



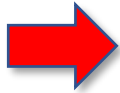
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Puerto Rico Energy Bureau  
Puerto Rico Hydrogen Strategy  
Technical Workshop 2  
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# Agenda



Hydrogen Strategy Initiative

Hydrogen Overview

Potential Role for Hydrogen in Puerto Rico

Puerto Rico Hydrogen Production Potential

Hydrogen Use Cases for Puerto Rico

Use Case Evaluation

Next Steps

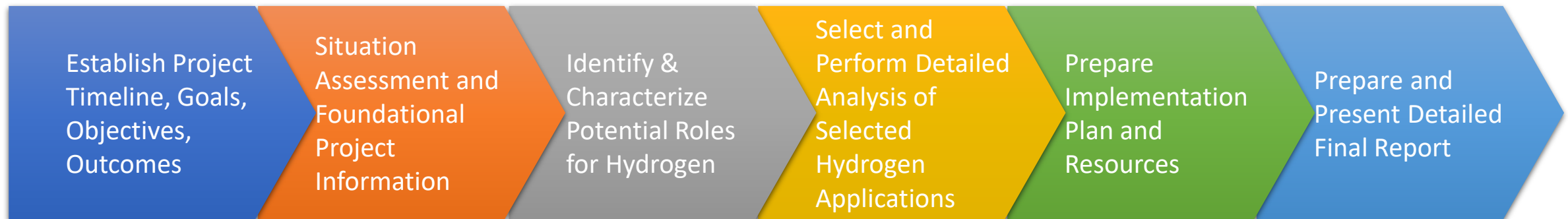
# Puerto Rico Hydrogen Strategy - Background

- ▶ 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

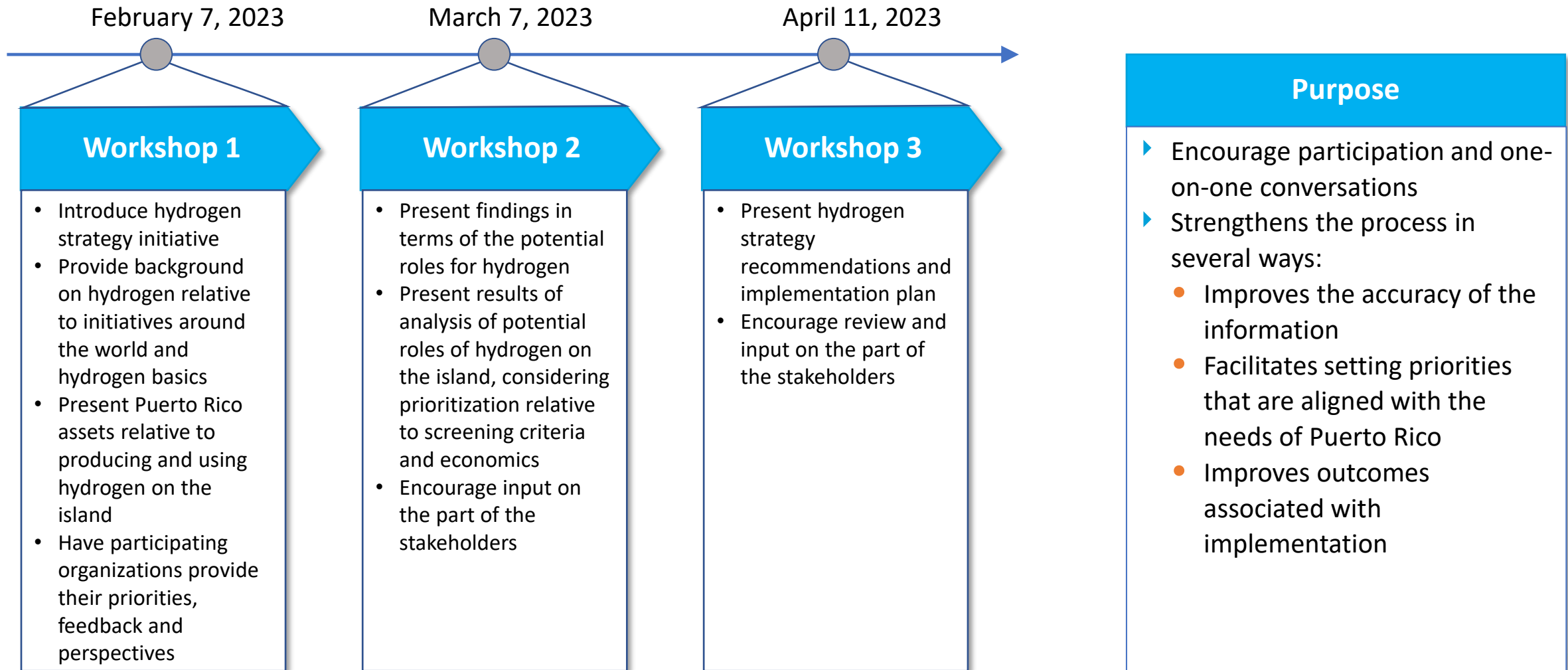
# Puerto Rico Hydrogen Strategy – Scope and Process

