TESTIMONY OF THE NATURAL RESOURCES DEFENSE COUNCIL

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Concerning the Merits and Limitations of Hydrogen Technology as a Decarbonization Tool

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Chairman Bizzarro, Representative Hohenstein, honorable members of the Committee: thank you for inviting me to comment on the merits and risks of hydrogen as Pennsylvania begins exploring it as part of the state's future energy mix. My name is Rachel Fakhry and I am a Senior Analyst for the Natural Resources Defense Council (NRDC), a member-based non-profit environmental organization with more than 90,000 members and activists in Pennsylvania. NRDC works in the U.S. and internationally to protect the air, water, and land that support human health and long-term economic growth. My work is focused on designing policy mechanisms that reduce emissions of greenhouse gases and other air pollutants across the U.S. I also lead NRDC's hydrogen work and engage with international and domestic stakeholders on designing the policy and regulatory frameworks that would both leverage the technology's potential to support the deep decarbonization of the economy and avoid the pitfalls that may ensue from its indiscriminate deployment. I have had the opportunity to be featured in a number of high-profile media outlets in relation to hydrogen (a list of media appearances is included in Exhibit A below).

The following testimony:

- Highlights the potential for hydrogen to support deep decarbonization goals by substituting for fossil fuels in the most challenging sectors of the economy, including aviation, maritime shipping, steelmaking and long-distance freight trucking.
- Provides some brief background on the current state of the hydrogen industry in Pennsylvania and the U.S.
- Discusses the two hydrogen production pathways currently receiving much of the policy and investor interest – zero-carbon hydrogen and blue hydrogen – and argues that zero-carbon hydrogen offers a more compelling case and a safer bet for Pennsylvania based on current evidence.
- Discusses the various end-use applications for hydrogen and argues that while it has great potential to decarbonize challenging sectors where electrification faces technical hurdles, it is inefficient relative to electrification in a wide range of applications –notably as a source of building heat.
- Calls into question claims that hydrogen would be a "no-disruption" solution relative to electrification owing to the potential to repurpose the existing gas network.
- Highlights the necessity of exercising caution in relation to hydrogen blending initiatives, the near-term repurposing of methane gas pipelines and the buildout of new dedicated hydrogen networks to avoid the stranding of methane gas and hydrogen assets and locking Pennsylvanians into expensive decarbonization routes.

- Puts forth what I consider to be a sensible policy framework for Pennsylvania policymakers to consider in relation to hydrogen that would both leverage the technology's unique potential and internalize the necessary guardrails to avoid saddling Pennsylvanians with unnecessary costs and undermine climate progress.

I. HIGH-LEVEL SUMMARY

Hydrogen has unique potential to support decarbonization goals, but it also has important drawbacks to which policymakers must be acutely sensitive.

Hydrogen can support the deep decarbonization of the economy by acting as a valuable complement to proven and established climate solutions like energy efficiency, clean electricity and electrification. It offers unique potential to substitute for fossil fuels in challenging sectors where electrification faces technical hurdles, including aviation, maritime shipping, steelmaking and long-distance freight trucking. It could also support a very high renewable grid by serving as a seasonal form of electric storage. In Pennsylvania, hydrogen can bolster the reliability of a highly clean electric grid and support the state's efforts to enact a strong clean energy standard and can unlock a competitive future for the state's steelmaking industry in a clean economy.

However, because the market for hydrogen is nascent, hydrogen's deployment as a decarbonization tool is fraught with uncertainties and requires that decisionmakers first understand hydrogen's strengths and limitations. Hydrogen's potential is accompanied by potential pitfalls associated with its production, transport and use, which I discuss below and to which policymakers and stakeholders must be acutely sensitive. One of the main risks associated with an overeager switch to hydrogen includes steering limited public and private investments away from deploying reliable, cost-effective and readily available decarbonization solutions like direct electrification. This could lock Pennsylvanians into unnecessarily expensive decarbonization pathways or lead to the stranding of hydrogen assets should challenges to hydrogen-heavy pathways prove too great, undermining necessary climate progress in this decade and beyond.

I recommend that Pennsylvania policymakers endeavor to design a strategic, targeted and evidence-based policy framework that leverages hydrogen's unique potential while avoiding unintended economic, public health and climate consequences. Specifically, I urge decisionmakers to adopt a policy framework for hydrogen within a broader ambitious clean energy agenda by:

1. Identifying hydrogen's strengths and limitations by way of an independent, system-wide assessment.
2. Endeavoring to ensure that a hydrogen agenda does not derail necessary action on proven, readily available solutions that must be taken today.
3. Orienting subsidies and support for hydrogen deployment towards applications where it adds the most value, commensurate with the system-wide assessment.
4. Orienting investments, policy incentives and subsidies towards zero-carbon hydrogen.
5. Exercising caution in relation to proposals for hydrogen blending, the repurposing of existing gas pipelines and the buildout of new hydrogen pipelines

II. HYDROGEN: BACKGROUND

The current hydrogen hype is largely driven by proliferating national deep decarbonization goals.

One of the main reasons that hydrogen is receiving an elevated level of hype, both globally and in the U.S., is the proliferating national commitments to deep decarbonization, commensurate with the demands of the climate crisis. To date, 59 countries have established economy-wide net-zero greenhouse gas (GHG) emissions targets by sometime around 2050. Those commitments have driven countries to grapple with the necessity of finding clean energy solutions to substitute for fossil fuels in the most challenging sectors of the economy, including aviation, maritime shipping, steelmaking and long-distance freight trucking[1]. Those applications require either a chemical feedstock to drive a chemical reaction – as in steelmaking – or dense forms of energy to propel heavy equipment like vessels, aircrafts, and large trucks across long distances. Electrification – the solution to decarbonize much of the economy – faces technical hurdles in those applications because it may either require an entirely new process to forgo chemical reactions which it cannot serve – as in steelmaking- or may require very large batteries to propel heavy equipment across long distances, creating weight and payload issues for freight trucks, aircrafts and

[1] Michael Liebreich, *Separating Hype from Hydrogen – Part Two: The Demand Side*, Bloomberg New Energy Finance, October 2020, https://about.bnef.com/blog/liebreich-separating-hype-from-hydrogen-part-two-the-demand-side/ ; Simon Evans, John Gabbatiss, *In-Depth Q&A: Does the World Need Hydrogen to Solve Climate Change*, CarbonBrief, November 2020, https://www.carbonbrief.org/in-depth-qa-does-the-world-need-hydrogen-to-solve-climate-change

shipping vessels. In contrast, hydrogen offers many of the attributes that those challenging applications demand: it has high energy density – nearly three times that of diesel or gasoline – and can act as a chemical feedstock in heavy industry applications. Hydrogen has thus emerged as a compelling potential tool for decarbonization, as a complement to established climate solutions like electrification, efficiency and renewable energy.

