Puerto Rico Energy Bureau

Puerto Rico Hydrogen Strategy

Technical Workshop 3

April 11, 2023

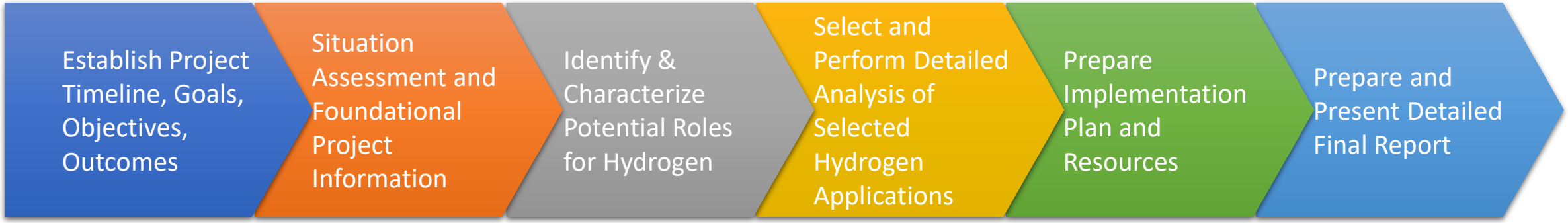
Brad Bradshaw
Steven Thomas
Charlie Krueger
Velerity LLC

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.



The priorities within the hydrogen roadmap for Puerto Rico has to be developed within the context of Puerto Rico's current situation and future plans

Situation

- High carbon emissions
- Expensive mix of fuel for power generation
- Challenging economic circumstance
- Frequent storms with devastating impacts on infrastructure and people's lives
- Power system resilience

Goals and Performance Metrics

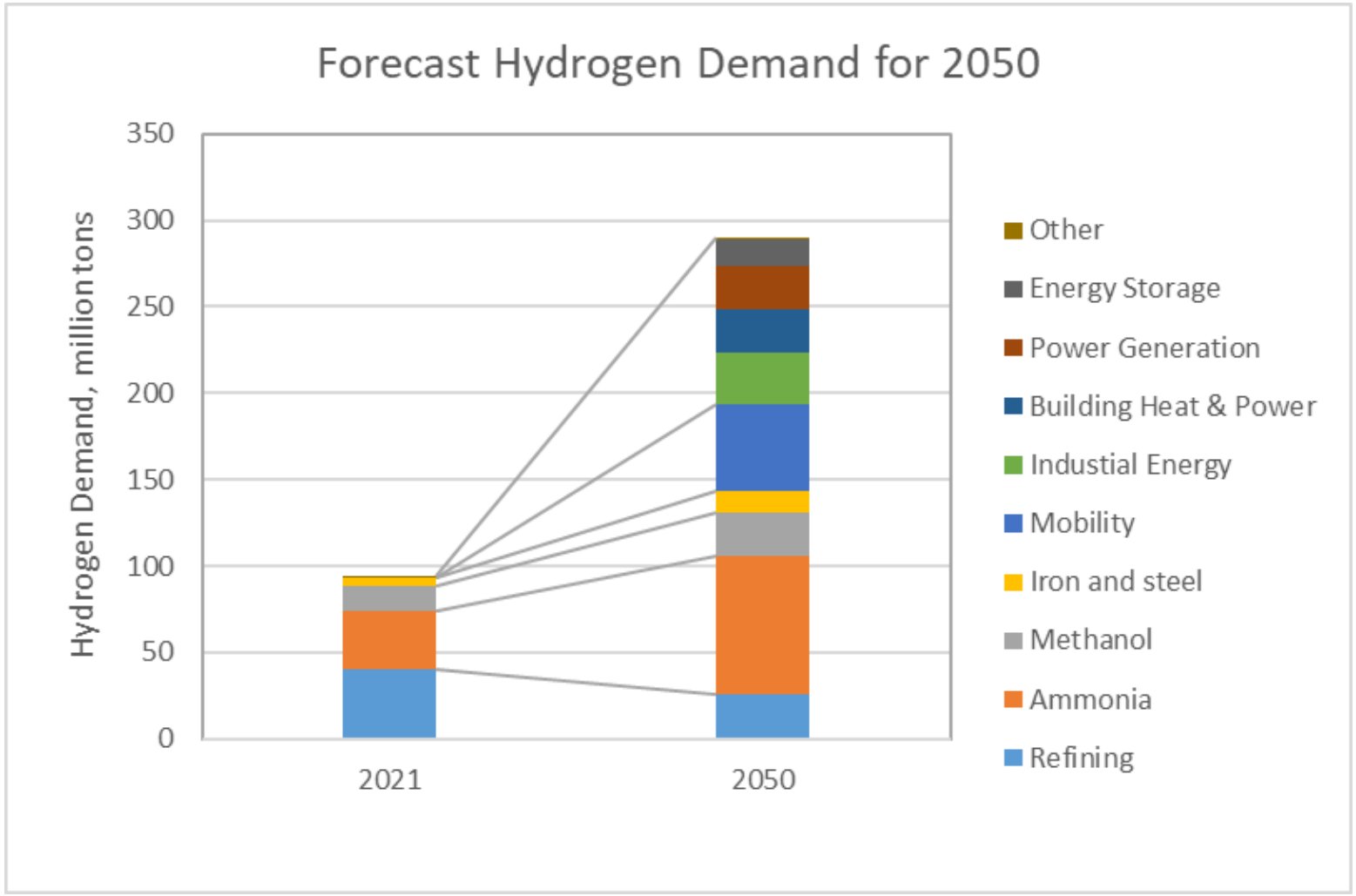
- Advance economic interests / create jobs
- Improve grid resilience / reduce recovery speed
- Lower power costs
- Reduce carbon emissions
- Reduce imports
- Reduce debt
- Provide benefits to the people of Puerto Rico

