BACKGROUNDER
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WHY WE SHOULD BE SKEPTICAL OF THE HYDROGEN ECONOMY

Hydrogen or Synthetic Fossil Fuels?

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Executive Summary

The concept of hydrogen as a 'buffer,' akin to a battery, to ensure consistent renewable power is more complex than it appears.

At first glance, using highly variable, intermittent, inexpensive renewable energy to produce hydrogen for energy supply stabilization seems logical. However, renewable energy is not always readily available. The concept of hydrogen as a 'buffer,' akin to a battery, to ensure consistent renewable power is more complex than it appears.

Upon further examination, the idea is impractical and expensive for several reasons. Among them, hydrogen has a low energy density by volume, compared to well-established and practical fuels such as gasoline, diesel, and natural gas. It also has a low ignition point and is three times as explosive as natural gas, which could be either positive or negative, depending on its use.

Contrary to claims, renewable energy is neither inexpensive nor environmentally benign. Storing hydrogen in a natural gaseous state requires massive, costly storage vessels. Electrolyzing is expensive and will likely remain that way. Similarly, the cost of producing hydrogen is higher than that of deriving it from natural gas, which produces carbon dioxide, which is unwanted. There are some other techniques, such as pressure, heat, and radiolysis from radiation emitted from nuclear reactors, that are feasible, perhaps in combination. Small 'micro nuclear reactors' may drive down these costs. Atomic reactors are already used in U.S. Navy aircraft carriers to produce aviation and diesel synthetic fuel.

There are also a series of impractical issues. Existing pipeline infrastructure cannot transport pure hydrogen due to hydrogen embrittlement, and hydrogen cannot easily be used as a transportation fuel. A new Teflon-coated pipeline and distribution system parallel to the existing natural gas network would have to be built, costing hundreds of billions of dollars in North America alone.

While the idea of synthetic fuels using hydrogen may seem more feasible, it would likely be limited to a 'niche role,' potentially in natural gas-deficient nations. However, this would still necessitate significant investment. Ultimately, diverting funds to this 'hydrogen economy' could be a misallocation of capital from other, potentially more viable, areas.

What to do with the excess electricity generated by renewable energy?

Solid skepticism about a hydrogen economy stems from the physical characteristics of hydrogen gas.

Every few years, a new 'entrepreneur' emerges within the energy sector with a supposedly revolutionary idea that often turns out to be nothing more than a repackaging of an old concept that failed to gain traction. The latest contender for this title is "the hydrogen economy."

Solid skepticism about a hydrogen economy stems from the physical characteristics of hydrogen gas. All technologies present learning curves and are subject to an equivalence of Moore's Law, which revolutionized the semiconductor industry. This is why internal combustion engines haven't significantly improved in fuel efficiency in over 40 years, why the supersonic Concorde was never economically viable, and why certain skeptics argue that battery electric vehicles might not see mass adoption for the middle-income groups.

One cannot 'squeeze blood out of a rock.'

The S-curve, bound by physical constraints, explains why politicians cannot 'simply' lower the price of electricity and why decarbonization poses a significantly greater challenge than environmental advocates typically recognize. The 'S-curve' is a common phenomenon in a new technology, product, service, process, or enterprise: It denotes a slow improvement or growth, then much more rapid, then a slowing of growth or improvement as the technology, product, process or enterprise enters into a more mature stage as it has penetrated the parts of society or economy where it finds a place.

Below, let's consider why we doubt that hydrogen will be able to perform in the long run when compared to synthetic fossil fuels that share the same physical properties as traditional fossil fuels. Synthetic fuels do require hydrogen production, with the advantage that hydrogen is consumed where produced. Hence, there is no need for additional infrastructure, such as pipelines and storage vessels that use alloys impervious to hydrogen embrittlement.

