CALIFORNIA HYDROGEN BUSINESS COUNCIL

Hydrogen Means Business in California!

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Brief Summary of Hydrogen Development around the World

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The following is a partial overview the development outside California of hydrogen as a clean energy and climate protection solution.

North America/United States

Part of the U.S. Department of Energy's multi-sector approach to developing advanced energy solutions is its H2@Scale Initiative, which is committed to exploring the potential for wide-scale production and utilization of hydrogen in the U.S. to foster grid resiliency, jobs, and other benefits. Demonstrating its continued commitment, the program recently announced $31 million of funding to research and develop electrolytic hydrogen for multiple applications.[1] Showing that advancing hydrogen carries bipartisan national support, both of the former U.S. Department of Energy Secretaries under President Obama are also focusing on renewable hydrogen as a key component of their continued effort to build a clean energy future. Secretary Chu advocates for storing electrolytic hydrogen produced with renewables in underground resources, in order to overcome the limitations of batteries to supply the scale of storage needed in a climate safe future.[2] Chu also recently forecast that the falling cost of renewable electricity holds promise to make renewable electrolytic hydrogen cost competitive with hydrogen produced with natural gas.[3] Secretary Moniz recently oversaw a report that identified hydrogen as among the handful of "breakthrough technologies" that are "major potential contributors to California's deep decarbonization over the long-term," adding that "(t)he work must pick up the pace today and be sustained to support their development."[4]

Large scale hydrogen projects are starting to be realized in North America, with a 1 GW storage project that will include hydrogen storage announced just last month to be under development in Utah.[5] A 2.5 MW electrolytic hydrogen storage project is also already up and running in Ontario, Canada, procured by national transmission grid operator to help integrate renewables and stabilize the grid.[6]

European Union

The European Commission issued an extensive report in November 2018 examining pathways to greenhouse gas neutrality for the European Union, which looked at eight scenarios and found that the only ways to achieve deep decarbonization of 90+% greenhouse gas emissions below 1990 levels by 2050 involve aggressively pursuing diversified approaches that focus not only on electrification or decarbonized gaseous fuels like hydrogen, SNG, or bio-based gas alone, but rather all of the above, along with efficiency, a circular economy, and smart

[1] https://www.energy.gov/eere/fuelcells/h2scale
[2] *Obama Secretary Flat on Battery Plants, The Australian*, February 1, 2018
[3] *Get Ready For 1.5¢ Renewable Electricity, Steven Chu Says, Which Could Unleash Hydrogen Economy,* Jeff McMahon, *Forbes*, April 2, 2019
[4] *Optionality, Flexibility, and Innovation – Pathways for Deep Decarbonization in California*, Energy Futures Initiative (Secretary Ernst Moniz, Founder & CEO); April 2019
[5] https://www.greentechmedia.com/articles/read/utah-aims-to-shatter-records-with-1000-mw-energy-storage-plant#gs.iwx5ic
[6] https://www.hydrogenics.com/2018/07/16/north-americas-first-multi-megawatt-power-to-gas-facility-begins-operations/

technologies, and that net carbon neutrality by 2050 and net negativity thereafter would require this same strategy, in addition to additional carbon capture or advanced management of land sinks.[7]

