electrolyzers will be supplied by Norway's HydrogenPro.

Today the world's largest green-hydrogen production facility, located in Fukushima, Japan, produces 2.4 tons a day from 10 MW of electrolyzers that are powered by on-site solar panels. It opened in 2020. In June, BP and partners announced plans to build a green-hydrogen facility in remote Western Australia. Known as the Asian Renewable Energy Hub, the project will be powered with 26 GW of wind and solar energy—enough to produce one-third of all electricity generated in Australia in 2020. When completed in 2027, it will have an annual capacity of 1.6 million tons of hydrogen or 9 million tons of green ammonia. Much of its output is intended to be shipped to markets in Asia.

Electrolysis must be powered with renewable energy to earn a green label. If powered with electricity from fossil-fuel-intensive power grids, electrolysis can be more than twice as carbon intensive as gray hydrogen—produced from natural gas without CO_2 capture and storage. That process is currently the source of nearly all the hydrogen produced globally.

In concert with the growth of renewable energy in the western US, especially in California, the amount of surplus solar and wind energy that can't be used during peak generation periods is growing. That is particularly the case during the late winter and early spring, when power

FUKUSHIMA HYDROGEN ENERGY RESEARCH FIELD

THE WORLD'S LARGEST green-hydrogen plant, the Fukushima Hydrogen Energy Research Field, opened in 2020 and produces 2.4 tons per day. It is powered by on-site solar panels.

demand is low relative to other times of the year (see the figure on page 24). The surplus renewable electricity will be transmitted to Utah via Intermountain Power's dedicated transmission lines.

The DOE loan is the first made to a renewable-energy project since 2011. The agency has loan and loan-guarantee authorizations totaling $40 billion, but Shah says clean-hydrogen-related projects are eligible for only $11 billion of that. DOE has already received loan applications that exceed that amount, he adds.

Mitsubishi and its partner, Magnum Development, are hoping to attract carbon-intensive industries to the Utah location. The water to be electrolyzed and that needed for power-plant operations will total about one-third of the water used by the existing coal power plant, Ducker says.

Hubs ahead

Meanwhile, states, cities, and regional entities across the US are lining up for a share of the $8 billion that DOE will dole out for a yet-to-be determined number of hydrogen hubs. The hubs were conceived by lawmakers as centers of clean hydrogen production, storage, distribution, and consumption.

On 6 June DOE published a notice of intent to issue a funding opportunity announcement, in which the department said it plans to award $6–7 billion of that $8 billion to 6–10 hubs. The Infrastructure Investment and Jobs Act requires that DOE award at least four hubs within one year of receiving proposals.

Each grant will range from $400–500 million to $1–1.25 billion, according to the announcement. The remaining $1–2 billion will be reserved for subsequent solicitations for future hubs, new technologies, or other purposes. Bidders are required to provide matching funds. The entire process, from planning to completion of hub construction, is expected to take 8–12 years. The hubs must be able to produce a minimum of 50–100 tons of clean hydrogen per day; DOE will give greater preference, and provide more funding, to bidders who show they can produce greater amounts. Bidders must have a plan for continuing financial viability once the federal funding runs out.

Congress set multiple requirements for choosing hubs. At least one must demonstrate so-called blue hydrogen, in which the CO_2 emissions in the production of hydrogen from methane are captured and permanently stored in geological formations. Nuclear energy and renewables are to power at least one hub each. Lawmakers further stipulated that at least one center demonstrate clean hydrogen use for electricity production, one for heavy industrial operations, one for residential and commercial heating, and another for transportation.

Congress also required DOE to ensure that the hubs be geographically dispersed and use energy resources that are abundant to their regions. The law instructs DOE to give priority to hub proposals that are expected to create opportunities for job training and long-term employment for the greatest number of residents in the area. The agency says it will require proposers to show "substantial engagement with key local and regional stakeholders to ensure these projects generate local, regional, and national benefits while mitigating significant environmental or community impacts." Additionally, 40% of the overall hub benefits should flow to disadvantaged communities, without exacerbating their already disproportionate exposure to pollution.

Although DOE hasn't committed to a date, some bidders say they expect the agency will formally open the competition for hubs in September or October. Bidders are then to submit concept papers within two months. The agency will notify bidders within a month regarding whether it encourages or discourages the bidders' plans. Full proposals will be due four months later, and the agency may take "several months" to review them before making awards.

Loads of interest

The Gulf Coast is a likely location for at least one hub. Most of the nation's existing hydrogen-pipeline network is located in Texas and Louisiana. Houston alone is home to one-third of US hydrogen production, according to the nonprofit Center for Houston's Future. Brett Perlman, the center's CEO, says the center has organized a wide-ranging coalition of companies, universities, and nongovernmental organizations to "help catalyze the Houston region, and Texas, into a clean energy hub." With an abundance of natural gas and wind-energy resources, Houston, and Texas generally, could qualify as both a blue- and green-hydrogen production hub.