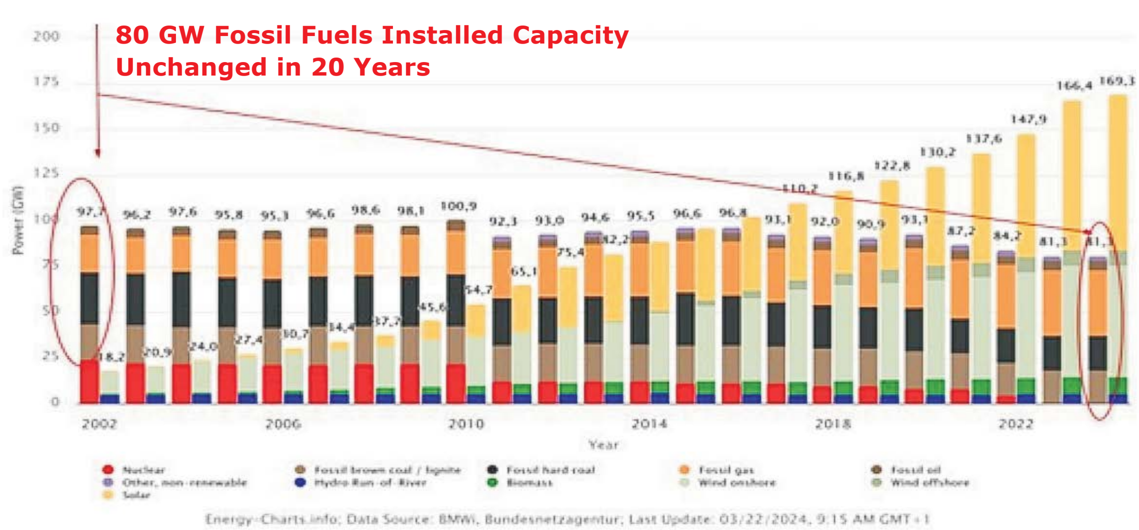
Synthetic fuel or synfuel is a liquid fuel, or sometimes gaseous fuel, obtained from syngas, a mixture of carbon monoxide and hydrogen, produced using the Fischer-Tropsch process. Fischer-Tropsch is a catalytic chemical reaction that converts carbon monoxide and hydrogen into liquid hydrocarbons, primarily for producing synthetic fuels from coal, natural gas, or biomass. The first country to attempt the industrial application of synthetic fuel was Nazi Germany when it wanted to become energy independent. Given its lack of oil resources and because of international sanctions during Apartheid, South Africa decided to utilize the Fischer-Tropsch process. It chose to produce synthetic fuels and chemicals to ensure energy independence and security. Since 1955, the flagship South African company Sasol has produced synthetic fuels by converting coal into liquids. South Africa relies on coal-to-oil technologies for up to one-third of all the automotive and synthetic aviation fuels it uses. Incidentally, the country already has a hydrogen production facility for industrial feedstock.

"...renewables have a second challenge: reliability during periods of no wind or sun.

Suppose we are genuinely committed to effectively utilizing the surplus power generated from renewable electricity sources. In that case, one viable option is to invest in creating synthetic fuels to supplant traditional fossil fuels. While renewable energy boasts the advantage of having no associated fuel costs, its drawback lies in its high coefficient of variation, necessitating capacity overbuilding, as is currently the case in Germany. A high coefficient of variation is a technical term meaning that the thing that is variable has wide swings in value. They are highly intermittent and unreliable, as are the solar and wind energy output cases.

Despite the overbuilding, renewables have a second challenge: reliability during periods of no wind or sun. That challenge is known as Dunkelflaute. It is the reason the Germans have not yet managed to shut down their generating plants that rely on fossil fuels. Those plants are still necessary to firm their electricity supply.

Figure 1 Net Installed Electricity Generation Capacity in Germany



As solar and wind power can be dangerously insufficient to meet demand, a combination of storage (batteries, at this time) or what are called ‘baseline’ or ‘peaker’ power supplies must be online to supply power when solar and wind are insufficient. The cost of running a parallel idle system with a renewable-based one might explain why German household electricity prices are among the highest in the world.

The recent drop in battery prices might change this situation, but it is uncertain whether it will be sustainable over the long term and whether the renewable battery backup system will prove reliable on its own; it is not currently cost-effective. At this time, and in the medium term, battery prices are too high, as the International Energy Agency has found, for this mechanism to be a significant solution to this oversupply problem.

