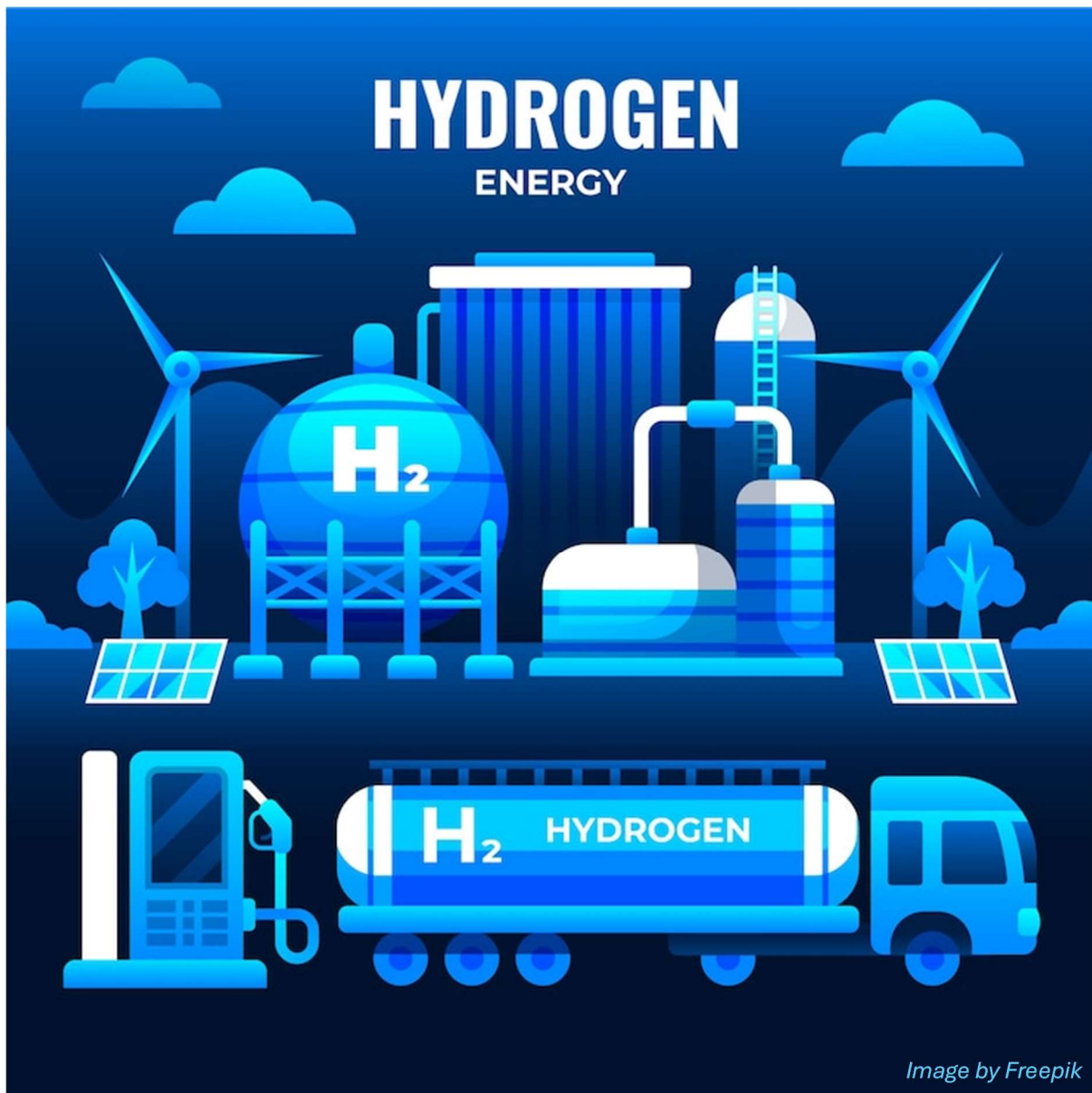


# Principles and Applications of Hydrogen Energy Technology

A Special Topic Document produced for the  
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Leaving Certificate 2025



*Image by Freepik*

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## Introduction

Fossil fuels cause great harm to the environment and humans through greenhouse gases, acid rain, and other pollutants. By comparison, the combustion of hydrogen produces only water, and has the potential to reduce carbon emissions across numerous sectors such as heavy industries (steel, chemicals), and transport such as buses, cars, trucks, and shipping. Thus there is enormous global interest in hydrogen as a clean and low-carbon energy alternative. As will be explained later, hydrogen is termed an “energy carrier” rather than a primary fuel.

Hydrogen can be extracted from a number of substances, such as water, oil, gas, biofuels, sewage sludge, etc. Splitting of water ( $\text{H}_2\text{O}$ ) by electrolysis is seen as the cleanest method of producing hydrogen, but this requires large amounts of electricity. However, as electrical energy from renewable technologies such as wind and solar increases, the production of hydrogen through electrolysis is expected to increase and may well be an ideal blend of supporting technologies.

Hydrogen technologies can also be small and produce at a local level reducing the need to import and distribute fuel. Consequently, many countries now feature hydrogen in their energy strategy, collaborating on research to develop and introduce these new hydrogen technologies.

## What is hydrogen?

Hydrogen is a chemical element represented by the symbol H on the periodic table and with an atomic number of 1 is the lightest of all the elements. Hydrogen is the most abundant chemical substance in the universe making up around 75% of all matter. It is a colourless, odourless, tasteless, non-toxic, and highly flammable gas. Hydrogen normally exists as a molecule of two atoms ( $\text{H}_2$ ) (see Figure 1) at room temperature and pressure. Hydrogen is found in compounds such as water ( $\text{H}_2\text{O}$ ), ammonia ( $\text{NH}_3$ ), and hydrocarbon fuels such as natural gas, coal, and oil.

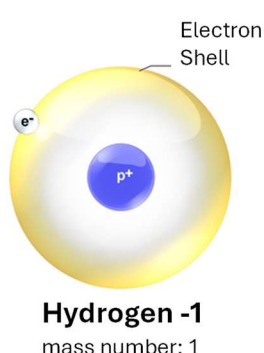


Figure 1: The hydrogen atom, and the hydrogen molecule as it commonly appears. [image 1, image 2]

Hydrogen is widely used in various applications including ammonia production, oil refining and energy. The most common methods for producing hydrogen are: steam reforming, oil reforming, coal gasification, and water electrolysis. Some of these processes are cheap but emit pollutants, others are carbon neutral and thus will be important in preventing climate change. Electrolysis powered by renewables is seen

as one of the low-carbon alternatives to the other three traditional production methods. Despite its advantage of cleanliness, it is currently the most expensive (see Figure 2), which makes scaling-up and commercialisation a challenge to overcome.

