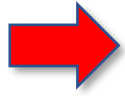




Puerto Rico Energy Bureau
Puerto Rico Hydrogen Strategy Workshop 1
February 7, 2023

Brad Bradshaw
Steven Thomas
Charlie Krueger
Velerity LLC

Agenda



Hydrogen Strategy Initiative

Hydrogen Drivers

Hydrogen Projects

Puerto Rico Economic and Energy Situation

Hydrogen Introduction

Puerto Rico Assets Relative to Hydrogen Production

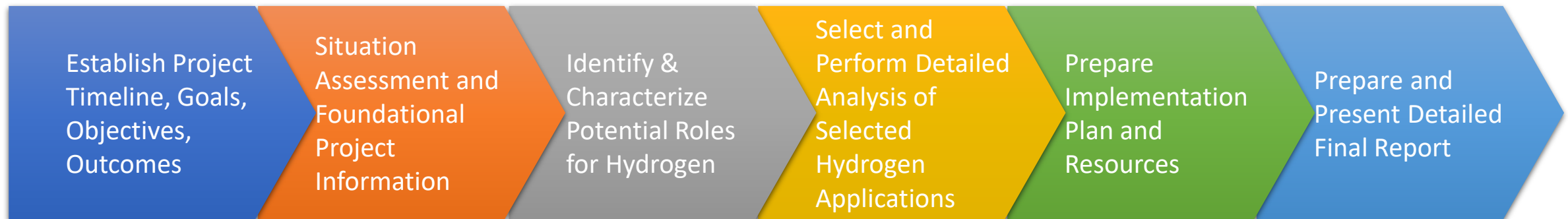
Puerto Rico Hydrogen Strategy - Background

- ▶ The governor of Puerto Rico, on March 24, 2022, signed executive order OE-2022-022 “for the purposes of recognizing the combustion of hydrogen as a source of renewable energy in Puerto Rico”. Key reasons identified include:
 - Building a more resilient energy system;
 - Contribute to building an economy built on renewable energy;
 - Addressing the impacts of hurricanes Maria and Irma;
 - Contributing to strengthening long term energy security;
 - Reduce emission that contribute to climate change;
 - Improve electric system reliability; and
 - Facilitate distributed generation and renewable energy integration.
- ▶ The Puerto Rico Energy Bureau initiated a study in the Summer of 2022 to develop Puerto Rico’s hydrogen study

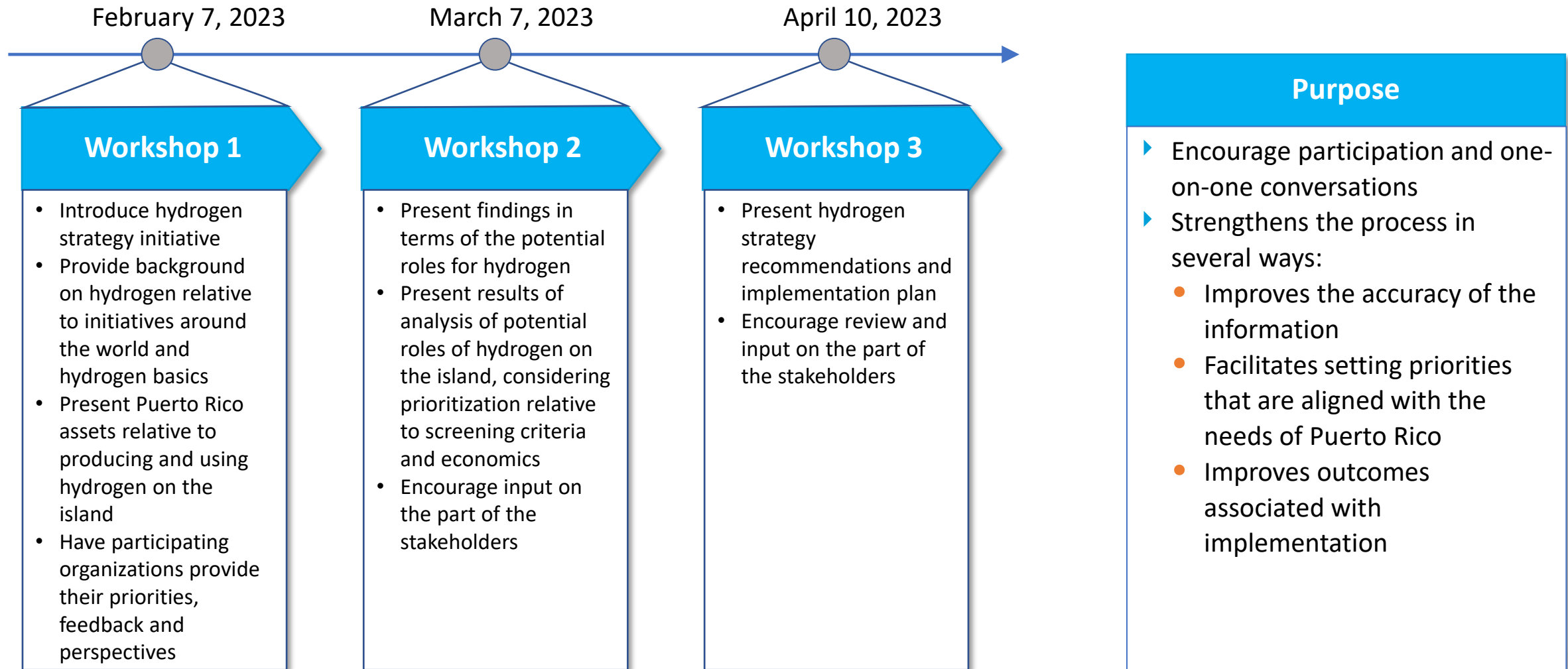
Puerto Rico Hydrogen Strategy – Scope and Process

► Scope and Process

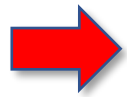
- Establishing a firm understanding of Puerto Rico’s current and future energy system;
- Understanding the important economic and social objectives associated with public initiatives and investments in Puerto Rico;
- Identifying, characterizing and prioritizing potential hydrogen initiatives and investments relative to advancing public good and welfare; and
- Establishing a hydrogen roadmap that includes public policy and private partnerships to advance the highest value initiatives to building a more robust, reliable, safe, lower carbon and lower cost energy system.



Stakeholder Process for the Puerto Rico Hydrogen Initiative



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Trends creating needs for new solutions and innovation

Carbon Emissions and Decarbonization

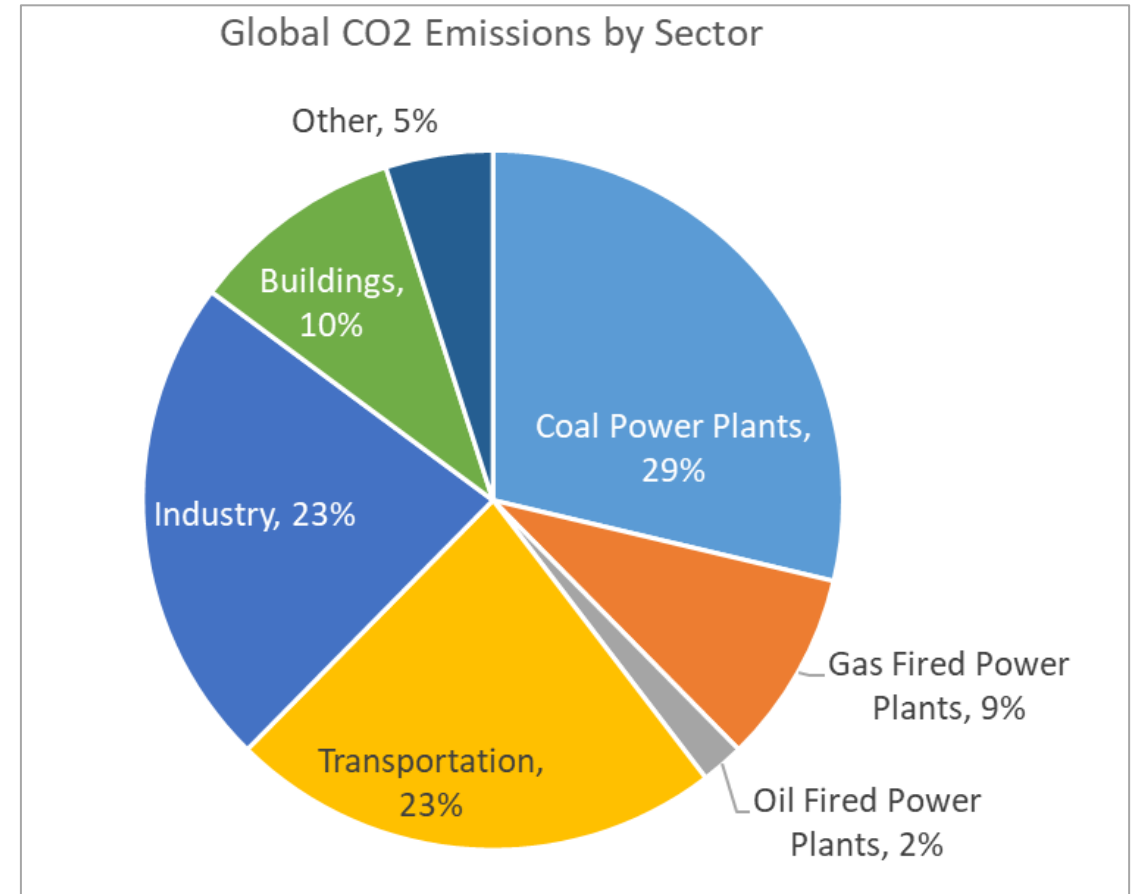
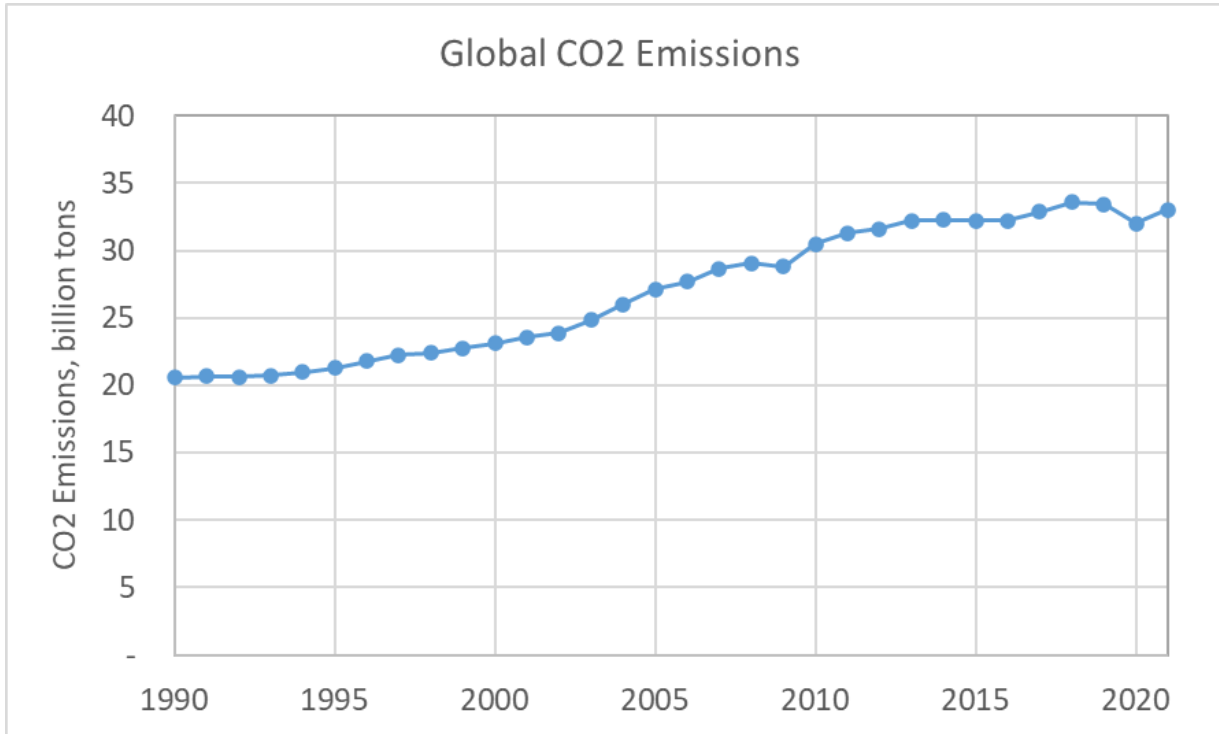
Declining Costs for Renewable Energy

