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Green Hydrogen

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الحمد لله رب العالمين

قال تعالى: {وَأَنْ لَّيْسَ لِلْإِنْسَانِ إِلَّا مَا سَعَىٰ وَأَنَّ سَعْيَهُ سَوْفَ يُرَىٰ} [النجم: ٣٩-٢٥]

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Dedication

I dedicate this work

**To the souls of my dear mother Saliha Aliouane
and my uncle DJamal, may God have mercy on them.**

To my father Nasser, who guided me to this level of success, and his wife

**To my beloved sister Ahlam, who has always been and continues to be my
strong support. To her children: Sirine, Maya, Meryouma, and Mero.**

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daughter.**

To my brother Ramzi, his wife Khadija, and their daughter Ghofran.

**To my brother Walid, his wife Hanine, and their children Bashir, Lujain,
and Aseel.**

And to all those I know.

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**And finally, I dedicate this work to myself, who worked tirelessly to achieve
this success.**

Abstract

In this study, green hydrogen was produced through simple electrolysis using solar energy, “a clean and sustainable form of hydrogen that represents an innovative solution to current environmental challenges”. Initially, we employed traditional methods to produce hydrogen using distilled water and adding electrolyte such as sodium hydroxide or potassium hydroxide" at different concentrations to discover the best production conditions from each electrolyte", while harnessing solar energy to activate the process. Although this method showed promising results, it consumed significant amounts of materials used. We improved the electrolysis process by designing and testing handmade cells, starting with a plastic model and incorporating steel electrodes. Despite our efforts, rusting posed a major challenge to the performance of the initial model. Therefore, the design was revised to a glass cell with graphite electrodes, leading to remarkable results that significantly outperformed the traditional method. As an alternative natural resource, we explored the use of dromedary camel urine, rich in nitrogen, urea, and ions, making it an exciting and effective option for electrolysis without the need for traditional additives. While productivity was modest initially compared to traditional methods of using electrolytes, enhancing technology performance and increasing dromedary camel urine availability will greatly enhance productivity soon. Through this approach, we aim to enhance innovations in sustainable energy and achieve a significant breakthrough towards a cleaner and more environmentally sustainable future, where green hydrogen plays a crucial role in achieving this goal.

Keywords: green hydrogen, electrolysis, solar energy, clean, sustainable, distilled water, dromedary camel urine, urea...

Résumé

Dans cette étude, nous avons produit de l'hydrogène vert par électrolyse utilisant l'énergie solaire, représentant ainsi une forme propre et durable d'hydrogène qui constitue une solution innovante aux défis environnementaux actuels. Nous avons initialement appliqué des méthodes conventionnelles pour produire de l'hydrogène en utilisant de l'eau distillée et en ajoutant des électrolytes tels que l'hydroxyde de sodium ou l'hydroxyde de potassium à différentes concentrations, afin de déterminer les conditions optimales de production pour chaque électrolyte, tout en exploitant l'énergie solaire pour activer le processus. Bien que cette méthode ait montré des résultats prometteurs, elle consommait des quantités significatives de matières premières. Nous avons amélioré le processus d'électrolyse en concevant et en testant des cellules fabriquées à la main, en commençant par un modèle en plastique avec des électrodes en acier. Cependant, la corrosion a constitué un obstacle majeur aux performances de ce premier modèle. Par conséquent, nous avons modifié le design pour utiliser une cellule en verre avec des électrodes en graphite, ce qui a conduit à des résultats remarquables surpassant considérablement la méthode traditionnelle. En tant que ressource naturelle alternative, nous avons exploré l'utilisation de l'urine de chameau dromadaire., riche en azote, en urée et en ions, la rendant ainsi une option prometteuse et efficace pour l'électrolyse sans nécessiter d'additifs traditionnels. Bien que la productivité initiale ait été modeste par rapport aux méthodes traditionnelles utilisant des électrolytes, l'amélioration des performances technologiques et l'augmentation de la disponibilité de l'urine de chameau devraient contribuer à accroître significativement la productivité à l'avenir. Grâce à cette approche, nous visons à promouvoir l'innovation dans le domaine de l'énergie durable et à réaliser une avancée significative vers un avenir plus propre et durable sur le plan environnemental, où l'hydrogène vert joue un rôle crucial dans l'atteinte de cet objectif.

Mots clés : Hydrogène vert, Électrolyse, Énergie solaire, Propre, Durable, Eau distillée, Urine de chameau dromadaire., Urée...

ملخص

تم في هذه الدراسة إنتاج الهيدروجين الأخضر بواسطة التحليل الكهربائي البسيط باستخدام الطاقة الشمسية، "وهو النوع النظيف والمستدام من الهيدروجين الذي يعد حلاً مبتكراً للتحديات البيئية الحالية". بدأت الرحلة باستخدام الطرق التقليدية لإنتاج الهيدروجين، حيث استخدمنا الماء المقطر وأضافنا مواد مثل هيدروكسيد الصوديوم أو هيدروكسيد البوتاسيوم (بتراكيز مختلفة لاكتشاف أفضل الشروط للإنتاج من كل مادة)، واعتمدنا على الطاقة الشمسية لتفعيل العملية. رغم أن هذه الطريقة أظهرت نتائج جيدة، إلا أنها كانت تستهلك كميات كبيرة من المواد المستعملة. تم تحسين عملية التحليل الكهربائي بتصميم واختبار خلايا مصنوعة يدوياً، حيث بدأنا باستخدام نموذج من البلاستيك وإضافة أقطاب من الفولاذ. ورغم محاولاتنا، فإن التصديق كان عائقاً رئيسياً لأداء النموذج الأول. لذا، تم تعديل التصميم إلى خلية زجاجية واستبدال الأقطاب بمواد من الغرافيت، مما أدى إلى تحقيق نتائج مبهرة تفوقت على الطريقة التقليدية بشكل كبير. وكمورد طبيعي بديل اتجهنا إلى استخدام بول الجمل احادي السنام، حيث يتميز بغناؤه بالنيتروجين واليوربا والشوارد، مما يجعله خياراً مبتكراً وفعالاً في عملية التحليل الكهربائي دون الحاجة إلى الشوارد التقليدية. ورغم أن الإنتاجية كانت متواضعة في البداية مقارنة بالطريقة استعمال كل من هيدروكسيد البوتاسيوم والصوديوم، إلا أن تحسين أداء التقنية وزيادة توفر بول الجمل سيساهمان بشكل كبير في تعزيز الإنتاجية في المستقبل القريب. بهذه الطريقة، نسعى إلى تعزيز الابتكارات في مجال الطاقة المستدامة وتحقيق نقلة نوعية نحو مستقبل أكثر نظافة واستدامة بيئياً، حيث يلعب الهيدروجين الأخضر دوراً حاسماً في تحقيق هذا التطلع.

الكلمات المفتاحية: الهيدروجين الأخضر، التحليل الكهربائي، الطاقة الشمسية، نظيف، مستدام، ماء مقطر، بول الجمل احادي السنام، يوربا....

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List of abbreviations

u	Atomic Mass Unit
DF	Dark Fermentation
PF	Photo Fermentation
PV	Photovoltaic
HER	Hydrogen Evolution Reaction
OER	Oxygen Evolution Reaction
AEM	Anion Exchange Membrane
MEA	Membrane Electrode Assembly
PEM	(Proton Exchange Membrane)
SOEC	The Solid Oxide Water Electrolysis Cell
TWSC	Thermochemical Water Splitting Cycle
GHG	Greenhouse Gas
K	Kelvin
°C	Degree Celsius
MT	Transition Metals
MOF	Metal Organic Framework
wt	Weight
P _{max}	Maximum Power
I _{mp}	Current at Maximum Power
V _{max}	Voltage at Maximum Power
I _{sc}	Short-Circuit Current
V _{oc}	Open-Circuit Voltage
T _{noct}	Nominal Operating Cell Temperature
RT	Room Temperature
E°	Standard Potential of The Ox/Red Couple
PR	Production Rate
Crea	Creatinine
Alb	Albumin
Au	Polina
Pi	Inorganic Phosphate

LIST OF ABBREVIATIONS

Gly Glucose
An, G Another Gas



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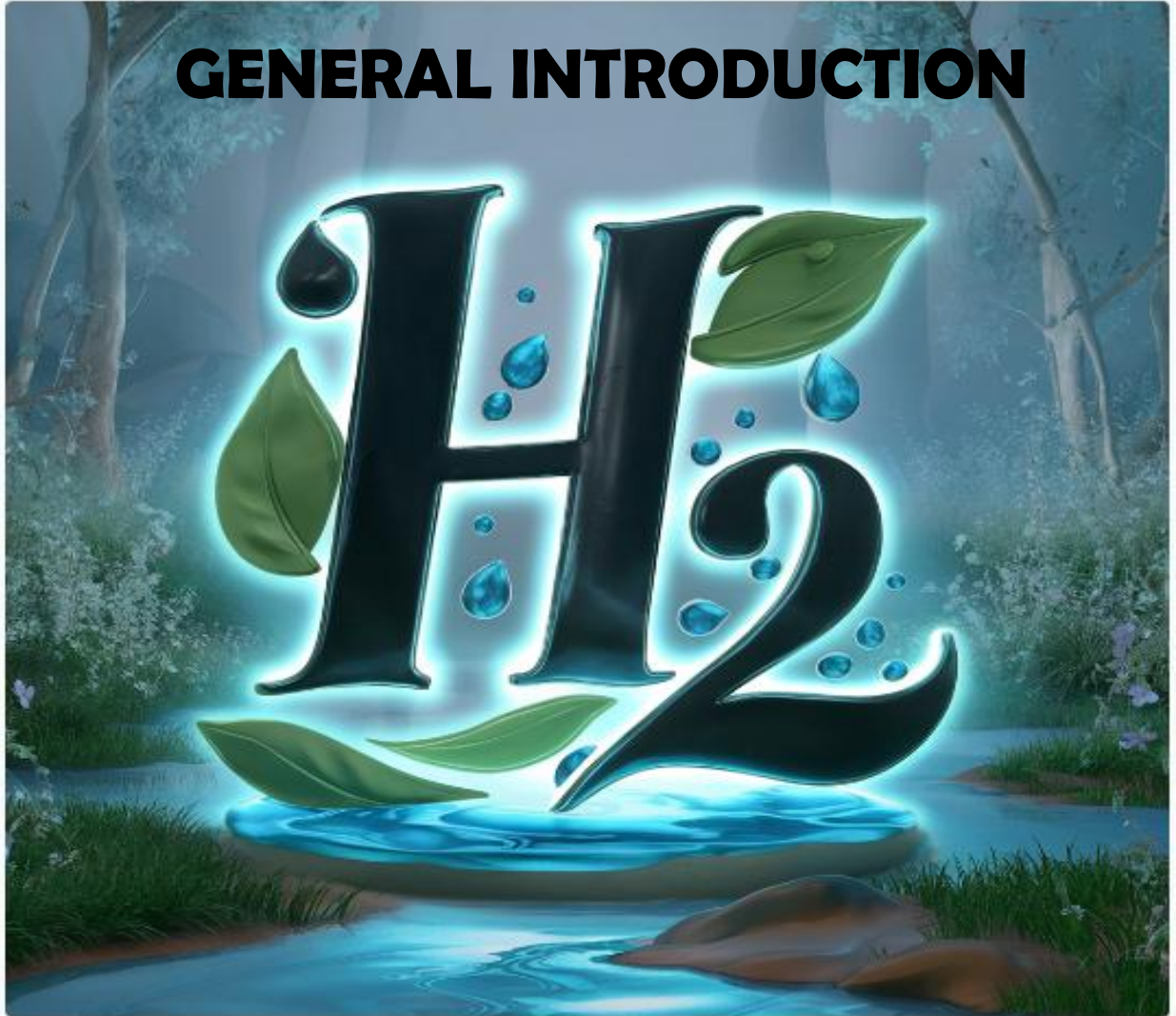
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GENERAL INTRODUCTION



General introduction

Currently, a significant proportion of global energy production is based on fossil fuels, resulting in greenhouse gas emissions and increased pollution. [1] Furthermore, the depletion of the world's oil and natural gas reserves, rising prices, and long-term supply insecurity, which makes the global energy situation incompatible with sustainable development goals, is leading to an increasing demand for new non-polluting renewable energy sources [2].

Climate change and the gradual erosion of natural resources are forcing a change in mindsets. The issue of renewable energy has become more pressing and preoccupying, and new patterns of production and consumption have emerged [3]. Currently, there are numerous renewable energy sources, including hydropower, geothermal energy, biomass energy, wind energy, and photovoltaic energy. The primary advantage of these renewable energies is that their use does not pollute the atmosphere and produces low levels of gases such as carbon dioxide and nitrogen oxides, which are responsible for global warming. One method of harnessing solar energy is through the conversion of solar radiation into electricity via solar cells. A system that combines a photovoltaic field with an electrolyzer allows for the storage of electricity in the form of hydrogen gas, making it an optimal choice for clean and efficient energy storage. [1]

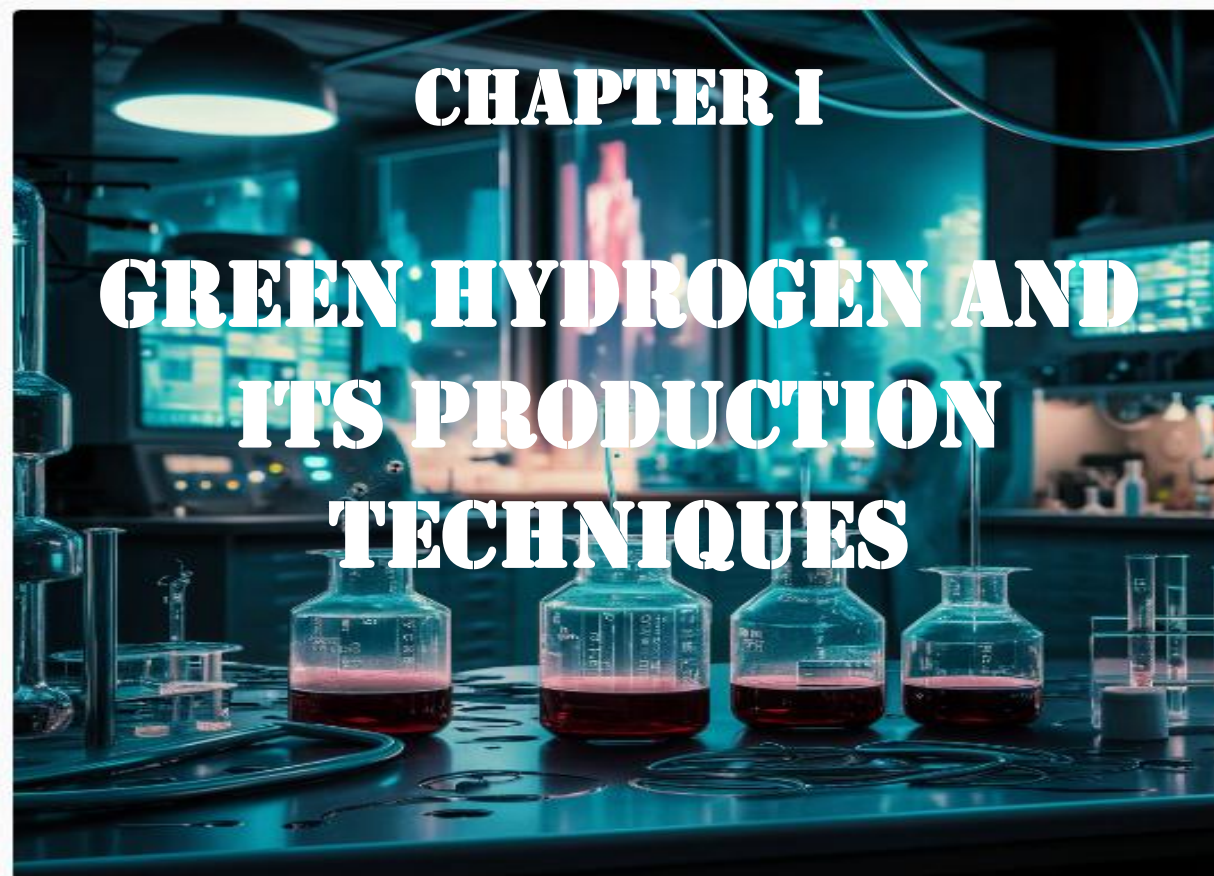
Green hydrogen, a pure and flexible gas, is considered a symbol of the promising future of energy. Thanks to its excellent environmental properties, it is one of the least harmful energy sources to the environment. Its benefits extend beyond providing electricity and heating homes, as it also offers a practical and sustainable solution to the problem of carbon emissions. Green hydrogen is not just an option but the future itself. With a closed energy cycle and high efficiency, green hydrogen opens doors to a new era of sustainability and innovation. As research and development continue, we will see more remarkable applications of this noble gas, making the future brighter and cleaner. [4]

The objective of the study presented in this thesis is to produce green hydrogen from natural resources, with a focus on the adopted technology. We used simple electrolysis for the production process, utilizing solar-generated energy. we produced hydrogen efficiently and effectively, enhancing efficiency and reducing environmental impact. This method not only provides a practical and clean energy solution but also guides future research towards further innovation in sustainable energy.

This study includes three main chapters: the first chapter discusses the properties of green hydrogen and extraction methods, the second chapter covers green hydrogen storage methods, and the third chapter, which is the core of the thesis, details the method we adopted for producing green hydrogen and highlights the key results obtained, along with their discussion and interpretation. Through this study, we aim to highlight the significant potential of green hydrogen as a sustainable solution to global energy problems. With advanced technologies and in-depth analysis, we hope to contribute to driving innovation and achieving a cleaner and more sustainable future.

