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Prize Winner

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Year 5-6

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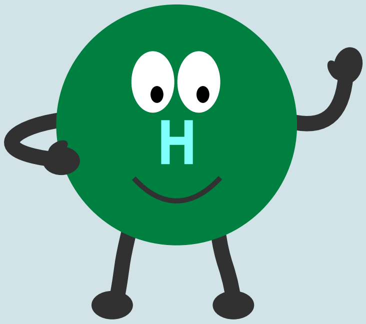
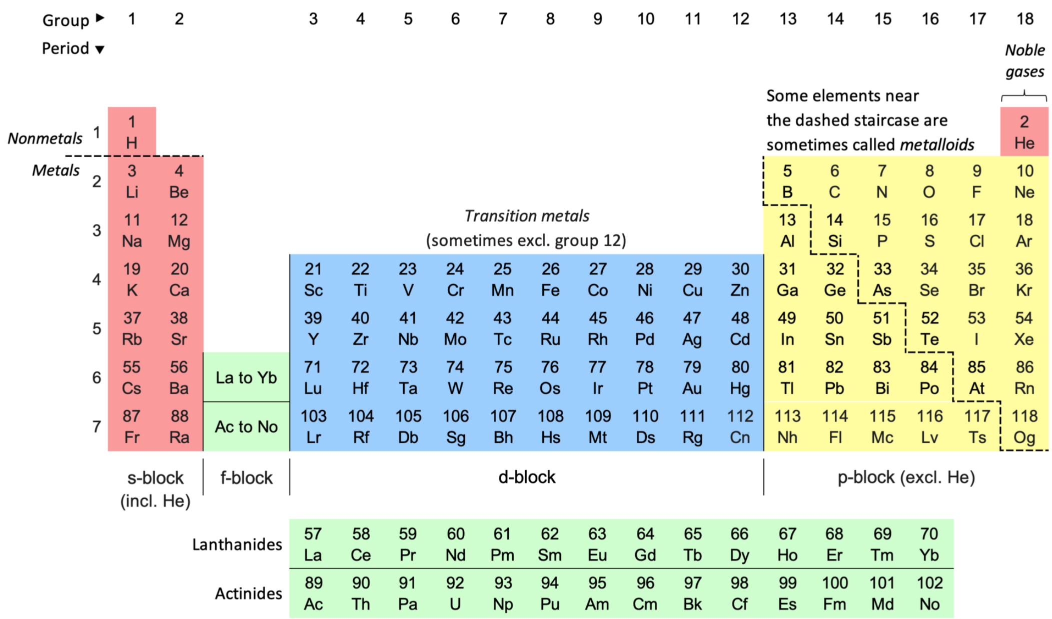
Green Hydrogen



I am Hydrogen! My symbol is H, and I am number 1 in the periodic table. I am most abundant in the universe, with ~75% of matter in the universe being hydrogen and ~73% of sun's mass consists of hydrogen! Why am I called a green hydrogen sometimes? Let's read on and I'll tell you more!

Figure 1: Periodic Table - Hydrogen is the first element



Note: From *Periodic table* (https://en.wikipedia.org/wiki/Periodic_table © Sandbh)

Earth is Getting Warmer!

Earth is in trouble! In 2023, Earth's average surface temperature was the warmest on record. According to scientists, carbon dioxide (CO_2) is the main contributor to climate change because it makes up the vast majority of greenhouse gases (~80%), which traps heat within the Earth's atmosphere.

CO_2 emissions are mainly a result from burning of fossil fuels, coal, oil and gas (~90%). Fossil fuels are burned to produce heat and generate electricity. They are also burned by vehicles with combustion engines. Fossil fuels consist mainly of carbon and hydrogen. When burned, oxygen combines with carbon to form CO_2, and oxygen combines with hydrogen to form water (H_2O):

$$\text{Burning fossil fuels} \rightarrow CO_2 + H_2O + \text{energy}$$

In contrast, burning hydrogen only creates water as by-product:

$$2H_2 \text{ (gas)} + O_2 \text{ (gas)} \rightarrow 2H_2O \text{ (liquid)} + \text{energy}$$

There is no CO_2 in the equation!

However, it is not easy to replace fossil fuels with hydrogen. There is very little pure hydrogen in our atmosphere (~0.00005%) because hydrogen is very reactive and combines with oxygen to form water.

What is Green Hydrogen?

Green hydrogen does not mean that the hydrogen is green. In fact, hydrogen gas is always colourless.

