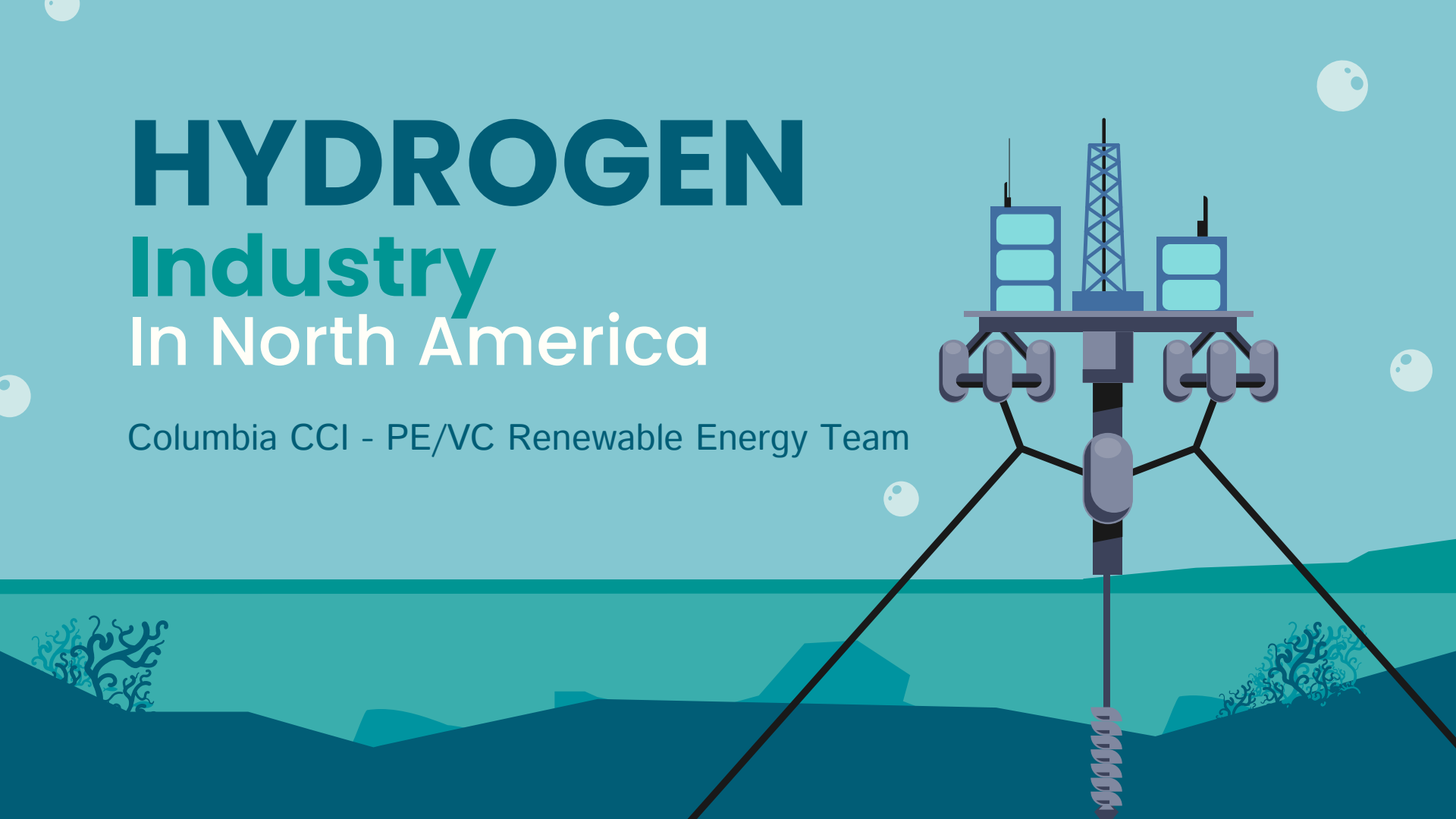
HYDROGEN
Industry
In North America

Columbia CCI - PE/VC Renewable Energy Team



Members Introduction

Xinyi Xian

SIPA MPA Energy & Env.
Archery and Piano

Lihui Yu

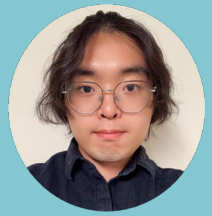
MSAA
Travel, Hiking, Kpop

Ziyi Shao

MSERM
Travel, Baking, Pilates

Jiajun Gu

MSOR
Hiking, Skateboarding, Karaoke



Mengle Hu

MSBA
Piano, Stand-up Comedian

Linhai Nie

MSERM
Basketball, Broadway shows

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Hydrogen: Key to Clean Energy

Clean and Renewable

- Hydrogen production via renewable-powered electrolysis emits not greenhouse gases
- Serves as a versatile energy carrier derived from renewable resources like solar and wind

