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Part-1: 5X Definitions of hydrogen and renewable energy latex and their importance

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Abstract

Hydrogen, the emerging zero carbon spectrum fuel that gears residential, commercial and industrial capacities across the world chasing COP 27 to NetZero. It is therefore essential to promulgate the awareness to societies and harness the Greenhouse emissions (GHG) from conventional sources. The hydrogen & renewable energies are breve raged to 40% by 2040 giving protection to Climate & environment that are susceptible to nature. In this paper are highlighted few definitions to beginners who shall revitalize the fuels and technologies of today and tomorrow.

Keywords: H_2; CO_2; e-fuels; PtX; CCUS; NetZero; GHG

1. Introduction

Primary energy sources take many forms such as nuclear energy, fossil energy like oil, coal, natural gas; and renewable sources like wind, solar, geothermal and hydropower. These primary sources are converted to electricity, a secondary energy source which flow through power lines and other transmission infrastructure.

1.1. Differentiate energy adoptions?

- Clean energy = clean air
- Green energy = sources from nature
- Renewable energy = recyclable sources

1.2. What is green energy?

What's the difference between green energy, renewable energy and clean energy? Often these terms are used interchangeably, but there are some differences. Green energy comes from natural sources, such as the sun and wind.

1.3. What is the difference between green energy and renewable energy?

Renewable energy comes from sources that are naturally renewed such as wind power and solar energy**.** Renewable energy is also often called sustainable energy.

Renewable energy sources are the opposite of fossil fuels, like coal and gas, which are a finite energy source plus the burning of fossils fuels to release energy is a cause of climate change**.**

The terms 'green energy' and 'renewable energy' are often used interchangeable, but there is one essential and sometimes confusing difference between them. While most green energy sources are also renewable but not all renewable energy sources are considered entirely green.

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For example, hydropower. While hydropower, energy generated from fast flowing water is renewable, some people argue that the process of generating vast amounts of power from water is not actually green, because of the industrialization and deforestation involved in the process of building large hydro dams.

2. About hydrogen

2.1. What is hydrogen?

Hydrogen is a clean alternative to methane, also known as natural gas. It's the most abundant chemical element, estimated to contribute 75% of the mass of the universe.

Here on earth, vast numbers of hydrogen atoms are contained in water, plants, and animals and of course humans. But while it's present in nearly all molecules in living things, it's very scarce as a gas less than one part per million by volume.

Hydrogen can be produced from a variety of resources such as natural gas, nuclear power, biogas and renewable power like solar and wind. The challenge is harnessing hydrogen as a gas on a large scale to fuel our homes and businesses.

2.2. What is the importance of hydrogen production?

For many years, we've used natural gas to heat our homes and businesses, and for power stations to generate electricity. In the UK, 85% of homes and 40% of the country's electricity currently relies on gas; in the US, 47% of households rely on natural gas and 36% on electricity.

Methane is the main constituent of 'natural gas' from oil and gas fields. We've continued to use natural gas because it's a readily available resource, it's cost effective and it's a cleaner alternative to coal – the dirtiest fossil fuel that we historically relied on for heating and to generate electricity.

When natural gas is burnt, it provides heat energy. But a waste product alongside water is carbon dioxide, which when released into the atmosphere contributes to climate change**.** Burning hydrogen does not release carbon dioxide.

2.3. Hydrogen as fuel?

There are already **cars** that run on hydrogen fuel cells. China has the highest number of hydrogen fueling stations for road vehicles worldwide, where you can fill up just as you would with petrol or diesel and in the same time frame as a traditional fuel car. Japan has the second highest number of these fueling stations, followed by South Korea, Germany and the US.

Hydrogen is also an exciting lightweight fuel option for road, air and shipping transportation. The international delivery company DHL already has a fleet of H_2 panel vans, capable of travelling 500km without refueling.

2.4. The future of hydrogen?

Hydrogen can be used to power vehicles, generate electricity, power industry and heat our homes and businesses. It could make a huge difference on our carbon emissions and will be critical to achieving net zero.

2.5. Is hydrogen colorless or colorful?

Hydrogen is a colorless and invisible gas. However, although there is no universal naming convention for H_2, we use a vivid color spectrum for differentiating types of hydrogen when referring to the production methods and origins. Let's have a look at the hydrogen rainbow and the significance behind the various colors.

