Hydrogen Strategy Options

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1. Introduction

- Hydrogen as a “green” alternative to fossil fuels is gaining a lot of attention lately, the market hype is often much more optimistic than the reality.
- Several countries (e.g. Australia, The EU, Saudi Arabia, Japan) have announced hydrogen “strategies” in one form or another, as have most multinational oil companies. These are in response to the popular drive for carbon neutrality, political need to transition away from fossil fuels and the need to address the demands of the capital markets. This latter issue is behind the initiatives by the likes of BP and Shell and are an attempt to stay relevant and attractive to investors as the perception of “maximum demand for oil” poses an existential threat.
- The impact of Hydrogen as an alternative energy source is not going to be uniform across the energy demand environment. The impact in heavy energy intensive industries, like steel and cement will be high, while the impact in the transportation sector is harder to predict. It is certain that hydrogen will see demand in shipping, rail, agriculture, mining and heavy goods vehicles, but for the light vehicles it’s much more uncertain. The engineering complexity (and cost) associated with the large scale transportation and storage of hydrogen make the retail consumer market more costly to service in an already competitive environment seeing the fast uptake of more efficient battery electric vehicles.
- Due to the low (volumetric) energy density of hydrogen its transportation and storage is a cost issue, high pressures and cryogenic temperatures create engineering complexity and cost. Therefore alternative hydrogen carrier options are emerging, ammonia and organic carries (e.g. Methylcyclohexane (MCH)) are the two most popular, these have higher volumetric energy densities and avoid most of the engineering complexity of hydrogen, but bring issues of toxicity and lack of scale.
- The purpose of this document is to explore some of these issues and highlight the key aspects to be considered in a hydrogen strategy.

2. Definitions

Types of H2 production:

Brown Hydrogen 57MWhr/Tonne H2(*)	• Comes from gasification (coal or lignite) • Common in China • CO2 intensive
Grey Hydrogen 42MWhr/Tonne H2(*)	• Produced from steam methane reformation (SMR) • CO2 intensive
Blue Hydrogen 46MWhr/Tonne H2(*)	• Pairing SMR with CCS • 70% - 90% reduction in CO2 emissions
Turquoise Hydrogen	• Pyrolysis directly splits methane into H2 and carbon black • No emissions but not yet commercially viable
Green Hydrogen 52MWhr/Tonne H2(*)	• Produced from water electrolysis powered by renewable electricity

For the purposes of this document the focus will be on the Grey, Blue and Green production methods.

The differences between Brown and Grey are insignificant (in general terms of CO2 production and costs) for the purposes of this document, Turquoise production is still undeveloped and commercial technology.

Green Hydrogen production will be considered as exclusively using electrical power from non-fossil fuel (Solar, Wind and Nuclear) sources, i.e. zero CO2 emissions.

(*) Approximate energy requirement, will vary based on technology employed, scale of production facilities and access to CO2 storage sites for CCS