Hydrogen is a well-established energy resource mainly used in the U.S. and global industrial sector.

Although interest in employing hydrogen as a decarbonization tool is nascent, the hydrogen industry is not. Hydrogen is a molecule that has been used in the U.S. industrial sector for several decades. Today, its two main applications are in the oil refining process, where it is used to strip sulfur impurities from crude oil, and as the primary feedstock in the production of ammonia, the main ingredient of agricultural fertilizer. The U.S. hydrogen industry is an $18 billion dollar industry. [2] Pennsylvania houses a few small-scale hydrogen facilities concentrated in the western part of the state, but it is unclear in which manner the hydrogen is consumed, although it can be reasonably assumed that a measurable portion of it serves the state's handful of refineries and fertilizer plants.[3]

III. HYDROGEN PRODUCTION

The current hydrogen production process is highly polluting.

Hydrogen gas is not found in stand-alone form on earth and must be produced from another element that contains it. More than 95% of all hydrogen used in the U.S. is produced from methane gas in a process called steam methane reformation (SMR)[4]. In this process, methane gas is both used as the source of hydrogen, i.e., "feedstock," and combusted at high temperatures to provide the energy that drives the process. SMR is a major source of climate pollution in the U.S., emitting more than 90 million metric tons of carbon dioxide per year – more than the total carbon footprint of Pennsylvania's power sector – as well as large amounts of health-damaging air pollutants such as nitrogen oxides, volatile organic

[2] Hydrogen Council, *Roadmap to a US Hydrogen Economy*, 2020, https://static1.squarespace.com/static/53ab1feee4b0bef0179a1563/t/5e7ca9d6c8fb3629d399fe0c/1585228263363/Road+Map+to+a+US+Hydrogen+Economy+Full+Report.pdf%22%20/
[3] U.S. Department of Energy, *Fact of the Month May 2018: 10 Million Metric Tons of Hydrogen Produced Annually in the United States*, May 2018, https://www.energy.gov/eere/fuelcells/fact-month-may-2018-10-million-metric-tons-hydrogen-produced-annually-united-states
[4] U.S. Department of Energy, *Hydrogen Production: Natural Gas Reforming*, https://www.energy.gov/eere/fuelcells/hydrogen-production-natural-gas-reforming

compounds and particulate matter.[5] Hydrogen produced through SMR is generally referred to as "grey" hydrogen.

Hydrogen production can be cleaned up to produce low and zero-carbon hydrogen.

The use of hydrogen as a tool for deep decarbonization is premised on the decarbonization of its production process. To date, various alternatives to conventional SMR have been proposed, but the two currently receiving the most interest and attention are electrolysis, particularly if powered by renewable electricity, and SMR coupled with carbon capture. In the electrolysis process, water is used as the hydrogen feedstock, rather than methane gas. Electricity is used to split water into its constituents, hydrogen and oxygen, and to the extent that the electricity is generated by a renewable resource such as wind, solar or hydro, the hydrogen is zero-carbon and air pollution-free. Hydrogen produced in this manner is often referred to as "green hydrogen." If the electricity is instead sourced from a nuclear plant, the hydrogen produced through electrolysis is sometimes referred to as "pink" hydrogen. For ease of reference, I will henceforth use the umbrella term "zero-carbon hydrogen" to refer collectively to both green and pink hydrogen.

Alternatively, the SMR process can be equipped with carbon capture to produce "blue hydrogen." In this case, the hydrogen produced is low-carbon, but for two reasons it is not zero-carbon. First, the efficiency of carbon capture has not been demonstrated beyond 90 to 95%, so the SMR process will likely result in a certain amount of residual emissions. Second, there will be methane emissions from leakage during the production of methane gas and its transport to the SMR facility.[6] This is particularly pertinent to Pennsylvania considering the state's grappling with elevated methane leakage rates at gas wells[7].

Today, zero-carbon and blue hydrogen are more costly than grey hydrogen. Green hydrogen currently costs up to 5 times more and blue hydrogen costs about 2 times more than grey hydrogen. However, significant cost reductions are projected by 2030 and beyond, notably in green hydrogen production (Figure 1). This is owing to anticipated large equipment cost reductions linked to projected increased deployment and ensuing economies of scale together with continued reductions in the costs of renewable

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[5] Pingping Sun, Ben Young, Amgad Elgowainy, Zifeng Lu, Michael Wang, Ben Morelli, and Troy Hawkins, *Criteria Air Pollutants and Greenhouse Gas Emissions from Hydrogen Production in U.S. Steam Methane Reforming Facilities*, ACS Publications, April 2018, https://pubs.acs.org/doi/10.1021/acs.est.8b06197

[6] Dennis Y.C. Leunga, Giorgio Caramannab M. Mercedes, Maroto-Valerb, An overview of current status of carbon dioxide capture and storage technologies, November 2014, Science Direct, https://www.sciencedirect.com/science/article/pii/S1364032114005450

[7] Environmental Defense Fund, *EDF Analysis Finds Pennsylvania Oil and Gas Methane Emissions are Double Previous Estimate*, May 2020, https://www.edf.org/media/edf-analysis-finds-pennsylvania-oil-and-gas-methane-emissions-are-double-previous-estimate

electricity[8]. Bloomberg New Energy Finance (BNEF) estimates that, preconditioned on strong policy support, green hydrogen could nearly compete with grey hydrogen and outcompete blue hydrogen in the U.S. by 2030. Recently announced federal and regional initiatives targeting ambitious green hydrogen cost reductions by 2030 - including the Department of Energy's Hydrogen Shot initiative and the HyDeal L.A. initiative in the West – increase the plausibility of the BNEF projections materializing[9]. By 2050, BNEF projects, green hydrogen will have a decisive cost advantage over both grey and blue hydrogen.