High Penetration Variable Renewable Energy

Resilience

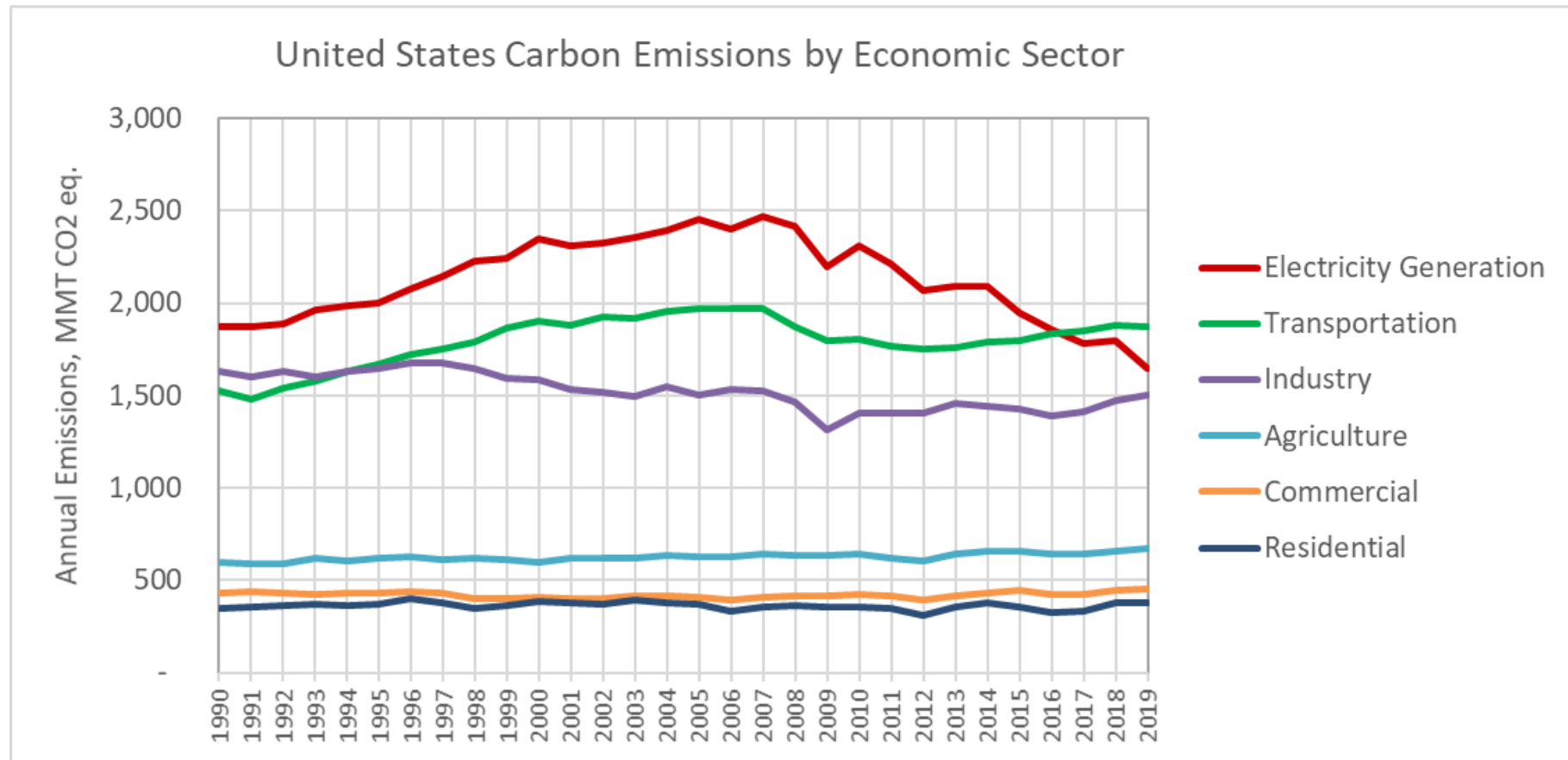
Need for Long Duration Storage

Efforts are increasing around the world to reduce carbon emissions in all economic sectors



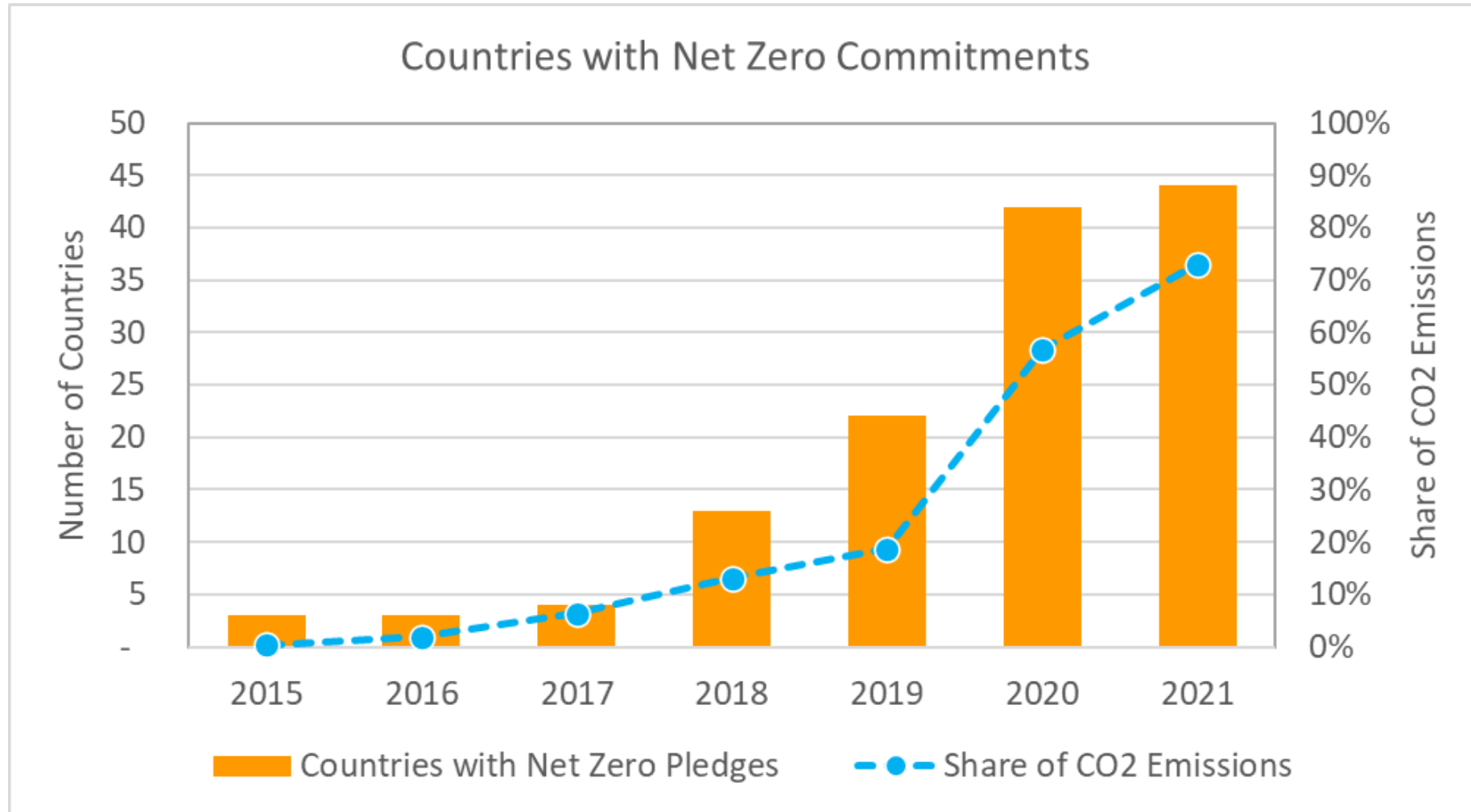
Source: IEA

Electric sector emissions have gone down while transportation emissions are increasing



Source: Environmental Protection Agency, U.S. Greenhouse Gas Inventory Data Explorer (cfpub.epa.gov/ghgdata/inventoryexplorer/index.html)

The number of countries making 2050 net zero commitments continues to increase, representing a significant share of global emissions



Source IEA

Broad initiatives are underway around the globe to drive down carbon emissions – with certain challenges emerging

Carbon reduction initiatives underway across the globe

- ▶ Renewable Portfolio Standards driving renewable energy to decarbonize electric grids
- ▶ Expanding onshore and offshore wind energy deployments
- ▶ Expanding solar photovoltaic
- ▶ Electrification of passenger vehicles
- ▶ Accelerating heat pump deployments for domestic hot water and heat

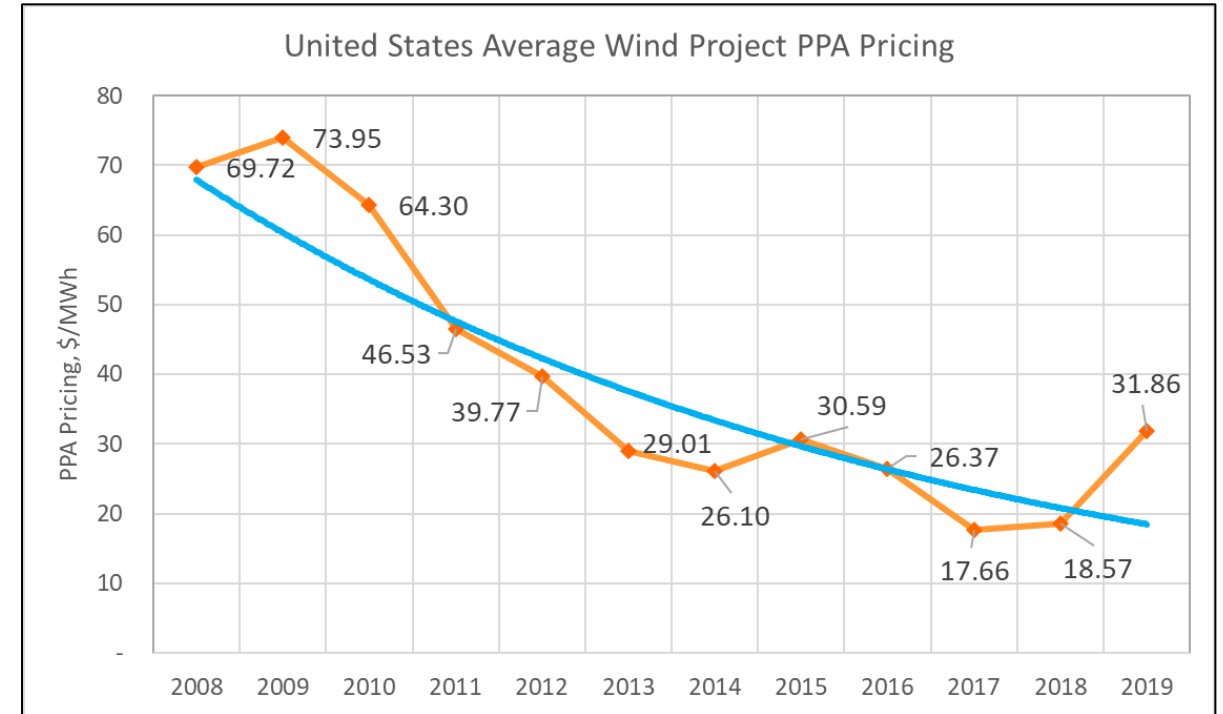
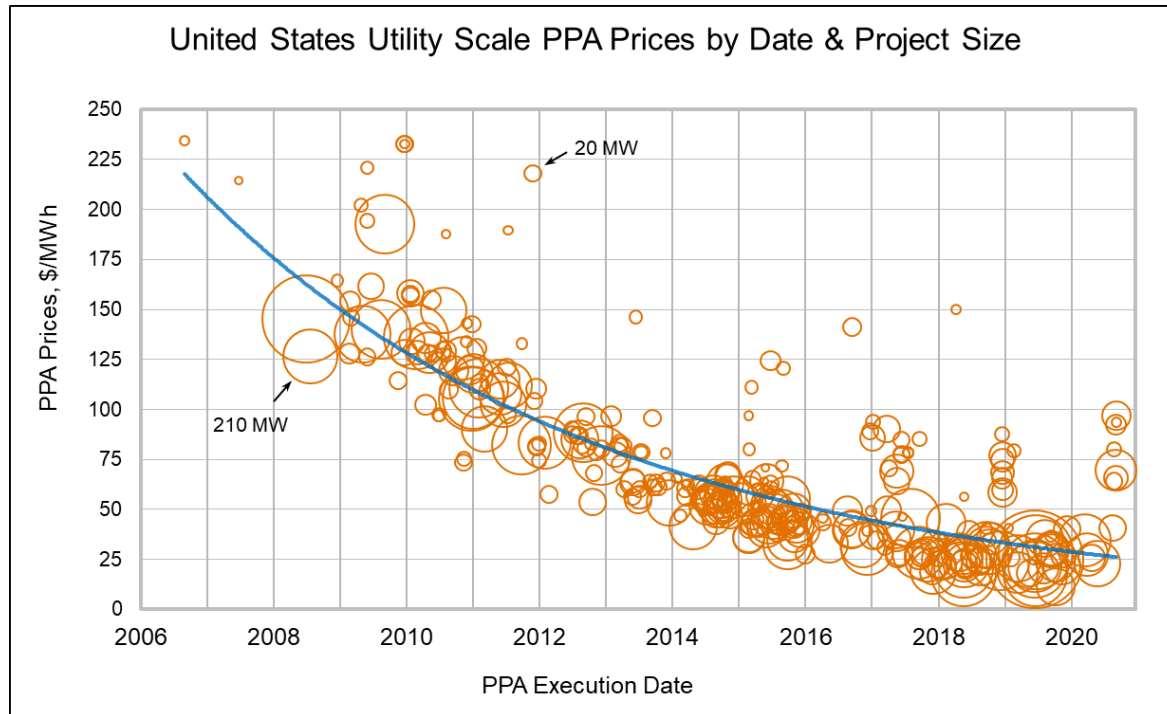
Areas with decarbonization or electrification challenges