Guardrails for Hydrogen Policy

- Land use
- Rooftop solar plus storage
- Utility scale solar
- Energy storage
- Water constraints
- Electric vehicle adoption
- High-cost fuel for power generation (petroleum)

In 2019, the Puerto Rico legislature passed the Puerto Rico Energy Public Policy Act (Act 17), setting a goal for the commonwealth to meet 100% of its electricity needs with renewable energy by 2050, with interim targets of 40% by 2025, 60% by 2040, the phaseout of coal-fired generation by 2028, and a 30% improvement in energy efficiency by 2040.

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

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***

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

Hydrogen Use Cases	**Transportation**	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
	Grid Resilience & Stability	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

Hydrogen Use Cases	**Industrial Feedstock**	10.	Ammonia production for domestic consumption and export
		11.	Methanol production for domestic consumption and export
	Power Generation	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
	Other	15.	Hydrogen for materials handling and forklifts in warehouses
		16.	Hydrogen for cell tower backup power

Based on an evaluation of potential use cases, a smaller set was selected for detailed analysis

- Ammonia production with offshore wind for multiple uses
- Hydrogen fuel for heavy vehicles including commercial trucks, municipal vehicles and ports
- Long duration energy storage with hydrogen for grid balancing
- eFuel production for sustainable aviation fuel
- Hydrogen for backup power
- Ammonia or hydrogen power generation
- Hydrogen or derivatives for powering microgrids
- Hydrogen or derivatives to provide thermal energy for industrial processes

The selection and prioritization of hydrogen initiatives for Puerto Rico is a function of multiple factors

Considerations for setting hydrogen priorities

- Economics and customer willingness to pay
- Technical potential
- Market adoption and timing
- Regulatory drivers
- Financial incentives
- Availability of capital
- Motivated market participants
- Impact on carbon emissions
- Ability to enable and support Puerto Rico's energy system priorities

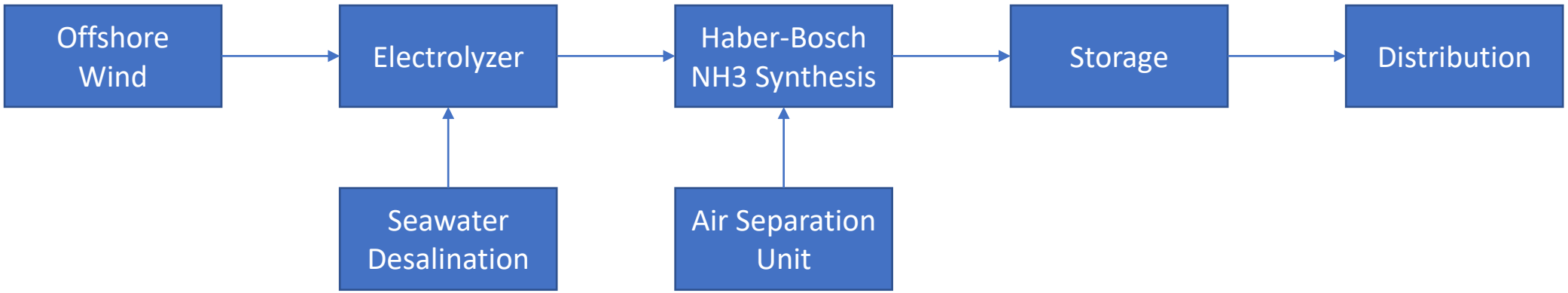
Factors influencing timing

- Economics compared to alternatives
- Technical potential
- Technology readiness
- Network effect - externalities