There is a colour-coding system to describe how hydrogen is obtained.

For example, a common way to obtain hydrogen is to extract hydrogen from natural gas or coal via steam reforming. CO_2 is released to the atmospheres in the process. We call the hydrogen obtained from this process a grey hydrogen. Burning of grey hydrogen does not release CO_2 but the production of grey hydrogen does.

If the CO_2 is instead captured and stored, then the carbon footprint is improved, and we have what is called a blue hydrogen.

To benefit Earth, we need green hydrogen which has much lower carbon footprint than the grey hydrogen or the blue hydrogen.

The general concept to obtain green hydrogen includes:

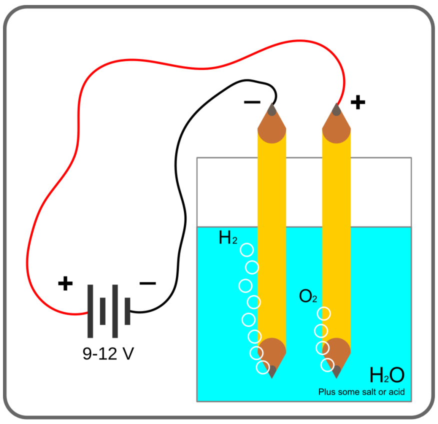
(A) Producing hydrogen using water electrolysis.

In electrolysis, water molecules are split into hydrogen and oxygen using electricity:

$$2\ H_2O\text{(liquid)} \rightarrow 2\ H_2\text{(gas)} + O_2\text{(gas)}$$

A simple electrolysis is shown in Figure 2.

Figure 2: A Simple Electrolysis



Note: From *Electrolysis of water* (https://en.wikipedia.org/wiki/Electrolysis_of_water © Nevit Dilmen)

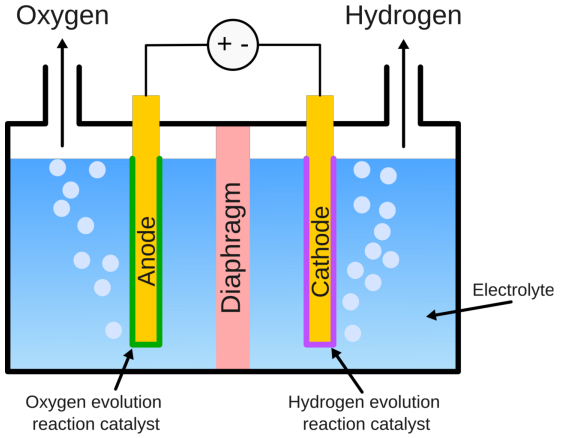
In this example, two electrodes - an anode and a cathode, are connected to a direct current (DC) battery. Hydrogen is produced from the cathode and oxygen from the anode. The proportion of hydrogen to oxygen is two parts to one.

Two main types of electrolysis used for green hydrogen production are:

(i) Alkaline electrolysis having two electrodes operating in a liquid alkaline electrolyte such as potassium hydroxide (KOH);

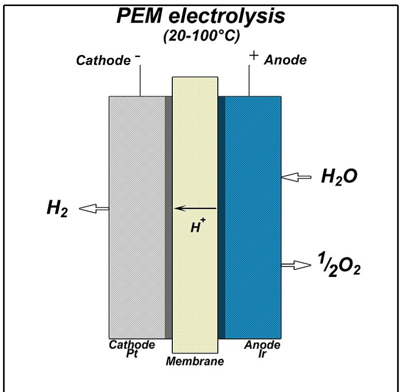
(ii) Proton Exchange Membrane (PEM) electrolysis having proton-exchange membrane located between the anode and cathode.

Figure 3: Alkaline Electrolysis



Note: From *Alkaline water electrolysis* (https://en.wikipedia.org/wiki/Alkaline_water_electrolysis © Kavin Teenakul)

Figure 4: Proton Exchange Membrane (PEM) Electrolysis



$$H_2O \longrightarrow 2H^+ + \tfrac{1}{2}O_2 + 2e^- \quad \textit{Anode}$$
$$2H^+ + 2e^- \longrightarrow H_2 \quad \textit{Cathode}$$
$$H_2O \longrightarrow H_2 + \tfrac{1}{2}O_2 \quad \textit{Total Reaction}$$

Note: From *Proton exchange membrane electrolysis* (https://en.wikipedia.org/wiki/Proton_exchange_membrane_electrolysis © Davidlfritz)

Scientists continue to research to find the right balance between cost, performance and durability of electrolysers.