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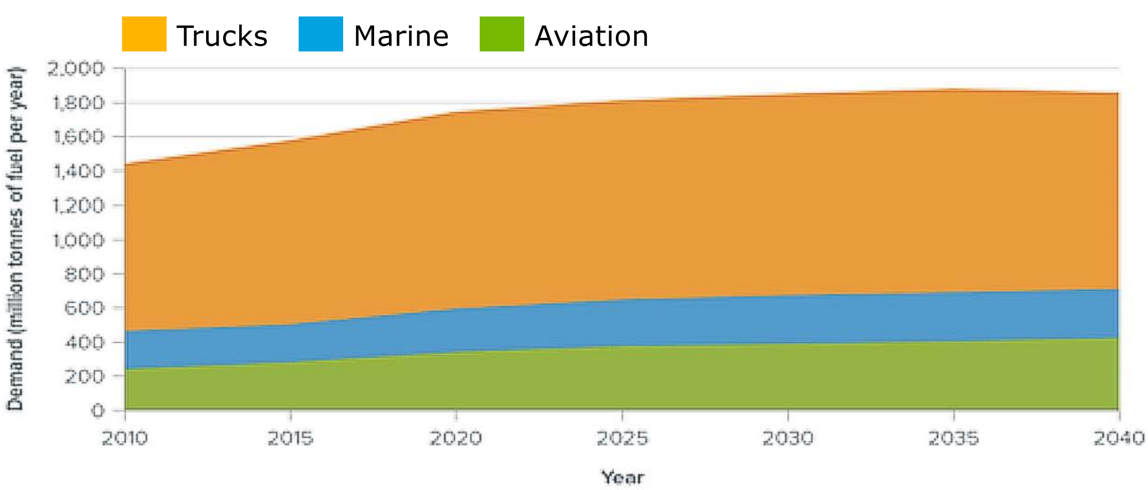
In the meantime, what do Europeans do with the excess energy that is currently dropping the wholesale price of electricity in Europe to below zero? This pricing system undermines traditional power sources, such as coal-fired or gas-fired generators, and nuclear power, where available (in France and as power imports from France, for example). This causes profits for these producers to turn into losses, so this excess superficially ultra-low-price power needs to go somewhere else where it will cause fewer problems and perhaps even be beneficial.

During periods of low demand, renewable power’s surplus energy can potentially be utilized to produce synthetic fuels suitable for niche transportation, such as mining, shipping, trucking or aviation.

Figure 2 Fuel Demand



Leveraging synthetic fuels will allow for the cost-effective substitution of traditional fossil fuels. The policy might even speak to the heart of the environmental activist because it's unlikely to increase carbon emissions significantly.

"Hydrogen is the energy of the future, and it will always be."

South Africa is ideally placed to take advantage of this leveraging because of Sasol's long experience with the Fischer Tropsch Process. South Africa should use it to its advantage for African development. It is a well-established technology that markets already understand. Nuclear energy, perhaps using small 'micro modular reactors', is a potentially more technically and commercially viable means of using electrolysis, heat, pressure and radiation to split water into hydrogen and oxygen. U.S. Navy aircraft carriers use the Fischer-Tropsch Process to make synthetic fuels for aircraft and landing vessels.

By contrast, the hydrogen economy will not be competitive. As the old joke goes, "Hydrogen is the energy of the future, and it will always be."

Fifteen basic reasons hydrogen is noncompetitive as an energy carrier

Figure 3 Feasibility of E-fuels Compared to the Most Commonly Used Fossil Fuels

E-fuel	Gravimetric energy density (LHV) [MJ/kg]	Density at atm and 20°C [kg/m³]	Volumetric energy density [MJ/l]	Boiling point [°C]	Technical feasibility in shipping	Technical feasibility in aviation
Hydrogen (H_2)	120	0.08	0.0108 (at atm) 3.12 (at 350 bar) 8.5 (liquid)	-252	Potentially feasible	Potentially feasible
(E-)Ammonia (NH_3)	18.8	0.73	12.8 (liquid)	-33	Potentially feasible	Not considered feasible.
(E-)Methanol (CH_3OH)	19.9	0.79	15.6	65	Feasible	Not considered feasible.
(E-)Methane (CH_4)	50	0.67	0.0378 (at atm) 20.8 (liquid)	-163	Feasible	Not considered feasible.
E-kerosene (Jet A)	45.7	0.8	~40	>150	Not considered feasible.	Feasible
Diesel fuels (MGO, MFO, VLSFO, HFO)	~43	0.82	~41	>250	Feasible	Not considered feasible.

Note: LHV = lower heating value; MGO = marine gasoil; MFO = marine fuel oil; VLSFO = very low sulphur fuel oil; HFO = heavy fuel oil; atm = atmospheric pressure. Natural gas is mainly composed of methane.

1. The physical properties of hydrogen.

The table below shows hydrogen's physical properties. The argument against its competitiveness is primarily based on these characteristics. It's an argument from first principles.

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Table 1 Physical Properties of Hydrogen

Property	Hydrogen	Comparison
Density (gaseous)	0.089 kg/m³ (0°C, 1 bar)	1/10 of natural gas
Density (liquid)	70.8 kg/m³ (–253°C, 1 bar)	1/6 of natural gas
Boiling point	–252.76°C (1 bar)	90°C below LNG
Energy per unit of mass (LHV)	120.1 MJ/kg	3 × that of gasoline
Energy density (ambient, LHV)	0.01 MJ/l	1/3 that of natural gas
Specific energy (liquefied, LHV)	8.5 MJ/l	1/3 that of LNG
Flame velocity	346 cm/s	8 × that of methane
Ignition range (% volume)	4–77%	6 × wider than methane
Autoignition temperature	585°C	220°C for gasoline
Ignition energy	0.02 mJ	1/10 of methane

From IEA 2019, p. 35.