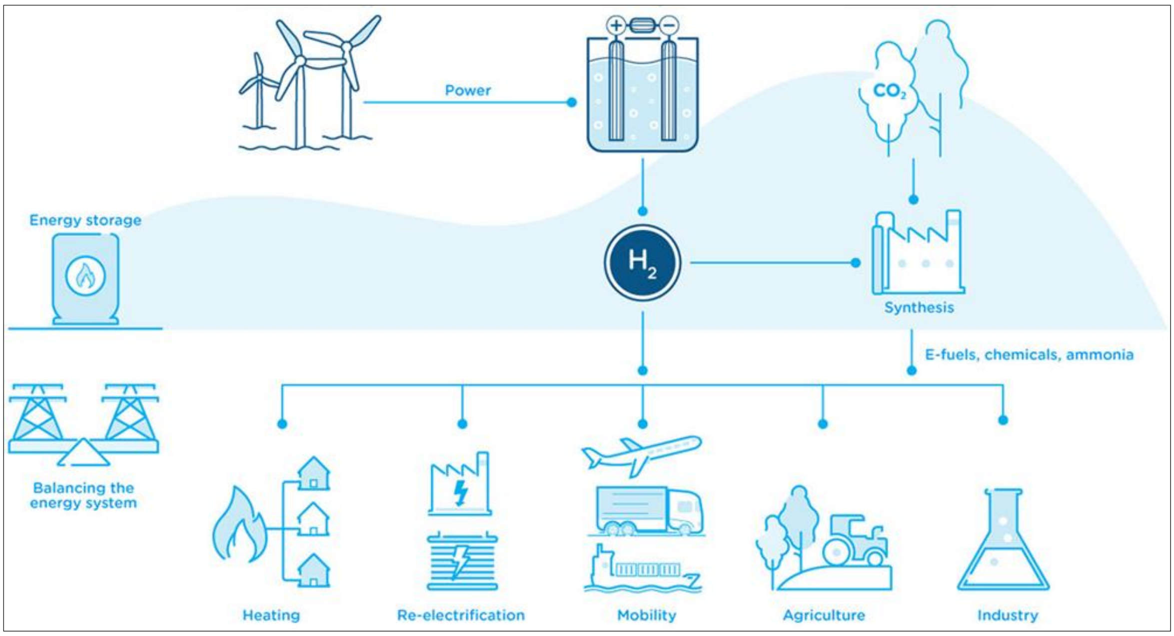
2.6. Define the color spectrums of hydrogen?

The color spectrum is used to describe how hydrogen is produced and the amount of CO_2 emitted in the process. So even though all types of H_2 have the same chemical and physical properties, they do not have the same carbon footprint. This has implications for our environment and the ongoing energy transition on a global scale.

2.6.1. Green hydrogen: the sustainable, carbon-free hydrogen

Let's start with the 'green' end of the hydrogen color spectrum. Green hydrogen is the term used for hydrogen that is made by means of electrolysis using renewable energy sources, such as wind, solar, or hydro power.

Electrolyzers use an electrochemical reaction to split water into its components of hydrogen (H_2) and oxygen (O_2) - emitting zero greenhouse gas (GHG) emissions in the process. Green hydrogen is the clean alternative to fossil fuels and has tremendous potential as a critical enabler in the global transition towards a sustainable energy economy.



Source: Rambøll Denmark A/S, 2023; From water to hydrogen - advancing water electrolysis as core technology.

Figure 1 Green hydrogen lifecycle

2.6.2. Blue hydrogen: the low carbon hydrogen

Blue hydrogen is made from fossil fuels, typically natural gas, by using steam-methane-reforming (SMR) or auto-thermal-reforming (ATR) processes. The output is H_2 but also carbon dioxide as a by-product. By capturing the CO_2 at the source and storing it underground, blue hydrogen can become a low carbon product. This is also referred to as carbon sequestration.

2.6.3. Grey hydrogen: the traditional process

Grey hydrogen is considered the 'traditional' method of producing H_2 and is currently the most common form of hydrogen production. Using a steam reforming process, grey hydrogen is produced from natural gas, but without capturing the carbon dioxide in the process.

2.6.4. Black (or brown) hydrogen: coal

At the very opposite end of the spectrum from green hydrogen is black hydrogen made from fossil fuels. Hydrogen is produced from black coal or lignite (brown coal) through a 'gasification' process.

2.6.5. Pink hydrogen: nuclear energy

Pink hydrogen also finds its place in the colour spectrum. Pink hydrogen refers to H_2 which is produced through electrolysis powered by nuclear energy. In some cases, this production-form is also referred to as purple or red hydrogen.