Specific projects and programs

- In **Europe**, there are over 30 power-to-gas (hydrogen or methane) projects that are operational or in development.[8]
- In the **United Kingdom (U.K.)**, Keele University is exploring hydrogen blending into its private gas network beginning in 2019 to reduce carbon emissions from heating buildings.[9] The HyDeploy Project plans to blend up to 20% hydrogen as part of their decarbonization efforts.[10] Blending hydrogen with natural gas across the U.K. is estimated to reduce 6 million tons of carbon annually, the equivalent of taking 2.5 million cars off the roads.[11] Leeds, one of the largest cities in the U.K., launched the Leeds H21 City Gate hydrogen project[12] in 2016, targeting the conversion of the existing natural gas supply and distribution system to deliver hydrogen to consumers. Leeds H21 has examined the engineering, costs, transition requirements, production, transportation, end use applications, and in parallel has assessed the initiative's impact on GHG emissions reduction.[13]
- In **France**, the Minister for the Ecological and Inclusive Transition has announced a "hydrogen strategy" to utilize hydrogen across all sectors with a goal of 10% hydrogen penetration in their industrial gas use by 2023 and 20% to 40% by 2028.[14] Additionally, the French utility, Engie, inaugurated the largest hydrogen utility fleet in France and an alternative multi-fuel station to fuel hydrogen hybrid vehicles.[15]
- In **Germany**, electrolytic hydrogen based gas (power-to-gas) and liquid are cornerstones of deep decarbonization, with national recognition that getting to 90+% greenhouse gas emissions or near carbon neutrality will not be possible without this. The German Energy Agency aims to ensure electrolytic hydrogen is fully commercialized by 2022.[16]
- In the **Netherlands**, a 440 MW Combined Cycle Gas Turbine (CCGT) in a 1.32 GW Magnum gas-fired power plant is expected to run on 100% hydrogen using Mitsubishi Hitachi's technology by end of 2023.[17]

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[7] *A Clean Planet for all - A European strategic long-term vision for a prosperous, modern, competitive and climate neutral economy,* European Commission, November 28, 2018 Specifically, the first five scenarios focus on impacts of specific technology pathways, varying in the intensity of application of electrification, hydrogen, electrolytic fuels, end user energy efficiency, as well as the role of a circular economy, as actions to reduce emissions. The study found that while all of these can likely achieve 80% greenhouse gas reductions below 1990 levels, none can achieve deeper decarbonization. To reduce emissions at least 90% below 1990 levels, all five pathways must be aggressively pursued in combination (the sixth pathway). To achieve net carbon neutrality followed by net carbon negativity, however, the seventh and eighth pathways studied add to the combination scenario either negative emissions technology in the form of bioenergy combined with carbon capture and storage, or reliance on a circular economy, change in consumer choices that are less carbon intensive, and strengthening the land use sink to reduce the need for negative emissions technologies.

[8] http://europeanpowertogas.com/projects-in-europe/

[9] https://networks.online/gphsn/news/1000904/trial-explore-blending-hydrogen-gas-network

[10] https://networks.online/gphsn/news/1000904/trial-explore-blending-hydrogen-gas-network

[11] https://www.telegraph.co.uk/business/2018/01/06/hydrogen/

[12] https://www.northerngasnetworks.co.uk/2016/07/12/watch-our-h21-leeds-city-gate-film/

[13] http://www.h2fcsupergen.com/news/hydrogen-in-the-north-the-h21-leeds-city-gate-report- launches/

[14] https://fuelcellsworks.com/news/french-minister-unveiled-his-100m-hydrogen-plan/

[15] https://www.engie.com/en/group/opinions/energy-transition-climate/isabelle-kocher- hydrogen-the-missing-link

[16] https://www.dena.de/en/topics-projects/projects/energy-systems/power-to-gas-strategy-platform/

[17] https://www.mhps.com/news/20180308.html

Asia

Japan is aiming to be the world leader in decarbonizing by becoming a hydrogen-based society and is adopting a multi-pronged strategy for realizing this vision.[18] Showcasing this ambition, the 2020 Olympics in Japan aims to run entirely on hydrogen. A report prepared for Japan by the International Energy Agency declares: "*This is a critical year for hydrogen. It is enjoying unprecedented momentum around the world and could finally be set on a path to fulfil its longstanding potential as a clean energy solution. To seize this opportunity, governments and companies need to be taking ambitious and real- world actions now*."[19] California ought to avoid the opposite pathway of inaction.