## ► 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

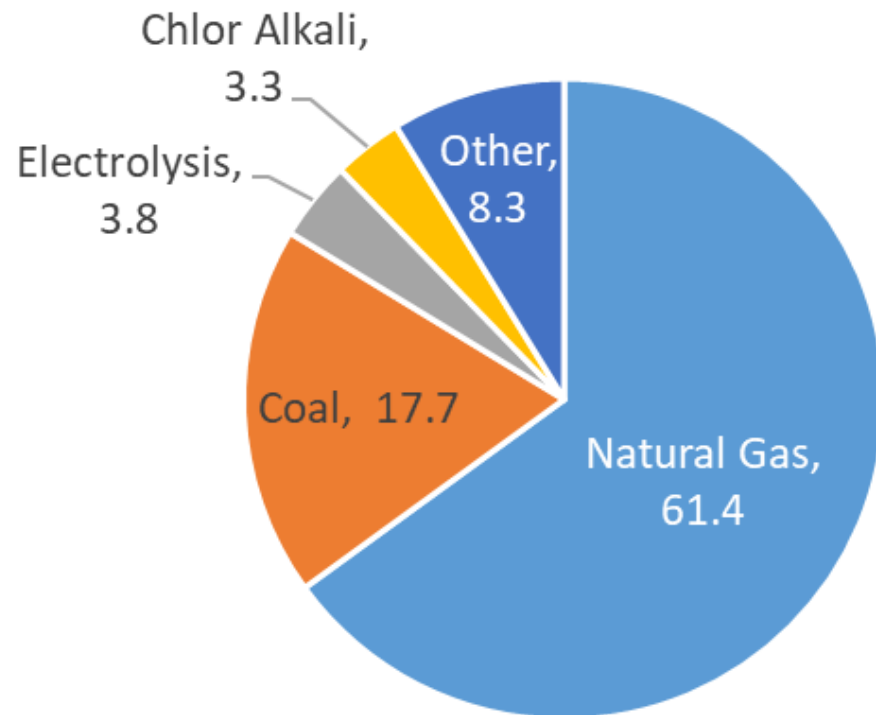


# Hydrogen has emerged as a potential valuable resource in achieving decarbonization goals around the world

- ▶ **Green Hydrogen Production Costs Have Dropped Significantly** - The cost of producing green hydrogen has dropped significantly with the falling costs of wind and solar energy – placing hydrogen within economic reach of many end-uses
- ▶ **Deep Decarbonization Initiatives Have Discovered Hard-to-Abate Sectors** – Certain sectors are difficult to electrify, including cement manufacturing, steel manufacturing, heavy trucks, large ships and aircraft
- ▶ **Existing Hydrogen Product Emissions are High** – Grey hydrogen is responsible for about 3% of global CO<sub>2</sub> emissions, due to steam methane reformation for desulfurizing petroleum, and producing ammonia and methanol
- ▶ **Clean Hydrogen can be used to Reduce Emissions Throughout the Global Economy** – Low carbon hydrogen can be used in power generation, energy storage, transportation fuel, thermal processes for industry, blending with natural gas for power generation and thermal applications, production of green ammonia for fertilizer, green methanol production, and the production of e-fuels for aviation and maritime use

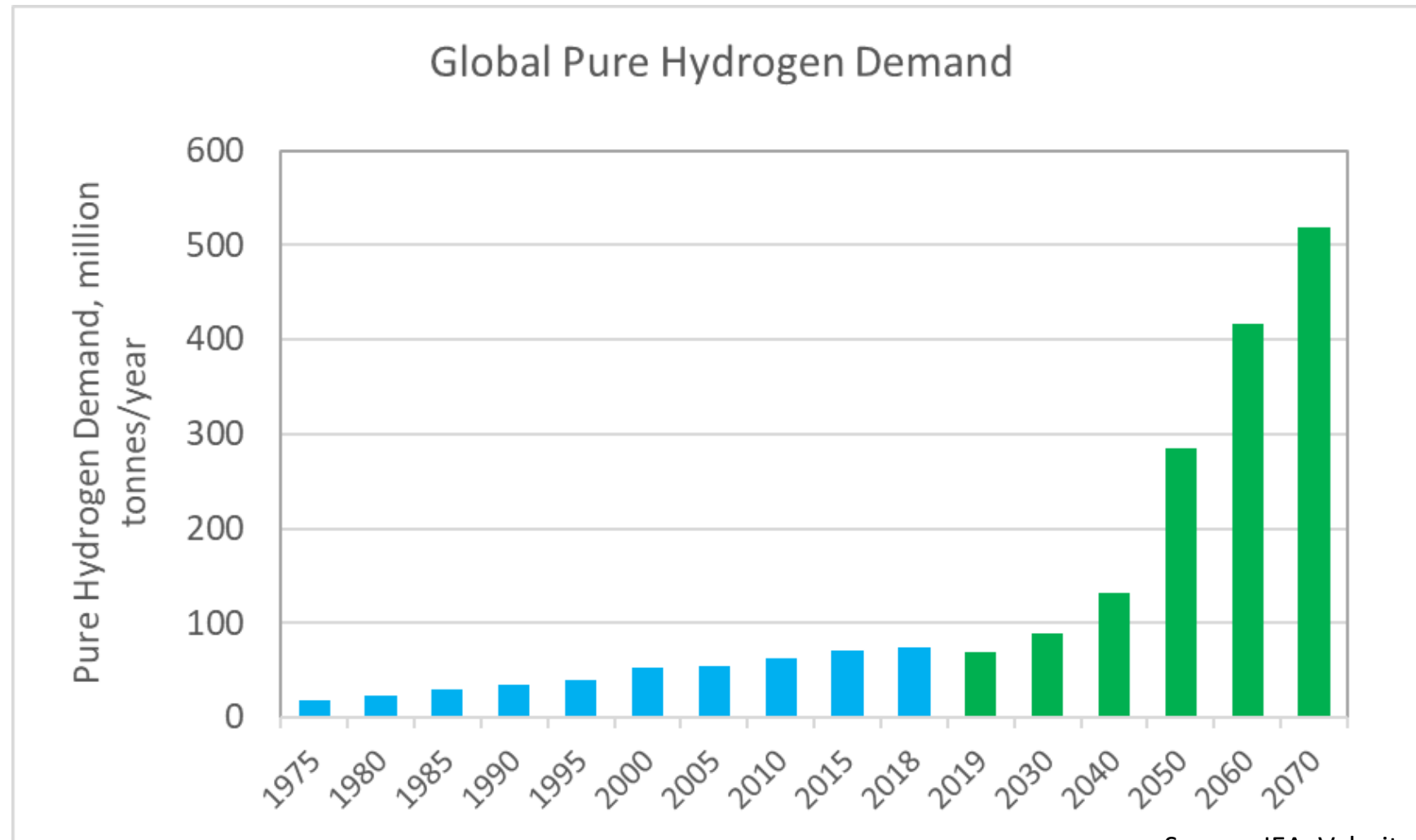
# Natural gas dominates hydrogen production today, using steam methane reformation