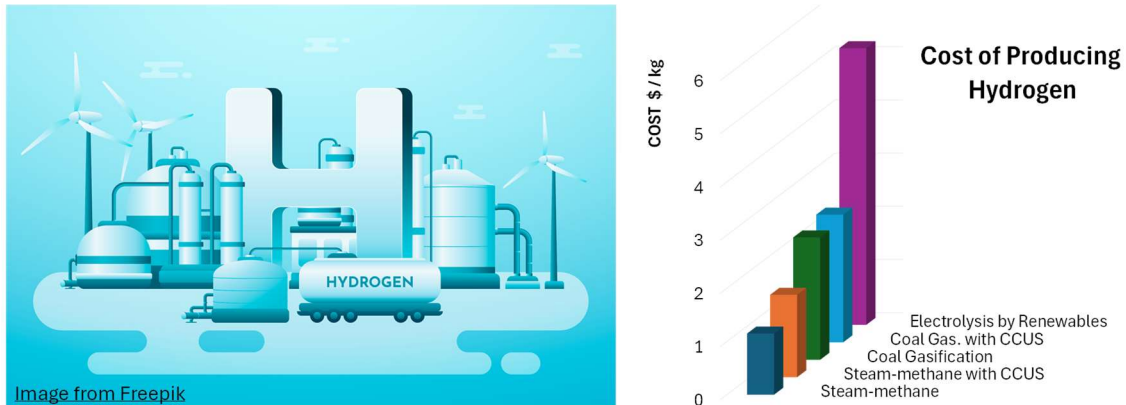


Figure 2: Cost of hydrogen production via industrial or renewable methods

Hydrogen is not classed as a primary energy source as it doesn't occur naturally as a fuel like coal or oil. However it is widely regarded as an ideal carrier or energy storage medium, as hydrogen can be converted from water through electrolysis, and easily re-converted when needed, back to electrical power using a fuel cell or hydrogen gas turbine. There are a number of different types of fuel and electrolysis cells available. The potential environmental impact depends primarily on the methods used to generate hydrogen. Like all fuels, hydrogen is flammable, and is even explosive in many concentrations which require precautions and safe handling practices. However hydrogen is non-toxic and even if released poses no threat to human health or the environment.

## The UN SDGs

The Sustainable Development Goals (SDGs) shown in Figure 3 are a collection of 17 interlinked global goals designed to be a “blueprint to achieve a better and more sustainable future for all”. Agreed by 193 countries in 2015 as part of the UN 2030 Agenda for Sustainable Development, the SDG's strive for the reduction of climate change and poverty, and the improvement of education, health, and economic growth.



Figure 3: The United Nations Sustainable Development Goals (SDGs)



Do you know all 17 SDGs?

<https://www.youtube.com/watch?v=0XTBYMfZyrM>

Hydrogen can positively influence several of these goals including Climate Action, Energy, Sustainability, Clean Water and Oceans, Health, and Infrastructure and Industry.

## How is hydrogen made?

There are several methods of producing hydrogen (see Figure 4), some based on traditional large industrial processes, while some newer processes are now in focus. The four main methods are: thermal reforming, gasification, electrolysis, and by-products from industrial processes. Other methods include solar-driven and biological processes.