- ▶ Heavy road vehicles including trucks, buses and other municipal vehicles
- ▶ Trains
- ▶ Very large marine vessels
- ▶ Aircraft
- ▶ Cement production
- ▶ Steel production
- ▶ Chemical processes

Key factors driving greater interest and investment in hydrogen

1. **Low-Cost Renewable Energy** - Low-cost renewable energy has reduced the cost of green hydrogen to be reasonably economic in specific applications
2. **High Levels of Renewable Energy** – Grids with an abundance of renewable energy are creating massive quantities of near zero cost electricity as well as expanding RE curtailment creating opportunities for capturing those electrons and generating competitively priced hydrogen
3. **Economic Incentives** – Production tax credits, government grants and carbon credits all contribute to narrowing economic gaps to potentially generate positive IRRs for hydrogen projects
4. **Demand** – The combination of government regulation requiring decarbonization and all manner of customers looking up the supply chain demanding lower carbon solutions are creating demand for hydrogen and hydrogen derivatives
5. **Innovation** – Innovations in technology are lowering electrolyzer capital costs, improving conversion efficiencies, while business model innovations are driving up integrated project scales and driving down hydrogen production unit costs, while innovations in integrated solar, wind, grid and storage combinations are enabling higher capital utilization factors
6. **Decarbonization** – Hard to abate applications and sectors

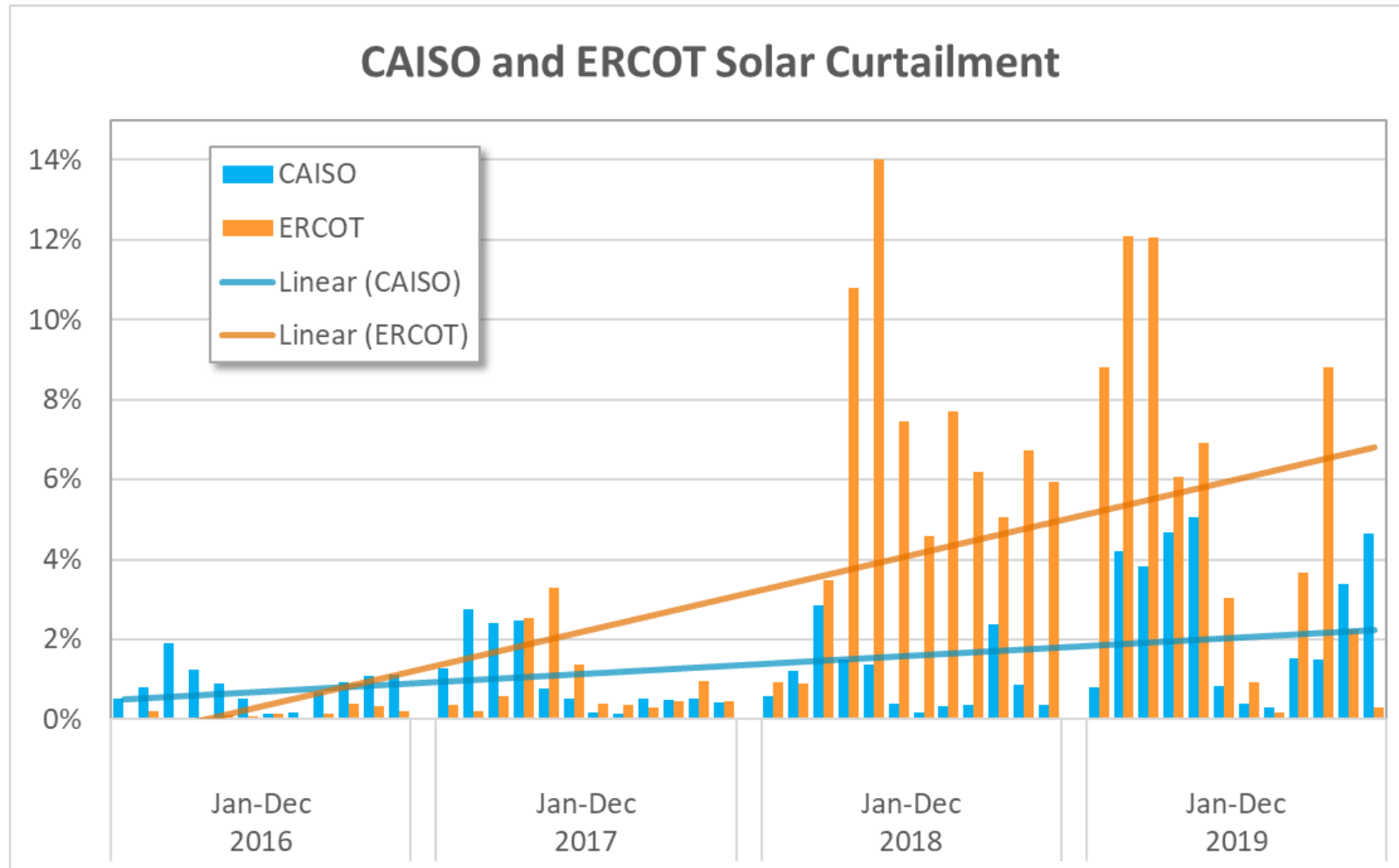
A fundamental driver creating an opportunity for hydrogen is the extraordinary drop in PPA prices for both solar and wind



Source SEIA



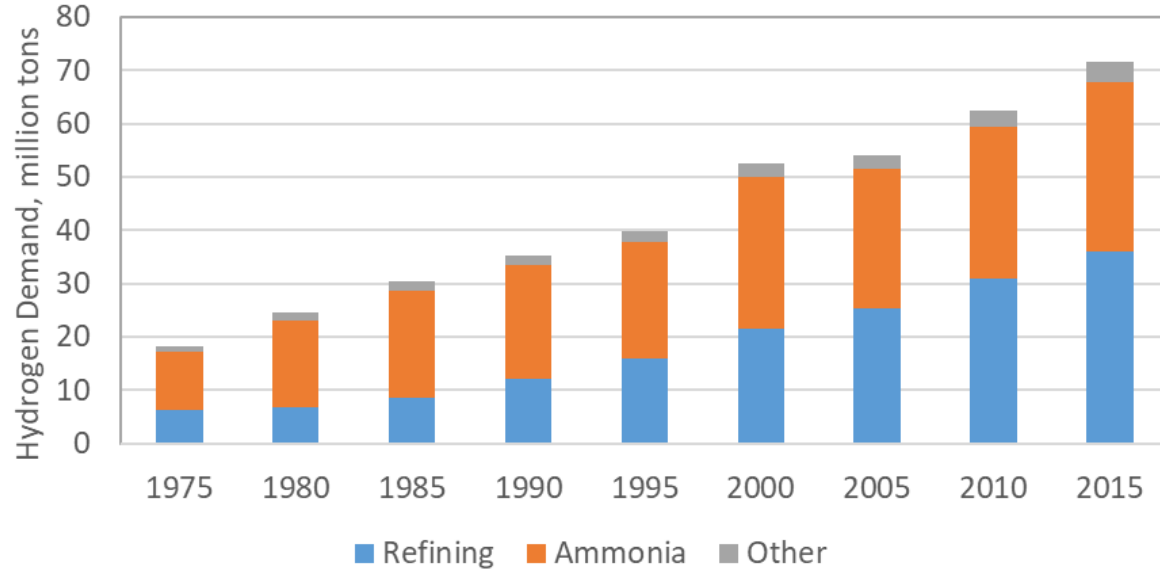
The issue of growing curtailment is impacting RE project economics and creating an opportunity for electrolytic hydrogen production



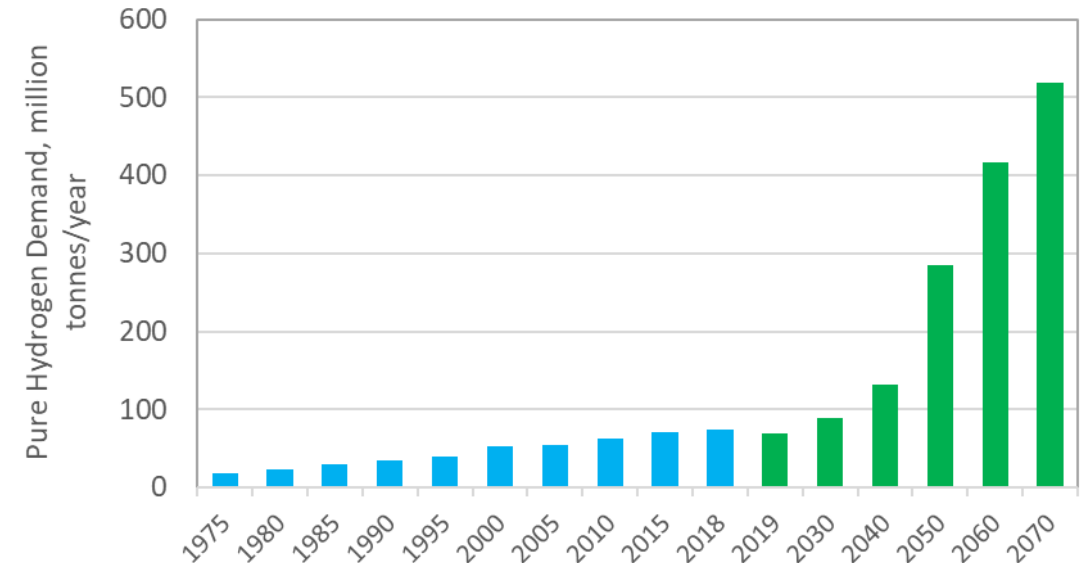
Source CAISO and ERCOT

Global demand for hydrogen is approximately 80 million tons per year now, and is expected to grow to 300 million tons per year by 2050

Current Demand for Hydrogen



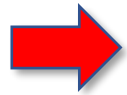
Global Pure Hydrogen Demand



Source IEA



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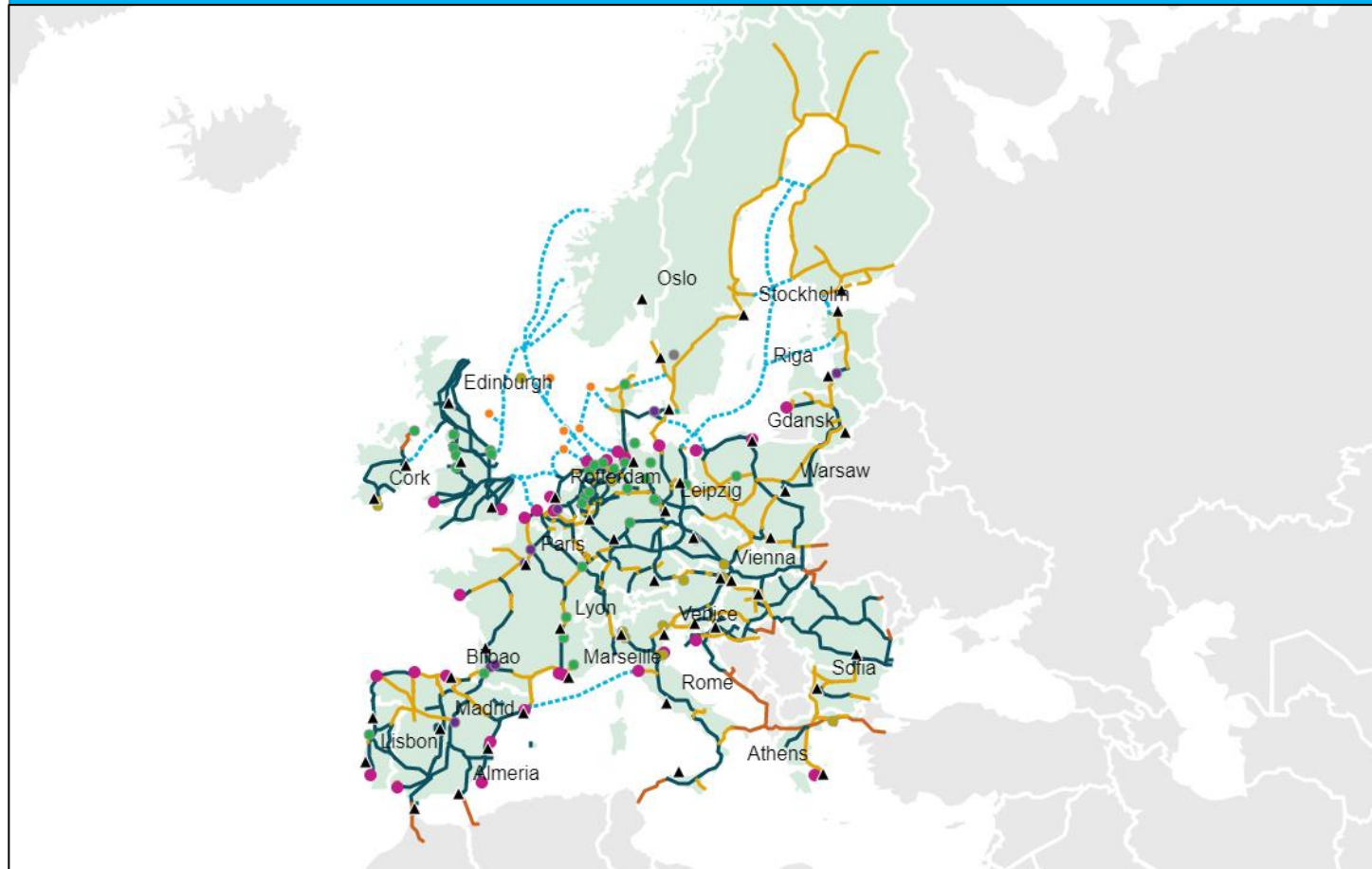
Puerto Rico Economic and Energy Situation