2.6.6. Turquoise hydrogen: methane pyrolysis

Finally, a recent addition to the spectrum is turquoise hydrogen. Turquoise hydrogen is made using methane pyrolysis, which splits methane into hydrogen gas and solid carbon. This is still very immature and unlikely to play a big role. In the future, turquoise hydrogen might be considered as a low-emissions choice depending on the process being powered by renewable energy and whether the carbon will be permanently stored or used.

2.6.7. Yellow hydrogen

Yellow hydrogen is a relatively new phrase for hydrogen made through electrolysis using **solar power.**

2.6.8. White hydrogen

White hydrogen is a naturally occurring, geological hydrogen found in underground deposits and created through fracking. There are no strategies to exploit this hydrogen at present.

3. Hydrogen production

Hydrogen is the simplest element on earth—it consists of only one proton and one electron—and it is an energy carrier, not an energy source. Hydrogen can store and deliver usable energy, but it doesn't typically exist by itself in nature and must be produced from compounds that contain it.

There are four main sources for the commercial production of hydrogen: natural gas, oil, coal, and electrolysis which account for 48%, 30%, 18% and 4% of the world's hydrogen production respectively [9]. Fossil fuels are the dominant source of industrial hydrogen. Carbon dioxide can be separated from natural gas with a 70–85% efficiency for hydrogen production and from other hydrocarbons to varying degrees of efficiency [9]. Specifically, bulk hydrogen is usually produced by the steam reforming of methane or natural gas [8].

For this process, high temperature steam (H_2O) reacts with methane (CH_4) in an endothermic reaction to yield syngas [11].

$$CH_4 + H_2O \rightarrow CO + 3\ H_2$$

In a second stage, additional hydrogen is generated through the lower-temperature, exothermic, *water-gas shift* reaction, performed at about 360 °C (680 °F):

$$CO + H_2O \rightarrow CO_2 + H_2$$

Essentially, the oxygen (O) atom is stripped from the additional water (steam) to oxidize CO to CO_2. This oxidation also provides energy to maintain the reaction. Additional heat required to drive the process is generally supplied by burning some portion of the methane.

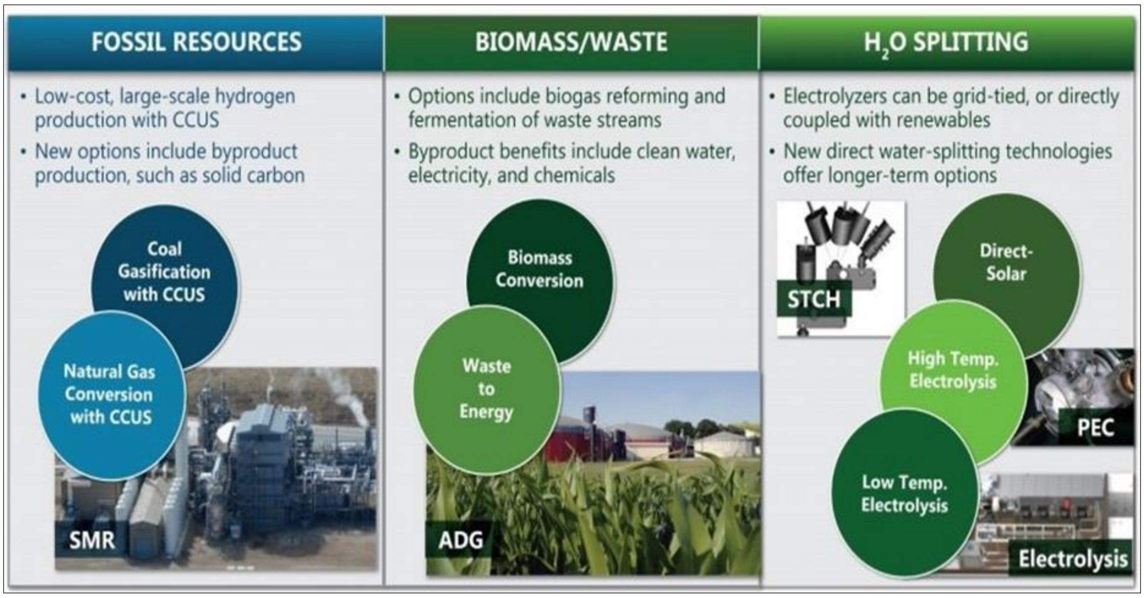


Figure 2 Resources of hydrogen production

3.1. Why study hydrogen production?

With more than 10 million metric tons (MMT) hydrogen is currently produced each year, the primary demand for hydrogen today is for petroleum refining and ammonia production. However, hydrogen can be used across multiple sectors to enable zero or near-zero emissions in other chemical and industrial processes, integrated clean energy systems, and transportation. Emerging hydrogen markets within these sectors include data centers, ports, steel manufacturing, and medium- and heavy-duty trucks.

