Hydrogen on the Horizon

Webinar with North Florida Clean Fuels Coalition

CENTER FOR Hydrogen SAFETY™
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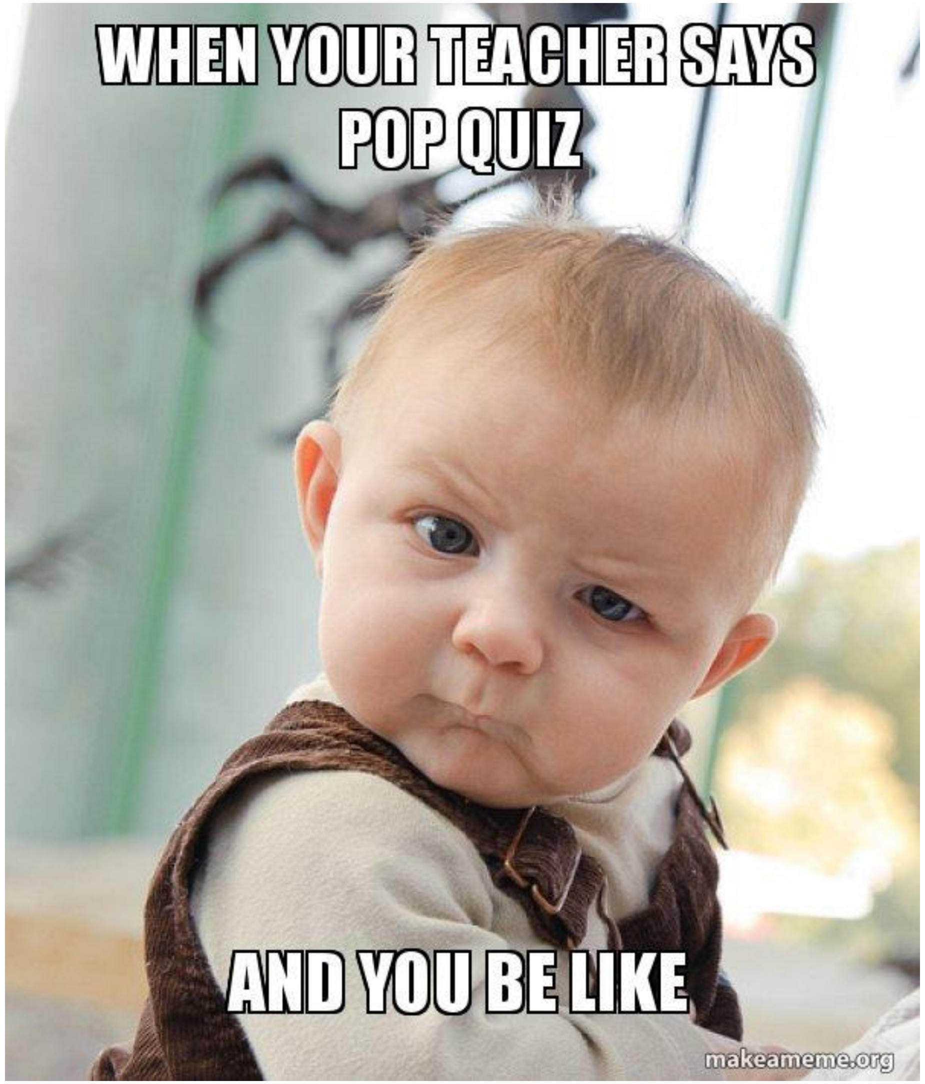
Pop Quiz



Q1: Hydrogen is known as most abundant element in universe, but in what form is it most prevalent on Earth?

A1: Water!

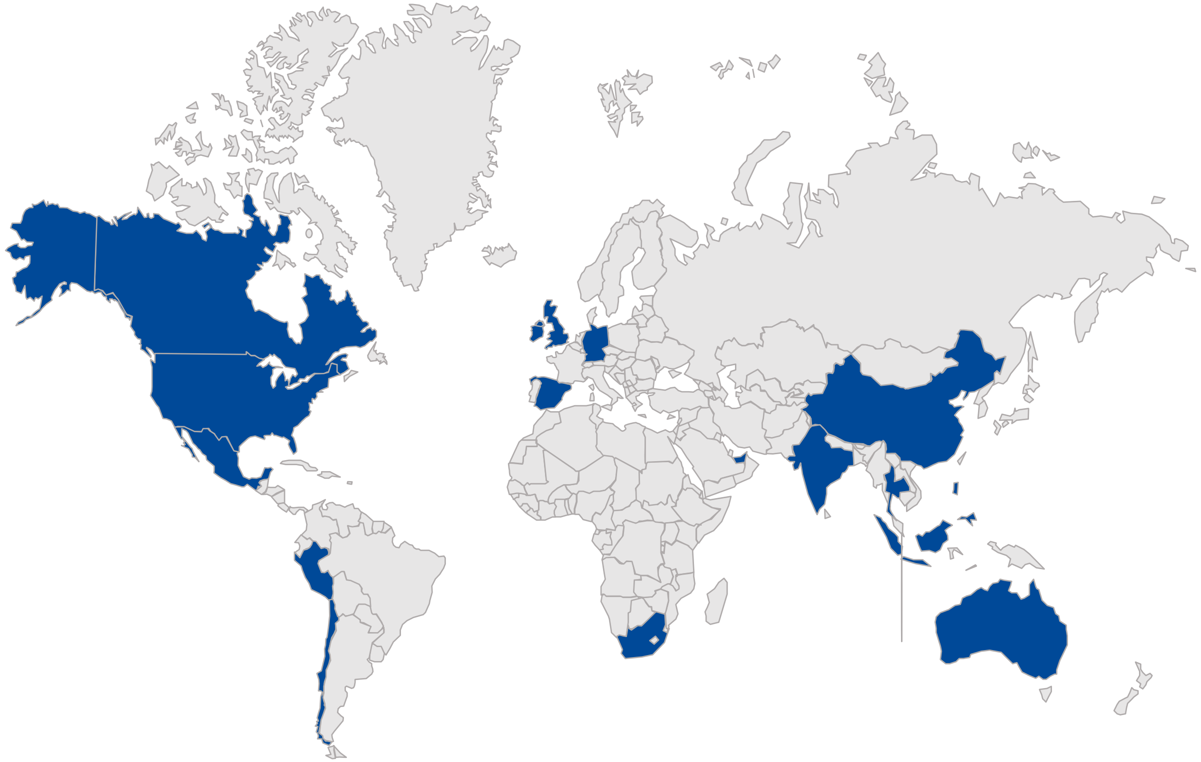
Black & Veatch: Nurturing Our Global Culture

