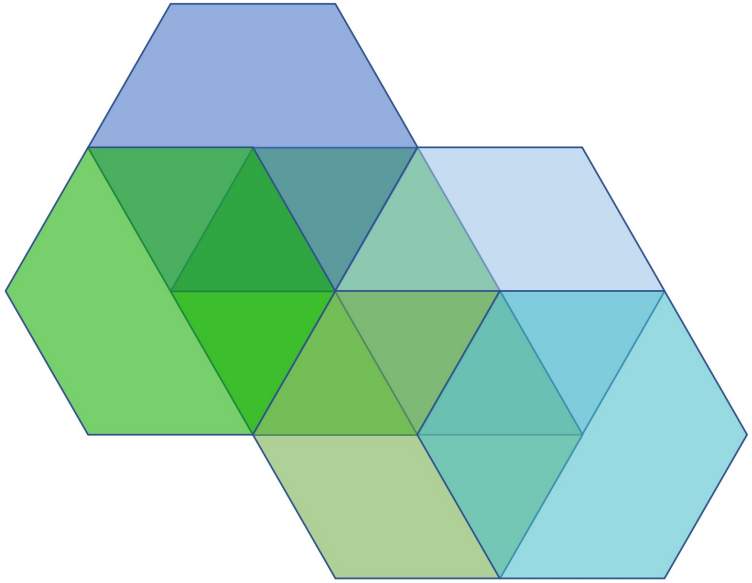
Hydrogen



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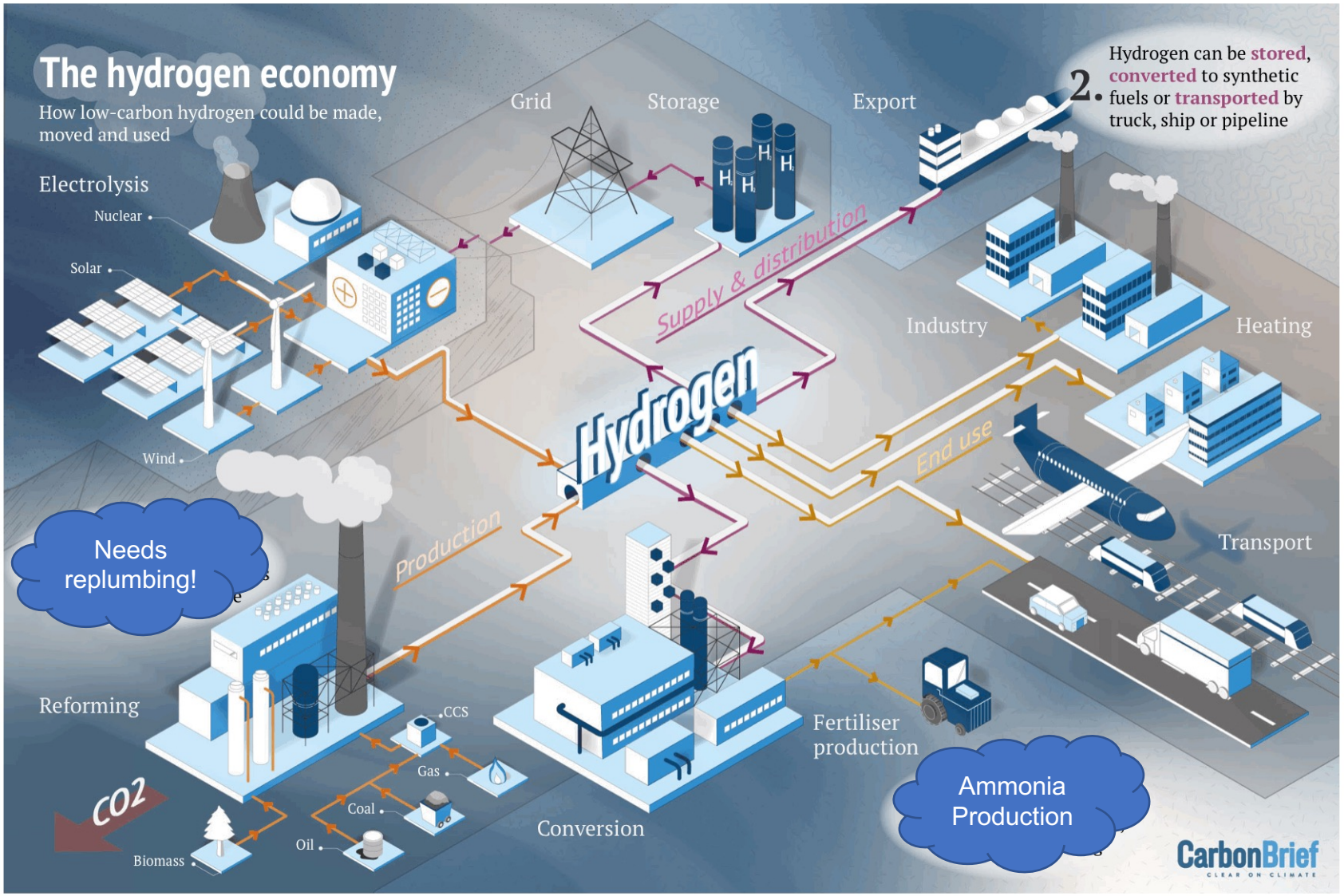
What is the “Hydrogen Economy”? – A Vision



The ~~Hydrogen~~ Economy

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The Hydrogen Economy

After WIKIPEDIA

"The hydrogen economy is an envisioned future in which hydrogen is used as a fuel for…….

heating

hydrogen vehicles

energy storage

long distance transport of energy

….in order to phase out fossil fuels and limit global warming. Hydrogen can be created from water using intermittent renewable sources (e.g. wind & solar). It's combustion only releases water vapour.

Currently R&D, pilots, demonstrators, small-scale systems.

TROVE separates the wheat….. but the chaff can still be viewed.

Separates reality/pragmatism from "Aspirational Goals" (Hype)

Bottom Line : Hydrogen is <u>not</u> a primary energy source.

Hydrogen is all about moving energy from a producing area to a usage or storage area

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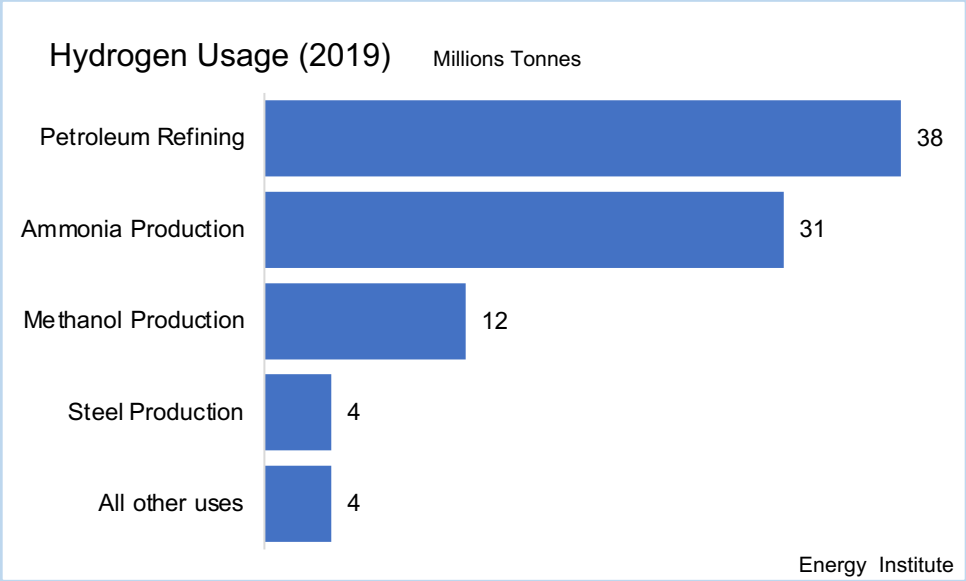
Hydrogen Uses Today

80 million tonnes per annum in 2021 (Fitch Solutions, May 21)
89 million tonnes per annum in 2019 (Energy Institute)

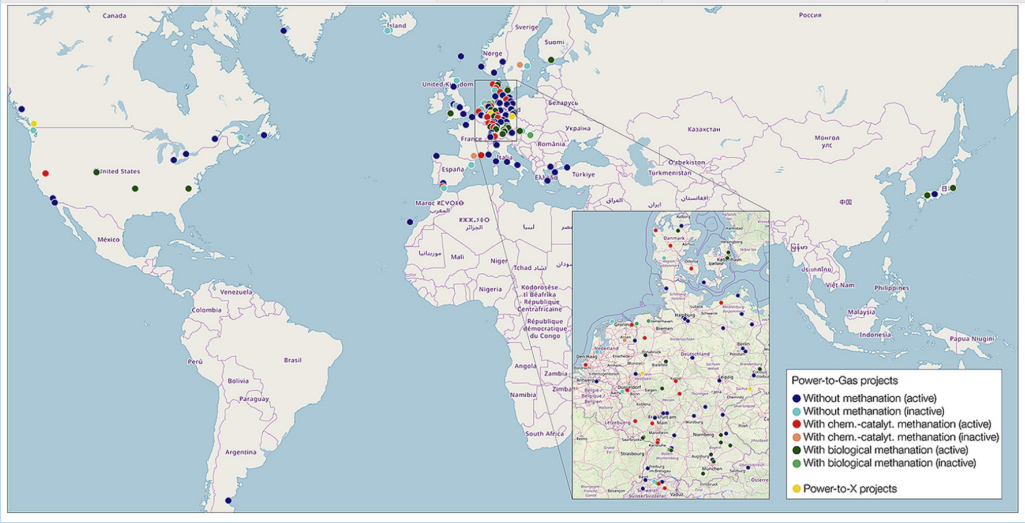


Source:

Methane Steam Reforming

85% Grey Hydrogen

Power-to-Gas (P2G) Projects



Europe
North America
Far East
Australia
Brazil

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Future Uses

Transport

- Cars, trucks, shipping & aviation

Buildings

- Spike H_2 into natural gas
- Heating

Power generation

- Storage
- Hydrogen & Ammonia in gas turbines.

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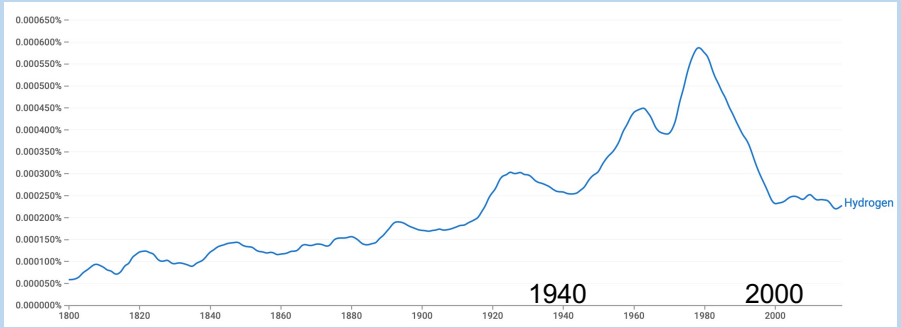
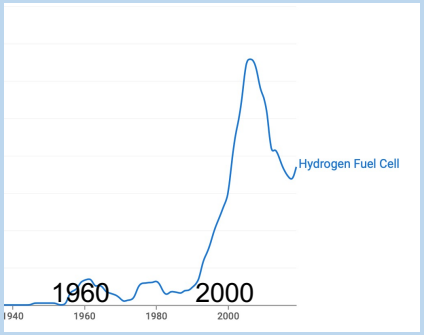
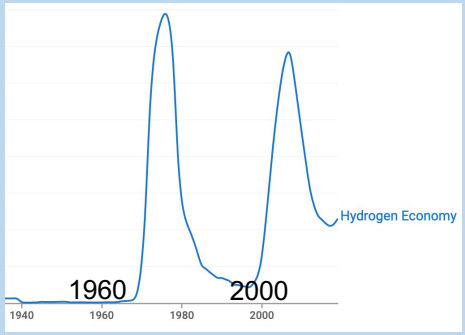
Why hydrogen?