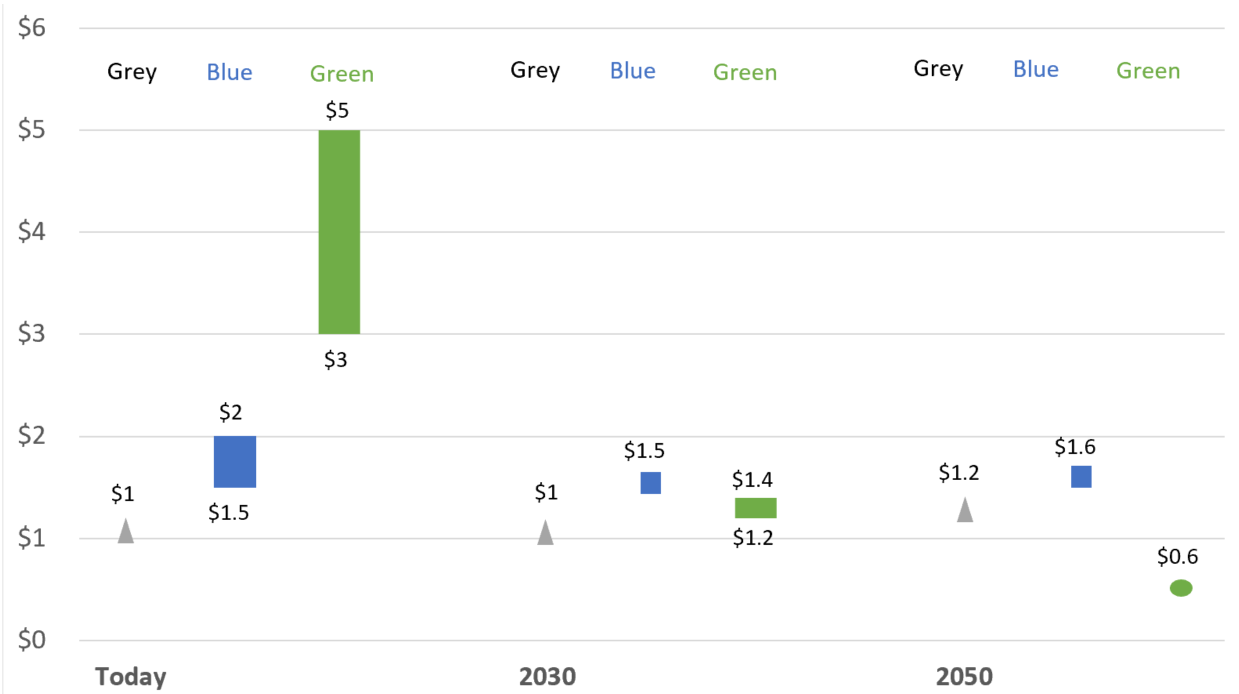

Figure 1: U.S. Hydrogen Production Costs ($/kg). Data sourced from BNEF, U.S. DOE and Resources for the Future[10].

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[8] HIS Markit, *IHS Markit: Production of Carbon-Free "Green" Hydrogen Could Be Cost Competitive by 2030*, July 2020, https://news.ihsmarkit.com/prviewer/release_only/slug/bizwire-2020-7-15-ihs-markit-production-of-carbon-free-green-hydrogen-could-be-cost-competitive-by-2030

[9] US Department of Energy, *Secretary Granholm Launches Hydrogen Energy Earthshot to Accelerate Breakthroughs Toward a Net-Zero Economy*, June 2021, https://www.energy.gov/articles/secretary-granholm-launches-hydrogen-energy-earthshot-accelerate-breakthroughs-toward-net ; BusinessWire, *LADWP Joins HyDeal LA, Targets Green Hydrogen at $1.50/kilogram by 2030*, May 2021, https://www.businesswire.com/news/home/20210517005210/en/LADWP-Joins-HyDeal-LA-Targets-Green-Hydrogen-at-1.50kilogram-by-2030

[10] BloombergNEF, *'Green' Hydrogen to Outcompete 'Blue' Everywhere by 203*0, May 2021, https://about.bnef.com/blog/green-hydrogen-to-outcompete-blue-everywhere-by-2030/ ; US Department of Energy, *Secretary Granholm Launches Hydrogen Energy Earthshot to Accelerate Breakthroughs Toward a Net-Zero Economy*; Jay Bartlett and Alan Krupnick, *Decarbonized Hydrogen in the US Power and Industrial Sectors: Identifying and Incentivizing Opportunities to Lower Emissions* , December 2020, Resources for the Future , https://www.rff.org/publications/reports/decarbonizing-hydrogen-us-power-and-industrial-sectors/

Zero-carbon hydrogen offers a more compelling case and a safer bet relative to "blue" hydrogen in the U.S. and Pennsylvania.

Zero-carbon hydrogen offers a more compelling case and a safer bet relative to blue hydrogen for the U.S. and Pennsylvania alike. Blue hydrogen faces a number of challenges to which Pennsylvania policymakers should be sensitive.

First, and as I discuss above, blue hydrogen is projected to face challenging medium and long-term economics relative to green hydrogen. A number of best available projections converge with BNEF and estimate that owing to its anticipated rapid scale up in this decade, green hydrogen could compete with, and even outcompete, blue hydrogen in the U.S. on a cost basis by 2030, with a widening cost differential in favor of green hydrogen thereafter[11]. This is owing to both projected dramatic cost reductions in the capital costs of electrolyzers – the equipment where the water splitting process occurs – and expected continued reductions in the cost of wind and solar energy. In contrast, the SMR process is fairly mature with markedly slimmer opportunities for cost reductions. The following quote by BNEF's lead hydrogen analyst, Martin Tengler, summarizes the cost dynamics well: "*By 2030, it will make little economic sense to build blue hydrogen production facilities in most countries, unless space constraints are an issue for renewables. Companies currently banking on producing hydrogen from fossil fuels with CCS will have at most ten years before they feel the pinch. Eventually those assets will be undercut, like what is happening with coal in the power sector today.*"[12] Therefore, it is a better bet for Pennsylvania to focus on a zero-carbon hydrogen trajectory that is poised to offer continuous cost reductions.

Second, the emissions from methane leakage and residual carbon emissions at the SMR site reduce the compatibility of blue hydrogen with a pathway to net-zero GHG emissions and thereby raise its risk profile due to the potential for asset stranding. This shortcoming is manifested in reputable and independent studies showing little blue hydrogen deployment in net-zero pathways relative to other clean hydrogen sources.[13] Furthermore, the air pollution impacts of blue hydrogen remain not fully understood, a potential drawback that may raise equity challenges for communities living in the vicinity of projects.