3. Features of a H2 Strategy

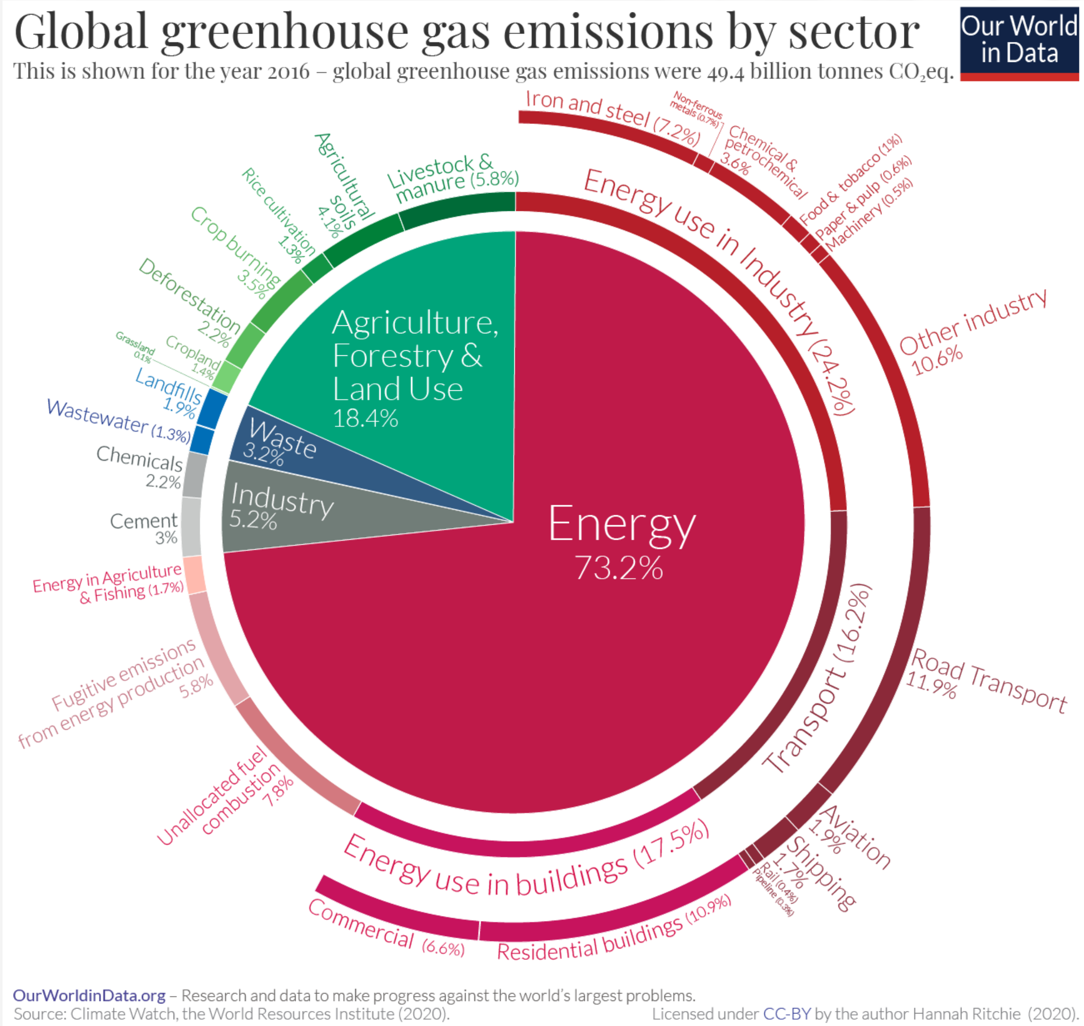
- Who is the audience ? Its likely there are multiple audiences for the strategy, diverse community of stakeholders with different agendas.
  - *Owners/Shareholders*
  - *Government*
  - *Capital markets (potential investor community)*
  - *Analysts*
  - *Activists*
  - *Employees*
- All will see the issues differently and expect a strategy that addresses these issues.
- What is typically seen is one or more of the following three actions by large oil companies;
  - *Announcements of long term intent for investment and market entry, often not supported by real investment budgets*
  - *Token demonstration projects, small very visible actions, e.g. opening H2 filling stations, albeit a token number with no supporting H2 sourcing plans.*
  - *Long term investments in new markets and diversification away from the core operations, e.g. Shell acquisition of BG and acquisition of an EV charging network in Europe.*
- An impactful strategy will include elements of all of these, but supported by a real strategy for the H2 supply chain and an analysis of the target market, H2 sourcing/production and supply chain logistics solutions, including H2 carrier options (NH3 etc.).

