ClientEarth

HYDROGEN HYPE

WHAT'S THE STORY? WHAT'S AT STAKE?

Hydrogen (H_2) isn't found, it's made — and making it takes energy.

THE BIG PICTURE

The world produces about 100 million tonnes of hydrogen annually.

That's equivalent to the weight of about 670,000 blue whales.

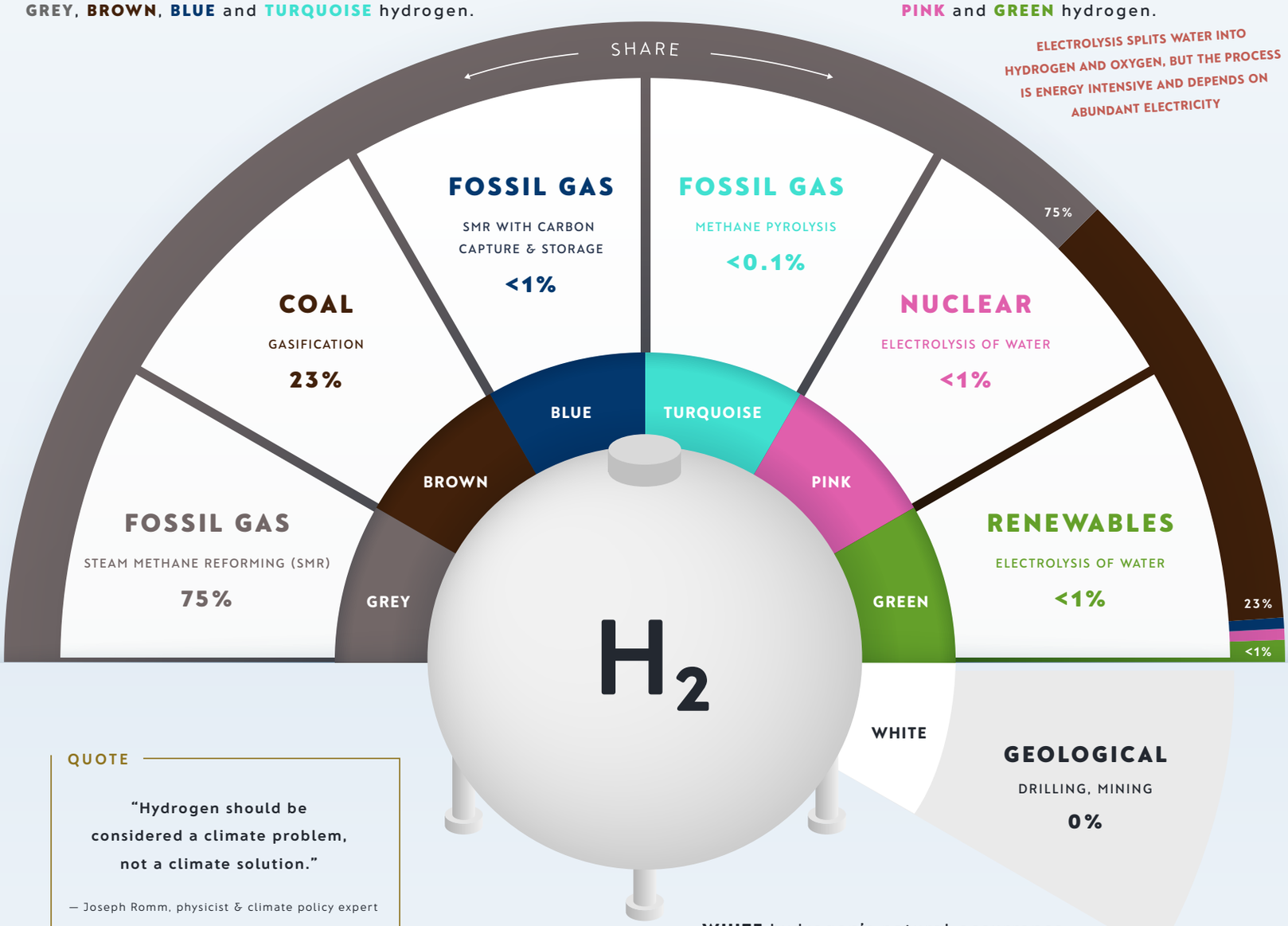
THE HYDROGEN 'RAINBOW'

Hydrogen is often labelled by colour, reflecting how it's produced and the emissions it creates.

