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Green Hydrogen for Power Generation in Puerto Rico: Do We Need It? Does It Make Sense?

Executive Summary

There has been a recent surge of interest in hydrogen as a fuel in Puerto Rico, as in the rest of the world. While hydrogen today is produced almost exclusively from fossil fuels, hydrogen produced from renewable energy sources ("green" hydrogen) has been promoted as a means to reduce greenhouse gas emissions in a variety of applications, from electricity production, to transportation to industrial processes. In Puerto Rico, hydrogen has been specifically proposed for power generation, but its application in other uses is also under investigation.

In this report, we evaluate possible applications for green hydrogen in Puerto Rico, focusing particularly on power generation, and find:

- It is not currently feasibly to burn 100% hydrogen in a power plant, so any construction of a dual-fuel hydrogen power plant would also lock in Puerto Rico to additional natural gas consumption for at least the next decade.
- Production of green hydrogen imposes significant land and water constraints. A future power plant that burned 100% hydrogen would require more than twice as much land as an equivalent amount of renewable energy and storage, and its water consumption would be greater than the estimated residential consumption of the municipality of Ceiba.
- A dual-fuel hydrogen power plant would generate power at above 23 cents/kWh, significantly higher than current power generation sources.
- Because of the high cost of the renewable energy required to produce hydrogen, we do not see Puerto Rico becoming a producer of green hydrogen for large-scale industrial applications or for aviation or shipping fuel.
- Although a possible advantage of hydrogen for power production is the ability to use it for seasonal storage, in the case of Puerto Rico, this is not a need in the near or mid-term and, in any case, would require further study of viability, desirability, impacts and implications. Modeling from CAMBIO has shown that Puerto Rico could achieve 75% renewable energy without considering hydrogen or other long-term storage technologies.

We conclude that investment in green hydrogen for power production is not a solution that makes sense for Puerto Rico in the near or mid-term. Over the next couple of decades, Puerto Rico could make significant strides in decarbonizing its electricity and transportation sectors – and in

achieving a resilient and affordable electrical system – by focusing on the widespread deployment of rooftop solar and storage.

Introduction

The possibility of using hydrogen as an energy source has recently started receiving more attention in Puerto Rico, as in many other parts of the world. Hydrogen can be produced from different sources, including both fossil fuels and renewable energy, and it has multiple possible applications in power generation, energy storage, transportation and industrial processes.

In March 2022, Governor Pedro Pierluisi issued Executive Order 2022-022 (EO 2022-022), announcing that it is the public policy of his administration to adopt hydrogen as a renewable energy source, stating also that the production of hydrogen should be "consistent" with Law 17-2019, the island's Energy Public Policy Act and Law 33-2019, Puerto Rico's Climate Change Mitigation, Adaptation and Resiliency Act. (These laws call for 20% of the island's electricity to be generated from renewable sources by 2022, 40% by 2025, 60% by 2040 and 100% by 2050. As such, any hydrogen production for electricity generation would have to be produced from renewable energy sources by 2050 at the latest, to comply with Law 17-2019 and Law 33-2019). EO 2022-022 mandates all agencies that are involved in implementing or overseeing the implementation of energy policy to consider hydrogen as a renewable energy source.[1] The Executive Order appears to leave the door open for hydrogen produced by natural gas or other non-renewable sources and used for transportation or industrial purposes to be considered as "renewable energy."[2]

Responding to this Executive Order, the island's energy regulator, the Puerto Rico Energy Bureau, initiated a proceeding to "identify the potential role for hydrogen as a source of renewable energy in Puerto Rico," "identify the potential challenges in the implementation of hydrogen as a power source," and "establish a hydrogen roadmap that includes public policy and partnerships to advance the implementation initiatives."[3] As of spring 2023, this proceeding is currently underway, with a series of technical workshops scheduled for these topics.