2023 Estimated Global Pure Hydrogen Production, million tons



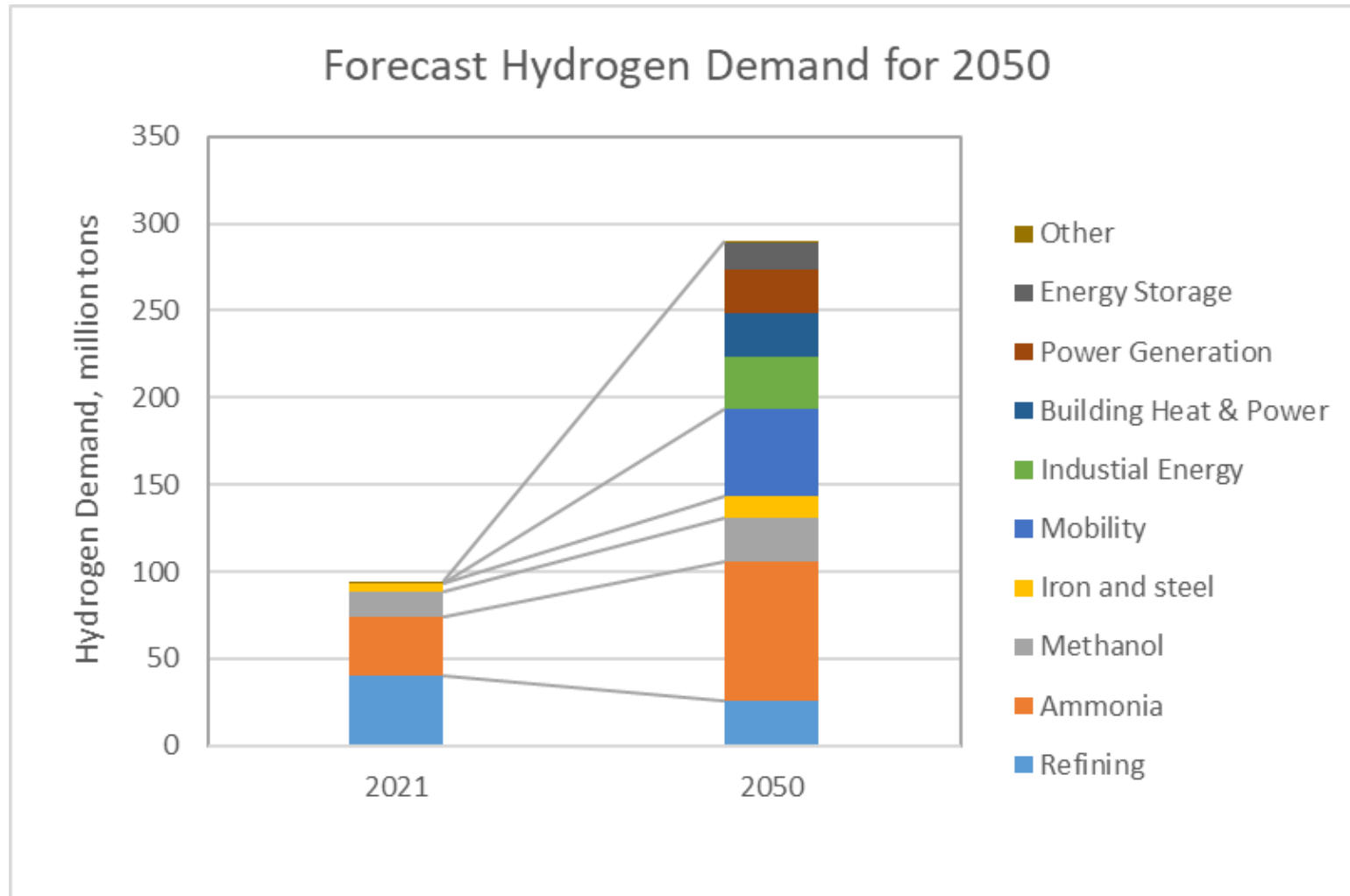
- ▶ Natural gas is the major source of hydrogen production using steam methane reformation
- ▶ Coal dominates China's hydrogen production, and is responsible for significant carbon dioxide emissions
- ▶ Hydrogen production is responsible for about 3% of global carbon emissions
- ▶ Electrolysis is the fastest growing method of clean hydrogen production

Global demand for pure hydrogen is approximately 95 million tons per year now, and is expected to grow to ~300 million tons per year by 2050



Source: IEA, Velerity

# Estimates of future demand for hydrogen vary widely, although significant growth dominates every forecast with new end-uses in transportation, power generation, energy storage and heat energy



Source: IEA, Hydrogen Council, Velerity



# There are a wide variety of end-use applications being implemented today

## Industrial Applications

### Feedstock

- ▶ Oil refining
- ▶ Ammonia production
- ▶ Methanol production
- ▶ Iron and steel production
- ▶ Food industry

### Energy

- ▶ High temperature thermal energy

## Mobility

- ▶ Forklifts / material handling
- ▶ Light duty vehicles
- ▶ Heavy duty vehicles (trucks, buses, municipal vehicles)
- ▶ Maritime (ammonia or methanol)
- ▶ Aviation (sustainable aviation fuel, hydrogen)
- ▶ Rail (hydrogen)