- Colourless
- Odourless
- Burns
- Produces only water vapour
- Less dense (than methane)
- Less viscous (than methane)
- High diffusivity
- Highly reactive





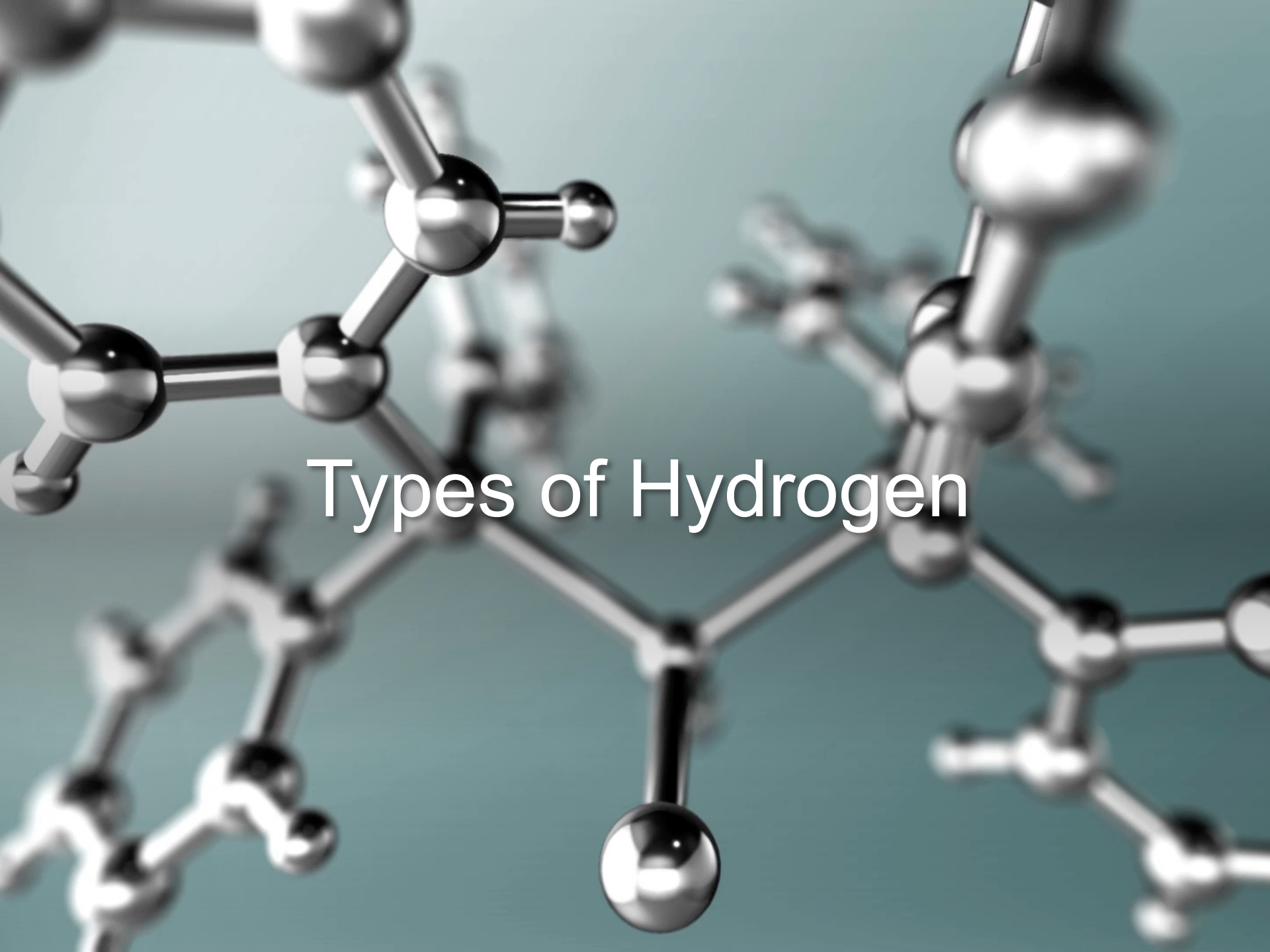


Google Books Ngram Viewer

- Change methane infrastructure to hydrogen
- Run transport, power generation & heating on hydrogen

Climate Change - Sorted!!

TROVE Renewables


Types of Hydrogen

The colours of hydrogen

No agreed definition.
Colour refers to the energy source used to produce hydrogen

White	Naturally-occurring geological hydrogen found in underground deposits
Green	Electrolysis of water, using electricity from surplus renewable energy sources
Pink	Electrolysis powered by nuclear energy. AKA Purple/red
Yellow	Electrolysis using solar power
Blue	Natural Gas + CO_2
Turquoise	Methane pyrolysis
Grey	Natural gas (Steam reforming) + CO_2 captured
Brown	Lignite (brown coal) - Gasification, syngas
Black	Black coal - Gasification, syngas
No Colour assigned	***Biomass -*** *Gasification of renewable organic resource*

Increasing Emissions

Biomass

What do these sources have in common?:

All but one are multi-step processes

All have considerable efficiency losses

(Don't shoot the messenger!!)

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Colours

TROVE Renewables

The reality of climate change…….

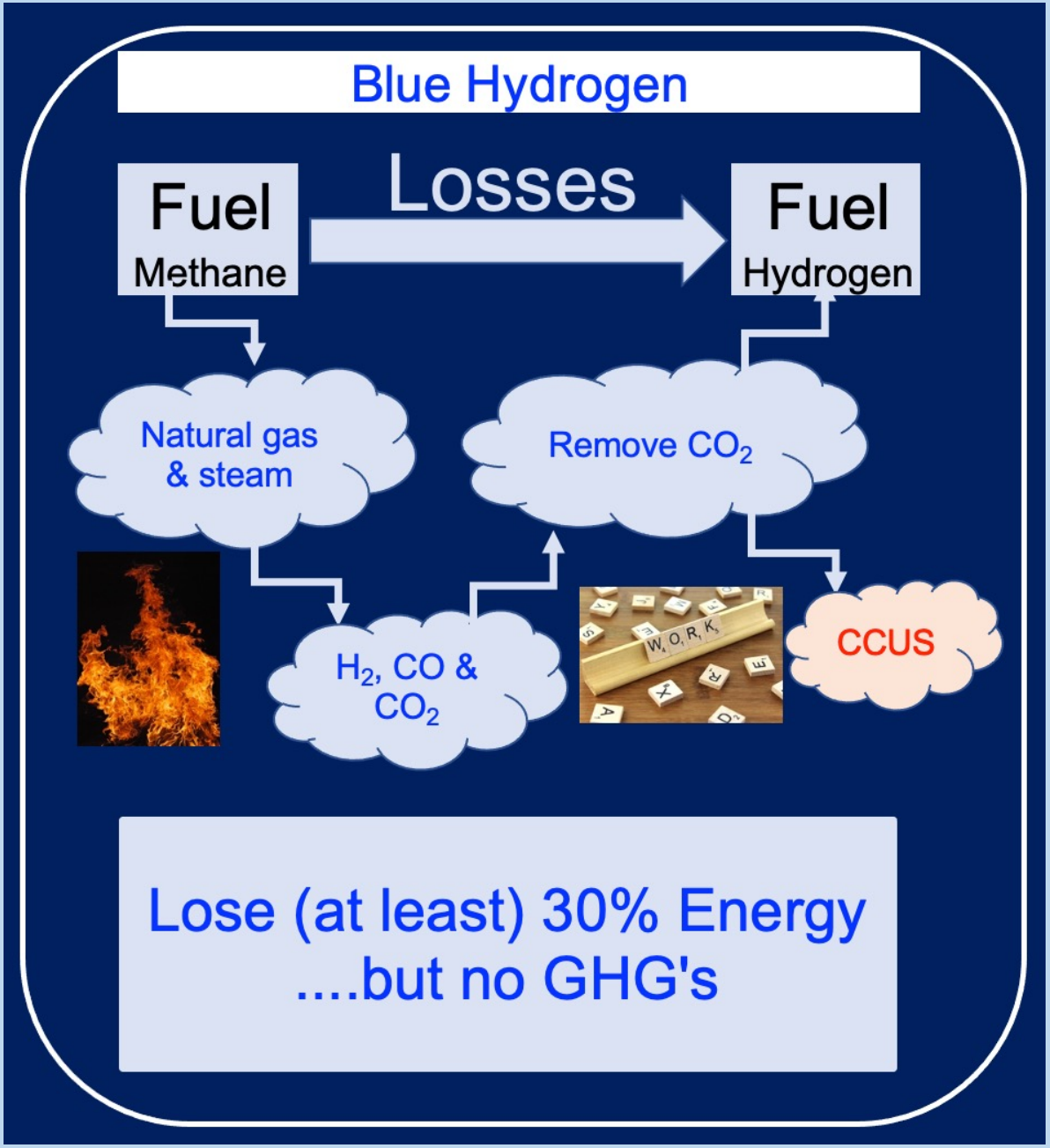
Our values	The atmosphere is critical for life
Economics	The atmosphere is a free open sewer

Methane Emissions	FREE
CO_2 Emissions	TAXED (but cheap)

Why use methane?		Hydrogen	
👍	Cheap	Expensive	👎
👍	Clean(er than coal)	Very Clean	👍
👍	Easy Transport	Harder	👎
👎	CO_2 emissions	"None"	👍
👎	Leakage	More leakage	👎

TROVE Renewables

Blue Hydrogen



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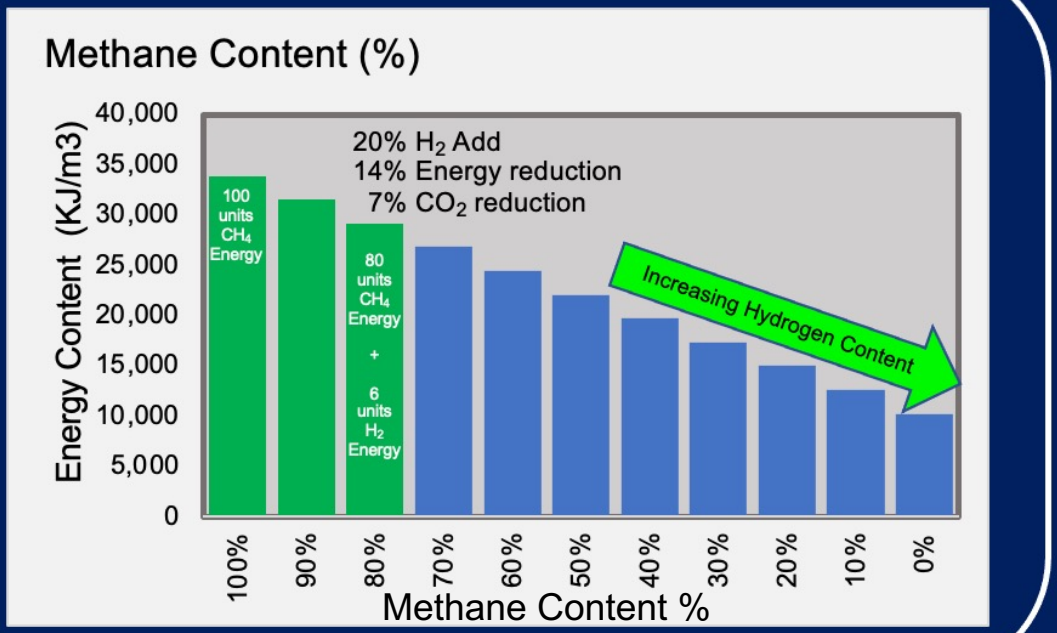
Just add hydrogen to methane……