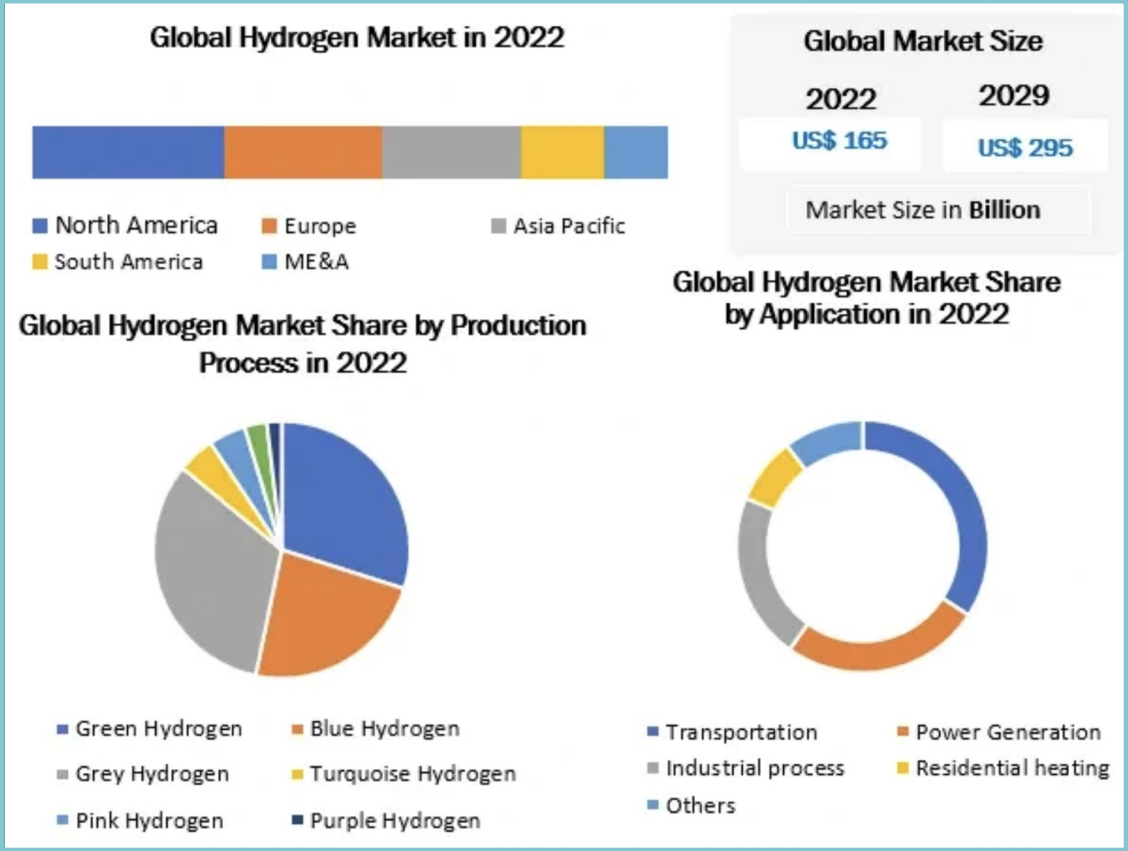
Significant Emission Reduction

- Capable of cutting annual CO2 emissions by up to seven gigatons by 2050
- Could account for over 20% of the required global emissions reductions to achieve net-zero

Rising Demand and Cost Competitiveness

- Anticipated to fulfill 660 million metric tons of global demand per year by 2050
- Expected decrease in production costs due to technological advancements and scale