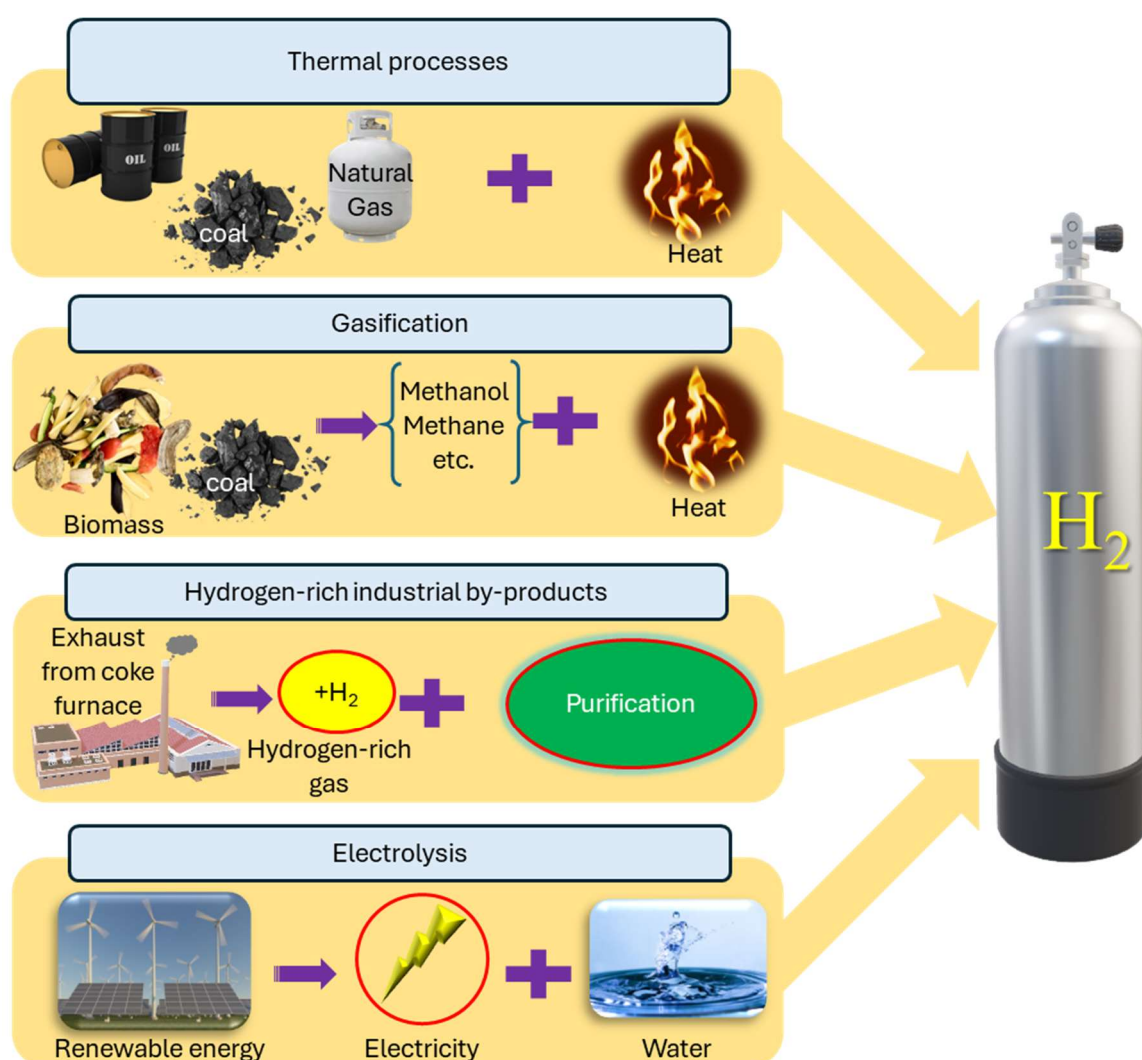


Figure 4. The main hydrogen production technologies [Image Authors]



Green Hydrogen - Production, Storage and Transportation

<https://www.youtube.com/watch?v=ZJcdQijE8T0>



## Thermal processes

These typically involve steam reforming, in which steam reacts with a hydrocarbon fuel at high temperature to produce hydrogen. Many fuels can be used, including natural gas, diesel, renewable liquid fuels, and gasified coal or biomass. Around 95% of all hydrogen is produced from a process known as “Steam Methane Reforming” (SMR) where methane ( $\text{CH}_4$ ) from natural gas and water ( $\text{H}_2\text{O}$ ) react to form carbon monoxide ( $\text{CO}$ ) and hydrogen ( $\text{H}_2$ ). Extra hydrogen is obtained when the  $\text{CO}$  combines with water to create harmless carbon dioxide and hydrogen. While the SMR process is efficient and cost-effective it emits greenhouse gases.



### Hydrogen generation by steam methane reforming

<https://www.youtube.com/watch?v=MllfovSOBY>

## Gasification:

Gasification converts coal, biomass, or domestic waste, into a gas mixture composed of hydrogen, carbon monoxide, and methane. By heating the feedstock in a controlled, low-oxygen vessel called a gasifier (typically between  $700^\circ\text{C}$  to  $1,000^\circ\text{C}$ ), the material undergoes a series of chemical reactions that break it down into simpler gases including hydrogen. This process can utilize a wide variety of feedstocks, but can lead to high  $\text{CO}_2$  emissions if not managed properly. In addition, the produced gas may contain impurities which need to be filtered out.



### Hydrogen from Biomass Gasification

[https://www.youtube.com/watch?v=DlySX\\_GD\\_5o](https://www.youtube.com/watch?v=DlySX_GD_5o)

## Hydrogen-rich industrial by-products

In some industries hydrogen is generated as a secondary product during the process. Production of chlorine and caustic soda through electrolysis produces a significant amount of hydrogen, as do coke ovens during steelmaking. The hydrogen can be captured and re used. Although the process is more economical and reduces waste, the purification technologies can be expensive.



### Hydrogen Industry Overview - How is Hydrogen Produced?

<https://www.youtube.com/watch?v=UHYmBFICDSY>

## Electrolysis

Electrolysis uses electricity to split water into hydrogen and oxygen, by passing an electric current through water, typically in the presence of an electrolyte (such as potassium hydroxide or sodium sulphate). Electrolysis is one step in the entire chain of hydrogen production as shown in Figure 5. It is this process that is currently of major interest globally and will be therefore receive more attention in this document.

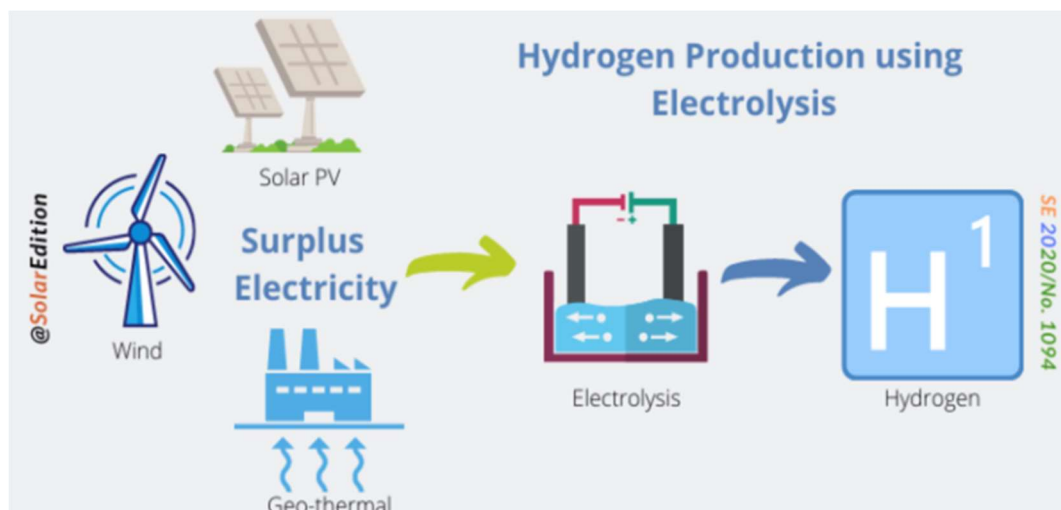


Figure 5: The chain of hydrogen production using electrolysis [<https://epcmholdings.com/green-hydrogen-technology-evaluation-criteria-for-electrolyser-selection/>]



### What Is Electrolysis?

[https://www.youtube.com/watch?v=7ullq\\_Ofzgw](https://www.youtube.com/watch?v=7ullq_Ofzgw)

### Other methods

A number of other methods are available which use solar power including photobiological, photoelectrochemical, and solar thermochemical.

- Photobiological uses the natural photosynthetic activity of bacteria and green algae
- photoelectrochemical use specialized semiconductors to split water
- Solar thermochemical use concentrated solar power and metal oxides

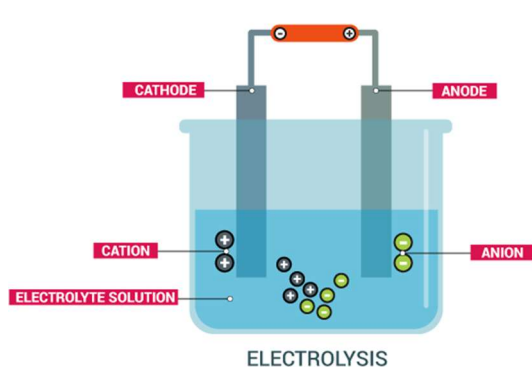
Biological processes use microbes such as bacteria and microalgae to generate hydrogen.