For a major oil company this may represent a serious challenge, protecting and leveraging the existing very large capital investments and oil and gas reserves is of major importance. A long term, well funded transition plan that leverages the existing asset base is critical to shareholder and "owner" support. For example, significant investment in Blue H2 for an oil company with mature oil field assets and access to gas reserves is a clear path forward that protects and leverages the current asset base. The use of natural gas in stream reforming to make H2 and/or Ammonia, utilising the captured CO2 for reservoir flooding for enhanced oil recovery from declining oil field assets, is a clear example of good shareholder support and recognition of the long term political and market realities.

> Given how central the energy transition will be to every company's growth prospects, we are asking companies to disclose a plan for how their business model will be compatible with a net zero economy," BlackRock's chairman and CEO Larry Fink wrote in his 2021 letter to CEOs.

4. End Use

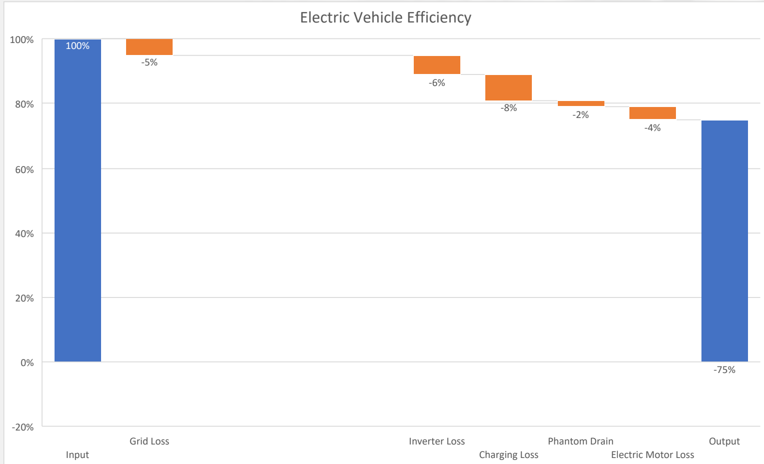
- A good strategy should target specific end use markets with a priority on those where the biggest impact can be made and existing infrastructure can be leverages. Initially the traditional Oil&Gas company markets. e.g. Transportation, PetroChemicals and Industrial, which total some 30% of CO2 emissions.
- Other targets to be considered are Iron and Steel production and Cement, both heavy CO2 emitting industries where H2 can have an immediate impact by substituting coal.
- The transport sector is also complicated and the current consensus is that rail, shipping and heavy vehicles are good targets for H2, while the consumer light vehicle market is somewhat more complicated to address.