Market Overview



Value Chain

Upstream

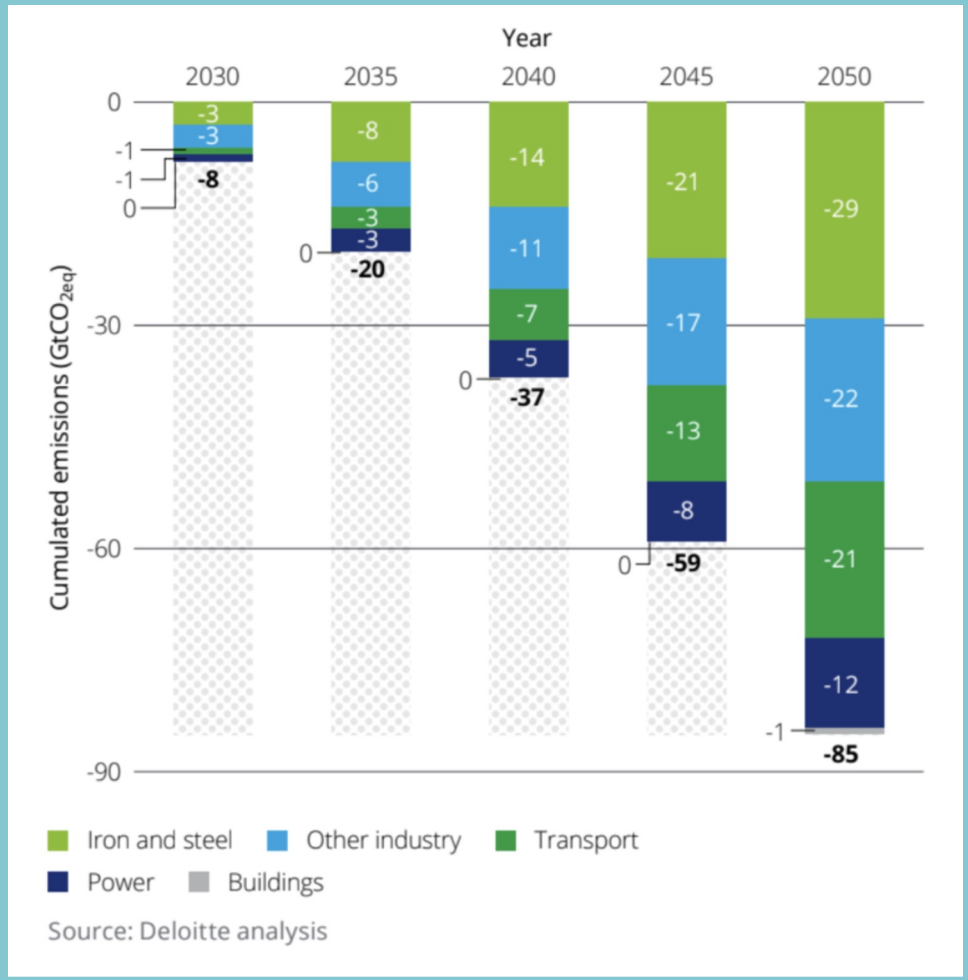
Natural Gas Reforming; Electrolysis

Midstream

Storage and Transportation

Downstream

Fuel Cells; Power Generation; Industrial Applications



GHG Emissions Abatement Unlocked by Clean Hydrogen, 2030 to 2050

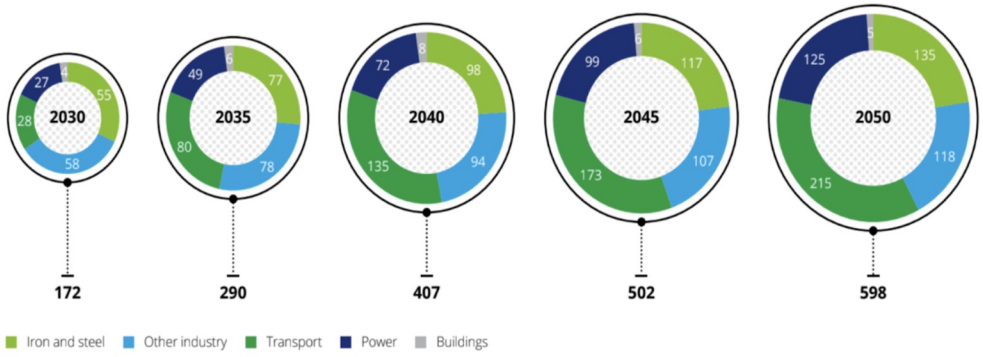
Achieve cumulative greenhouse gas emission abatement **up to 85 GtCO2eq** across industries by 2050:

- **Iron and Steel**: -29 GtCO2eq
- **Transportation**: -22 GtCO2eq
- **Power**: -12 GtCO2eq
- **Other Industries**: -23 GtCO2eq

Growing importance of clean hydrogen in global efforts to reduce carbon emissions and combat climate change

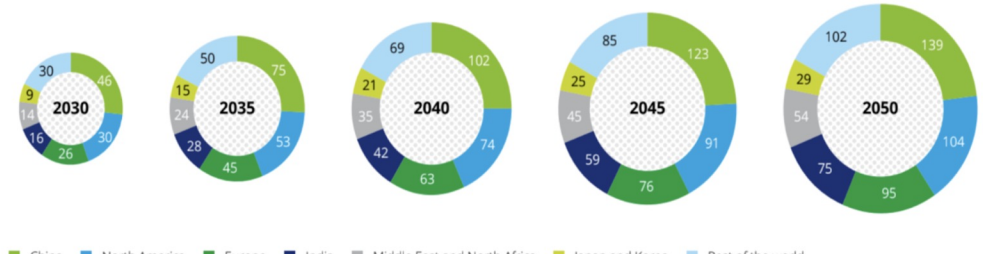
Rising Demand and Cost Competitiveness

Evolution of clean hydrogen demand by sector, 2030 to 2050 (MtH_{2eq})