3.2. How hydrogen production works?

Hydrogen can be produced through low-carbon pathways using diverse, domestic resources including fossil fuels, such as natural gas and coal, coupled with carbon capture and storage; through splitting of water using nuclear energy and renewable energy sources, such as wind, solar, geothermal, and hydro-electric power; and from biomass through biological processes. Learn more about hydrogen production processes.

3.3. What are research and development goals?

The research and development of a wide range of technologies to produce hydrogen economically and via net-zero-carbon pathways are inevitable.

The overall challenge to hydrogen production is cost. DOE's Hydrogen and Fuel Cell Technologies Office is focused on developing technologies that can produce hydrogen at $2/kg by 2026 and $1/kg by 2031 via net-zero-carbon pathways, in support of the Hydrogen Energy Earth shot goal of reducing the cost of clean hydrogen by 80% to $1 per 1 kilogram in 1 decade [16].

4. Hydrogen delivery

A viable hydrogen infrastructure requires that hydrogen be able to be delivered from where it is produced to the point of end use, such as an industrial facility, power generator, or fueling station. Infrastructure includes the pipelines, liquefaction plants, trucks, storage facilities, compressors, and dispensers involved in the process of delivering fuel.

Delivery technology for hydrogen infrastructure is currently available commercially, and several U.S. companies deliver bulk hydrogen today. Growth in hydrogen demand will require regional expansion of this infrastructure and development of new technologies, such as chemical carriers to transport hydrogen at high density and high-throughput fueling technologies for heavy-duty fuel cell transportation.

4.1. Why study hydrogen delivery?

Hydrogen is not just the smallest element on earth, it is also the lightest—as a point of comparison, the mass one gallon of gasoline is approximately 2.75 kg where one gallon of hydrogen has a mass of only 0.00075 kg (at 1 atm pressure and 0 °C). In order to transport large amounts of hydrogen it must be either pressurized and delivered as a compressed gas, or liquefied.

Where the hydrogen is produced can have a big impact on the cost and best method of delivery. For example, a large, centrally located hydrogen production facility can produce hydrogen at a lower cost because it is producing more, but it costs more to deliver the hydrogen because the point of use is farther away. In comparison, distributed production facilities produce hydrogen on site so delivery costs are relatively low, but the cost to produce the hydrogen is likely to be higher because production volumes are less.

4.2. How hydrogen delivery works?

Today, hydrogen is transported from the point of production to the point of use via pipeline and over the road in cryogenic liquid tanker trucks or gaseous tube trailers. Pipelines are deployed in regions with substantial demand (hundreds of tons per day) that is expected to remain stable for decades. Liquefaction plants, liquid tankers, and tube trailers are deployed in regions where demand is at a smaller scale or emerging. Demonstrations of hydrogen delivery via chemical carriers (e.g., in barges) are also underway in large-scale applications such as export markets.

At the point of hydrogen use, additional infrastructure components that are commonly deployed include compression, storage, dispensers, meters, and contaminant detection and purification technologies. For example, stations being deployed to dispense hydrogen into medium and heavy duty fuel cell vehicles are expected to compress the hydrogen to 350–700 bar pressure and dispense at up to 10 kg/min. High-throughput technologies to meet these performance requirements are currently under development.

About the following hydrogen delivery, on-site storage, and dispensing technologies:

- Gaseous hydrogen
- Gaseous compression
- Pipelines
- Tube trailers
- Liquid hydrogen
- Novel hydrogen carriers
- On-site and bulk storage
- Dispensing hydrogen fuel to vehicles.

4.3. What are research and development goals?

Delivery technology for hydrogen infrastructure is currently available commercially to deliver bulk hydrogen today. Some of the infrastructure is already in place because hydrogen has long been used in industrial applications, but wide-scale growth of hydrogen demand will require research and development (R&D), expansion of the supply chain, and new deployments. Because hydrogen has a relatively low volumetric energy density, its transportation, storage, and final delivery to the point of use comprise a significant cost and result in some of the energy inefficiencies associated with using it as an energy carrier.