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Puerto Rico Assets Relative to Hydrogen Production

Europe is building out 40,000 kilometers of hydrogen pipelines by 2040, including converting natural gas lines and building out new

Europe's Proposed Hydrogen Pipelines



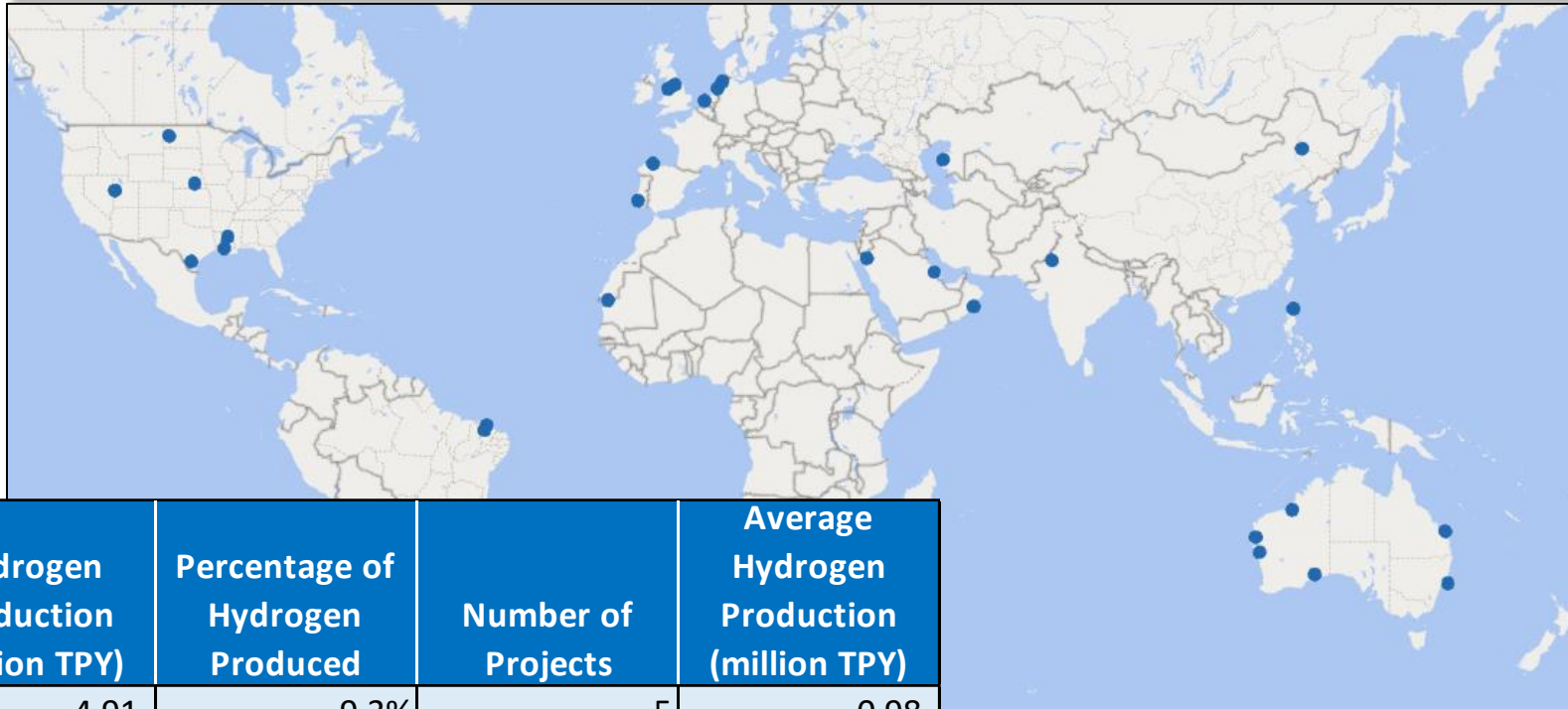
An estimated 52 projects have been announced regarding the use of hydrogen to reduce carbon emissions of steelmaking

Steelmaking Facilities with Hydrogen Ambitions



Thirty largest Hydrogen Hub projects around the world

30 Largest Announced Hydrogen Hubs



Source	Hydrogen Production (million TPY)	Percentage of Hydrogen Produced	Number of Projects	Average Hydrogen Production (million TPY)
Natural Gas	4.91	9.3%	5	0.98
Petroleum	1.00	1.9%	1	1.00
Renewable Energy	46.79	88.8%	24	1.95
Total	52.69	100.0%	30	1.76

Project Example: Asia Renewable Energy Hub

A \$36 billion investment in Northwestern Australia

Asia Renewable Energy Hub

- ▶ Project will be developed in multiple phases up to 26 GW of combined solar and wind power capacity – the equivalent of producing over 90 terawatt hours per year, which is around a third of all electricity generated in Australia in 2020.
- ▶ Will produce around 1.6 million tons of hydrogen or 9 million tons of green ammonia, per year.
- ▶ Will abate around 17 million ton of carbon in domestic and export markets annually, which would equate to roughly 0.5 gigatons (Gt) of carbon savings over the lifetime of the project.

Asia Renewable Energy Hub		
Investors		
BP	40.50%	
Intercontinental Energy	26.40%	
CWP Global	17.80%	
Macquarie Capital	15.30%	
Footprint		
	6,500	square miles
Wind & Solar	26	MW
Electrolyzer	14	MW
Hydrogen	2.4	million TPY
Ammonia	9	million TPY
Capital Requirements	\$36	billion

Long duration (seasonal) energy storage with hydrogen – the \$1.9 billion Intermountain Power Project in Delta, Utah

- ▶ 840m MW natural gas combined cycle power plant
- ▶ 68% capacity factor
- ▶ Hydrogen ready turbine
- ▶ Commission date July 1, 2025
- ▶ Two salt caverns with 300 GWh of hydrogen energy storage
- ▶ 100% hydrogen in 2040



Heavy Vehicle Example: Hyzon Motors deployment in New Zealand

- ▶ Hiringa, New Zealand
 - 1,500 trucks over 5 years
 - GVW 58 tonnes
 - Range 260 kilometers
 - Manufacture Netherlands
 - Hiringa to build out fueling stations
 - 8 by 2022
 - 24 by 2025
 - 95% market coverage in New Zealand
 - 100 stations by 2030



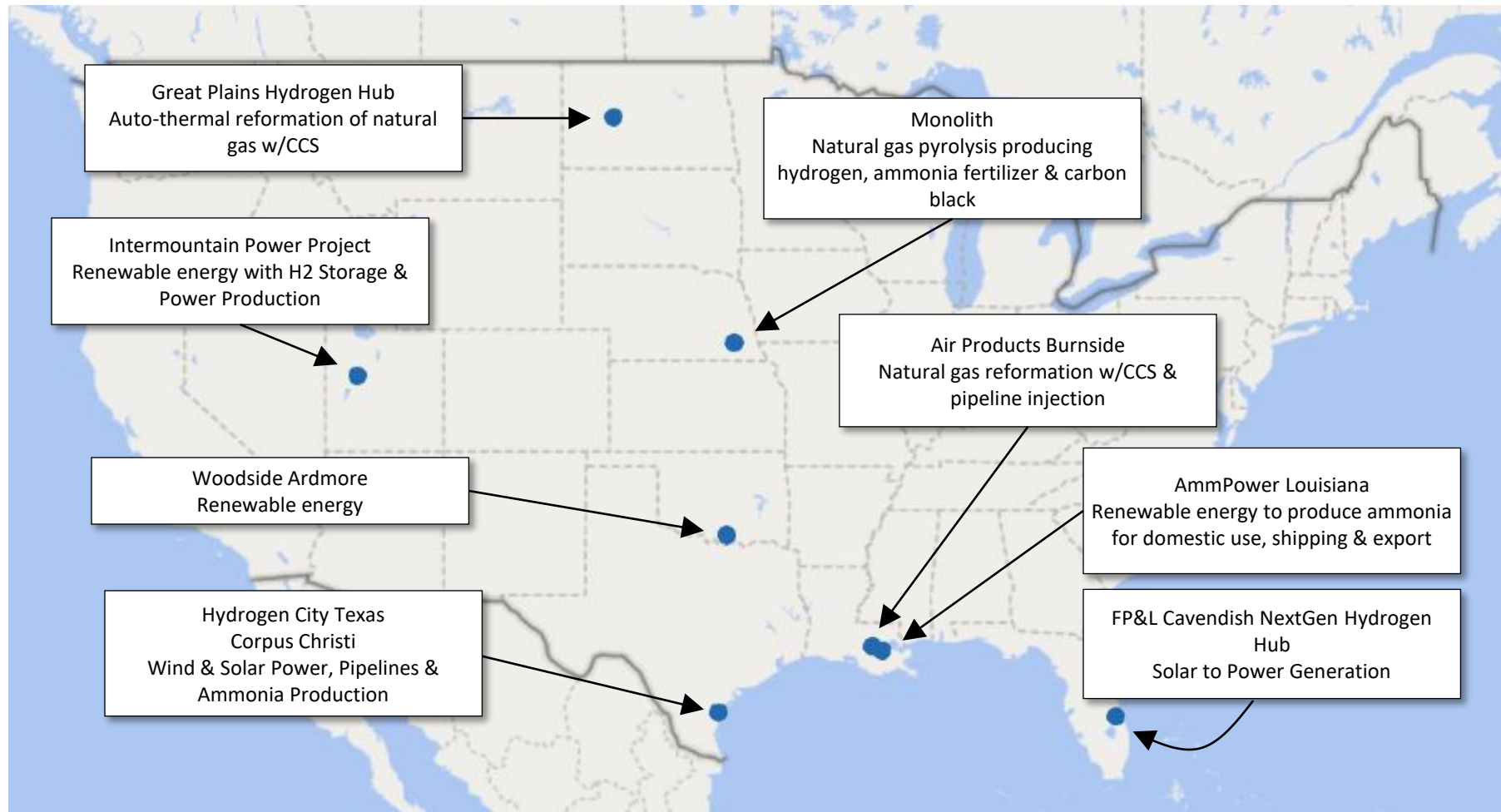
Project Example: AquaVentus

Converting offshore wind power to hydrogen



- ▶ Electricity from offshore wind farms is converted to hydrogen.
- ▶ Hydrogen is also produced at high sea, directly at the wind turbines or in the immediate vicinity of the wind farms.
- ▶ The green hydrogen is transported to Heligoland via pipelines.
- ▶ AquaVentus cooperation partners alongside RWE are the Island of Heligoland, Reuther, Vattenfall, Shell, Gasunie, Siemens, Parkwind and MHI Vestas.
- ▶ Electrolyzer – 10 GW
- ▶ Hydrogen – 1 million TPY
- ▶ Undersea Hydrogen Pipelines

