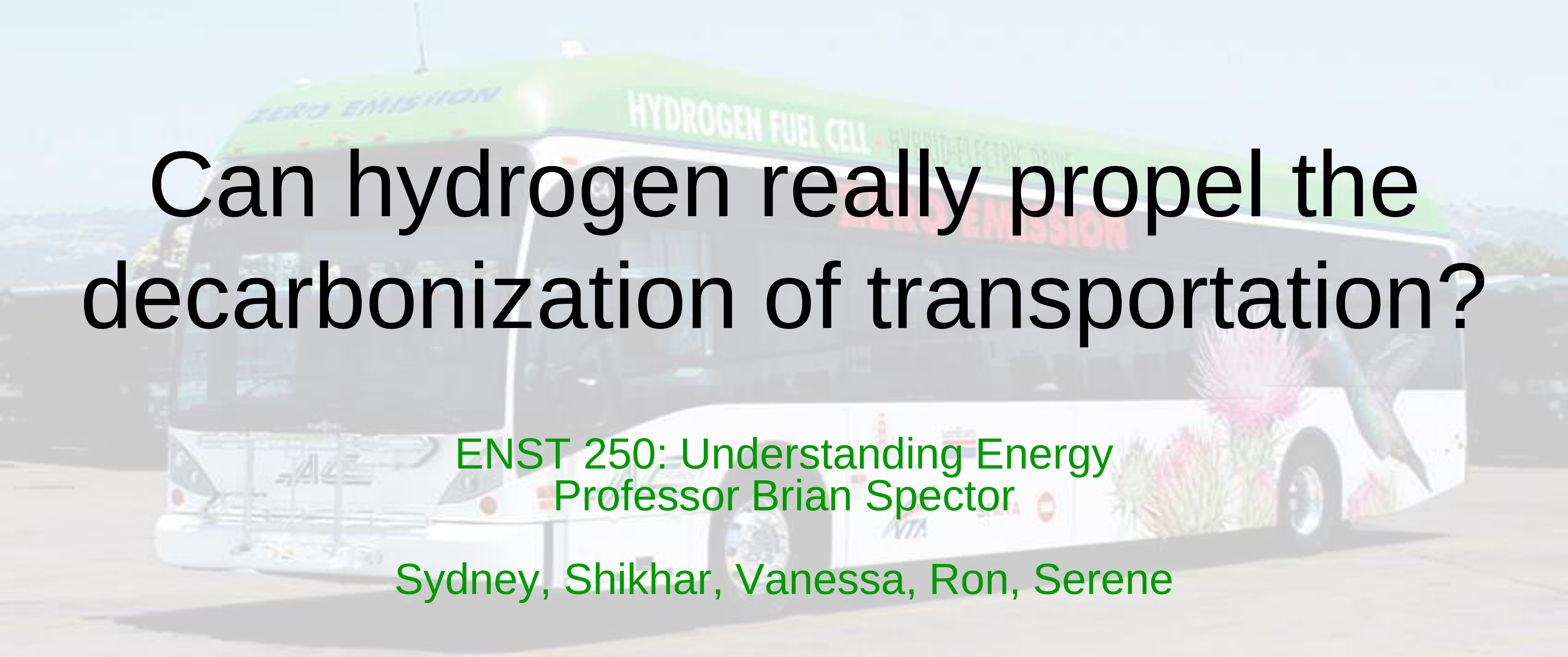
Can hydrogen really propel the decarbonization of transportation?



ENST 250: Understanding Energy
Professor Brian Spector

Sydney, Shikhar, Vanessa, Ron, Serene

Overview

- Introduction: History of Hydrogen
- Hydrogen Spectrum
- Blue Hydrogen vs Green Hydrogen
- Hydrogen in Transportation
- Conclusion
- Questions and Discussion

History of Hydrogen

- First identified 1776 by Henry Cavendis
- 1804 first internal combustion engine
- Energy storage mention in 1923
- Impractical until nuclear experimentation
- 1970s “Hydrogen Economy”
- Quest for novelty/experimentation

Hydrogen Color Spectrum

- Refers to source/process
- GHG = Greenhouse Gas Footprint
- Grey most common globally
- Black/Brown most common in US