5. Hydrogen storage

Both water and methane are different sources for creating hydrogen. However, water consists of 11.12% hydrogen produced by electrolysis, whereas methane gas consists of 25.13% hydrogen produced through steam reforming [1,6].

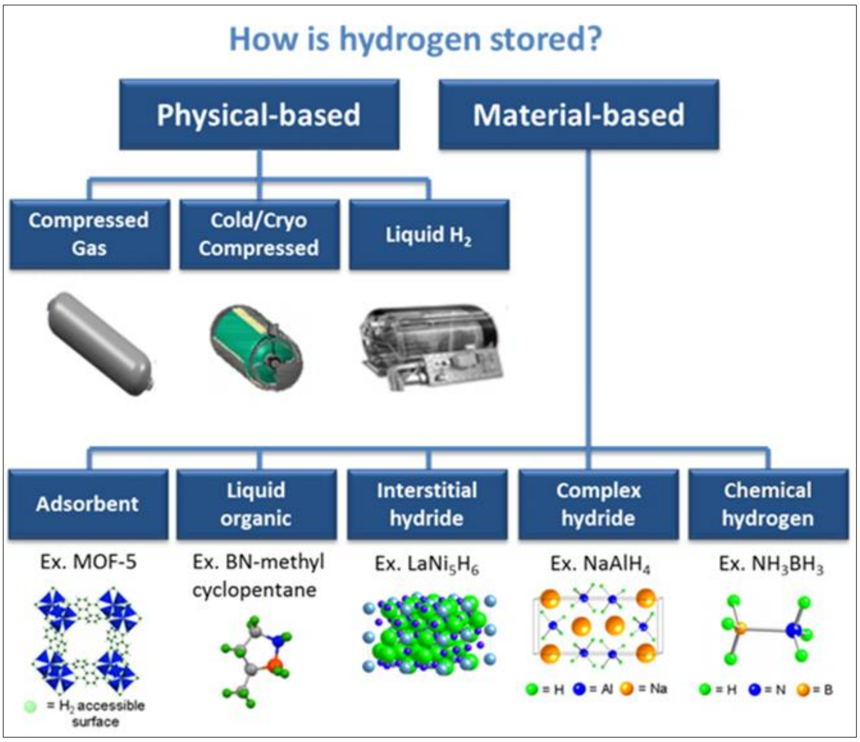


Figure 3 Methods of hydrogen storage

6. About Pt[X]

6.1. What is Power-to-[X] or PtX?

PtX, such as Power-to-gas, Power-to-chemicals, or Power-to-fuels, refers to different processes that turn electricity from renewable energy sources like wind and solar into heat, hydrogen, synthetic fuels or chemicals that would be used in different sectors. PtX aims to utilize the environmental and economic potential of renewable energy. The term PtX emerged due to the increasing number and large diversity of applications relevant to it [3,4].

Power-to-X is essential in achieving a carbon neutral society that meets an increasing demand for energy. Through electrolysis and CO_2 reutilization, Power-to-X can unlock carbon neutral solutions that mitigate unavoidable emissions from industry, for instance by capturing concentrated CO_2 streams from biomass-fired power plants or anaerobic digestion. It also offers a competitive option for energy storage.

New technologies are now being deployed at scale across sectors to decarbonize society, limit global warming and combat climate change. Fossil fuels are being replaced by renewable energy such as wind, solar, and hydro power. Also, direct electrification of household heating and passenger transport in cars is on the rise.

However, some sectors cannot easily be electrified. Where high amounts of energy are required, batteries will not be sufficient to store and transport energy. Heavy duty transport, shipping, and aviation all require fuel in a liquid or gaseous form, as the weight of batteries makes it unsuitable for these applications.

6.2. How to produce synthetic fuels from renewable electricity?

The term Power-to-X covers processes for converting renewably sourced electricity (power) to a substance or energy carrier ("X"). This can be in gaseous form such as hydrogen or methane (synthetic natural gas, Power-to-Gas), or it can be liquid synthetic fuels such as methanol, ammonia, synthetic diesel, or kerosene (Power-to-Liquid). Liquid fuels from Power-to-X are also often referred to as electrofuels or merely e-fuels.

One of the core technologies behind Power-to-X is electrolysis, where water is split into hydrogen (H_2) and oxygen (O_2). Electrolysis is a relatively mature and thoroughly tested technology that has long been used in various industrial processes. However, electrolysis used for dedicated hydrogen production has not yet been widely adopted at scale.