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CHAPTER I

GREEN HYDROGEN AND ITS PRODUCTION TECHNIQUES

I.1 Introduction

Against a backdrop of growing concerns about greenhouse gas emissions and climate change, and the need to transition to cleaner, more sustainable energy sources, green hydrogen is emerging as a promising solution. Green hydrogen, also known as renewable hydrogen, is produced from renewable energy sources such as solar and hydroelectric power and is a key energy carrier for decarbonizing several industrial and transport sectors.

In this chapter, we'll find out more about green hydrogen and its production techniques. What is green hydrogen? What are the most production techniques and the challenges to be overcome for widespread adoption of this clean, renewable energy source?

I.2 Green hydrogen

I.2.1 Definition

The name hydrogen comes from two words: hydro = water and gen = generator, so hydrogen means "generator of water", which is the most abundant element in the universe (it makes up 75% of the mass of all matter in stars and galaxies).

Fuel for the sun (every second 620 million tons of hydrogen are converted into 615.7 million tons of helium). Jupiter is made up of 99.8% hydrogen and helium.

Hydrogen is a diatomic gas and holds first place in Mendeleev's classification, and has the simplest atomic structure (one proton in its nucleus and one electron in its atom). [1]

However, Hydrogen H_2 is very abundant on the earth's surface, but does not exist in a pure state. It is always linked to other chemical elements, in molecules such as water, hydrocarbons, etc.[2]

Dihydrogen is not a source of energy, but an energy carrier [3] as it must be extracted, like electricity, from main sources like hydrocarbons, biomass, or water [2]. It must be manufactured before it can be stored and used [3].

The element hydrogen is also found in living things, such as plants and animals. Thus, another possible source of hydrogen is biomass[2].

Hydrogen has the potential to be an almost limitless source of energy, as long as it can be produced in large quantities and at a competitive cost, ideally using nuclear or renewable energy sources [2].

It has the following characteristics [1, 4]:

- Colorless, odorless and non-toxic.
- Highly flammable in air: 4% to 74.5% (20°C and 1atm).
- Burns with an inconspicuous flame and detonates easily.

- Lighter than air.
- Very powerful reduction.

I.2.2 Hydrogen (H₂) properties

Table I.1: Physic-chemical properties of hydrogen. [5].

Designations	Characteristics
Chemical series	Non-metals
Group; period; block	1 ; 1 ; s
Volumic mass	0,084 Kg / m ³
Molar mass	2,016(H ₂)
Atomic mass	1,008 u
Atomic radius	0,59 Å
Electronic configuration	1s ¹
Crystal structure	Hexagonal
Melting point	-259,14°C (H ₂)
Boiling point	-252,8 °C (H ₂)
Energy of evaporation	445 KJ/ Kg
Theoretical energy of liquefaction	14112 KJ / Kg
Specific heat	14,3 KJ / Kg. K
Electronegativity	2,1
Diffusion coefficient in air	0,61cm /s

I.2.3 History of green hydrogen definitions

The term 'green' or 'renewable' hydrogen was first mentioned by NREL (1995) [6], who used 'renewable hydrogen' (hydrogen produced from renewable sources) as a synonym for 'green'. The State of California (2006) [7] defined 'green hydrogen' as hydrogen produced cleanly and sustainably using a renewable source such as solar or wind power.

The first mention of green hydrogen in EU political documents is the declaration to establish a green hydrogen economy in Europe [8].

Green hydrogen is hydrogen produced from renewable energies such as solar, wind or hydroelectric power. Green hydrogen is often presented as an alternative to fossil fuels, and as a way of reducing greenhouse gas emissions in certain sectors (industry, transport, etc.). [2]

I.3 Production techniques of green hydrogen

I.3.1A BRIEF HISTORY: [9, 10]

- 1671: Robert Boyle dissolves iron turnings in dilute hydrochloric acid and reports that the 'vapors' released are highly flammable.
- 1766: The British chemist Henry Cavendish succeeds in isolating a strange gaseous substance which, when burnt in air, produces water: "Hydrogen".
- 1781: Previously known as "flammable gas", this gas was named "Hydrogen" in 1783 by the great French chemist Antoine Lavoisier, who synthesized water.
- 1782: The Montgolfier brothers inflated small balloons with hydrogen to see them take off.
- On 1 December 1783, Jacques Charles continued this work and took off with a balloon inflated with hydrogen and travelled 35 km.
- 1804: The Frenchman Louis Joseph Gay-Lussac and the German Alexander Von Humboldt jointly demonstrate that water is composed of one part oxygen to two parts of hydrogen.
- 1839: The Englishman William R. Grove discovers the principle of the fuel cell: it is a chemical reaction between oxygen and hydrogen. With the simultaneous production of electricity, heat and water, using porous platinum electrodes and sulfuric acid as the electrolyte.
- 1898: James Dewar produces liquid hydrogen for the first time.
- 1900: The first "Zeppelin" makes its maiden flight, filled with hydrogen.
- 1931: Harold Urey discovers deuterium.
- 1939 - 1953: The Englishman Francis T. Bacon makes progress with chemical electricity which enabled the first industrial power prototype to be built.
- In the early 1950s, the idea of using hydrogen in a reactor for aircraft propulsion.
- 1960: From this date onwards, NASA used the fuel cell to power its space vehicles (Apollo and Gemini capsules).

I.3.2 Techniques

Hydrogen can be sourced from a variety of materials, ranging from renewable to non-renewable origins. In 2020, the predominant method (95%) for hydrogen production involved non-renewable fossil fuels, primarily through steam reforming of natural gas, a process responsible for emitting 830 million tons/year of CO₂. However, a portion of hydrogen production stemmed from renewable sources, such as water electrolysis. [11-14]

Different methods of hydrogen production yield distinct types of hydrogen, categorized by their production technology, energy source, and environmental impact. These classifications are represented by colors, including blue, grey, brown, black, and green. Green hydrogen, for instance, is derived from renewable sources like biomass processes (biological or thermochemical) and water splitting (electrolysis, thermolysis, and photolysis).

Within the realm of biomass processes, there are various pathways, such as biophotolysis, dark fermentation (DF), and photo fermentation (PF). Furthermore, the biomass pathway can be segmented into biological and thermochemical routes. The thermochemical pathway encompasses processes like pyrolysis, gasification, combustion, and liquefaction, all of which have undergone extensive research and analysis.[15-17]

I.3.2.1 Production technologies reliant on renewable sources

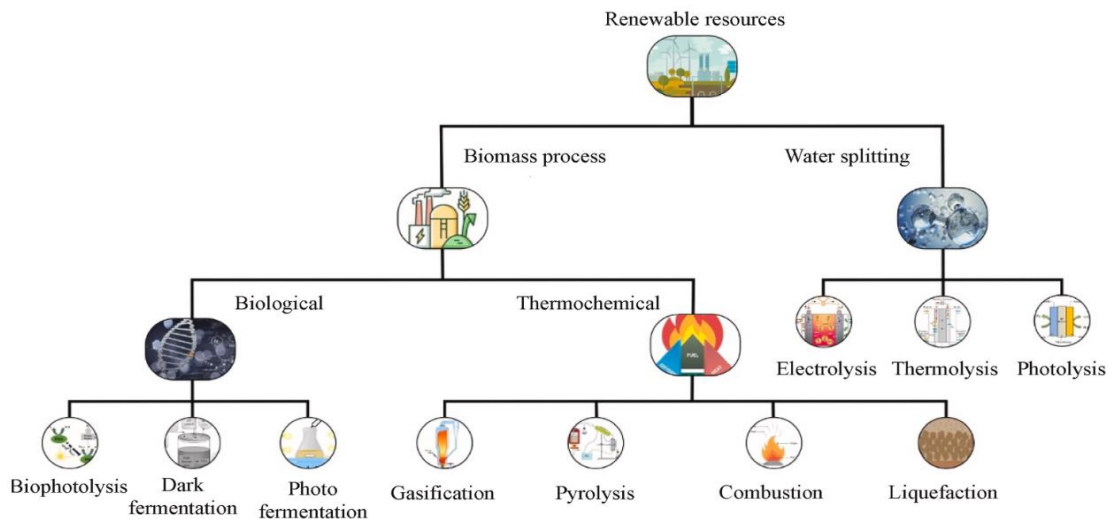


Figure.I.1 : Renewable sources-based production technologies.[17]

a. Water-splitting technology

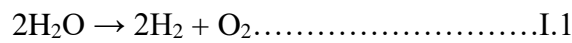
Hydrogen, which consists of two parts hydrogen and one-part oxygen, can be produced from water, a resource that is widely available [18]. By providing adequate energy, it is possible to break down the water molecule into its hydrogen and oxygen constituents. This process of water splitting can be achieved using various technologies. Hydrogen extraction from water can occur through electrolysis, photolysis, or thermolysis [18, 19].

a.1. Electrolysis

Electrolysis stands as a fundamental method in the scientific and academic realms to produce hydrogen from water. However, it is crucial to note that this process is characterized by its high endothermic nature, demanding a substantial supply of electrical energy. This

energy input is commonly sourced from photovoltaic (PV) panels or steam turbines, underscoring the interdisciplinary nature of its application [20-22].

In electrolysis, electrical energy undergoes conversion into chemical energy, leading to the formation of hydrogen (H₂) and oxygen (O₂) as primary byproducts. Both the anode and cathode electrodes facilitate two simultaneous reactions, each contributing to the overall process efficiency [23]. A separator is strategically positioned between these electrodes to ensure the effective segregation of the resultant gases. Upon the application of an electric current, water molecules undergo a splitting reaction, with hydrogen evolving at the cathode and oxygen evolving at the anode. This electrochemical process can be represented by the following equation [24]:



Electrolysis encompasses a range of methodologies. Figure.I.2 presents the schematic configuration for four distinct electrolyzer technologies.

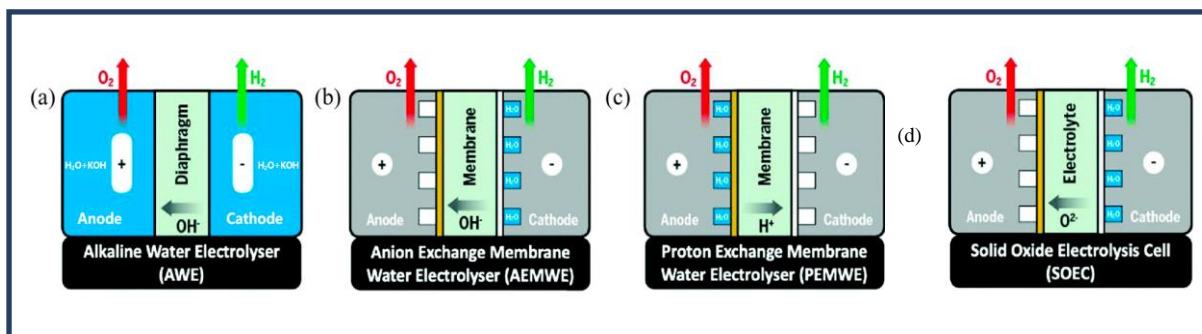


Fig.I.2: The conceptual configuration of four distinct electrolysis cell technologies. [24]

a.1.1. Alkaline water electrolysis

This technology utilizes a solution of potassium hydroxide (KOH) and sodium hydroxide (NaOH) as electrolytes. Alkaline electrolysis, favored for its lower investment costs compared to other electrolysis technologies, benefits from the simplicity of its material requirements. With efficiencies ranging between 68% and 77%, alkaline electrolysis offers limited potential for efficiency enhancement and exhibits low responsiveness to power fluctuations.

This characteristic poses a challenge for integration with intermittent energy sources but presents minimal disadvantages for hydrogen production via hydroelectric power. Potential improvements in this technology pertain to manufacturing costs, operating pressure, and compatibility with intermittent energy sources. Additionally, research into alkaline fuel cells could eventually provide some benefits. However, given the maturity of alkaline electrolysis,

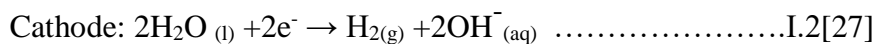
these advancements are relatively modest, leading research efforts to focus more on alternative electrolysis technologies that promise greater performance improvements.[25]

a.1.1.1 . Working principle of alkaline water electrolysis

Alkaline water electrolysis is an electrochemical process wherein water is split in the presence of electricity. This method involves two distinct half-cell reactions: the hydrogen evolution reaction (HER) is occurring at the cathode and the oxygen evolution reaction (OER) taking place at the anode. In the context of alkaline electrolysis, initially, two moles of alkaline solution at the cathode undergo reduction to produce one mole of hydrogen (H₂) and two moles of hydroxyl ions (OH⁻).

The hydrogen gas produced can then be extracted from the cathodic surface. Subsequently, the remaining hydroxyl ions (OH⁻) migrate through a porous separator to the anode side under the influence of an electric circuit. At the anode, these hydroxyl ions (OH⁻) are discharged, leading to the generation of half a molecule of oxygen (O₂) and one molecule of water (H₂O), as illustrated in Fig.I.3.

At the cathode, the protons pass through the membrane and reduce with the electrons to form hydrogen (reduction): [26].



At the anode, electrons are formed as a result of the oxidation of water into oxygen and protons (oxidation):[27].

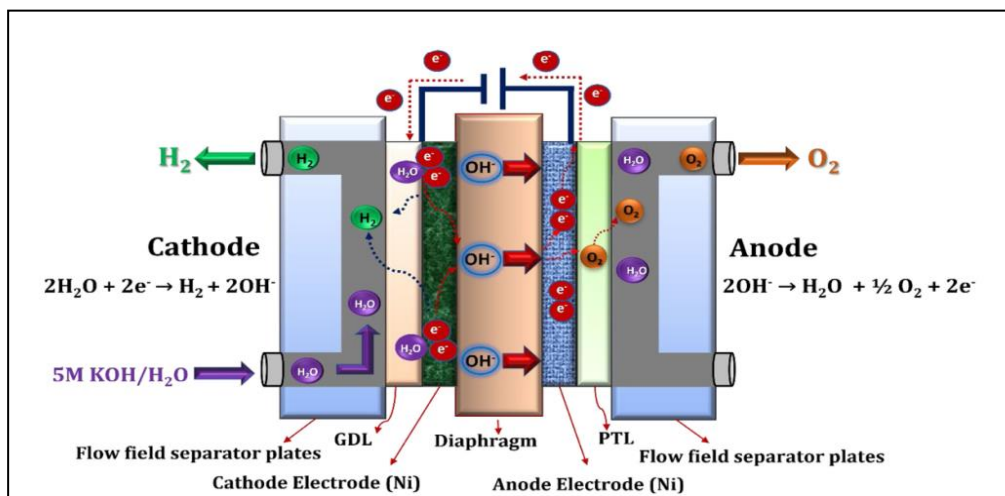
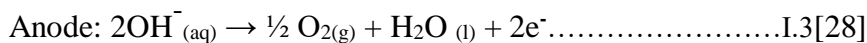


Fig.I.3: Schematic illustration of alkaline water electrolysis working principle.[29]

a.1.1.2 . Advantages of Alkaline water electrolysis

- Well established Technology
- Successfully implemented in various industrial applications
- Electrocatalysts free of noble metals
- Exhibiting a comparatively affordable price
- Demonstrating excellent long-term stability.[29]

a.1.1.3 . Disadvantages

- Current densities are limited.
- Gases intermix.[29]

a.1.2. Anion exchange membrane (AEM) water electrolysis

AEM water electrolysis represents an emerging technology within the domain of green hydrogen production. Various research organizations and institutions have actively contributed to the advancement of AEMWE due to its cost-effectiveness and superior performance relative to traditional electrolysis methods. The seminal scholarly work on AEMWE was authored by Scott in 2011, and since then, numerous researchers have made substantial contributions to its progress.

AEM water electrolysis bears resemblance to conventional alkaline water electrolysis, albeit with a notable difference in the utilization of an anion exchange membrane (Specifically, quaternary ammonium ion exchange membranes) instead of conventional diaphragms like asbestos. This approach offers several advantages. It employs cost-effective transition metal catalysts in place of noble metal catalysts and permits the use of distilled

water or low-concentration alkaline solutions (e.g., 1M KOH) as electrolytes, contrary to high-concentration solutions (e.g., 5 KOH solution).

Despite these advantages, further investigation and enhancements are necessary to bolster the stability of the membrane electrode assembly (MEA) and cell efficiency, particularly for large-scale or commercial applications. Presently, reported stability figures indicate 2000 hours with Sustain ion, 1000 hours for Fumatech (A 201 and FAA3-50), and over 35,000 hours for the Enapter multicore AEM electrolyzer.[29]

a.1.2.1 . Working principle of AEM water electrolysis

AEM water electrolysis is a technique for electrochemical water splitting that utilizes an anion exchange membrane and electrical energy. This process involves two half-cell reactions: the hydrogen evolution reaction (HER) and the oxygen evolution reaction (OER).

Initially, at the cathode, water molecules undergo reduction to produce hydrogen (H_2) and hydroxyl ions (OH^-) through the addition of two electrons. The hydrogen gas is liberated from the cathode surface, while the hydroxyl ions (OH^-) diffuse through the ion exchange membrane towards the anode, attracted by its positive charge. Simultaneously, electrons flow through the external circuit towards the anode.

At the anode, the hydroxyl ions recombine to form water molecules and oxygen, releasing electrons in the process. The oxygen produced is then released from the surface of the anode.

This process follows the basic principle of electrochemical water splitting and involves the half-cell reactions described above. Refer to Fig.I. 4 [29] for a visual representation of the principle and half-cell reactions involved in AEM water electrolysis.

