# Green hydrogen as an environmentally-friendly power source

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***Abstract:*** *Hydrogen is the most plentiful chemical element in the visible universe. The mass composition of the visible universe is approximately 74% hydrogen, 24% helium, 1% oxygen, and the rest of all other chemical elements is about 1%. Hydrogen has the symbol H and the atomic number 1. It is placed in the first position in Mendeleev's periodic table of elements, in the upper left corner. It is an easily flammable, colorless, tasteless, odorless gas, and in nature, it is found mainly in the form of the diatomic molecule,* $H_2$*. With an atomic mass unit of 1.00794, hydrogen is the lightest chemical element. Etymologically, the word hydrogen is a combination of two Greek words* ***hydor*** *and* ***gennan*** *meaning: water producer. Hydrogen (*$H_2$*) has a very good calorific value per mass unit 143 MJ/kg which is 3.33 times more than the calorific value of kerosene or diesel fuel. Green hydrogen (clean hydrogen or renewable hydrogen) is produced by electrolysis of water (splitting of water into hydrogen and oxygen) using electricity from renewable sources such as solar energy, wind energy, seawater waves energy, or tidal power. Green hydrogen is an environmentally-friendly power source (no harmful gases). This paper presents recent documentary research by the authors on green hydrogen as an environmentally-friendly power source: for space rocket launches and for hydrogen fuel cells used in the space shuttle as electrical power generators and drinking water generators from launch to return from the space mission; as fuel for a modified turboprop engine (Rolls-Royce and easyJet); as fuel for the European Destinus aircraft using the Jungfrau technology system for a planned hypersonic aircraft using a modified commercial afterburning engine; as fuel for modified gas turbine engines and hydrogen fuel cells to supply electrical power to supplement the gas turbine for the Airbus ZEROe aircraft, etc.*

***Key Words:*** *hydrogen, green hydrogen, environmentally friendly, power source, calorific value, direct combustion, modified gas turbine engines, hydrogen fuel cells*

## 1. INTRODUCTION

Hydrogen is the most plentiful chemical element in the visible universe. The mass composition of the visible universe is approximately 74% hydrogen, 24% helium, 1% oxygen, and the rest of all other chemical elements is about 1% [1, 2, 3]. Hydrogen was produced immediately after the Big Bang event. Hydrogen has the symbol H and the atomic number 1. It is placed in the first position in Mendeleev's periodic table of elements, in the upper left corner. It is an easily flammable, colorless, tasteless, odorless gas, and in nature, it is found mainly in the form of the diatomic molecule, $H_2$. With an atomic mass unit of 1.00794, hydrogen is the lightest chemical element.

Etymologically, the word hydrogen is a combination of two Greek words **hydor** and **gennan** meaning: water producer.

Hydrogen ($H_2$) has a very good calorific value per mass unit 143 MJ/kg [4, 5, 6] that is, 3.33 times more than the calorific value of kerosene or diesel fuel e.g. [4, 5].

The hydrogen and oxygen combine violently, and an amount of energy is released (hydrogen is a highly reactive fuel), in an oxidation process, by the following relationship:

$$H_2 + \tfrac{1}{2}O_2 \rightarrow H_2O + 143\ \text{MJ/kg} \quad (1)$$

Green hydrogen (clean hydrogen or renewable hydrogen) is produced by electrolysis of water (splitting of water into hydrogen and oxygen) using electricity from renewable sources such as solar energy, wind energy, seawater (oceanwater) waves energy, or tidal power. Green hydrogen is an environmentally-friendly power source that reduces or eliminates the environmental footprint.

A hydrogen fuel cell produces cleanly and efficiently electricity, water, and heat according to relationship (1). It is very important to keep hydrogen away from sources of fire and to take measures against electrostatic charging.

Hydrogen is used as fuel for rocket engines to send crew and cargo in space. It is also used as fuel for modified gas-turbine engines with or without afterburning. Hydrogen is converted into electrical power and hot water by hydrogen fuel cells. The generated water is used as potable water in space missions and the electrical energy is used to operate the space vehicle or to actuate the electric engines of the aircraft propellers [7 -12].

Below are some examples of the use of hydrogen in recent aerospace projects. A European start-up is about to develop a hydrogen-powered hypersonic plane that will be able to cut travel time by 2/3 compared to normal flights and, for example, will be able to make a flight from Germany to the US in just two and a half hours, thanks to hydrogen-powered engines.

The Destinus aircraft is designed to fly at 5 Mach speed. Established in 2021, the start-up with a team of 120 specialists from Spain, France, and Germany has already successfully tested the first two prototypes and hopes to transport the first passengers after 2030 as shown in Figure 1 [12, 13].