Energy losses

Dilutant

Compression costs

Modest emissions saving

Hydrogen Energy Content per Unit Mass

Hydrogen Energy Content per Unit Volume

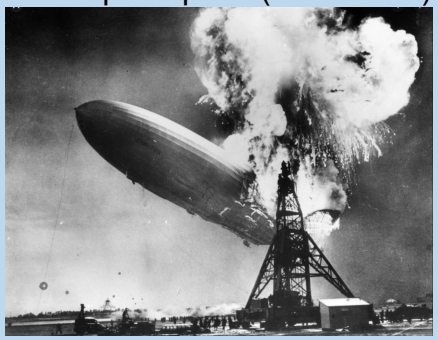
Need to move 3.2-3.6 volumes for same energy

More compression, higher pressures
More pipe friction
More leaks (smallest molecule)
Burners (cooking gas rings) & Turbines

H_2 explosive range 4-75%

Stenching agents (Thiols & mercaptans are incompatible)

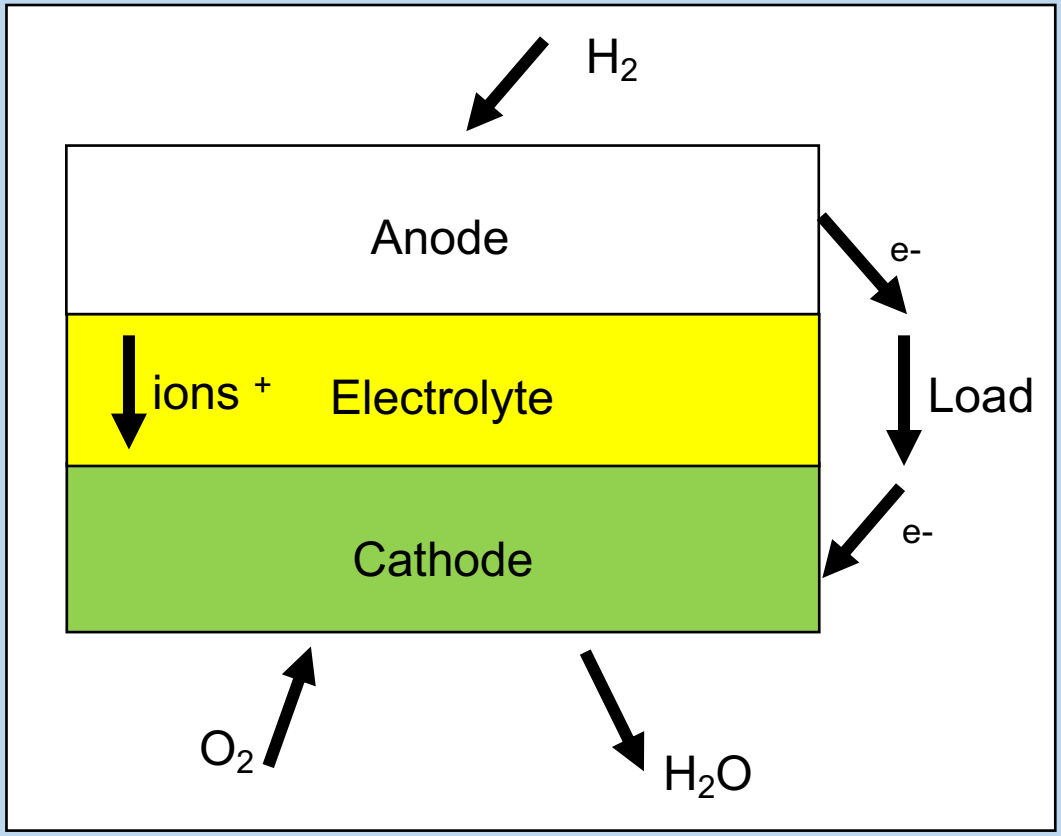
Public perception (unfounded)

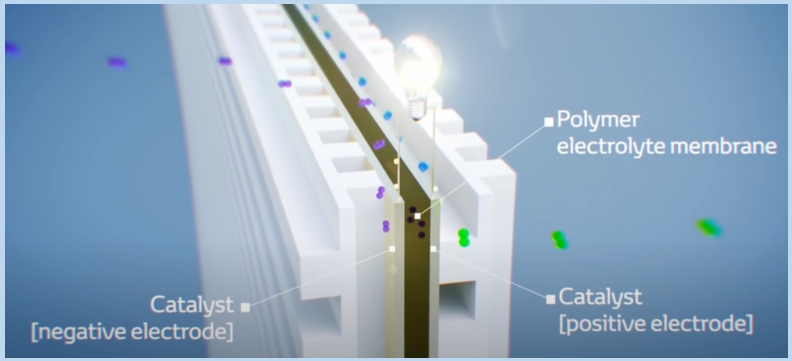


TROVE Renewables

Green Hydrogen - Electrolysis - Hydrogen Fuel Cells

Arguably a NASA spin-off technology (Gemini & Apollo)

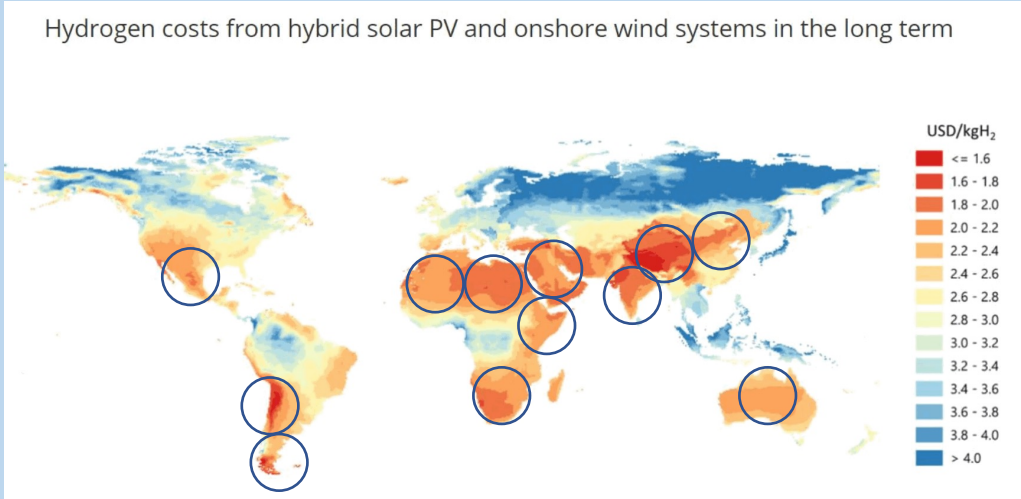




PEM - Proton Exchange Membrane

TROVE Renewables

Yellow (Green) Hydrogen



Take many developing countries (et al) out of energy poverty

Relative Cost

	US$/kg Cost
Grey Hydrogen	1-2
Blue Hydrogen	2-4
Green Hydrogen	3-6

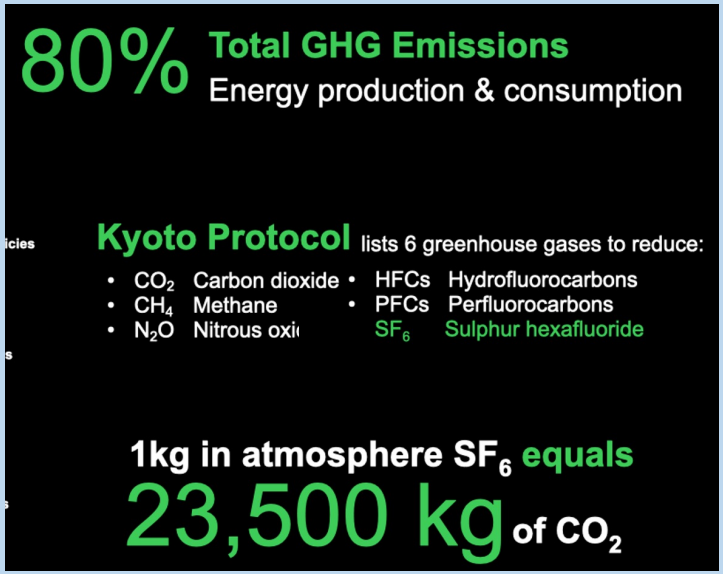
Fitch Solutions, May 2021

COP26 & Carbon Pricing

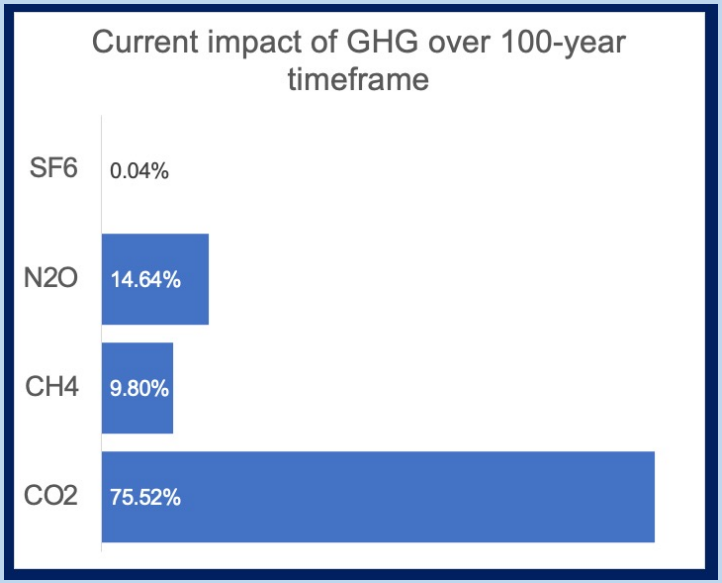
TROVE Renewables


Pollution

It's not all about fossil fuels…..



Schneider Electric, 2021



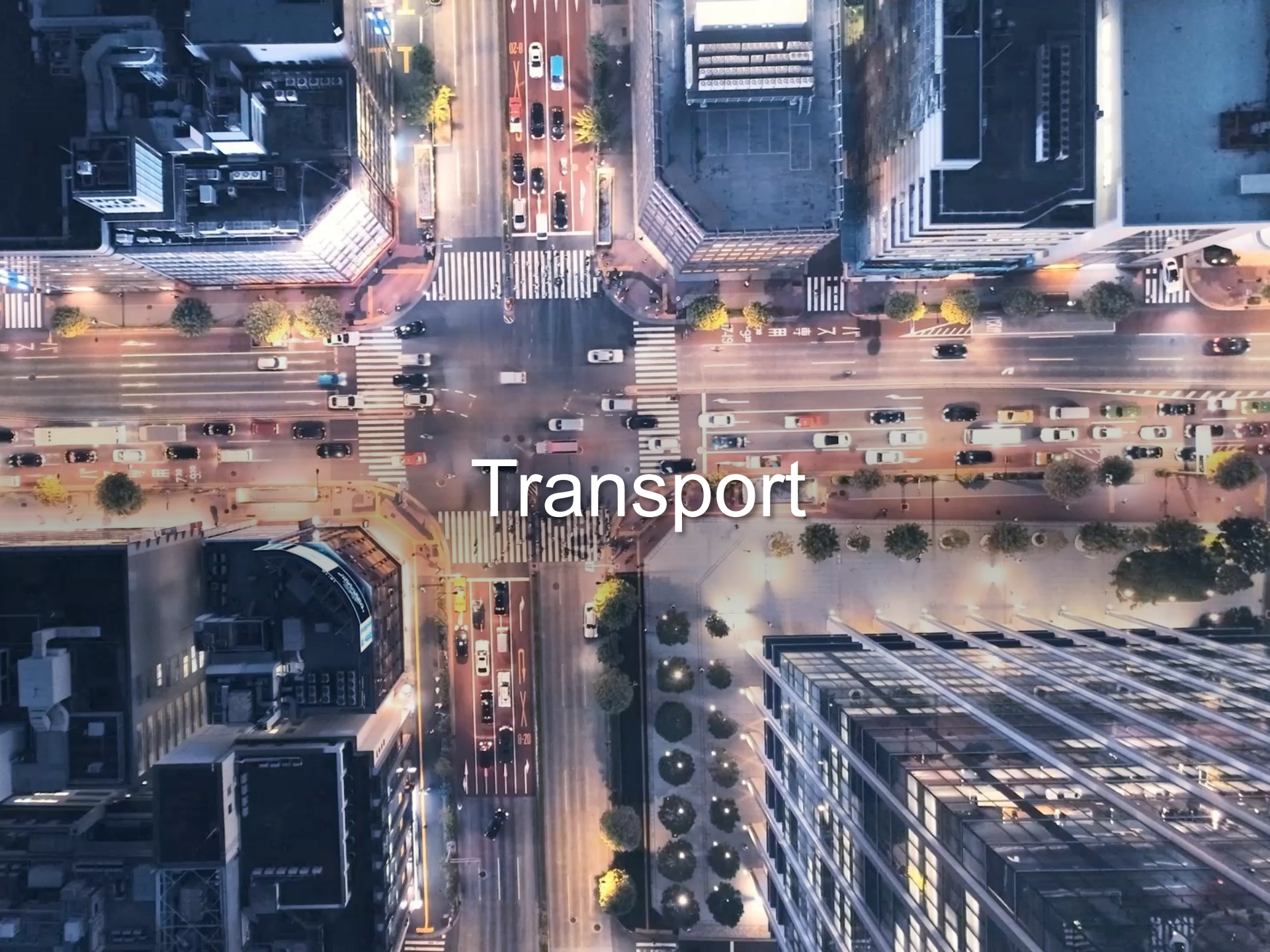
Sulphur hexafluoride is used
as an insulator
in switchgear circuit breakers

Leakage from wind turbines cited as contributary factor - overstated
Atmospheric residency for SF_6 reported as >1000 years.