More than 98% is made from fossil fuels:
GREY, **BROWN**, **BLUE** and **TURQUOISE** hydrogen.

About 1% is made using low-carbon energy:
PINK and **GREEN** hydrogen.

ELECTROLYSIS SPLITS WATER INTO HYDROGEN AND OXYGEN, BUT THE PROCESS IS ENERGY INTENSIVE AND DEPENDS ON ABUNDANT ELECTRICITY



QUOTE

"Hydrogen should be considered a climate problem, not a climate solution."

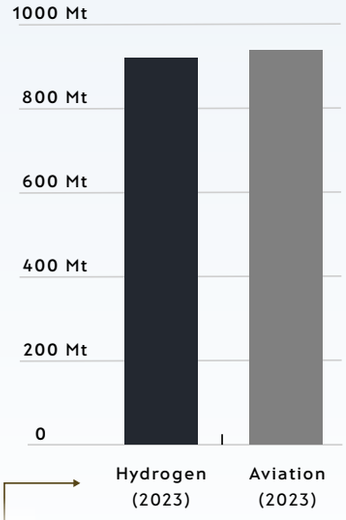
— Joseph Romm, physicist & climate policy expert

WHITE hydrogen's natural occurrence is so limited that, for now, it's more a geological

curiosity than a scalable energy solution.

EMISSIONS

Fossil fuel generated hydrogen produces 2.5% of global emissions.



DECARBONISING HYDROGEN PRODUCTION WOULD TAKE ABOUT 5,000 TERAWATT HOURS OF CLEAN ELECTRICITY PER YEAR — MORE THAN THE ENTIRE U.S. GRID DELIVERS PER YEAR TODAY

USE

Today, hydrogen is overwhelmingly used as a **CHEMICAL FEEDSTOCK** for the fertilser and petrochemical industries.

40%

REFINING

To remove sulphur and other impurities from fuels in oil refineries.

50%

CHEMICALS

For producing **ammonia** (used in fertilisers) and **methanol** (used in plastics and other chemicals).

10%

INDUSTRY

Used as a reducing agent in steelmaking and for specialised applications in other sectors.

QUOTE

"Today, hydrogen is mainly used in the refining and chemical sectors and produced using fossil fuels such as coal and natural gas, and thus responsible for significant annual CO_2 emissions."

— International Energy Agency (2023)

GREEN HYDROGEN may play a limited role in a future sustainable energy system — but only where cleaner, simpler options like direct electricity aren't feasible, and where more sustainable ways of meeting societal needs aren't available.

H_2 HYPE

Globally, policy momentum is strong. In total, more than 60 governments (including the EU) have adopted hydrogen strategies.

H_2 REALITY

The physics and economics are very weak. Production, transport and use face huge energy losses, high costs and tricky infrastructure challenges.

SEE BELOW FOR WHY

Any role for green hydrogen will likely be limited to use as a **CHEMICAL FEEDSTOCK** and in **NICHE SECTORS**.

Regardless of its colour, hydrogen is a deeply flawed **ENERGY CARRIER**.

Decarbonising hydrogen production for **CHEMICAL FEEDSTOCKS** must come first, not scaling it as an inefficient **ENERGY CARRIER**. Given limited sustainable supply, **GREEN HYDROGEN** beyond feedstocks remains unlikely. If surplus ever does emerge, its best role may be in **NICHE SECTORS** — such as replacing coal in virgin steelmaking, fueling long-haul shipping or storing excess renewable electricity.

BUT EVEN EARLY PILOT PROJECTS REVEAL PERSISTENT TECHNICAL AND FINANCIAL HURDLES, UNDERSCORING THE BROADER CHALLENGE OF SCALING GREEN HYDROGEN AND THE NEED TO RIGOUROUSLY EVALUATE ALTERNATIVES

ENERGY CARRIER VS ENERGY SOURCE

- An energy source provides primary energy directly from nature, such as sunlight, wind, nuclear fuel (uranium) or fossil fuels.
- An energy carrier stores, transports and delivers that energy in usable form, often with conversion losses — e.g. electricity or hydrogen.