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[11] IRENA, *Green Hydrogen Cost Reduction*, December 2020, https://irena.org/-/media/Files/IRENA/Agency/Publication/2020/Dec/IRENA_Green_hydrogen_cost_2020.pdf

[12] Institute for Energy Economics and Financial Analysis, Green hydrogen to be cost-competitive by 2030—BloombergNEF, April 2021, https://ieefa.org/green-hydrogen-to-be-cost-competitive-by-2030-bloombergnef/

[13] James H. Williams, Ryan A. Jones, Ben Haley, Gabe Kwok, Jeremy Hargreaves, Jamil Farbes, Margaret S. Torn , Carbon-Neutral Pathways for the United States, January 2021, https://agupubs.onlinelibrary.wiley.com/doi/full/10.1029/2020AV000284 ; Princeton University, *Net-Zero America Project*, December 2020, https://acee.princeton.edu/rapidswitch/projects/net-zero-america-project/; Sustainable Development Solutions Network, *America's Zero Carbon Action Plan*, November 2020, https://www.unsdsn.org/Zero-Carbon-Action-Plan

Third, pursuing a blue hydrogen-heavy pathway forgoes a set of compelling benefits associated with zero-carbon hydrogen. As I discuss in section IV below, green hydrogen production can bolster the economics and reliability of a highly renewable grid. Similarly, the production of pink hydrogen could bolster the profitability of Pennsylvania's nuclear fleet, maximizing its value in the state's energy future and protecting the economic activity linked to it.[14] Accordingly, pursuing zero-carbon hydrogen is consistent with the state's exploration of an ambitious clean electricity standard.

It would therefore be prudent for Pennsylvania policymakers to hedge against the series of risks and uncertainties associated with blue hydrogen by orienting investment agendas to zero-carbon hydrogen, harnessing the full potential of the state's abundant renewables potential and nuclear resource. In parallel, policymakers could commission independent assessments evaluating specific contexts where blue hydrogen may offer additional value relative to zero-carbon hydrogen; those may include opportunities to retrofit existing hydrogen production facilities with carbon capture. Should a predominant focus on zero-carbon hydrogen prove challenging, the deployment of blue hydrogen is always an option. However, based on current evidence, a focus on a zero-carbon hydrogen pathway would be a safer and better bet for Pennsylvanians.

The challenges facing blue hydrogen also have bearing on the prudence of pursuing a twin track approach whereby Pennsylvania seeks to deploy blue hydrogen in the near-term as a transition to a zero-carbon hydrogen future. There is growing skepticism among experts around this qualification of blue hydrogen as a "bridge" technology largely due to multiplying projections that green hydrogen could compete with it by 2030 on a cost basis.[15] Blue hydrogen also requires investments in long-lived infrastructure and assets such as carbon pipelines and carbon storage basins which may impede a cost-effective switch to a zero-carbon hydrogen track. Therefore, pursuing a twin track approach carries a risk of lock-in to a blue hydrogen pathway that may be costlier than a zero-carbon one. Expert groups in the U.K. are now urging their government to abandon intentions to pursue such a twin track approach on account of those risks[16].

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[14] US Department of Energy, *Could Hydrogen Help Save Nuclear?*, June 2020, https://www.energy.gov/ne/articles/could-hydrogen-help-save-nuclear; Sonal Patel, Hydrogen May Be a Lifeline for Nuclear—But It Won't Be Easy, PowerMag, June 2020, https://www.powermag.com/hydrogen-may-be-a-lifeline-for-nuclear-but-it-wont-be-easy/;

[15] David Iaconangelo, *Hydrogen with CCS faces same fate as coal — report*, E&E News, April 2021, https://www.eenews.net/energywire/2021/04/08/stories/1063729469

[16] Juliet Philipps, Lisa Fisher, *Between hope and hype: a hydrogen vision for the UK*, E3G, March 2021, https://www.e3g.org/publications/between-hope-and-hype-a-hydrogen-vision-for-the-uk/

IV. HYDROGEN END-USE APPLICATIONS

Hydrogen is uniquely suited to decarbonize the challenging sectors of the economy where electrification faces hurdles.

The production and use of hydrogen typically involve a series of energy conversions that incur high efficiency losses. For instance, more than 20% of electricity is lost in the production of green hydrogen, and hydrogen equipment and appliances such as fuel cell cars and boilers are generally much less efficient than electric alternatives. These losses make hydrogen a relatively costly option for many applications that can be feasibly served by more efficient solutions like direct electrification. It stands to reason that using renewable electricity directly to power building appliances and cars would be a more efficient solution relative to using it to first produce hydrogen which would then serve the various applications. The most compelling technical and economic case for hydrogen is therefore in applications where it is uniquely suited to the task – i.e. where direct electrification is either not technologically feasible or is very costly.[17] Those include aviation, maritime shipping, steelmaking, chemicals productions and long-distance freight trucking.

Zero-carbon hydrogen could also bolster the reliability and cost-effectiveness of a highly clean grid. On the one hand, green hydrogen is a promising form of seasonal electricity storage.[18] It can be produced when there is excess renewable energy, especially in the fall and spring, stored for several months and then burned in turbines or run through fuel cells to generate electricity when wind and solar output is low. By helping the electricity grid ride through the seasonal differences in renewables performance, green hydrogen could meaningfully bolster the reliability and resiliency of a very high renewable grid. On the other hand, by making use of excess renewable or nuclear electricity that would otherwise be curtailed, zero-carbon hydrogen could bolster the cost-effectiveness of a highly clean grid and lower costs for Pennsylvania customers given that power projects would need to recoup less of their investment from electricity customers.

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[17] Michael Liebreich, *Separating Hype from Hydrogen – Part Two*; Evans et. al, *In-Depth Q&A: Does the World Need Hydrogen to Solve Climate Change*, CarbonBrief

[18] National Renewable Energy Laboratory, *Answer to Energy Storage Problem Could Be Hydrogen*, June 2020, https://www.nrel.gov/news/program/2020/answer-to-energy-storage-problem-could-be-hydrogen.html#:~:text=An%20analysis%20from%20NREL%20researchers,energy%20storage%20in%20the%20future.&text=They%20developed%20a%20multi%2Dmodel,technologies%20in%20determining%20cost%2Dcompetitiveness.

The visual below provides a helpful summary of hydrogen's potential across the energy sector and ranks applications based on feasibility and economics relative to other available solutions like direct electrification (Figure 2).