VELERITY

Offshore wind to ammonia represents a significant opportunity for Puerto Rico

- Offshore wind dedicated for ammonia production for multiple uses including:
  - Fertilizer production for Puerto Rico
  - Ammonia for export
  - Ammonia for shipping fuel
  - Ammonia for power generation
- Configuration



Offshore wind to hydrogen – initial parameters

- 1 GW offshore wind farm
  - 100 turbines, 10 MW each
  - Power production - 4,204,800 MWh/yr
- Electrolyzer
  - 1 GW
  - Hydrogen production - 87,600 tons/yr
- Haber Bosch Ammonia Production
  - Ammonia production - 494,635 tons/yr
- Desalination Plant
  - Water production - 192,000,000 liters/yr

VELERITY

Hydrogen fuel for heavy vehicles including commercial trucks, municipal vehicles and ports

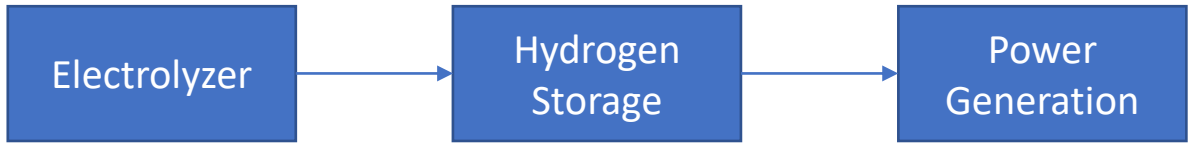
- Acquire, distribute and dispense hydrogen for refueling heavy vehicles, including:
  - Commercial vehicles
  - Municipal vehicles including trash trucks and buses
  - Materials handling and drayage trucks in Puerto Rico's ports
- Profile
  - Number of stations 125
  - Daily H2 dispensing 5.1 tons/day

Type	Number of Vehicles	H2 Fuel, tons/yr
Trucks	106,446	231,265
Buses	3,698	3,614
Total	110,144	234,879

VELERITY

Long duration energy storage with hydrogen for clean energy balancing

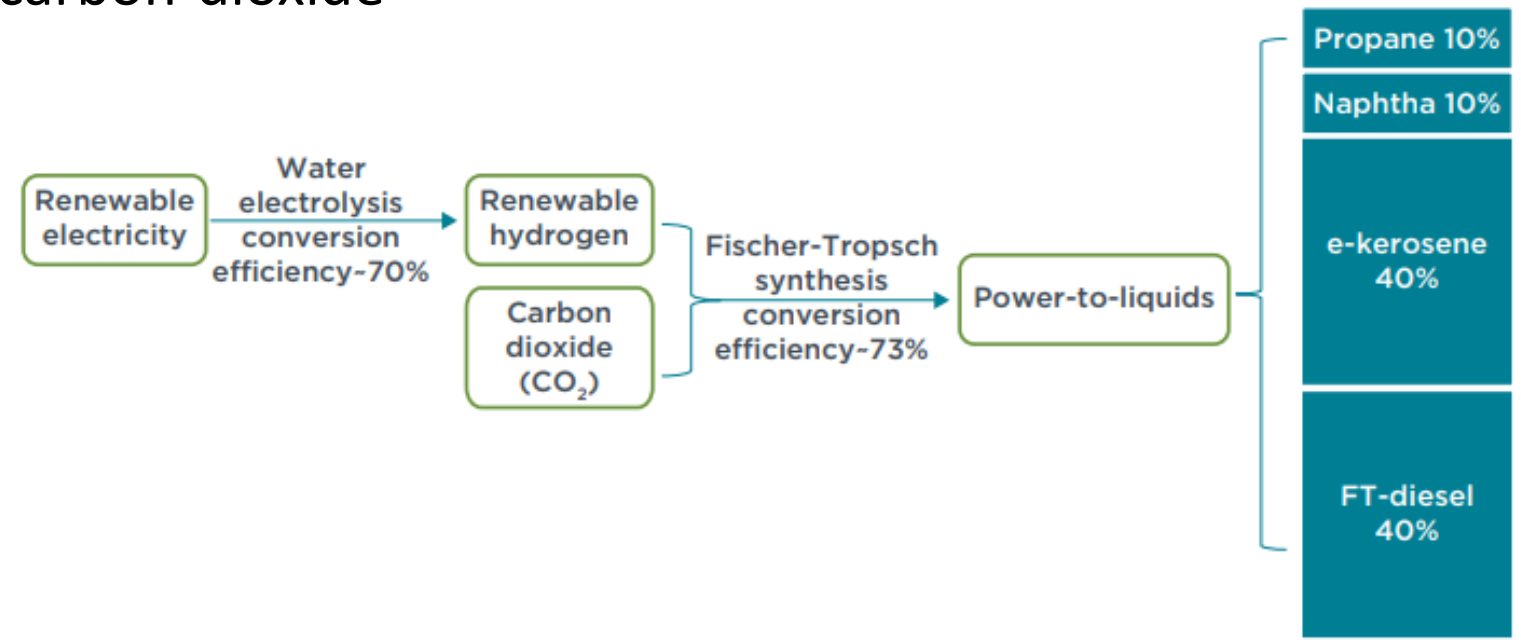
- Build a hydrogen generation, storage and generation system that generates hydrogen during times of energy overproduction, stores the hydrogen, then regenerates electricity during low RE production times
- Design system for 2030 timeframe
- Electrolyzer – 400 MW
- Hydrogen Storage – 1,000 tons, lined rock storage
- Power generation – 200 MW combined cycle gas turbine (100% hydrogen)
- Cycles per year – 24
- Includes water desalination