- Microbial biomass conversion, microbes break down organic biomass or wastewater
- In photobiological processes, microbes use sunlight as the energy source.
- Photoelectrochemical water splitting uses sunlight and semiconductor materials to convert water into hydrogen.

These methods have potential for low-cost hydrogen production but many require advanced materials and are still in the research phase.

## Making Hydrogen through Electrolysis

Electrolysis uses electricity to split water into its constituent parts of oxygen ( $O_2$ ) and hydrogen ( $H_2$ ). Low voltages are sufficient, typically 1.5 volts is enough. An electrolytic cell contains a water and dissolved salt mixture called an electrolyte shown in Figure 6. A DC current flows between the two electrodes, the water in the electrolyte splits at the cathode and the anode.



### ELECTROLYSIS

- A cell contains a water and dissolved salt mixture called an electrolyte
- A DC current flows between the two electrodes,
- The cathode is (-), and the anode (+)
- The water in the electrolyte, splits into gas at the cathode, and the anode
- Hydrogen ( $H_2$ ) forms at the cathode
- Oxygen ( $O_2$ ) forms at the anode

Figure 6: Electrolysis of Hydrogen [<https://senzahydrogen.com/hydrogen-production-from-electrolysis/>]

At the cathode, water molecules gain electrons and form hydrogen gas. This hydrogen can then be collected and used as a clean energy carrier. At the anode, water molecules lose electrons to produce oxygen gas, which is either released into the atmosphere or captured for other uses. Electrolysis produces hydrogen without greenhouse gas emissions when powered by renewable energy sources such as solar, wind, or hydroelectric power.

Water electrolysis can be divided into three types, alkaline water electrolysis, proton exchange membrane (PEM) water electrolysis, and solid oxide water electrolysis.



### The Hydrogen Electrolyser

<https://www.youtube.com/watch?v=WfkNf7kMZPA>

### Alkaline Electrolysis

Alkaline electrolysis is a well-established method of hydrogen production. This process involves splitting water molecules ( $H_2O$ ) into hydrogen ( $H_2$ ) and oxygen ( $O_2$ ) using an alkaline electrolytic cell as seen in Figure 7(a). An alkaline electrolyte solution, typically potassium hydroxide (KOH) or sodium hydroxide (NaOH), helps conduct the flow of ions between electrodes. The anode and cathodes are typically made of durable and corrosion-resistant materials such as nickel, stainless steel, or other metals.

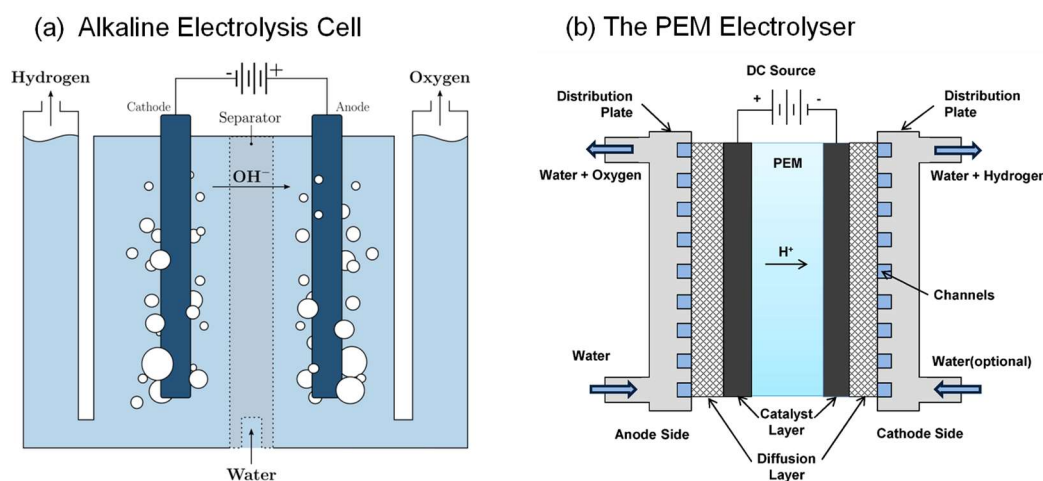


Figure 7: (a) Alkaline Electrolysis Cell and (b) PEM Electrolyser [<https://stargatehydrogen.com/blog/basics-of-hydrogen-electrolysis/>]



Proton Exchange Membrane (PEM) Electrolysis is another method used for splitting water into hydrogen and oxygen. The PEM electrolysis cell again consists of two electrodes, an anode, and a cathode, this time separated by a solid polymer electrolyte membrane, typically made of a specialized polymer (Nafion is commonly used) as seen in Figure 7(b).

The anode and cathode are usually made of precious metals such as platinum, but efforts are ongoing to develop low cost alternatives. When an electric current passes through the PEM electrolysis cell, water oxidation takes place at the anode releasing of oxygen gas ( $O_2$ ). Hydrogen ions migrate through the electrolyte to the cathode producing hydrogen gas ( $H_2$ ). The PEM electrolyser is compact and suits small-scale applications.

### Solid Oxide Hydrogen Electrolysis

Solid oxide hydrogen electrolysis uses a solid oxide material as an electrolyte to split water into hydrogen and oxygen gases but at elevated temperatures (typically above 700 degrees Celsius). The cell again consists of three main components: the electrolyte, an anode, and a cathode, however both the anode and cathode are porous to facilitate electrochemical reactions.

When an electric current is applied across the solid oxide hydrogen electrolysis cell, the oxygen ions migrate through the electrolyte to the cathode where they form oxygen gas. At the anode, water vapor (steam) or a mixture of steam and carbon dioxide is formed which splits to produce hydrogen gas.

Solid oxide electrolysis operates at high temperatures, which enables faster ion transport through the solid electrolyte, enhancing the overall efficiency of the process. Additionally, the high operating temperatures allow for the utilization of waste heat from industrial processes or other sources, increasing the overall energy efficiency of hydrogen production.

### How can this hydrogen be used?

As stated earlier, hydrogen is not a primary fuel, but rather regarded as an energy carrier acting as a “store” of energy which can then be converted when needed. This conversion can be by combusting the hydrogen in a turbine or engine, or else converting it back to electricity in a fuel cell. These will be explained in the next section.