10,600+ professionals

$4.3 billion in 2023 revenue

Work in 100+ countries
on six continents

Consistently high industry rankings in Power, Telecom, Water, Environmental and more



Corporate Safety Culture

- Example set by leadership
- Responsibility for safe operations belongs with everyone
- Protect people, property, environment
- Continuous training and communication
- Means of raising issues
- Improvements implemented and relayed to across organization

When We Continue to

Think•Plan•Act

We Will Achieve
Zero Injuries Today

“Why Hydrogen?” and Relevance

Versatility

- Use as feedstock for other chemicals/fuels
- Use as an energy carrier
- Use as a fuel for transportation and mobility

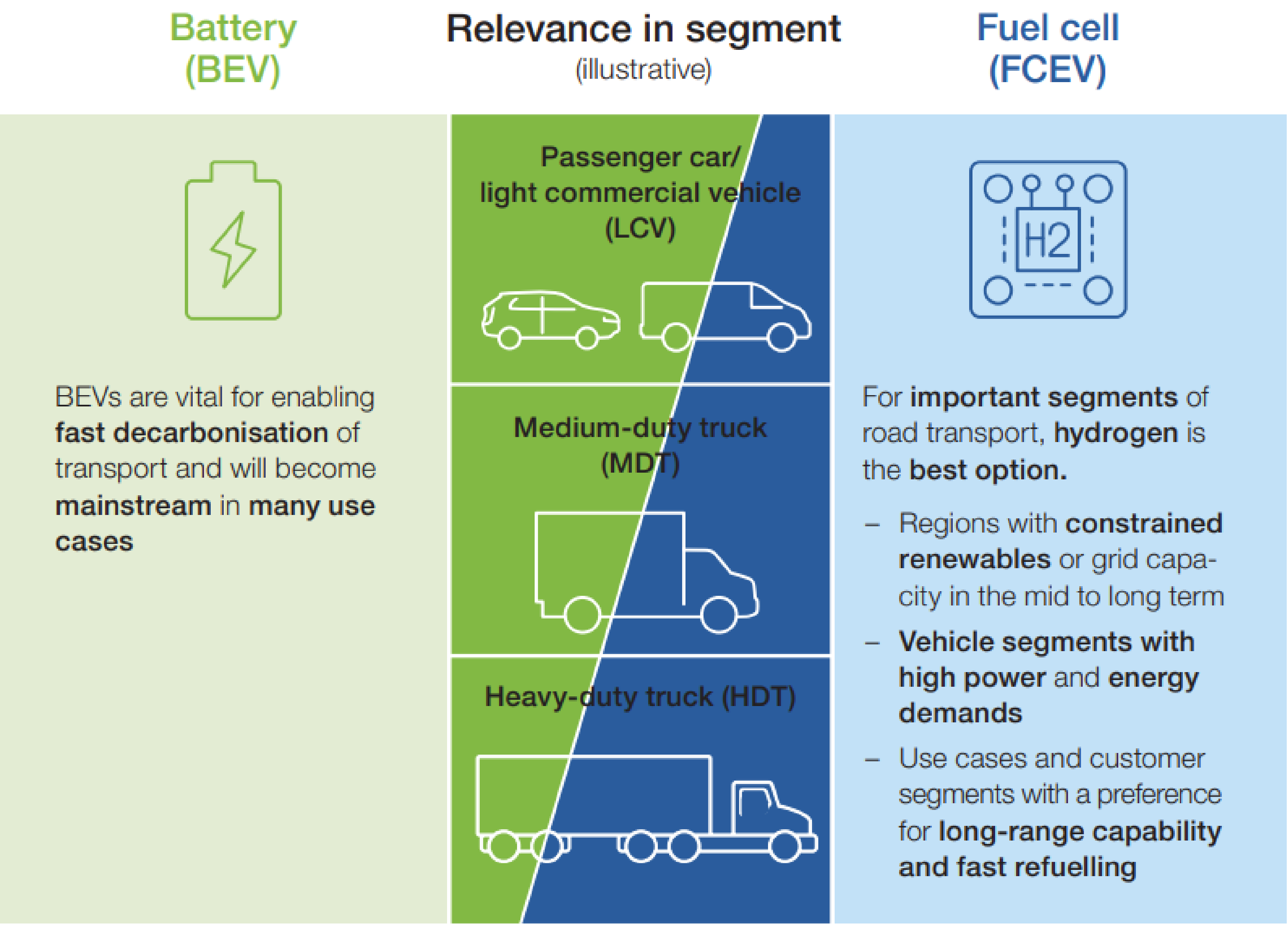
Availability and Variety of Production Methods