THE CHALLENGING PHYSICS

Hydrogen's unique physical properties complicate its affordable and efficient use as an energy carrier. It's very different to fossil gas (mostly methane), even though people often compare the two.

TEENY TINY

Hydrogen is the smallest and lightest molecule in the universe, so can slip through microscopic gaps in pipelines and valves.

MEANING HYDROGEN IS LEAKY: UNDETECTED HYDROGEN LEAKS CAUSE ABOUT ONE-THIRD OF HYDROGEN ACCIDENTS

LOW ENERGY DENSITY

It contains about one-third the energy of gas per cubic metre, making storage and transportation extremely challenging and inefficient.

MEANING THREE TIMES MORE HYDROGEN WOULD HAVE TO FLOW TO DELIVER THE SAME ENERGY AS FOSSIL GAS

HIGH FLAMMABILITY

Accidental ignition is more likey than with fossil gas because it can catch fire and burn across a wider range of concentrations.

HIGH GRAVIMETRIC ENERGY DENSITY

Hydrogen is energy-dense by weight — about twice that of fossil gas. But for the purposes of storage, transport and energy, volume matters most...

VERY LOW VOLUMETRIC ENERGY DENSITY

At normal temperature and pressure, a given volume of hydrogen has a **very low energy per unit volume**, one third that of fossil gas.

COMBUSTION

Hydrogen combustion produces water vapour, whereas the combustion of methane releases carbon emissions (CO_2).

BUT HYDROGEN COMBUSTION CAN STILL PRODUCE NITROGEN OXIDES (NOx), HARMFUL POLLUTANTS FORMED AT HIGH TEMPERATURES

LIQUEFACTION

Hydrogen only liquifies at -253°C (boiling point), whereas methane (fossil gas) liquifies at -162°C (LNG) — making storage and transportation less efficient and more challenging.

EMBRITTLEMENT

Hydrogen atoms can infiltrate metals like steel and weaken its structure, making it more prone to cracking under stress.

THE PRODUCTION & USE CHALLENGE

Producing green hydrogen cheaply, efficiently, safely and conveniently is hard.

EXPENSIVE

Green hydrogen is far costlier than direct electrification options (or fossil fuels).

ANY COST REDUCTIONS ARE LIMITED BY ITS PHYSICAL CONSTRAINTS

BRUTALLY INEFFICIENT

Producing, transporting and using hydrogen wastes the majority of the original energy.

THERMODYNAMICALLY SPEAKING, IT'S A LOSING BATTLE — ELECTRICITY WINS ALMOST EVERY TIME

ENERGY-INTENSIVE

Producing, storing and using hydrogen consumes large portions of energy at every stage.

HYDROGEN IS ONE OF THE MOST ENERGY-INTENSIVE FUELS AVAILABLE

EVs vs H_2 VEHICLES

Battery-powered electric vehicles are about **three times** more energy efficient than hydrogen fuel cell cars.

HYDROGEN FUEL CELL CARS TYPICALLY CONVERT ONLY 25–35% OF ORIGINAL ENERGY INTO PROPULSION

HEAT PUMPS vs H_2 BOILERS

Heat pumps use about **five times** less renewable energy than powering boilers by green hydrogen.

HEAT PUMPS PRODUCE ABOUT THREE UNITS OF HEAT FOR EVERY ONE UNIT OF ELECTRICAL ENERGY USED

THE WEAKEST LINK IN THE CHAIN: ENERGY LOSS

Energy is lost at every stage: from producing green hydrogen (via electrolysis), to compressing or liquefying it, transporting it, and finally converting hydrogen back to electricity or other useful energy.

Losses can occur over long distances due to the resistance in high-voltage transmission lines.

-5%

QUOTE

"The electricity you use to make [hydrogen] would have to be ridiculously cheap. And if you have that, why use it to make hydrogen?"

— Saul Griffith, Inventor & electrification expert

Hydrogen must be compressed, liquefied or bound to 'carriers' (e.g. ammonia), all of which use additional energy.

ELECTRICITY GENERATION

ELECTRICITY TRANSMISISON

ELECTROLYSIS

HYDROGEN STORAGE

TRANSPORT & DISTRIBUTION

END USE

-10% COMPRESSION

-30% LIQUEFACTION

Hydrogen is then used in fuel cells, combustion or industrial processes, but with more energy loss.