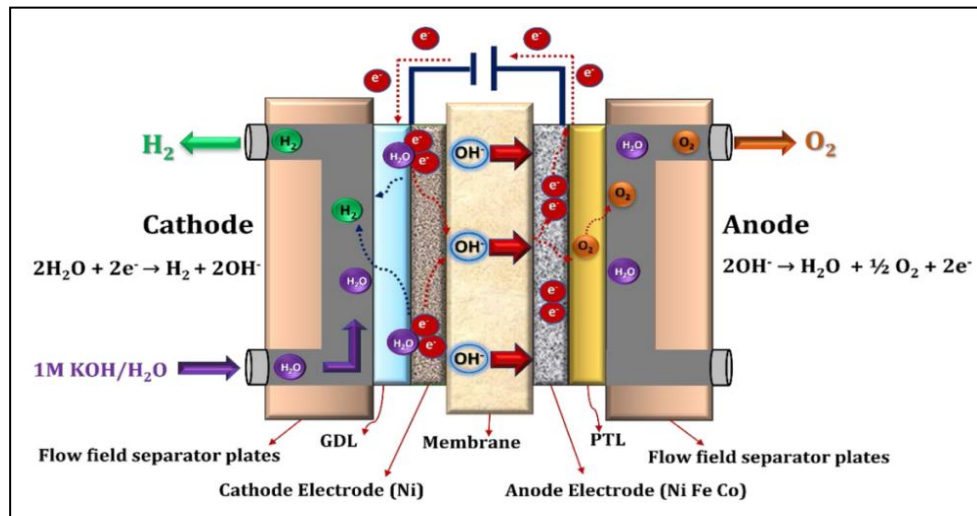


Fig.I.4: Schematic view of AEM water electrolysis working principle[29].

a.1.2.2 . Advantages of AEM

- Electrodes that do not contain noble metals [29]

a.1.2.3 . Disadvantages of AEM

- Limited stability

- Currently in the process of being developed [29]

a.1.3 PEM (Proton Exchange Membrane) water electrolysis

A second electrolyzer technology employs a polymer membrane (PEM for Proton Exchange Membrane) as the electrolyte. This transition from a liquid to a solid electrolyte markedly reduces maintenance and servicing costs, because of the liquid electrolyte on the plant, as well as the cost of compressing the hydrogen output. Furthermore, PEM electrolysis offers an optimal solution for decentralized production, thanks to its greater responsiveness to power variations and system compactness.

With efficiencies of 62% to 77%, this technology is employed in select niche markets, notably in submarines. However, it is still in the developmental phase for mass use. The use of noble materials, notably platinum, the service life of the membranes and the size limitations of the assemblies present the main obstacles to be overcome.

The current costs for PEM electrolyzer are approximately twice those of alkaline technologies. Nevertheless, this technology is benefiting from significant research into PEM fuel cells, which have demonstrated promising characteristics, including a high accepted current density and high pressure. The prospects for improvement identified lie mainly in the capacity of the stack, the reduction of the use of noble materials and the length of the membranes.

Finally, laboratory research is experimenting with this high-temperature technology (130-180°C, compared with 70 to 80°C for current electrolyzer). [25]

a.1.3.1 Working principle of PEM water electrolysis

During the process of PEM water electrolysis, the act of splitting water into hydrogen and oxygen occurs through electrochemical means. Initially, at the anode side, water molecules are decomposed, resulting in the generation of oxygen (O₂), protons (H⁺), and electrons (e⁻). The oxygen that is produced is subsequently removed from the surface of the anode, while the remaining protons traverse through a membrane that conducts protons towards the cathode side. Simultaneously, the electrons travel through an external circuit towards the cathode side. Upon reaching the cathode side, the protons and electrons combine once again to yield H₂ gas. The fundamental principle of PEM water electrolysis is visually represented in Figure.I.5 [29].

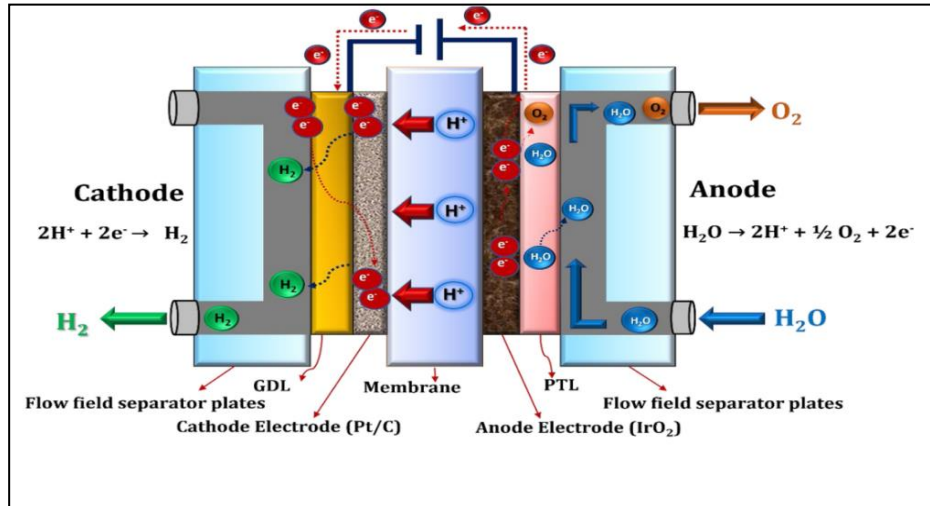


Fig.I.5: Schematic view of PEM water electrolysis working principle[29].

a.1.3.2 Advantages of PEM

- Technology that has been made into a commercial product.
- Works with higher levels of electric current.
- Ensures that the gases used are of a very high level of purity.
- Designed in a way that takes up minimal space.
- Responds quickly to changes.[29]

a.1.3.3 . Disadvantages of PEM

- Expense of cell components
- Precious metal electrocatalysts
- Acidic electrolyte solution.[29]

a.1.4. Solid oxide water electrolysis

The solid oxide water electrolysis cell (SOEC) is one of the electrochemical conversion cells, it converts electrical energy into chemical energy. The development of solid oxide water electrolysis was begun in USA in the year of 1970s by General Electric and Brookhaven National Laboratory, followed by Dornier in Germany [30]. Typically, the solid oxide water electrolyzer operates with water in the form of steam at high temperatures (500–850 °C) can

drastically reduce the power consumption to split the water into hydrogen and oxygen consequently increase the energy efficiency [31].

This improvement in energy efficiency can lead to a strong reduction in hydrogen cost due to power consumption being the main contributor to the hydrogen production cost in electrolysis[32]. Apart from that, solid oxide water electrolysis offers two major advantages compared to the existing electrolysis technologies, the first one is high operating temperature which resulted in favorable thermodynamics and reaction kinetics allowing unrivaled conversion efficiencies.

The second one is that solid oxide water electrolysis can be thermally integrated easily with downstream chemical synthesis i.e., the production of methanol, di-methyl ether, and ammonia [33]. Moreover, the solid oxide water electrolysis does not require the use of noble metal electrocatalysts and gives high conversion efficiency. Despite these advantages, insufficient long-term stability has prevented the commercialization of solid oxide water electrolysis. As of now, the reported stability is only 20,000 h with yttria-stabilized zirconia thin electrolyte[34].

a.1.4.1 .Working principle of solid oxide water electrolysis

Typically, the process of solid oxide water electrolysis takes place at elevated temperatures and involves the utilization of water in the form of steam, resulting in the production of environmentally friendly hydrogen and oxygen. In this process, the water molecule is initially reduced into hydrogen (H_2) and oxide ion (O^{2-}) through the addition of two electrons at the cathode side. Subsequently, the hydrogen is released from the cathodic surface, while the remaining oxide ion (O^{2-}) and hydrogen ions undergo transportation across the ion exchange membrane towards the anode side. At the anode side, the oxide ions (O^{2-}) undergo further reduction to generate oxygen and electrons, with the produced oxygen being liberated from the anodic surface and the electrons traversing the external circuit to reach the cathode side due to the electrostatic attraction exerted by the cathode. The fundamental operational principle of solid oxide water electrolysis is illustrated in Figure.I.6 .[29]

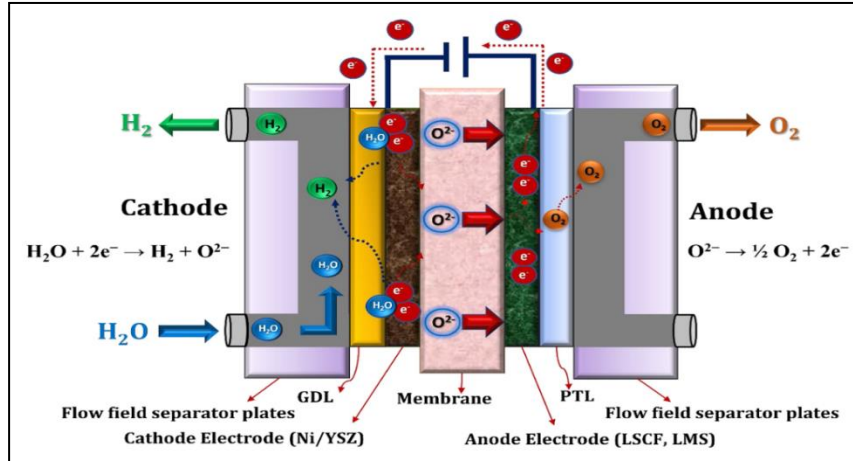


Fig.I.6: Schematic view of solid oxide water electrolysis working principle. [29]

a.1.4.2. Advantages of SOEC

- Elevated operating temperature
- Enhanced effectiveness[29]

a.1.4.3. Disadvantages of SOEC

- Stability limitations
- In developmental stages[29]

a.2. Thermolysis/thermochemical water splitting (TWSC)

The Thermochemical Water Splitting Cycle (TWSC), also known as thermolysis, involves the direct application of thermal energy to initiate a series of iterative chemical reactions that result in the separation of water molecules [35]. A critical requirement for the disintegration of water is for the Gibbs energy to reach zero ($\Delta G = 0$), necessitating a temperature of approximately 2500 °C. However, materials capable of withstanding this temperature and sustainable heat sources are not readily available [35]. Therefore, thermochemical water splitting cycles that involve oxidation/reduction chemicals have been proposed to lower the required temperature.

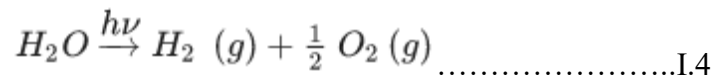
Several technologically feasible methods have been investigated, including copper-chlorine (Cu–Cl), iodine-sulphur (I–S), cerium-chlorine (Ce–Cl), magnesium-chlorine (Mg–Cl), magnesium-iodine (Mg–I), vanadium-chlorine (V–Cl), iron-chlorine (Fe–Cl), hybrid chlorine, hybrid sulphur (HyS), and copper-sulphate (Cu–SO₄) cycles. Most of these cycles necessitate high process heat, typically around 800 °C, except for the Cu–Cl cycle, which requires significantly less (540 °C). TWSCs are classified into two types: two-step and multi-

step cycles. Research has shown that increasing the number of steps in a specific thermochemical cycle reduces the maximum temperature required for the entire cycle, allowing for a broader range of heat sources to be utilized. Since the 1960s, over 300 thermochemical cycles for water splitting have been explored. However, only a few proposals for large-scale hydrogen synthesis have been advanced [36, 37].

a.3. Photolysis

Photo-electrolysis, a method that utilizes sunlight to initiate the production of hydrogen from water within a photo-electrochemical cell, is currently regarded as the most Economically viable and efficient approach for generating hydrogen from renewable sources [38]. The equipment employed in photoelectrolysis is similar to that used in photovoltaic (PV) systems, as it utilizes semiconductor materials in both technologies. In this process, a photoelectrode functions as a photo-electrochemical device, capturing incident light to facilitate water electrolysis.

This photoelectrode comprises a semiconducting material capable of absorbing solar radiation and generating the necessary voltage for the dissociation of water molecules into hydrogen (H₂) and oxygen (O₂) [38]. When the photoelectrode is immersed in an aqueous electrolyte and exposed to solar irradiation, it generates an adequate electrical potential to drive the production of H₂. The reaction can be presented as follows:



b. Biomass technologies

Biomass, derived from plant and animal-based materials, encompassing energy crop remnants, forest refuse, industrial by-products, animal and human waste, as well as other miscellaneous sources [39], is an example of a renewable energy source. The utilization of biomass as an environmentally friendly alternative energy option is gaining popularity due to its renewability, minimal carbon dioxide emissions, and low levels of sulphur content [40]. Biomass conversion technologies can be classified into two distinct pathways: thermochemical and biological. Thermochemical methods encompass techniques such as pyrolysis and co-pyrolysis, gasification, combustion, and liquefaction, which facilitate the conversion of biomass into hydrogen and hydrogen-rich gases [41]. On the other hand, biophotolysis (both direct and indirect), photofermentation, dark fermentation, and biological shift reactions are potential pathways that can be explored for biological hydrogen synthesis.

b.1. Thermochemical

Thermochemical methodologies that transform biomass fuel into hydrogen or even gaseous streams abundant in hydrogen are the most viable. The utilization of hydrogen or syngas derived from biomass holds potential as a practical measure in the pursuit of a zero-greenhouse gas (GHG) emissions environment, a crucial element in the advancement of sustainable renewable energy systems [42].

The production of hydrogen from different sources is now possible thanks to a number of technological advances. The most common method is steam reforming of natural gas, which involves reacting methane with water to produce a mixture containing hydrogen and CO₂. This CO₂ can be captured and stored to produce carbon-free hydrogen.

Gasification enables the production of a mixture of CO and H₂ by combustion from coal (a solution that emits a significant quantity of CO₂) or biomass. Another method employs organic compounds, predominantly composed of hydrogen and carbon, such as natural gas, coal or biomass. This method currently accounts for over 90% of hydrogen production. The process utilizes either an electric current for electrolysis or a series of chemical reactions for thermochemical cycles that "break" water molecules to obtain hydrogen.

An alternative pathway utilizes renewable energies, such as solar and wind power, which are derived from sunlight and wind. Hydrogen can also be produced biologically using algae, chemical algae, chemical reduction, or heat (thermolysis). Additionally, hydrogen can be generated through nuclear energy. [43]

b.2. BIOLOGICAL HYDROGEN PRODUCTION

Micro-organisms (enzymes that enable the reduction of protons to hydrogen) mainly produce hydrogen by two methods: photosynthesis and fermentation. Apart from the need for light, the major difference between the two processes is the source of electrons for the reaction. Among these mechanisms, there are several specific methods:

- photolysis of water by photosynthetic algae and cyanobacteria,
- photofermentation of organic acids by photosynthetic bacteria,
- anaerobic fermentation of organic compounds,
- a hybrid two-stage process involving anaerobic fermentation followed by photofermentation.

Water photolysis: Photolysis of water by photosynthetic algae and cyanobacteria is also known as direct bio photolysis. This process works through the photosynthetic apparatus of these organisms. This method of hydrogen production could be attractive to the industrial sector, since the hydrogen produced comes from the splitting of water.

This simplicity could make water bio photolysis more energy-efficient than some alternatives.

Photofermentation: is a process that takes advantage of the sun's energy for the organism's growth. However, unlike photosynthesis, which uses water as an electron donor, photofermentation uses organic molecules to supply electrons required for growth. A significant advantage of photofermentation is the ability to utilize a diverse range of substrates as electron donors. Examples of potential electron donors include butyric acid, succinic acid, lactic acid, malic acid, and acetic acid.

In contrast to direct biophotolysis, which produces hydrogen via the electron transport chain and electron transfer between Fd(ox) and hydrogenase, hydrogen evolution by photofermentation occurs through the action of nitrogenase. [44]

c. HYDROGEN PRODUCTION USING RENEWABLE ENERGIES

Pierre-Etienne Franc, head of the Air Liquid Group's global hydrogen energy division, strongly believes that "electricity is the main vector which, with hydrogen, will one day enable us to do without fossil fuels." A symbiotic relationship can be established between hydrogen and intermittent renewable energies, such as solar and wind power. When solar radiation or wind speed is sufficient, photovoltaic panels or wind turbines generate electricity.

When energy demand matches the supply, the system functions as intended. However, any surplus electricity not sold is lost unless it is utilized to produce hydrogen through the electrolysis of water, a process known as "power-to-hydrogen."

This clean, sustainable hydrogen can replace fossil fuels in various applications. It is appealing to manufacturers to decarbonize their processes. Additionally, hydrogen can fuel refueling stations for hydrogen-powered vehicles (e.g., cars, trucks, buses, forklifts, boats), which emit no fine particles or CO₂, only water. An illustrative example is the HyBalance project led by Air Liquide in Denmark, the largest site of its kind in Europe, with a 1.2 MW electrolyzer producing carbon-free hydrogen for industry and mobility. Similarly, the GRHYD project, led by Engie near Dunkirk, is experimenting with injecting 20% green hydrogen into natural gas heating networks.