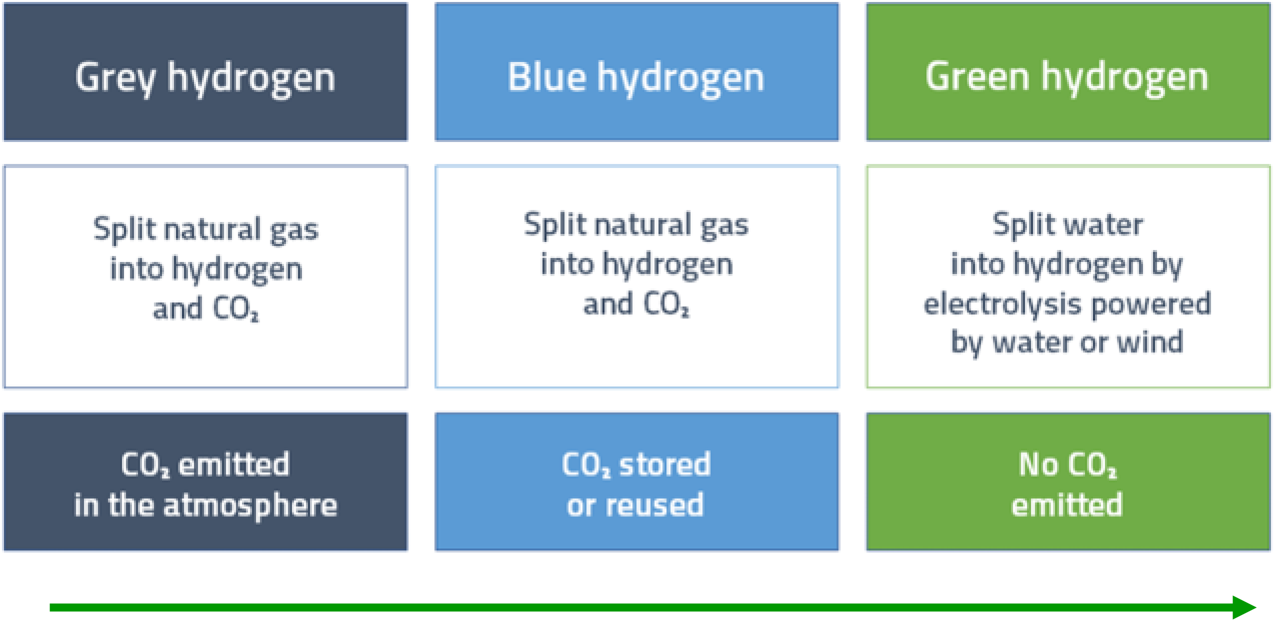
	Terminology	Technology	Feedstock/ Electricity source	GHG footprint*
PRODUCTION VIA ELECTRICITY	Green Hydrogen	Electrolysis	Wind | Solar | Hydro Geothermal | Tidal	Minimal
	Purple/Pink Hydrogen		Nuclear	
	Yellow Hydrogen		Mixed-origin grid energy	Medium
PRODUCTION VIA FOSSIL FUELS	Blue Hydrogen	Natural gas reforming + CCUS Gasification + CCUS	Natural gas | coal	Low
	Turquoise Hydrogen	Pyrolysis	Natural gas	Solid carbon (by-product)
	Grey Hydrogen	Natural gas reforming		Medium
	Brown Hydrogen	Gasification	Brown coal (lignite)	High
	Black Hydrogen		Black coal	

*GHG footprint given as a general guide but it is accepted that each category can be higher in some cases.

Uses

- Growing industry
- Fertilizer production
- Hydrocracking
- Consumers
- Potential: transportation economy

Hydrogen Spectrum



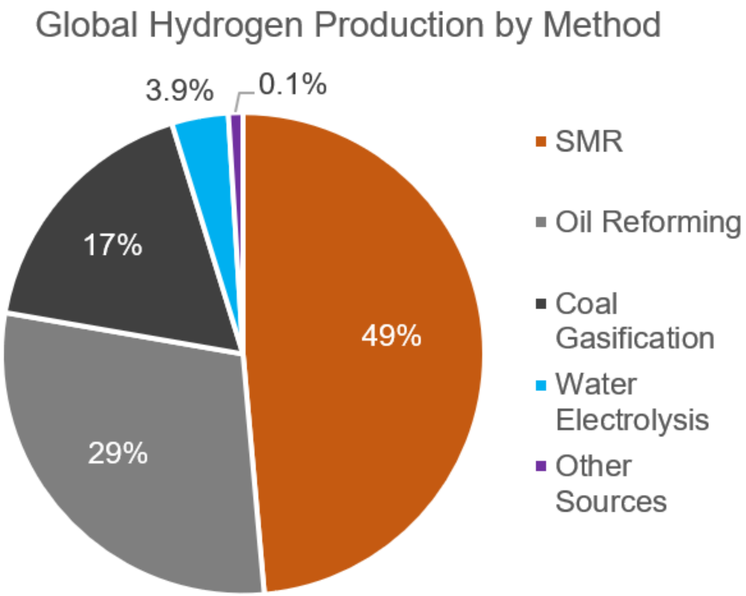
Highest carbon intensity to lowest carbon intensity

Blue Hydrogen

What is blue hydrogen?