### Combustion

Hydrogen can be used alone or blended with natural gas in combustion gas turbines to produce electricity. Commercial exploration of this is ongoing however, there are limits to hydrogen blending in the gas network and existing combustion gas turbines need to be modified for use with pure or blends of hydrogen. Research and demonstration projects are also exploring turbines that can directly burn hydrogen in the form of ammonia. However ammonia is a toxic chemical, and can also generate products leading to acid rain. In May 2023 a venture between Airbus and Safran, successfully completed a proof-of-concept of a hydrogen ‘conditioning system’

adapted to power an aircraft jet engine (Figure 8). The hydrogen had to be stored at a bone-numbing  $-253^{\circ}\text{C}$  and required special equipment to 'condition' the hydrogen for combustion within the aircraft engine.



Figure 8: Development work is ongoing in hydrogen powered jet engines  
[<https://www.airbus.com/en/newsroom/stories/2023-06-at-airbus-hydrogen-power-gathers-pace>]



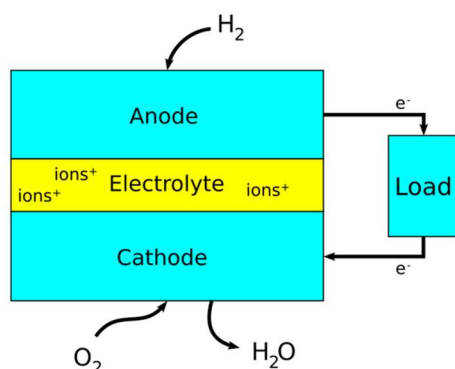
**Watch Airbus Reveal ZEROe Hydrogen-Powered Jet**

<https://www.youtube.com/watch?v=B9WMEMyvG3M>

## Fuel Cells

A fuel cell is a device that generates electricity from the chemical energy of a fuel (hydrogen) and an oxidising agent (air) through an electrochemical reaction, not combustion. It consists of two electrodes, a negative electrode (anode) and a positive electrode (cathode) sandwiched around an electrolyte. A fuel, such as hydrogen, is fed to the anode, and air is fed to the cathode. Schematic and actual cells are shown in Figure 9.

(a) Fuel Cell Schematic



(b) Actual Fuel Cell

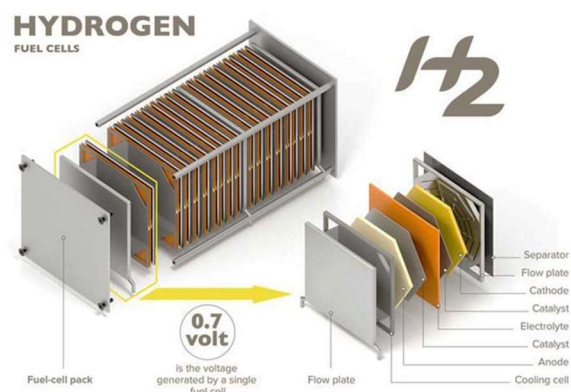


Figure 9: Schematic of fuel cell [[https://en.wikipedia.org/wiki/File:Fuel\\_Cell\\_Block\\_Diagram.svg](https://en.wikipedia.org/wiki/File:Fuel_Cell_Block_Diagram.svg)], and actual fuel cell [<https://genh2hydrogen.com/blog/advantages-of-hydrogen-fuel-cells/>]

A catalyst at the anode separates the hydrogen fuel molecules into electrons and protons, which take different paths to the cathode.

As the fuel is consumed, the electrons create a flow of electricity which can be used to power electrical devices, while the protons migrate through the electrolyte to the cathode, where they unite with oxygen and the electrons to produce water and heat. Fuel cells operate similarly to batteries, but do not run down or need recharging, producing electricity and heat as long as fuel is supplied. As there are no moving parts, fuel cells operate silently and with extremely high reliability.



### How does a Fuel Cell work?

<https://www.youtube.com/watch?v=bS9XVbUN8R8>

Due to their chemistry, fuel cells are very clean. Fuel cells that use pure hydrogen fuel are completely carbon-free, with their only by-products being electricity, heat, and water.

Some types of fuel cell systems can use hydrocarbon fuels like natural gas, biogas, methanol, and others. Because fuel cells generate electricity through chemistry rather than combustion, they can achieve much higher efficiencies (over 60%) than traditional energy production methods such as steam turbines and internal combustion engines. To push the efficiency even higher, a fuel cell can be coupled with a combined heat and power system that uses the cell's waste heat for heating or cooling applications.

Fuel cells are also scalable. This means that individual fuel cells can be joined with one another to form stacks. In turn, these stacks can be combined into larger systems. Fuel cell systems vary greatly in size and power, from combustion engine replacements for electric vehicles to large-scale, multi-megawatt installations providing electricity directly to the national electricity grid. Hydrogen fuel cells can be used in numerous areas, including vehicles (see Figure 10), buildings, industry, and for long-term energy storage for the electricity grid.

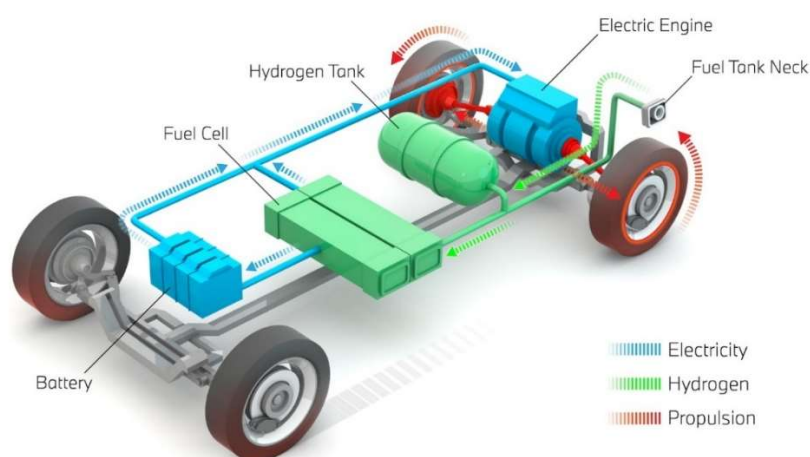


Figure 10: Integration of fuel cell with other components of an EV [<https://www.bmw.com/en/innovation/how-hydrogen-fuel-cell-cars-work.html>]

Hydrogen fuel cells have several benefits over conventional combustion-based technologies currently used in power plants and vehicles. They can operate at higher efficiencies, have fewer moving parts, are much quieter, and produce fewer emissions.