Limited options for decarbonization in hard-to-abate industries

Energy efficiency benefits when combined with fuel cell power train

Lack of EV charging infrastructure and interconnection constraints

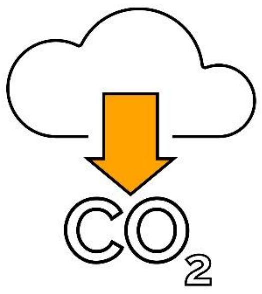
A Combined Approach is Greener, Faster and Cheaper



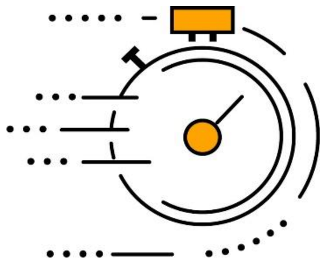
Source: The Hydrogen Council, 2021.

Greener, Faster, Cheaper

Combined, electric and hydrogen fuel cell vehicles speed decarbonization and de-risk the monumental shift to net-zero across transportation.



- BEVs and FCEVs are similarly beneficial in CO_2 life cycle assessment
- Hydrogen can store local renewable energy across seasons and enable renewable energy import from optimal production locations



- Transition towards decarbonized transport is happening, and EV and FCEV must jointly accelerate
- One path is not enough. Faster decarbonization occurs with a modular system that combines several clean modes of energy and transportation.

- Two infrastructures are cheaper than one: hydrogen supply can reduce peak loads and reduce necessary grid upgrades
- Hydrogen could be the cheapest option in many road transport segments in this decade

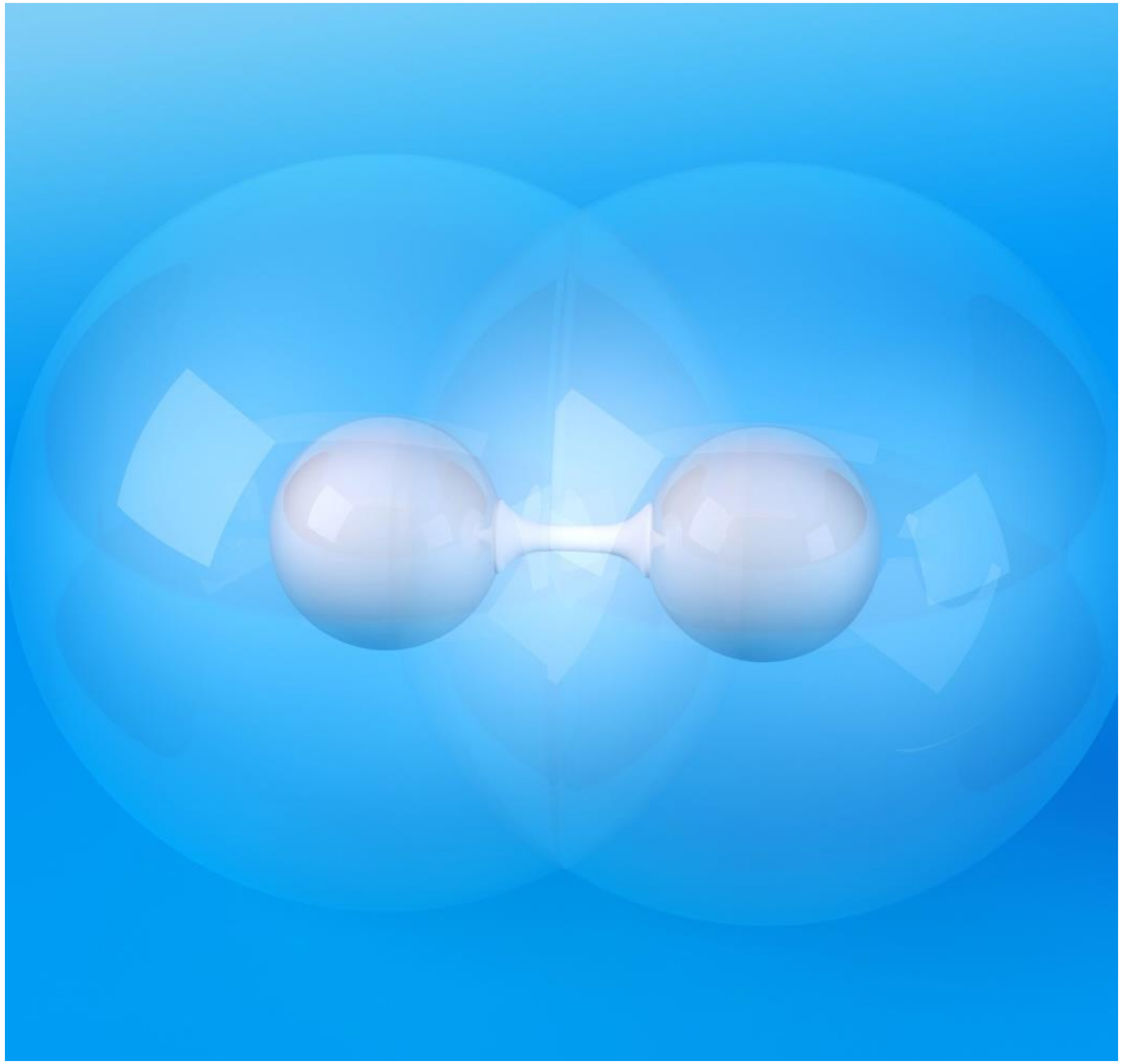
Introduction to Hydrogen

Hydrogen is a colorless/ odorless diatomic gas (at STP)