Michael Liebreich's "hydrogen ladder" chart identifying the merits of use cases for clean hydrogen. Photo: Liebreich Associates

Figure 2: Hydrogen- The Ladder[19]

In Pennsylvania, a hydrogen roadmap, which I discuss in Section VI below, would be critical in identifying applications where hydrogen would add value relative to other climate solutions. Based on the set of consensus high-value applications for hydrogen (Figure 2 above), there exists a subset of potentially compelling use cases in Pennsylvania that merit investigation. Notably, hydrogen could support a competitive future for certain industries, such as steel and freight, and bolster the decarbonization of the power sector:

- **Steelmaking:** Hydrogen could constitute an effective decarbonization solution for Pennsylvania's cohort of steel plants by substituting for fossil fuels as the feedstock driving the chemical reaction. Considering Pennsylvania's robust steelmaking legacy, hydrogen could help make this sector and

[19] Leigh Collins, *Liebreich: 'Oil sector is lobbying for inefficient hydrogen cars because it wants to delay electrification',* Recharge News, June 2021, https://www.rechargenews.com/energy-transition/liebreich-oil-sector-is-lobbying-for-inefficient-hydrogen-cars-because-it-wants-to-delay-electrification-/2-1-1033226

the jobs and economic activity associated with it a long-term, sustainable and climate-compatible economic engine for the state.

- **Heavy-duty freight trucks:** Pennsylvania's central standing along the I-80 corridor creates an opportunity for the state to be a pioneer in driving the decarbonization of the U.S. fleet of heavy-duty freight trucks. It could do so by launching near-term demonstration programs for heavy-duty fuel cell trucks and investigating the potential to deploy job-creating hydrogen refueling stations along the portion of corridor located in the state.
- **Support for a clean electricity grid:** Hydrogen could bolster the reliability and cost-effectiveness of a highly clean grid by making use of excess renewable and nuclear generation that would otherwise be wasted and acting as a seasonal storage option to help the grid ride through long periods of low wind and solar output. Hydrogen thereby merits consideration in discussions concerning the development of an ambitious Clean Energy Standard in Pennsylvania.

The inefficiencies of hydrogen use to heat buildings, and why prioritizing direct electrification instead is a sensible strategy.

Hydrogen gas can technically substitute for methane gas in supplying heat to buildings. However, a growing base of evidence demonstrates that hydrogen as a large-scale solution for building heating is likely an inefficient and costly solution relative to readily available and proven solutions like direct electrification. A range of studies estimate that heating a home with green hydrogen would require 5 to 6 times more renewable electricity than heating that same home with a highly efficient heat pump.[20] This wide differential is driven by inefficiencies on both the hydrogen production side and the end-use side (Figure 3). Sourcing renewable electricity to produce hydrogen is inefficient compared to directly using this renewable electricity, with more than 20% of the electricity lost in the production process. On the end-use side, readily available high-efficiency heat pumps can be up to 4 to 5 times more efficient relative to the still pre-commercial hydrogen boilers. The large efficiency differential has important implications on the costs of a hydrogen-heavy pathway and the required infrastructure buildout. Prioritizing direct electrification as a readily available and proven to be cost-effective solution to decarbonize buildings heat

[20] Jan Rosenow, Heating homes with hydrogen: Are we being sold a pup?, RAP, September 2020, https://www.raponline.org/blog/heating-homes-with-hydrogen-are-we-being-sold-a-pup/ ; Fraunhofer IEE, *Green hydrogen or green electricity for building heating?*, July 2020, https://www.iee.fraunhofer.de/en/presse-infothek/press-media/overview/2020/Hydrogen-and-Heat-in-Buildings.html#:~:text=The%20study's%20findings%20are%20clear,equivalent%20number%20of%20heat%20pumps.

would be a sensible strategy to avoid imposing unnecessary high costs on Pennsylvanians, with hydrogen explored in niche contexts.

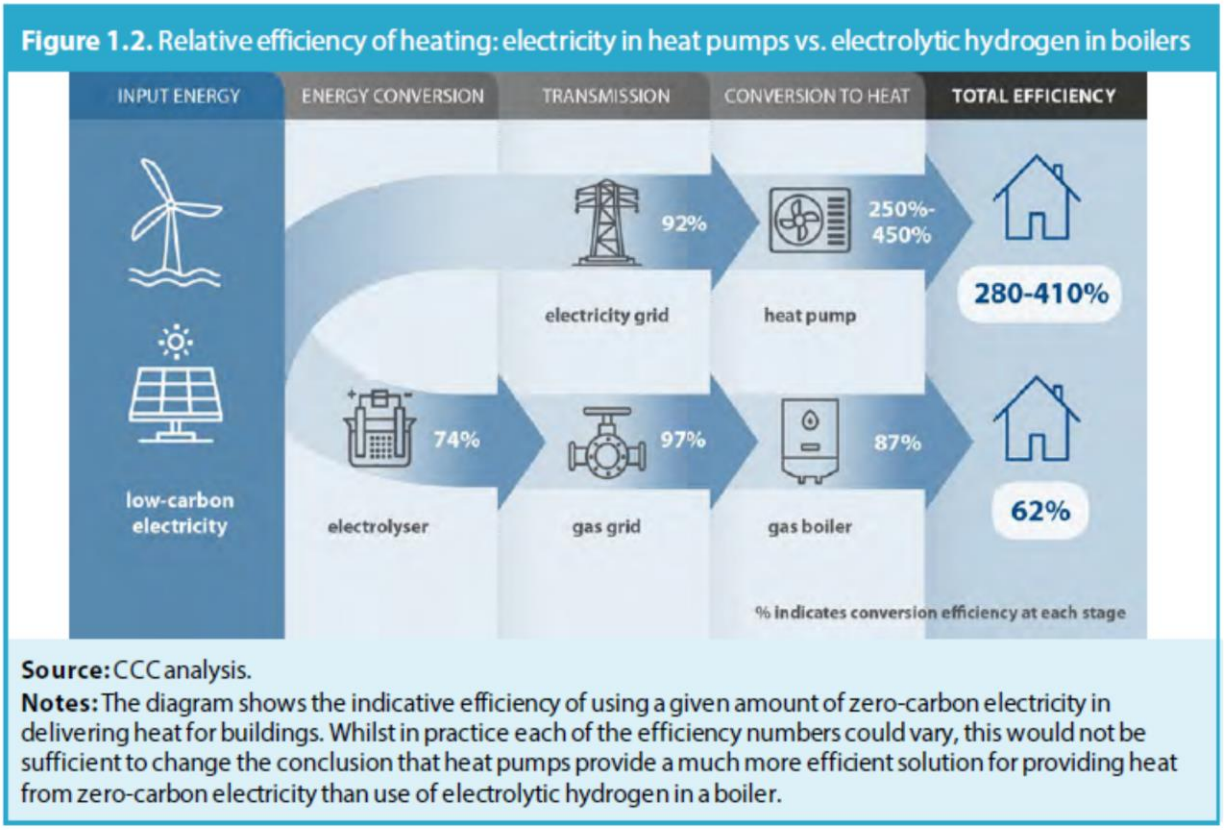

Figure 3: Relative Efficiency of Heating Electricity in Heat Pumps vs. Electrolytic Hydrogen in Boilers- Pulled from the study conducted by the U.K. Climate Change Committee[21]

The issue with the "no-disruption" slogan propagated by some in the gas industry.