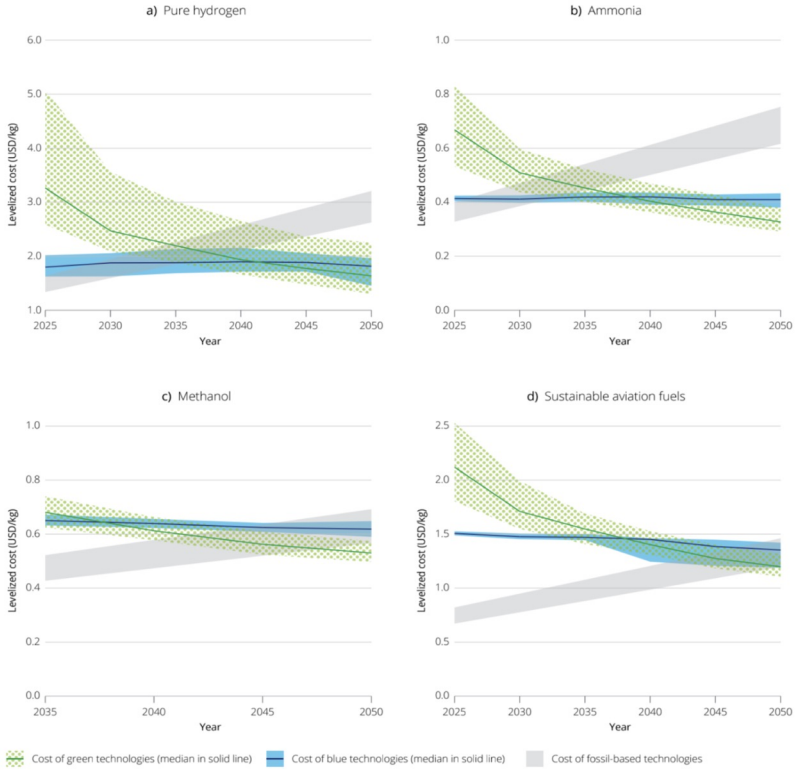
Source: Deloitte analysis

Regional demand for clean hydrogen and its derivatives, 2030 to 2050 (MtH_{2eq})



Source: Deloitte analysis

Outlook on production costs of clean hydrogen and its derivatives, 2025 to 2050



Policy Landscape

Inflation Reduction Act

- Signed into law in 2022
- The largest investment in clean energy and climate action ever
- Subsidies up to $3/kg of production tax credit (PTC) by carbon intensity ($/kg), for hydrogen with emissions under 4 kg CO2/kg H2
- Producers can qualify for low-carbon hydrogen and renewable energy tax credits (a PTC of up to 2.6 cents/kWh) simultaneously

Bipartisan Infrastructure Law

- Passed in late 2021
- Allocates $9.5 billion in direct grant programs for hydrogen production and infrastructure: $7 billion to establishing H2Hubs, $1 billion toward strengthening the demand for clean hydrogen, and $1.5 billion towards advancing electrolysis technologies and improving manufacturing and recycling capabilities for all clean-hydrogen technologies.

Hydrogen Production

Different production method

- Fossil-derived hydrogen
- Fossil-derived hydrogen with carbon capture
- Water via electrolysis

Environmental impact of analysis of each methods

The Landscape overview of hydrogen production trend

Environmental Impact

Fossil-derived hydrogen eg. Coal and Natural Gases

	Advantage	Disadvantage
Coal	Wealthy Resources, Low Cost, and Mature technology	The high emission of Greenhouse Gases
Natural Gases	Wealthy Resources, Low Cost	The high emission of Greenhouse Gases

Fossil-derived hydrogen with carbon capture eg. Coke-Oven Gas, Chlor-Alkali

	Advantage	Disadvantage
Coke-Oven Gas	Low Cost	Air pollution, construction sites are limited by raw materials
Chlor-Alkali	Abundant Raw material, High product purity	construction sites are limited by raw materials

Environmental Impact

Electrolysis eg. Alkaline Electrolysis, Proton exchange membrane electrolysis, solid oxide electrolysis cell

	Advantage	**Disadvantage**
Alkaline Electrolysis	Relatively mature technology, Low Cost	Gas production requires dehydrogenation and stable energy sources
Proton exchange membrane electrolysis	Flexible operation, small equipment size, High output pressure	Rare metals are required, cost is high and supply is large
solid oxide electrolysis cell	High Conversion Efficiency	The technology is immature and the hydrogen purity is low

Classification Based on hydrogen Colors

Production Method	**Description**
Gray Hydrogen	Produced from fossil fuels like natural gas through steam methane reforming (SMR)
Blue Hydrogen	Similar to gray but with carbon capture, utilization, and storage (CCUS) to reduce emissions
Green Hydrogen	Obtained from water via electrolysis using renewable energy sources