Simplest and most abundant substance in universe

Flammability over 4 – 75 vol. % in air

Lighter than air and high diffusivity (disperses in well-ventilated area)

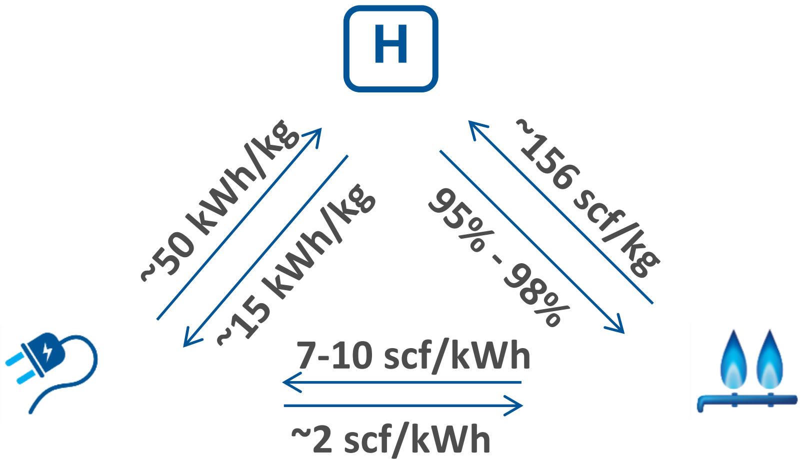


Hydrogen Energy Equivalents

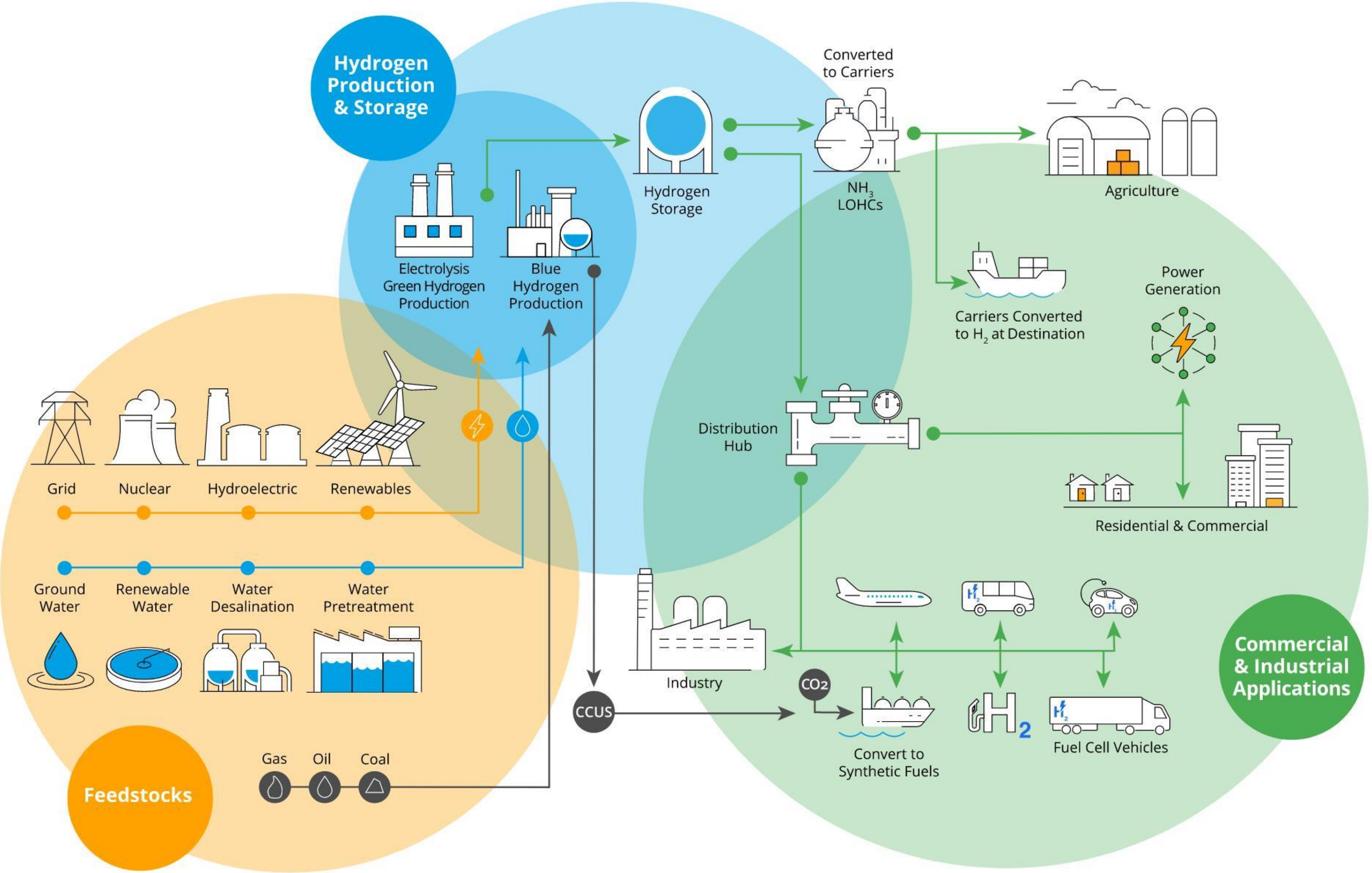
Hydrogen has broad applications, and can be used to substitute/complement existing energy sources (following given in kg-H2 energy equivalents):