Furthermore, hydrogen-powered fuel cells provide electricity for isolated areas or serve as an emergency power supply for sensitive sites. Hydrogen can also store locally produced renewable energy, ensuring the autonomy of "non-electrified" sites, i.e., those not connected to the national electricity grid. This comprehensive approach facilitates the effective use of renewable energy and supports the transition to a sustainable energy future.[45]

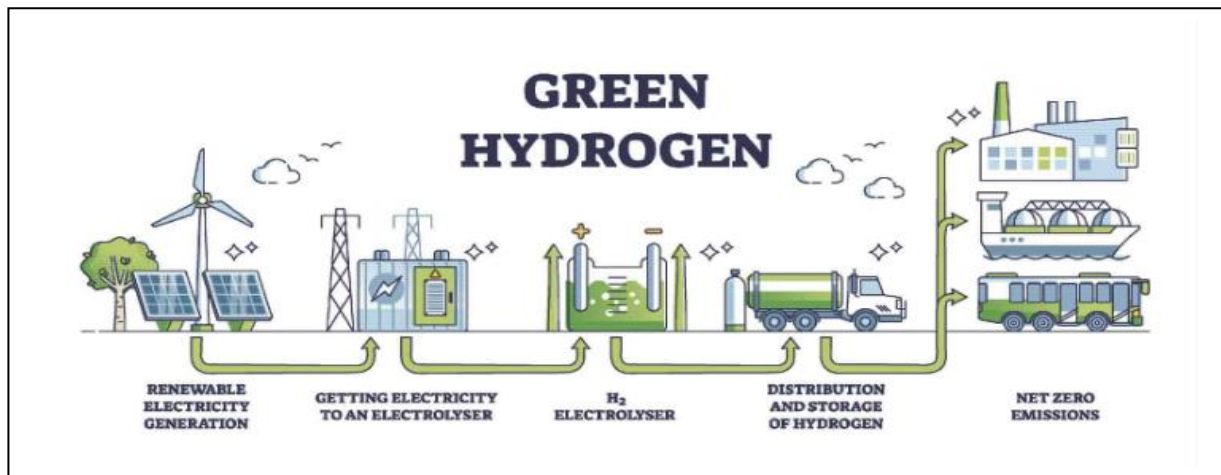


Fig.I.7: Producing green hydrogen from renewable energy sources [46]

I.4. Conclusion

Green hydrogen is recognized as a highly promising fuel in the context of future sustainable development and energy transition. This is primarily due to its production process, which involves the electrolysis of water using renewable energy sources, thereby eliminating greenhouse gas emissions. Consequently, green hydrogen is being increasingly advocated as a solution to combat climate change and fulfill global net-zero objectives. Furthermore, there is anticipation of a substantial surge in global demand for green hydrogen and its various applications in the coming decade. Encouragingly, numerous projects are already underway worldwide aimed at producing green hydrogen utilizing renewable energy sources such as wind and solar.[47]

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CHAPTER II

**STORAGE
OF GREEN
HYDROGEN**

II.1. Introduction

Efficient, cost-effective, and safe storage of hydrogen is crucial for the development of hydrogen technology [1]. Hydrogen is a lightweight gas that occupies a large volume under standard pressure conditions, making storage a technical and scientific challenge. To overcome this challenge, the volume of hydrogen must be greatly reduced. Therefore, it is important to find ways to store hydrogen that are both efficient and safe. The use of dihydrogen as an energy carrier is dependent on its efficient storage. The potential for dihydrogen leakage must be considered due to its flammable and explosive nature under certain conditions. Dihydrogen's small molecule size allows it to pass through many materials, including certain metals and can weaken them by making them brittle. Depending on the intended use of the gas, various storage methods should be considered for industrial, domestic, mobile, or nomadic purposes. [2]

The objective of this chapter is to examine the current state of storage technologies for green hydrogen, as well as the obstacles that must be overcome to facilitate the extensive adoption of this environmentally friendly and sustainable energy alternative.

II.2. Storage of hydrogen

The concept of hydrogen storage involves various technologies for storing dihydrogen for later use as a chemical product or energy carrier [3]. Hydrogen can be stored in three different forms: gaseous, liquid, or solid [4].

The storage of hydrogen presents technical challenges. Gaseous hydrogen requires high pressure, liquid hydrogen requires very low temperatures, and solid hydrogen must be combined with other components, often in the form of hydrides [3]. However, these modes do not fully meet the technical criteria that currently define the H₂ storage market. As a result, other modes are being sought. Performance is assessed primarily based on the volumetric and gravitational density of the hydrogen and its storage device, as well as the general conditions for hydrogen storage and recovery, such as efficiency, speed, and auxiliary devices. Safety and cost criteria are also crucial in determining the feasibility of a storage method [5-6]. Each method has its own advantages and disadvantages [3].

Different storage methods include the following:

- Physical processes, such as compression (gas), liquefaction, annealing and adsorption on carbon materials (activated carbon, carbon nanofibers, nanotubes).
- Chemical processes, such as NaBH₄, metal hydrides, fullerenes, NH₃, and methanol [5-6].

II.2.1 Physical Processes

II.2.1.1 Gaseous Storage





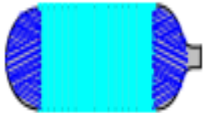

Gaseous storage of hydrogen entails compression at high pressures, often reaching up to 700 bar, in order to enhance its volumetric energy density. However, this approach is accompanied by certain drawbacks.

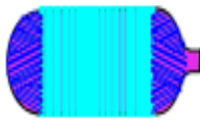

Firstly, there is a notable energy loss of approximately 20% incurred during the compression process. Moreover, stringent safety measures must be implemented due to the potential hazards associated with high-pressure storage. Furthermore, there are economic considerations, as the quantity and cost of the composite materials required to reinforce the storage tank structure contribute to additional expenses.

Consequently, current research endeavors are directed towards the development of more cost-effective composite materials that can uphold both volumetric and gravimetric storage capacities. To enhance the efficiency of gaseous storage, two primary strategies are being pursued. Firstly, efforts are being made to optimize the shape of the cylindrical tank to maximize space utilization within the vehicle. Additionally, exploring the option of compressing hydrogen at 77 K, equivalent to the temperature of liquid nitrogen, has shown promise. This method facilitates increased gas storage within the same volume [7].

For their design, gas tanks are grouped into 4 types:

Table II .1: Different Types of Gas Reservoirs [8,9]

Type	Schema	Realization
I metal cylindrical tank		
II A reservoir containing a metal casing for mechanical strength, reinforced by continuous fibers impregnated with resin.		
III A reservoir consisting of a metal casing to contain the hydrogen and a shell of continuous fibers impregnated with resin for mechanical strength		

<p style="text-align: center;">IV</p> <p>A reservoir composed of a non-metallic casing to contain the hydrogen and a shell of continuous fibers impregnated with resin for mechanical integrity.</p>		
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The choice of envelope (liner) for each type of tank is crucial, particularly in terms of its contact with the hydrogen. For Type I tanks, the liner directly absorbs mechanical stresses, making a material with a high yield point (such as steel) the preferred option. Conversely, for Type III and IV tanks, the liner serves as a hydrogen barrier, necessitating a material with low hydrogen permeability (such as aluminum for Type III). [10]

Storing hydrogen under pressure has the advantage of being highly controllable and allowing for rapid filling. However, this technique [11] also has several drawbacks, including:

- low volumetric density
- The need to design impact-resistant tanks that can be adapted to vehicles for on-board applications. [12]

II.2.1.2 Liquid Storage

The storage model described is an attractive solution due to the higher density of liquid hydrogen, which is achieved by cooling it to -253°C . However, this type of storage requires a significant amount of cooling energy, equivalent to 25% of the energy used to burn the hydrogen.

The storage of hydrogen at such low temperatures has led to significant technological developments. Hydrogen is stored in double-walled tanks, with a space between them containing super-insulation or liquid air to limit heat exchange.

The tanks are constructed from either steel or composite materials to reduce their weight. At a temperature of 20 K and a pressure of 1 bar, hydrogen has a density of 71.1 kg/m^3 in its liquid state, meaning that 1 kg of hydrogen occupies a volume of 14.06 L. This is significantly higher than the density of gaseous hydrogen under pressure. Additionally, the volume capacity of liquid hydrogen is 2 to 3 times greater than that of its gaseous state. [13]

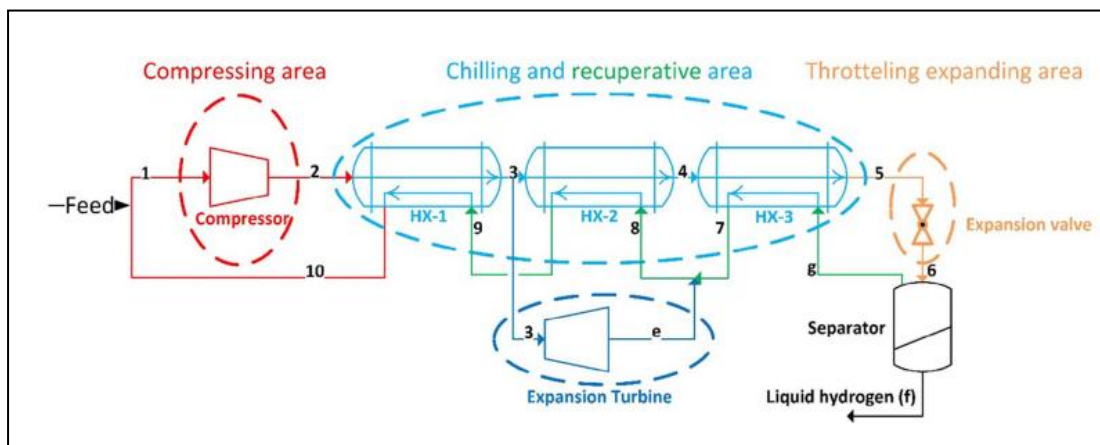


Fig II.1: Example of a simplified hydrogen liquefaction process: Claude cycle. [14]

As of the beginning of 2019, the global hydrogen liquefaction capacity was limited to approximately 200 tons per day, with a maximum of 54 t/d per plant. Hydrogen liquefaction is a costly process, both financially and energetically. Currently, plant consumption is equivalent to approximately 1/3 of the energy content of hydrogen. The widespread adoption of liquid hydrogen will necessitate a substantial expansion of liquefaction facilities, along with a considerable reduction in their cost and energy consumption. Liquid hydrogen is stored in cryogenic tanks. [15]



Fig II.2: Examples of liquid hydrogen tanks. [16,17]

II.2.1.3 Solid Storage

Storing hydrogen in solid form at near-normal temperature and pressure conditions requires combining it with another chemical element. This type of storage shows promise as a research avenue. Certain materials, such as metals called hydrides and potentially nanostructures like carbon nanotubes, have the property of absorbing or adsorbing hydrogen in a reversible way by changing temperature or pressure conditions. Solid hydrogen storage has numerous advantages,

- including drastically reduced risks compared to high-pressure or cryogenic solutions, a completely reversible system for storage and unstorage
- No memory effect, and the ability to be 100% discharged where power and energy are decoupled.
- It is also flexible in use, absorbing variations in electrolyzer hydrogen production, making it ideal for intermittent renewable energy storage and reactive applications.
- The system has operated for 10 years without requiring significant maintenance, completing one storage cycle per day, and has shown no signs of degradation over time.
- The system allows for floating storage or de-storage, which can be requested by the grid. This makes it a more effective hydrogen storage solution than pressurized or liquid solutions.
- The system is designed to be easily installed and used, with a 'plug and play' approach.
- The system stores hydrogen in atomic (H) form, rather than molecular (H₂) form as in previous systems, which provides a more efficient storage solution. [2]

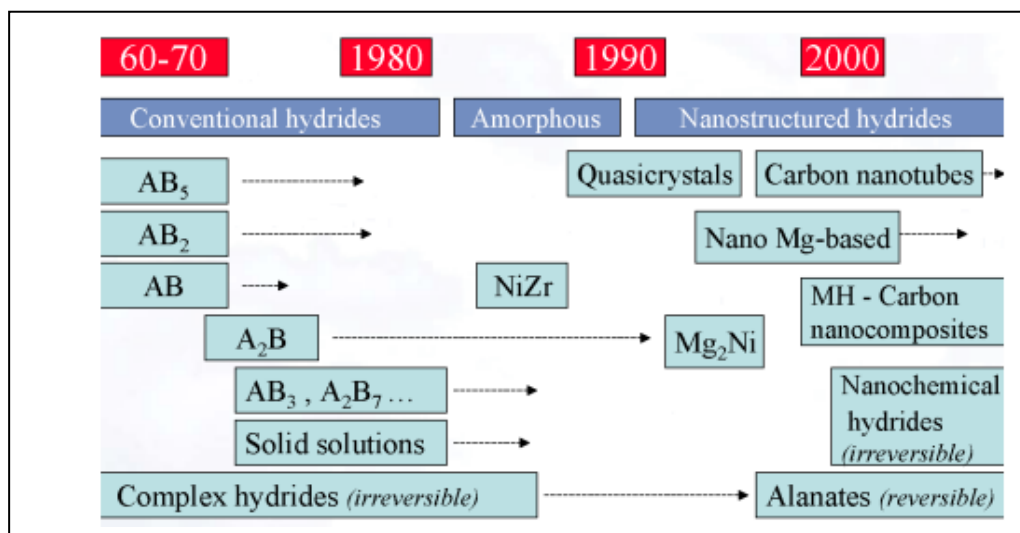


Fig II.3: Development of solid storage over the past 50 years [18].

It seems that solid storage is the most promising avenue for further development. The volume capacities of solid storage are considerably higher than those of liquid storage,

which is an attractive feature. Some forms of solid storage operate under standard temperature and pressure conditions. Solid storage is available in a few forms, as illustrated in **Fig II.4**, which presents a flow chart of these forms. Intermetallic compounds are listed in the reversible hydrides section. [19]

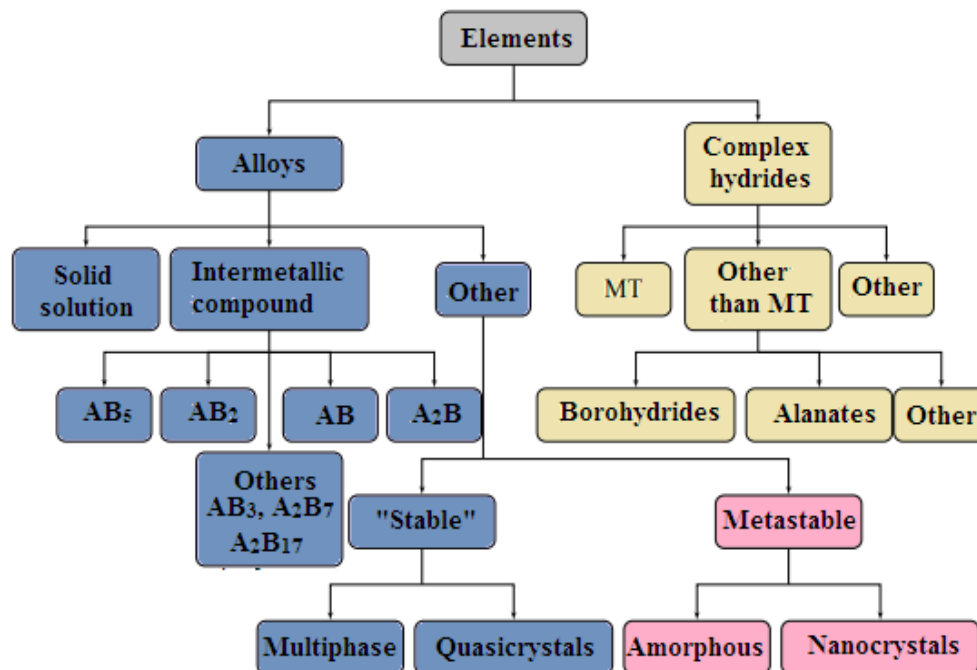


Fig II.4: Family for solid storage [19]. MT= transition metals

II.2.1.4 Storage by Adsorption

Hydrogen can be concentrated by absorption on the surface of a suitable adsorbent. Although adsorption of hydrogen by various materials is theoretically possible, only carbon adsorption is significant and can be considered for technological applications. Densities of around 0.5% by weight have been achieved under normal conditions. However, at very low temperatures and high pressures, the density can increase up to 8%. To ensure the effectiveness of this storage method, it is crucial to develop adsorbents with large specific areas. Nanotubes and nanofibers are currently being considered for hydrogen storage, although they are still in the research and development stage [20].

a. Carbons

Various types of microporous carbon have been studied for hydrogen storage, such as activated carbons, carbon nanotubes, nanofibers, and tempered microporous carbons [21]. Carbon is an attractive host due to its low molar mass, chemical stability, and ability to be synthesized in various forms. Porous carbons are already commercially produced in large quantities for various applications and are relatively inexpensive from a practical standpoint.

a.1 Activated Carbon

Activated carbon is a porous form of carbon that can be synthesized through chemical or physical activation methods. The resulting carbon will have a specific porous structure, which may not be clearly defined depending on the raw material, activation method, and conditions used. While activated carbons can be predominantly macroporous or mesoporous, it is the microporous variety that is mainly used for hydrogen storage. Activated carbonates typically have slit-shaped pores [22,23], but also exhibit a relatively broad pore size distribution. This contrasts with crystalline adsorbents, such as zeolites or metal organic framework (MOF) materials, which have well-defined pore size and geometry. Studies have been conducted on hydrogen adsorption by activated carbon. According to Yorum et al [21], these studies have shown that gravitational storage capacities can reach 5.5% by weight at a temperature of 77 K. This contrasts with crystalline adsorbents, such as zeolites or metal organic structure (MOF) materials, which have well-defined pore size and geometry. However, carbon pores can take various forms depending on the chosen activation method and raw materials used for synthesis [24].

a.2 Carbon Nanotubes and Other Carbon Nanostructures

Carbon nanostructures, such as nanotubes and nanofibers, have been extensively studied for their hydrogen adsorption properties. The storage properties of some of these materials have been debated since the first report on the possibility of storing hydrogen at room temperature using carbon nanotubes [25].

Carbon nanotubes are cylindrical nanostructures made of graphene coils. The diameter of nanotubes can range from 0.7 nm to several nanometers. They can form single- or multi-walled tubes that bundle tightly [26]. In 1997, Dillon et al reported that room-temperature storage potentials were 5-10 wt.%, a figure derived from a somewhat optimistic extrapolation of thermal desorption data measured on a sample composed of around 0.1-0.2 wt.% nanotubes (the remainder of the sample was uncharacteristic soot).