	TODAY'S ATMOSPHERIC CONCENTRATION (PARTS PER MILLION)	100-YEAR GWP Global Warming Potential	RECENT ATMOSPHERIC INCREASE (PARTS PER MILLION PER YEAR)
CO_2	410	1	2.5
CH_4	1.9	28	0.008
N_2O	0.3	265	0.00085
SF_6	0.00001	23500	0.0000003

https://theconversation.com/why-sf-emissions-from-the-renewable-energy-sector-should-not-be-considered-a-dirty-secret-130734

TROVE Renewables


Transport

Cars – the Great Debate

Ford Focus FCV

Honda FCX Clarity, 2017

Nissan X-Trail FCV, 2021

Hyundai
Toyota
General Motors
Nissan
Audi
Mercedes-Benz
BMW
Fiat
Mazda
Chevrolet
Kia
PSA
Renault
Roewe
Maxus
Alfa Romeo
Chang'an
Daimler
FAW
Mitsubishi
Peugeot
Riversimple
Ronn Motor
SAIC
Suzuki
Volkswagen

Fuel Cell (Electric) Vehicles or Hydrogen Fuel Cell Vehicles

Battery Electric Vehicles

TESLA

RIVIAN LUCID gm

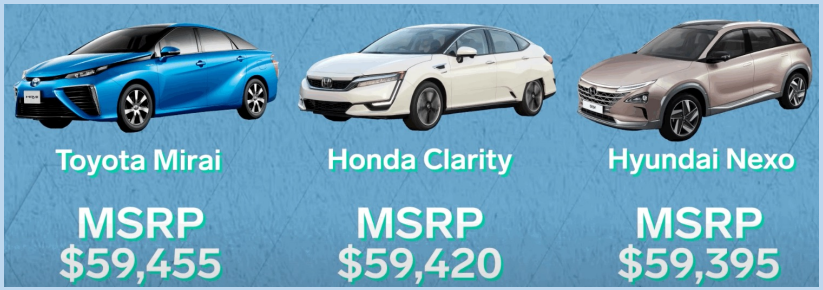
"Fool Cells" *Elon Musk*

Too long to charge	HFC
Limited range	HFC
Cost	BEV

Cost

BEV

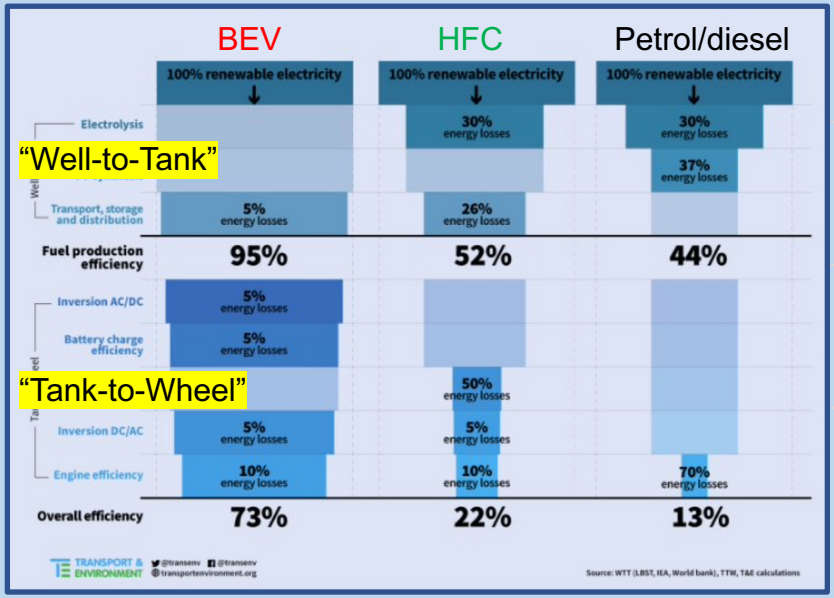
FCV



Dec 2019 Snapshot

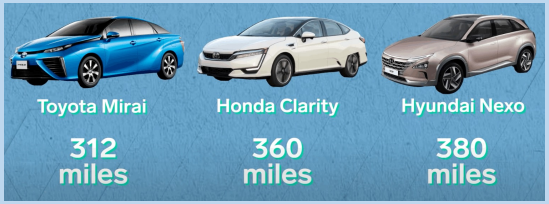
TROVE Renewables

Efficiency

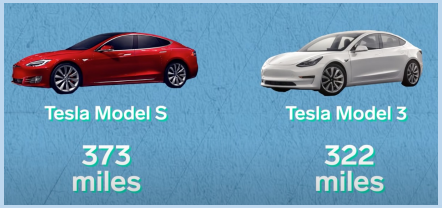


Range

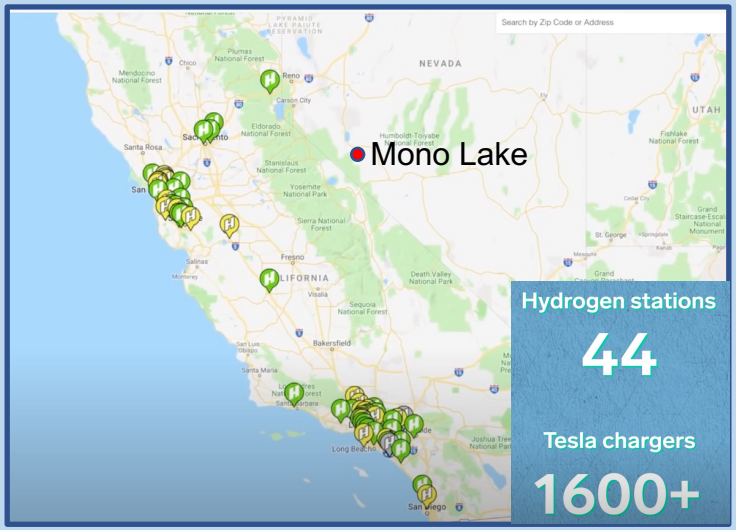
FCV



BEV

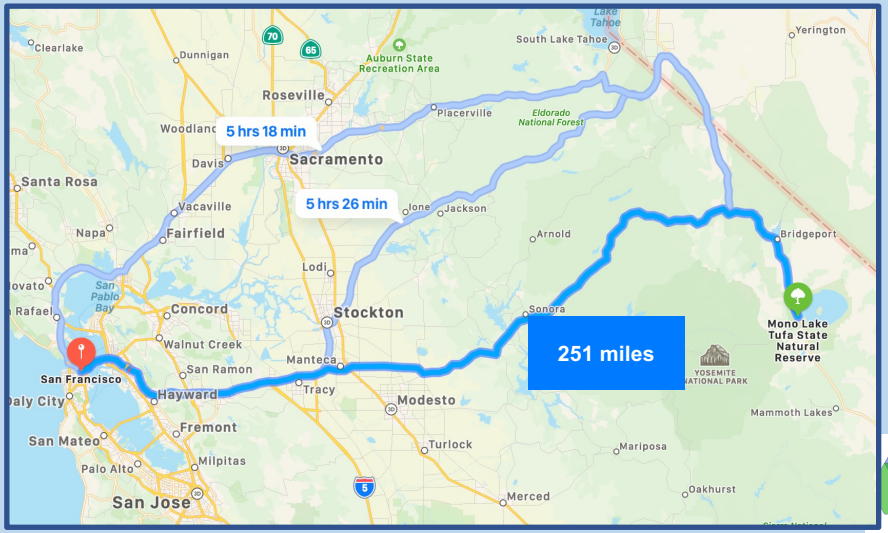


Infrastructure



~150,000 US Petrol Stations

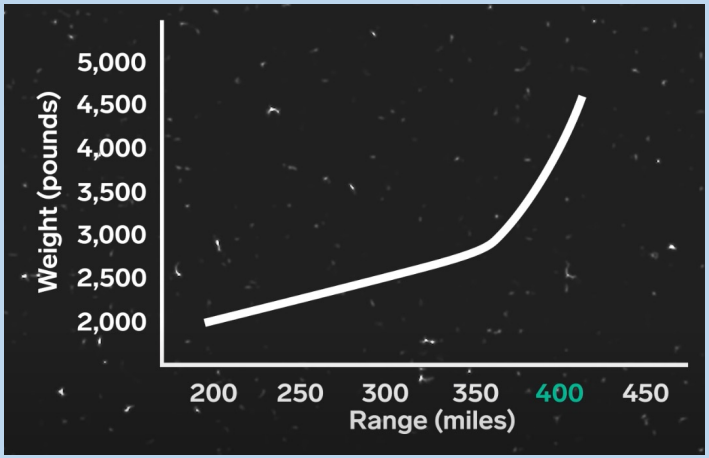
Fast-moving developments. Lack of H_2
Infrastructure is currently a major differentiator



TROVE Renewables

Fuel Cell Future

BEV



Diminishing returns for increased battery capacity

Tesla market share is 60% US EV Market

But only 2% of entire US Car Market

FCV

More H_2 stations

More cars

Economies of scale

Lower costs

Solar panels at existing petrol stations

Make H_2 on site

Will there be a period of petrol stations, hydrogen stations & battery chargers?!!

TROVE Renewables

Trucks

12,000 Fuel Cell Powered Fork Lifts (~2016)
>25,000 worldwide today

H_2-fuelled Trucks range (500-750 miles) & refuelling time (15 mins). Similar to diesel trucks. Batteries are very heavy.

10,000 new H_2 trucks were added in China (2019)

Buses

Numerous schemes worldwide including the 2020+1 Olympic Games

Jul 27, 2019 - 03:14 pm

Holland: Qbuzz provinces order 20 fuel cell buses

DRENTE | ELECTRIC BUSES | FCEV | FUEL CELL | GRONINGEN | NETHERLANDS | PUBLIC TRANSPORT | QBUZZ | VAN HOOL

The public transport operator Qbuzz has ordered 20 fuel cell buses from the Belgian manufacturer Van Hool for use in the Dutch provinces of Groningen and Drente. An order was also placed for a hydrogen fuel station.

The vehicles are scheduled to go into operation in December 2020. Because of their targeted range of 350 to 400 kilometres, they will then be used on intercity routes in the two provinces in the north of the country. In total, Qbuzz has ordered over 164 electric buses, and battery electric buses are to be used on the city lines – including at Ebusco, VDL and Heuliez.

The Groningen Drenthe transport authority has also awarded Shell the contract to build a hydrogen fuel station in the city of Groningen and to supply the hydrogen. There is currently only one hydrogen filling station in the two provinces, an industrial plant operated by Nouryon in Delfzijl. But that would have meant a detour of 35 kilometres – to avoid this, a plant is now being built in Groningen.