- 1 gasoline-gallon equivalent (GGE)
- 117 cubic feet of natural gas (421 cubic feet by volume) (0.134 MMBtu HHV)
- 33 kWh of electricity

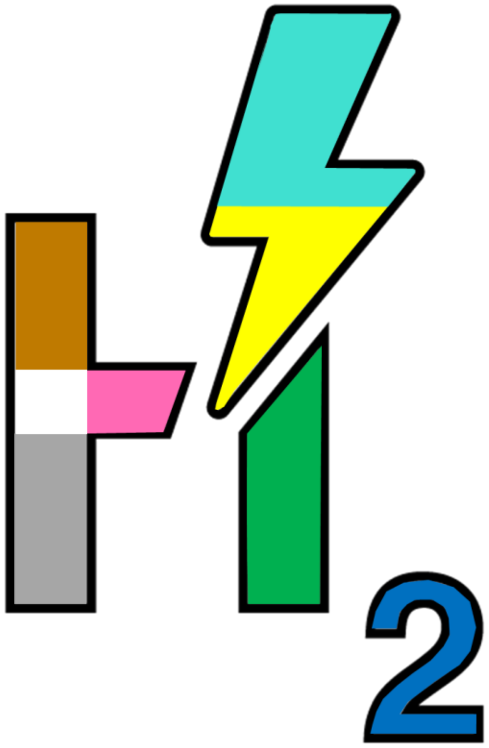
Energy conversions are costly and there are fuel uses and losses during transportation and storage

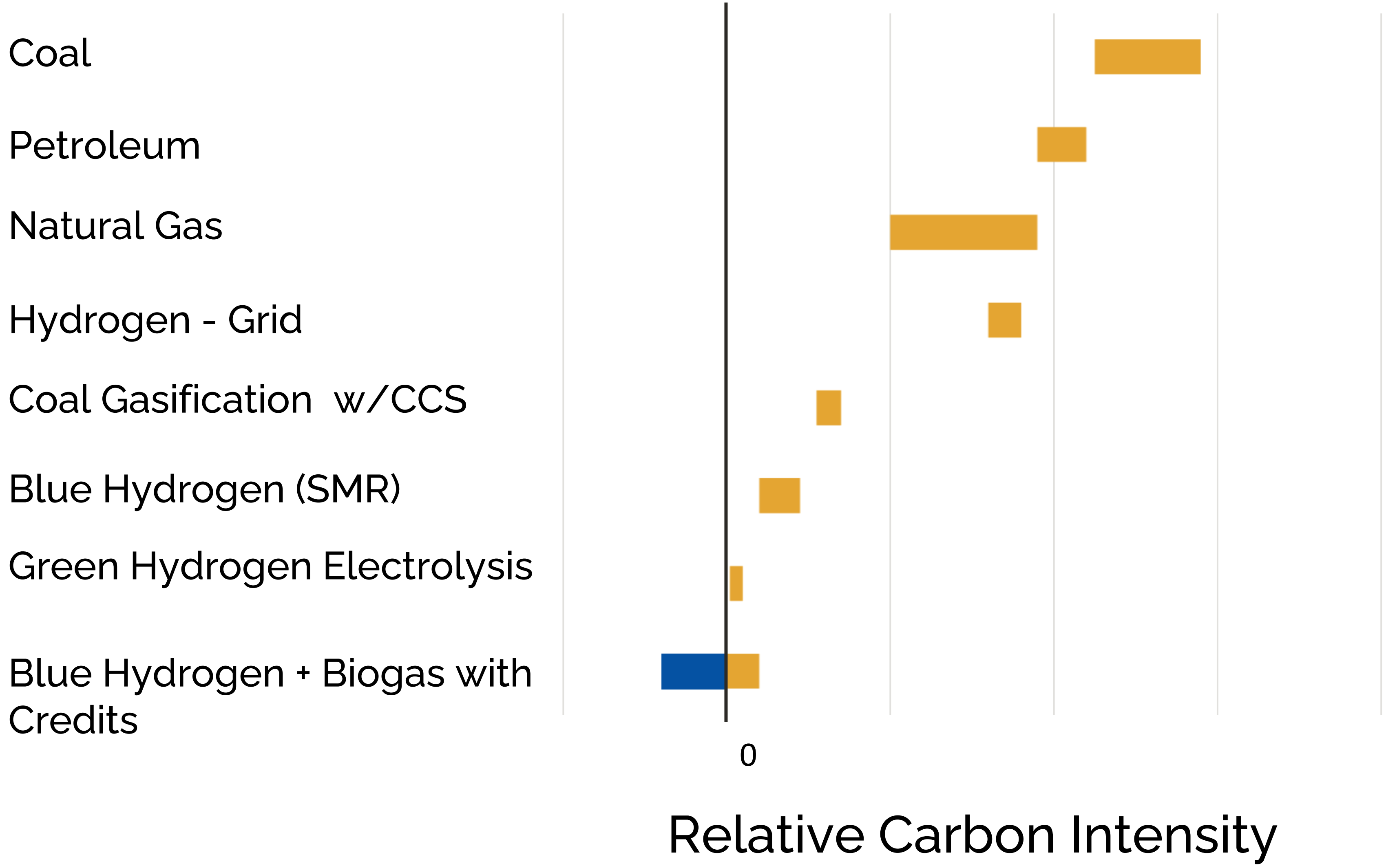


Hydrogen Value Chain



Carbon Reduction Before Color





“Typical” Definitions for Colors of Hydrogen

Green – Water electrolysis using renewable energy resources

Gray – Steam methane reforming using natural gas

Brown – Gasification using fossil fuels such as coal/petcoke

Blue – Grey or brown hydrogen combined with carbon capture

Yellow – Water electrolysis using grid energy

Pink – High-temperature water electrolysis using nuclear energy

Turquoise – Methane pyrolysis using natural gas

White – Byproduct of industrial process such as chlor-alkali electrolysis

Lack of industry-wide agreement on colors/definitions warrants caution in application