Some interests have argued that using hydrogen to heat buildings is a "no-disruption" solution relative to electrification via heat pumps, owing to the potential to utilize the existing gas network to transport the hydrogen. However, this is a misleading claim. Hydrogen is a fundamentally different gas relative to methane gas, and when it is blended with methane gas at high levels, its chemical properties cause embrittlement to steel gas pipelines. Consequently, while blending hydrogen with methane in low proportions (e.g. 5 to 15% by volume) could be achieved with minimal investments into the existing gas system, any quantity of hydrogen exceeding this threshold is likely to require either major network

[21] UK Climate Change Committee, *Hydrogen in a low-carbon economy*, November 2018, https://www.theccc.org.uk/publication/hydrogen-in-a-low-carbon-economy/ . The CCC is an independent, non-departmental public body, formed to advise the UK and devolved Governments and Parliaments on tackling and preparing for climate change.

upgrades and repurposing measures or the buildout of an entirely new dedicated hydrogen pipeline network.[22] Existing gas boilers and cookstoves would also have to be replaced with hydrogen-compatible alternatives, which remain pre-commercial and require additional demonstration. As of today, there is no blueprint for such investments, and the costs and technical implications remain decidedly uncertain. For all these reasons, and because of the inefficiencies of hydrogen use in buildings relative to electrification, the premise that hydrogen would be a cost-effective solution for buildings due to the capacity to repurpose an existing gas network in some fashion is tenuous, at best. In fact, the U.K.- based Climate Change Committee recently found that the sunk costs of having an extensive gas grid do *not* give the hydrogen pathway a decisive advantage over electrification[23]. Of course, utilizing existing assets in lieu of wholesale decommissioning is an attractive proposition, and there may be specific cases where repurposing portions of the existing gas network would be expedient to climate and economic goals. However, it would be prudent to exercise caution in relation to both near-term proposals for hydrogen repurposing efforts and proposals for continued investments in the gas grid that contemplate future repurposing.

Why claims around the benefits of widespread hydrogen use in buildings in lieu of electrification may be harmful to Pennsylvanians and undermine climate progress.

There is a risk that the promise of hydrogen either dulls necessary near-term investments in proven and readily available solutions or encourages a set of misguided near-term actions. “Tech-crastination” is a coinage to refer to this risk whereby the promise of a future technology derails investments in proven and reliable technologies that should be made today[24]. Pursuing large-scale investments in the existing gas system with future repurposing to hydrogen in mind risks derailing necessary investments in building electrification and locking in Pennsylvanians into a relatively expensive and inefficient pathway to deep decarbonization. It could also result in the stranding of gas or hydrogen networks, following an ultimate switch to electrification. As I note above, it would be prudent for policymakers to decisively proceed with proven, readily available and cost-effective solutions for buildings like electrification and energy efficiency and consider potential niche roles for hydrogen – and associated infrastructure implications – if and when new evidence emerges to warrant such consideration.

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[22] M. W. Melaina, O. Antonia, and M. Penev, *Blending Hydrogen into Natural Gas Pipeline Networks: A Review of Key Issues*, NREL, March 2013, ,https://www.nrel.gov/docs/fy13osti/51995.pdf

[23] UK Climate Change Committee, *Hydrogen in a low-carbon economy*

[24] Stian Westlake, *Bionic Duckweed: making the future the enemy of the present*, September 2020,https://stianstian.medium.com/bionic-duckweed-using-the-future-to-fight-the-present-3e471b642c28; Evans et. al, *In-Depth Q&A: Does the World Need Hydrogen to Solve Climate Change*, CarbonBrief

V. HYDROGEN BLENDING AND TRANSPORT

Safeguards are needed to avoid that hydrogen blending initiatives produce lock-in effects into expensive decarbonization pathways.

Hydrogen blending initiatives in the existing gas network are proliferating across the U.S.[25] Blending low shares of hydrogen in the existing gas network could be an effective measure to boost demand for zero-carbon hydrogen production, modestly reduce the carbon emissions of delivered gas and build the knowledge base in relation to the behavior of hydrogen in existing gas pipes. However, as I note above, blending hydrogen beyond the low threshold of 5% to 15% by volume would potentially require major network and appliance refurbishing costs.[26] Therefore, and in considering potential future hydrogen blending proposals in Pennsylvania, it would be prudent for policymakers to institute robust guardrails limiting blending to low thresholds warranting little to no investments in network upgrades; similar safeguards are necessary to avoid that blending programs lock-in Pennsylvanians in a potentially expensive pathway on account of major expenses poured into the gas network. The Renewable Hydrogen Coalition- a hydrogen lobby group in Europe- has recently argued for the avoidance of hydrogen blending altogether, citing the risks that investments in the gas grid to accommodate high blends of hydrogen become stranded.[27]

The need to exercise caution in relation to proposals for the refurbishing of existing gas pipelines or the buildout of dedicated hydrogen networks to avoid lock-in effects into expensive pathways and the stranding of assets.