Fig. 1 Destinus a hydrogen-powered hypersonic plane [13]

Airbus company is developing three types of hybrid-hydrogen aircraft under the concept named ZEROe or Zero emission.

The three types of hybrid-hydrogen aircraft are a turbofan, a turboprop, and a Blended-Wing Body (BWB) [12].

The turbofan has two hybrid-hydrogen turbofan engines to provide thrust, and the liquid hydrogen storage and distribution system is located behind the rear pressure bulkhead (Figure 2 (a)) [12].

The turboprop has six hybrid-hydrogen turboprop engines powered by hydrogen fuel cells, which drive eight-bladed propellers made of composite materials, to provide thrust, and the liquid hydrogen storage and distribution system is located behind the rear pressure bulkhead (Figure 2 (b)) [12].

The Blended-Wing Body (BWB) has two hybrid-hydrogen turbofan engines to provide thrust, and the liquid hydrogen storage tanks and distribution system are stored under the wings, thanks to the generous wide interior [12].


(a)

(b)

(c)

Fig. 2 AIRBUS ZEROe the three types of hybrid-hydrogen aircraft [12]

Rolls-Royce and easyJet have confirmed they have initiated another landmark in aviation with a modern hydrogen-powered aircraft engine using green hydrogen.

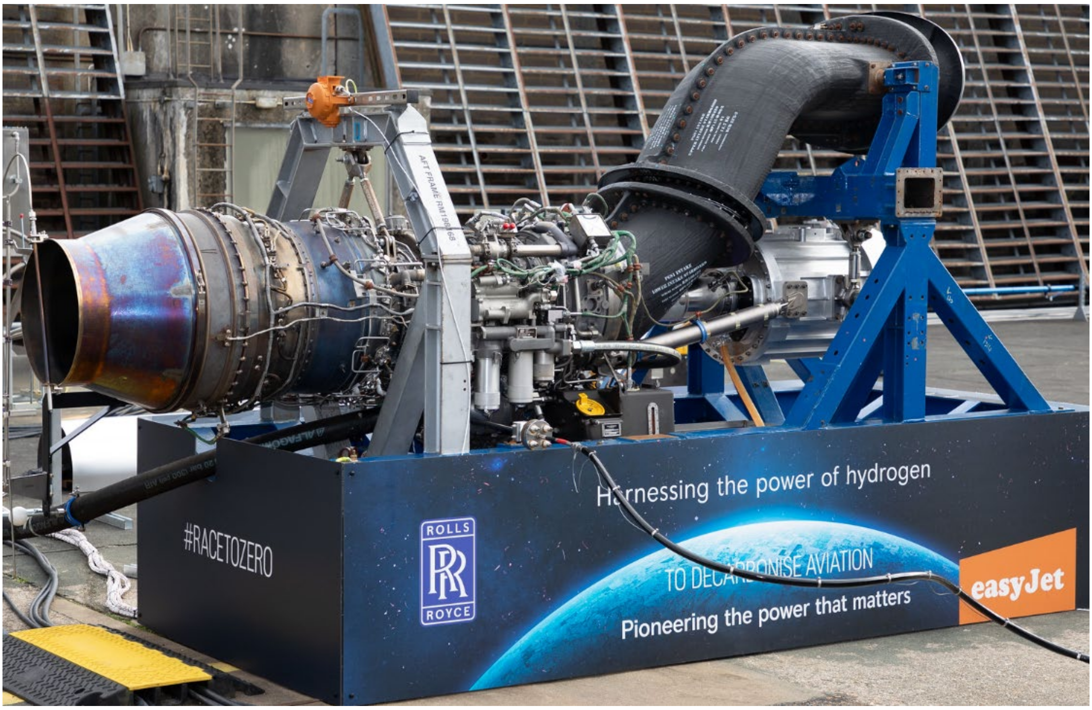


Fig. 3 Rolls-Royce AE 2100 - A Hydrogen test for race to net zero, EasyJet [10]

## 2. FUNCTION AND DESIGN OF HYDROGEN FUEL CELLS

The hydrogen fuel cell is a device that produces electricity based on an electrochemical process but without burning it. In each hydrogen fuel cell, oxygen ($O_2$) or air is used as an oxidant for green hydrogen ($H_2$) that is used as fuel, as presented above. The conversion process has zero pollutant emissions so it is an environmentally friendly power source because only electrical power, heat, and water are emitted following this conversion process.