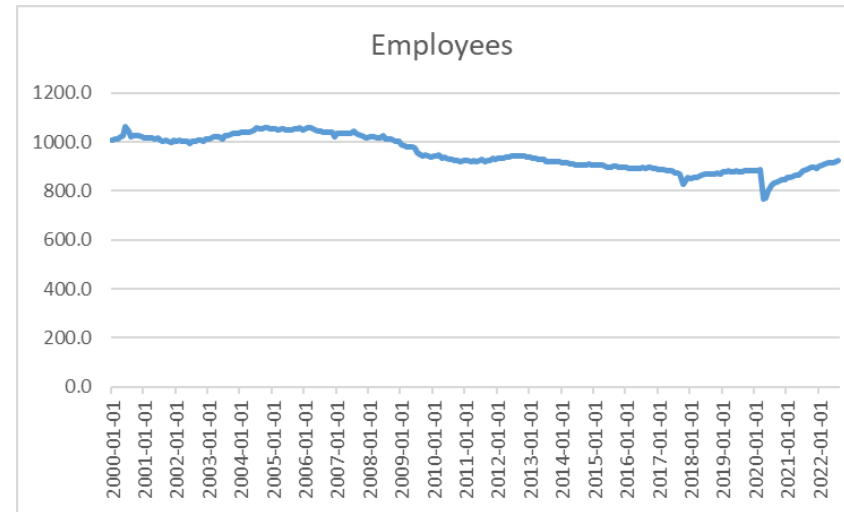
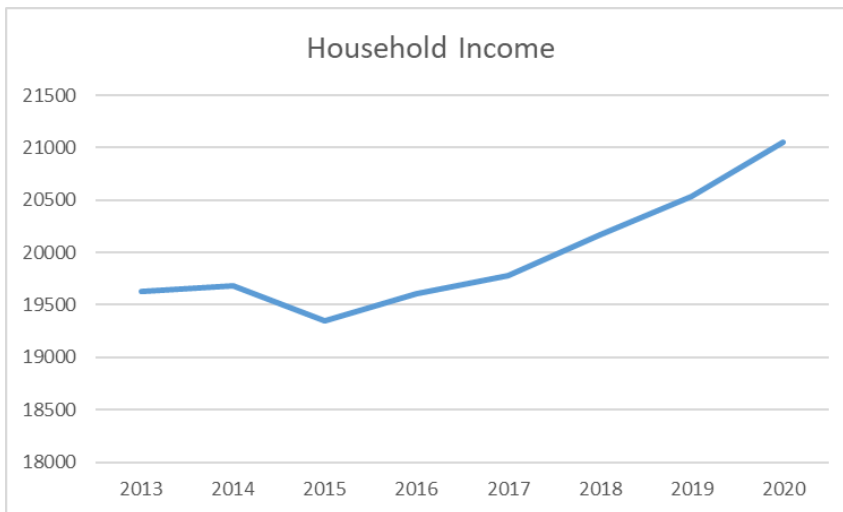
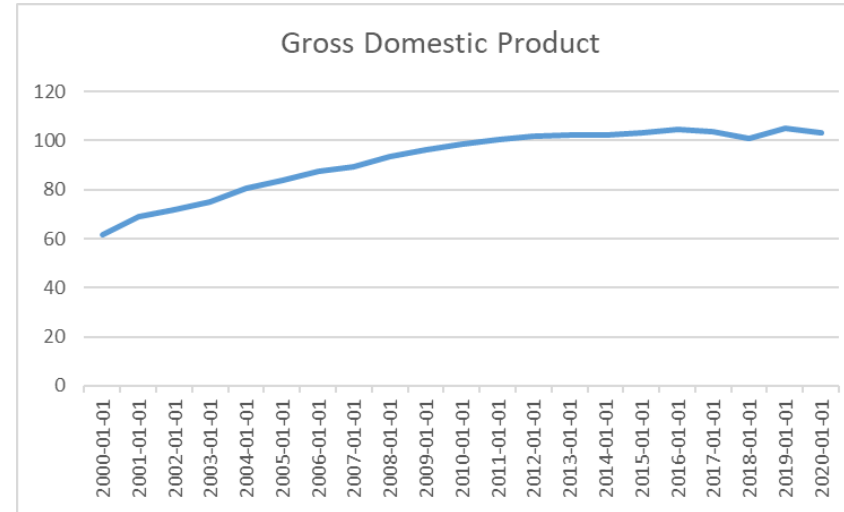
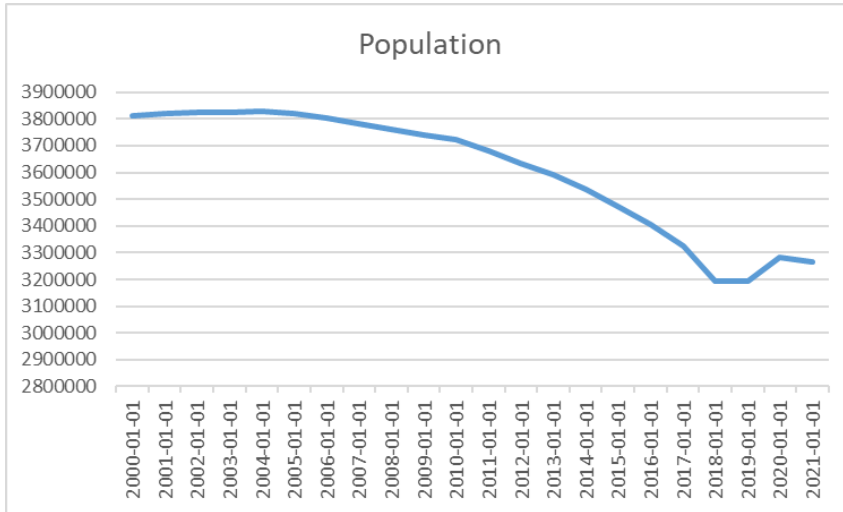
United States Hydrogen Hubs Announced and In-Development (illustrative sample)



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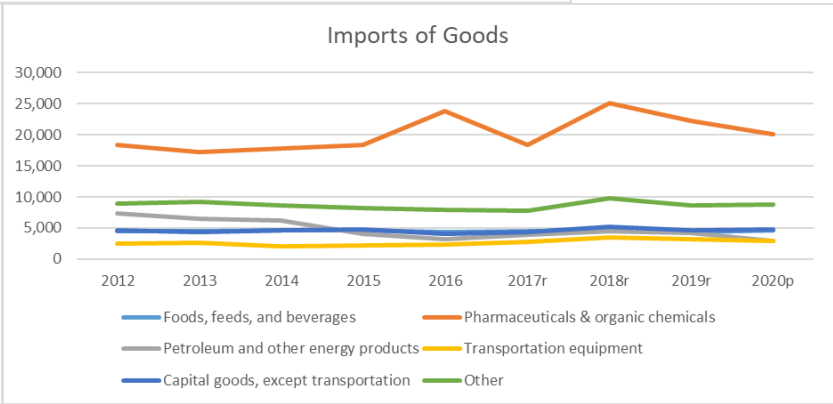
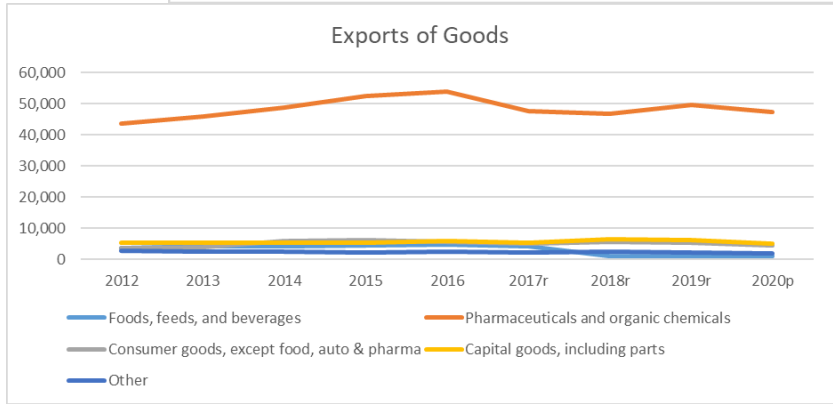
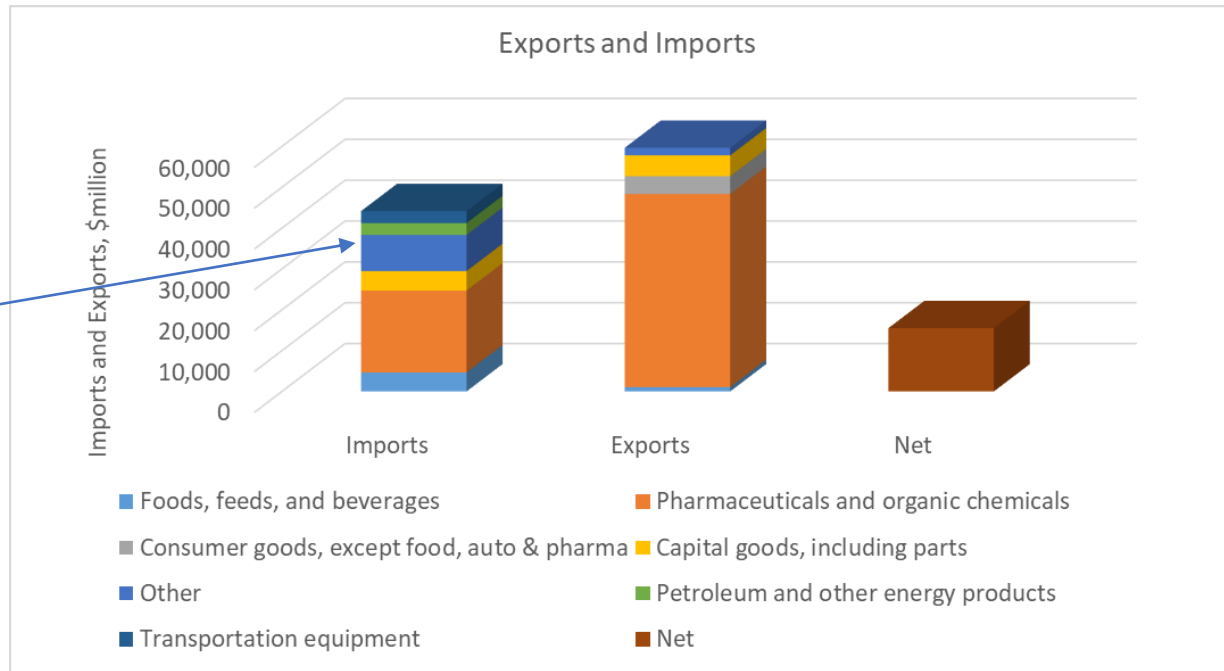


Puerto Rico Economy and Demographics

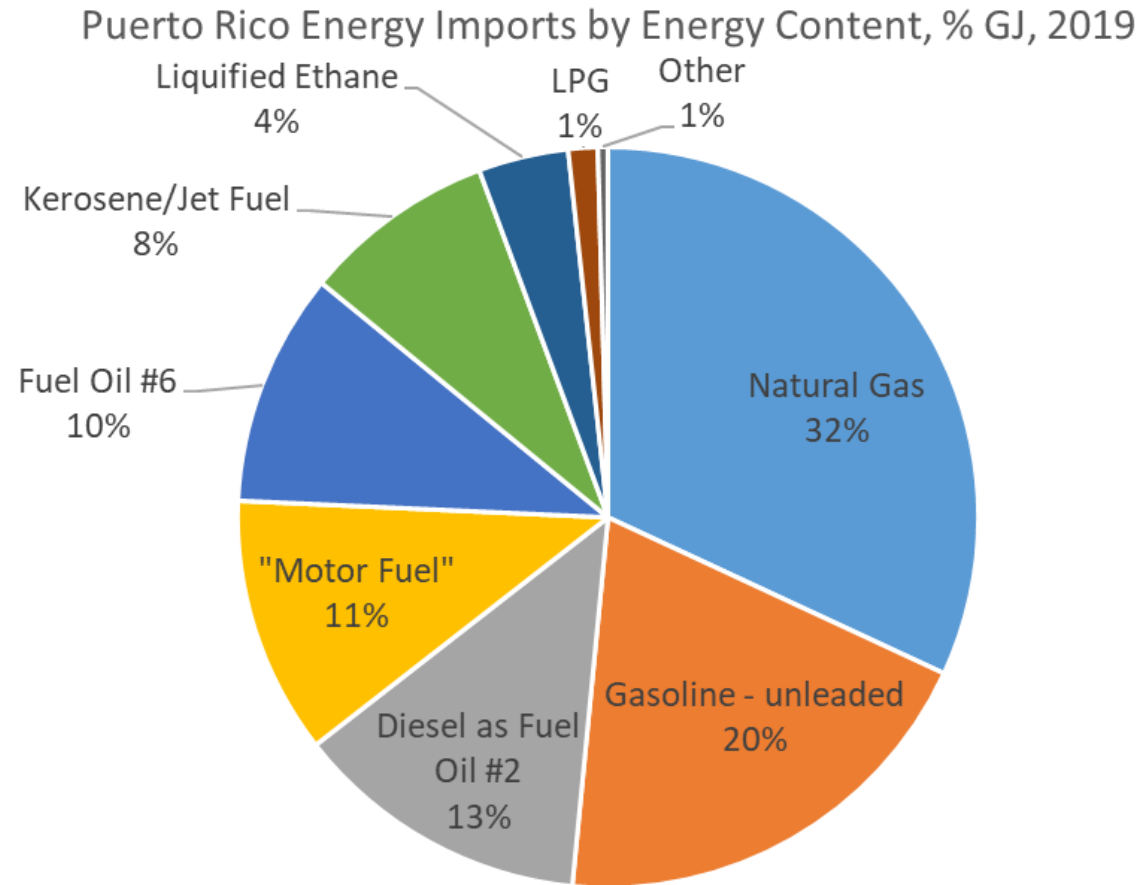


Puerto Rico has a favorable balance of trade due to high value pharmaceutical business. Puerto Rico spends approximately \$3.7 billion/year importing energy