Additionally, in August 2022, the Energy Bureau issued an order calling for a request for proposals for a new, 300 MW combined cycle natural gas plant. The order specified that the plant should be dual-fuel, capable of burning hydrogen, which should be "green" hydrogen (i.e. hydrogen

[1] Orden Ejecutiva, OE-2022-022, March 24, 2022.
[2] "Como política pública de esta Administración en materia de diversificación energética se adopta la combustión de hidrogeno como fuente de energia renovable en Puerto Rico."
[3] Puerto Rico Energy Bureau, Resolution and Order, Case No. NEPR-MI-2022-0006, December 21, 2022.

derived from renewable energy sources) by 2050.[4] The request for qualifications for this project was issued on March 1, 2023.[5]

In January 2023, the Puerto Rico Public-Private Partnerships Authority signed a ten-year contract with Genera PR to operate and maintain the Puerto Rico Electric Power Authority (PREPA)'s generating assets, as part of the ongoing privatization of PREPA.[6] The parent company of Genera is New Fortress Energy, a natural gas supply company. Currently the vast majority of the world's hydrogen is produced from steam reforming of methane (natural gas), and many companies in the natural gas industry see hydrogen as an opportunity to expand their business model. New Fortress Energy is no exception.[7] The expanded role of New Fortress Energy in Puerto Rico's electrical system could lead to a greater industry push for hydrogen on the island.

This push for hydrogen comes at a moment when the direction of the island's electrical system continues to be highly contested. Although the island's energy public policy clearly establishes renewable energy benchmarks, Puerto Rico has already missed the first benchmark (20% by 2022) and it is evident that the second of these benchmarks (40% by 2025) will not be met either. At the same time the government continues to award contracts, such as the Genera contract, that are not consistent with the renewable energy goals. Additionally, there is a lack of consensus at state and federal government policy level over whether the future of the grid should be decentralized, i.e. based on rooftop solar and storage, or centralized, based on large-scale solar and wind installations. Recent modeling developed by CAMBIO has shown the technical viability of a decentralized renewable energy future for the island, as well as the advantages that this would provide in adapting to higher penetrations of electric vehicles.[8]

This report explores the role for hydrogen in Puerto Rico in the context of these debates, first providing background on hydrogen production and uses and then evaluating the implications for Puerto Rico of different hydrogen applications being discussed worldwide. We focus particularly on the impacts of hydrogen for electricity generation and storage, which is the proposal currently being considered by government.

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[4] Puerto Rico Energy Bureau, Resolution and Order, Case No. NEPR-MI-2021-0003, August 3, 2022..

[5] Puerto Rico Public-Private Partnerships Authority, Request for Qualifications: LNG to H2 Combined Cycle Generation Plant, March 1, 2023.

[6] Puerto Rico Thermal Generation Facilities Operation and Maintenance Agreement, January 24, 2023.

[7] "We are also making investments to develop green hydrogen energy technologies as part of our long-term goal to become one of the world's leading providers of carbon-free energy. In October 2020, we announced our intention to partner with Long Ridge Energy Terminal and GE Gas Power to transition a power plant to be capable of burning 100% green hydrogen over the next decade, and we made our first hydrogen-related investment in H2Pro, an Israel-based company developing a novel, efficient, and low-cost green hydrogen production technology." (New Fortress Energy, 2021 10-K).

[8] See https://cambiopr.org/solmastechos/.

Background: Production and uses of hydrogen

Because elemental hydrogen is not available, hydrogen must be produced from other energy sources, either fossil fuel-based or renewable. Hydrogen is often categorized according to the following color scheme, which is based on the fuel and technology used to produce it:

- "Gray" hydrogen: hydrogen produced from natural gas via steam reformation.
- "Blue" hydrogen: hydrogen produced from natural gas via steam reformation, in which the carbon emissions from this process are captured and stored underground. Recent analysis of the lifecycle greenhouse gas emissions of blue hydrogen, taking into account both the methane leakage during natural gas production and the energy needed to capture the carbon, shows that the greenhouse gas emissions from blue hydrogen are actually higher than direct combustion of natural gas.[9]
- "Green" hydrogen: hydrogen produced via electrolysis of water, with the energy for electrolysis provided from renewable energy sources.
- Additional categories include: black hydrogen (hydrogen produced via gasification of coal), turquoise hydrogen (hydrogen produced from natural gas via pyrolysis), and pink hydrogen (hydrogen produced from nuclear energy via electrolysis).[10]

According to the International Energy Agency, less than 1% of the world's hydrogen is blue or green.[11] The vast majority is produced from natural gas or coal without capturing the carbon.