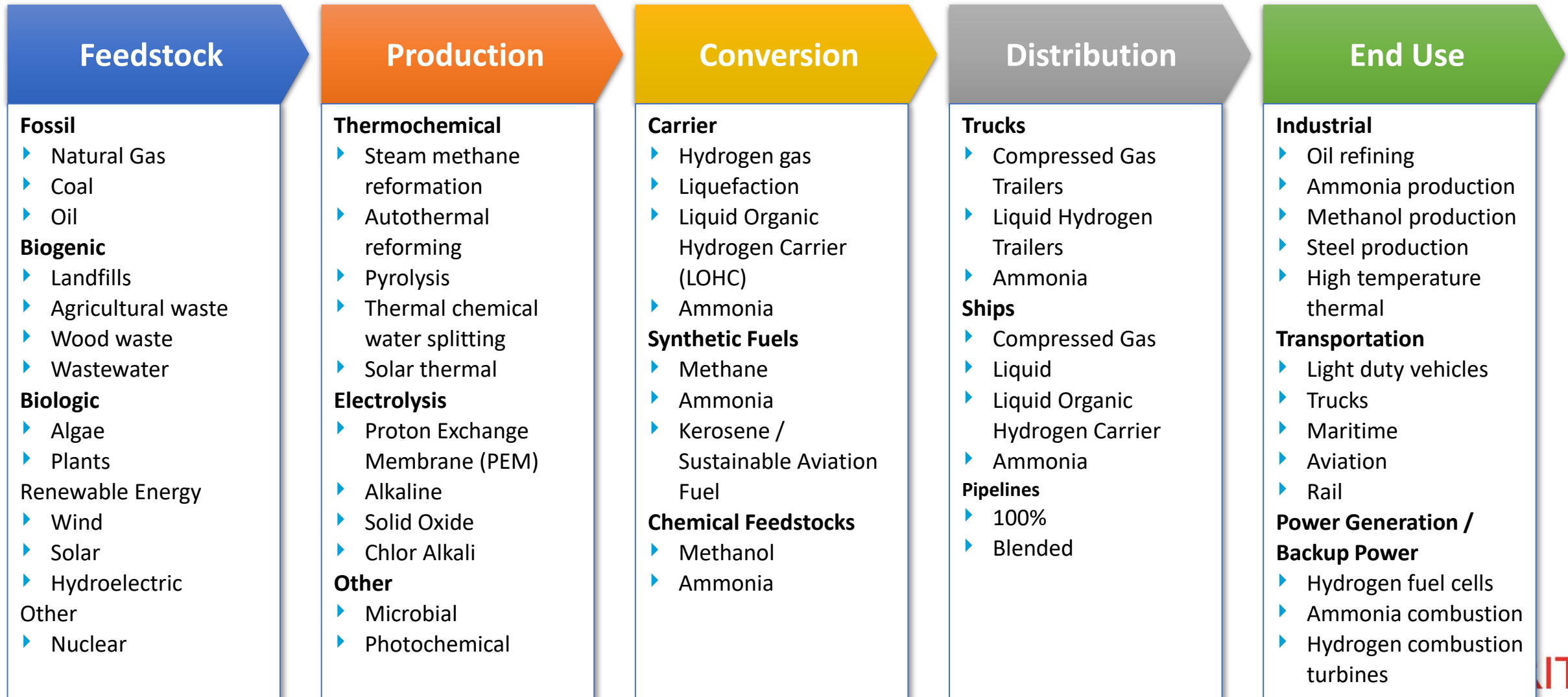
## Power Generation

- ▶ Co-firing ammonia in power plants
- ▶ Distributed power generation
- ▶ Power generation for micro-grids
- ▶ Backup power / emergency power generation for end-users
- ▶ Long duration energy storage
- ▶ Grid resilience

## Gas Energy

- ▶ Blending with natural gas
- ▶ Producing synthetic methane
- ▶ 100% hydrogen pipelines

# Potential hydrogen production-to-use pathways are also quite numerous



# Many refer to the “colors of hydrogen” corresponding to sources and carbon intensities

- ▶ **Grey** – Hydrogen produced from fossil fuels including natural gas with steam methane reformation, autothermal reformation and coal gasification plus water-gas shift
- ▶ **Blue** – Hydrogen produced from fossil fuels including natural gas and coal with the carbon dioxide emissions captured and sequestered
- ▶ **Green** – Hydrogen produced using renewable energy and electrolysis to split water into hydrogen and oxygen
- ▶ **Turquoise** – Hydrogen produced from methane pyrolysis to form hydrogen and elemental (solid) carbon
- ▶ **Pink** – Hydrogen produced from nuclear power using either electrolysis and/or thermal water splitting

# Hydrogen can play several important roles in Puerto Rico's energy and industrial future

## Drivers

- Grid stability and resilience
- Domestic energy production
- Stabilize energy prices
- Export opportunity
- Reduce emissions

## Potential roles for hydrogen in Puerto Rico

- Transportation
- Power Generation
- Heat for Industry
- Derivatives Production
- Grid Resilience and Stability
- Minigrids and Microgrids
- Export

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
<b>Solar</b>	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
<b>Wind</b>	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
<b>Landfills</b>	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
<b>Wastewater Treatment</b>	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
<b>Agricultural Waste</b>	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**



# The project team identified sixteen hydrogen use cases to evaluation for Puerto Rico

<b>Hydrogen Use Cases</b>	<b>Transportation</b>	1.	Hydrogen fuel for light passenger vehicles
		2.	Trucks and heavy duty on-road transport
		3.	Hydrogen for municipal vehicles including waste hauling trucks and transit buses
		4.	Fuel for drayage trucks and materials handling in ports
		5.	Fuel for ships
		6.	Producing Sustainable Aviation Fuel or hydrogen for aircraft
	<b>Grid Resilience &amp; Stability</b>	7.	Distributed energy storage with hydrogen for critical facilities
		8.	Distributed energy storage with hydrogen for grid resilience with minigrids and microgrids
		9.	Long duration hydrogen storage for grid balancing and price arbitrage with high penetration variable renewable energy

# Hydrogen Use Cases

<b>Hydrogen Use Cases</b>	<b>Industrial Feedstock</b>	10.	Ammonia production for domestic consumption and export
		11.	Methanol production for domestic consumption and export
	<b>Power Generation</b>	12.	Blend hydrogen with natural gas for combustion turbines and power generation
		13.	Blend ammonia with fuel for combustion turbines and coal fired power generation
		14.	Utilize hydrogen fuel cells for distributed power generation
	<b>Other</b>	15.	Hydrogen for materials handling and forklifts in warehouses
16.		Hydrogen for cell tower backup power	