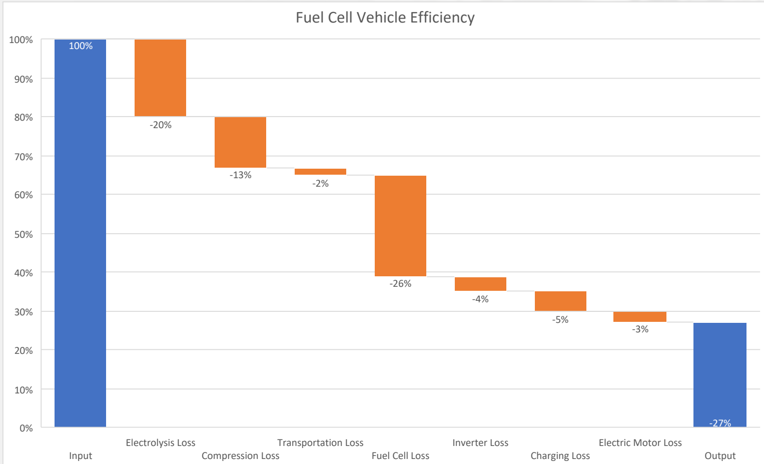


4. End Use….. H2 vs Electric Vehicles, More than an Efficiency Debate

- This starts with efficiency, the charts to the right show the "Grid to Wheels" efficiency of battery electric vehicles and H2 fuel cell vehicles. Even with the best currently demonstrated electrolyser/fuel cell technology, battery electric vehicles are 3 times more efficient than H2 fuel cell vehicles. It is not expected that this gap will close as both technology categories are showing continuous improvement.
- In the consumer retail market the efficiency is not the whole story, H2 fuel cell cars are similar to gasoline or diesel cars from an end user experience They can be refuelled quickly, have similar ranges and a very similar retail experience. The battery electric vehicles offer a different experience, unfamiliar to the average consumer, with more opportunistic charging practices, similar to a mobile phone, also with short ranges than fuel cell or gasoline vehicles.
- These two issues will be mitigated by advanced in battery technology with ever faster recharging and every greater capacity (i.e. range).
- The final issue for a company considering a H2 strategy is the auto industry and consumer momentum. The bulk of the auto manufacturers are going for EV's, only Toyota is pushing fuel cell cars as its main focus. Also EV's have a strong market presence and strong demand growth, these cannot be ignored nor would it be wise to fight against the market, especially given the very large efficiency advantage EV's have.

"You won't see any hydrogen usage in cars," said Volkswagen chief executive Herbert Diess,
"Not even in 10 years, because the physics behind it are so unreasonable," Diess said.





5. Transport Logistics

- H2 is very low density…. And has engineering challenges to transport, storage and end use
  - Hydrogen must be compressed to very high pressures, and/or liquified to transport in bulk, 1m3 of liquid hydrogen weighs only 71kg and is the energy equivalent to 0.27 m3 of gasoline, so many more m3 are required for the same energy demand.
  - Liquid hydrogen is at -252.9C at ambient pressure, this makes it extremely difficult and expensive to store and handle as it requires sophisticated insulation and expensive materials.
  - High pressure storage, typically 300-700bar is used to store and move gaseous hydrogen, this results in very heavy storage containers and limits the amount carried by road transport. Also hydrogen leaks very easily and requires special seals to minimise losses. In addition hydrogen causes “steel embrittlement” as it “dissolves in the steel of the containers” this is overcome with special coatings and more exotic steels.
- Repurposing Natural Gas supply infrastructure
  - There are a number pf proposals to supplement natural gas supplies with hydrogen, up to 80% hydrogen.
  - The biggest proposals are new NordStream 2 pipeline for moving “grey” and “blue” hydrogen from Russia to Western Europe and in the UK with proposals to widely distribute hydrogen in the domestic gas system, with one pilot project underway.
  - This usually requires some upgrades to that infrastructure to deal with the impact of hydrogen on leakage in compression and pipeline assets as described above.

5. Transport Logistics

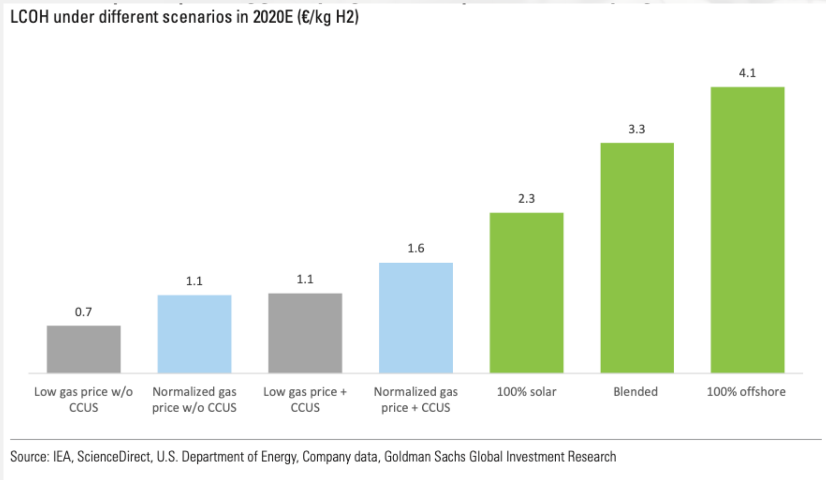
- Ammonia, MCH and other transport options
  - Due to the issues described above, other options for storing and transporting hydrogen are under active consideration, with numerous demonstration projects underway.
  - This is especially important for heavy vehicle transport and marine shipping where carrying large quantities is necessary for economic viability, but where the space requirements need to be minimised.
  - The use of ammonia as a carrier for hydrogen is becoming a popular option, a m3 of liquid ammonia actually contains more mass of hydrogen than a m3 of liquid hydrogen (122kg compared to 71kg).
  - There are other transport options under consideration, one recently demonstrated by a Japanese led consortium using MethylCycloHexane (MCH), this involves the catalytic hydrogenation of Toluene to MCH and the catalytic dehydrogenation of of MCH back to Toluene at point of use. While the use of MCH for transport is simpler than ammonia, ambient temperate and no special materials need, the hydrogen intensity lower. One m3 of MCH will only carry 53kg of hydrogen compared to 122kg for ammonia.
- Production at Point of Use
  - For remote H2 fuel cell use there is the option of generating the hydrogen at point of use, there by eliminating the bulk of the storage and handling issues. For example a H2 refilling station for light road vehicles could have an electrolyser on site converting electrical power to H2 for refilling vehicles. Similar operations for steel making is possible and is being demonstrated in Sweden with an on site electrolyser producing hydrogen to use in place of coal in a purpose built steel making plant.