Irrespective of how it is produced, it is important to note that hydrogen itself has an impact on climate change by extending the atmospheric lifetime of other greenhouse gases. Hydrogen emissions are estimated to have a hundred-times greater warming impact than carbon dioxide over ten years. [12] Although hydrogen emissions are not currently significant, the potential for leakage during the hydrogen lifecycle (for example, in production, pipeline transportation and storage) would need to be taken into account as hydrogen production is scaled up.

Hydrogen is currently being promoted for the possible applications of blue and green hydrogen in decarbonizing the global energy system (despite the scientific findings noted above demonstrating the lack of the emissions reductions associated with blue hydrogen). The idea is to produce hydrogen as a zero-emissions fuel that can then be used to decarbonize applications which currently depend on fossil fuels and would be difficult or impossible to convert directly to renewable electricity. These applications include:

[9] Howarth and Jacobson, How green is blue hydrogen?, Energy Science & Engineering, August 2021.
[10] National Grid, The hydrogen color spectrum, https://www.nationalgrid.com/stories/energy-explained/hydrogen-colour-spectrum
[11] International Energy Agency, Global Hydrogen Review 2022, September 2022 (hereafter, IEA 2022).
[12] Z. Fan et al, "Hydrogen Leakage: A potential risk for the hydrogen economy," Columbia University Center on Global Energy Policy, July 2022.

- Industrial applications: Hydrogen can be converted into ammonia which is a principal ingredient in fertilizers[13]; it is also used in oil refining, methanol production and steel production. The International Energy Agency finds that "ammonia and methanol production are two demand segments for which low-emission hydrogen offers the largest potential to substitute existing emissions-intensive industrial hydrogen production."[14] These two segments currently account for more than half of global hydrogen demand. It is important to keep in mind the negative environmental and health impacts associated with some of these industrial practices and to ensure that the interest in low-emission hydrogen is not used to extend undesirable practices thus preventing more sustainable alternatives from gaining traction.
- Land transportation fuel: Hydrogen can be used in fuel cells to power vehicles. This application could be particularly relevant for heavy vehicle fleets whose electrification would create greater strain on the electrical grid. Germany deployed the first hydrogen-fueled train in 2022, although the train runs on grey hydrogen.[15] Hydrogen-fueled buses and trucks accounted for more than 80% of the hydrogen demand in the transportation sector, with cars accounting for less than 20%. More than 85% of fuel cell buses are in China.[16]
- Aviation fuel: Hydrogen has been proposed as a substitute aviation fuel, but this is not yet commercially available.[17]
- Maritime fuel: Ammonia or methanol derived from hydrogen have been proposed as a substitute for bunker fuel in marine shipping applications, although neither is yet commercially available.[18, 19]
- Power generation and long-duration storage: Although using renewable electricity to produce hydrogen to produce electricity seems counterproductive, hydrogen could offer the possibility for long-duration storage in the electricity sector. A project under development in Utah, backed by a $504 million Department of Energy loan guarantee, aims to produce hydrogen from renewable energy that would otherwise be curtailed and store it in underground salt caverns. The hydrogen would be burned in a power plant (initially co-fired with natural gas) to supply electricity at other times of the year when