Herscher et al [27] demonstrated that the high-temperature adsorption peak, which Dillon et al claimed indicated the room-temperature storage capacities of the nanotube sample for potential storage materials, was caused by metal nanoparticles deposited during an ultrasonic purification process [26].

Carbon nanofibers consist of graphene layers arranged in various orientations relative to the fiber axis, including parallel and perpendicular configurations, as well as configurations with overlapping angles (known as chevrons). In 1998, Chambers et al. [28] reported that carbon nanofibers had extremely high capacities, up to 67% by weight [21]. Although the issue has not yet been fully resolved, it appears that nanotubes and nanofibers are unlikely to

be the solution for hydrogen storage, as some authors have suggested. Fullerenes and carbon nanofibers have also been studied, experimentally or theoretically, for their hydrogen storage properties [29, 30].

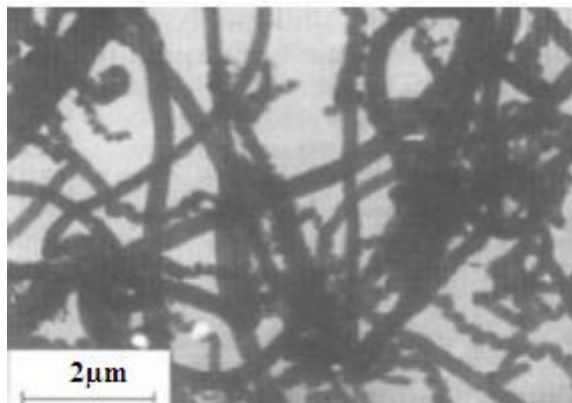


Fig II.5: Nanofibers [31]

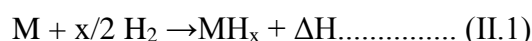
a.3 Templated Carbons

Tempered carbon is a type of microporous or mesoporous carbon that is usually synthesized by introducing carbon precursors, such as sucrose or acetonitrile, into the pores of an inorganic template. The carbonization process and subsequent removal of the template result in a relatively well-defined pore structure compared to activated carbon [32, 33].

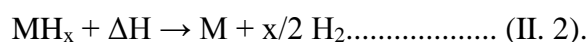
II.2.2 Chemical Processes

II.2.2.1 Hydride Storage

Hydrogen can be stored in atomic form in compounds called hydrides. The hydride formation process is described by the following reaction [20]:



The hydrogen discharge process is represented by the following reaction:



The Van't Hoff equation ($\ln P = \Delta H/RT - \Delta S/R$) relates pressure (P) to temperature (T) during charging and discharging processes. The equation involves the enthalpy (ΔH) and entropy (ΔS) of the hydrate process, as well as the gas constant (R).

There are two classes of hydride: metal hydrides and complex hydrides.

- Metal hydrides are characterized by metal bonds. Metal hydrides are capable of absorbing hydrogen atoms in lattice defects through a process known as hydrogen absorption or hydration, which occurs at specific temperatures and pressures. There are several families of metal hydrides currently in existence or under development.

Although the storage capacity of metal hydrides is satisfactory, their volume density and desorption capacity fall short.

- Complex hydrides are structures comprising alkali metals (typically lithium and sodium) and hydrogen, which is a group 13 element (usually boron and aluminium). The storage of complex hydrides is achieved through chemical reactions and site occupation, without the latticework involved in metal hydrides. However, this process is limited by the low energy densities, slow filling kinetics and high cost of hydrides.
- Other storage processes include: Other types of hydride, such as the amin borane family ($\text{NH}_x \text{BH}_x$), are currently under development. They represent a highly promising means of storing hydrogen, particularly for applications. Some of these hydrides, such as the NH_3 compound BH_3 , can absorb at least 20% by weight, are stable under normal conditions and can absorb at moderate temperatures.

Hydrogen can be used either directly in internal combustion engines or as a fuel in a fuel cell. A fuel cell is an electrochemical energy generator that directly transforms the chemical energy of a fuel (hydrogen, hydrocarbons, alcohols, etc.) into electrical and thermal energy, without any external energy input [20].

II.3. COMPARISON OF STORAGE METHODS

The hydrogen era has begun. Buses in regular service (MAN, Daimler Chrysler) are already equipped with gas tanks [34]. This technology is creating a market for infrastructure. Since the 1970s, BMW has been imagining hydrogen as the future of the automobile. Currently, BMW utilizes cryogenic storage for its petrol/hydrogen hybrid internal combustion vehicles. However, in order to enhance range (5 kg of hydrogen for 500 km for a standard vehicle, 8 kg for 200 km for the BMW Hydrogen 7), solid-state storage must be integrated, either in conjunction with gaseous storage (Toyota's Solhy project, Toyota's MHHP) or by optimizing gravimetric performance.

Table II .2: Comparison of storage technologies [35].

Hydrogen storage technology	Advantages	Limitations
Compressed hydrogen gas	Mastered technology up to 350 bar Low cost potential	Low densities. Even compressed to 700 bar, storage densities are lower than for liquid hydrogen storage. High compression costs.
Hydrogen liquid cryogenic	Mastered technology Good storage densities	Evaporation Difficult to insulate High energy consumption for liquefaction
Hydrides metallic	Some available technologies Operating temperature and pressure close to the standard condition Complex shapes possible	Heavy Cycling Current cost Heat flow management
Structures	Inexpensive Light	High storage capacity to be demonstrated.

II.4. CONCLUSION

Dihydrogen is emerging as a promising energy carrier, thanks to its multiple advantages. With its wide range of applications, from transport to stationary and portable uses, it offers a versatile solution to meet human energy needs. Furthermore, its high energy efficiency makes it an attractive option for the transition to a more sustainable economy. However, it is crucial to note that its safe use requires rigorous measures, due to its explosive nature and high penetration capacity. Consequently, for green hydrogen to achieve its full potential, further progress in storage and safety technologies is imperative. By investing in research and development and implementing appropriate regulations, we can harness the benefits of hydrogen while minimizing the potential risks, paving the way for a cleaner, more sustainable energy future. [36]

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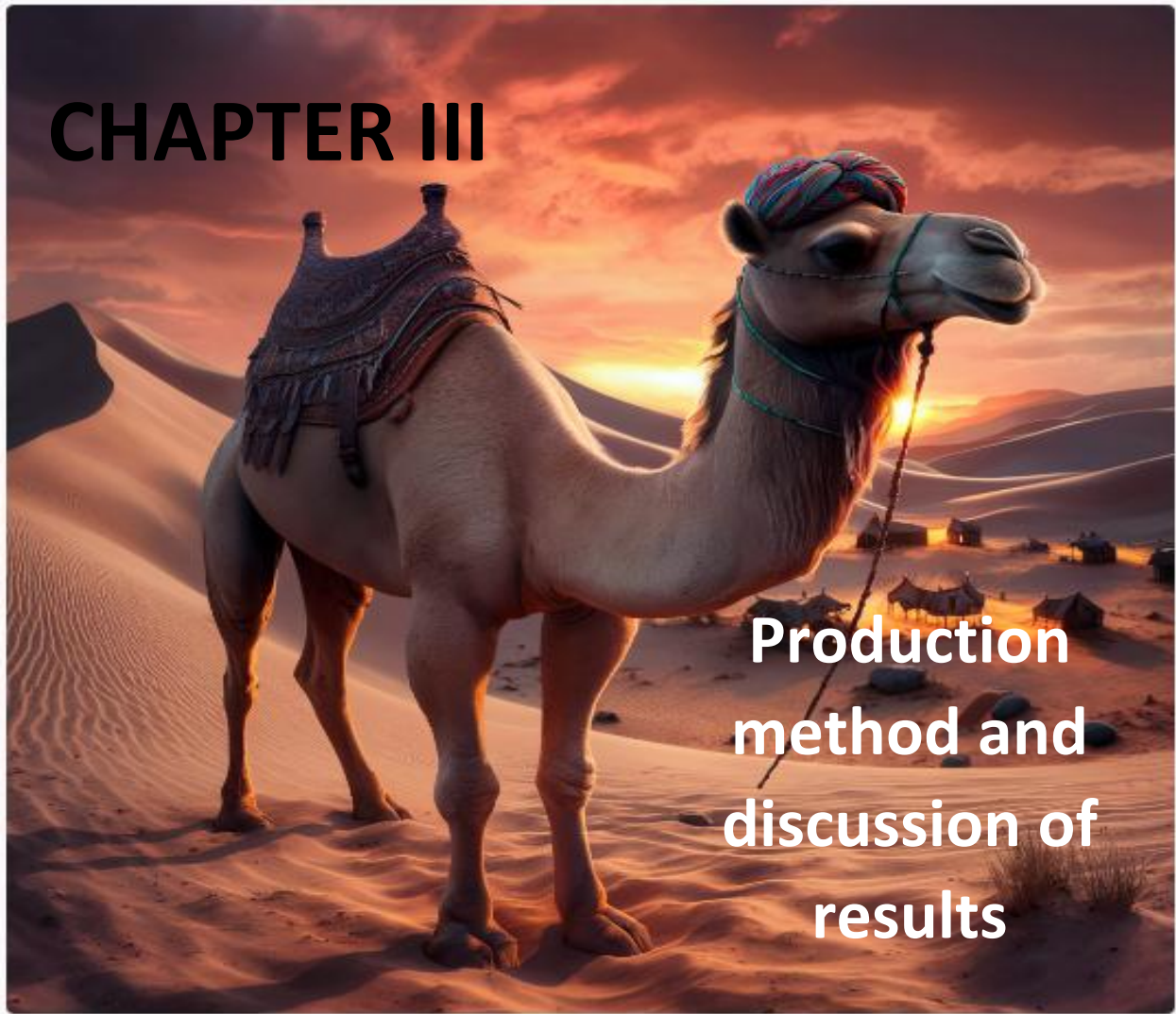
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CHAPTER III

Production
method and
discussion of
results




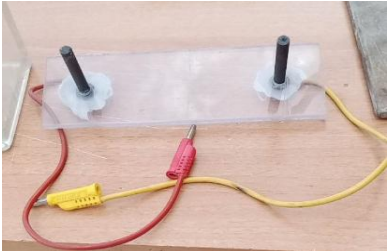
III.1. Introduction

This chapter presents the method I have chosen to produce green hydrogen, which is based on the electrolysis of water using solar energy. The scientific mechanism behind this method is detailed, along with an explanation of the equipment used and the experimental steps I followed to achieve efficient hydrogen production.

The results of my various experiments are then presented, with a careful analysis of the data and comparison of performance between different experimental conditions. The chapter will highlight the efficiency, purity and quantities of hydrogen produced, as well as the factors affecting the process, such as temperature, pressure and the type of catalyst used. Finally, the results will be discussed in the context of the desired objectives and the challenges encountered. The strengths of the method and shortcomings that may require further research and development will be addressed.

III.2. Devices used

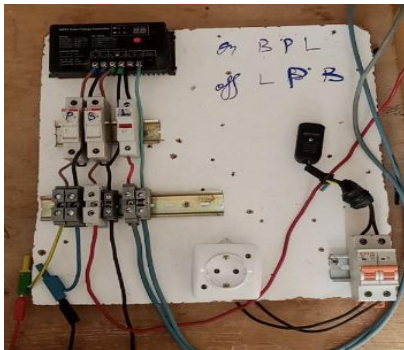
Table.III.1: devices used in the experience

Device	Description
	<ul style="list-style-type: none"> • Electrolysis Cell • Chemical reaction resistant glass • Capacity: 3.5 liters
	<ul style="list-style-type: none"> • graphite electrodes (anode and cathode) • Height of the electrode: 5.5 cm • Diameter of the electrode: 0.8 cm • Dimensions of the mounting piece: 20 cm x 6cm • Distance between the electrodes: 14 cm



Solar panel



- **Suntec**
- Model number STP190S-24/Ad+
- Rated maximum power (Pmax) 190 W
- Output tolerance 0/+5
- Current at Pmax (Imp) 5.20A
- Voltage at Pmax (Vmax) 36.6V
- Short-circuit current (Isc) 5.62A
- Open-circuit voltage (Voc) 45.2V
- Nominal operating cell temp (Tnoct) 45°C±2°C
- Weight 15.5Kg
- Dimension 1580mm×808mm×35mm
- Maximum system voltage 1000V
- Maximum series fuse rating 15A
- Cell technology mono-Si
- Application class A



A power distribution board combines a charge controller, which regulates and protects battery charging, with fuses that safeguard electrical circuits from over currents.



Battery used for storing energy.

	The pH meter is used to measure pH and potential.
	The balance is used to measure mass accurately.

III.3. the Experience

We have chosen the method of water electrolysis as the basis for our work and have divided this experience into two parts. The system was operated under specific conditions to ensure the stability of the experiment, with the current set at **5A** and the voltage set at **12V**.

(Note: Unlike the methods described in scientific articles, where current and voltage are often varied, we chose to maintain constant conditions (current of 5A and voltage of 12V) throughout our experiment. This approach was selected to ensure experimental stability and to simplify the analysis of our results).

In the first part, we used different types of electrolytic catalysts in varying concentrations, to find out which ones are most effective in producing larger amounts of hydrogen gas.

In the second part, we aimed for something completely unconventional: using dromedary camel urine without any additives to achieve hydrogen production.

III.3.1. Experiment description

The general montage adopted in all experiments conducted during this study is attached in the following figure.

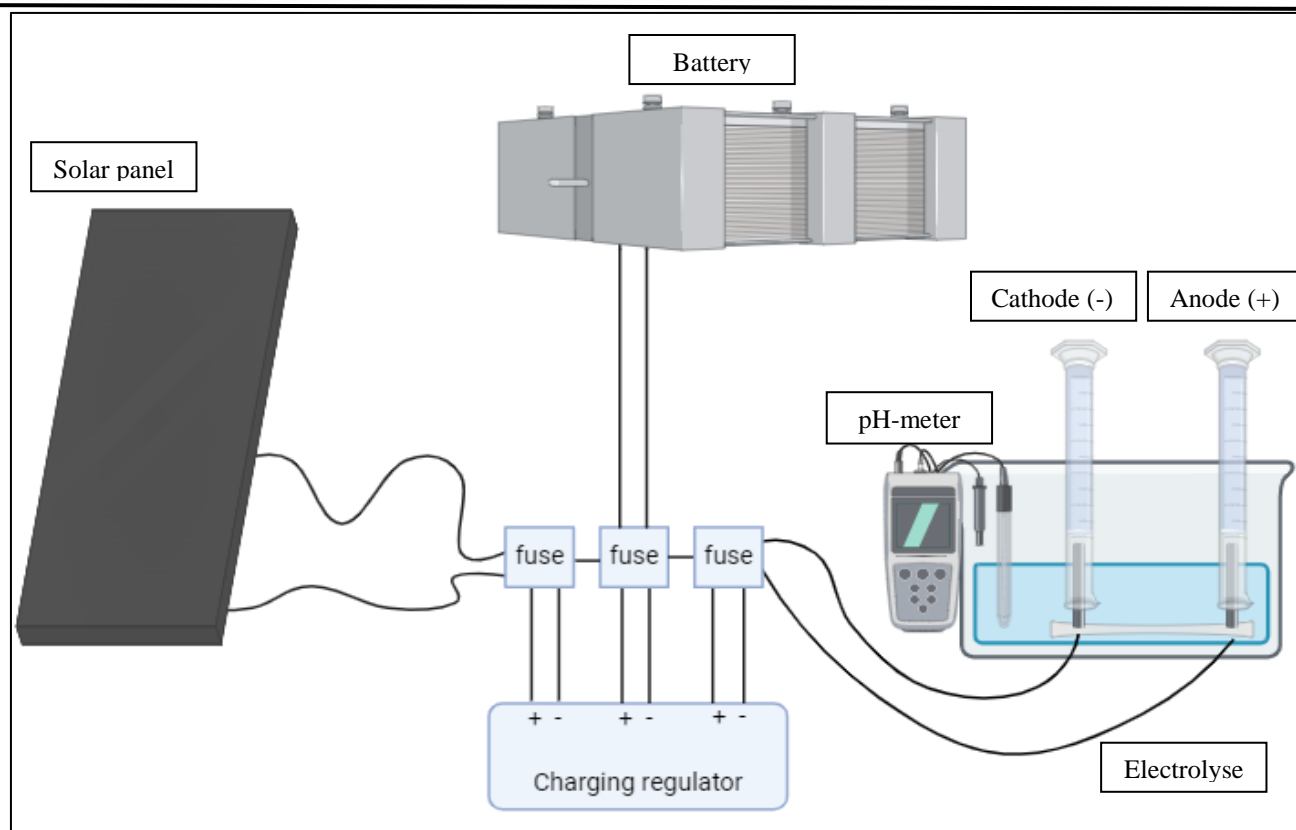


Fig.III.1: the montage used

➤ **To start the system, follow these steps:**

1. Charge the battery: The battery is charged by the solar panel to serve as a backup power source in the event of cloudy weather.
2. Switch on the solar panel: Next, the solar panel is activated to provide the system with direct energy from the sun, thereby enhancing the system's overall efficiency.
3. Switch on the electrolyzer: Finally, the electrolyzer is switched on to start the electrolysis of the solution.

III.3.2. Part I: Using Electrolytes

The electrolytes KOH and NaOH were employed in conjunction with distilled water for specific and important reasons.

1. This process facilitates the transfer of electrons.
2. The conductivity of the solution can be increased by: Distilled water is inherently a poor conductor of electricity due to the absence of a significant number of free ions. Upon the addition of sodium hydroxide or potassium hydroxide, these substances readily dissociate in water into ions,

thereby increasing the concentration of ions in the solution. It is these ions that facilitate the conduction of electric current through the solution.