Puerto Rico spends approximately \$3.7 billion per year on energy imports and industrial feedstocks

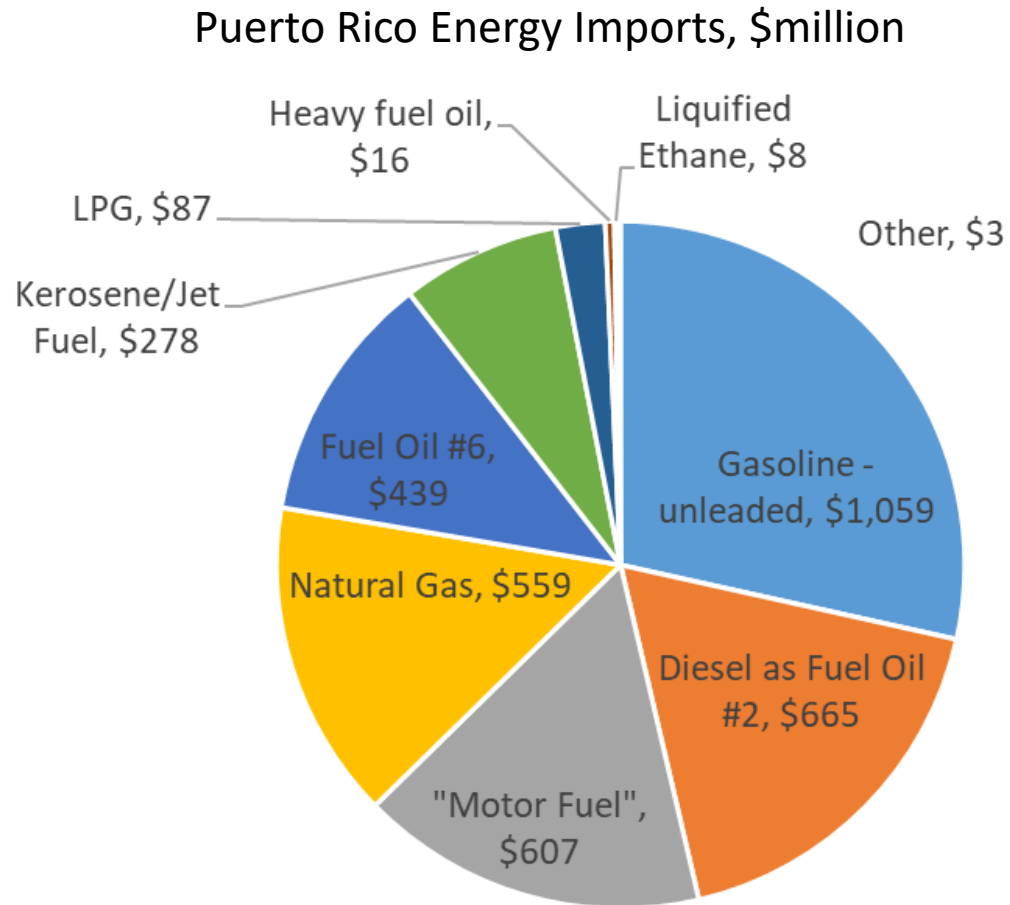


Puerto Rico imports an estimated 368 million GigaJoules per year for power, transportation, residential & consumer energy, and industrial processes



Category	Energy Content, GJ	Percentage
Electricity	117,748,434	32%
Transportation	161,376,575	44%
Building Energy	43,576,238	12%
Aviation Fuel	31,062,921	8%
Other End Uses	14,650,143	4%
Total	368,414,312	100%

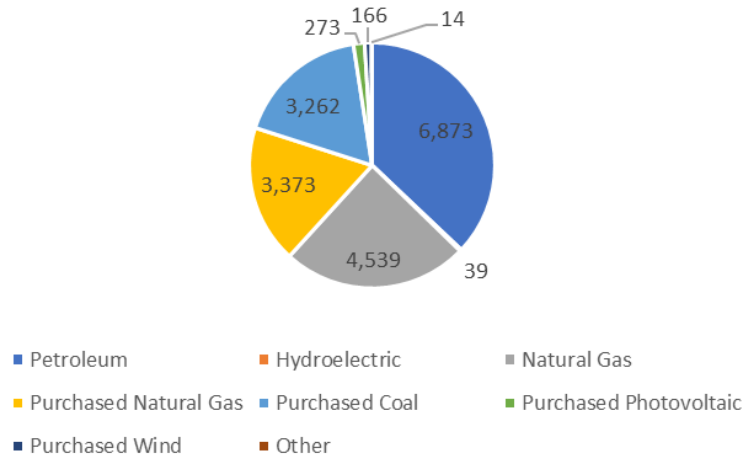
Puerto Rico spends approximately \$3.7 billion per year on energy imports and industrial feedstocks



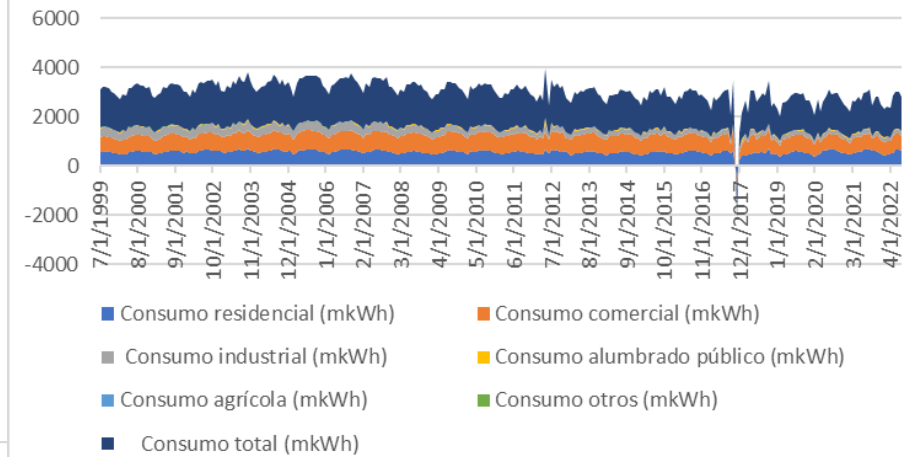
These imported energy sources are potential end-use markets for on-island electrification, hydrogen and synthetic fuels as well as importing decarbonized forms of energy

Electric energy system

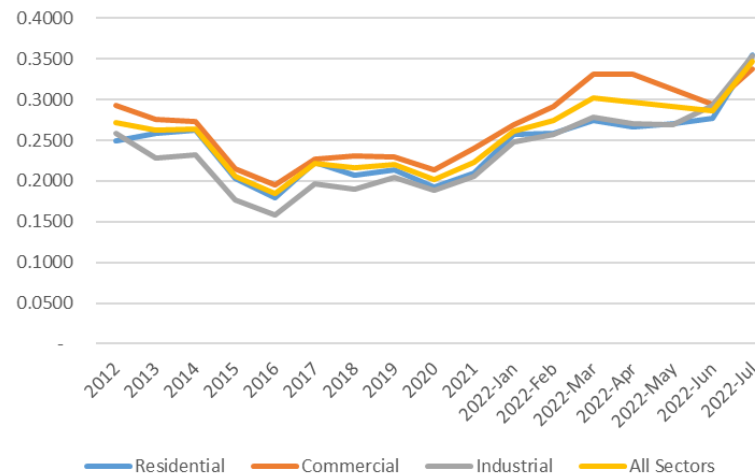
2021 Generation Mix



Monthly Electricity Sales by Customer Type

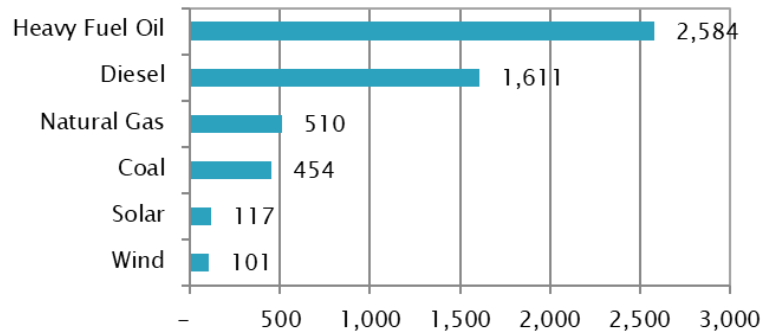


Electric Rates

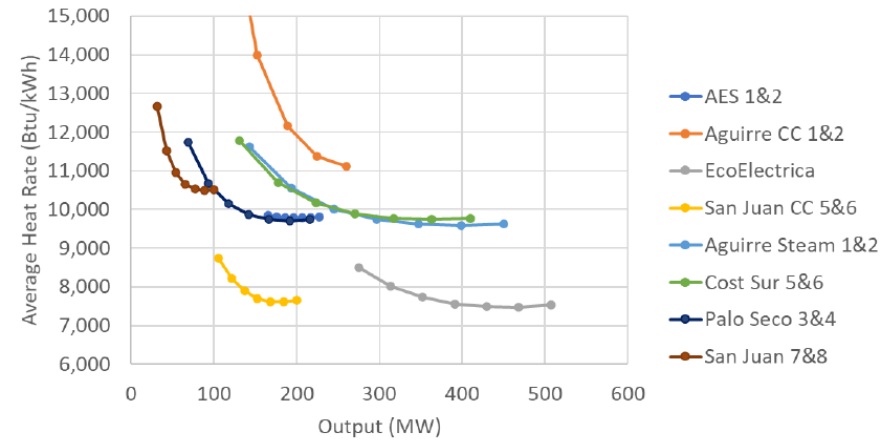


Puerto Rico Generation Resources

Power Generation Units Installed Capacity



Fossil Unit Average Heat Rate Curves



Electricity Production

	2020 mkWh		2021 mkWh	
Petroleum	9085.2	50%	6873	37%
Hydroelectric	50.2	0%	39	0%
Natural Gas	2188.9	12%	4539	24%
Purchased Natural Gas	3341.4	18%	3373	18%
Purchased Coal	3064.8	17%	3262	18%
Purchased Photovoltaic	259.4	1%	273	1%
Purchased Wind	142.7	1%	166	1%
Other	9.4	0%	14	0%
	18142	100%	18539	100%

Electricity Snapshot

Installed Capacity	5,839 MW
Peak Demand	2,866 MW
Total Generation	18,886 MWh
Renewable Energy	
Biomass	4.8 MW
Hydropower	34 MW
Solar	147.1 MW
Wind	121 MW

Puerto Rico is rebuilding its energy infrastructure to be more resilient due to the devastation of Maria and other disasters

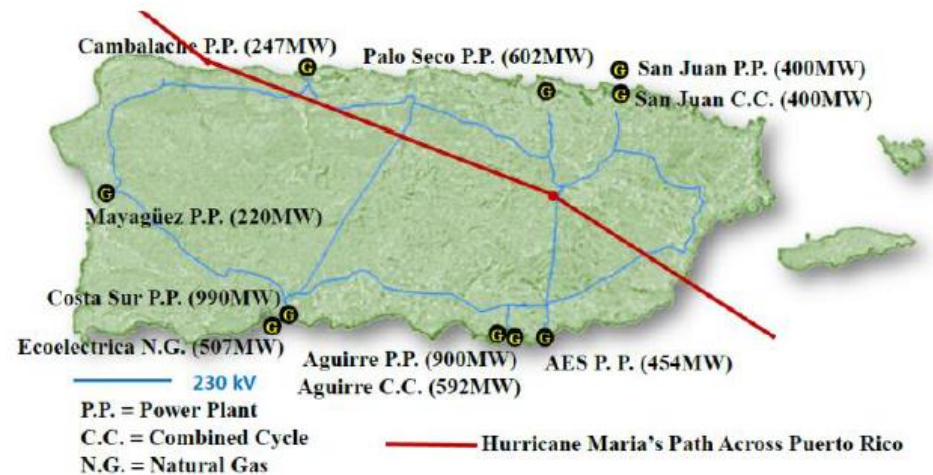
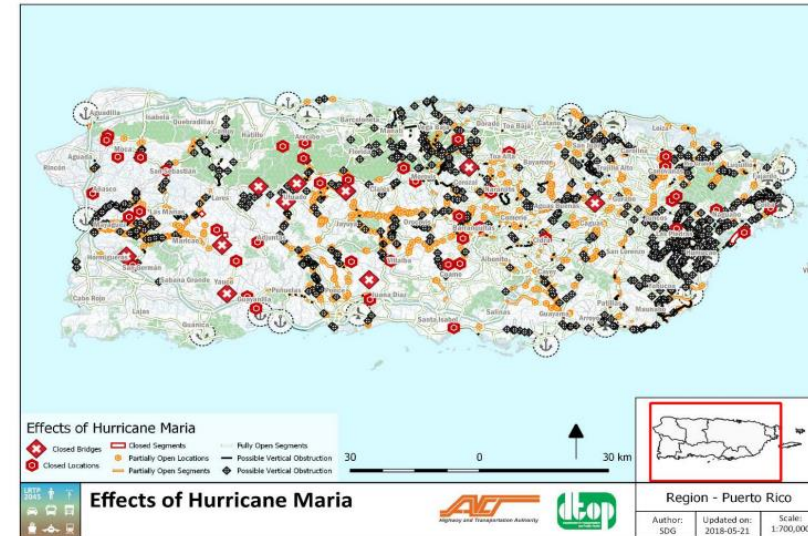


Fig. 1. Main transmission and generation assets of Puerto Rico's power grid.