[13] Seventy percent of global ammonia production is used for fertilizer. (IEA 2022, p. 31)
[14] IEA 2022, p. 37.
[15] S. Barry, "Why the world's first hydrogen rail may not be as environmentally friendly as it seems," EuroNews, August 25, 2022.
[16] IEA 2022, p. 43.
[17] IEA 2022, p. 15.
[18] IEA 2022, p. 15.
[19] M. Gallucci, "Why the shipping industry is betting big on ammonia," IEEE Spectrum, February 2021.

renewable electricity production is lower.[20] However, the Utah project still faces uncertainties.[21]

As of 2021, the overwhelming majority of global hydrogen production is used for traditional industrial applications, including fertilizers, chemicals, steel and refining. Only 0.04% of hydrogen was used for other applications such as transportation and power generation.[22]

There are many initiatives globally to scale up green and blue hydrogen production. In the United States, for instance, the Bipartisan Infrastructure Bill allocated $8 billion to develop clean hydrogen hubs. Public-private partnerships are currently competing for this funding to build hubs that will link hydrogen production to end-use applications. Proposals submitted to DOE include green, blue and pink hydrogen.[23] Australia is aiming to develop a significant hydrogen export economy, and according to the International Energy Agency, is on track to be the world's largest hydrogen exporter by 2050.[24] In 2022, the first demonstration delivery of liquefied hydrogen was completed, from Australia to Japan (the hydrogen was produced from coal gasification).[25]

The International Renewable Energy Association (IRENA) has emphasized the importance of establishing priorities for green hydrogen use, given the investment and resource intensity of producing and transporting green hydrogen at the same time that renewable energy investment in general must be dramatically scaled up worldwide. IRENA proposes that green hydrogen be prioritized for industrial applications where no substitute to hydrogen exists (such as ammonia production), and in applications such as aviation fuel and maritime fuel, where no alternative carbon-free fuel has been commercially developed.[26]

Green hydrogen in Puerto Rico

The Energy Bureau's August 2022 order presents a concrete proposal for use of green hydrogen for power production in Puerto Rico, as it calls for a request for proposals for a new natural gas power plant that would be dual-fuel for hydrogen and would burn green hydrogen by 2050. In this section, we evaluate the economics and other impacts (land use, water consumption,

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[20] E. Howland, "DOE closes on $504M loan guarantee for Utah hydrogen storage project with 150 GWh seasonal capacity," Utility Dive, June 9, 2022.
[21] R. Sammy, "This Tiny Utah Town Could Shape the West's Energy Future," LA Times, May 19, 2022.
[22] IEA 2022, p. 19.
[23] Press release: "California Launches Statewide Alliance to Establish Federally Co-Funded Hydrogen Hub," October 6, 2022; "Appalachian Regional Clean Hydrogen Hub Encouraged to Submit a Full Application for the Department of Energy's Hydrogen Hub Funding," BusinessWire, January 12, 2023; "Great Lakes Clean Hydrogen Coalition Encouraged to Submit Full Application by U.S. Department of Energy," Energy Harbor, January 13, 2023.
[24] B. How, "Australia to be world's largest hydrogen exporter by 2050: IEA", InnovationAus, October 28, 2022.
[25] S&P Global, "Japan's Suiso Frontier in Australia to load first liquefied hydrogen cargo", January 20, 2022.
[26] International Renewable Energy Agency, "Green Hydrogen for Industry: A Guide to Policy Making,"2022.

emissions) of hydrogen for power production and then evaluate other possible applications for hydrogen in Puerto Rico.

i. Economics of hydrogen for power production

Current power plant technology does not allow 100% combustion of hydrogen; hydrogen is instead blended with natural gas. According to gas turbine manufacturers GE and Mitsubishi, hydrogen can be co-fired up to 20% by volume without turbine modifications.[27] Thus, it is important to emphasize that a new power plant capable of burning hydrogen will, for at least the next decade, also lock Puerto Rico into burning more natural gas.