To scale manufacturing and deployment and drive down costs, it calls for more powerful and efficient electrolyzers. Today, electrolyzers are typically tested in megawatt scale and aiming for 100 megawatts and gigawatts before 2030. To give an indication of production volumes, a 1 MW electrolysis unit will typically produce 20 kg hydrogen per hour or approximately 220 Nm3.

Electrolysis capacity deployment is expected to grow rapidly, and the total number, scale of projects, and installed capacity are already rapidly increasing. According to the International Energy Agency (IEA), capacity development set new records for three years in a row between 2018-2020, with Europe being the dominant region with 40% of global installed capacity.

6.3. Green hydrogen fuel of the future

Green hydrogen, or renewable hydrogen, is currently gaining unpresented momentum and international attention. The green hydrogen estimates to meet 24% of global energy demand by 2050.

For green hydrogen to be the key lever in accelerating the green energy transition, it will require adoption into sectors. Its versatility means that it can be harnessed by many industries and presents opportunities for sectors that are difficult to decarbonize with renewable electricity, such as steel, glass, plastic, agriculture, and heavy transport. The increasing interlinking of potential applications is known as sector coupling.

6.4. The "green" in green hydrogen

Through electrolysis, electricity is used to split water into its elements of hydrogen (H_2) and oxygen (O_2). When the electrolyzer is powered by a renewable energy source, for example wind farms or solar, we can produce hydrogen without any greenhouse gas (GHG) emission, therefore the term green hydrogen also called renewable hydrogen.

6.5. What's the market potential for Power-to-X?

The paths towards carbon neutrality are many and most of them involve significant investments into and contributions from Power-to-X. In a route of global study, there has been analyzed the global market potential and technology readiness for Power-to-X and carbon capture utilization and storage (CCUS). Thus the global market potential of Power-to-X is estimated to reach 601-2,319 billion EUR by 2035 [3].

The largest market potentials are observed in fuel cell engines for road transport, both heavy road and light road (such as hydrogen trucks and cars). We estimate that trucks will account for 80% of hydrogen demand in road transport (projected by IEA), whereas light road vehicles will likely be dominated by electric vehicles. In shipping and for marine transport, methanol engines have a larger market potential than ammonia engines and direct hydrogen fuel cells in the projections for 2035.

7. About carbon capture, utilization & storage (CCUS)

7.1. What is carbon capture and storage?

Carbon capture and storage (CCS) is a way of reducing carbon emissions, which could be key to helping to tackle global warming. It's a three-step process, involving, capturing the carbon dioxide produced by power generation or industrial activity, such as steel or cement making; transporting it; and then storing it deep underground. Here we look at the potential benefits of CCS and how it works.

CCS involves the capture of carbon dioxide (CO_2) emissions from industrial processes, such as steel and cement production, or from the burning of fossil fuels in power generation. This carbon is then transported from where it was produced, via ship or in a pipeline, and stored deep underground in geological formations.

7.2. How does CCS actually work?

There are three steps to the CCS process:

7.2.1. Capturing the carbon dioxide for storage:

The CO_2 is separated from other gases produced in industrial processes, such as those at coal and natural-gas-fired power generation plants or steel or cement factories.

7.2.2. Transport:

The CO_2 is then compressed and transported via pipelines, road transport or ships to a site for storage.

7.2.3. Storage:

Finally, the CO_2 is injected into rock formations deep underground for permanent storage.

7.3. Where are carbon emissions stored in CCS?

Possible storage sites for carbon emissions include saline aquifers or depleted oil and gas reservoirs, which typically need to be 0.62 miles (1km) or more under the ground.

As an example, a storage site for the proposed *'Zero Carbon Humber project'* in the UK is a saline aquifer named 'Endurance', which is located in the southern North Sea, around 90km offshore. Endurance is approximately 1 mile (1.6km) below the seabed and has the potential to store very large amounts of CO_2.

Similarly, in the US there are multiple large-scale carbon sites such as the *'Citronelle Project'* in Alabama. This saline reservoir injection site is about 1.8 miles (2.9km) deep.

CCUS has been in operation since 1972 in the US, where several natural gas plants in Texas have captured and stored more than 200million tons of CO_2 underground [1].

8. What is Netzero (carbon neutrality)

Carbon neutrality is a state of net zero carbon dioxide emissions. This can be achieved by balancing emissions of carbon dioxide by eliminating emissions from society (the transition to the "post-carbon economy") or by removing carbon dioxide from the atmosphere. The term is used in the context of carbon dioxide releasing processes associated with transport, energy production, agriculture, and industry.