# Each use case was characterized for evaluation

## Light Duty Vehicles (passenger vehicles)

<b>Description</b>	Build out hydrogen fuel cell passenger vehicle market including hydrogen fuel cell passenger vehicles, fueling infrastructure, and the hydrogen supply chain
<b>Problem Statement</b>	Transportation emissions are high, fuel costs are high and variable, petroleum handling has negative environmental impacts
<b>Hydrogen Source</b>	Hydrogen will be produced on island from renewable energy sources including wind, solar, hydropower and biogenic sources
<b>Hydrogen Distribution</b>	Hydrogen will be distributed in gaseous form to filling stations via high-capacity tube trailers
<b>Hydrogen End-Use</b>	Hydrogen will be dispensed to light duty vehicles
<b>Addressable Market</b>	Puerto Rico has 2,421,055 passenger vehicles which travel an estimated 5,600 miles per year, and approximately 542 million gallons per year of gasoline. At 60 miles per kilogram, 100% conversion to FCEVs would consume 226,000 tons/year of hydrogen

<b>Alternatives</b>	Electric passenger vehicles are a compelling alternative to FCEV's with costs and range in line with consumer expectations, which will thwart FCEV adoption
<b>Supply Chain</b>	Renewable energy, electrolyzers, hydrogen tube trailers, fueling stations, dispensing equipment, passenger vehicles
<b>Benefits</b>	Provides a zero emission, short refueling time, long range option for passenger vehicles, and on-island fuel source stabilizing prices and reducing imports
<b>Challenges</b>	Requires significant investment for the refueling infrastructure, fuel costs are at least twice as high as for electric vehicles, requires twice as much renewable energy than for equivalent for electric vehicles
<b>Fit with Puerto Rico</b>	Although technically feasible, hydrogen fuel cell vehicles have a low fit with Puerto Rico, given low average trip distances, limited amount of renewable energy, and low household incomes

# Trucks and heavy duty on-road transport

<b>Description</b>	Build out a hydrogen fuel cell truck infrastructure including fuel sources and fueling stations. Start with back-to-base depots followed by building out fueling stations across the island.	<b>Alternatives</b>	Electric trucks will make inroads in truck transportation, although the refilling time and battery weight will limit market uptake in larger trucks and those with more demanding routes.
<b>Problem Statement</b>	Transportation emissions are high, fuel costs are high and variable, petroleum handling has negative environmental impacts.	<b>Supply Chain</b>	Renewable energy, electrolyzers, hydrogen tube trailers, liquid hydrogen production, liquid hydrogen trailers, fueling stations, dispensing equipment, fuel cell trucks
<b>Hydrogen Source</b>	Hydrogen will be produced on island from renewable energy sources including wind, solar, hydropower and biogenic sources	<b>Benefits</b>	Provides a zero emission, short refueling time, long range option for trucks and heavier vehicles, and an on-island fuel source stabilizing prices and reducing imports
<b>Hydrogen Distribution</b>	Hydrogen will be distributed in gaseous form to filling stations via high-capacity tube trailers. A high penetration of fuel cell trucks may warrant liquid hydrogen production and distribution.	<b>Challenges</b>	Requires significant investment for the refueling infrastructure, fuel costs are at least twice as high as for electric vehicles, requires twice as much renewable energy than for equivalent for electric vehicles
<b>Hydrogen End-Use</b>	Hydrogen will be dispensed to trucks and heavy on-road vehicles via filling stations first in private depots and filling stations in San Juan followed by broader distribution across the island.	<b>Fit with Puerto Rico</b>	There is a moderate to strong fit with Puerto Rico as it provides benefits to larger trucks over electrification. It also benefits from a fuel infrastructure separate from the electricity grid.
<b>Addressable Market</b>	Puerto Rico has 106,446 trucks on the island which may travel about 35,000 miles per year, consuming approximately 466 million gallons of diesel per year. At 10 miles per kilogram, 100% conversion to FC trucks would consume 372,000 tons/year of hydrogen	<b>Considerations</b>	

# Hydrogen for municipal vehicles including waste hauling trucks and transit buses

<b>Description</b>	Build out hydrogen depot-based fueling infrastructure for heavier municipal vehicles, including waste hauling trucks and transit buses	<b>Alternatives</b>	Buses and municipal trucks are reasonably strong candidates for electrification. Perhaps 25% of the trucks and buses could be converted to hydrogen for more demanding routes
<b>Problem Statement</b>	Transportation emissions are high, fuel costs are high and variable, petroleum handling has negative environmental impacts.	<b>Supply Chain</b>	Renewable energy, electrolyzers, hydrogen tube trailers, liquid hydrogen production, liquid hydrogen trailers, fueling stations, dispensing equipment, fuel cell trucks and buses
<b>Hydrogen Source</b>	Hydrogen will be produced on island from renewable energy sources including wind, solar, hydropower and biogenic sources	<b>Benefits</b>	Provides a zero emission, short refueling time, long range option for trucks and buses and an on-island fuel source stabilizing prices and reducing imports
<b>Hydrogen Distribution</b>	Hydrogen will be distributed in gaseous form to filling stations via high-capacity tube trailers. As demand for hydrogen as a transportation fuel increases, distribution may shift to liquified hydrogen.	<b>Challenges</b>	Requires significant investment for the refueling infrastructure, fuel costs are at least twice as high as for electric vehicles, requires twice as much renewable energy than for equivalent for electric vehicles
<b>Hydrogen End-Use</b>	Hydrogen will be dispensed to municipal depots, stored and dispensed to waste hauling trucks and transit buses.	<b>Fit with Puerto Rico</b>	There is a moderate to strong fit with Puerto Rico as it provides benefits to larger trucks over electrification. It also benefits from a fuel infrastructure separate from the electricity grid.
<b>Addressable Market</b>	Puerto Rico has 3,698 buses on the island which may travel about 40,000 miles per year, consuming approximately 15 million gallons of diesel per year. At 12 miles per kilogram, 100% conversion to FC heavy vehicles, municipal trucks and buses would consume 12,000 tons/year of hydrogen	<b>Considerations</b>	