-40% FUEL CELLS

-60% COMBUSTION

Total system efficiency comes in at about 20-30%

Only about 70% of the electrical energy needed for electrolysis ends up stored in the hydrogen.

-30%

MOLECULARLY, HYDROGEN IS TIGHTLY BOUND UP IN WATER, MAKING IT ENERGY-INTENSIVE TO EXTRACT

Pipelines or trucks deliver hydrogen, with leakage risks and further energy losses.

-5%

QUOTE

"[T]he EU's massive policy support for the hydrogen value chain does not sufficiently reflect the techno-economic limits of hydrogen and its most efficient uses in an integrated and decarbonised energy system."

— European Scientific Advisory Board on Climate Change (2024)

THE INFRASTRUCTURE CHALLENGE

Hydrogen poses major infrastructure challenges: it's energy-intensive to store and transport, degrades metal pipelines and carries considerable safety risks.

WEAKENS METAL

Hydrogen can seep into steel pipelines, making them brittle and

HARD TO HANDLE

Hydrogen is difficult to store and transport. It requires costly, specialised, energy-intensive

HAZARDOUS

In industrial settings, preventing explosions demands major investments in safety systems, reducing fracture resistance.

INCREASING THE RISK OF CRACKING AND FAILURE OVER TIME

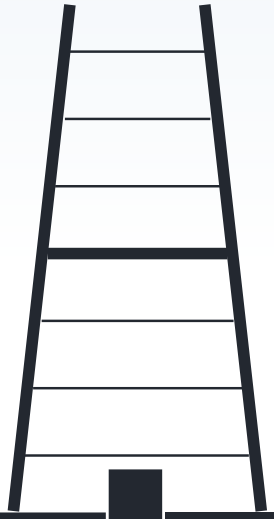
infrastructure: either high-pressure tanks or cryogenic storage at **below -253°C**.

specialised training and strict protocols.

HYDROGEN'S LOWER VOLUMETRIC ENERGY DENSITY WOULD NEED TO BE COMPENSATED BY INCREASING PIPELINE PRESSURE

WHAT ABOUT RETROFITTING EXISTING GAS PIPELINES?

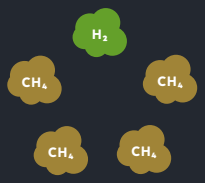
Building high-pressure storage and transport systems is expensive and requires specialised engineering.



Hydrogen is the wrong molecule for the wrong pipes — it leaks easily, raises costs and weakens steel, and could turn today's gas grid into tomorrow's liability.

What about blending green hydrogen H_2 with gas CH_4 ?

- It reduces the energy content, meaning more gas is needed to deliver the same amount of energy, raising costs.
- It has limited emission savings: mixing 20% of hydrogen with fossil gas — the maximum that most existing gas infrastructure can carry before needing expensive upgrades — can only save around 7% of CO_2 emissions.



THE EXPORT CHALLENGE

Countries with high potential for renewable energies have declared interest in producing GREEN HYDROGEN at scale for export. But transporting hydrogen over long distances is extremely costly and inefficient, with significant energy losses throughout the value chain.

OVERLAND EXPORTS

Keeping liquefied hydrogen supercold (-253°C) during transport is challenging — movement causes sloshing which speeds up 'boil-off', raising tank pressure and forcing the release (venting) of hydrogen gas. This makes long-distance overland export especially difficult and costly.

In the vast majority of potential hydrogen use cases, there are low-carbon alternatives — where almost all of the energy generated at source is used to directly deliver 'energy services'.