Hydrogen's reliance on fossil fuels

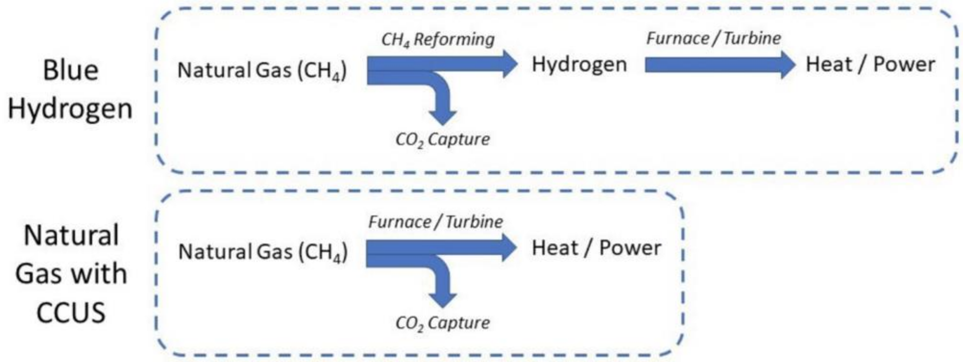
In 2019, over 98% of worldwide demand for hydrogen – estimated at 76.5 million metric tons – was supplied by a fossil fuel production method.



(Dincer & Acar, 2015)

Blue hydrogen only exists due to CCUS, why not apply that directly to the point of use e.g. power generation?

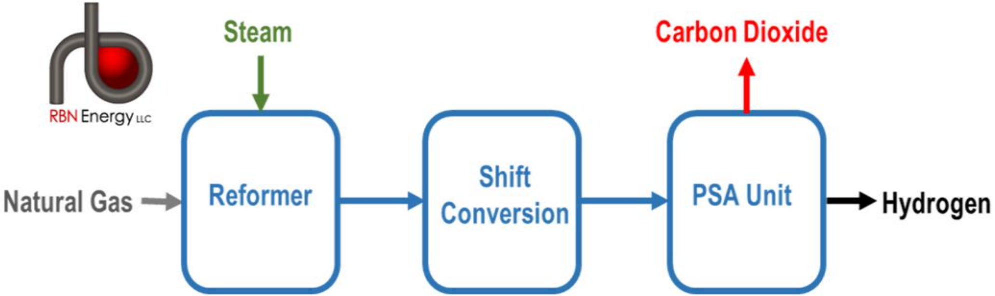
Figure 1. Blue Hydrogen and End-Use CCUS, from Natural Gas to Heat or Power Generation



- Obviates the need for CO_2 capture equipment and transportation infrastructure at the point of use,supporting distributed generation
- Higher concentration of CO_2 in gas stream leads to cheaper carbon capture
- Hydrogen is a prevalent industrial feedstock. Since contemporary, grey, hydrogen production generates substantial CO_2 emissions, blue hydrogen can displace an otherwise high-emitting process.

Steam Methane Reforming (SMR)

- High-temperature steam (700°C–1,000°C) is used to produce hydrogen from a methane source, such as natural gas.
- Reformer: Methane reacts with steam under pressure in the presence of a catalyst to produce hydrogen, carbon monoxide, and a relatively small amount of carbon dioxide.
- Shift Conversion: The carbon monoxide and steam are reacted using a catalyst to produce carbon dioxide and more hydrogen.
- Pressure-swing Adsorption: carbon dioxide and other impurities are removed from the gas stream, leaving essentially pure hydrogen.