We assume a new 300 MW combined cycle power plant that co-fires hydrogen and natural gas at a 20/80 ratio, and then is converted to 100% hydrogen by 2040.[28] The hydrogen is assumed to be produced at the power plant site, to avoid the safety risks involved in transporting hydrogen by pipeline or truck across the island. To produce green hydrogen, the power is assumed to be purchased via power purchase agreement from a solar farm and wheeled across the utility transmission and distribution lines. The cost of purchasing this electricity is based on existing power purchase agreements signed in Puerto Rico, plus the cost of using the existing grid infrastructure, based on Puerto Rico's existing wheeling tariff.[29] Natural gas costs are based on the current cost structure in the contract with New Fortress Energy for the supply of natural gas to the San Juan power plant.[30] Table 1 summarizes the scenario and key financial assumptions.

[27] Mitsubishi Power, Hydrogen Power Generation Handbook, 2021; GE, "Press release: Long Ridge Energy Terminal and GE Commission & Demonstrate First Advanced Class Hydrogen-Burning Power Plant Worldwide Using GE HA Gas Turbine," April 22, 2022.

[28] See Northern Indiana Public Service Company 2021 Integrated Resource Plan for estimated cost of converting a combustion turbine to 100% hydrogen.

[29] Recently signed power purchase agreements for solar farms have prices starting at approximately 9.2 cents/kWh and escalating at 2% per year (see for example, Power Purchase and Operating Agreement between Puerto Rico Electric Power Authority and Clean Flexible Energy LLC, August 26, 2022). Wheeling regulations in Puerto Rico establish the wheeling tariff to be equal to the non-fuel and purchased power component of the existing tariff, or approximately 8 cents/kWh (Puerto Rico Energy Bureau, Resolution and Order, Case No. NEPR-AP-2018-0004, March 24, 2022). It is assumed that Puerto Rico is eligible for the hydrogen production tax credit of $3/kg established in the Inflation Reduction Act.

[30] This contract bases pricing on 115% of the Henry Hub price, plus an adder. The Henry Hub price forecast was obtained from the Energy Information Administration's 2022 Annual Energy Outlook.

Table 1. Scenario and Key Financial Assumptions

Combined cycle power plant size, MW	300		First-year cost (cents/kWh) of renewable electricity	9.3
Power plant capacity factor	60%		First-year transmission and distribution costs, cents/kWh	7.9
Initial H2 co-firing (by volume)	20%		Electrolyzer cost, $/kW in 2025	$630
Year to convert to 100% hydrogen	2040		First-year cost ($/m3) of water	$2.96
Power plant capital cost, $/kW	$941		Green hydrogen tax credit, $/kg	$3.00
Power plant fixed operating cost, $/kW-year	$28		Annual inflation	2%
Power plant variable operating cost, $/MWh	$2		Weighted-average cost of capital	6.50%
Power plant heat rate, MMBTU/kWh	6.36			
First-year cost of natural gas, $/MMBTU	$10.27			

The resulting levelized cost of power generation from the new combined cycle power plant is above 23 cents/kWh.[31] Nearly 60% of this cost is the cost of supplying hydrogen to the plant. This levelized cost is significantly higher than current power generation costs in Puerto Rico. This is not surprising given that most analyses of hydrogen for power generation assume that the hydrogen can be produced via electricity that costs less than 5 cents per kWh.[32] The most recent contracts for large-scale renewable energy in Puerto Rico sell power at more than 9 cents per kWh, and when costs are added for wheeling that power over the transmission and distribution system, the delivered cost for electrolysis would be even higher.

Alternatively, to produce electricity from green hydrogen at lower cost, the hydrogen could be produced from renewable energy that would otherwise be curtailed. This would require producing the hydrogen at the renewable energy facility and then transporting it via pipeline or truck to be burned in a power plant. It would also mean that the electrolyzer utilization would be much lower, since renewable energy would only be available for hydrogen production in this scenario for a few percent of the hours in the year; this results in higher electrolyzer capacity

[31] The plant is assumed to operate at a 60% capacity factor, based on projections from PREPA's most recent Integrated Resource Plan. Assumptions for plant capital costs, fixed and variable operating costs, and heat rate were taken from the National Renewable Energy Laboratory's 2022 Annual Technology Baseline. Electrolyzer capital costs were obtained from Lazard's 2021 Levelized Cost of Hydrogen Analysis.