Although the term "carbon neutral" is used, a carbon footprint also includes other greenhouse gases, measured in terms of their carbon dioxide equivalence. The term climate-neutral reflects the broader inclusiveness of other greenhouse gases in climate change, even if CO_2 is the most abundant.

The term netzero is increasingly used to describe a broader and more comprehensive commitment to decarbonization and climate action, moving beyond carbon neutrality by including more activities under the scope of indirect emissions, and often including a science-based target on emissions reduction, as opposed to relying solely on offsetting.

The energy sector is the source of around three quarters of greenhouse gas emissions today and holds the key to averting the worst effects of climate change. Reducing global carbon dioxide (CO_2) emissions to net zero by 2050 is consistent with efforts to limit the long term increase in average global temperature to 1.5 °C. This calls for nothing less than a complete transformation of how we produce, transport and consume energy.

8.1. Conference of the Parties (COP)

COP stands for Conference of the Parties, and the summit was attended by the countries that signed the United Nations Framework Convention on Climate Change (UNFCCC), a treaty that came into force in 1994. This was the 26th COP summit and was hosted in partnership between the UK and Italy.

In November 2021, the UK hosted the 26th annual summit – giving it the name COP26. With the UK as President, COP26 took place in Glasgow. Below are the four goals the UK Presidency set for itself ahead of hosting COP26 [14, 15].

8.1.1. Secure global net zero by mid-century and keep 1.5 degrees within reach

Countries are being asked to come forward with ambitious 2030 emissions reductions targets that align with reaching net zero by the middle of the century.

To deliver on these stretching targets, countries will need to:

- Accelerate the phase-out of coal
- Curtail deforestation
- Speed up the switch to electric vehicles
- Encourage investment in renewables.

8.1.2. Adapt to protect communities and natural habitats

The climate is already changing and it will continue to change even as we reduce emissions, with devastating effects.

At COP26 we need to work together to enable and encourage countries affected by climate change to:

- Protect and restore ecosystems
- Build defences, warning systems and resilient infrastructure and agriculture to avoid loss of homes, livelihoods and even lives

8.1.3. Mobilize finance

To deliver on our first two goals, developed countries must make good on their promise to mobilize at least $100bn in climate finance per year by 2020.

International financial institutions must play their part and we need work towards unleashing the trillions in private and public sector finance required to secure global net zero.

8.1.4. Work together to deliver

We can only rise to the challenges of the climate crisis by working together.

At COP26 we must:

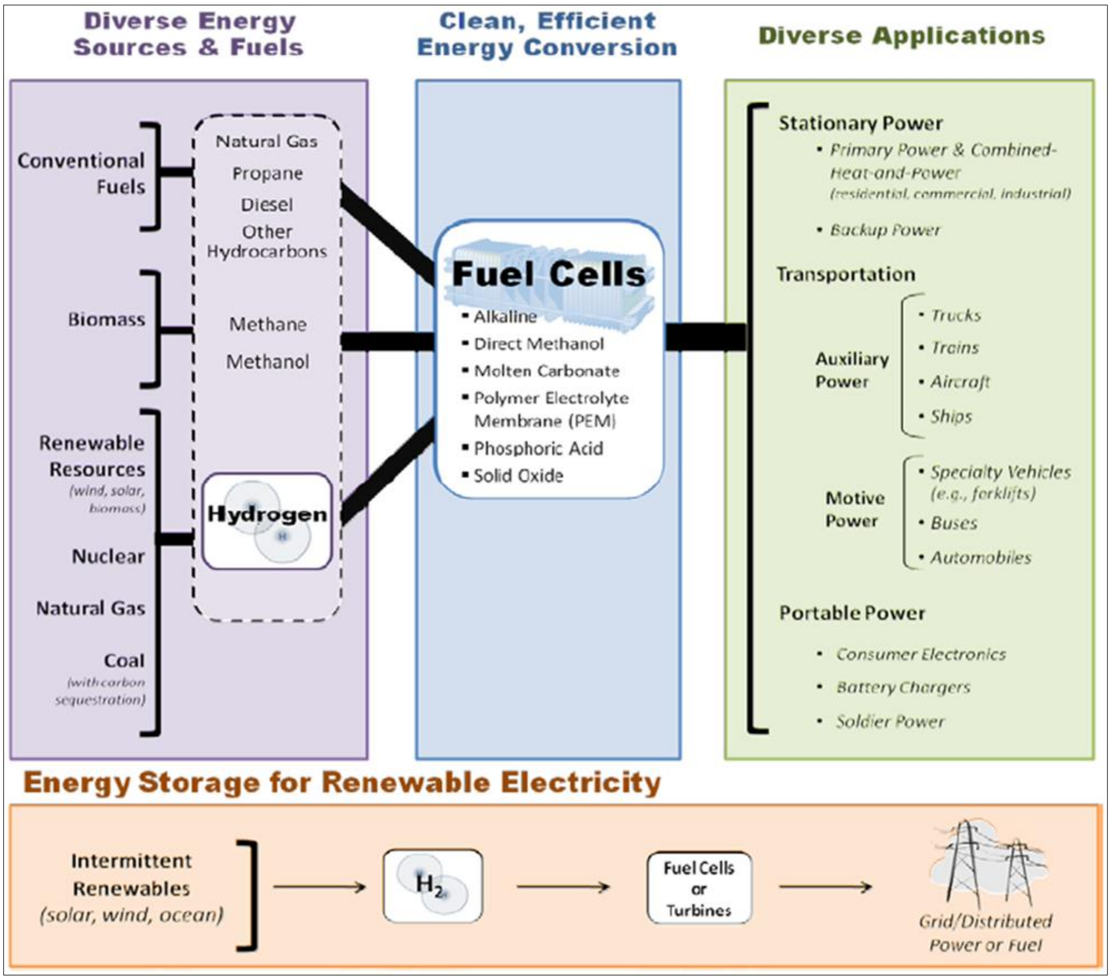
- Finalize the Paris Rulebook (the detailed rules that make the Paris Agreement operational
- Accelerate action to tackle the climate crisis through collaboration between governments, businesses and civil society.