Overview of hydrogen production trend

- Dominated by Natural gas without CCUS and Coal for hydrogen production before 2021 with 62% and Composition with 19%
- Russia's invasion of Ukraine in early 2022 promotes a new transformation had directly increased the cost, which forces the alternative seeking of renewable hydrogen like electrolysis

2021 Cost of Low-Emission hydrogen production	Type	Cost (USD)
	Unabated Natural Gas	$1.0-2.5/kg
	Natural Gas with CCUS	$1.5-3.0/kg
	Electrolysis with renewable electricity	$4.0-9.0/kg
2022 Cost of Low-Emission hydrogen production	Unabated Natural Gas	$4.8-7.8/kg
	Natural Gas with CCUS	$5.3-8.6/kg
Prediction of 2030	Electrolysis from solar PV	$1.5/kg
Prediction of 2050 (in Good Solar Condition)	Electrolysis from solar PV	$1/kg

Table: Cost of Hydrogen Production
Sources: IEA (International Energy Agency)

Company 1: Bloom Energy

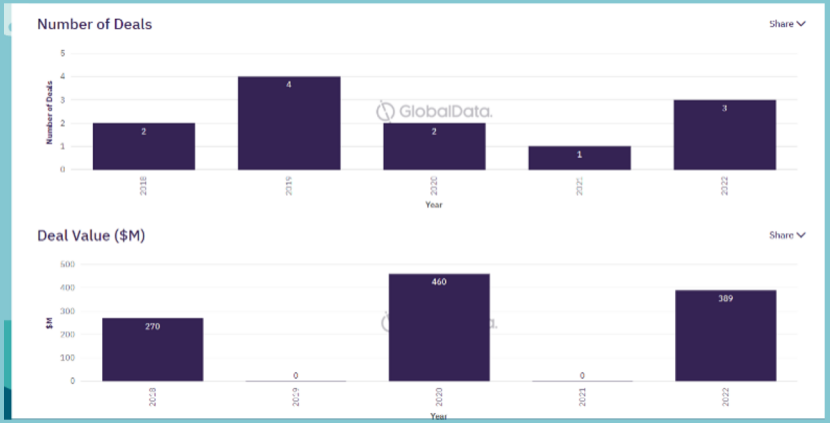
Global top 20 Hydrogen Electrolyzer Manufacturer

Introduction

Bloom Energy Corp is a renewable energy company based in San Jose, California, USA. The company utilizes fuel cell energy technology, producing air and fuel from electricity generated by solar panels. Additionally, it develops solid oxide fuel cell technology that converts fuel into electricity through an electrochemical process.

Financials

Ticker: BE (NYSE)
Market Cap: $3.2B
Revenue (2022): $1.2B



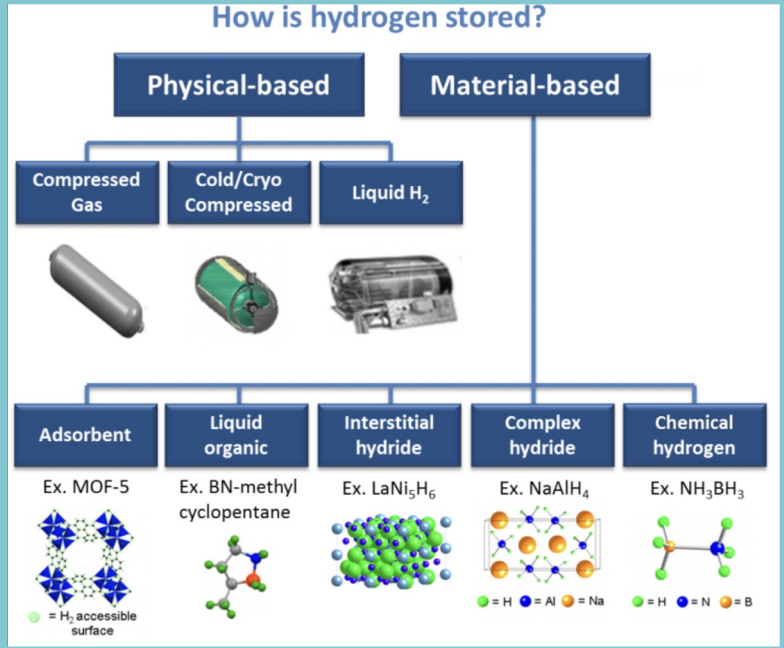
Product

Bloom Electrolyzer

- Solid oxide fuel cell-based power generation platform
- Electricity and hydrogen generation
- Applications include:
- Biogas energy
- Electrolyzers
- Hydrogen fuel cells
- Certified gas
- Microgrids
- Heat capture
- Carbon capture
- Marine fuel cell
- Primary power