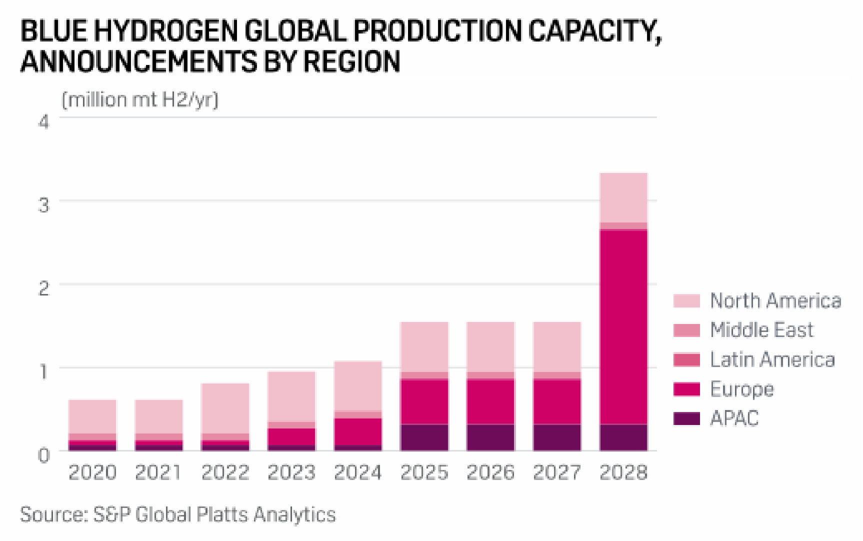
Steam-methane reforming reaction

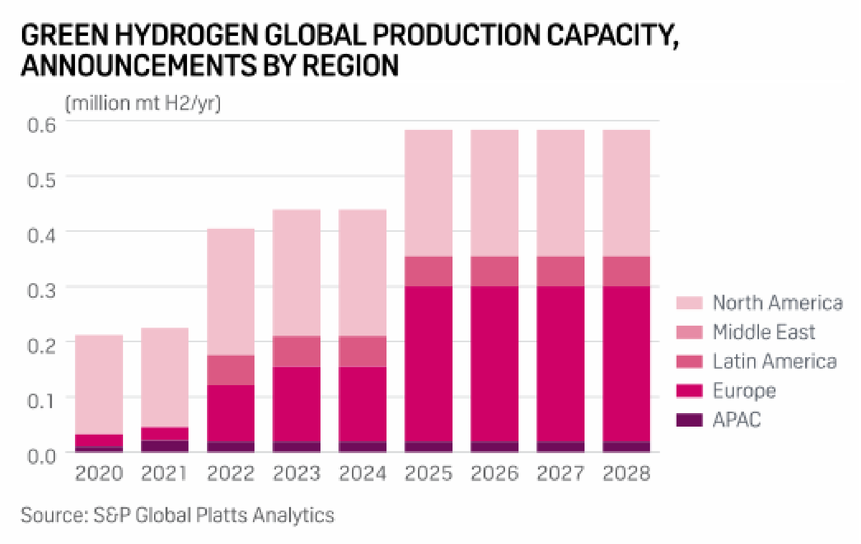
$CH_4 + H_2O$ (+ heat) → $CO + 3H_2$

Water-gas shift reaction

$CO + H_2O \rightarrow CO_2 + H_2$ (+ small amount of heat)

Global production capacity growth





Blue Project Highlights: UK and Saudi Arabia

- BP announced UK's largest blue hydrogen production facility, H2Teesside, targeting 1GW of hydrogen production by 2030.
- Two million tonnes of CO_2 stored per year → emissions from the heating of one million households.
- Close proximity to North Sea storage sites and existing CO_2 and hydrogen infrastructure→supporting jobs, regeneration and the revitalisation of the surrounding area.
- Industries in Teesside account for over 5% of the UK's industrial emissions and the region is home to five of the country's top 25 emitters.

Home > News > Saudi Arabia commits $110B gas field for blue hydrogen development

Saudi Arabia commits $110B gas field for blue hydrogen development

By **MATTHEW MARTIN AND SALMA EL WARDANY** on **10/24/2021**

(Bloomberg) - Saudi Arabia said it would use one of the world's biggest natural-gas projects to make blue hydrogen, as the kingdom steps up efforts to export a fuel seen as crucial to the green-energy transition.

A large portion of gas from the $110 billion Jafurah development will be used for blue hydrogen, according to Energy Minister Abdulaziz bin Salman. It is made by converting natural gas and capturing the carbon dioxide emissions.

"We are the biggest adventurers when it comes to blue hydrogen," Prince Abdulaziz said at a climate conference in Riyadh on Sunday. "We're putting our money where our mouth is on hydrogen. We have a terrific gas base in Jafurah we will use it to generate blue hydrogen."

Source: BP

Caveat: Lifecycle Emissions

- For every unit of heat in the natural gas at the start of the process, only 70-75% of that potential heat remains in the hydrogen product
  - You would need to use 25% more natural gas to make blue hydrogen than if it was used directly for heat.
- US researchers found that methane emissions released when the fossil natural gas is extracted and burned are much less than blue hydrogen.
  - More methane needs to be extracted to make blue hydrogen, and it must pass through reformers, pipelines and ships, providing more opportunities for leaks
  - Research indicates, to make blue hydrogen 20% worse for the climate than just using fossil gas.