...energy density is just one factor that determines the competitiveness of an energy carrier.

2. Energy per unit of mass

Hydrogen's primary advantage over natural gas (often cited by its proponents) lies in its energy per unit of mass, which is 3 times that of gasoline.

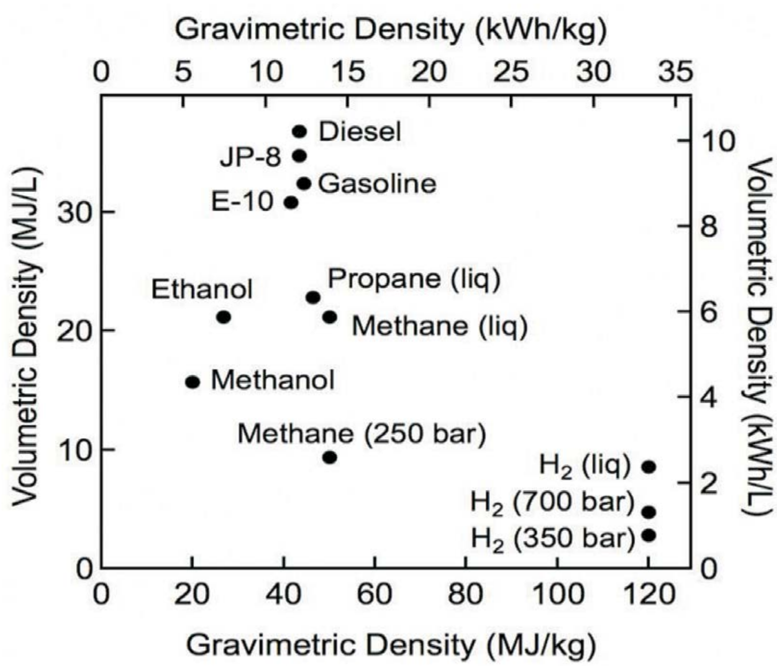
While this may seem appealing, it's important to recognize that energy density is just one factor that determines the competitiveness of an energy carrier.

3. Energy by Volume

Hydrogen has only half of the energy per volume compared to Liquified Natural Gas.

The graph below shows why fossil fuels are so competitive: transportation takes place in volumes, not mass.

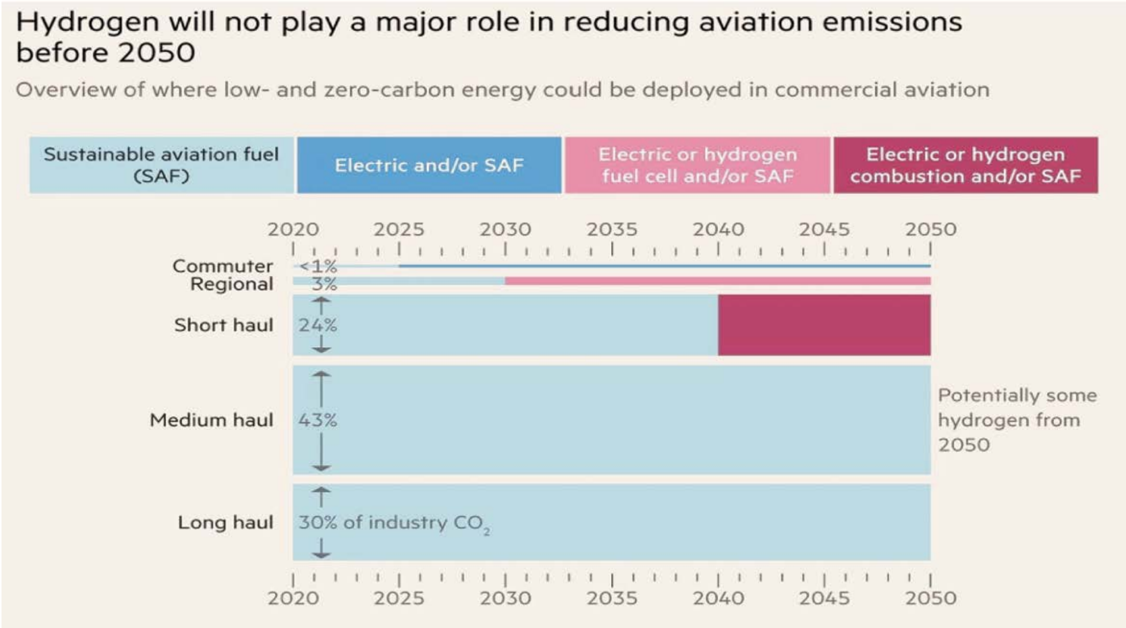
Figure 4 Feasibility of E-Fuels Compared to the Most Commonly Used Fossil Fuels