# Fuel for drayage trucks and materials handling in ports

<b>Description</b>	Build out a hydrogen fueling infrastructure in Puerto Rico's ports targeting drayage trucks and cargo handling equipment, with the focus on the Port of San Juan.	<b>Alternatives</b>	Electrification of drayage trucks provides port operators an alternative to diesel. The value proposition on materials handling is favorable for switching to hydrogen and fuel cells.
<b>Problem Statement</b>	Transportation emissions are high, fuel costs are high and variable, petroleum handling has environmental impacts.	<b>Supply Chain</b>	Renewable energy, electrolyzers, hydrogen tube trailers, liquid hydrogen production, liquid hydrogen trailers, dispensing equipment, fuel cell drayage trucks & fuel cell container handlers
<b>Hydrogen Source</b>	Hydrogen will be produced on island from renewable energy sources including wind, solar, hydropower and biogenic sources	<b>Benefits</b>	Provides a zero emission quick refueling option for drayage trucks and materials handling equipment, eliminating the concerns over battery waste and recharging logistics.
<b>Hydrogen Distribution</b>	Hydrogen will be distributed in gaseous form to the ports via high-capacity tube trailers. A high penetration of fuel cell vehicles may warrant liquid hydrogen production and distribution.	<b>Challenges</b>	Requires significant investment for the refueling infrastructure, fuel costs are at least twice as high as for electric vehicles, requires twice as much renewable energy than for equivalent for electric vehicles
<b>Hydrogen End-Use</b>	Hydrogen will be dispensed to drayage trucks and materials handling equipment in the ports via fuel dispensing equipment.	<b>Fit with Puerto Rico</b>	There is a strong fit with Puerto Rico as it provides benefits to larger trucks over electrification. It also benefits from a fuel infrastructure separate from the electricity grid.
<b>Addressable Market</b>		<b>Considerations</b>	

# Hydrogen and hydrogen derivative fuels for ships including container ships, cruise ships, support ships, etc.

<b>Description</b>	Produce ammonia or methanol for powering ships, to be sourced from renewable energy, combined with either nitrogen for ammonia or a source of carbon for methanol production	<b>Alternatives</b>	Ships have few alternatives for decarbonization other than ammonia and methanol. Some are pursuing onboard carbon separation. Some low carbon fuels will likely be imported.
<b>Problem Statement</b>	The global shipping industry, through the auspices of the International Maritime Organization, as well as through their own efforts, are promulgating new carbon reduction rules for ships.	<b>Supply Chain</b>	Renewable energy, electrolyzers, fuel synthesis plants, ammonia and methanol trailer trucks, fuel dispensing equipment, alternative fuel ready ships.
<b>Hydrogen Source</b>	Hydrogen will be produced on island from renewable energy sources including wind, solar, hydropower and biogenic sources, and converted to ammonia or methanol.	<b>Benefits</b>	Provides a solution for ships to refuel with low carbon fuels. Builds a new line of business for Puerto Rico, other than reselling bunker fuel.
<b>Hydrogen Distribution</b>	Hydrogen will be distributed on island in liquid form via ammonia or methanol on trailer trucks. As volumes increase, the use of pipelines will likely be more economical.	<b>Challenges</b>	The pace of deployment will be wholly contingent on the pace of ships built to operate on methanol or ammonia, and the selection of Puerto Rico as a route to decarbonize.
<b>Hydrogen End-Use</b>	Hydrogen will be converted to liquid ammonia or methanol and dispensed to ships in the Port of San Juan.	<b>Fit with Puerto Rico</b>	Strong opportunity although moderate fit with Puerto Rico, although the scale economies of ammonia production may be better elsewhere.
<b>Addressable Market</b>		<b>Considerations</b>	

# Producing Sustainable Aviation Fuel or hydrogen for aircraft

<b>Description</b>	Produce and provide sustainable aviation fuel or hydrogen to fuel aircraft.	<b>Alternatives</b>	Aircraft can decarbonize via offsets, sustainable aviation fuel, use liquid hydrogen or electricity. Offsets are considered ineffective and electricity not suitable for large aircraft.
<b>Problem Statement</b>	Airlines are responsible for 2% of global carbon emissions and are interested in finding ways to decarbonize flight operations. Solutions are extremely limited.	<b>Supply Chain</b>	Renewable energy, electrolyzers, fuel synthesis plants, SAF ships or pipelines, blending plants
<b>Hydrogen Source</b>	Hydrogen will be produced on island from renewable energy sources including wind, solar, hydropower and biogenic sources, and converted to sustainable aviation fuel.	<b>Benefits</b>	Provides significant emissions reduction and is easy to implement as a drop in fuel for existing aircraft.
<b>Hydrogen Distribution</b>	Sustainable aviation fuel will be transported to the airport via ship or pipeline depending on volume.	<b>Challenges</b>	Requires a large source of carbon and large investment in processing and blending infrastructure
<b>Hydrogen End-Use</b>	Sustainable aviation fuel will be blended with conventional kerosene and distributed to aircraft via existing aviation fuel distribution systems including pipelines, storage and fueling trucks.	<b>Fit with Puerto Rico</b>	There is a strong fit with Puerto Rico as it provides benefits to the airline industry and generates new economic activity for Puerto Rico.
<b>Addressable Market</b>		<b>Considerations</b>	