6. Production

Hydrogen is produced from two primary energy sources, light hydrocarbons (e.g. natural gas) or electricity. As result the production of hydrogen is by definition less energy efficient (and more expensive) than the direct use of the primary energy source used to create it, i.e. natural gas or electricity, the raw input costs in the production of H2.

There are essentially only two technologies for the production of hydrogen at commercial scale;

- **Steam reforming** of light hydrocarbons (typically natural gas) with or without CO2 capture and storage (grey or blue hydrogen). This is a well proven and very mature technology, it has been in commercial scale use in refineries, ammonia, methanol and other plants at scale for more than 60 years. Incremental improvements in efficiency and reliability have been achieved through the use of more efficient catalysts and better, more durable materials for the high temperature reforming reactors. This is still the cheapest, at scale production method, even with CCUS, especially given the relative abundance of cheap natural gas.
- **Electrolysis of water**, R&D is incrementally improving efficiency, current state of the art is around 65% for commercial scale operations, some R&D has demonstrated higher efficiencies at laboratory scales. This process is dependent on the cost of electricity, when sourced from Wind or Solar, electrolysis is around double the cost per kg of H2 produced when compared to stream reforming of natural gas.



7. Scale

The big issue that needs to be addressed by any hydrogen strategy is that of scale, its often hard to conceive the scale of the global energy usage at a personal level. Today the world emits annually more than 40 billion tonnes of CO2 per year and is consuming around 11.7 Billion toe of fossil fuel (4.7 Billion toe of Oil, 3.3 Billion toe of Natural Gas, 3.8 Billion toe of Coal).

The current global annual production of hydrogen is approximately 74Million Tonnes (a mere 211 million toe). This is around 2% of the total fossil fuel based energy consumption. Its important to note that almost none of this capacity is available for "green" uses, the bulk of this production is used for either ammonia production (40%) or oil refinery consumption for desulphurization of oil products (50%), predominately gasoline, diesel and jet fuel.

To have meaningful impact on CO2 emissions, electrolyser hydrogen production need to expand dramatically from its almost zero level today, e.g. the predictions for the EU electrolyser hydrogen production forecast a 1000 fold increase by 2030 to around 60GW of capacity (120 million toe). This is still a very small proportion of the fossil fuel consumption (~1% of the total and 2.5% of oil consumption). Clearly other renewable energy initiatives will have a much larger impact, solar, wind and hydro power generation when combined with increased electrification of industry and transport.

To have a meaningful impact the scale of hydrogen production will need to be very large, even when targeted specifically at heavy industrial and heavy vehicle (ships, trains, heavy mining and agriculture) use. It would need to reach the 100 of millions to billions of tonnes per year globally, an extraordinary investment and almost certainly impossible in a reasonable time frame.