The hydrogen fuel cell is far more productive compared to an internal combustion engine because the internal combustion engine uses fuel to create heat and consecutively transforms heat into mechanical energy used to actuate an electric generator. The fuel cell produces electricity, water, and heat directly from hydrogen and oxygen. Fuel cells are like batteries, but luckily, they do not need recharging and will continue to work as long as fuel ($H_2$) and oxygen ($O_2$) or air is delivered.

The hydrogen fuel cell contains some cells that are electrically interconnected but separated one from another in a stack with layers of cells. The middle of each hydrogen fuel cell is formed by an electrolyte in a solid or liquid state, which is enclosed, on both parallel edges, by electrode plates: anode (+) and cathode (-), such that electrolysis plays a crucial part in the operation of hydrogen fuel cells.

Each electrode plate has a permeable spreading coat or a gas spreading coat, which conduct the reaction gases above a catalyst, i.e., a stimulating surface made of a suitable metal, acting in low and medium temperature. In this way, the hydrogen is split at the anode (+), and the released electrons form the electric current. The hydrogen protons move through the electrolyte to the cathode (-), where they combine with the introduced oxygen or with air to form water ($H_2O$) as shown in Figure 4 [14, 15].

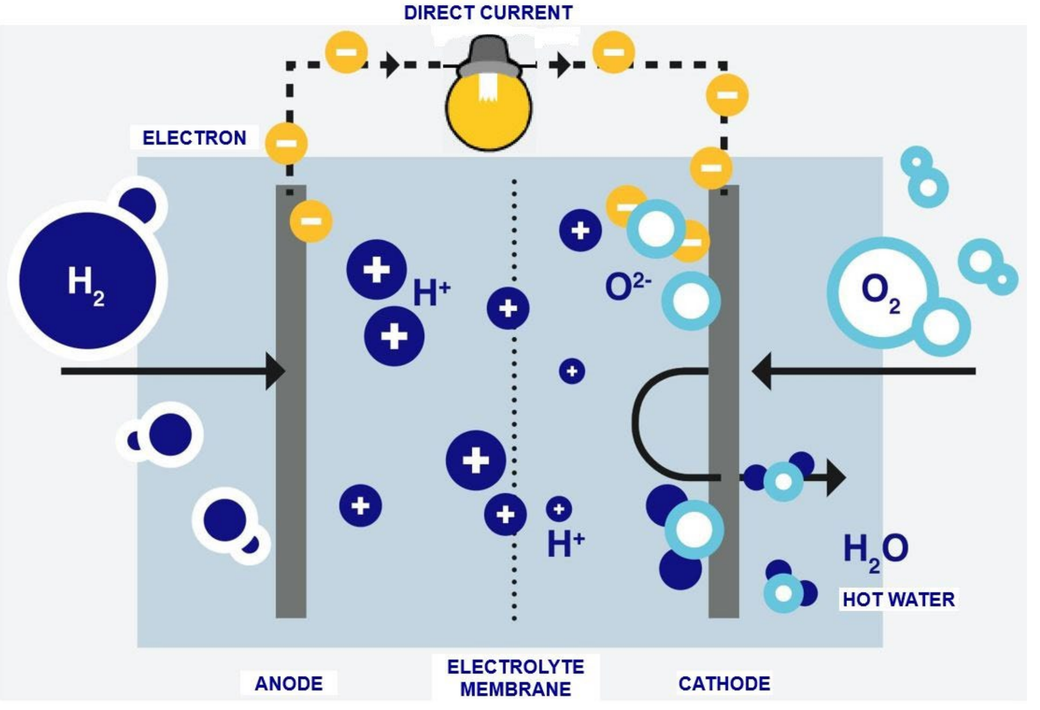


Fig. 4 Hydrogen fuel cell [15]

A hydrogen fuel cell power system is the total set of components that integrate with the hydrogen fuel cell stack so that electricity is produced. The fuel cell requires other systems to make it a complete power source, such as hydrogen ($H_2$), oxygen ($O_2$), or air and various control systems [14, 15].

## 3. CATEGORIES OF HYDROGEN CELLS

As presented above, hydrogen cells ensure the production of electricity and water by oxidizing hydrogen, a very efficient and non-polluting process.

The different categories of hydrogen fuel cells are presented in the following table [15].