# Distributed energy storage with hydrogen for critical facilities

<b>Description</b>	Implement long term electricity storage using hydrogen at critical facilities including police, fire, health care, communications, water and sewerage.	<b>Alternatives</b>	Battery systems and diesel generators also provide backup power. Battery systems are limited in the duration they are able to provide, and diesel is subject cost and supply disruptions.
<b>Problem Statement</b>	Resilience is a key priority given the historic vulnerability of Puerto Rico's infrastructure to hurricanes.	<b>Supply Chain</b>	Renewable energy, electrolyzers, compressors, storage vessels, fuel cells, power controllers
<b>Hydrogen Source</b>	Hydrogen will be produced on site at the critical facilities either by on-site solar photovoltaics or use of the power grid. Alternative is delivered gaseous hydrogen.	<b>Benefits</b>	Provides a long duration power solution to critical facilities in the event of power outages or disruptions. When integrated with onsite solar, will provide limited power on a continuous basis.
<b>Hydrogen Distribution</b>	Onsite generation does not require distribution. If distribution is pursued, will be done through small trucks with k-cylinders of hydrogen.	<b>Challenges</b>	Capital requirements are high requiring subsidization.
<b>Hydrogen End-Use</b>	Hydrogen will be used to power fuel cells for power generation.	<b>Fit with Puerto Rico</b>	There is a strong fit with Puerto Rico as a resilience solution.
<b>Addressable Market</b>		<b>Considerations</b>	

# Distributed energy storage with hydrogen for grid resilience with minigrids and microgrids

<b>Description</b>	Integrate hydrogen production, storage and fuel cell power generation with minigrids and microgrids for resilience and reliability.	<b>Alternatives</b>	Battery systems and diesel generators also provide backup power. Battery systems are limited in the duration and diesel is subject cost and supply disruptions.
<b>Problem Statement</b>	Resilience is a key priority given the vulnerability of the Puerto Rico's infrastructure to hurricanes. Efforts to improve resilience includes developing distributed generation.	<b>Supply Chain</b>	Renewable energy, electrolyzers, compressors, storage vessels, fuel cells, power controllers
<b>Hydrogen Source</b>	Hydrogen will be produced on site integrated with the minigrids and microgrids using onsite solar or the grid.	<b>Benefits</b>	Improves availability of electricity for customers on the minigrids and microgrids.
<b>Hydrogen Distribution</b>	Onsite generation does not require distribution. If distribution is pursued, will be done through small trucks with k-cylinders of hydrogen likely in six packs.	<b>Challenges</b>	Capital requirements are high requiring subsidization.
<b>Hydrogen End-Use</b>	Hydrogen will be used to operate fuel cells for power generation.	<b>Fit with Puerto Rico</b>	There is a strong fit with Puerto Rico as a resilience solution.
<b>Addressable Market</b>		<b>Considerations</b>	

# Long duration hydrogen storage for grid balancing and price arbitrage with high penetration variable renewable energy

<b>Description</b>	Build out large volume underground hydrogen storage for seasonal energy storage to feed gas combustion turbines for power generation, grid balancing and energy price arbitrage	<b>Alternatives</b>	The alternative is using dispatchable power to generate power during peak demand times including natural gas and hydropower. Batteries to absorb curtailed power are not cost effective.
<b>Problem Statement</b>	Puerto Rico's plan for a high level of variable renewable energy on the grid will create significant imbalances between under and oversupply, including significant RE curtailment.	<b>Supply Chain</b>	Renewable energy, electrolyzers, storage compressors, gas combustion turbines
<b>Hydrogen Source</b>	Hydrogen will be produced via large scale renewable energy sources, principally wind power, and stored in underground caverns for multi-week storage	<b>Benefits</b>	Provides grid balancing, absorbs curtailed renewable energy, and provides dispatchable power to meet peak demand.
<b>Hydrogen Distribution</b>	Hydrogen will be consumed in the place it is stored, not requiring any distribution.	<b>Challenges</b>	High capital requirements and significant construction costs for building out the geologic storage.
<b>Hydrogen End-Use</b>	Hydrogen will be used to generate power using gas combustion turbines.	<b>Fit with Puerto Rico</b>	There is a strong fit with Puerto Rico as a solution to providing balancing with high renewable energy penetration on an islanded grid.
<b>Addressable Market</b>		<b>Considerations</b>	

# Ammonia production for domestic consumption and export

<b>Description</b>	Build out large scale ammonia production facility, integrating wind power and solar power with a Haber-Bosch ammonia production plant including air separation units for nitrogen production	<b>Alternatives</b>	The alternative is to import ammonia and not participate in the export opportunity. .
<b>Problem Statement</b>	Puerto Rico has limited means to create value domestically.	<b>Supply Chain</b>	Renewable energy, electrolyzers, Haber-Bosch processing plant, air separation units for nitrogen production, ammonia distribution systems
<b>Hydrogen Source</b>	Hydrogen will be produced via large scale renewable energy sources, principally wind power and solar power.	<b>Benefits</b>	Provides a domestic source of fertilizer production and creates an export market for Puerto Rico.
<b>Hydrogen Distribution</b>	Hydrogen will be consumed in the place it is produced, not requiring any distribution. The ammonia will require distribution, which will take place by trailer truck, pipelines, barges and ships.	<b>Challenges</b>	High capital requirements and significant construction costs and the importance of achieving scale to achieve economies of scale to be competitive in the Caribbean and Gulf States markets
<b>Hydrogen End-Use</b>	Hydrogen will be used to produce ammonia. Ammonia can be used to produce power on the island, used to produce fertilizer used on the island, and be exported.	<b>Fit with Puerto Rico</b>	There is a strong fit with Puerto Rico
<b>Addressable Market</b>		<b>Considerations</b>	

# Methanol production for domestic consumption and export

<b>Description</b>	Build out large scale ammonia production facility, integrating wind power and solar power to produce hydrogen for methanol production. Will require a source of carbon such as biomass.	<b>Alternatives</b>	The alternative is to import methanol and not participate in the export opportunity.
<b>Problem Statement</b>	Puerto Rico has limited means to create value domestically.	<b>Supply Chain</b>	Renewable energy, electrolyzers, methanol synthesis plant, carbon processing plant, methanol distribution systems
<b>Hydrogen Source</b>	Hydrogen will be produced via large scale renewable energy sources, principally wind power and solar power.	<b>Benefits</b>	Provides a domestic source of methanol and creates an export market for Puerto Rico.
<b>Hydrogen Distribution</b>	Hydrogen will be consumed in the place it is produced, not requiring any distribution. The methanol will require distribution, which will take place by trailer truck, pipelines, barges and ships.	<b>Challenges</b>	High capital requirements and significant construction costs and the importance of achieving scale to achieve economies of scale to be competitive in the Caribbean and Gulf States markets
<b>Hydrogen End-Use</b>	Hydrogen will be used to produce methanol. Methanol is an industrial feedstock that will be used on the island and exported.	<b>Fit with Puerto Rico</b>	There is a strong fit with Puerto Rico
<b>Addressable Market</b>		<b>Considerations</b>	