Source: Hurricane Maria impacts were geolocated with the aid of information obtained from multiple meetings with the Highway and Transportation Authority Regional Directors during the first quarter of 2018.

- ▶ Power transmission and distribution has been hampered by insufficient maintenance, low stocks of replacement parts, limited availability of skilled personnel, poor equipment and personnel logistics
- ▶ Power generation is located far from load centers, compounding long line challenges with maintaining and repairing power distribution systems, specifically the transmission system, which is also challenged with very difficult access to towers and lines due to challenging and limited access mountainous terrain.
- ▶ Temporary bridges have been wiped out from prior storms
- ▶ Diesel fuel deliveries after storms has been hampered by the Jones Act, destroyed roads and bridges, unavailable due to insufficient stocks, high prices and challenging on-island distribution due to destroyed roads and bridges
- ▶ A large number of residential and commercial buildings may be substandard in design, materials and construction associated with insufficient resources in the local economy to bring them up to standard, further compounding the impacts of weather and geologic forces.

Puerto Rico Energy Transition Roadmap

Puerto Rico Grid Resilience and Transition Plan to 100% Renewables by 2050

- ▶ Target Renewable as Percentage of Total Power Generation
 - 20% by 2022 / 40% by 2025 / 60% by 2040 / 100% by 2050
- ▶ Initiatives have been formed around expanding wind and solar, including offshore wind, as well as repowering dormant hydropower facilities
- ▶ Expanded energy storage and the addition of MiniGrids and Microgrids have also been identified as core elements of building a more resilient energy future for Puerto Rico
- ▶ Renewables are currently approximately 3% to 4% of overall power generation
- ▶ Six solar tranches are planned, for a total of 3 GW of new solar capacity

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Hydrogen Strategy Initiative

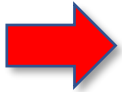
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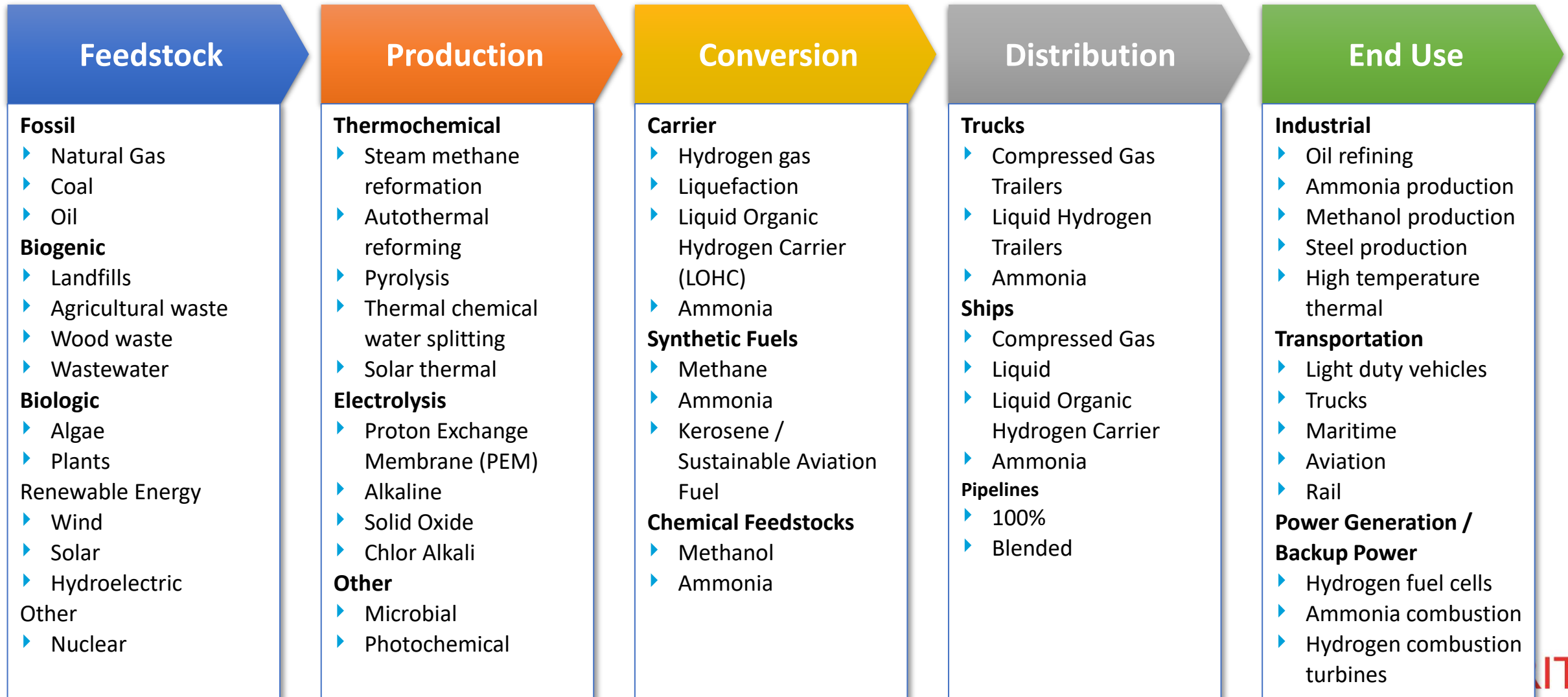
Puerto Rico Economic and Energy Situation

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Puerto Rico Assets Relative to Hydrogen Production



The hydrogen value chain



Different types of hydrogen, considering the source and carbon intensity

Green hydrogen

Technology: Electrolyser

Input: Renewable electricity

Process: Splitting water into hydrogen and air

GHG emissions: Depends on the GHG emissions from electricity supply

Blue hydrogen

Technology: (1) Steam Methane Reforming (SMR) plant with Carbon Capture and Storage (CCS); (2) Coal gasification plant with CCS

Input: (1) Natural gas; (2) Coal

Process: Converting (1) natural gas/(2) coal into hydrogen and CO₂

GHG emissions: Low, CO₂ stored and/or reused

Turquoise hydrogen

Technology: Methane pyrolysis plant with Carbon Capture and Utilisation (CCU)

Input: Mainly natural gas

Process: Splitting methane into hydrogen and solid carbon

GHG emissions: Depend on the input to generate the necessary heat

Grey hydrogen

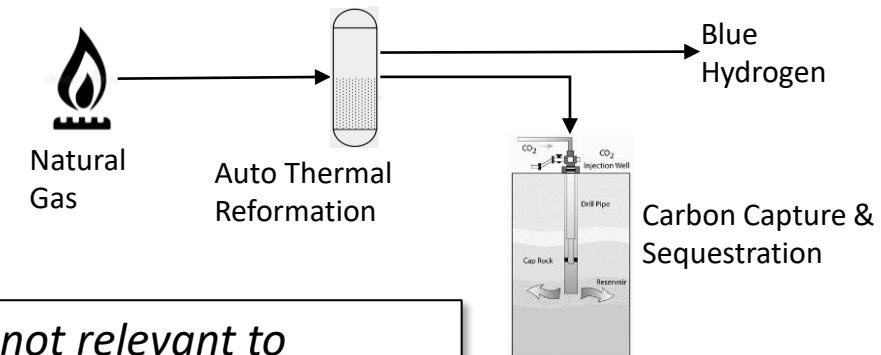
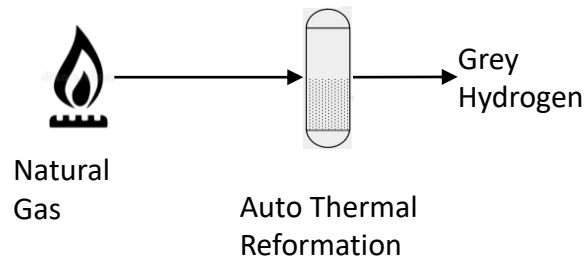
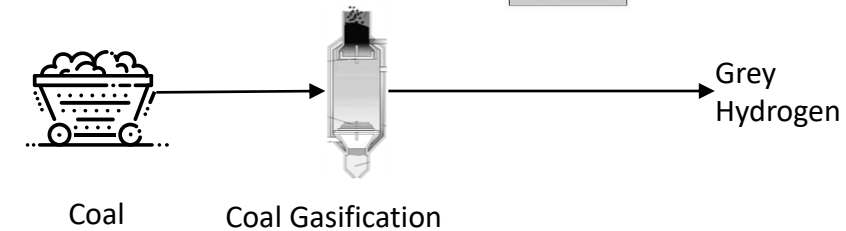
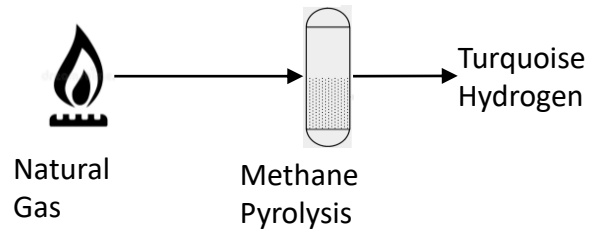
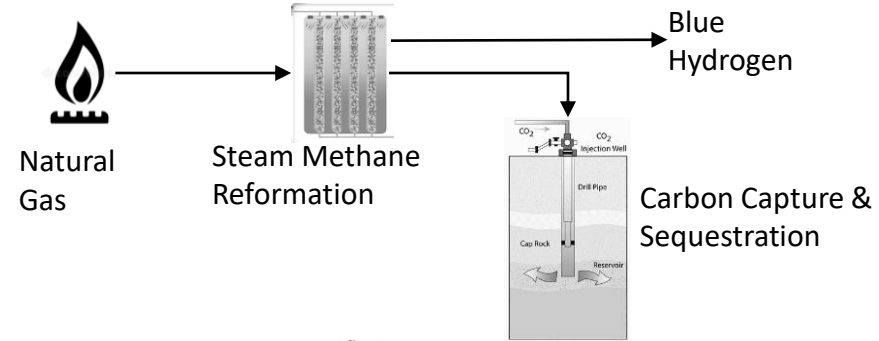
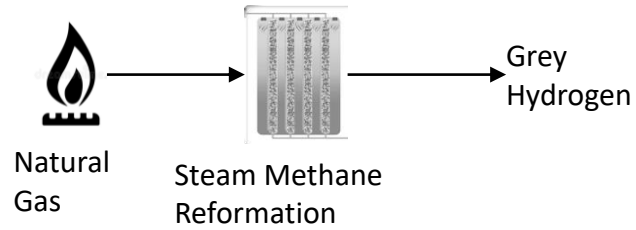
Technology: (1) Steam Methane Reforming (SMR) plant; (2) Coal gasification plant