### **BMW i Hydrogen NEXT Fuel Cell Technology Powertrain**

[https://www.youtube.com/watch?v=xyw\\_VrOlvuI](https://www.youtube.com/watch?v=xyw_VrOlvuI)

In general, all fuel cells have the same basic configuration, an electrolyte and two electrodes. But there are different types of fuel cells, classified primarily by the kind of electrolyte used. The electrolyte determines the kind of chemical reactions that take place in the fuel cell, the temperature range of operation, and other factors that determine the most suitable application for that type.

## **Research and Development Goals**

Despite the benefits of cleanliness and zero emissions, there are challenges to integrate hydrogen into our existing energy systems. These include production, delivery, storage of the gas. At the user end, more research into fuel cells, vehicles and the manufacturing systems for these new technologies require development and investment.



*Figure 11: Much research into hydrogen systems is still required [image from Freepik]*

Research and development (R&D) is important to make the cost of producing hydrogen cheaper and more competitive with conventional fuels such as oil and gas, while minimizing the environmental impacts of production.

R&D helps improve technologies to distribute hydrogen cost-effectively from the point of production to the point of end-use, such as in fuel cell vehicles. These include piping, transport tanks, delivery systems.

Storage technologies must be improved so fuel cell electric vehicles can store enough hydrogen onboard to enable a driving range of at least 300 miles without taking up excessive space or adding excessive weight.

Fuel cell system costs and size need to be minimised for vehicles, while the performance and durability of electrolyser fuel cell systems likewise. Car users will require greater electrical power from fuel cells, and also demand long lifetimes before



the cell output degrades. This requires research into new materials including metals, polymers and electrolytes.

Manufacturing R&D is important to help the current Hydrogen technologies which are low volume and quite specialised, to move to high-volume, reliable, commercially manufactured products.

## Future of Hydrogen in Ireland

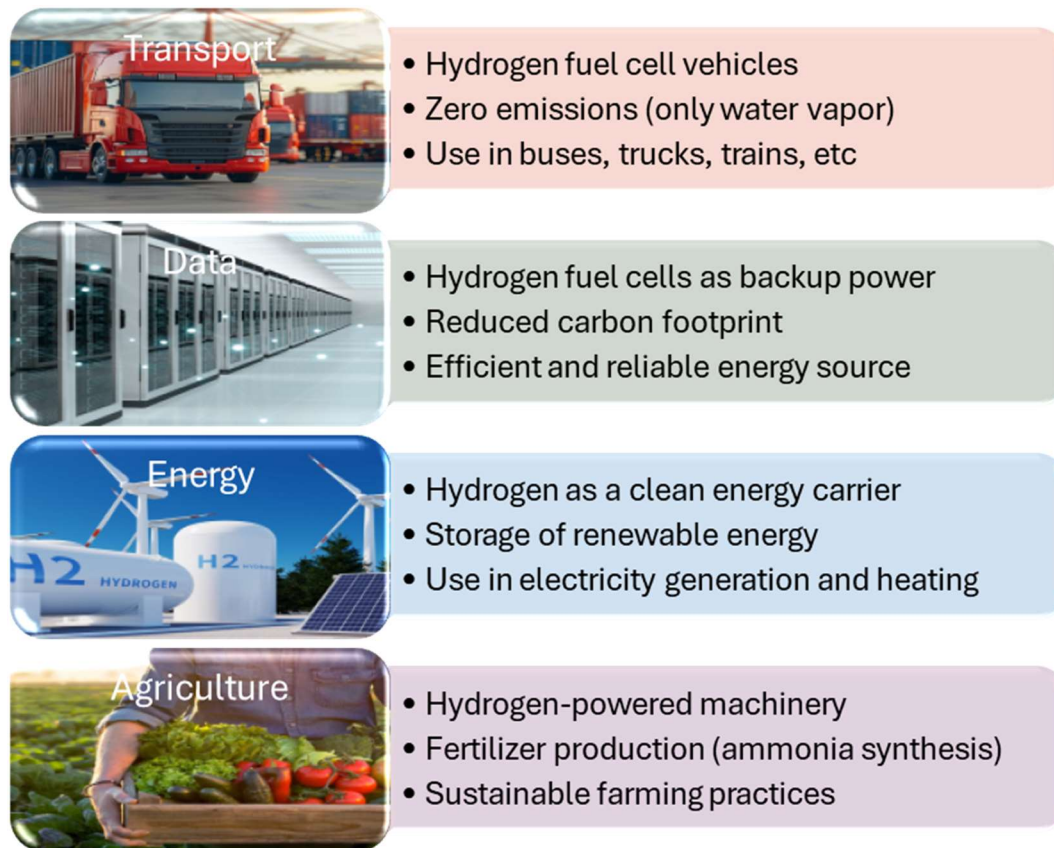


Figure 12: Hydrogen uses in Ireland [Image Authors]

Hydrogen is already starting to be part of Ireland's transition to a green economy, with uses in numerous areas such as transport, energy, data, and agriculture as seen in Figure 12. For example, three double-decker hydrogen fuel cell buses were introduced in 2022 on the Bus Éireann Route 105x, operating with zero emissions and offering a quieter, cleaner alternative to traditional buses. These trials mark the beginning of a national hydrogen network needed for heavy-duty transport and public transit.

## Datacentres

Ireland has a high number of data centres which consume large amounts of electricity to power servers, maintain network operations, and run the cooling systems. Utilizing hydrogen as an energy source for data centres can provide a sustainable and environmentally friendly alternative to traditional fossil fuels. This shift will help reduce carbon emissions and combat climate change.



The proposed Rhode Green Energy Park in County Offaly is conducting a feasibility study to develop data centres powered by green hydrogen (see Figure 13). The study aims to integrate renewable energy with data centres to attract investment and create jobs. The park hopes to leverage green hydrogen produced from renewable sources, ensuring sustainable development and satisfying energy demand from the data centre sector.

An Energy Park is a site housing a range of low to zero carbon energy generation and storage assets. This diagram shows an example of the technologies being considered.