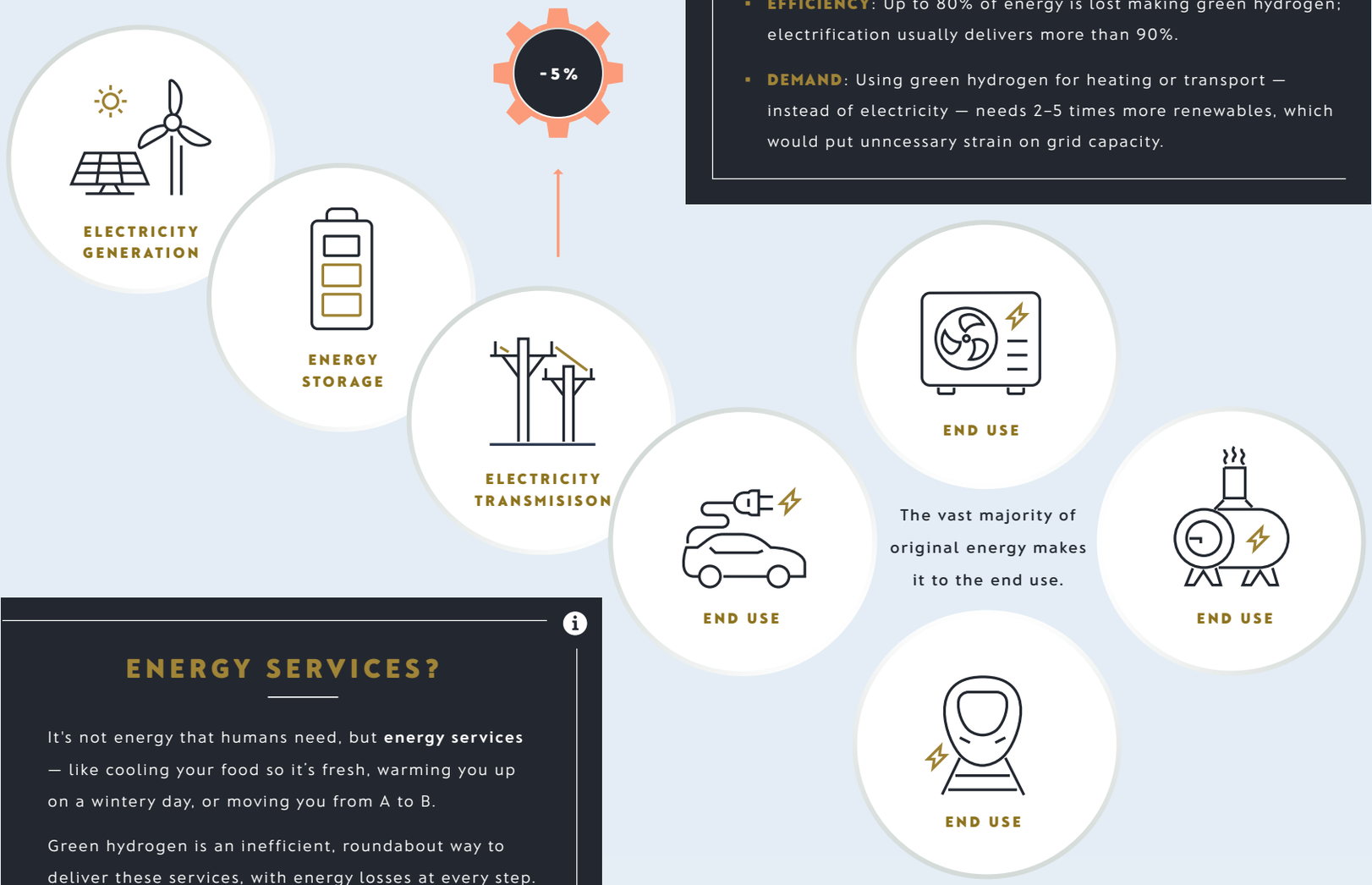
A diversified mix of renewables, firmed with modest battery storage and delivered via high-voltage transmission, offers greater efficiency and a lower levelised cost of electricity (LCOE) than the costly detour of converting electricity to hydrogen, transporting it, then converting it back again.

UP TO 40% OF THE ENERGY CAN BE LOST BEFORE IT DELIVERS ANYTHING

OPPORTUNITY COSTS

Trying to avoid emissions via green hydrogen costs 2–4 times more than direct electrification, diverting funds away from deploying cheaper technologies. And the costs aren't just financial:

- **ATTENTION**: It steals focus from proven, scalable solutions like direct electrification and grid upgrades.
- **EMISSIONS**: Every megawatt of renewables used to produce green hydrogen is one less displacing fossil fuels.
- **EFFICIENCY**: Up to 80% of energy is lost making green hydrogen; electrification usually delivers more than 90%.
- **DEMAND**: Using green hydrogen for heating or transport — instead of electricity — needs 2–5 times more renewables, which would put unncessary strain on grid capacity.