This means that a truck running on hydrogen would either travel one-third of the distance or need to discard one-third of the cargo to achieve equivalent energy transport, if we assume that the fuel tank has the same capacity.

Furthermore, given its volume density constraints, hydrogen is unlikely to play a significant role in aviation.

Figure 5 Hydrogen's Role In Aviation Emmisions



> *... hydrogen's low ignition point is why the Zeppelins went out of business after the Hindenburg Disaster.*

4. Low density and high reactivity

Due to its low density (1/10th of gas), hydrogen necessitates specialized transportation planning. Hydrogen, for example, leaks through most metals and will require specialized alloys to control the leakage, increasing the storage cost. Furthermore, hydrogen in the metal lattice degrades the mechanical properties of the metal, causing hydrogen embrittlement. This necessitates building entirely new networks of pipelines and distribution systems either using different alloys or Teflon coating.

5. Hydrogen's ignition temperature

With a low ignition temperature (1/10th that of gas), hydrogen is explosive.

Incidentally, hydrogen's low ignition point is why the Zeppelins went out of business after the Hindenburg Disaster. The vessel, filled with hydrogen, caught fire and was destroyed during its attempt to dock with its mooring mast at Naval Air Station Lakehurst. The accident caused 35 fatalities (13 passengers and 22 crewmen) from the 97 people on board (36 passengers and 61 crewmen) and an additional fatality on the ground. When hydrogen is produced, and oxygen very likely is as well in most processes, both gases must be separated and stored immediately and carefully to ensure there are no catastrophic and deadly incendiary or explosive accidents.

6. Hydrogen's boiling point

With a low boiling point (90°C) below methane, hydrogen will require much more energy to keep it compressed in a liquid and safe state.

7. Hydrogen is a secondary greenhouse gas

...if [hydrogen] leakages are not controlled, there will be no benefit over the industries that it is trying to offset.

Hydrogen is indeed a secondary greenhouse gas and, particularly for those who subscribe to emissions based warming models, it may contribute to global warming. Oxford concluded in 2022, if leakages are not controlled, there will be no benefit over the industries that it is trying to offset.

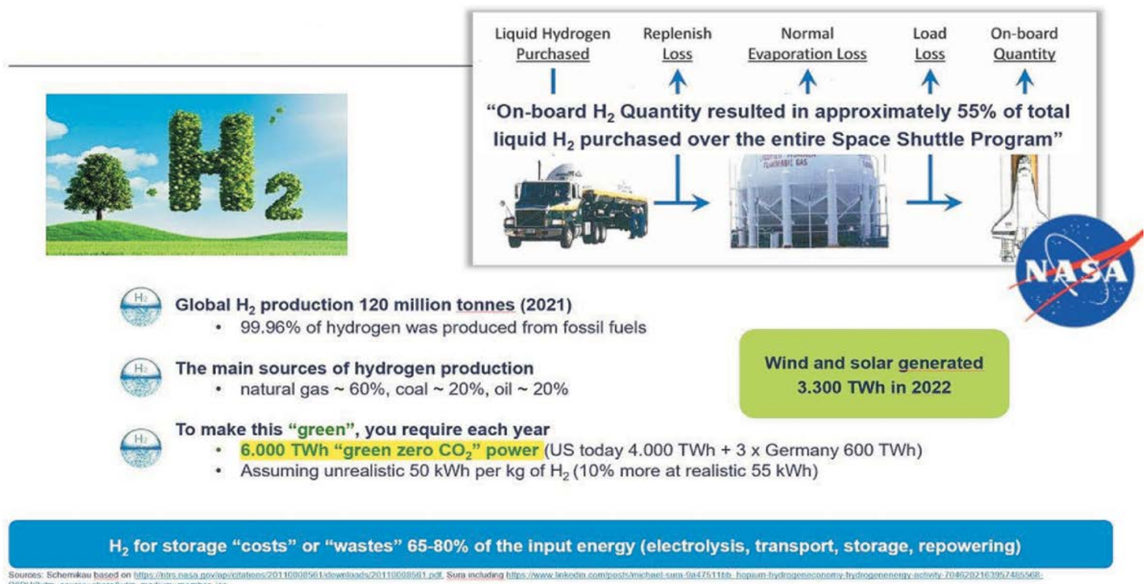
"Nevertheless, any hydrogen leakage will affect atmospheric composition (with implications for air quality) and have an indirect warming effect on climate, partially offsetting some of the climate benefits of the reduction in carbon dioxide."