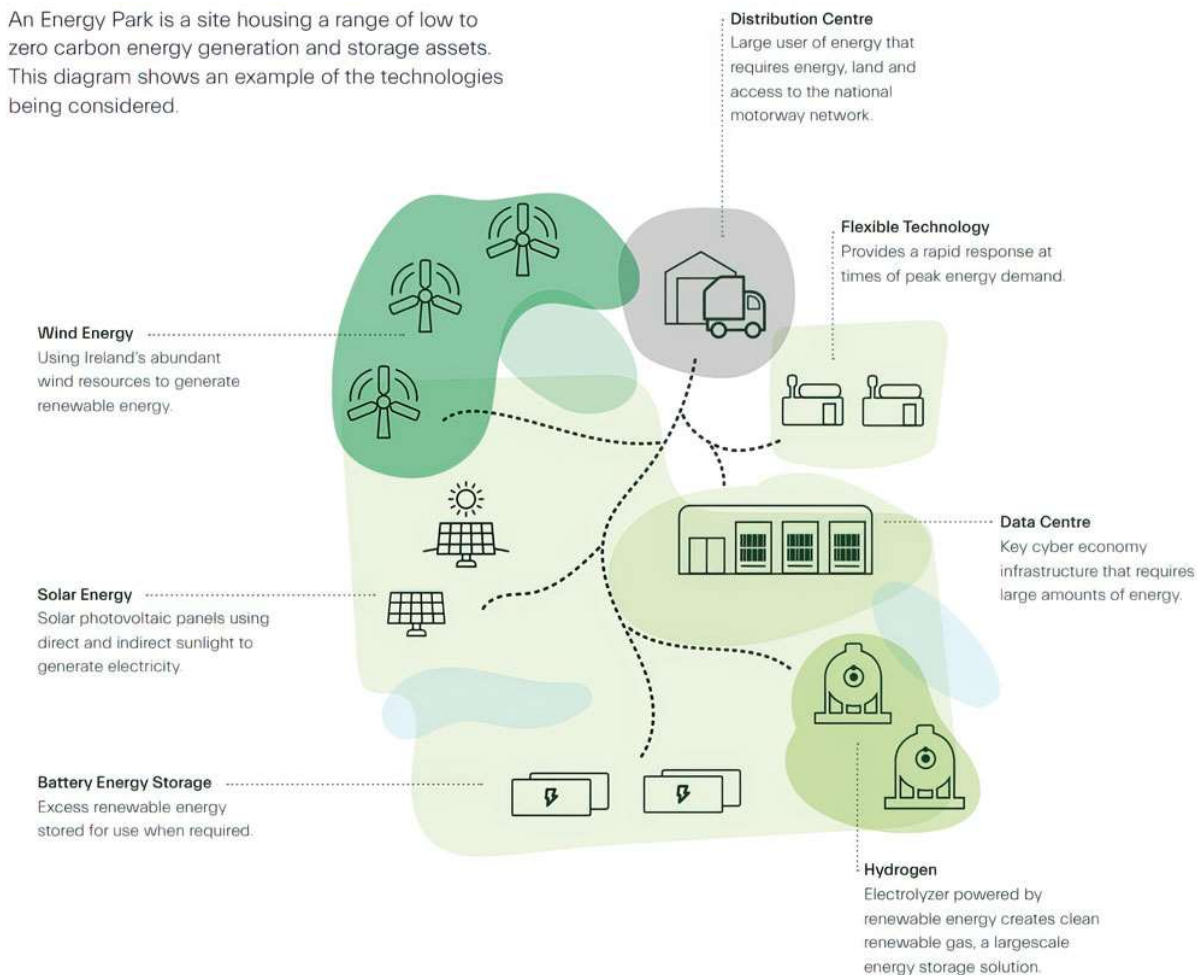


Figure 13:BNM infographic showing Energy park concept [<https://www.energyireland.ie/green-hydrogen-will-play-a-key-role-in-irelands-energy-transition/>]

## Energy

The push for hydrogen as an energy source aligns with Ireland's targets for reducing greenhouse gas emissions and achieving net-zero carbon emissions by 2050. Hydrogen is key to decarbonise areas that are difficult to electrify directly, such as heavy-duty transport and energy-intensive industries such as steel, cement, fertilizer, and chemical production.

## Agriculture

In agriculture, hydrogen can be used to produce ammonia for fertiliser essential for farming. Hydrogen produced through electrolysis powered by renewable energy, offers a sustainable alternative to conventional ammonia production, which typically relies

on natural gas. In the future, hydrogen-powered tractors and machinery further reduce the carbon footprint of traditional farming.

## Advantages and disadvantages of Hydrogen Technologies

Hydrogen technologies are at the forefront of the global transition to sustainable energy. They utilise hydrogen as a clean and versatile energy carrier, capable of fuelling cars and industrial processes with minimal environmental impact. The primary advantage is its potential for zero emissions, producing only water as a byproduct when used in fuel cells. However, challenges such as high production costs, storage difficulties, and the need for extensive infrastructure development remain significant hurdles. Here, some of the advantages and disadvantages are discussed

### Advantages of Hydrogen Technologies:

*Clean Energy:* Hydrogen produces only water when burned, making it a zero-emission energy source. This is especially valuable in reducing greenhouse gas emissions and combating climate change, as it provides a clean alternative to fossil fuels in various sectors, including transportation and industry.

*Abundant Resource:* Hydrogen is the most abundant element in the universe and can be produced from a variety of sources such as water, biomass, and natural gas. However, on Earth, hydrogen is rarely found as a free gas and mostly exists in compounds like water and organic materials. Extracting hydrogen from these sources can be complex, but its abundance makes it a promising long-term energy resource. More information <https://www.figarosensor.com/challenge/h2.html>).

*Versatility:* Hydrogen is highly versatile, capable of powering fuel cells for electricity generation, being used as fuel for transportation (e.g., hydrogen-powered vehicles), and serving in various industrial processes such as ammonia production and metal refining. This flexibility makes it a valuable component in multiple sectors of the economy.

*Energy Storage:* Hydrogen can store energy for long periods, balancing supply and demand in renewable energy systems. It can be produced when renewable energy is abundant (e.g., solar or wind power) and stored for use when energy demand is high, making it an effective solution for stabilizing energy grids and providing backup power.

### Disadvantages of Hydrogen Technologies:

*Production Challenges:* Producing hydrogen, especially green hydrogen (which is made using renewable energy), is currently energy-intensive and expensive. The process often requires significant amounts of electricity, and the high costs of production limit its widespread adoption in the short term.

*Storage and Transport:* Hydrogen is difficult to store and transport due to its low density and high flammability. It requires high-pressure tanks or extremely low temperatures to be stored as a liquid, and its small molecular size makes it prone to leakage, complicating safe handling and distribution.