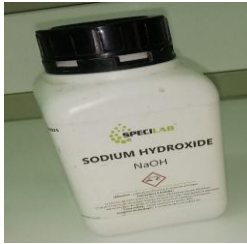
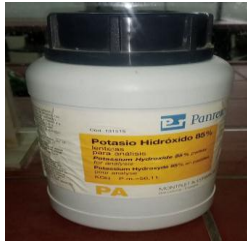
3. The formation of more mobile ions is encouraged. Sodium hydroxide and potassium hydroxide produce sodium (Na^+) or potassium (K^+) ions and hydroxide (OH^-) ions, which are small, fast-moving ions. The ions in question significantly enhance the electrical conductivity of the solution.

4. The catalyzing of reactions at the electrodes: The presence of free ions facilitates the catalysis of the requisite chemical reactions at the electrodes. At the cathode, hydrogen ions (H^+) facilitate a reduction reaction, resulting in the formation of hydrogen gas. Conversely, at the anode, hydroxide ions (OH^-) facilitate an oxidation reaction, resulting in the formation of oxygen gas.

It is imperative that the requisite equipment is prepared in advance. This includes ensuring that all apparatus and instruments are in a state of readiness, including the electrolytic cell, electrodes, glassware, and pH meter calibration. Furthermore, it is essential to don personal protective equipment, such as gloves and a lab coat, prior to commencing the experiment.

A. Products used

Table.III.2: products used in the first part of the experience

Product	Description
	<ul style="list-style-type: none"> • Sodium hydroxide NaOH • The Purity: 99% • Molar mass: 40 g/mol
	<ul style="list-style-type: none"> • Potassium hydroxide KOH • The Purity: 85% • Molar mass: 56.11 g/mol



- Distilled water was used to ensure purity and enhance the efficiency of hydrogen production

B. Preparation of the electrolyte solution

In this section , we use KOH and NaOH electrolytes at different concentrations of 5%, 10% and 15% by weight for each of them, where the method of preparing the solution to be electrolyzed is as follows: (This method was applied for all the different product proportions)

✓ **Preparation of 5% by weight KOH solution or NaOH solution**

To prepare 3 kg (3000 g \approx 3000 ml approximately) of 5% by weight KOH solution or NaOH, follow these steps:

✓ **Calculate the mass of KOH or NaOH required:**

$$\text{Mass of KOH or NaOH} = \text{Concentration (wt \%)} \times \text{Mass of solution} \dots\dots\dots \text{III.1}$$

$$\text{Mass of KOH or NaOH} = 0.05 \times 3000\text{g} = 150\text{g} \dots\dots\dots \text{III.2}$$

✓ **Calculate the mass of water required:**

$$\text{Mass of water} = \text{Mass of solution} - \text{Mass of KOH or NaOH} \dots\dots\dots \text{III.3}$$

$$\text{Mass of water} = 3000\text{g} - 150\text{g} = 2850\text{g}$$

Since the density of water is approximately 1 at room temperature (RT), 2850 g of water is approximately 2850 ml.

So:

- The mass of KOH or NaOH required: 150g.
- Mass of water required: 2850 g (or 2850 ml).



Fig.III.2: representation of solution preparation.

C. Using Potassium Hydroxide KOH Electrolyte in Electrolysis

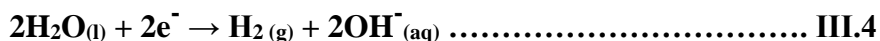
After preparing the KOH solution with a concentration (wt %) of 5%, 10%, and 15% according to the above calculations, the experiment was carried out according to the above montage in Figure III.1

C.1. Observing the reaction

When the reaction inside the electrolysis cell begins, the following happens:

The two electrodes (cathode and anode) are immersed in two graduated chambers containing the solution to be analyzed, with each electrode in a separate chamber.

- ✓ The cathode: This is where hydrogen gas is released.



(**water reduction**), the standard potential of the ox/red couple is: $E^{\circ}_{\text{H}_2\text{O}/\text{H}_2} = -0.83 \text{ V}$

- ✓ Anode: This is where oxygen gas is released.



(**water oxidation**), the standard potential of the ox/red couple is: $E^{\circ}_{\text{O}_2/\text{H}_2\text{O}} = 1.23 \text{ V}$

➤ **Distinguishing gases**

The two gases can be distinguished by observing that the volume of gas evolved at the cathode (negative electrode) is twice the volume of gas evolved at the anode (positive electrode).

When water is electrolyzed (water electrolysis), hydrogen gas is produced at the cathode and oxygen gas at the anode. The chemical equation for the reaction is as follows:



From this equation, for every two molecules of water analyzed, two molecules of hydrogen (H₂) and one molecule of oxygen (O₂) are formed. Since volume is directly proportional to the number of molecules (at the same conditions of pressure and temperature), the volume of hydrogen gas produced will be twice the volume of oxygen gas. Therefore, at the cathode, twice the volume of gas is produced compared to the anode, (see figure.III.3 below).

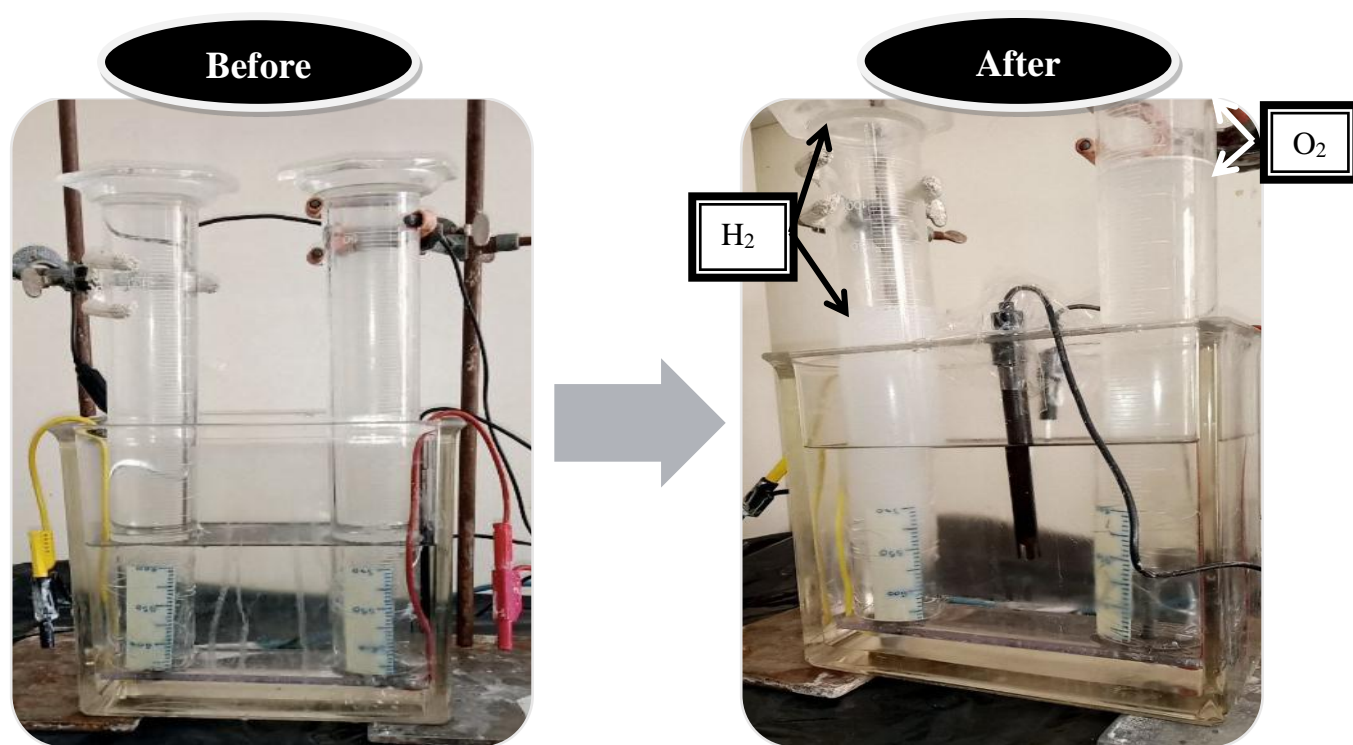


Fig.III.3: Before and after reaction chart (gas build-up during electrolysis).

The volume of gas in each part of the experiment was measured using the inverted graduated cylinder method. Two graduated cylinders were filled with the solution to be analyzed and then inverted over each of the electrodes separately to submerge them. At the start of the reaction, gas bubbles rise, causing the solution level inside the cylinder to drop. The volume of gas evolved is represented by the space left by the descending solution.

C.2. Results obtained

The results of the experiments conducted to observe the reactions of potassium hydroxide solutions at different concentrations (5%, 10%, and 15% by weight) are as follows. The results collected accurately represent the chemical reactions that took place during the electrolysis process. And show the effect of solution concentration on both the quantity and quality of the gases produced.

The results obtained will enable us to analyze and understand the relationship between the potassium hydroxide concentration and the efficiency of the electrolysis process. This will contribute to optimizing performance and developing future applications. The detailed results will be presented with a comprehensive analysis of the influencing factors and a discussion of the scientific implications.

The results are recorded every ten minutes to accurately document the process.

Table.III.3: The results of using KOH electrolyte.

Electrolyte	POTASSIUM HUDROXYDE KOH								
Concentration (Wt %)	5%			10%			15%		
Time (min)	Volume H ₂ (ml)	Volume O ₂ (ml)	Potential E (mV)	Volume H ₂ (ml)	Volume O ₂ (ml)	Potential E (mV)	Volume H ₂ (ml)	Volume O ₂ (ml)	Potential E (mV)
0	0	0	-380,3	0	0	-387,5	0	0	-435,9
10	150	75	-378	200	100	-386,9	295	145	-358,6
20	250	125	-377,3	400	200	-386,5	605	300	-370,6
30	355	175	-376,3	580	290	-385,7	895	445	-370,1
40	450	225	-375,2	780	390	-385,1	1170	585	-377,9
50	520	260	-374,3	980	490	-384,6	1530	765	-395,3
60	600	300	-373,6	1180	590	-384,1	1845	920	-401,9
70	690	345	-366,8	1380	690	-374,2	2130	1065	-428,9
80	800	400	-364,8	1560	780	-362,6	2590	1295	-424,3
90	960	480	-362,4	1755	875	-354,8	2920	1460	-424,8
100	1030	515	-361,6	1935	965	-349,6	3205	1600	-439,8
110	1130	656	-360,7	2160	1080	-349,6	3485	1740	-430
120	1230	615	-359,8	2385	1190	-349,1	3715	1855	-431,3

130	1360	680	-356	2590	1295	-348,8	3855	1925	-432
140	1510	755	-354,5	2840	1420	-348	3985	1990	-432,7
150	1630	815	-353	3080	1540	-347,6	4105	2050	-433,4
160	1770	885	-352	3330	1665	-347,1	4205	2100	-434,1
170	1890	945	-351,2	3530	1765	-346,7	4305	2150	-434,8
180	2000	1000	-349,8	3730	1865	-346,5	4405	2200	-435,5

C.3. Analyze the results

In this section, we will analyze the results recorded for different concentrations of KOH (5%, 10%, and 15%) by plotting graphs of the rising V_{H_2} , V_{O_2} , and potential (E) in terms of time (T).

C.3.1. Analyze the results of the volume of hydrogen gas released

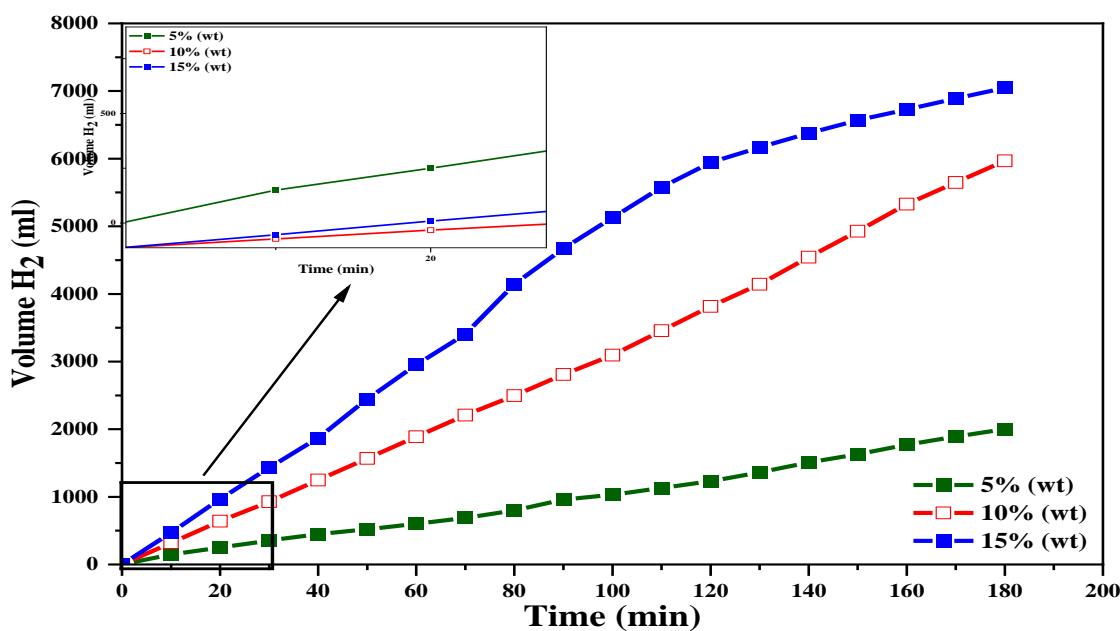


Fig.III.4: Graph representing the volume of hydrogen gas (V) as a function of time (T) for different concentrations of potassium hydroxide (KOH) (5%, 10%, 15%)

C.3.1.1. Interpretation

a. Concentration 5% “the green graph”

Experimental conditions before the reaction:

- ❖ pH value: 14.87
- ❖ Temperature: 29.8 °C

The volume of hydrogen gas produced commenced at zero and subsequently increased over time. However, it was observed that the rate of increase in hydrogen volume was lower than that recorded at higher concentrations of KOH. This can be attributed to the fact that the 5% concentration of KOH has a lower ionic density, which results in the generation of less hydrogen gas over the same period. Consequently, the ionic density of the solution is of paramount importance in determining the efficiency of hydrogen gas production.

A higher ionic density increases the electrical conductivity and accelerates the reaction rate, resulting in a greater quantity of hydrogen being produced in a shorter period.

b. Concentration 10% “the red graph”

Experimental conditions before the reaction:

- ❖ pH value: 14.94
- ❖ Temperature: 36.0 °C

At a concentration of 10% KOH, the curve demonstrates a notable increase in the volume of hydrogen gas in comparison to a concentration of 5%. It was observed that the production rate was particularly high during the initial stages of the reaction. As the concentration of the solution increases to 10%, the density of ions within it also increases, which in turn enhances the speed of the reaction. This results in the production of a greater quantity of hydrogen gas in a shorter period of time, due to the enhanced electrical conductivity, which accelerates the electrolysis rates and intensifies the production of hydrogen.

c. Concentration 15% “the blue graph”

Experimental conditions before the reaction:

- ❖ pH value: 15.08
- ❖ Temperature: 42.0 °C

At a concentration of 15% KOH, the hydrogen gas volume curve exhibits the greatest rate of increase among all the concentrations tested. Despite the considerable increase in production, a saturation of the rate of increase was observed after a certain period. This is due to the fact that the 15% concentration provides the highest density of ions, which significantly increases the speed of the reaction initially. Nevertheless, electrode saturation or additional resistance effects may occur over time, thereby reducing the efficiency of the production process.

Furthermore, minor corrosion was observed at the anode level in the direction of the oxygen gas build-up. This corrosion may be attributed to the harsh conditions of the electrode process at

high concentrations of KOH, which has the potential to reduce the lifespan of the electrodes and alter the reaction dynamics over time.

C.3.2. Analyze the results of the volume of oxygen gas released

Having discussed the effect of different KOH concentrations on the production of hydrogen gas, we will now look at analyzing the oxygen gas volume curve in terms of time for the different concentrations of KOH used in the electrolysis. We always note that the volume of oxygen gas released is half the volume of the hydrogen gas released.

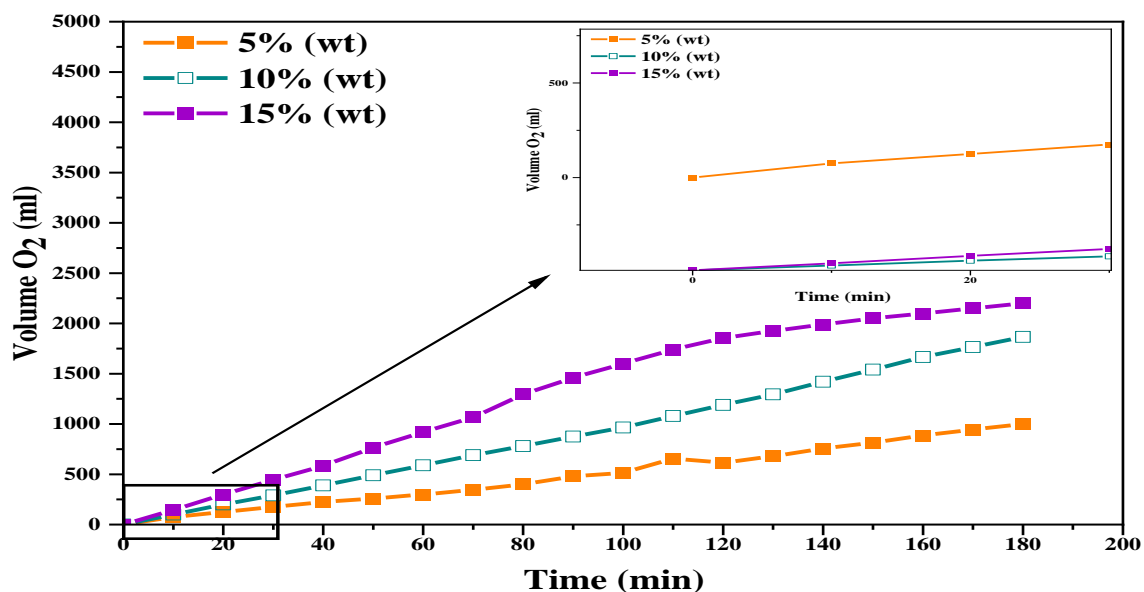


Fig.III.5: Graph representing the volume of oxygen gas (V) as a function of time (T) for different concentrations of potassium hydroxide (KOH) (5%, 10%, 15%)

C.3.2.1. Interpretation

The analysis of the results indicates that increasing the concentration of KOH from 5% to 15% leads to a progressive increase in the volume of oxygen produced through the electrolysis process. At a 5% concentration “**The orange graph**” the oxygen production rate was constant and continuous, reflecting the reaction's efficiency.