# Blend ammonia with fuel for combustion turbines and coal fired power generation

<b>Description</b>	Source ammonia for power generation, blending with natural gas as a fuel in combustion turbines, or in the oil fired power plant	<b>Alternatives</b>	The alternative is to reduce power generation emissions by deploying solar power and wind power, and importing ammonia instead of producing it on the island
<b>Problem Statement</b>	Puerto Rico is seeking to reduce emissions of power generation	<b>Supply Chain</b>	Renewable energy, electrolyzers, ammonia synthesis plant, ammonia distribution systems
<b>Hydrogen Source</b>	Hydrogen will be produced via large scale renewable energy sources, principally wind power and solar power and converted into ammonia, or the ammonia is sourced from off the island	<b>Benefits</b>	Provides a domestic source of ammonia and creates a potential export market for Puerto Rico in addition to supplying ammonia to the on island power plants.
<b>Hydrogen Distribution</b>	Hydrogen will be consumed in the place it is produced, not requiring any distribution. The ammonia will require distribution, which will take place by trailer truck, pipelines, barges and ships.	<b>Challenges</b>	Economics of using ammonia for power generation are poor with renewable assets better used for generating electricity directly instead of producing ammonia for power generation.
<b>Hydrogen End-Use</b>	Hydrogen will be used to produce ammonia for power generation.	<b>Fit with Puerto Rico</b>	There is no fit with Puerto Rico's envisioned goals and objectives
<b>Addressable Market</b>		<b>Considerations</b>	

# Evaluation criteria and considerations

## Evaluation Criteria

- Readiness
- Fit with needs
- Economics
- Timing
- Uncertainty
- Operational considerations
- Capital formation

## Characterization

- Description
- Technology
  - Production
  - Distribution
  - Use
- Addressable market
- Economics
- Competing alternatives
- Supply chain
- Other considerations

# The timing of hydrogen deployments is subject to an array of factors

- ▶ **Market demand** – For example, the demand for ammonia for maritime fuel is subject to international agreements and competing low carbon alternatives and is highly uncertain at this time
- ▶ **Economic viability** – The “willingness to pay” is an important factor considering the price gap that may exist between existing fuel prices and hydrogen alternatives
- ▶ **Scale** – The scale of a hydrogen project will influence the timing, with larger projects being more challenging to deploy quickly due to permitting, design and other factors
- ▶ **Complexity** – Projects that require integrated solutions will take longer to deploy, such as combined wind and solar hydrogen production combined with ammonia production
- ▶ **Importance to Puerto Rico** – Certain hydrogen projects may be fast tracked to address specific solutions for Puerto Rico, such as grid resilience.

# Hydrogen use case characterization

		Carbon Reduction	Economic Viability	Resilience Impact	Economic Growth	Inclusivity/ Job Creation	Timing	Hydrogen Required
1	Hydrogen fuel for light passenger vehicles	5	4	1	3	2	4	4
2	Trucks and heavy duty on-road transport	4	5	1	3	2	5	3
3	Hydrogen for municipal trucks and transit buses	3	5	1	3	2	5	3
4	Fuel for drayage trucks and materials handling in ports	3	5	1	3	2	5	3
5	Fuel for ships	4	2	1	4	4	2	4
6	Producing Sustainable Aviation Fuel or hydrogen for aircraft	4	3	1	4	4	2	4
7	Distributed energy storage with hydrogen for critical facilities	1	4	4	1	1	4	1
8	Distributed energy storage with microgrids	1	4	4	1	1	4	1
9	Long duration hydrogen storage for grid balancing	4	2	3	4	3	2	4
10	Ammonia production for domestic consumption and export	2	2	1	5	5	3	5
11	Methanol production for domestic consumption and export	2	2	1	5	5	3	5
12	Blend ammonia with fuel for power generation	5	2	2	4	4	3	4
13	Utilize hydrogen fuel cells for distributed power generation	2	2	5	2	2	4	1
14	Hydrogen for materials handling and forklifts in warehouses	1	5	1	2	1	5	1
15	Hydrogen for cell tower backup power	1	5	5	1	1	5	1

On a preliminary basis, we have provided sequenced timing of potential hydrogen initiatives for Puerto Rico, considering a variety of factors that influence timing.

		2025 - 2030	2030 - 2035	2035 - 2040	2040 - 2045	2045 - 2050
1	Hydrogen fuel for light passenger vehicles			→	→	→
2	Trucks and heavy duty on-road transport		→	→	→	→
3	Hydrogen for municipal trucks and transit buses	→	→	→	→	→
4	Fuel for drayage trucks and materials handling in ports	→	→	→	→	→
5	Fuel for ships				→	→
6	Producing Sustainable Aviation Fuel or hydrogen for aircraft				→	→
7	Distributed energy storage with hydrogen for critical facilities		→	→	→	→
8	Distributed energy storage with microgrids		→	→	→	→
9	Long duration hydrogen storage for grid balancing			→	→	→
10	Ammonia production for domestic consumption and export		→	→	→	→
11	Methanol production for domestic consumption and export			→	→	→
12	Blend ammonia with fuel for power generation		→	→	→	→
13	Utilize hydrogen fuel cells for distributed power generation		→	→	→	→
14	Hydrogen for materials handling and forklifts in warehouses	→	→	→	→	→
15	Hydrogen for cell tower backup power	→	→	→	→	→