[32] See, for example, Lazard's 2021 Levelized Cost of Hydrogen Analysis.

costs. We estimate that this scenario would result in a levelized cost of power at around 13 cents/kWh, not including the social costs and risks associated with hydrogen transport.

Importing green hydrogen could also, in theory, be a way to lower cost. There is a robust shipping industry for transporting ammonia, but not for hydrogen, with the first marine shipment of liquid hydrogen undertaken in 2022.[33] There is a significant energy penalty (30%) to cool and compress hydrogen to the point where it becomes liquid. The alternative is to convert hydrogen to ammonia, ship the ammonia, and re-convert the ammonia to hydrogen (which also carries a similar energy penalty, but the infrastructure for shipping ammonia is better-developed).[34] At this point it would be difficult to certify the provenance of the ammonia to ensure it is derived from green hydrogen and not blue, grey or some other form. Furthermore, an important benefit in moving to renewables on the island is to reduce dependency on fuel imports. Importing hydrogen, even if it is green hydrogen, would just create a new fuel dependency that would keep us susceptible to external market cost fluctuations. Thus, we do not see importing hydrogen to Puerto Rico as likely to be a feasible option.

ii. Other impacts of hydrogen for power production

In addition to the high cost, use of green hydrogen for power production would have impacts on land use, water consumption and air emissions.

Significantly more land is required to produce renewable energy and convert it to hydrogen for power production than to use the renewable energy directly. Specifically, we found that twice as much solar capacity - and hence twice as much land - would be required to produce hydrogen for power production from a combined cycle power plant (fired at 100% hydrogen) than for an equivalently sized renewable energy plus battery storage facility.[35] Given Puerto Rico's island context and limited available land, renewable energy deployment should avoid competing land uses with agricultural development/food security and ecological and natural preservation. In this context green hydrogen's requirement for additional large scale renewable energy and thus additional land, should be an important constraint.

In terms of water consumption, we found that a 300 MW power plant consuming 100% hydrogen (after 2040) would require over 390 million gallons of water per year. (Currently hydrogen is produced from fresh water; desalinization of seawater would add a significant cost that was not included in our analysis). The Puerto Rico Aqueduct and Sewer Authority estimates that each person on the island consumes 85 gallons of water per day.[36] Thus, the water requirement for the

[33] Australia Department of Climate Change, Energy, the Environment and Water, "World's first liquid hydrogen shipment to set sail for Japan", January 21, 2022.
[34] R. Service, "Ammonia – a renewable fuel made from sun, air and water – could power the globe without carbon," Science, July 2018.
[35] This calculation takes into consideration the roundtrip efficiency of the battery storage as well.
[36] https://www.recursosaguapuertorico.com/aaa.html

300 MW hydrogen power plant represent the water use of about 12,600 residents, more than the estimated residential water use for the entire municipality of Ceiba.

Finally, it is important to note that hydrogen combustion, because it occurs at such high temperatures, also leads to significant production of oxides of nitrogen (NOx), a local air pollutant. Specifically, according to the National Energy Technology Laboratory, hydrogen combustion would result in up to eight times more NOx emissions than natural gas without any emissions controls.[37] A recent test of blending 35% hydrogen with natural gas in a combustion turbine in New York resulted in higher NOx emissions, but still within permitted levels, with existing control technology.[38] However, the technology for low NOx emissions at high blends of hydrogen, or 100% hydrogen, is still under development and may be up to twenty years away.[39]