Hydrogen, Natural Gas, and Gasoline Properties

Differentiators	Hydrogen	Natural Gas	Gasoline
Basic Properties	Colorless, odorless, tasteless, non-toxic gaseous fuel with no viable odorants	Colorless, odorless, tasteless, non-toxic gaseous fuel used with odorants	Mixture of liquid hydrocarbons and additives with color, taste, and toxicity
Flammability Range (% in air)	4 – 75 vol. %	5 – 15 vol. %	1.4 – 7.6 vol. %
Autoignition Temperature	1,085°F	1,000°F	450°F
Minimum Ignition Energy	0.02 mJ	0.29 mJ	0.24 mJ
Flame Characteristics	Pale blue color, detection required, radiate little infrared heat, high flame velocity	Dark blue color, detection often not required, higher infrared heat, low flame velocity	Orange color, detection often not required, higher infrared heat, low flame velocity
Safety Requirements	Leak detection, flashback/overpressure protection, personnel training, etc.	Overpressure protection, minimal personnel training	Storage in approved containers, minimal personnel training

Hydrogen Hazard Overview

Leakage

- Minor vs. Major
- Diffusion vs. Accumulation

Combustion events

- Ignition Sources
- Flames
- Explosions: Unignited and Ignited
- Deflagration vs. Detonation

Asphyxiation

Additional Concerns with LH2

- Frostbite, Hypothermia, Ice Formation
- Condensed Air Oxygen Enrichment

Current State of Hydrogen Storage and Transportation

Long-distance transportation and local distribution challenging

Blending of hydrogen in natural gas network highly dependent on local pipeline design/regulations

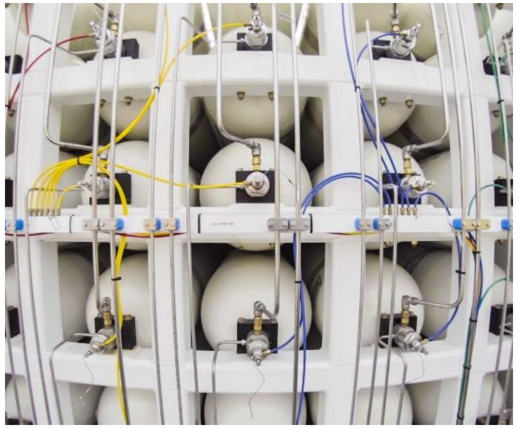
Pipelines expected to be economical at distances <1,500 km

Shipping of ammonia or liquid organic hydrogen carriers expected to be economical >1,500 km

Hydrogen Carriers and Storage

Fuel	Energy/Weight (kJ/kg)[1]	Energy/Volume (kJ/m3)[1, 2]	Energy Efficiency (Energy out/Energy In)[1]
Gaseous Hydrogen[3]	120,000	2,110,100	83%
Liquid Hydrogen	120,000	9,323,200	56%
Ammonia	18,600	11,457,600	62%
Natural Gas[4]	46,800	2,601,150	99%
LNG	49,300	21,217,000	93%

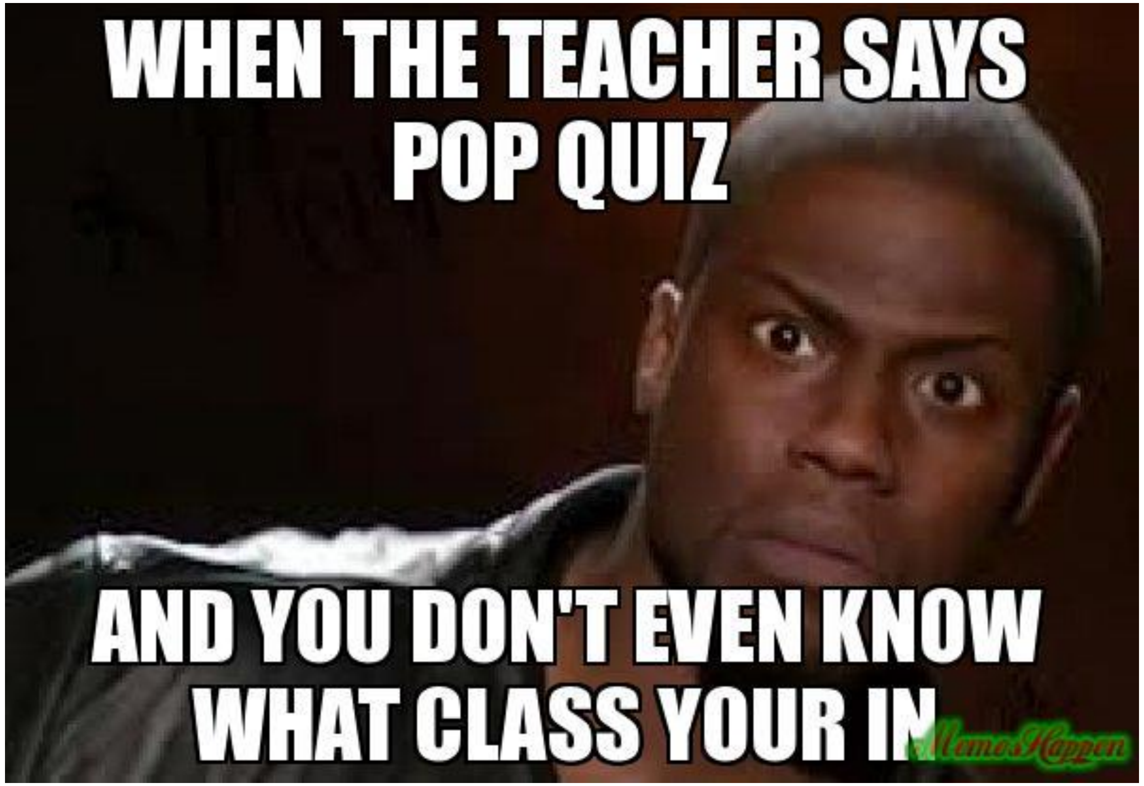
(1) Table is based on lower heating values (LHV)
(2) Energy/Volume based on storage conditions
(3) Compressed hydrogen is at 245 barg and 20°C
(4) Compressed natural gas is at 70 barg and 20°C