Cost-benefit Analysis

Strengths

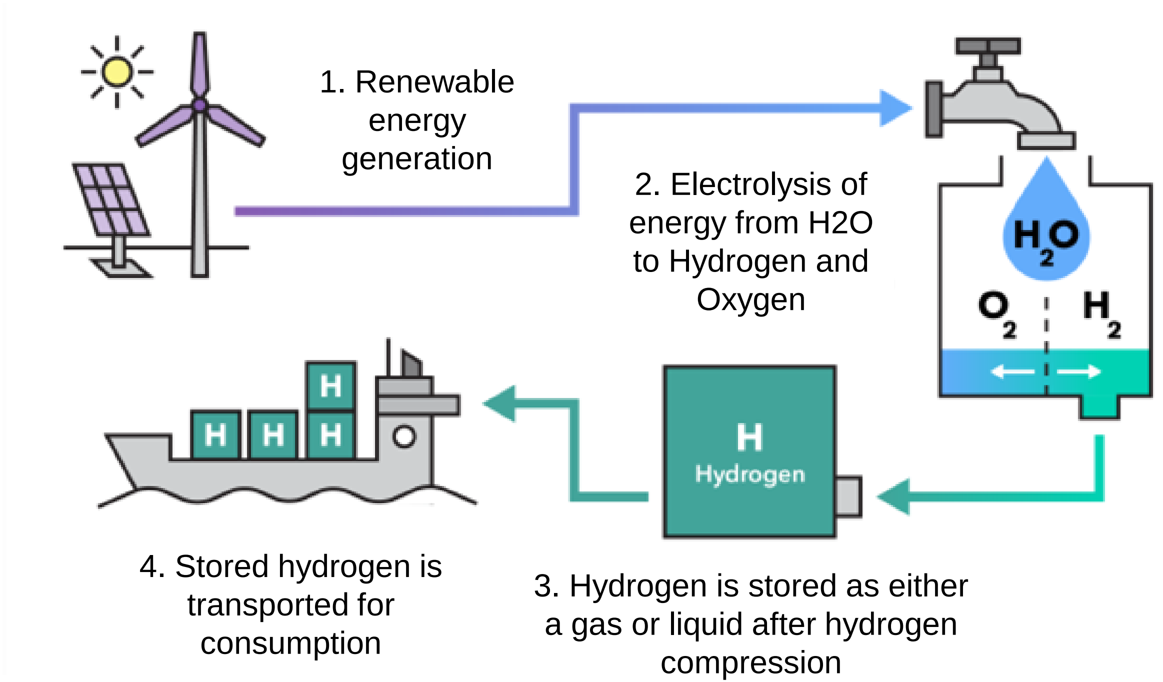
- **Cost-effective**: In 2017, blue hydrogen cost 21.6 cents per mile vs the new gasoline vehicle average at 14 cents per mile
- **Scalable**: Infrastructure for SMR and hydrogen transportation exists and technical expertise from O&G can be transferred
- **Economically opportunistic**: Countries with natural gas endowment like US and Saudi are inclined to capitalize on their resources in a sustainable manner

Weaknesses

- **Poor Lifecycle Emissions:** larger amounts of natural gas required to produce same amount of energy leads to higher methane leak risk
- **Reliance on low cost natural gas:** Countries without abundant natural gas will have higher costs
- **Feasibility of permanent CO_2 storage:** Getting permits for permanent storage wells is extremely difficult, and while CCUS is a tested technology, its scale has been relatively small

Green Hydrogen

Green Hydrogen Electrolysis



Source: Solar Thermal World

Green Hydrogen Highlights

Fueling a Toyota hydrogen vehicle in Fountain Valley, Calif. Philip Cheung for The New York Times

Source: NYT

pv magazine

News Features Events Awards Partner news pv magazine tes

The Hydrogen Stream: 8 GW green hydrogen project announced in Chile

Source: PV Magazine

SUSTAINABLE ENERGY

Huge $2.6 billion green hydrogen project planned for Europe

PUBLISHED FRI, DEC 3 2021·7:13 AM EST | UPDATED FRI, DEC 3 2021·7:47 AM EST

Anmar Frangoul

SHARE

Source: CNBC

Economic Breakdown of Green Hydrogen Production

Table 1 – Hydrogen costs for PEM electrolysis from H2A with associated inputs of electricity cost, capacity factor, and uninstalled system capital cost.[4]