Input: (1) Natural gas; (2) Coal

Process: Converting (1) natural gas/(2) coal into hydrogen and CO₂

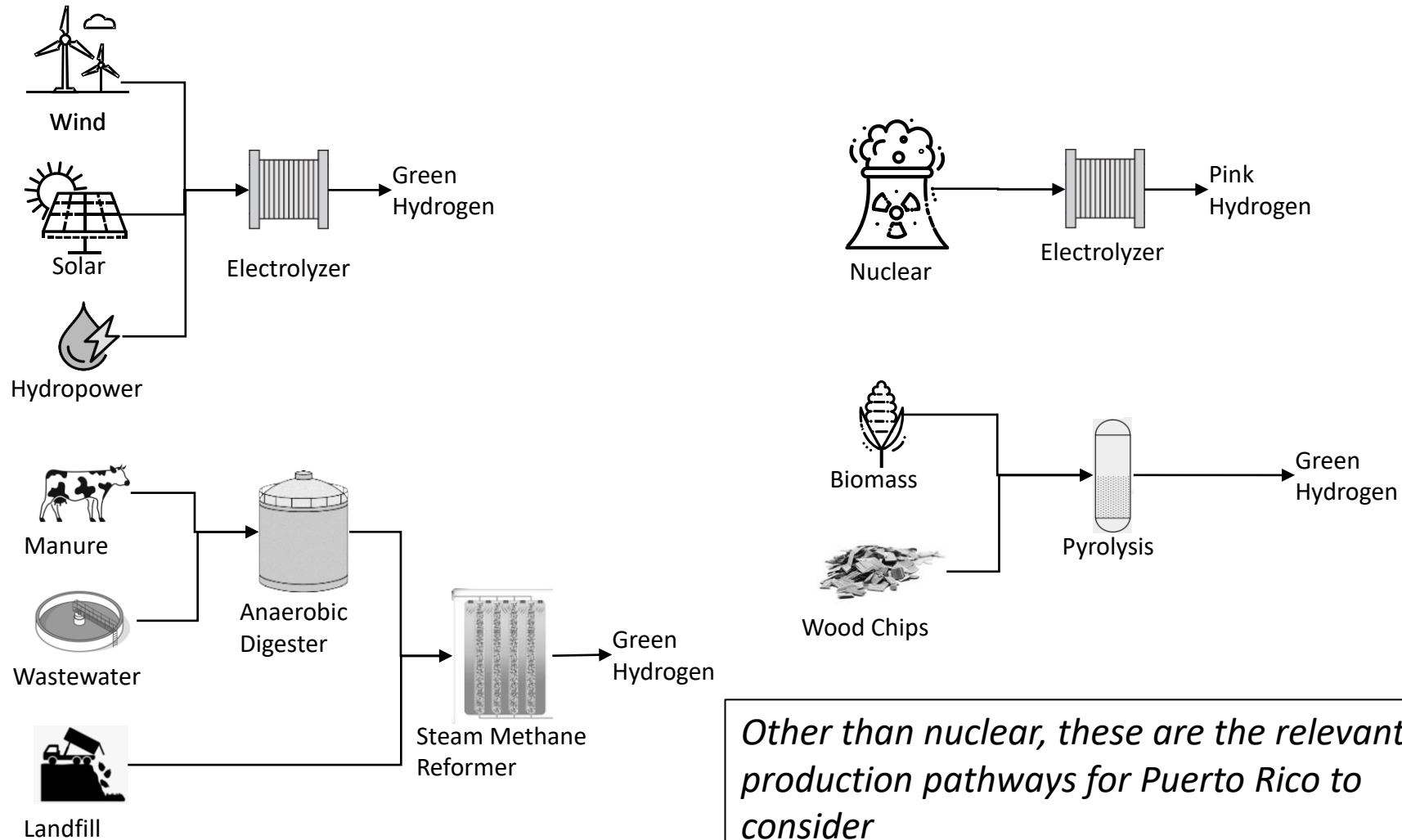
GHG emissions: Yes

Many pathways are available to generate hydrogen from natural gas and coal

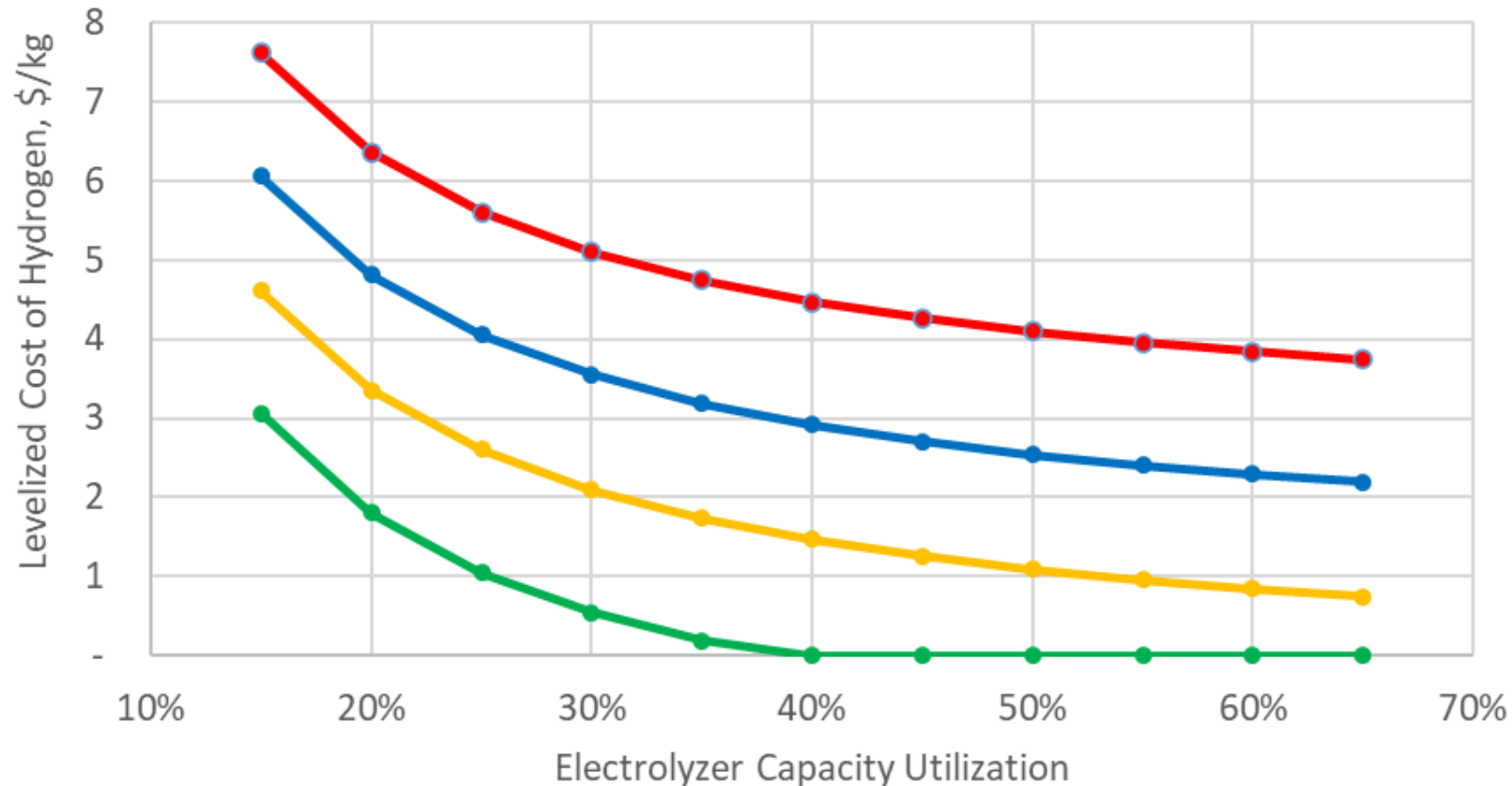


Fossil pathways are not relevant to hydrogen production in Puerto Rico

There are also many low carbon renewable energy and nuclear energy pathways available for low carbon hydrogen production



Levelized cost of hydrogen, varying electrolyzer capacity utilization, power costs & PTC



● \$0.05/kWh ● \$0.02/kWh ● \$0.05/kWh w/PTC ● \$0.02/kWh w/PTC

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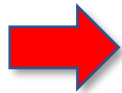
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Significant solar and wind resources have been identified, representing technical potential – actual developed resources will be less, subject to certain constraints

Solar

- ▶ Excellent Irradiance along coastal regions bounded by use of land constraints such as agricultural uses
- ▶ NREL Analysis of Utility-Scale Solar PV Development Potential Found Greater Than 20 GW Total

Onshore Wind

- ▶ 6.81 GW potential capacity of assuming 2,270 km² of developable land or 24% of Puerto Rico's land mass (including Culebra and Vieques).
- ▶ Technical potential for onshore wind ranges from 6.4 to 7.9 GW assuming 2,150 to 2,640 km² of developable area

Offshore Wind

- ▶ 40,760 MW potential capacity assuming 13,587 km² of developable area, of which 21,240 is within territorial waters and 19,520 in federal waters (75% within 15 nautical miles from shore)

Agriculture can be a source of hydrogen and renewable fuels as well as a market for hydrogen

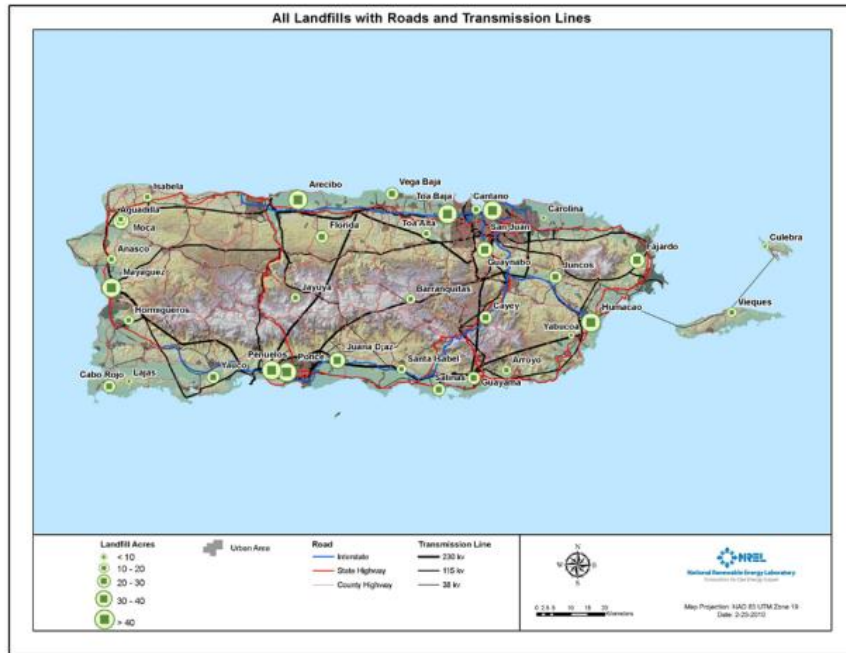
- ▶ In 2018 there were 8,230 farms in Puerto Rico, down from 13,159 in 2012, a decline of 37.5%
- ▶ The amount of land allocated to agriculture was 487,774 cuerdas (473,630 acres) in 2018, down from 584,988 cuerdas (568,023 acres) a 16.6% drop.
- ▶ The land allocated to agriculture in 2018 represented 21.6% of all land in Puerto Rico.

Livestock & Poultry	Farms	Number of Animals
Cattle and calves	2,849	234,250
Hogs and pigs	464	45,710
Chickens	647	8,969,808
Other livestock	997	997
Total	4,957	9,250,765

1. Agriculture represents a potential market for ammonia which needs hydrogen for production
2. Agricultural waste can be used for hydrogen production as well as producing renewable natural gas

Landfills can be a good source for hydrogen and methane which can be used to produce additional renewable fuels

- ▶ Puerto Rico has an estimated 29 operating landfills and a number of closed landfills.



Puerto Rico Landfill Consent Orders and Consent Decree - Closure Status

Landfill	Closure Status	Recycling & Composting Program Required	New Cell Construction
Aguadilla	Closed April 2010	No	No
Arecibo (Consent Decree)	After reaching final capacity (circa 2020)	Yes	No
Arroyo	Permanent waste receipt cessation required June 2019	Yes	No
Cayey	Permanent waste receipt cessation required January 2018	Yes	Under consideration
Florida	Overdue - permanent waste receipt cessation required June 2016	Yes	No
Isabela	June 2020 (only limited waste now being received)	Yes	Planned
Juncos	Permanent waste receipt cessation required December 2014 – Extended	Yes	Under construction
Lajas	December 2017	Yes	Planned
Moca	After reaching final capacity (circa 2019)	Yes	Planned
Santa Isabel	Interim closure completed September 2014	Yes	No
Toa Baja	Permanent waste receipt cessation September 2014 (achieved September 2015) and closure thereafter per closure plan schedule (pending)	Yes	Operational
Vega Baja	Permanent waste receipt cessation July 2013 (achieved July 2015) and closure thereafter per closure plan schedule (pending)	Yes	Operational

Landfills can also be used to host photovoltaic power plants

Wastewater treatment plants can be a source of hydrogen as well as several derivatives, such as methane, and methanol and other hydrocarbons.

	Facilities	Population Served
Wastewater Treatment Plants	41	1,443,321

The technical potential for hydrogen production on the island is 3.5 million tons per year, mostly driven by offshore wind, which, at a unit price of \$3/kg, implies a \$10.5 billion annual value

Initial Estimates

Sources			
	Summary	Future Scenario	Hydrogen Production
Solar	Currently there is approximately 147.1 MW of solar on the island. It has been estimated that the potential for additional solar is 20 GW distributed solar and 20 GW utility scale solar	7.6 GW grid solar w/20% curtailment	44,237 tons/yr
		15 GW dedicated H2 solar	436,027 tons/yr
Wind	Currently there is an estimated 121 MW of wind on the island. The onshore wind potential is between 6.4 to 7.9 GW. The potential for offshore wind is 40.76 GW	3.2 GW wind w/20% curtailment	44,237 tons/yr
		40 GW dedicated H2 wind	2,735,856 tons/yr
Landfills	Currently there are 29 operating landfills and a number of closed landfills	Estimate for Puerto Rico is the potential for 18,775 tons/year of hydrogen production (rough estimate)	18,775 tons/yr
Wastewater Treatment	Currently there are 41 wastewater treatment plants on the island serving 1,443,321 people	41 wastewater plants serve 1.44 million people which could generate 177 tons/year of hydrogen	177,343 tons/yr
Agricultural Waste	The island 4,957 farms and 9.3 million animals including cattle, hogs, pigs, chickens and other livestock	9.3 million animals produce 3 million tons/yr of manure which can produce 15.1 thousand tons/yr of hydrogen	15,100 tons/yr

Total potential for hydrogen production in Puerto Rico

3,471,569 tons/year