Pop Quiz #2

Q2: Which properties of hydrogen represent the most significant safety hazards?

A2: Wide flammability range and low ignition energy

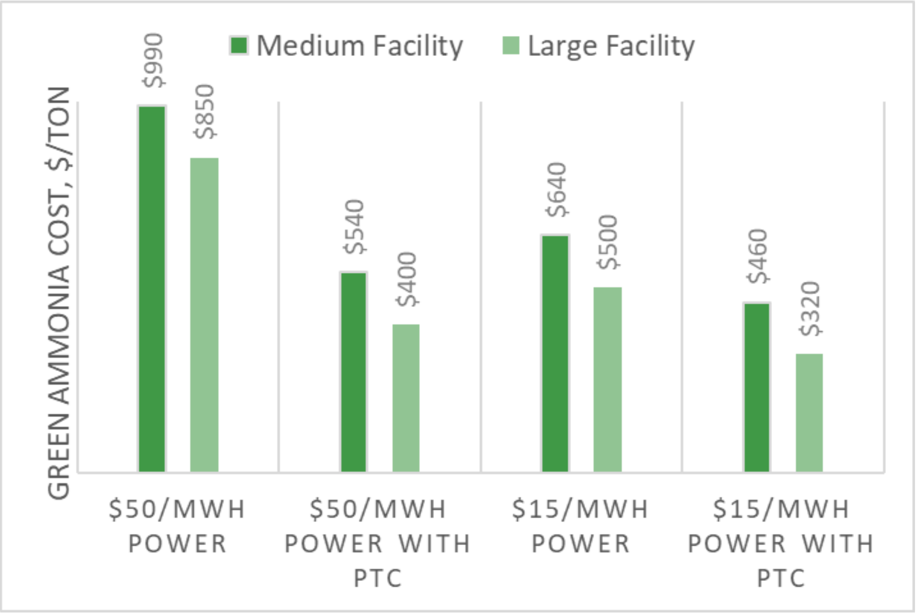


Ammonia as an Energy Carrier

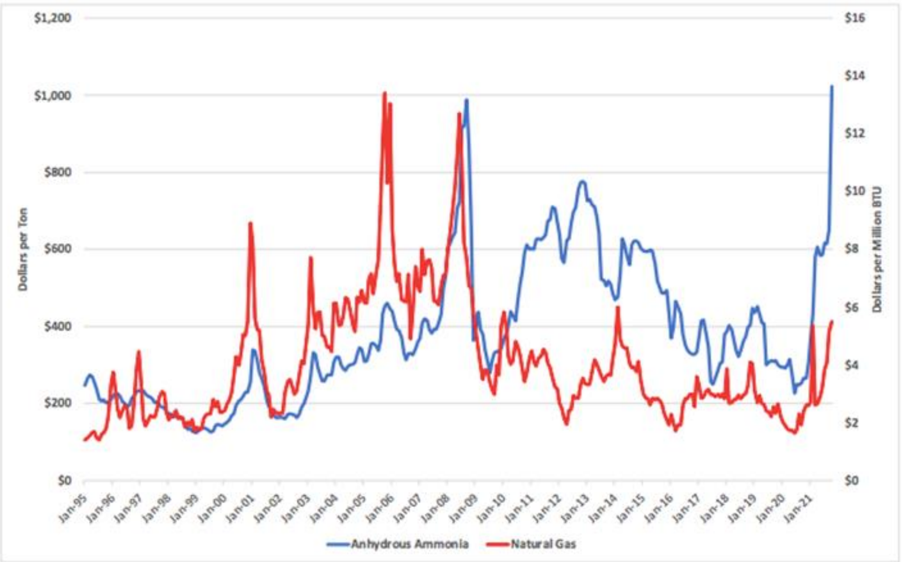
Higher Density Liquid

- Storage
- Global shipping
- Feedstock and fuel
- Crack to hydrogen or use as ammonia