Storage

Storage Method	Description
Gas	High- pressure tanks(350–700 bar [5,000–10,000 psi] tank pressure)
Liquid	Cryogenic temperatures (the boiling point of hydrogen at one atmosphere pressure is 252.8°C.
On the surfaces of solids or within solids	By absorption



Transportation

Transportation Method	Description
Gas	Hydrogen can be transported in gaseous form, typically in a pipeline. Because hydrogen gas is highly reactive, the pipeline or other container must be able to resist interacting with the gas. Hydrogen's low density at atmospheric pressure means that gas transport is suitable only for low volume requirements
Liquid	Hydrogen switches to the liquid phase at −253 °C (−423.4 °F). Thus, transporting liquid hydrogen requires sophisticated refrigeration technologies such as cryogenic tanker trucks and liquefaction plants.
Compound	Hydrogen can be reacted with other elements to form a variety of compounds. This allows it to be transported in either liquid (e.g., water) or solid form. One variation on this concept is to transport atomic silicon, produced using renewable energy. Mixing silicone with water separates water's oxygen from its hydrogen without requiring additional energy. The hydrogen can then be oxidized with the oxygen (or air) to produce energy (with water as the only byproduct).
Mechanochemical	Mechanochemistry refers to chemical reactions triggered by mechanical forces as opposed to heat, light, or electric potential. Ball milling can crush material such as boron nitride or graphene, allowing hydrogen gas to be absorbed by the powder, storing the hydrogen. The hydrogen can be released by heating the powder. These techniques offer the potential of substantial net energy savings.

Company 2: Air products and Chemicals, Inc.

01 Overview

Air Products supplier of industrial gases and equipment, specialty and intermediate chemicals, and environmental and energy systems.

02 Team

Air Products and Chemicals has ***13*** current employee profiles, including VP, Human Resources and Communications Lynn C. Minella.

Air Products and Chemicals has ***8*** board members and advisors, including Charles Cogut.

03 Products

Air Products and Chemicals uses 21 technology products and services including HTML5, jQuery, and Google Analytics, according to G2 Stack.

Company 2: Air products and Chemicals, Inc.

04 IPO & Stock price

IPO Date: Jan 13, 1978

05 Funding

Air Products and Chemicals is registered under the ticker : NYSE:APD
Air Products and Chemicals has made **2 investments**. Their most recent investment was on Jan 6, 2004, when PsiloQuest raised $7M.

Air Products and Chemicals has had **1 exit**, which was H2Gen Innovations.

Air Products and Chemicals has acquired **15 organizations**. Their most recent acquisition was Oxygen & Argon Works on Feb 12, 2020. They acquired Oxygen & Argon Works for $ 575M.

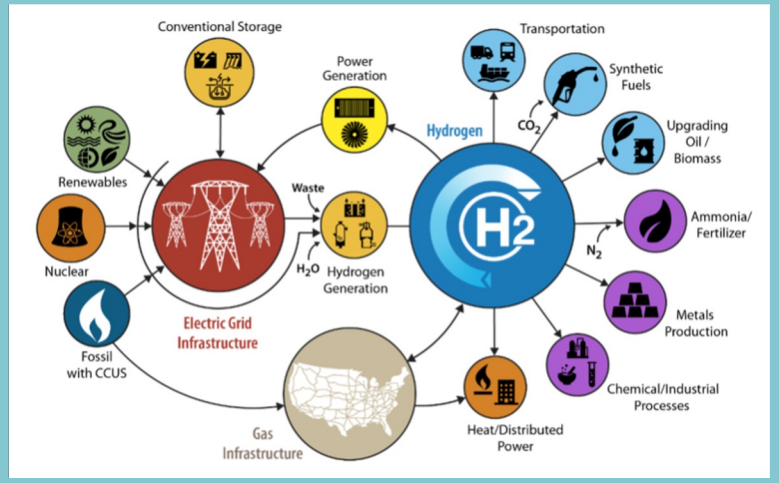
06 Highlight & Risk

- Speed
- State-of-the-art engineering, technology and manufacturing centers, strategically located in emerging markets
- Around the world
- be innovative in response to our customers' needs.