8. Hydrogen is not a primary energy source

Hydrogen serves as an energy carrier rather than a primary energy source, requiring production from other energy sources such as natural gas or renewable electricity.

The figure below shows the required energy.

Figure 6 Hydrogen - An Energy Loss Nightmare



A study by Mickael Coriat published in France24 in late 2022 highlighted the challenges of scaling up hydrogen production for aviation. It illustrated that producing enough for an airport like Charles de Gaulle would require a substantial energy investment equivalent to 16 nuclear power plants.

That is almost one quarter of France's installed power capacity, just for one airport. The equivalent with wind turbines would have to cover the size of one of France's departments (provinces).

Coriat called the numbers "dizzying."

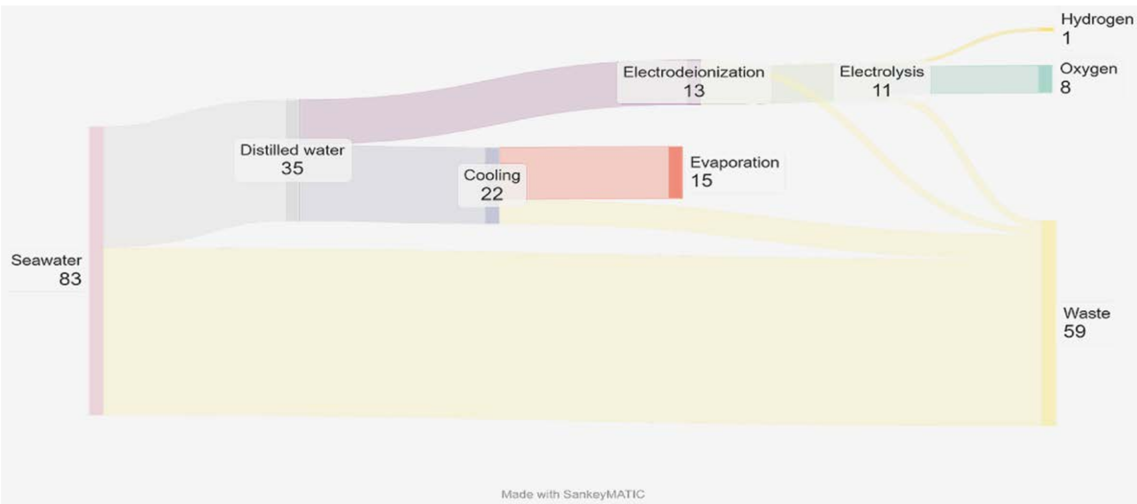
9. Freshwater usage

Certain methods of hydrogen production require high freshwater usage. However, some methods can use seawater, making this not necessarily a 'deal-breaker.' On average 9 to 10 litres of freshwater for every gram of hydrogen. This should not even be an option for water-scarce countries such as South Africa.

It's worth pointing out that synthetic fuels also require hydrogen, but with less per volume consumed. Investment in desalination is probably going to be required if mass adaptation is to take hold.

> *...Investment in desalination is probably going to be required if mass adaptation is to take hold.*

Figure 7 Production From Seawater to Hydrogen



10. Hydrogen Splitting

High-temperature processes (750°C to 1000°C), such as high-temperature electrolysis, may be necessary for efficient hydrogen production—even when using nuclear power that can pose challenges for materials. Gas-cooled nuclear reactors cannot operate economically above 750°C and will require additional energy—most likely in the form of electrolysis.

11. Competition for Storage

Hydrogen faces competition from various other energy storage technologies, including battery electric vehicles (BEVs), pumped storage, and others. Why make hydrogen if the prices of batteries, for example, have fallen?

12. Lack of Infrastructure

Hydrogen infrastructure may be less developed and more costly than traditional energy transmission systems. Transitioning to a hydrogen economy would require significant changes to existing infrastructure, such as adapting the natural gas pipelines with more expensive alloys. As the Hydrogen Council admitted, there are only 4,500 km of hydrogen pipelines installed globally!

...hydrogen technologies, such as fuel cells for transportation, still face technical challenges and limitations...

The United States alone has 5 million kilometers of pipelines, so this will not be a cheap replacement.