As the concentration increased to 10% “**the green graph**” there was a significant rise in the volume of oxygen produced, particularly in the early stages of the reaction, indicating the effect of higher ionic density.

At a 15% concentration “**The purple graph**” the rate of increase in oxygen volume was the highest, but a saturation point was observed after a certain period, likely due to electrode saturation or additional resistive effects within the solution. Additionally, slight corrosion was observed at

the anode due to oxygen buildup, which may impact the efficiency and sustainability of the process over time.

C.3.3. Analyze the measured potential results

The potential difference is quantified by a pH meter during the electrolysis of water to produce hydrogen. This is achieved by placing the sensor of the device in the electrolyte solution between the anode and cathode electrodes. The device measures the potential difference resulting from the distribution of hydrogen ions (H^+) in the solution. The concentrations of hydrogen ions increase near the anode and decrease near the cathode. This differential in concentration is converted into an electrical signal, which is displayed on the pH meter.

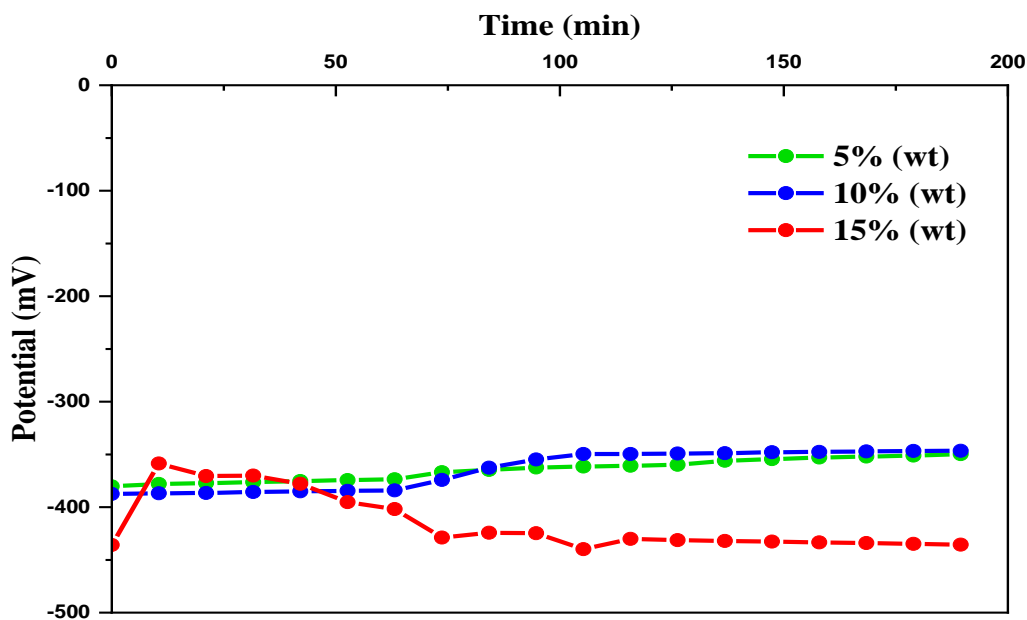


Fig.III.6: A graph representing the potential (E) as a function of time (T) for different concentrations of potassium hydroxide (KOH) (5%, 10%, 15%).

C.3.3.1. Interpretation

a. Concentration 5% “the green graph”

The potential starts with a high negative value at -380.3 mV.

- **Reason:** At the beginning of the reaction, the internal resistance is high, and the ion density is low.

Gradual increase in potential:

The potential gradually increases to -349.8 mV.

- **Reason:** As the reaction starts, the ions react better, reducing the internal resistance and increasing the efficiency of electrolysis, resulting in a higher potential.

Potential stabilization:

After an initial increase, the voltage tends to stabilize gradually over time.

- **Reason:** After reaching a stable stage of reaction, the potential stabilizes as a result of the balance between ion generation and depletion.

b. Concentration 10% “the blue graph”

The potential starts with a high negative value at -387.5 mV.

- **The reason:** A 10% concentration of KOH leads to a higher internal resistance due to the high ion density at the beginning of the reaction.

Gradual decrease in potential:

The potential gradually decreases from -387.5 mV to -346.5 mV.

- **Reason:** As the reaction proceeds, the internal resistance gradually decreases as a result of improved interaction between ions and electrodes, resulting in a gradual decrease in the negative potential value.

The potential stabilizes:

After a gradual decrease, the potential tends to stabilize at less negative values (-346.5 mV).

- **Reason:** To reach a dynamic balance between ions produced and ions consumed in the electrical reaction.

c. Concentration 15% “the red graph”

The potential starts at a very high negative value of -435.9 mV. This is due to the fact that a KOH concentration of 15% leads to a higher internal resistance due to the very high ion density at the beginning of the reaction. The potential fluctuates, dropping rapidly to -358.6 mV before beginning to oscillate between different negative values. Rapid fluctuations in ion concentration and electrical activity can result in oscillations in the potential, as saturation of the electrodes and alterations in reaction dynamics may occur.

C.4. Summary

The results of the graphical analysis of the electrolysis reaction using potassium hydroxide (KOH) at different concentrations (5%, 10% and 15%) indicate a significant effect of KOH concentration on both the volume of gas produced (hydrogen and oxygen) and the potential.

Regarding the hydrogen gas volume, the reaction at 5% concentration is characterized by a gradual increase in volume, while at 10% concentration; the speed of hydrogen production is significantly faster.

At a concentration of 15%, the increase in hydrogen volume is initially rapid and then tends to stabilize, indicating that the system is saturated with ion density. This is consistent with the observed trends in oxygen gas volume, where the production speed increases significantly with increasing KOH concentration, and a stabilization of the final gas volumes appears at the highest concentration (15%).

For the potential values, those at all concentrations begin with negative values, gradually increasing at the 5% concentration, and decreasing more markedly at the 10% concentration. At the 15% concentration, the potential fluctuated significantly before eventually stabilizing at higher negative values. These oscillations reflect the rapid changes in ion concentration and the intense reactive activity resulting from high ion concentrations.

The results demonstrate that an increase in the KOH concentration enhances the efficiency of the electro reaction and the production rates of hydrogen and oxygen. However, this comes with the potential for oscillations at high concentrations, indicating the importance of maintaining a balance between concentration and electrical stability for optimal performance.

D. Using Sodium Hydroxide NaOH Electrolyte in Electrolysis

After preparing the NaOH solution with a concentration (wt %) of 5%, 10%, and 15% according to the above calculations, the experiment was carried out according to the above montage in Figure III.1

D.1. Observing the reaction

The cathode and anode reactions for Sodium Hydroxide (NaOH) are the same as those observed with Potassium Hydroxide (KOH).

➤ Distinguishing gases

The gases were differentiated by their volumes and characteristic properties. The volume of hydrogen gas collected at the cathode was approximately twice the volume of oxygen gas collected at the anode, consistent with the stoichiometry of water electrolysis ($2 \text{ H}_2: 1 \text{ O}_2$), (see Figure III.3).

D.2. Results obtained

The following are the results of experiments performed to monitor the reactions of sodium hydroxide solutions at different concentrations (5%, 10% and 15% by weight). The results

accurately represent the chemical reactions that occurred during the electrolysis process and show the effect of solution concentration on the quantity and quality of the gases produced.

The results are recorded every ten minutes to accurately document the process.

Table.III.4: the results of using NaOH electrolyte.

Electrolyte	SODIUM HUDROXYDE NaOH								
	5%			10%			15%		
Concentration (wt %)	5%			10%			15%		
Time (min)	Volume H ₂ (ml)	Volume O ₂ (ml)	Potential E (mV)	Volume H ₂ (ml)	Volume O ₂ (ml)	Potential E (mV)	Volume H ₂ (ml)	Volume O ₂ (ml)	Potential E (mV)
0	0	0	-361,1	0	0	-398,9	0	0	-381,4
10	150	75	-366,3	180	90	-402,5	200	100	-361,7
20	350	175	-364,4	500	250	-399,5	400	200	-346,5
30	550	275	-361,3	840	420	-399,3	670	335	-342
40	750	375	-350,6	1240	620	-398,4	1030	515	-337,9
50	950	475	-344,3	1670	935	-389,7	1310	655	-334,2
60	1100	550	-341,9	1900	950	-388	1580	790	-330
70	1300	650	-340,1	2140	1070	-387,1	1900	350	-327,9
80	1450	725	-334,4	2320	1160	-394,3	2160	1080	-332,3
90	1650	825	-331,8	2580	1290	-395,4	2450	1225	-327,5
100	1800	900	-329,7	2850	1425	-396,9	2690	1345	-325,4
110	2000	1000	-329	3120	1560	-394,7	2990	1495	-322,7
120	2140	1070	-329,3	3250	1625	-392,5	3120	1560	-320
130	2290	1145	-327,6	3400	1700	-390,3	3250	1625	-317,3
140	2440	1220	-326,9	3550	1775	-388,1	3380	1690	-314,6
150	2590	1295	-326,2	3700	1850	-385,9	3510	1755	-311,9
160	2740	1370	-325,5	3850	1925	-383,7	3640	1820	-307,2
170	2840	1420	-324,8	4000	2000	-381,5	3770	1885	-306,5
180	2980	1490	-324,1	4150	2075	-379,3	3900	1950	-303,8

D.3. Analyze the results

In this section, we will analyze the results recorded for different concentrations of NaOH (5%, 10%, and 15%) by plotting graphs of the rising V_{H_2} , V_{O_2} , and potential (E) in terms of time (T).

D.3.1. Analyze the results of the volume of hydrogen gas released

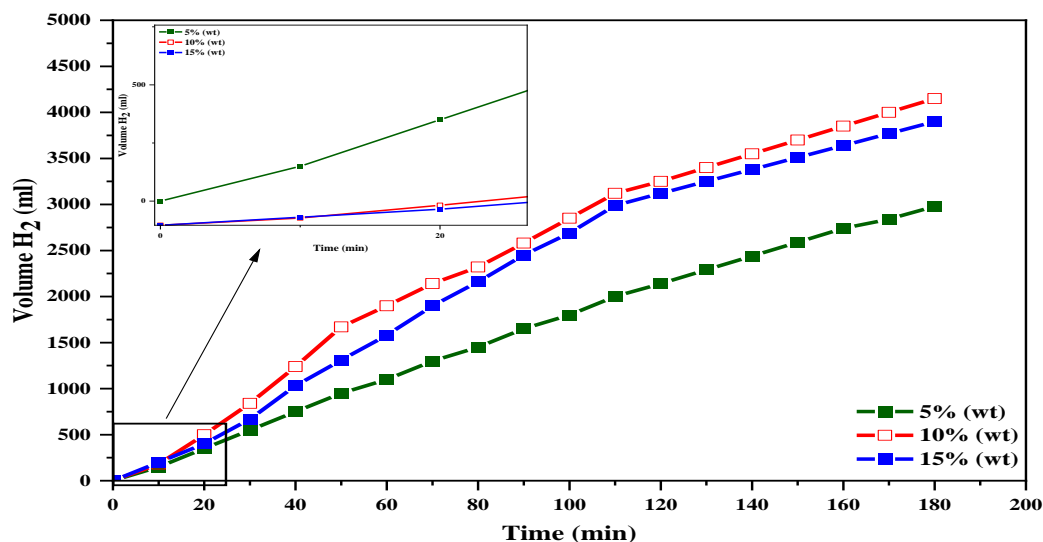


Fig.III.7: Graph representing the volume of hydrogen gas (V) as a function of time (T) for different concentrations of sodium hydroxide (NaOH) (5%, 10%, 15%)

D.3.1.1. Interpretation

a. Concentration 5% “the green graph”

Experimental conditions before the reaction:

- ❖ pH value: 14.44
- ❖ Temperature: 31.8 °C

The results for the volume of hydrogen gas produced at different time intervals using a 5% concentration of sodium hydroxide (NaOH) show a stable and consistent increase.

The key points are as follows:

- **Initial stages (0-30 minutes):** The reaction starts stably, with the gas volume increasing by 150ml every 10 minutes.
- **Intermediate stages (40-90 minutes):** The rate of hydrogen volume increase continues steadily, indicating stable electrolysis conditions.
- **Later stages (100-180 minutes):** The volume continues to increase at a similar rate, showing no slowdown or low efficiency of the reaction.

Explanation:**➤ Electrolyte efficiency:**

The linear increase in hydrogen volume indicates that 5% NaOH is an effective concentration for electrolysis, providing a stable ionic environment that supports continuous hydrogen production.

The continuous increase in gas volume indicates that the electrolyte concentration is ideal for maintaining a continuous and efficient electrolysis process without significant resistance or depletion of reactive ions.

b. Concentration 10% “the red graph”

Experimental conditions before the reaction:

- ❖ pH value: 14.92
- ❖ Temperature: 32.5 °C

The results confirm that using 10% NaOH as the electrolyte in the electrolysis process significantly increases the efficiency of hydrogen gas production compared to 5%. This concentration provides a faster and more efficient reaction, making it suitable for applications that require high hydrogen production in a short time.

- **Initial stages (0-30 minutes):** We observe a rapid increase in the volume of hydrogen gas, indicating a strong start to the reaction.
- **Intermediate stages (40-90 minutes):** The gas volume continues to increase at a rapid rate, reflecting the effectiveness of the reaction with 10% NaOH.
- **Later stages (100-180 minutes):** The gas volume continues to increase but at a slightly lower rate, indicating that the reaction is approaching a steady state or saturation.

Explanation:**➤ Higher efficiency of the electrolyte:**

Faster reaction rate: The rapid increase in hydrogen volume at 10% concentration reflects a higher efficiency of the electrolyte in transporting ions and supporting the reaction.

This concentration provides an optimal environment for hydrolysis, contributing to the efficient production of hydrogen gas.

c. Concentration 15% “the blue graph”

Experimental conditions before the reaction:

- ❖ pH value: 15.59

❖ Temperature: 42.8 °C

The hydrogen gas production curve for a 15% NaOH concentration demonstrates an initially high production rate, followed by a period of reduced efficiency, and then a slight increase again.

- **High Rate at the Beginning:** The graph shows a rapid initial increase in hydrogen volume. This is due to the very high ionic strength of the 15% NaOH solution, resulting in efficient electrolysis. The abundance of ions greatly enhances conductivity, facilitating rapid hydrogen gas production.
- **Efficiency Decreases in the Middle Stages:** A noticeable decrease in hydrogen production rate occurs during the intermediate stages. This may be attributed to gas bubbles forming on the electrodes, creating a barrier that reduces electrolysis efficiency. Additionally, the high concentration may increase the rate of side reactions, consuming some of the current that would otherwise contribute to hydrogen production.
- **Slight Increase in Downstream Stages:** Towards the later stages, there is a slight increase in hydrogen production rate. As electrolysis continues, the stirring effect of the rising gases may help displace gas bubbles from the electrodes, partially restoring process efficiency. Furthermore, the electrolyte may stabilize after the initial fluctuations in reaction dynamics.

In summary, while 15% NaOH initially produces hydrogen rapidly due to high ionic strength, the formation of gas bubbles and potential side reactions reduce efficiency in the middle stages. The process regains some efficiency as the system stabilizes and gas bubbles are displaced.