Other regional partnerships have formed in anticipation of the hub

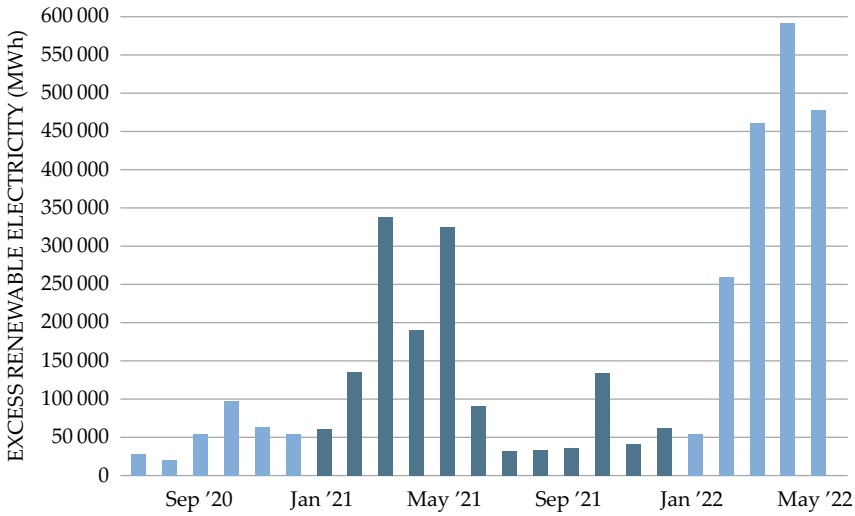
competition. In March, New York Governor Kathy Hochul announced a collaboration with Massachusetts, Connecticut, and New Jersey that also includes dozens of corporations and universities. The governors of Louisiana, Arkansas, and Oklahoma have agreed to collaborate on a regional hub, and Colorado, Utah, New Mexico, and Wyoming have joined forces. Other states that are preparing solo bids or have pending legislation to do so include Arizona, California, Illinois, Kentucky, Nebraska, Pennsylvania, and West Virginia.

The Delta site may become the anchor for one hub, Shah says. There is room at the location for at least 70 more caverns of the same size as those to be excavated for the ACES Delta project, says Ducker. That amount of hydrogen-storage capacity "provides opportunities to help balance [electricity] load across the entire West," he says.

Some states have multiple proposals. The University of Toledo is convening an Ohio-focused hub proposal. Frank Calzonetti, the university's vice president for research, says the hub will power electrolysis with both nuclear and solar energy. The collaboration is to include the Davis-Besse nuclear plant near Toledo, which is already operating a 2 MW electrolyzer in a hydrogen demonstration that DOE is supporting with a $9.2 million grant. (See Physics Today, August 2020, page 20.)

The infrastructure act requires that hubs arrange purchase agreements with consumers of hydrogen. Northern Ohio is home to a lot of heavy industry, including the largest flat-rolled steel plant in the nation and glass manufacturing. Industry partners that have signed on to the Toledo collaboration include General Electric Aviation, which in February announced a collaboration with Airbus to develop hydrogen-fueled aircraft engines. Others include the glassmaker Owens-Illinois, solar-panel manufacturer First Solar, and sustainable-aviation-fuel producer LanzaTech.

With an abundance of natural-gas resources in the region, the Columbus-based Ohio Clean Hydrogen Hub Alliance will focus on blue hydrogen. That process is in place at a handful of plants around the world. Most of those consume the hydrogen for their own industrial needs, such as fertilizer and synthetic-fuel production. In the US, a DOE-funded blue-hydrogen facility in Texas operated by the industrial-gas producer Air Products has been in operation since 2013. Its output is used in petroleum refining, while the CO_2 is piped to the state's oil fields for enhanced oil recovery. Air Products said in October 2021 that it will build a $4.5 billion blue-hydrogen plant in Louisiana, with completion expected in 2026.



SURPLUSES of renewable electricity generation have grown as more wind and solar power is added to California's grid. The excess energy, which can't be stored, can be used to produce hydrogen to fuel electricity generation during times of peak demand. (Data from the California Independent System Operator.)

HyDeal Los Angeles, organized in Southern California by the Green Hydrogen Coalition, is projecting a green-hydrogen cost below $2/kg. Achieving that target will require pipelines to transport the hydrogen to salt-dome storage, the coalition says. The nonprofit has identified demand for 1–3 million tons of the light gas in heavy-duty transport, industry, and power generation in the Los Angeles basin. The largest prospective consumer for HyDeal LA is the Los Angeles Department of Water and Power, which operates four natural-gas-fired power plants in the area, with a combined capacity of 1600 MW. Los Angeles also has significant cement and oil refining activities, and it is home to more hydrogen fueling stations than anywhere else in the US.