13. Hydrogen is simply expensive

Hydrogen technologies can be expensive compared to existing alternatives, which may hinder widespread adoption, especially in cost-sensitive markets. The graph below shows the estimates for their levelized cost pales compared to carbon capture and storage.

Table 3 Costing Hydrogen

CCC central estimates for levelised costs of hydrogen production technologies.

	SMR with CCS £/MWh	Electrolysis £/MWh
Capex	4	4
Opex	3	7
Carbon and CCS costs	6	0
Fuel costs	25	63
Total	38	74
Lower bound	27	54
Upper bound	57	80

Source: Redrawn with additional calculations from CCC 2018, supporting charts and data.[68] CCC note: Cost of capital is assumed to be 10% across all technologies, and a 3.5% discount rate is applied to future costs. Load factors are assumed to be 90% across all technologies. Carbon prices rise to £227/tCO_2 by 2050. Gas prices: 39p/th [£13.31/MWh], 67p/th [£22.86/MWh], 83p/th [£28.32/MWh]. Electricity prices: £30/MWh, £46/MWh, £53/MWh.

Almost two thirds of the fuel cost of hydrogen is in making the fuel!

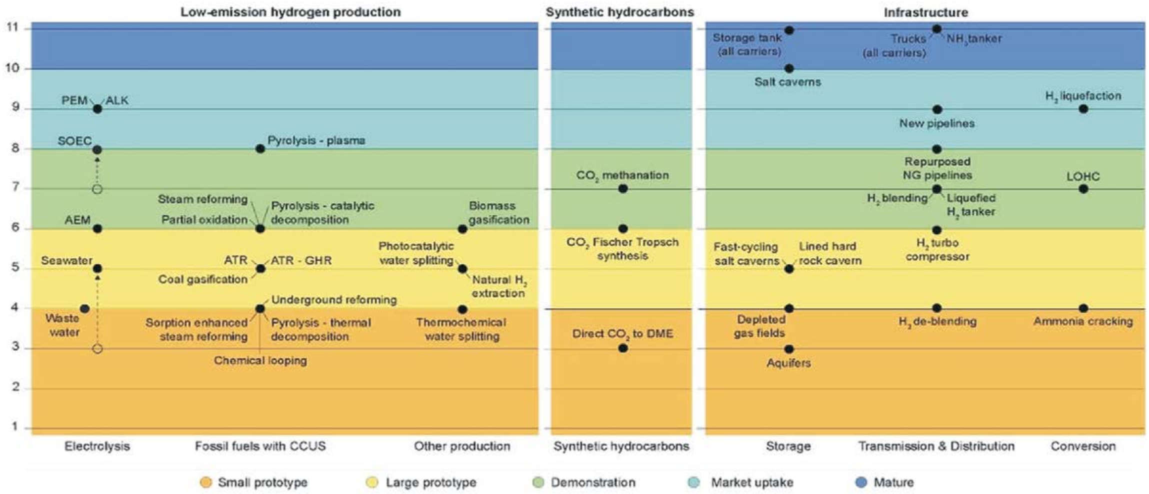
Hydrogen is useful in optimizing the Fischer-Tropsch process because by the end of this decade green hydrogen is set to become cheaper than grey hydrogen. This is the projection, although it may prove optimistic.

14. Technology Readiness

Some hydrogen technologies, such as fuel cells for transportation, still face technical challenges and limitations, including durability, efficiency, and cost, all of which may hinder their widespread adoption.

Figure 8A Technology Readiness: Production and Infrastructure

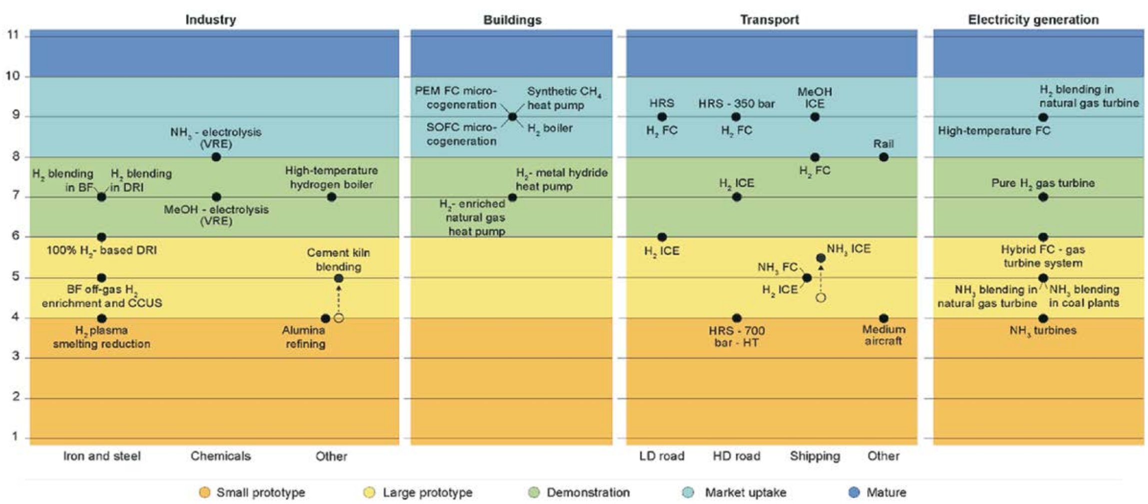
Technology readiness levels of production of low-emission hydrogen and synthetic fuels, and infrastructure