Table 1 Types of hydrogen fuel cells [15]

| Type | Anode ⊕ | Cathode ⊖ | Electrolyte | Functional temperature | Performance | Cell productivity |
|---|---|---|---|---|---|---|
| Alkaline fuel cell (AFC) | Hydrogen | Oxygen | Potassium hydroxide solution | 20 °C - 90 °C | Up to 100 kW | 60 % - 70 % |
| Proton exchange membrane fuel cell (PEMFC) | Hydrogen | Air or oxygen | Polymer membrane | 20 °C - 80 °C | Up to 500 kW | 50 % - 70 % |
| Phosphoric acid fuel cell (PAFC) | Hydrogen | Air or oxygen | Phosphoric acid | 160 °C - 220 °C | Up to 10 MW | 55 % |

**AFC – Alkaline Fuel Cell**

This category of fuel cells is characterized as fuel cells that operate at low temperatures and is considered the basis of the development of fuel cell technology. The alkaline fuel cell (AFC) was principally used for space travel, to power submarines, and the passenger boat. The alkaline fuel cell (AFC) is a potent system, but it has a relatively short lifetime. The alkaline fuel cell (AFC) does not produce a high-power density in comparison with the next category of fuel cells [14, 15].

**PEMFC, PEM – Proton Exchange Membrane Fuel Cell**

Proton Exchange Membrane Fuel Cell (PEMFC or PEM) has a low-temperature working regime, and it is extensively used in various ways due to the very good dynamics of the power output, minimum size, and weight. This category of fuel cell is often used in aviation, space travel, and many other demands such as cars, vans, buses, or shipping. Another category of its applications includes the emergency power supply in rail transport, telecommunications, hospitals, data storage, and processing centers, and municipal or domestic emergency power supply. PEMFC or PEM fuel cell has an extraordinary potential for use and development in the nearest future [14, 15].

**PAFC – Phosphoric acid fuel cell**

Phosphoric acid fuel cell (AFC) has a medium temperature working regime, but also a definite forbearance to carbon monoxide (CO) and carbon dioxide ($CO_2$), so that it can run firstly with transformed natural gas. Because of its acidic and very aggressive electrolyte, the cell has a relatively short lifespan. Phosphoric acid fuel cell (AFC) is used for power production and combined heat in static power supply for commercial buildings, industrial buildings, health centers, or residential buildings, but not in space applications [14, 15].

## 4. PURPOSE OF THE RESEARCH

National Institute for Aerospace Research “Elie Carafoli” intends to build an experimental stand containing a hydrogen fuel cell used to power electric motors for the propellers of an aircraft with a maximum takeoff weight (MTOW) of about 1200 kg.

Figure 5 presents a hybrid simplified scheme of a hydrogen fuel cell used to power the propellers of an aircraft.

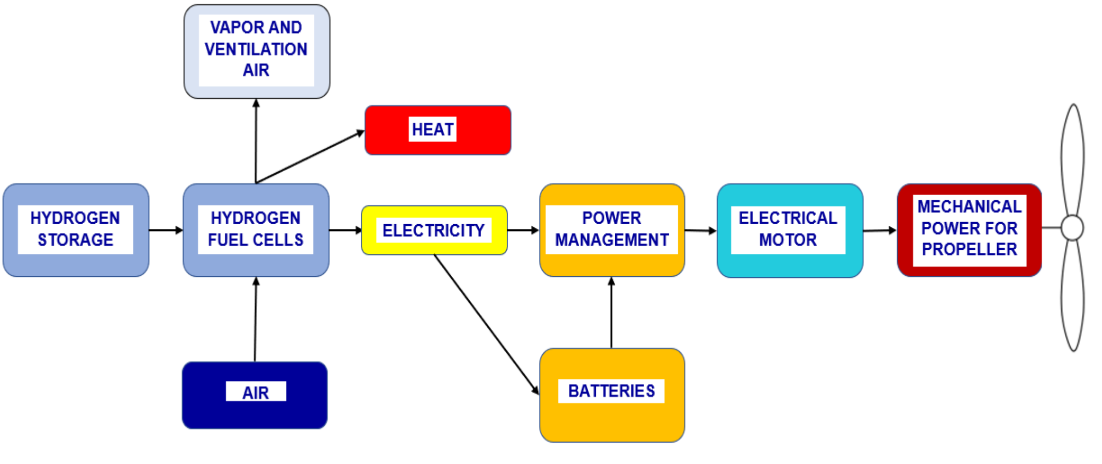


Fig. 5 Hybrid simplified scheme of a hydrogen fuel cell used to power the propellers of an aircraft

The hydrogen fuel cell selected is Proton Exchange Membrane Fuel Cell (PEMFC or PEM) due to the very good dynamics of the power output, minimum size, and weight.

## 5. CONCLUSIONS

The experimental stand containing a hydrogen fuel cell used to power electric motors for the propellers of an aircraft with a maximum takeoff weight (MTOW) of about 1200 kg is designed and built by the Technology transfer department - technological and conceptual development. The team is currently selecting the components of the experimental stand and will soon start purchasing and then building the stand so that the work can be completed within the next 18 months.

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