In **China**, the "father" of China's electric vehicle industry and vice chairman of China's national advisory body for policy making, Wan Gang, who convinced Chinese leaders twenty years ago to adopt battery electric vehicle technology, is now saying the country should be looking into "establishing a hydrogen society" and is seeking to have China similarly become a global leader in developing hydrogen technology.[20]

On June 27, 2019, Bloomberg reported that they have tracked more than $17 billion worth of announced hydrogen investments through 2023, including $7.6 billion by China National Heavy Duty Truck Group and $363 million for fuel cell stacks/components in hopes of getting to 300,000 fuel cell stacks on the horizon. They also report that 5,000 passenger and commercial FCEVs will be on China's roads by next year and that the "Made in China" national industrial strategy supports both battery and FCEV technology. Hydrogen has been consistently subsidized over the last few years with the nation's policy lead committed to a long-term view and believing that "springtime" is happening now for hydrogen in China.[21]

The **South Korean** government also reportedly has a $2.33 billion public-private investment plan to accelerate hydrogen fuel cell infrastructure, manufacturing capabilities and technology development for transportation and stationary applications.[22]

Hydrogen is also gaining interest in the **Middle East**, and a multi-megawatt solar hydrogen project has broken ground in Dubai,[23] among other projects.

Australia

Hydrogen is being pursued as a strategy in individual states like New South Wales, which is developing an electrolytic hydrogen storage project that will use existing gas pipelines to store and transport renewable electricity in the form of hydrogen.[24] Hydrogen is also on the national agenda of Australia. The nation's Chief Scientist states that the country's "vision is a future in which hydrogen provides economic benefits to Australia through export revenue and new industries and jobs, supports the transition to low emissions energy across

[18] https://www.meti.go.jp/english/press/2017/pdf/1226_003a.pdf
[19] P. 1, *The Future of* Hydrogen, *Seizing Today's Opportunities, Executive Summary and Recommendations,* IEA, June 2019 https://webstore.iea.org/download/summary/2803?fileName=English-Future-Hydrogen-ES.pdf
[20] https://www.supplychainbrain.com/articles/29843-chinas-father-of-electric-cars-says-hydrogen-is-the-future
[21] https://www.bloomberg.com/news/articles/2019-06-27/china-s-hydrogen-vehicle-dream-chased-by-17-billion-of-funding
[22] p. 56, *Hydrogen for Australia's Future,* Hydrogen Strategy Group (Chaired by Australia Chief Scientist, Dr. Alan Finkel); August 2018
[23] https://gulfnews.com/uae/first-green-hydrogen-project-breaks-ground-in-dubai-1.1549175502065
[24] https://arena.gov.au/news/hydrogen-to-be-trialled-in-nsw-gas-networks/

electricity, heating, transport and industry, improves energy system resilience and increases consumer choice."[25] By 2030, it is estimated that the Australian hydrogen industry could be worth over a billion dollars and provide 2,800 jobs.[26] Notably, a 2017 study by the Australian Gas Infrastructure Group with input from Deloitte comparing an electrification to a hydrogen conversion pathway to decarbonizing the state of Victoria's gas consumption found that although costs of long-term hydrogen storage need to be better understood, modeling showed that the hydrogen conversion pathway would cost about 40% less than the full electrification pathway, largely because of the flexibility of electrolysis to meet gas demand, lower long-term requirement for electricity storage though batteries or hydro, and lower network upgrade costs because of the use of the existing gas infrastructure.[27]

Other

The **International Energy Agency** recently released an extensive report on the global future of hydrogen, which the agency's Director prefaces by stating, "Hydrogen is today enjoying unprecedented momentum.[28] The world should not miss this unique chance to make hydrogen an important part of our clean and secure energy future."

Specific highlights include:

- There are **around 50 targets, mandates and policy incentives** in place today that direct support hydrogen, with the majority focused on transport.
- **Fuel costs are the largest cost component**, accounting for between 45% and 75% of production costs. Low gas prices in the Middle East, Russia and North America give rise to some of the lowest hydrogen production costs.
- **With declining costs for solar PV and wind generation, building electrolyzers at locations with excellent renewable resource conditions could become a low-cost supply option for hydrogen**, even after taking into account the transmission and distribution costs of transporting hydrogen from (often remote) renewables locations to the end-users.
- The IEA has **identified four value chains that offer springboard opportunities to scale up** hydrogen supply and demand, building on existing industries, infrastructure and policies: industrial hubs, mobility, gas grids, and international trade.

[25] p. i, ibid.
[26] p. 12, Ibid.
[27] Ibid, p. 30
[28] https://www.iea.org/hydrogen2019/