When broken down by sector, it's clear that the market still requires significant hydrogen technology development.

Figure 8B Technology Readiness: End Uses By Sector

Technology readiness levels of hydrogen end uses by sector

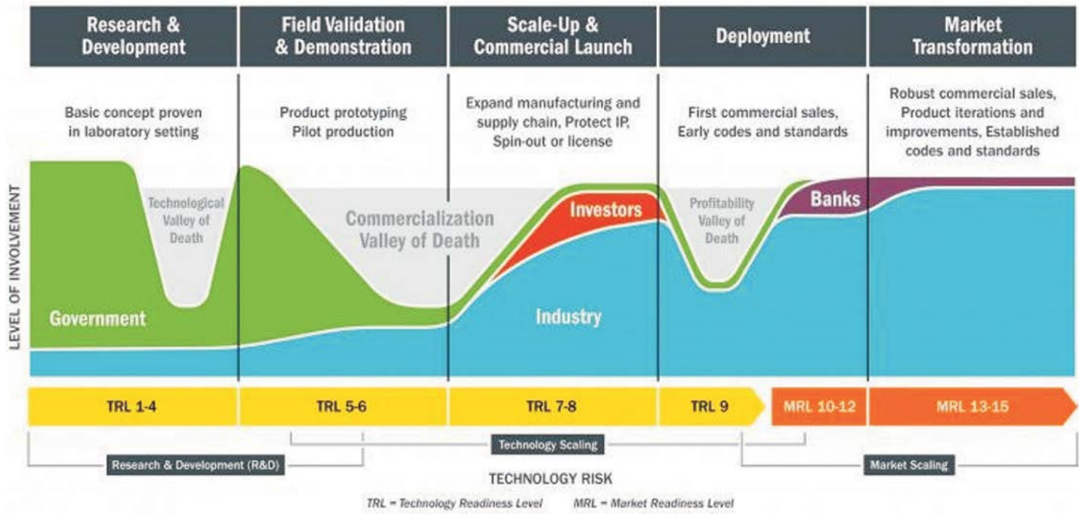


Various phases of the technology are still at phase 5 to 6, which means that these technologies, or enterprises based on these technologies, still require government assistance before investors take them seriously.

Unfortunately, many ideas die in the "commercialization valley of death." This phase requires substantial investment with negligible (usually zero) revenue to offset expenses. Considerable errors and readjustments occur.

...these technologies or enterprises based on these technologies still require government assistance before investors take them seriously.

Figure 9 Hydrogen Technology Risk and Involvement



"...many ideas die in the "commercialization valley of death."

The 'valley of death' designation refers to a phase where the process, technology, or firm has a high fatality rate. For example, early-stage venture capitalists, after rigorous vetting and examination of the technology, founders, technologists and others in an early-stage firm, assume that only one or two out of any random ten new entities they invest in will be 'ten baggers' (return ten or more times the money invested in them), one or two will be complete write-offs, and the rest will be mediocre-to-satisfactory.

15. Skepticism from prominent voices

Several prominent voices within the energy sector have expressed skepticism about the hydrogen bubble—noting Michael Leibriech, Mark Jacobzon, Robert Bryce, John Constable, Mickael Coriat, and many others.

Conclusion

Hydrogen, on its own, as a parallel energy storage and transmission system to make intermittent renewable energy truly commercially viable, does not withstand close examination and analysis. The Fischer-Tropsch process, which produces hydrogen as a byproduct, makes more sense if the main end products are synthetic fuels. However, other than in natural gas-poor places such as Europe and South Africa, it has no obvious attraction for investors.

> ***Hydrogen, on its own, … does not withstand close examination and analysis.***

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