VELERITY

Sustainable Aviation Fuel

- Puerto Rico imports 180,351,234 gallons/yr of jet fuel
- This quantity of jet fuel is responsable for approximately 2.2 million tons per year of carbon dioxide emissions
- The process exists to produce synthetic kerosene with renewable hydrogen and captured carbon-dioxide



VELERITY

Sustainable Aviation Fuel

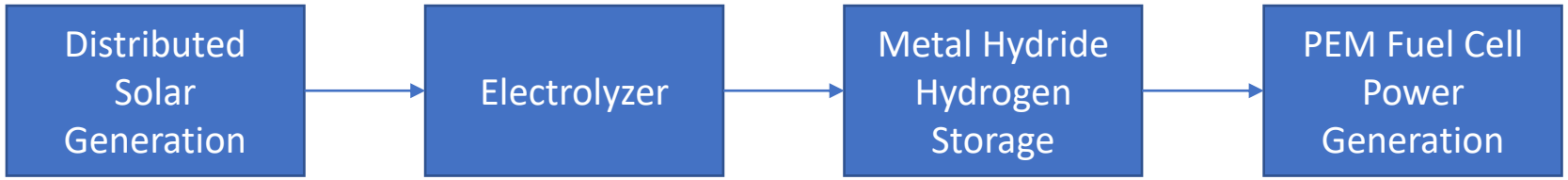
- Imports of aviation fuel to PR amount to 700,000 tons per year.
- Burning 700,000 tons per year of aviation fuel will emit 2.2 million tons per year of CO2
- To make that much kerosene using CO2 and renewable hydrogen at a 40% yield would require 5.5 million tons per year of CO2 and 0.75 million tons per year of hydrogen. Not all of the carbon ends up in the e-fuel of choice, but most of it will end up as a hydrocarbon of some sort.
- The rest of the energy contained in the hydrogen would be present in the form of non-kerosene hydrocarbons across a range of molecular weights and usable heat energy from the synthetic fuel process.
- The actual H2 going into the kerosene would only be 40% of the total.
- Such a project would be an enormous undertaking, requiring a large scale CO2 capture plant, a synthetic hydrocarbon production plant (for processing raw CO2 and H2 into fuels), and a refinery/purification/distillation facility to provide the final kerosene product. All of these technologies exist and are practiced at scale today (although synthetic fuels production is quite limited today in the world).