ENERGY SERVICES?

It's not energy that humans need, but **energy services** — like cooling your food so it's fresh, warming you up on a wintery day, or moving you from A to B.

Green hydrogen is an inefficient, roundabout way to deliver these services, with energy losses at every step.

MARITIME EXPORTS

Hydrogen can only be transported in the form of a derivative like e-methane, e-methanol or ammonia.

E-METHANE **E-METHANOL** **AMMONIA**

BOTH FUELS WOULD DEEPEN RELIANCE ON UNPROVEN CCS APPROACHES

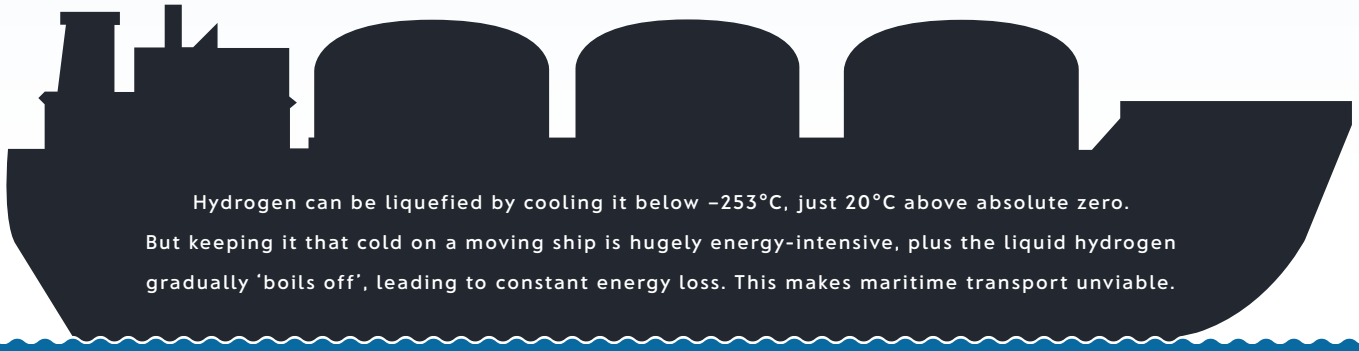
Produced by combining low-carbon hydrogen with captured CO_2, e-methane is prohibitively expensive today.

A liquid fuel that offers easier storage and handling than hydrogen. Like e-methane, produced from low-carbon hydrogen and captured CO_2.

A hydrogen-derived chemical that can be used as a fuel or carrier. Easier to transport than hydrogen, but toxic and corrosive.

TURNING HYDROGEN INTO AMMONIA AND THEN BACK INTO HYDROGEN IS ENERGY INTENSIVE, WITH TOTAL ENERGY LOSSES OF ABOUT 30-40% OR MORE ACROSS THE FULL CYCLE

WHAT ABOUT MOVING LIQUID HYDROGEN BY SHIP?



Hydrogen can be liquefied by cooling it below –253°C, just 20°C above absolute zero. But keeping it that cold on a moving ship is hugely energy-intensive, plus the liquid hydrogen gradually 'boils off', leading to constant energy loss. This makes maritime transport unviable.

THE ENVIRONMENTAL CHALLENGE

Producing, transporting and using green hydrogen at scale would be water-thirsty, land-hungry and energy-intensive. The risk of leakage further undercuts its 'green' credentials.

1.5
BILLION m³

Annual hydrogen production today uses a lot of freshwater.

THAT'S EQUIVALENT TO THE VOLUME OF 600,000 OLYMPIC SWIMMING POOLS

WATER SCARCITY

Around 40% of planned low-emissions hydrogen production projects are in water-stressed regions.

1200
LITRES

The volume of water required to produce one tonne of green hydrogen.

H_2

LAND FOOTPRINT

Green hydrogen has a much higher land footprint compared with direct renewable-powered electricity.

AIR POLLUTION

Combusting hydrogen can release high levels of nitrogen oxides (NOx), unless emissions are controlled.