ESG Risk Ratings
Total ESG Risk Score: 12

Environment: 7.4
Risk: 1.5
Governance: 3.3

Utilization



Uses of Hydrogen:

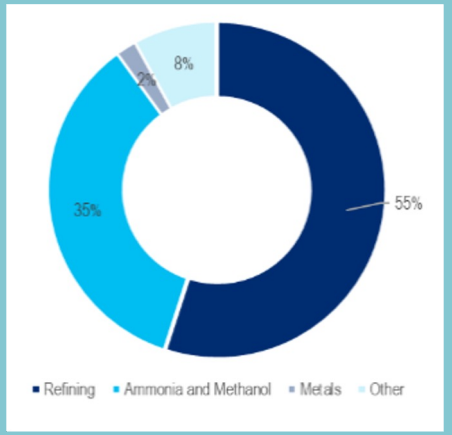
Fuel

- Fuel Cells
- Engines/Turbines
- Energy Storage

Chemical

- Petroleum Recovery & Refining
- Methanol Production
- Electronics
- Ammonia Production
- Metal Production & Fabrication
- Food Processing
- Cosmetics

Hydrogen Consumption in the US by End Market (2021)



Sources: Department of Energy, Citi Research, IHS Markit

Company 3: Plug Power

Industry: Hydrogen Fuel Cell
NASDAQ: PLUG

Overview: Plug Power is a pioneer in the hydrogen fuel cell industry. It created the first commercially viable market for hydrogen fuel cell technology. It has deployed an industry-leading 60,000 fuel cell systems for the e-mobility market (using electric powertrain technologies to power vehicles and fleets). It's one of the world's largest hydrogen buyers and operates a leading hydrogen refueling network in North America with more than 180 fueling stations.

Team: CEO Andy Marsh joined Plug as President and CEO in April 2008. Under his guidance, Plug has become the leading provider of turnkey hydrogen solutions for the global green hydrogen economy.

Risks: The company's exposure to changes in foreign currency rates is primarily related to sourcing inventory from foreign locations and operations of hyPulsion, S.a.S., its French subsidiary that develops and sells hydrogen fuel cell systems for the european material handling market. The Company does not hold any derivative products that are sensitive to market volatility.

Company 3: Plug Power

Fuel Cell Products

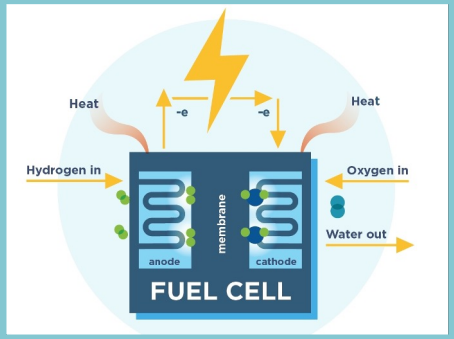
“ProGen” Fuel Cell Engines

- Flexible, power-building blocks for use in transportation and stationary power products
- Support light, medium, and heavy-duty EVs. Ex. AGVs, small robotics, light duty cargo trucks, long-haul trucking, etc.
- ProGen engines offer needed flexibility to OEM companies from low power to high

GenSure Backup Power

- Indoor and outdoor cabinet and container options
- Delivers reliable backup power over a range of operating environments, ranging from -40°F to 122°F

How Fuel Cell Works:

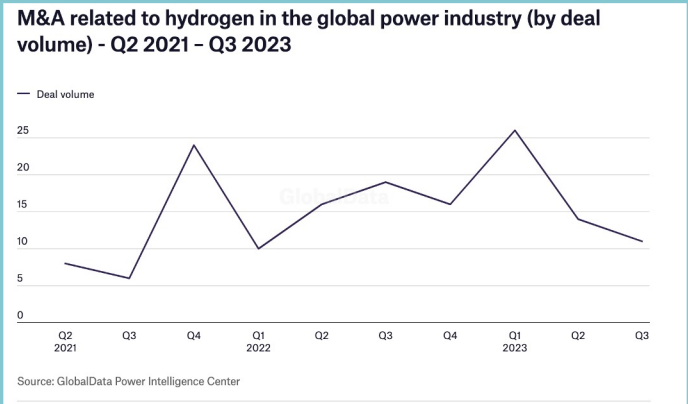


Unlike electrolyzers, which use electricity to split water into hydrogen and oxygen, fuel cells essentially operate **in reverse**. They generate electricity through a chemical reaction, typically using hydrogen as the fuel and oxygen from the air.

Key components of a hydrogen fuel cell include the anode, cathode, electrolyte, hydrogen supply, and oxygen supply. The most technologically advanced part of a fuel cell is often considered to be the **electrolyte**, which facilitates the movement of ions while preventing the direct mixing of hydrogen and oxygen gases.

Investment Opportunities

1. Analysis of the key themes driving M&A activity reveals that hydrogen accounted for 11 power deals announced in Q3 2023, worth a total value of $2.6bn. The $2.4bn minority acquisition of Avaada Energy by REC was the industry's largest disclosed deal. GlobalData's Power Industry Mergers and Acquisitions Deals report for Q3 2023 uncovers key trends behind the power market M&A deals and helps gain a comprehensive understanding of the disruptive themes driving most notable deals.
2. In value terms, hydrogen-related deal activity decreased by 24% in Q3 2023 compared with the previous quarter's total of $3.4bn and rose by 46% as compared to Q3 2022. Related deal volume decreased by 21% in Q3 2023 versus the previous quarter and was 42% lower than in Q3 2022.