There are emerging proposals across Europe and recently, in the U.S. west, to build dedicated hydrogen pipelines and/or repurpose the existing gas network to accommodate hydrogen in anticipation of a

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[25] Tom DiChristopher, *How National Grid plans to advance US renewable gas, hydrogen deployment*, S&P Global, January 2021, https://platform.mi.spglobal.com/web/client?auth=inherit#news/article?id=62227805&cdid=A-62227805-12335&KeyProductLinkType=58&utm_source=MIAlerts&utm_medium=scheduledalert&utm_campaign=Alert_Email

[26] M. W. Melaina, et.al, *Blending Hydrogen into Natural Gas Pipeline Networks: A Review of Key Issues*, NREL

[27] Camilla Naschert, EU hydrogen lobby group calls for guarantees of origin, downplays gas blending, S&P Global, June 2021, https://platform.marketintelligence.spglobal.com/web/client?#news/article?id=65119834&KeyProductLinkType=58&utm_source=MIAlerts&utm_medium=realtime-minewsresearch-newsfeature-energy%20and%20utilities-the%20daily%20dose&utm_campaign=Alert_Email

growing market.[28] Those would entail large investments in long-lived assets that require a clear near, mid and long-term business case. This is largely lacking as of today, due to the nascency of the hydrogen market, and such investments thereby remain fairly premature- a case of putting the cart before the horse. In particular, there remain many uncertainties in relation to hydrogen's ultimate scope in the economy and the mid and long-term landscape of its supply and demand centers.[29] A near-term leap into hydrogen transport infrastructure risks imposing unnecessary costs on Pennsylvanians and creating stranded assets. Recognizing the risks, an increasing group of stakeholders across Europe are now arguing for holding off on large-scale investments in hydrogen pipelines until a clear demand pattern has emerged.[30] Other groups have proposed to future-proof near-term investments in hydrogen pipelines or repurposing efforts by focusing on a small-scale buildout of pipelines around what are expected to be secure long-term hydrogen demand centers, and gradually expanding networks if and when an economic and climate case for such an expansion emerges[31]. Considering the scale of the investments and the risks that they become stranded, a judicious approach for Pennsylvania policymakers and regulators to consider would be to start by advancing zero-carbon hydrogen use in hubs- or a cohort of hydrogen suppliers and users situated in close proximity such that large-scale hydrogen transport infrastructure is unnecessary- and commission independent assessments investigating where new hydrogen networks or repurposing measures would be cost-effective, secure investments that carry low risks of becoming stranded.

VI. RECOMMENDATIONS

The building blocks of a targeted policy framework that would both develop hydrogen to leverage its potential and internalize the guardrails critical to addressing the potential drawbacks.

A strategic vision for hydrogen deployment must start with a recognition that the hydrogen space is new and that a series of uncertainties still exist across its value chain in relation to the most expedient

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[28] Enagás, Energinet, Fluxug Belgium, Gasunie, GRTgaz, NET4GAS, OGE, ONTRAS, Snam, Swedegas, Teréga, *European Hydrogen Backbone*, July 2020, https://gasforclimate2050.eu/wp-content/uploads/2020/07/2020_European-Hydrogen-Backbone_Report.pdf

[29] Camilla Naschert, Hydrogen lobbying sets wrong priorities, says BloombergNEF founder, S&P Global, May 2021, https://platform.marketintelligence.spglobal.com/web/client?auth=inherit#news/article?KeyProductLinkType=2&id=64534120 ; Evans et. al, *In-Depth Q&A: Does the World Need Hydrogen to Solve Climate Change*, CarbonBrief

[30] Camilla Naschert, Hydrogen lobbying sets wrong priorities, says BloombergNEF founder, S&P Global

[31] Agora Energiewende, *No-Regret Hydrogen*, February 2021, https://static.agora-energiewende.de/fileadmin/Projekte/2021/2021_02_EU_H2Grid/A-EW_203_No-regret-hydrogen_WEB.pdf; Climate Action Network Europe, *CAN Europe's Position on Hydrogen*, February 2021, https://caneurope.org/content/uploads/2021/02/CAN-Europe_position-on-hydrogen_February-2021.pdf

production, transport and use patterns. In addition, the hydrogen agenda is currently in part driven by vested interests of those with stakes in the technology's indiscriminate deployment, which may not align with the interests of Pennsylvanians.[32] Pennsylvania policymakers should endeavor to future- proof hydrogen policies and investments by pursuing evidence-based decision-making that roots choices in independent studies and avoids an overeager leap to hydrogen that may engender unintended economic, public health and climate consequences to Pennsylvanians. The following recommendations constitute the building blocks of a prudent hydrogen strategy:

1. Identify hydrogen's strengths and limitations by way of an independent, system-wide assessment.

While hydrogen could act as a valuable complement to proven and established climate solutions like energy efficiency, renewable energy and electrification, evidence suggests that it will not be the most cost-effective nor efficient decarbonization pathway for many sectors. Therefore, a sensible and strategic hydrogen strategy should begin with a clear-eyed understanding of its strengths and limitations. Pennsylvania policymakers are advised to begin by commissioning independent and rigorous system-wide studies evaluating applications where hydrogen offers value relative to other solutions in deep decarbonization pathways and where hydrogen deployment would deliver benefits to Pennsylvanians. Such assessments could then constitute the bedrock of a state hydrogen strategy or roadmap guiding investments in a manner that is aligned with broader economic, public health and climate goals. For example, a California bill under deliberation [SB 18] directs state agencies to investigate the potential role for green hydrogen in supporting the state's climate goals and to produce a hydrogen roadmap pursuant to such an assessment. Similarly, Government Cuomo recently announced a planned collaboration between New York state agencies and the National Renewable Energy Laboratory on a hydrogen strategy study aiming to identify hydrogen opportunities and evaluating how those may be commensurate with broader renewable energy and climate goals.[33]

[32] Leigh Collins, *Liebreich: 'Oil sector is lobbying for inefficient hydrogen cars because it wants to delay electrification',* Recharge News

[33] Office of the Governor, New York State, *Governor Cuomo Announces New York Will Explore Potential Role of Green Hydrogen as Part of Comprehensive Decarbonization Strategy*, July 2021, https://www.governor.ny.gov/news/governor-cuomo-announces-new-york-will-explore-potential-role-green-hydrogen-part

2. Endeavor to ensure that a hydrogen agenda does not derail necessary action on proven, readily available solutions that must be taken today.

The promise of hydrogen should not delay, let alone be substituted for, necessary near-term steps to decarbonize Pennsylvania's economy. Policymakers are advised to pass and implement programs and policies targeting the large-scale deployment of clean electricity resources and widespread electrification of end-uses, notably buildings and passenger cars. Those are proven, cost-effective and readily available solutions and will be central pillars of any decarbonization strategy, regardless of the ultimate role of hydrogen.

3. Orient subsidies and support for hydrogen deployment towards applications where it adds the most value, commensurate with the system-wide assessment.