Consequently, a hydrogen strategy needs to be realistic and practical around in relation to this scale issue and include a hybrid production strategies to maximise capacity, from green and blue hydrogen sources over the long term.

(toe – tonnes of oil equivalent)

8. Shareholder Value

In the preceding sections, the issue of maintaining shareholder value and return of capital employed for existing large oil and gas companies has been touched on. This is becoming a serious issue, manifesting initially in investor sentiment and pressure from shareholders for long term decarbonisation strategies from Oil & Gas companies. The response has been mixed, with the likes of BP and Shell announcing initiatives, directing investments away from tradition oil industry categories and into "green" energy sectors. Others, like Exxon, prefer to stay with a "business as usual" approach, relying on their track record of returns to investors to sustain investor confidence. This latter approach is unlikely in to succeed the medium/long term, and is reminiscent of the tobacco industry tactics of the past, given the increasing pressure from the traditional investment community (e.g. Blackrock). It is no longer just activist investors demanding a decarbonisation strategy from the industry, its now mainstream. Increasingly, the traditional oil and gas industry is not seen as a source growth driven returns on investment as it once was.

The balancing act for any large Oil & Gas company will be to develop a decarbonisation strategy that simultaneously defines an end goal that the investor community will accept, as well defining a credible road map for achieving that goal and finally protect and maximise returns on existing assets. This latter point is critical, not just for supporting the existing investor community, but also to provide the cash flow to support the decarbonisation transition costs.

It will be increasingly attractive for established, large scale Oil & Gas companies to view hydrogen is a critical, very public, component of a decarbonisation strategy. The logic is based on leveraging existing assets for hydrogen production using gas and light hydrocarbons as the feedstock and using existing mature/declining oil fields as storage sinks for captured CO2 from that hydrogen production.

It is increasingly important for Oil & Gas companies to credibly rebrand as "energy" companies as an important part of the management of shareholder perceptions and maintenance of capital market confidence long term.

Some additional Industry Observations

- The most developed H2 strategies are those of several countries looking to tap into the growing trend toward a hydrogen energy market. Notably, Australia, Japan, South Korea and some Middle Eastern oil producing countries, the EU is more fragmented and member states are starting to produce statements of intent and demonstration/proof of concept projects.
- The multinational oil companies have tended to be more concerned with responding to investor and capital market pressure to release statements of intent rather than strategies, i.e. wishing to be seen to be responding to the “Green” agenda. These are more evolutionary and aspirational, rather than concrete and actionable strategies.
- For example, in the case of BP this has resulted in a portfolio restructuring plan with “green” components, but is largely driven by the need to rebuild and restructure following the financially damaging Deep Horizon oil spill and the heavy costs associated. BP is managing risk and trying to respond to the longer term oil demand decline predicted by announcing its intent to transform into a more divers, greener energy company. BP at its heart is a commodity trading company mostly concerned with short term profits and has been closing refining capacity for many years, recently accelerated by COVID demand related issues. It has also not committed significant capital to this “green” transformation agenda, nor has BP been specific about the strategy behind the “green” capital expenditure planned.
- Shell has been more aggressive in following a somewhat similar transformation plan to a more diverse energy company and betting mostly on gas with the acquisition of BG as well as the purchase of EV charging stations in western europe. Shell has been closing refining capacity, possibly more associated with the short term demand decline cost reduction resulting from COVID, and conveniently rebranded as part of the diversification agenda.
- SINOPEC has announced a project to build 1000 H2 filling stations in China over 5 years, the hydrogen supply for these is believed to be coming from existing hydrogen production capacity in their refineries, i.e.“Grey” hydrogen. This looks like a proof of concept for distribution and sales of H2 to test the market and as a PR “event” and not associated with a real H2 strategy. The sourcing of hydrogen for this from existing non-green sources (at least initially) confirms the PR priority of this project.

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