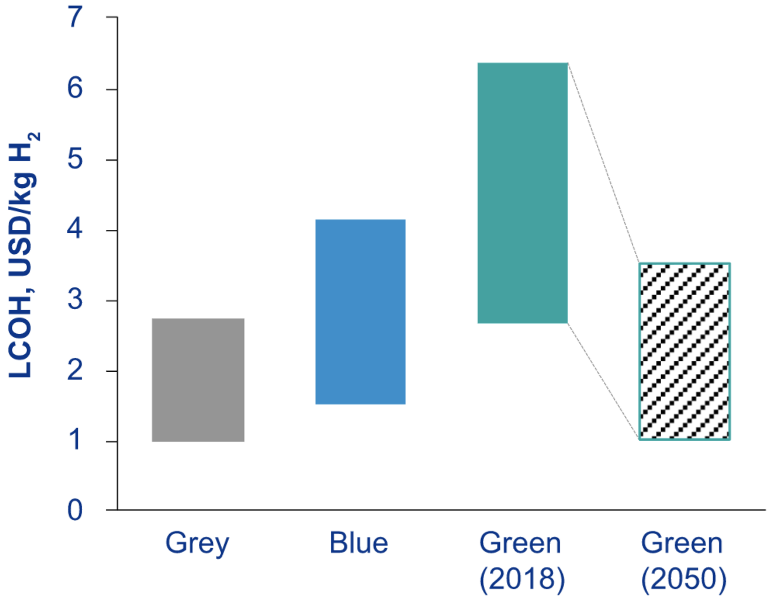
	Electricity Cost (¢/kWh)	Capacity Factor	System CapEx ($/kW)	H_2 Cost ($/kg)
Grid Low	5.0	90.0%	1,500	**$5.13**
			1,000	**$4.37**
Grid High	7.0	90.0%	1,500	**$6.27**
			1,000	**$5.50**

- Hydrogen can be produced at a cost of ~$5 to $6/kg-H2
- Additional costs: electrolyzer (<$1,500/kW), and grid electricity prices ($0.05/kWh to $0.07/kWh).
- PEM: Polymer Electrolyte Membrane electrolyzers
- Grid low/high: low versus high volume electrolyzer capital costs
- Capacity Factor: % of time in operation

Source: DOE

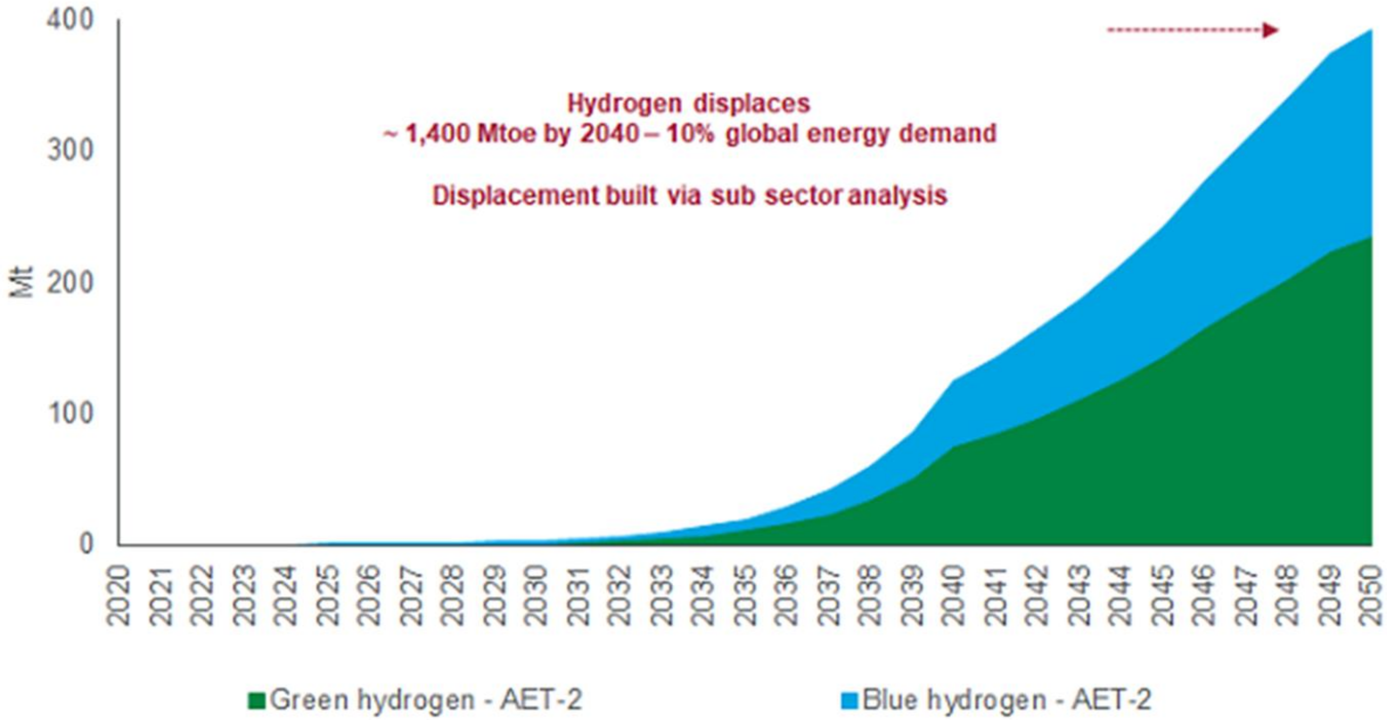
Economic Comparison of Green Hydrogen

- LCOH: Levelized Costs of Hydrogen
- Short-term cost: 2.5-6 USD/kg H2
- Long term cost: 1-3.5 USD/kg H2