Although, as mentioned earlier, a possible advantage of hydrogen for power production is the ability to use it for seasonal storage, as in the Utah project described in Section II, above, it is important to note that modeling studies have shown the feasibility of achieving 75% renewable energy in Puerto Rico without needing hydrogen or other seasonal storage technologies.[40] Therefore, considering hydrogen for seasonal storage is not something that is needed in the near or mid-term and in any case would require further study of viability, desirability, impacts and implications. Thus, there no requirement for near-term investment in hydrogen (and natural gas) for power generation.

iii. Other possible applications for hydrogen

As discussed in Section II above, other possible applications for green hydrogen include as a fuel for ground-based, air and marine transportation and in industrial applications. Puerto Rico is not currently a producer of air and marine transportation fuels and, given the high cost of electricity on the island relative to other U.S. jurisdictions, it would not be a cost-competitive place to manufacturer green hydrogen for those industries. Similarly, none of the industrial processes that are major consumers of hydrogen (ammonia production, methanol production, steel production or oil refining) currently exist in Puerto Rico, nor should Puerto Rico consider establishing such production facilities using green hydrogen, as costs would not be competitive and, as noted earlier, such production processes pose significant health and environmental impacts that would only represent added burdens for frontline communities.

For decarbonization of ground transportation, Puerto Rico is moving in the direction of electric vehicle integration. Over the next five years, the island will receive more than $13.6 million of federal funds, of which it has already received $4.9 million, to implement a plan to establish 15

[37] National Energy Technology Laboratory, "A literature review of hydrogen and natural gas turbines", August 2022.
[38] Electric Power Research Institute, "Hydrogen Cofiring Demonstration at New York Power Authority's Brentwood Site: GE LM6000 Gas Turbine," 2022, p. 7.
[39] National Energy Technology Laboratory, "A literature review of hydrogen and natural gas turbines", August 2022.
[40] https://cambiopr.org/solmastechos/

public charging stations around the island.[41] Grid operator LUMA Energy projects that Puerto Rico will achieve 38% electric vehicle penetration in twenty years.[42] CAMBIO has published detailed grid modeling that shows that a decentralized electrical grid, with 75% rooftop solar and storage, can integrate higher penetrations of electric vehicles with less investment needed in the distribution system than the current centralized grid. As such, it would make little sense to develop a parallel charging infrastructure system for hydrogen vehicles when the transportation system can be decarbonized through electrification, with less impact on land and water resources.

Comparison with Distributed Solar

Puerto Rico has strong policy mandates for renewable energy: 20% by 2022, 40% by 2025, 60% by 2040 and 100% by 2050. CAMBIO has previously published grid modeling demonstrating the feasibility and advantages of undertaking this renewable energy transformation via investments in distributed rooftop solar and storage. Specifically, in 2021, CAMBIO published a viability study of achieving 75% rooftop solar and storage penetration within 15 years, including equipping all homes on the island with a small-scale solar and battery system for resiliency. Under this scenario[43]:

- Puerto Rico could achieve affordable and stable rates of 15 cents per kWh if available federal funds were used to implement this transformation, and 20 cents per kWh in the absence of federal funds.
- Puerto Rico would dramatically reduce its dependence on imported fossil fuels, achieving a fuel budget of $430 million a year (compared to $2,460 million in 2022[44]).
- No new fossil fuel-based power plants or conversion of existing plants to natural gas would be required. Certain existing fossil fuel-based plants, starting with the AES coal plant, could be retired.
- Electrical system carbon dioxide emissions would be reduced nearly 70%.
- Integration of electric vehicles could be achieved at far lower cost. Specifically, at 40% electric vehicle penetration, the grid investment required is ten times lower in the case of a decentralized grid versus the current centralized grid.[45]

Rooftop solar has already been rapidly growing in Puerto Rico, despite the lack of policy support (the only financial incentive is net metering). As of December 2022, more than 68,000 customers