**Infrastructure Gaps:** The infrastructure needed for hydrogen production, distribution, and use is underdeveloped. This includes a lack of widespread hydrogen refuelling stations, pipelines, and storage facilities, which poses a significant barrier to the growth of hydrogen technologies.

**Safety Concerns:** Hydrogen is highly flammable and more explosive than natural gas or propane, posing potential safety risks if not handled properly. Due to its small molecular size, hydrogen can leak easily and is difficult to detect as it is colourless and odourless. These factors increase the need for stringent safety measures and monitoring systems.

## Conclusion

Hydrogen offers a promising route to a cleaner and more sustainable energy future, with the potential to significantly cut carbon emissions and help meet global climate targets. Its flexibility as an energy carrier, combined with its zero-emissions production and energy storage capabilities, makes it a compelling alternative to fossil fuels across various sectors such as transportation, industry, and power generation.

Nevertheless, the widespread adoption of hydrogen faces several challenges, including high production costs, storage issues, transportation hurdles, and the need for new infrastructure. Addressing these obstacles requires ongoing research, investment, and innovation. As countries around the world increasingly focus on sustainability, hydrogen stands out as a key player in moving toward a low-carbon economy and building a more resilient and environmentally friendly energy system.

## Glossary of Terms

Term	Definition
<b>Acid Rain</b>	A harmful rain that is significantly more acidic than normal due to the presence of pollutants such as sulfur and nitrogen oxides (NO <sub>x</sub> )
<b>Alkaline</b>	A chemical solution with a pH greater than 7, indicating that it is basic rather than acidic.
<b>Ammonia</b>	A compound of nitrogen and hydrogen (NH <sub>3</sub> ), used in fertilisers, various industrial processes, and as a potential hydrogen carrier.
<b>Biofuels</b>	Fuels derived from biological materials (such as plants or animal waste) which can be used to produce hydrogen.
<b>Carbon Emissions</b>	Release of carbon (mainly in the form of CO <sub>2</sub> ) into the atmosphere from burning fossil fuels or other processes, contributing to climate change.
<b>Catalyst</b>	A substance that speeds up a chemical reaction without being consumed in the process.
<b>Carbon-Neutral</b>	Processes or technologies that do not increase the amount of carbon dioxide in the atmosphere.
<b>Carrier</b>	A medium or substance used to transport or store another substance, such as hydrogen carried via ammonia.
<b>Coal Gasification</b>	A process that converts coal into a gas mixture of hydrogen, carbon monoxide, and methane by heating it in a low-oxygen environment.

<b>Combustion</b>	A chemical reaction where a substance reacts with oxygen to produce heat and release energy, typically associated with burning fuels.
<b>Ion</b>	An atom or molecule with a net electrical charge due to the loss or gain of electrons.
<b>Element</b>	A fundamental substance that cannot be broken down into simpler substances.
<b>Electrolysis</b>	A process using electricity to split water (H <sub>2</sub> O) into hydrogen (H <sub>2</sub> ) and oxygen (O <sub>2</sub> ), essential for producing green hydrogen.
<b>Feedstock</b>	Raw material used to supply a manufacturing process, such as water or natural gas in hydrogen production.
<b>Fuel Cell</b>	A device converting chemical energy directly into electrical energy through a reaction between hydrogen and oxygen.
<b>Hydrogen Economy</b>	The concept of using hydrogen as an energy carrier and fuel source to replace fossil fuels and reduce greenhouse gas emissions.
<b>Green Hydrogen</b>	Hydrogen produced via electrolysis using electricity from renewable sources, considered environmentally friendly.
<b>Hydrocarbon</b>	Organic compounds consisting of hydrogen and carbon, like methane and propane, used in fossil fuels.
<b>Research and Development (R&amp;D)</b>	Activities that innovate, improve, and develop new products or technologies, essential in advancing energy technologies.
<b>UN SDGs</b>	United Nations Sustainable Development Goals, a set of goals to address issues including poverty, inequality, and climate change
<b>Zero-Emission</b>	Technologies or processes that emit no pollutants or greenhouse gases during operation.

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<b>Figure 3</b>	<a href="https://www.cso.ie/en/unsdgs/">https://www.cso.ie/en/unsdgs/</a>
<b>Figure 4</b>	Authors
<b>Figure 5</b>	<a href="https://epcmholdings.com/green-hydrogen-technology-evaluation-criteria-for-electrolyser-selection/">https://epcmholdings.com/green-hydrogen-technology-evaluation-criteria-for-electrolyser-selection/</a>
<b>Figure 6</b>	<a href="https://senzahydrogen.com/hydrogen-production-from-electrolysis/">https://senzahydrogen.com/hydrogen-production-from-electrolysis/</a>
<b>Figure 7</b>	<a href="https://stargatehydrogen.com/blog/basics-of-hydrogen-electrolysis/">https://stargatehydrogen.com/blog/basics-of-hydrogen-electrolysis/</a>
<b>Figure 8</b>	<a href="https://www.airbus.com/en/newsroom/stories/2023-06-at-airbus-hydrogen-power-gathers-pace">https://www.airbus.com/en/newsroom/stories/2023-06-at-airbus-hydrogen-power-gathers-pace</a>
<b>Figure 9</b>	Schematic of fuel cell: <a href="https://en.wikipedia.org/wiki/File:Fuel_Cell_Block_Diagram.svg">https://en.wikipedia.org/wiki/File:Fuel_Cell_Block_Diagram.svg</a>

	Actual fuel cell: <a href="https://genh2hydrogen.com/blog/advantages-of-hydrogen-fuel-cells/">https://genh2hydrogen.com/blog/advantages-of-hydrogen-fuel-cells/</a>
<b>Figure 10</b>	<a href="https://www.bmw.com/en/innovation/how-hydrogen-fuel-cell-cars-work.html">https://www.bmw.com/en/innovation/how-hydrogen-fuel-cell-cars-work.html</a>
<b>Figure 12</b>	image from freepik at <a href="https://www.Freepik.com">https://www.Freepik.com</a>
<b>Figure 13</b>	Authors
<b>Figure 14</b>	<a href="https://www.energyireland.ie/green-hydrogen-will-play-a-key-role-in-irelands-energy-transition/">https://www.energyireland.ie/green-hydrogen-will-play-a-key-role-in-irelands-energy-transition/</a>