State subsidies and support programs for hydrogen should be oriented to channel the deployment of hydrogen toward applications where it adds value relative to alternative solutions, in accordance with the system-wide analysis of deep decarbonization pathways. Policy mechanisms could include financial support for projects aiming to demonstrate and advance the use of hydrogen as a feedstock in steelmaking and chemicals manufacturing, supporting fleet demonstrations for hydrogen heavy duty trucks, and funding demonstrations of seasonal hydrogen storage.

4. Orient investments, policy incentives and subsidies towards zero-carbon hydrogen.

That Pennsylvania has an abundant gas resource should not muddle the objective advantages that zero-carbon hydrogen is likely to have over blue hydrogen and the likelihood of it being a safer bet for Pennsylvanians. As I mention above, green hydrogen is projected to either compete with or outcompete blue hydrogen in this decade owing to larger opportunities for technology cost reductions and virtuous learning effects, with a decisive cost advantage for green hydrogen after 2030. In addition, the residual greenhouse gas emissions associated with blue hydrogen reduce its compatibility with a net-zero pathway, raising its risk profile due to the potential stranding of assets. Blue hydrogen also raises equity concerns for communities situated in the vicinity of production facilities due to potential public health concerns. Therefore, Pennsylvania policymakers would be advised to orient policy incentives and subsidies towards the deployment of zero-carbon hydrogen, harnessing the state's large renewable energy and nuclear potential, and investigate targeted opportunities where blue hydrogen may offer a compelling economic, climate and public health case for Pennsylvanians. Should a strong focus on zero-carbon hydrogen prove too challenging, deployment of blue hydrogen is always an option.

5. **Pursue an ambitious clean energy agenda.**

The success and scalability of zero-carbon hydrogen is closely tied to the rapid deployment of renewable and zero-carbon electricity. The enactment of a clean energy standard (CES) that includes hydrogen could help set up the foundation for a strong zero-carbon hydrogen industry in Pennsylvania, and the prospects for the development of such an industry furnishes an additional reason to double down on CES ambition or add hydrogen to a strengthened Alternative Energy Portfolio Standard.

6. **Exercise caution in relation to proposals for hydrogen blending, the repurposing of existing gas pipelines and the buildout of new hydrogen pipelines**

Pennsylvania policymakers are advised to exercise caution in relation to near-term proposals for blending hydrogen in the existing gas network, the repurposing of the existing network and the buildout of new hydrogen-dedicated pipelines. In particular, in considering blending proposals, I would recommend that policymakers implement safeguards to limit hydrogen blending to low thresholds- not exceeding 15% of hydrogen blended by volume- warranting little to no investments in network upgrades. An equal level of prudence is warranted in considering proposals for the wholesale repurposing of existing pipelines or the buildout of a new hydrogen-dedicated network; as I discuss above, such investments are largely premature as of today on account of the chain of uncertainties that permeate the long-term hydrogen vision and risk locking Pennsylvanians into expensive pathways or becoming stranded. Considering the risks, I would advise Pennsylvania policymakers to start by advancing zero-carbon hydrogen use in hubs, requiring no major hydrogen transport infrastructure. In parallel, policymakers should commission independent and transparent studies identifying future-proof and no-regret pipeline corridors- commensurate with secure future hydrogen demand centers teased out by the system-wide assessment- with the buy-in and meaningful participation of local communities impacted by said pipeline corridors.[34] Hydrogen pipeline networks could then be gradually expanded if and when a techno-economic and equity case for such an expansion emerges. Some European expert groups are now advocating for such sensible, no-regret early investments in hydrogen transport infrastructure.[35]

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[34] Camilla Naschert, *Prioritizing heavy industry cuts stranded asset risk for hydrogen infrastructure* , S&P Global, February 2021, https://platform.marketintelligence.spglobal.com/web/client#news/article?KeyProductLinkType=2&id=62620184

[35] Agora Energiewende, *No-Regret Hydrogen*, February 2021, https://static.agora-energiewende.de/fileadmin/Projekte/2021/2021_02_EU_H2Grid/A-EW_203_No-regret-hydrogen_WEB.pdf

Chairman Bizzarro, Representative Hohenstein, thank you again for the opportunity to testify on the merits and drawbacks of hydrogen and put forth my recommendations for a sensible policy framework to maximize the benefits for Pennsylvanians and avoid unintended consequences. I would be happy to answer any questions you may have.

EXHIBIT A

- Panelist on the *BBC News* podcast "The Real Story". Discussed the pros and cons of using green hydrogen to replace fossil fuels. The story was picked up by over 180 *National Public Radio (NPR)* affiliate radio stations as well as *Sirius XM* Radio.

- Sole guest on Marketplace's Tech podcast explaining green hydrogen, how it can reduce climate emissions in difficult to electrify sectors, and its pitfalls and potential. The Marketplace broadcast portfolio is heard by more than 14 million unique listeners each week on more than 800 public radio stations nationwide.

- Guest speaker on S&P Global's ESG Insider podcast discussing the hydrogen opportunity in the U.S. and globally.

- Quoted in a number of major news outlet in relation to hydrogen:
    - "The new fuel to come from Saudi Arabia", BBC News, https://www.bbc.com/future/article/20201112-the-green-hydrogen-revolution-in-renewable-energy
    - "Green Hydrogen Backers See Opening in Biden Climate Ambition, Bloomberg, "https://news.bloomberglaw.com/daily-tax-report/green-hydrogen-backers-see-big-chance-for-sector-development?context=search&index=0
    - "California coalition aims to make hydrogen power cost-competitive by 2030", UtilityDive, https://www.utilitydive.com/news/california-coalition-aims-to-make-hydrogen-power-cost-competitive-by-2030/600239/

- “Green Hydrogen: Could It Be Key to a Carbon-Free Economy?”, Yale Environment 360, https://e360.yale.edu/features/green-hydrogen-could-it-be-key-to-a-carbon-free-economy
- “Hydrogen: 3 things to watch in 2021”, E&E News, https://www.eenews.net/stories/1063721655
- “Meet the 'hydrogen home': Is it key to a 100% clean grid?”, E&E News https://www.eenews.net/energywire/2020/12/21/stories/1063721161?utm_campaign=edition&utm_medium=email&utm_source=eenews%3Aenergywire
- “Utilities launch groundbreaking 'green' hydrogen-gas project”, E&E News https://www.eenews.net/stories/1063719323
- “Developer plans to build hydrogen plant that runs on waste in Southern California”, Utility Dive, https://www.utilitydive.com/news/developer-plans-to-build-hydrogen-plant-that-runs-on-waste-in-southern-cali/578381/