[41] El Nuevo Dia, "El gobierno de Biden aprueba el plan de Puerto Rico para construir infraestructura de carga para vehículos eléctricos," 14 de septiembre de 2022; The White House, "President Biden's Bipartisan Infrastructure Law is Delivering in Puerto Rico," November 2022.
[42] LUMA Energy, "Draft Phase I Electric Vehicle Plan," Case No. NEPR-MI-2021-0013, September 1, 2022.
[43] https://cambiopr.org/solmastechos/
[44] Puerto Rico Electric Power Authority, Monthly Report to the Governing Board, December 2022.
[45] CAMBIO, "Estudio de integración de vehículos eléctricos en Puerto Rico," January 2023.

have gone solar, connecting more than 450 MW of rooftop solar to the grid. The number of customers with rooftop solar grew 69% in 2022 alone. Rooftop solar now contributes 3.7% of the island's electricity generation, as compared to 2.2% from utility-scale renewable energy.[46] Households that can afford to do so have been moving rapidly in the direction of rooftop solar and storage because of the resiliency it offers in the face of frequent grid outages and severe storms.

By comparison, as shown above, use of green hydrogen as a near-term power source in Puerto Rico would:

- Tie Puerto Rico to new investments in natural gas infrastructure, given that it is not currently feasible to burn 100% hydrogen without co-firing natural gas.
- Perpetuate a centralized generation system, which does not provide the resiliency benefits from generating power close to where it is consumed.
- Result in greater usage of scarce land and water resources for hydrogen production. Conversion to 100% hydrogen power generation would require approximately twice as much land than an equivalent amount of renewable energy and storage.
- Result in significantly higher power generation costs than a scenario with high penetration of rooftop solar and storage.

Conclusion

Investment in green hydrogen for power production is not a solution that makes sense for Puerto Rico in the near or mid-term. As this report has shown, production of hydrogen from electrolysis for power generation would result in a high-cost source of power generation, greater consumption of scarce land and water resources, and greater dependence on natural gas. Hydrogen's potential value for long-term grid-scale storage is not something that is needed in the near or mid-term (at least until significantly higher penetrations of renewable energy (greater than 75%) are achieved) and in any case would require further study of viability, desirability, impacts and implications.

In general, hydrogen's role as an energy carrier appears most suitable to those applications which are the most difficult to decarbonize, and the global investment in hydrogen infrastructure will be most effective from a climate change perspective if it is directed to those ends. These applications include industrial processes, maritime shipping and aviation fuel. Given that these industries are not currently active in Puerto Rico and given the high cost of renewable energy to

[46] Puerto Rico Electric Power Authority, Monthly Report to the Governing Board, December 2022; LUMA Energy, "Motion submitting interconnections progress report for October through December 2022 and presentation for next compliance hearing: Annex 1," Puerto Rico Energy Bureau Case No. NEPR-MI-2019-0016, January 13, 2023.

produce green hydrogen in Puerto Rico, it seems unlikely that Puerto Rico will end up contributing to these solutions.

As has been the case in many other instances related to energy sector transformation on the island, it appears that government's interest in green hydrogen is not the product of objective evaluation. Given the increased role of private energy sector players with a stake in the natural gas and hydrogen market, such as New Fortress and Genera, the hydrogen attention seems to be guided by intentions to favor and accommodate such interests and not necessarily to provide benefit to the people of Puerto Rico. It thus important to ensure that hydrogen does not become the new excuse or cause for additional delay in Puerto Rico's urgent need to transition to a decentralized solar-based renewable grid or an avenue to channel public funds for private sector profits.

Decentralized rooftop solar and storage should be prioritized as the near-term solution for accelerating Puerto Rico's renewable energy transition. Decentralized rooftop solar and storage already supplies more of Puerto Rico's electricity needs than centralized renewable energy, without any financial incentive beyond net metering. Detailed grid modeling has shown the technical feasibility, resiliency benefits and cost reductions achievable from rapid deployment of grid-connected rooftop solar and storage (achieving 75% penetration in 15 years), as well as its potential to contribute to higher electric vehicle deployment. Rooftop solar and storage is a solution better suited to meeting Puerto Rico's resiliency needs, at lower cost and resource consumption, than investment in green hydrogen.