Green Ammonia Levelized Production Costs

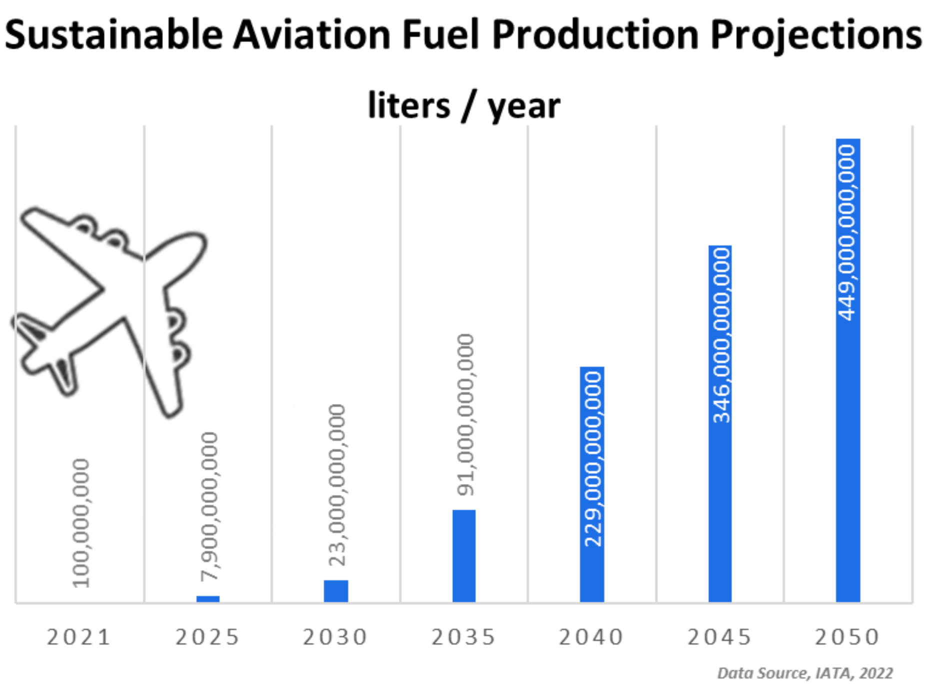


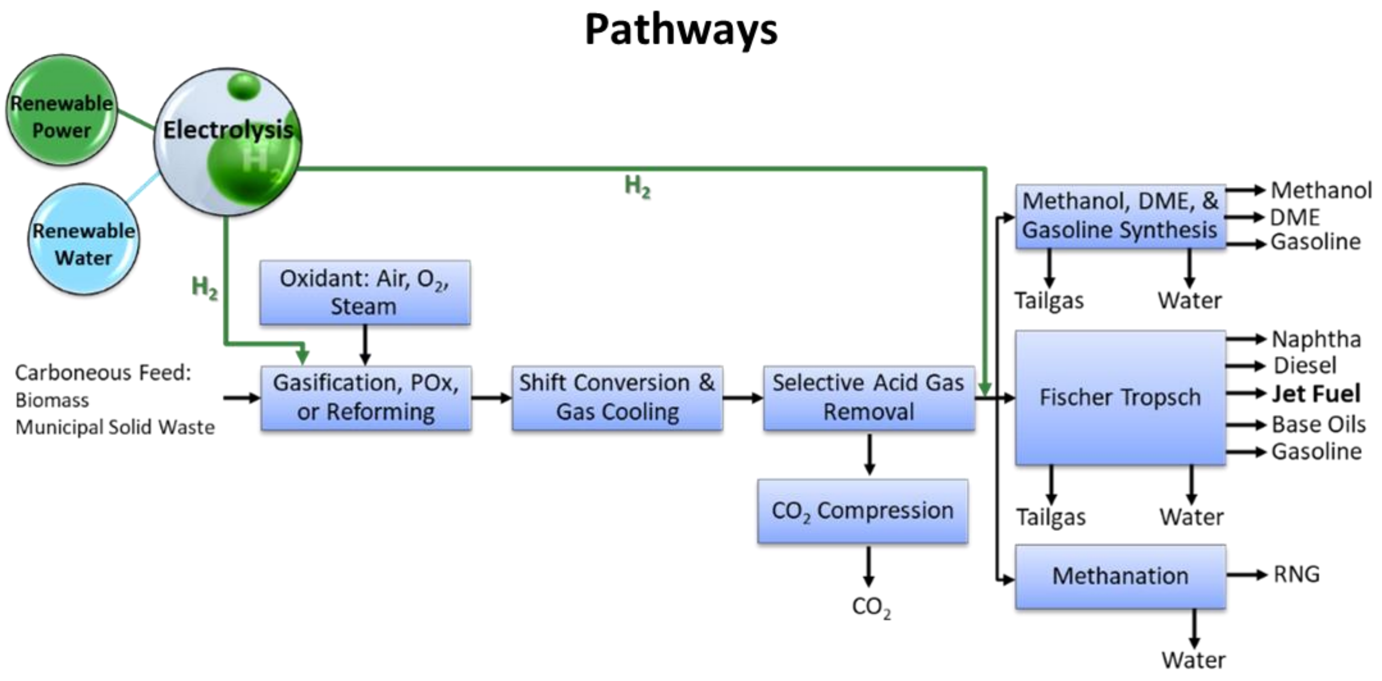
Grey Ammonia Price History



European and Japanese LNG Prices

Sustainable Aviation Fuel/Hydrocarbon Pathways





Lower cost liquid fuels than P2X

Workshop Key Take-Aways

Hydrogen is versatile, widely available, and has manageable safety hazards

Hydrogen can be used as a gas, liquid, or derivative(s)

Strong interest in hydrogen pipelines

- Most cost efficient for large-scale storage and transport
- Limitations of blending in natural gas pipelines

LH2 viewed as more favorable, near-term alternative for mobility

- Lack of pipelines
- Emission implications of derivatives
- Regional distribution via road/rail

BV working on several initiatives in hydrogen industry

- Biggest challenges associated with siting/space constraints
- Economics still challenging for many end uses

Discussion