The COP27 program is underpinned by four key areas:

- **Net-Zero:** Enabling companies to set net-zero aligned science-based targets through our Net-Zero Standard.
- **Scope3:** Helping to scale science-based decarbonization across the value chain.
- **FLAG (Forest, Land and Agriculture):** Unleashing the vast, untapped potential of FLAG companies through our new guidance and pathway for the sector.
- **Global South:** Demonstrating how science-based targets can help drive climate investment in the global south.

9. Fuel cell technologies program of USA

The Fuel Cell Technologies are actively involved in coordination activities with the DOE Hydrogen and Fuel Cells Program, which includes hydrogen and fuel cell research and development efforts within DOE's Offices of Energy Efficiency and Renewable Energy (EERE), Nuclear Energy, Fossil Energy, and Science. Some EERE Programs sponsor research on technologies that can be used to produce or use hydrogen [7,16].



Source: U.S. Department of Energy, Fuel Cell Technologies Office [16]

Figure 4 Fuel cell technologies

EERE includes the following programs:

- Wind and Water Power Program
- Geothermal Technologies Program
- Solar Energy Technologies Program
- Biomass Program
- Vehicle Technologies Program
- Building Technologies Program
- Federal Energy Management Program
- Weatherization and Governmental Program
- Advanced Manufacturing Office

Hydrogen can play a key role in the realization of several of these technologies, and will benefit from the relevant research and development taking place. Advanced electrolysis technologies, conversion of biomass to hydrogen, polymer electrolyte membrane fuel cell development, and application of hydrogen for stationary energy needs are examples to achieving the technical targets.

10. Conclusion

The designations of above definitions exemplify the emerging green and renewable energy sources for conventional and non-conventional fuels & technologies like: Aluminum, Appliances & equipment, Aviation, Bioenergy, Building envelopes, Carbon capture utilization & storage, Cements, Chemicals, Cooling Data Centre's & Networks, Demand response, Electric vehicles, Energy storage and Fuel economy, Heating, Hydrogen, Hydropower, International shipping, Iron & steel, Lightning, Other renewables, Pulp & paper, Rail, Smart grids, Solar, Trucks & buses and Wind.

Hydrogen and fuel cells offer a broad range of benefits for the environment that include:

- Reduced greenhouse gas emissions
- Reduced oil consumption
- Expanded use of renewable power (through use of hydrogen for energy storage and transmission)
- Highly efficient energy conversion
- Fuel flexibility (use of diverse, domestic fuels, including clean and renewable fuels)
- Reduced air pollution and
- Highly reliable grid-support.

Compliance with ethical standards

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Disclosure of conflict of interest

No conflict of interest.

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