Source: KPMG

Future Growth



Source: KPMG

Analysis Breakdown

Advantages

- **Sustainable**: Green hydrogen saves 830 million tons of CO_2 emissions
- **Versatile**: Green hydrogen can be transformed into electricity or synthetic gas to be used for domestic, commercial, industrial or transportation purposes

Disadvantages

- **High cost of production**: Energy from renewable sources is more expensive to generate, making hydrogen more expensive to obtain
- **High energy consumption**: The production of green hydrogen in particular requires more energy than other hydrogens
- **Safety issues**: Hydrogen is a highly volatile and flammable. Extensive safety measures are required to prevent leakage and explosions
- **Transport issues**: High pressure environments are needed to compress Hydrogen while transporting

Source: Iberdrola

Potential for Hydrogen - Transport Fuel

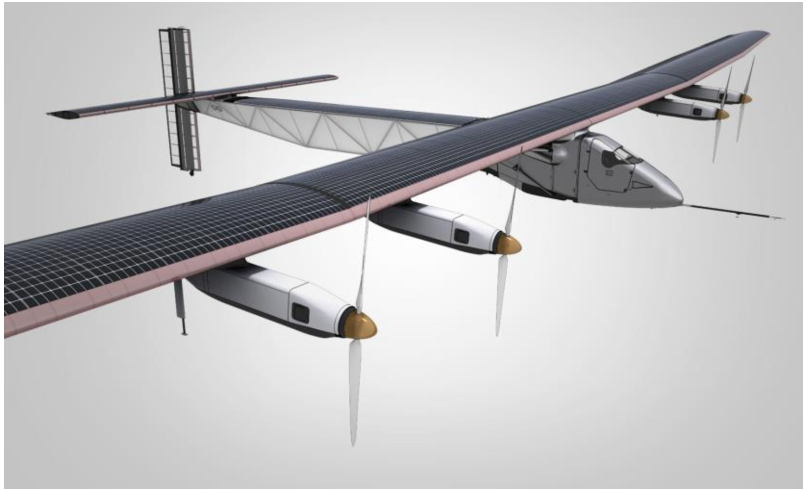
Why Transport Fuel?

- Why not wind and solar?

- Potential benefits not just sustainability?

Current Advancements in Flight

- Smaller planes -> Proven Concept



Established Manufacturers

- Airbus is committed

- Parisian Hub among developments

Implications

- 2.5 percent of global CO_2 emissions

Development Challenges

- Storage
- Airport Infrastructure
- Long range flights
- Production at Scale
- Actual Hydrogen Acquisition

Ships in a similar position

- 3 percent of global CO_2 emissions

Limitations as Transport Fuel

Limitations of Hydrogen

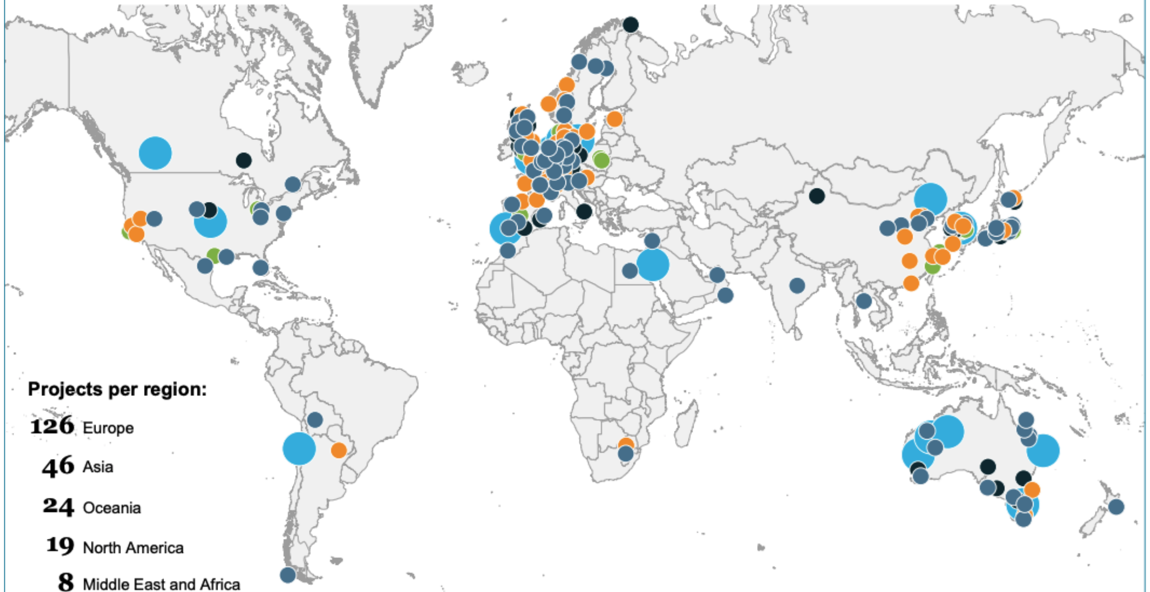
- Difficult to Store/Transport
  - Compressed gas or Liquid
- Expensive
- Time Consuming to Make
- Causes Embrittlement
- Highly Flammable and Dangerous