The order follows a field trial: two hydrogen buses have been in regular service since December 2017. Both the pilot bus project and the 20 buses in Groningen are supported by the Ministry of Infrastructure and Environment, the EU via the FCHJU project and the provinces of Groningen and Drenthe.

For Van Hool, this is the second largest order for fuel cell buses after the 40 H2 buses for the German cities of Cologne and Wuppertal. According to Van Hool, it has already built 131 hydrogen buses, 21 of which have even been exported to North America.

Jul 24, 2019 - 02:20 pm

Aberdeen orders another 15 hydrogen buses

ABERDEEN | BALLARD POWER SYSTEMS | EU | FCEV | FUEL CELL | JIVE | PUBLIC TRANSPORT | SCOTLAND | STREETDECK FCEV

The Scottish city of Aberdeen is procuring 15 more fuel cell buses. They have been ordered from the Northern Irish manufacturer Wrightbus, and Ballard Power Systems is supplying the fuel cell technology.

Aberdeen already has ten Van Hool H2 buses in service. The 15 new buses – all double-decker – are co-financed as part of the EU JIVE project and are scheduled to go into operation this year. The vehicles can transport up to 64 passengers.

In the basic version, the range of the 10.9 metre long double-decker is around 320 km. Wrightbus presented the model called StreetDeck FCEV only at the beginning of November at the latest Euro Bus Expo. The StreetDeck FCEV uses Ballard's FCVelocity FC fuel cell system and a Siemens drive train. The FC bus was developed as part of the EU-funded JIVE project.

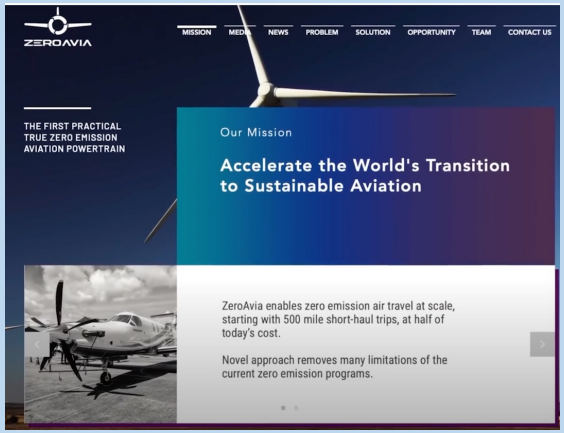
The order volume is expected to be 7.5 million pounds, i.e. 500,000 pounds per vehicle – the equivalent of 560,000 euros. "We are very pleased to contribute to the financing that has made this exciting next phase of Aberdeen's hydrogen journey possible," said Scottish Energy Minister Paul Wheelhouse. "This important investment will help the city achieve its decarbonisation goals and further consolidate its reputation for innovation and technology".

It's not the first major order for Wrightbus: two months ago, London's public transport operator Transport for London ordered 20 fuel cell buses worth £12 million from the Ballymena-based company.

IOC president experiences Japan's fuel cell tech designed for 2020 Tokyo Games

November 28, 2018 | By ALICIA MOORE

Planes



Airbus - 2030 target for green H_2 zero emission aircraft.
ZeroAvia developing a six-seater H_2-fuelled plane, 500-mile range.
Energy Density$_{\text{Jet fuel}}$ > Energy Density$_{\text{Hydrogen}}$

Trains

Concentrated distribution

Faster recharging than batteries

1st H_2 train (built by Alstrom) has run since 2018 in Germany. Japan & UK to follow

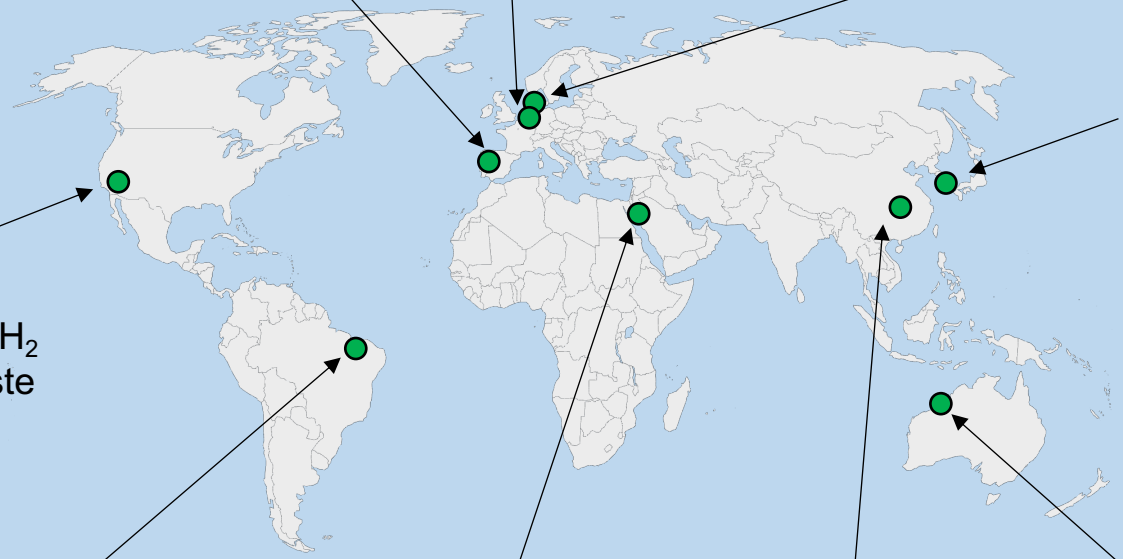
Boats & Ships

Hystra – World's first hydrogen carrier

Not yet fuelled by hydrogen


Developments

Future Hydrogen “Cities” & large scale projects



HyDeal Ambition – Spain/France
67GW solar
To produce green H_2 for use across Europe

NorthH2 – Netherlands
10GW Offshore Wind
To produce green H_2 for heavy power industry

AquaVentus – Germany
10GW Offshore Wind
To produce green H_2 for use across Europe

Ansan – S. Korea
Tidal power to H_2 production, 232 homes, two buses & forklifts

Lancaster – USA
3.8 million tonnes of H_2 per year – using waste

Base One – Brazil
3.4GW Wind and Solar
International export

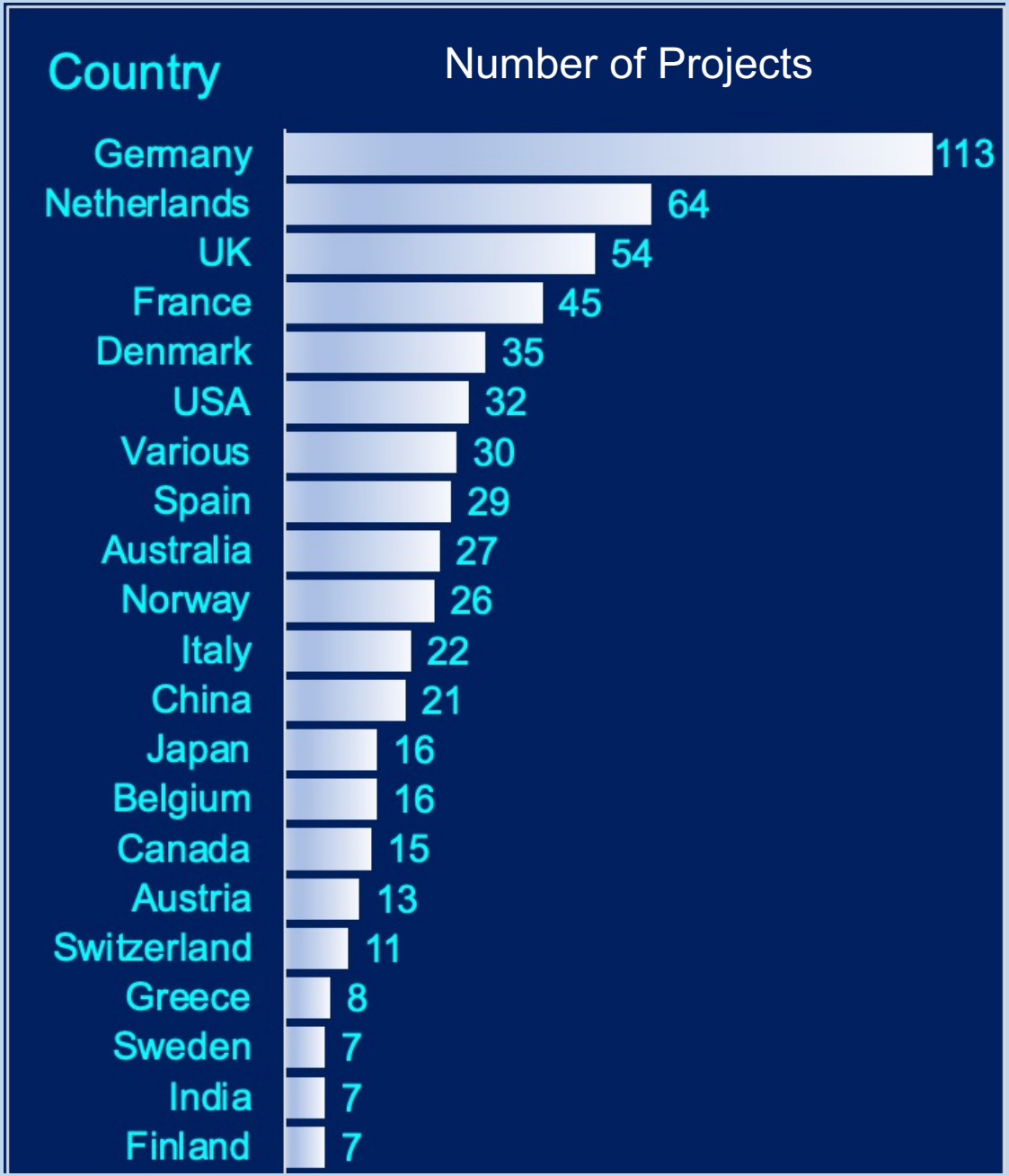
NEOM - Saudi Arabia
4GW Wind & Solar to produce H_2, 170 km pipeline

Wuhan – China
Up to 100 fuelling stations by 2025
21 H_2 busses

Asian Renewable Energy Hub – Australia
26 GW Wind & Solar
1.75 million tonnes per year of H_2 & NH_3
InterContinental Energy, CWP Energy Asia, Vestas & Macquarie (FID 2025)

TROVE Renewables

Hydrogen World Leaders



Source: TROVE May 2021

728 Projects

Europe dominates (but also most transparent & published).

Varying stages of R&D, pilot, demonstrator, commercial, completed project status

AUSTRALIA
~37GW electrolyser projects planned, incl. 4GW under development

TROVE helps separate the wheat from the chaff

TROVE Renewables


Storage
FRAGILE

Hydrogen Storage

100-300 atmospheres Pressure
-250 C liquid

Scale-up sustainable renewable energy

Transport 1/800th volume, 8,000 tonnes (gross)
2500m^3

TROVE Renewables

Hydrogen Storage – Existing Pipelines

- Liquid H_2 71kg/m3 (boils at -161 C)
- Methane 420kg/m3

- Hydrogen embrittlement – not an issue for mild steel but pipelines are made of hard steel (also welds & heat-affected equipment). Replacing all pipework – massive capital cost.

- H_2 line-pack energy (1hr) ~1/3 methane line pack energy (3/4 hrs)

- Methane storage is already a major strategic reserve – multiple fields, existing infrastructure, domestic appliances optimised etc.

- Hydrogen can't compete with methane due to high cost of electrolysers and expensive storage costs.