A European model

HyDeal LA is patterned after Europe's HyDeal Ambition, a coalition of producers and consumers who have committed to making and using 3.6 million tons of green hydrogen annually at €1.50/kg by 2030, equivalent to the price of delivered natural gas in Europe. The coalition was formed after the European Commission announced in July 2020 a goal for 10 million tons of green hydrogen a year by 2030. HyDeal Ambition's first component, HyDeal España, will pipe green hydrogen produced at renewable-energy facilities in northern Spain to an industrial complex in the region beginning in 2025. That project aims for an electrolyzer capacity of 7.4 GW by 2030. Partners in the venture include the steelmaker ArcelorMittal, which last year announced it will spend $1 billion to halve CO_2 emissions from its Spanish operations within five years through the use of green hydrogen.

Jonathan Lewis, director of transportation decarbonization at the nonprofit Clean Air Task Force and an adviser to HyDeal LA, says that project is estimated to cost $25 billion. Although he notes that DOE has received some "pushback" from prospective hub proposers on the 50% cost-share requirement, he applauds the hub program. "The most compelling part of the policy is that it lifts both the demand side and supply side. Neither side has to make a leap of faith," he says. "As producers are building out capacity, they know there is also investment being made on the demand side."

State-government funding is likely to be needed for the cost sharing. Calzonetti says he is hoping to attract support from other states and institutions. He says that

DOE may try to foster interstate collaborations, perhaps by marrying the Toledo-led collaboration with Illinois, the state with the most commercial nuclear plants. Illinois's own proposal includes the University of Illinois at Urbana-Champaign and Argonne National Laboratory.

Although there is "tremendous demand" for hydrogen in industrial applications, he says, much will depend on the price. DOE's Hydrogen Shot program, launched a year ago, established a target cost for green hydrogen of $1/kg in 10 years. That's an 80% reduction from its current cost of around $5/kg, the agency says.

Ultimately, a hydrogen economy will require spokes as well as hubs. "We shouldn't be looking at this as a competition between regions," Houston's Perlman told a panel discussion organized by the nonprofit Energy Futures Initiative. "Creating a real network is where the real power is going to come from, working together across the US to create a national market for hydrogen."

David Kramer

College instructors adapt their teaching to prevent cheating

WEBS EDGE

Pressures, isolation, and the temptation of easy online answers are changing why and how students cheat.

ANGELA SPECK, chair of physics and astronomy at the University of Texas at San Antonio, teaches astronomy in a flipped classroom, in which students watch prerecorded lectures on their own time and solve problems together in class. When students work on problems in class, they have less incentive and opportunity to cheat, and instructors get a sense of students' grasp of concepts.

Have your students used unfamiliar variables in test solutions? Have they followed bizarre chains of logic? Have multiple students submitted identical wrong answers on homework or tests? If so, chances are they turned for answers to Chegg or some other online education company.

Chegg offers libraries of searchable solutions and the option to post new problems with requests for solutions. Other companies, such as Quizlet, Bartleby, and Course Hero, provide similar services. Quizlet profits through advertising; the others charge monthly fees ranging from $9.95 to $39.99.

The companies bill themselves as tutorial services for many subjects, including physics. "Everything we do is designed to put students first and let them achieve greater success with less stress and less cost," Chegg president and CEO Dan Rosensweig says in a promotional video. But students can—and do—use the services to cheat.

Cheating isn't new, but university instructors say its incidence has grown significantly with the easy access afforded by the internet and with changes in social and study habits brought on by the COVID-19 pandemic. Teaching "in the time of Chegg" is challenging, says a physics and astronomy professor at a medium-sized university in the Southeast who requested anonymity because of departmental politics surrounding the issue of how to handle students' cheating. "Students think I want to see the right answer. That's not true. I want to see that they have learned the material."

College instructors across the US and beyond are grappling with how to deter cheating and reassessing how they assess their students. "The educational system will break down if cheating is widespread," says the anonymous professor. "I regard it as a public health problem rather than a crime."

Detecting foul play

Before the pandemic lockdowns, Mark Messier, a neutrino physicist at Indiana University Bloomington, was grading exams for the introductory mechanics course he was teaching. It was obvious that some students had cheated, he says. "I saw idiosyncratic features repeated in the solutions that multiple students turned in." A quick Google search turned up five of the six problems from the take-home exam on Chegg. "I could see they were scanned versions of my exam problems," he says.

Samantha Kelly graduated this past spring from the University of California, Berkeley, with a double major in math and physics. After she finished an online