60
MILLION ha

Meeting 646 Mt of green hydrogen demand in 2050 could devour land the size of Ukraine if powered by solar. (Tonelli et al., 2023)

OR FIVE ARGENTINAS IF POWERED BY WIND

AS WE KNOW, HYDROGEN LEAKS...

CLIMATE IMPACT

It's not a greenhouse gas (GHG), but hydrogen indirectly extends the lifetime of methane and ozone, both potent GHGs.

OVER 20 YEARS, HYDROGEN HAS 30-40 TIMES THE GLOBAL HEATING IMPACT OF CO_2

EVEN THOUGH IT SKIPS THE USUAL FOSSIL FUEL SUSPECTS: CO, CO_2, SO_2

6x

Burning hydrogen-enriched gas can release up to six times more NOx than methane in industrial settings.

From a climate standpoint, the world can achieve far more emission reductions far more cheaply by scaling up renewable energy to displace fossil fuels directly.

THE POLICY CHALLENGE

Governments are beginning to support and subsidise gas-fired power plants, pipelines and LNG terminals based on vague pledges that this infrastructure will eventually become 'hydrogen ready' — and later be converted to use hydrogen or one of its derivatives.

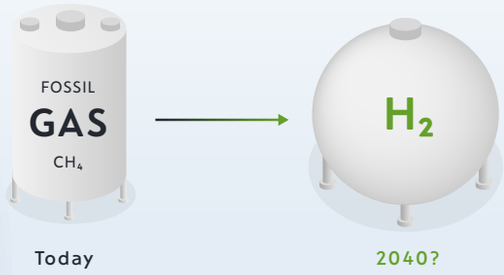
'HYDROGEN READINESS': THE RISKS

QUOTE

"The EU should decide on the strategic way forward towards decarbonisation without impairing the competitive situation of key EU industries or creating new strategic dependencies."

— European Court of Auditors (2024)

DEPENDENCY



Imported hydrogen increases domestic exposure to volatile international energy markets.

RISKING A REPEAT OF THE SAME FOSSIL GAS IMPORT DEPENDENCY MANY COUNTRIES ARE NOW TRYING TO ESCAPE

PRICE

Hydrogen may stay expensive or scarce, incentivising continued fossil gas use and exposure to volatile external prices.

FINANCIAL

Hydrogen projects risk stranding assets and litigation for infringement of contract obligations or misleading claims.

FOSSIL

GAS

CH_4

AND RISKS MISSING SMARTER INVESTMENTS — LIKE FUNDING CHEAPER, CLEANER ENERGY SOLUTIONS

LEGAL

Misleading claims about hydrogen readiness, like boilers 'ready for hydrogen blends', have already triggered investigations.

UK REGULATORS HAVE ALREADY FOUND SUCH MARKETING CONSTITUTES GREENWASHING

POLICY

The focus on hydrogen-readiness risks derailing net zero and other decarbonisation goals — including the EU's 55% cut by 2030 and climate neutrality by 2050.

LOCK-IN

Building 'hydrogen-ready infrastructure' is possible but would lock in expensive assets, future emissions and sticky policies. What's more, it risks entrenching fossil fuel dependence for decades to come.

ASSET LOCK-IN

Deploying 'hydrogen-ready' infrastructure risks committing to long-term fossil gas or hydrogen use, even when better alternatives emerge.

CARBON LOCK-IN

Carbon-intensive energy sources like fossil fuels can crowd out cleaner options due to entrenched systems and incentives.

INSTITUTIONAL LOCK-IN

Governments may be incentivised to continue to support harmful technologies or policies, making it harder to pivot to cleaner, cheaper solutions.

Remember, the overwhelming majority of hydrogen today is made from fossil fuels.

THE BOTTOM LINES

Understanding hydrogen's limitations as an energy carrier helps ensure that scarce resources go towards cheaper, proven solutions with greater climate impact. Low-carbon hydrogen may have a role to play, but only in sectors that truly need it.

HIGH COST & HIGH RISK

DISTRACTION & DELAY

PHYSICAL LIMITS & INEFFICIENCY

TRADE-OFFS & MISALLOCATIONS

SOURCES

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A COLLABORATION BETWEEN CLIENT EARTH & JOHN LANG | CREATIVE COMMONS