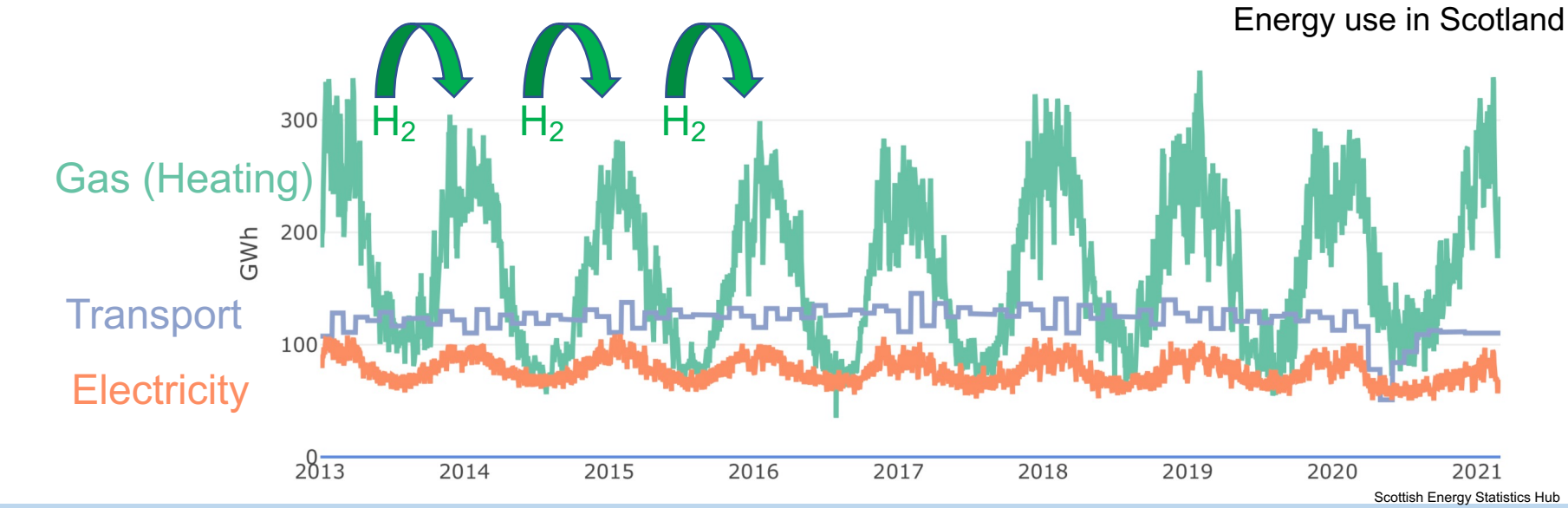
Can't use existing gas infrastructure

TROVE Renewables

Hydrogen Storage

- Large scale energy storage on the grid

Battery Farms/Banks	Store for hours better than days
P2G2P H2 Storage	Store for weeks/months



All webinars in series available online

Will large scale energy storage on the grid work?

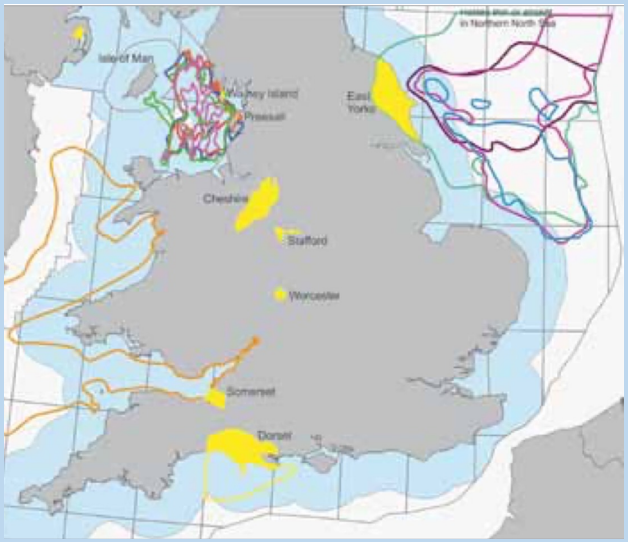
Demonstrator: H100 Fife & H100 Argyll

TROVE Renewables


Underground
Storage

Underground Storage

There are over 30 large salt caverns in use across the UK today



BGS Study

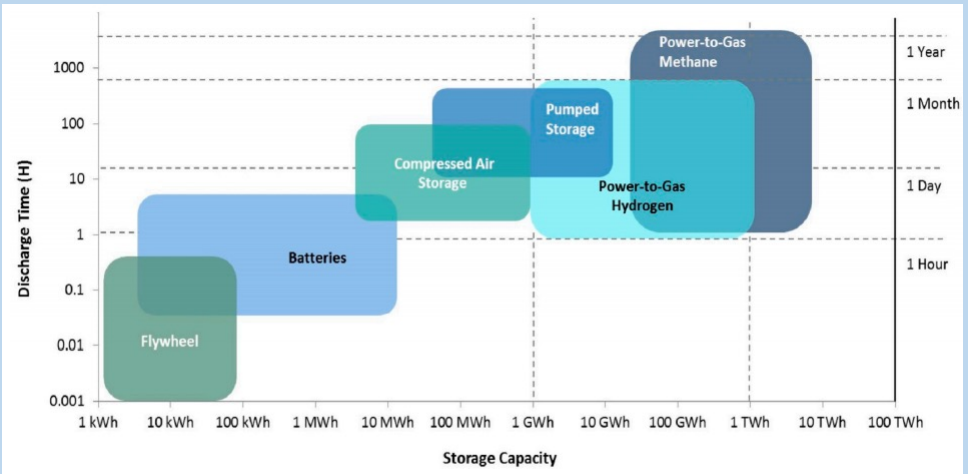


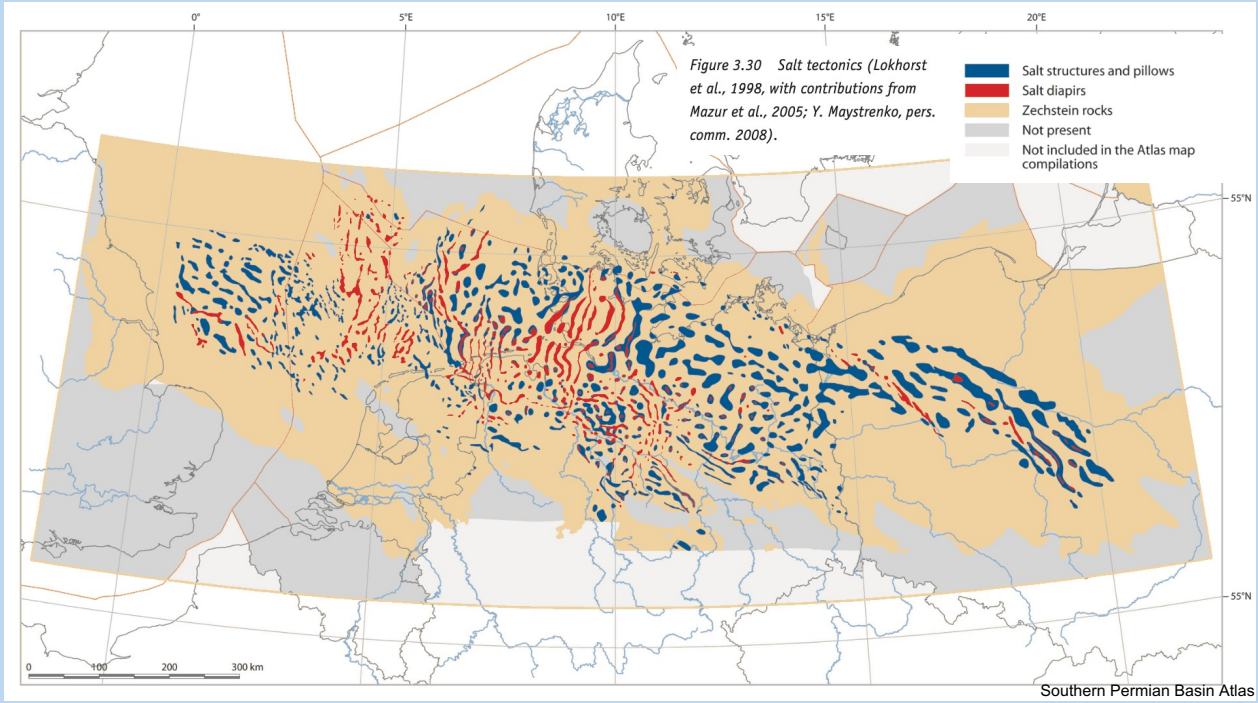
Figure 3. Comparison of discharge time vs capacity of energy storage technologies [24].

https://www.researchgate.net/figure/Comparison-of-discharge-time-vs-capacity-of-energy-storage-technologies-24_fig2_306523823

Geographically discrete locations (e.g. ? none in Scotland)

TROVE Renewables

Underground Storage – Salt Caverns



Other stores

Deep saline aquifers

Depleted oil & gas fields

Lined or unlined rock caverns

Challenges

Different physical and chemical properties (e.g. CO_2, CH_4, Air)

Reaction with the subsurface minerals and fluids

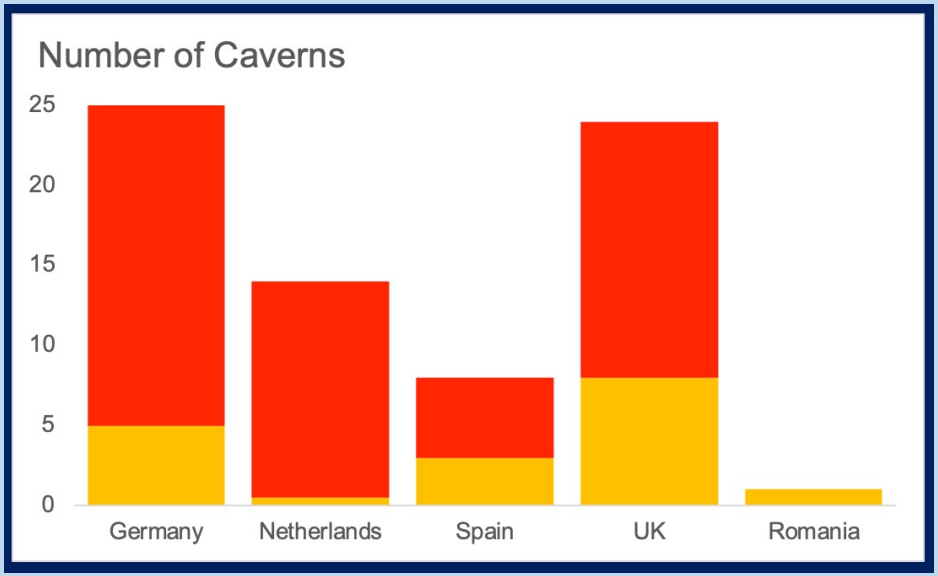
Growth of hydrogen consuming microbes in the subsurface

Containment may be compromised by repeated injection-reproduction cycles

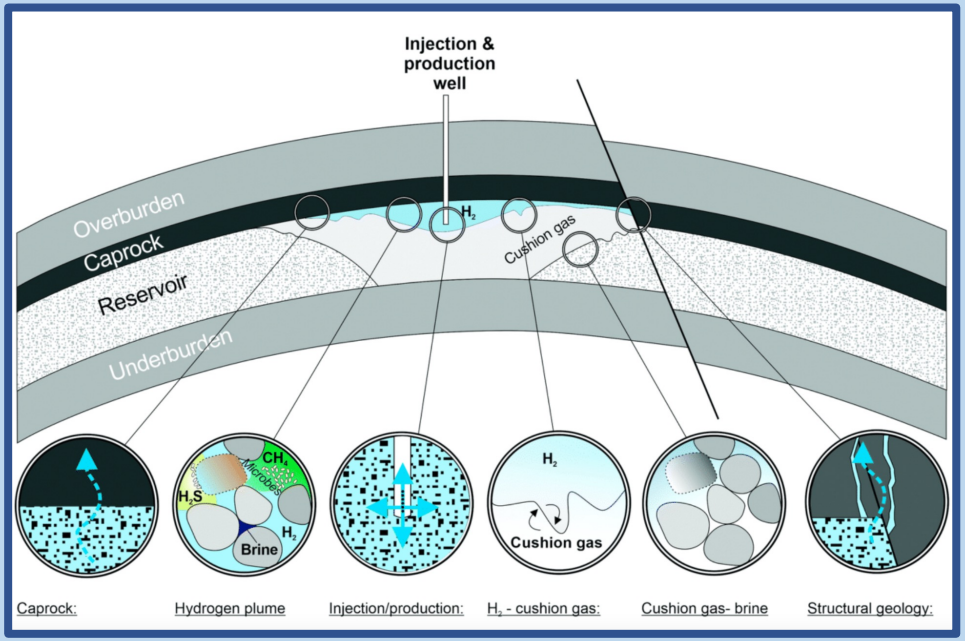
Induced seismicity

TROVE Renewables

Hydrogen Underground Storage



Hyunder, 2019



Why Salt Caverns?