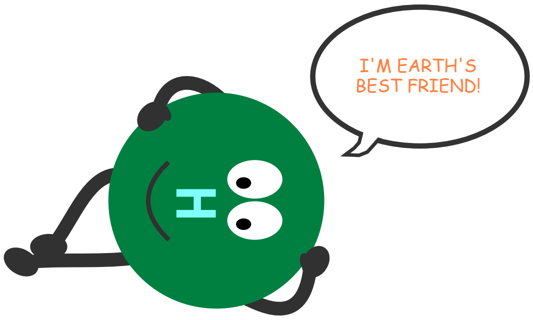
(B) The electricity for water electrolysis is produced through renewable energy sources such as solar, wind, or hydroelectric power

Solar system, wind turbines or hydroelectric dams are good renewable sources to provide green electricity for the electrolysis process to produce hydrogen. This will keep the CO_2 emission to a minimum.

Thus the full process to produce green hydrogen is:

Renewable energy sources → Production of hydrogen (via electrolysis)
→ Burn hydrogen (Without the release of CO_2) → Energy

The process above does not involve CO_2 emissions, hence the hydrogen produced is environmental friendly.



Advantages of Green Hydrogen

Hydrogen is beneficial in many ways. Being green makes it even more attractive!

Only water and no greenhouse gases are produced when hydrogen is burned as compared with using fossil fuels in conventional combustion engines.

It also allows faster refuel for hydrogen-powered vehicles (< 5 minutes to refuel for a light vehicle) as compared with charging electric vehicles (EV), which can take hours.

Hydrogen holds more energy per unit weight compared with common lithium-ion batteries used in EV. As a result, hydrogen vehicles are lighter and offer longer travel distance than EV.

Hydrogen is also a good energy storage for renewable energy. It can be stored for a longer period with minimal energy loss, whilst battery type storage experiences some level of self-discharge over time. Hydrogen can then be burned at any time to supplement renewable energy sources like solar and wind and improve the reliability of energy sources.

Not Cheap!

However, using green hydrogen is not without challenges.

The biggest challenge is currently cost. The electrolysers and the ongoing electricity used for the electrolysis process can contribute to the high cost. Hydrogen is also very combustible, thus extra safety measures are needed during storage and transportation of hydrogen.

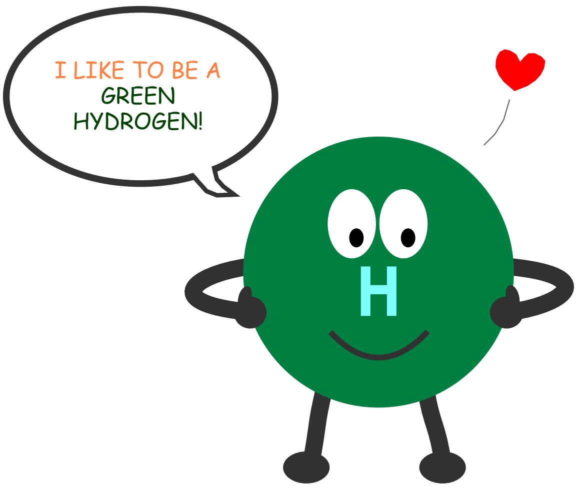
The cost of producing green hydrogen falls within a range of AU$4/kg to AU$6/kg of hydrogen. Australia aims to reduce the cost down to AU$2/kg in future to compete with fossil fuels, coal, oil and gas.

Figure 5: Projected Reduction of Cost of Green Hydrogen

Year	$/MWh renewable cost	Electrolyser capacity implied GW	Electrolyser Capital expenditure $/kW	Cost of hydrogen $/MWh	Cost of hydrogen $/kg
2010	360	n/a	1500	$600	24
+0 year [2021]	30-45	0.3	950	$100-140	4-5.5
+ 5 years	20-35	25	330	$45-70	2-3
+ 10 years	15-27	50	270	$35-55	1.5-2
Large-scale adoption	10-13	>50	170	$22-28	<1

Note: From *The Hydrogen Revolution* – A Blueprint for the Future of Clean Energy, page 229

With technology advancement (such as more efficient electrolysers, cheaper electricity from renewable sources) and large-scale adoption of green hydrogen, the cost of green hydrogen is expected to decrease. When green hydrogen becomes more affordable, more people will start using it. This will in turn help with the reduction of greenhouse gas emissions.



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