Risk Assessment

Risk 1: Lack of Hydrogen Pipeline

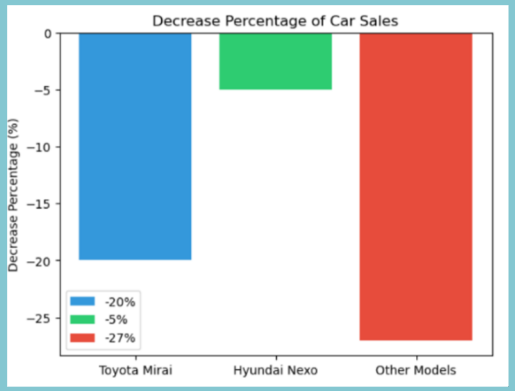
1. The requirements for Hydrogen Vehicle Corridors (HVD) include the condition that the distance between public hydrogen stations on the corridor should not exceed 100 miles.
2. More than 90% of these pipelines are located along the Gulf of Mexico in Texas, Louisiana, and Alabama

Thus

1. Lack of motivation to launch the pipeline project in other states
2. Expected time of investment return deprives investment motivation of potential investment institutions
3. The industry is still in early stage

Risk 2: Downstream Sales is Below Expectation

1. The annual sales of hydrogen fuel vehicles in 2022 were 2,707, **a 19% decrease compared to the previous year.**
2. The total number of fuel cell vehicles is on the rise.



Risk 3: Hydrogen Storage Technology

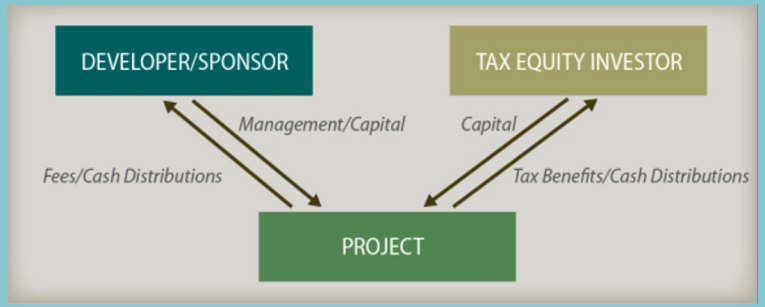
Hydrogen Storage and Distribution

1. Efficiency
2. Cost
3. Safety

Hydrogen Transportation Cost: 1.88$/kg - 0.119$/kg
Oil Transportation Cost: 0.0375$/kg - 0.147$/kg

Financing Method: Tax Equity

1. The IRA has given the implementation of ITC, PTC and additional bonus tax credits for certain renewable energy projects. For hydrogen projects, $3 per kg of hydrogen produced to projects with low lifecycle greenhouse gas emissions intensity is awarded.
2. The IRS is constantly giving out additional guidance on the Tax Equity front which will focus on pushing renewable energy forward.
3. To better understand what the Section 45V Hydrogen Production Tax Credit entails, it's important to gain clarity about what is being discussed when the term "qualified clean hydrogen" is used. First, the use of "qualified clean hydrogen" refers to a project that produces greenhouse gas emissions not exceeding 4kg of CO_2 per kg of hydrogen, and the corresponding tax credits are then organized in four tiers, which reward a greater tax credit to those who produce a considerably cleaner form of hydrogen.The first tier provides a 20% applicable percentage when the emissions rate ranges from 4kg to 2.5kg of CO_2 per kg of hydrogen.



Financing Method: Debt

1. Bonds
    a. Issuers of green bonds typically provide transparency about how the funds are being used. This often includes detailed reporting on the environmental impacts of the projects financed by the bonds.
    b. The green bond market has grown rapidly in recent years as more investors seek environmentally friendly investment options and as awareness of climate change increases.
2. Loans
    a. Bank loans work similarly to the types of loans we see normally. Hydrogen energy producers will enter the contract and pay back the portion of the principle loan and interest over a set period of time.

Findings and Conclusions

- The hydrogen energy industry works more like the start-up space with major players focusing more on investing potential technology breakthroughs. Infrastructure is a key investment trend in the US to transmit Green Hydrogen energy however it is slowed by the rise of interest rates like many other project based industries.
- The industry is also closely related to the amount of renewable energy being produced such as solar, wind, and geothermal and etc. The market is expected to reach 10% of overall energy production in the USA in the future.
- The green hydrogen supply chain is expected to experience significant growth and increasing demand in the near future.
- In the United States, policy incentives for the hydrogen supply chain primarily revolves around two pieces of legislation: the Bipartisan Infrastructure Law (BIL) and the Inflation Reduction Act (IRA).