- Proven track record for methane (et al) storage
- Flexibility when operated on a highly cyclical basis
- Low proportion of cushion gas required
- “Clean” (unlike depleted HC fields)

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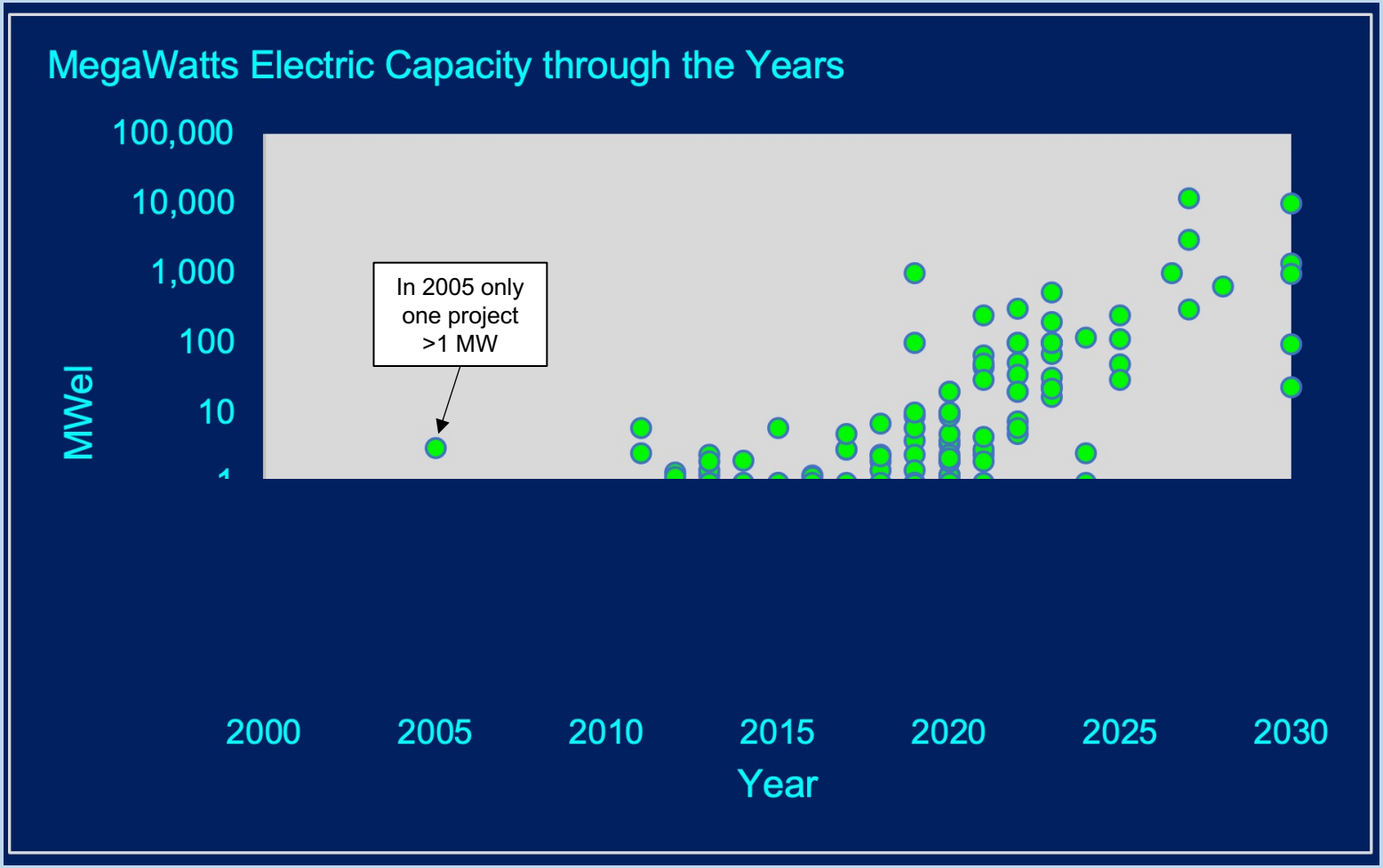
Summary

TROVE Hydrogen Analysis

Global Hydrogen Projects – sizes vary by over 7 orders of magnitude

Rate of Growth is……



Exponential !!

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Conclusions

- Hydrogen has a place in the future. Focus where better solutions are required.
- It is typically twice as efficient to move electricity than to move hydrogen.
- Existing methane pipelines highly unlikely to work for hydrogen.
- Without a meaningful (punitive) Carbon Tax, methane will continue to be the cheapest solution.
- Tackle the “big wins” early. Cars have alternatives (BEV’s). Focus on buses & trucks.
- Global government policy alignment is needed to agree carbon tax, initiate infrastructure development etc.
- COP26 may well determine the future for hydrogen
- Find useful data FAST!! Use TROVE.

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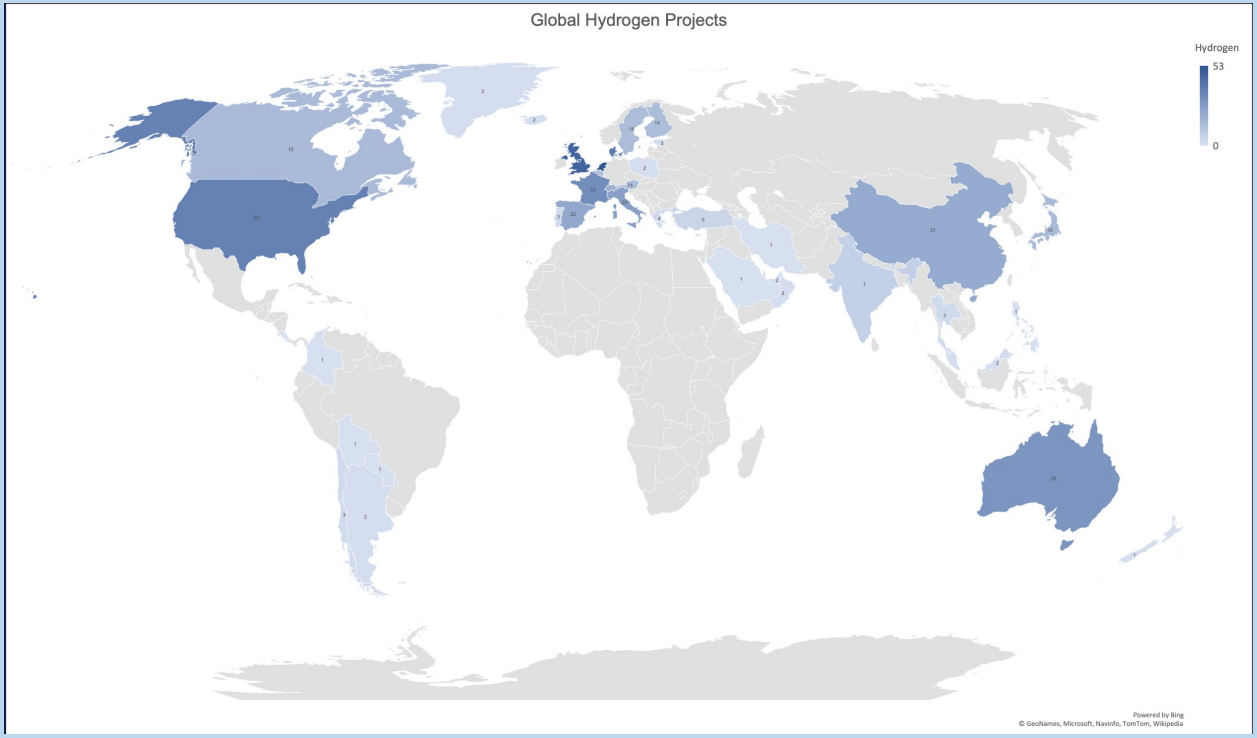
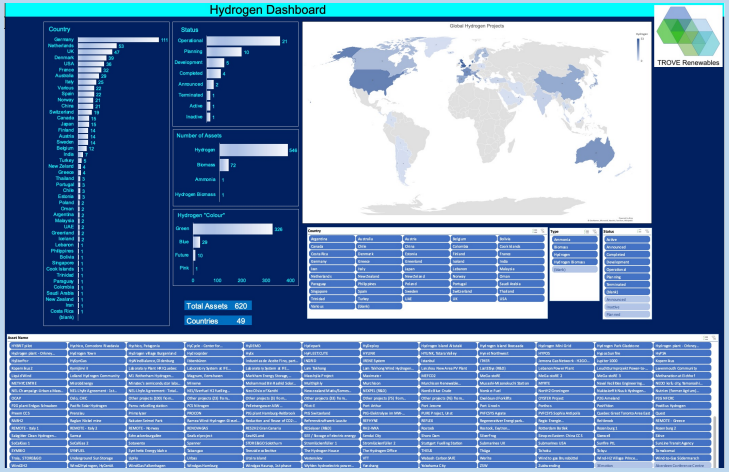
TROVE
Hydrogen
(in 104 seconds)

What's in TROVE Hydrogen KnowledgeBase?

- 700+ Assets
- Excel-based
- Project Descriptions
- 50+ Country Overviews
- Technology Overviews