Power Generation – modelling under way

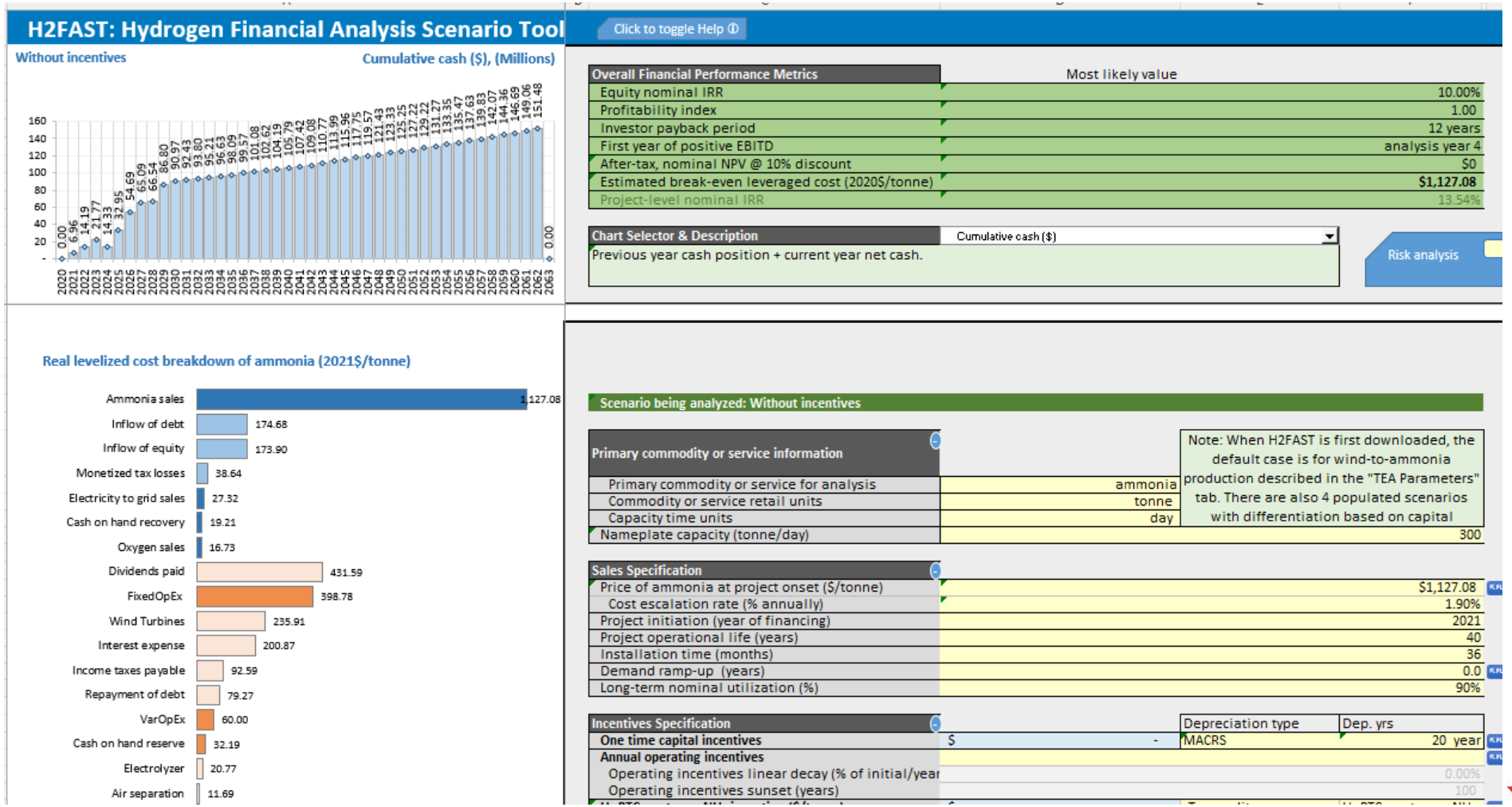
- Case 1 – Import blue ammonia for power generation
  - 300 MW power plant
  - Ammonia fired combined cycle gas turbine
- Case 2 – Produce green ammonia for power generation
  - 300 MW power plant
  - Produce green ammonia utilizing offshore wind
  - Ammonia fired combined cycle gas turbine
- Case 3 – Methane pyrolysis for power generation
  - Import LNG
  - Separate and use or sequester solid carbon using methane pyrolysis
  - Hydrogen fired combined cycle combustion turbine

Hydrogen for long duration distributed backup power

- Up to five days of onsite energy storage for critical loads and facilities
- Hydrogen generated using onsite solar energy or grid power



Detailed financial modelling using H2Fast



Next Steps

- Complete detailed initiative modelling
- Develop final recommendations on initiatives
- Develop implementation plan including policy and other recommendations

Leverage Markets and Industry → **Leverage Available Funding Mechanisms and Incentives** → **Integrate with Puerto Rico's Infrastructure Development** → **Legislation and Regulation**