Hydrogen Storage Tank

Limitations of Hydrogen in Jet Fuel

- Airbus released statement:
    - “Hydrogen planes won’t take off until 2050”
- Low Volumetric Energy Density
    - New model plane needed
- Reduces passenger capacity
- Limits range

Exhibit 2: Global hydrogen projects across the value chain



Projects per region:

- **126** Europe
- **46** Asia
- **24** Oceania
- **19** North America
- **8** Middle East and Africa
- **5** Latin America

228 announced projects

17 — **Giga-scale production:** renewable H_2 projects >1GW and low-carbon H_2 projects >200 kt p.a.

90 — **Large-scale industrial usage:** refinery, ammonia, power, methanol, steel, and industry feedstock

53 — **Transport:** trains, ships, trucks, cars and other hydrogen mobility applications

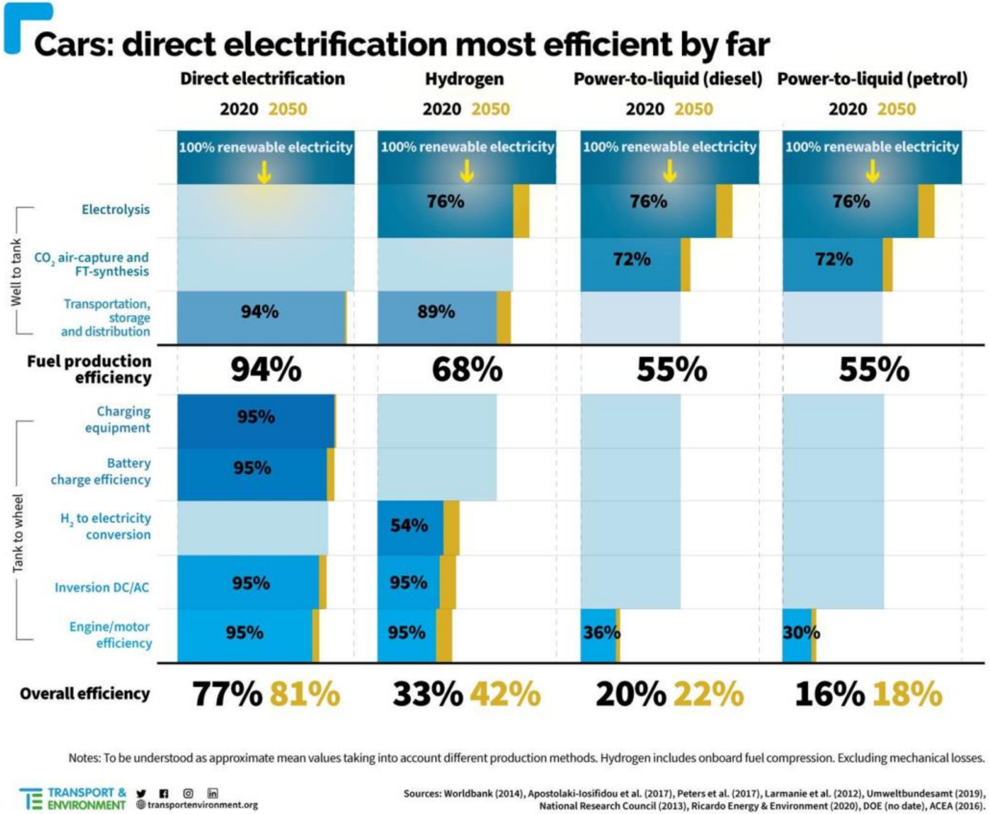
45 — **Integrated H_2 economy:** cross-industry, and projects with different types of end-uses

23 — **Infrastructure projects:** H_2 distribution, transportation, conversion, and storage

Conclusion: Hydrogen's Competition

- BEV's take longer to charge vs a hydrogen refill

- Battery storage capacity and hence mileage is limited



Questions?