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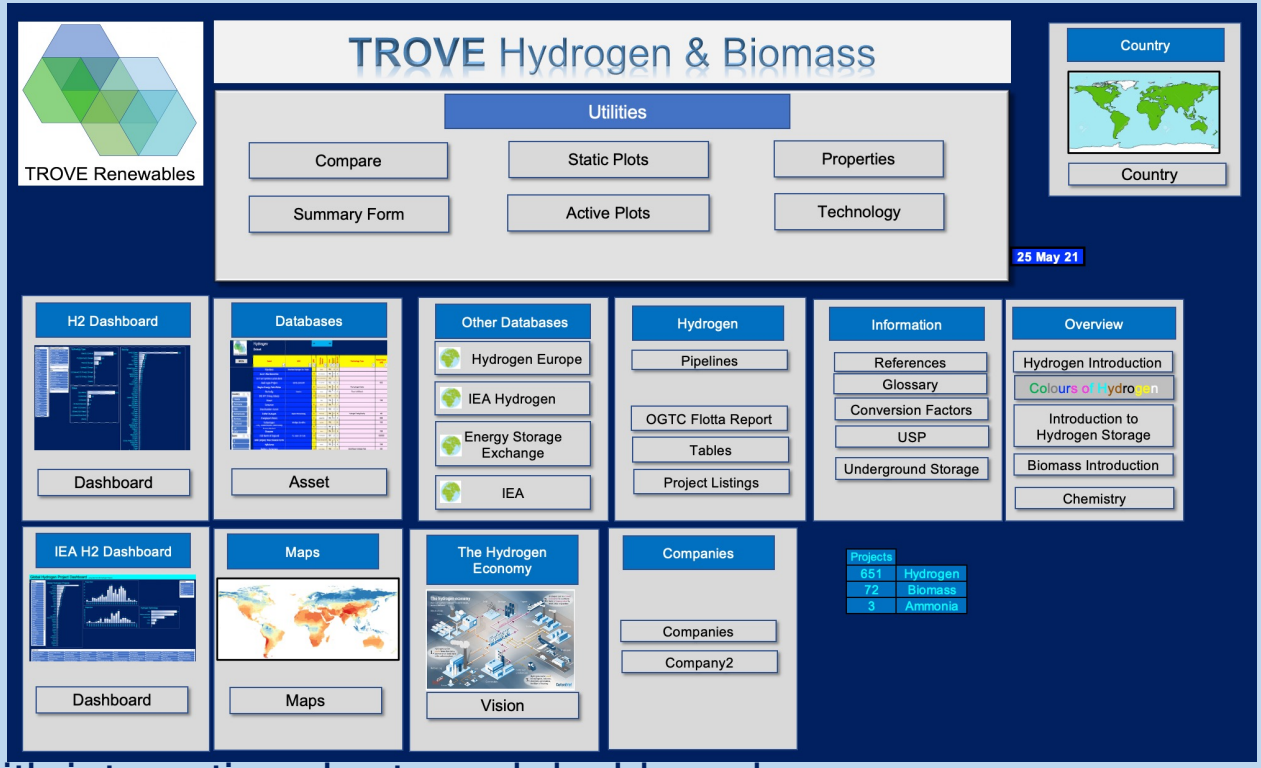
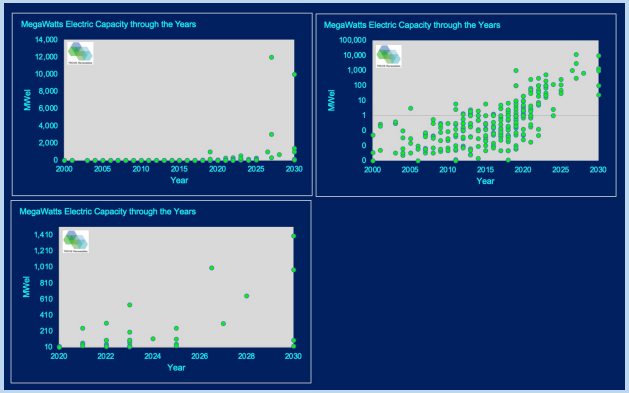
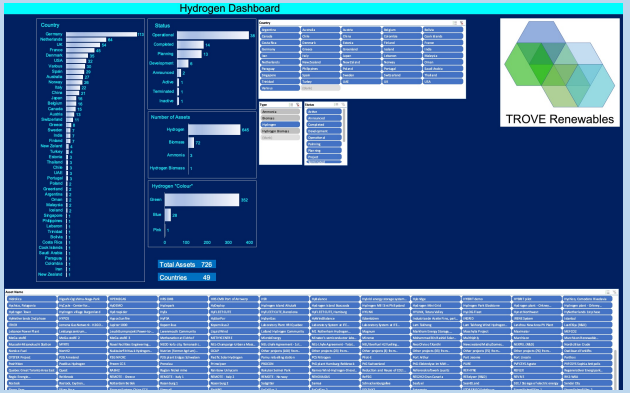
Hydrogen Assets

Excel-driven app with advanced functionality



Presented with interactive charts and dashboards:





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Hydrogen Assets

>700 Hydrogen projects with detailed descriptions, maps, histories, project descriptions and more……

3Emotion

Aberdeen buses

AltHytude

Arrowsmith

Balance

Big Hit

Carbon2Chem

Dolphyn

Electrochaea

TROVE Renewables

Country Overviews

50 country profiles with detailed descriptions, maps, histories, policies etc

Australia

Belgium

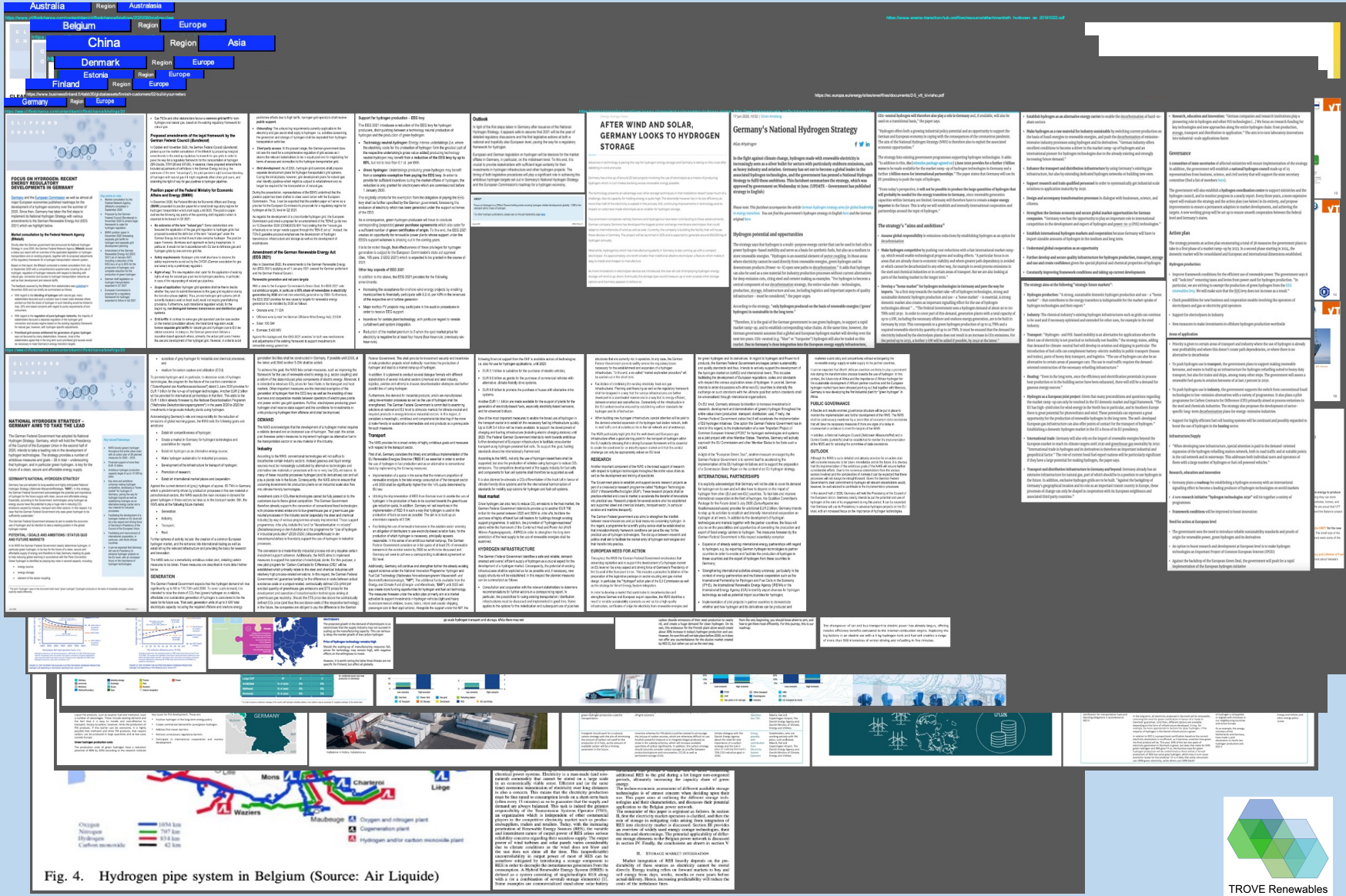
China

Denmark

Estonia

Finland

Germany



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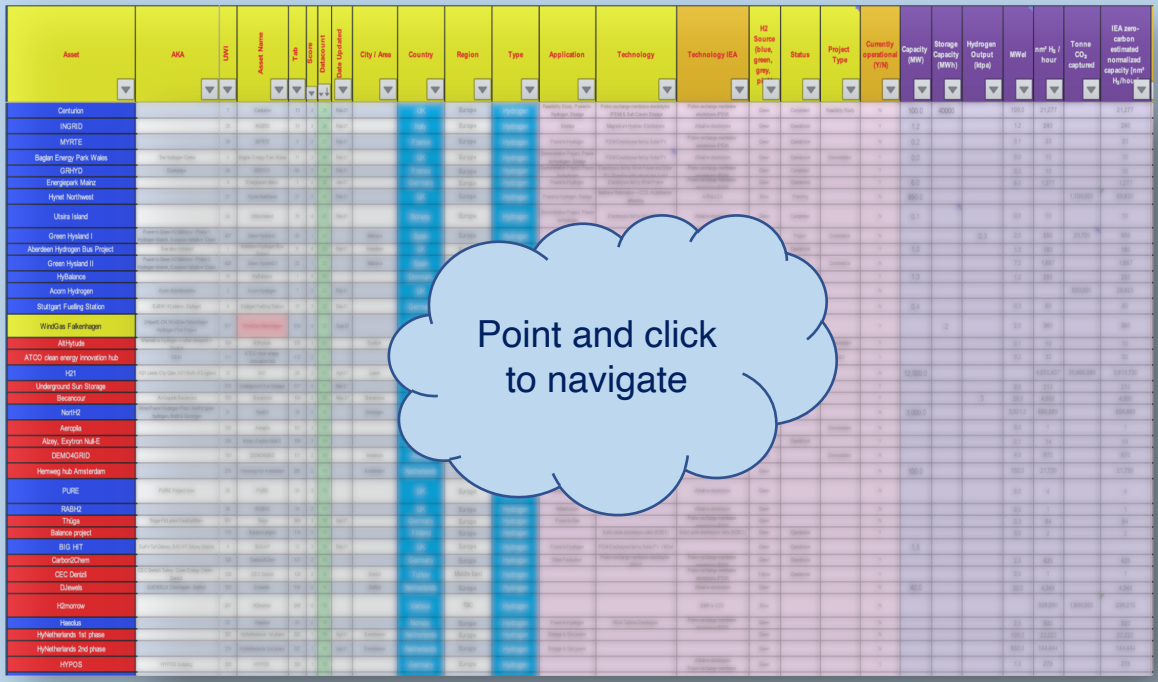
TROVE Hydrogen KnowledgeBase

Key Data

- **Date of Commissioning and Development Stage**
- **Capacity**
- **Management**
  - **Developer, Owner, Operator**
- **Location Data**
  - **Region, Country, Latitude & Longitude**
- **Colour (Source)**
- **And more…..**



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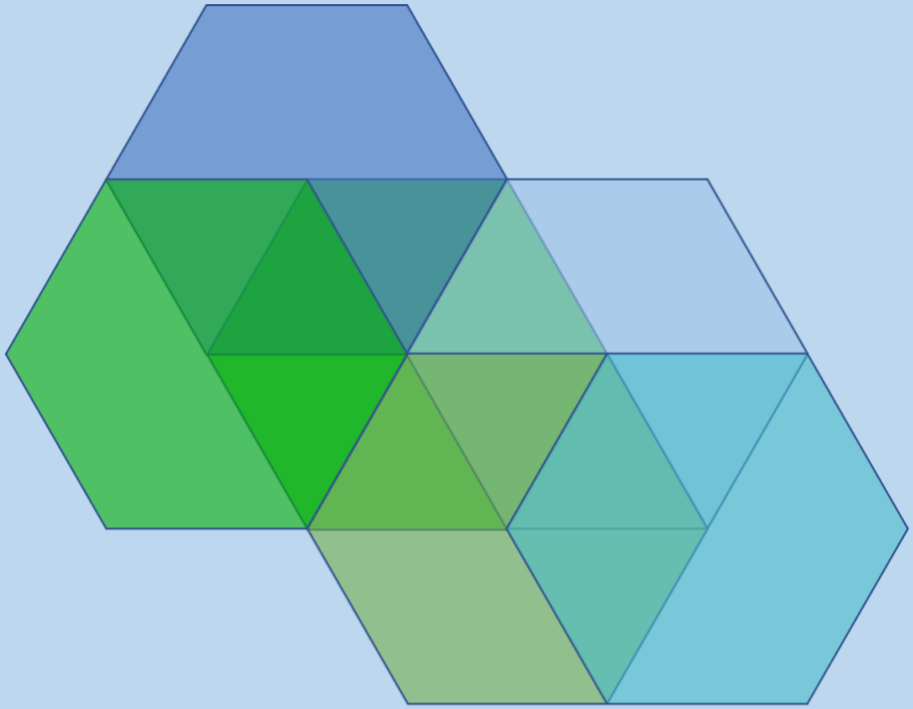

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