D.3.2. Analyze the results of the volume of oxygen gas released

When sodium hydroxide (NaOH) at different concentrations (5%, 10%, and 15%) is used in the electrolysis of oxygen gas production, patterns like those observed with potassium hydroxide (KOH) can be observed, the results are as follows:

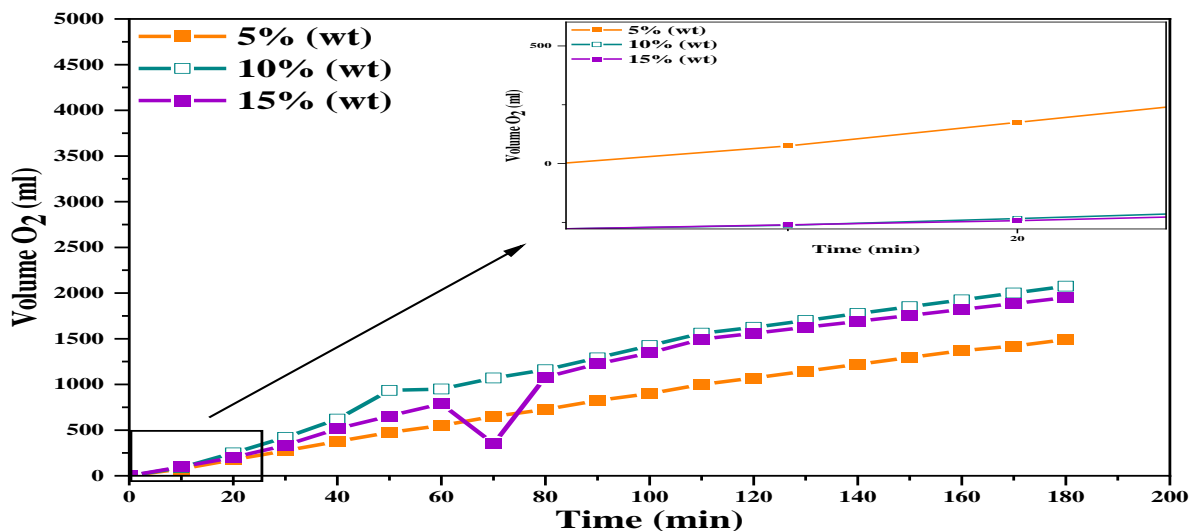


Fig.III.8: Graph representing the volume of oxygen gas (V) as a function of time (T) for different concentrations of sodium hydroxide (NaOH) (5%, 10%, 15%)

a. **concentration 5%** “the orange graph”

A gradual and steady increase in the volume of oxygen gas over time, reflecting the stability and efficiency of the electrolysis process.

b. **concentration 10%** “the blue graph”

Significant increase in oxygen production compared to the 5% concentration, with the best results in terms of the volume of oxygen produced continuously and steadily, indicating high efficiency without significant saturation or corrosion.

c. **concentration 15%** “the purple graph”

Highest rate of increase in the volume of oxygen produced, but with saturation observed after a certain period and possible anode corrosion, which may affect efficiency and sustainability.

D.3.3. Analyze the measured potential results

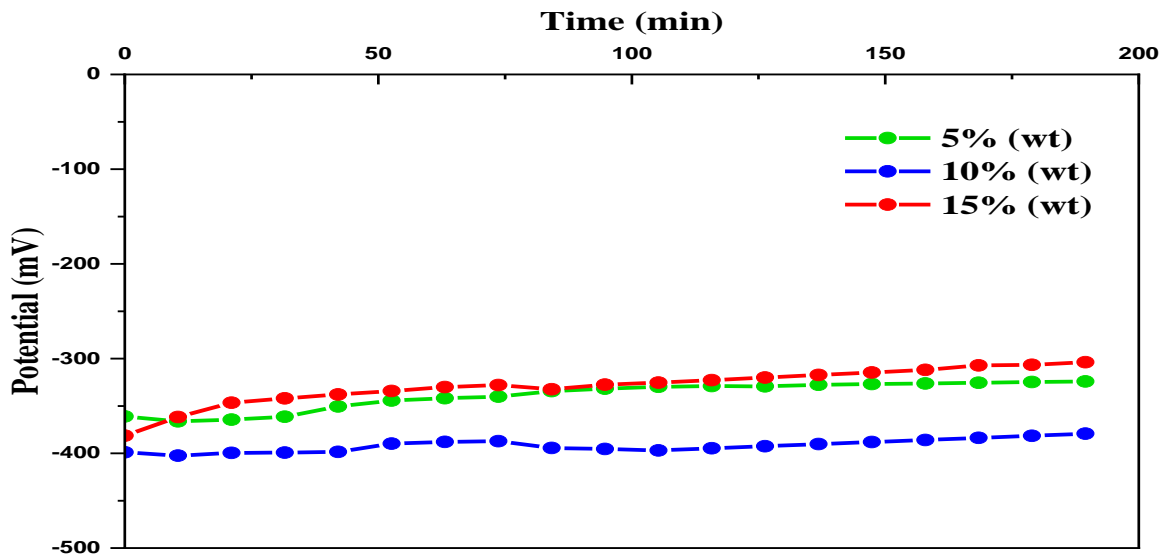


Fig.III.9: A graph representing the potential (E) as a function of time (T) for different concentrations of sodium hydroxide (NaOH) (5%, 10%, 15%).

a. At 5% concentration the “green graph”

- **Start:** The voltage starts at about -400 mV, indicating that the process begins at a relatively low voltage.
- **Evolution:** The voltage gradually and steadily increases over time, reaching about -300 mV after 200 minutes.

➤ Causes:

Low ion concentration: At a concentration of 5%, the number of ions in the solution is relatively low, leading to their slow consumption and a gradual increase in resistance.

Formation of insulating layers: The formation of insulating layers on the electrodes as a result of the reaction may contribute to a gradual increase in resistance.

b. At 10% concentration “blue graph”

- **Start:** The potential starts at approximately the same point (-400 mV) and remains stable for a longer period compared to the 5% concentration.
- **Evolution:** Significant voltage stabilization occurs during most of the reaction period, ending at around -350 mV after 150 minutes.

➤ **Reasons:**

Perfect ion balance: At 10% concentration, there is a good balance between the number of ions and the reaction speed, which keeps the voltage stable for longer.

High efficiency: High ion density optimizes the electrochemical reaction and reduces the internal resistance of the solution.

c. At 15% concentration “red graph”

- **Starting:** The voltage starts at around -400 mV but rises more rapidly compared to the other two concentrations.
- **Development:** The voltage rises rapidly and reaches about -250 mV after 150 minutes.

➤ **Causes:**

Rapid increase in resistance: Rapid reaction and increased ion density leads to the rapid formation of insulating layers on the electrodes, which increases the internal resistance.

Corrosion of the electrodes: Rapid reaction at 15% concentration may lead to faster anode corrosion, increasing resistance and affecting process efficiency.

Saturation of the solution: High ion concentration can quickly saturate the solution, hindering the electrochemical reaction over time.

e. Comparison of sodium hydroxide and potassium hydroxide in the production of hydrogen gas

After analyzing the results of using different electrolytes in the electrolysis of water to produce hydrogen gas, production rates were calculated for sodium hydroxide (NaOH) and potassium hydroxide (KOH) at different concentrations (5%, 10%, 15%). The results showed that both substances are effective in producing hydrogen gas, but there are clear differences between them.

To calculate the average hydrogen production rate for each concentration of NaOH and KOH, we use the recorded data of the evolved gas volume every 10 minutes, then calculate the production rate for each time interval and finally calculate the average production rates.

We calculate the production rate for each time interval (10 minutes) using the equation:

$$\text{Production Rate (PR)} = \frac{\Delta \text{Volume}}{\Delta \text{Time}} \dots \dots \dots \text{III.7}$$

Where:

- ✓ Δ Volume is the difference in the volume of gas evolved between two consecutive readings.

✓ Δ Time is the time difference (10 minutes).

After calculating the production rates for each time period, we calculate the average of these rates: (For the method of obtaining these values, see the Appendix.)

Average PR of 5% NaOH=

$$\frac{15.0 + 20.0 + 20.0 + 20.0 + 20.0 + 15.0 + 20.0 + 15.0 + 20.0 + 15.0 + 20.0 + 14.0 + 15.0 + 15.0 + 15.0 + 15.0 + 10.0 + 14.0}{18}$$

Average PR \approx 16.56ml/min

“We use the same method for all concentrations of each electrolyte”

Table.III.5: the results of comparing the average hydrogen gas production rate using sodium hydroxide and potassium hydroxide at different concentrations

Concentration	KOH (ml/min)	NaOH (ml/min)
5%	11.67	16.78
10%	20.72	22.56
15%	24.53	21.22

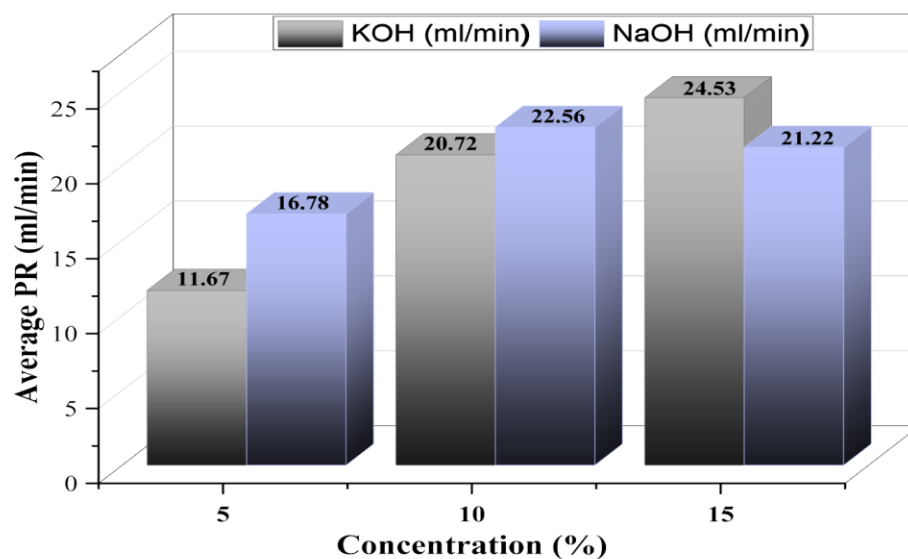


Fig.III.10: Average Hydrogen Gas Production Rate: Comparison Between Sodium Hydroxide and Potassium Hydroxide Usage

Following the analysis of the results and the calculation of the average hydrogen production rates using sodium hydroxide (NaOH) and potassium hydroxide (KOH) at different concentrations (5%, 10%, 15%), the results indicated varying performances.

At a 5% concentration, the mean production rate using NaOH was approximately 16.78 ml/min, in comparison to 11.67 ml/min for KOH.

At a 10% concentration, the average production rate was 22.56 ml/min for NaOH and 20.72 ml/min for KOH.

Finally, at a 15% concentration, the average production rate was 21.22 ml/min for NaOH and 24.53 ml/min for KOH. These findings indicate that while NaOH is more efficacious at lower concentrations, KOH offers superior performance at higher concentrations.

Nevertheless, other variables, such as cost, availability, and chemical stability, must also be considered when selecting the most suitable electrolyte for hydrogen production.


III.3.3. Part II: Using Dromedary Camel's urine

Dromedary Camel urine is distinguished by its distinctive properties, which are the result of the camel's adaptation to life in harsh environments and deserts. Its high concentration of organic and inorganic substances endows it with a distinctive capacity to conserve water. This chemically rich liquid may offer advantages in multiple uses, including scientific and industrial applications, due to its unique combination of biological potency and distinctive physical and chemical properties.

This section is divided into sections according to the analyses and experiments conducted on the sample. Prior to the process of urine electrolysis, the sample was analyzed and observed to identify any changes. Firstly, we will present an overview of the chemical composition of dromedary camel urine. We will then proceed to present the results of the analyses conducted on the sample before and after the reaction. Following this, we will discuss the experimental results and their implications. Finally, we will present a comprehensive discussion of the results, including logical explanations and necessary findings.

a. Products used

Table.III.6: Dromedary camel urine and the description of the sample

Product	Description
	<ul style="list-style-type: none"> • Sample type: dromedary Camel urine. • Gender: Female. • Age: 10 years old • Reproductive status: She has had three births. • Production status: The camel is milking (she is in the milk production period).

b. Different analysis of camel urine

The table below presents various characteristics of dromedary camel urine before and after the electrolyze. This provides a baseline understanding of the physical and chemical properties that are being affected by the process.

b.1. physical properties

Table.III.7: physical properties of dromedary camel’s urine before and after the electrolysis

Physical Property	Before reaction	After reaction (change in the nature of urine)
Ph	8.0	6.0
Odor	Intense	Very intense
Color	yellow	Dark yellow to orange

b.2. chemical properties

Camel urine has a unique chemical composition resulting from the camels' adaptation to their harsh desert environment. Here are some of the important chemical properties of camel urine. According to the scientific literature (Alkhamees, O. A., & Alsanad, S. M. (2017). A review of the therapeutic characteristics of camel urine. African Journal of Traditional, Complementary and

Alternative Medicines, 14(6), 120-126.). Based on which the sample was analysed to detect the concentrations of camel urine chemical compounds

Table.III.8: chemical composition of camel urine before and after reaction

Element	Value Before reaction	Value After reaction
Creatinine (Crea)	43.21 mg/L	530.93 mg/L
Albumin (Alb)	2500 mg/L	2090 mg/L
Polina (Au)	0.13 mg/l	7.92 mg/l
Inorganic phosphate (Pi)	40.05 mg/l	22.77 mg/l
Potassium (K⁺)	977.5 mg/l	1368.5 mg/l
sodium (Na⁺)	1725 mg/l	1955 mg/l
Chloride (Cl⁻)	2662.5 mg/l	3017.5 mg/l
Sulfate (SO₄)	124.87 mg/l	172.90 mg/l
Glucose (Gly)	0.00 mg/L	0.01 mg/L
Urea	150.15 mg/l	90.09 mg/l
hippuric acid	44.79 mg/l	26.87 mg/l
Purines	58.84 mg/l	33.62g/l

b.3 Analyze the sample before and after the reaction using infrared (IR)

Analyzing a sample of dromedary camel urine using an infrared (IR) device involves several steps. First, the urine sample is collected in a clean and sterilized container. Then, the sample is prepared by filtering it to remove impurities and solid particles. Next, a small amount of the prepared sample is placed in a special sample cell that fits into the IR device. The cell is inserted into the instrument, and the instrument emits infrared radiation through the sample. dromedary Camel urine selectively absorbs the radiation based on its chemical composition, resulting in a characteristic absorption spectrum. This spectrum is analyzed to identify the chemical compounds present in the sample, by comparing the data with known spectral databases.

The following results were obtained:

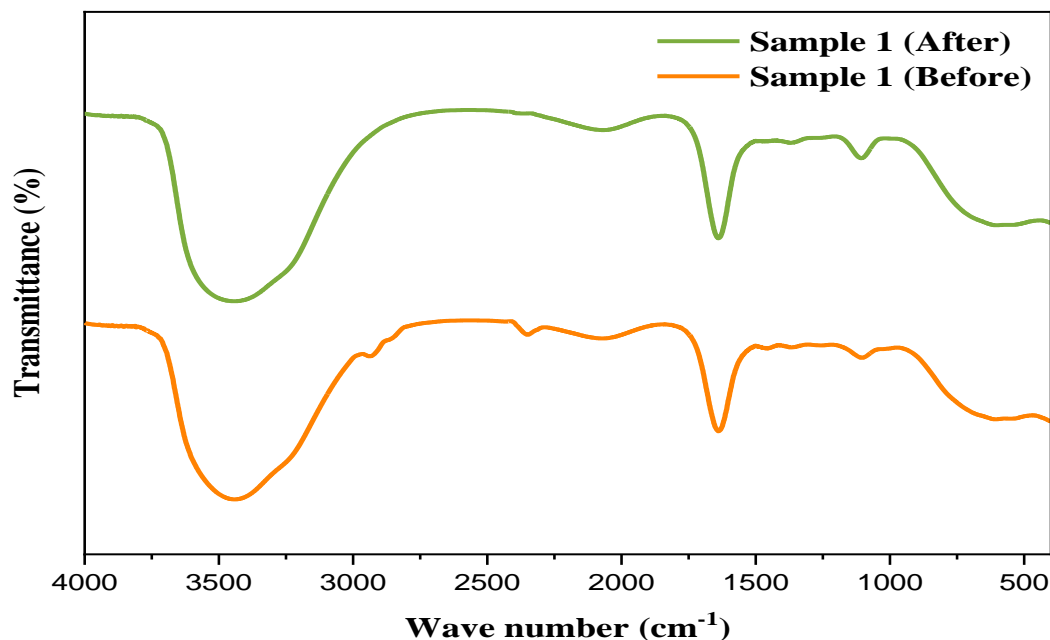


Fig.III.11: IR Spectrum of dromedary Camel Urine Sample Before and After Reaction

➤ **Spectral interpretation**

- **Sample before the reaction (orange spectral region):**

Table.III.9: spectral area of the peaks of the sample before the reaction and its function

Spectral area (cm^{-1})	The function
3200-3600	OH groups (water or alcohol)
2800-3000	C-H bonds in alkanes
1600-1700	C=O bonds (carbonyl)
1000-1500	C-N or C-O bonds

- **The sample after the reaction (green spectrum):**

Table.III.10: spectral area of the peaks of the sample after the reaction and its function

Spectral area (cm^{-1})	The function
3200-3600	OH groups (water or alcohol)
1600-1700	C=O bonds (carbonyl)
1000-1500	C-N or C-O bonds

- **Changes and interpretation:**

- ✓ 3200-3600 cm^{-1} region (OH groups in water or alcohol):

Before electrolysis: Strong peaks appear, indicating the presence of a large amount of water or OH groups from alcohol.

After electrolysis: There is a noticeable decrease in the peaks, reflecting a decrease in the amount of water or the transformation of some OH groups as a result of the reaction, where hydrogen and oxygen are produced.

- ✓ 2800-3000 cm^{-1} region (C-H bonds in alkanes):

Before electrolysis: The peaks appear stable, indicating the presence of alkanes.

After electrolysis: No significant changes are observed, indicating that the alkanes may be largely unaffected by the reaction.

- ✓ 1600-1700 cm^{-1} region (C=O bonds):

Before electrolysis: The peaks are clear, indicating the presence of carbonyl bonds such as ketones and aldehydes.

After electrolysis: A decrease in the peaks is observed, indicating the degradation of complex carbonyl compounds by the electrolytic reaction.

- ✓ 1000-1500 cm^{-1} region (C-N or C-O bonds):

Before electrolysis: Multiple peaks appear, reflecting the presence of compounds containing C-N or C-O bonds.

After electrolysis: Changes in the peaks reflect shifts in the chemical structure of the compounds, reflecting the effectiveness of electrolysis in decomposing complex compounds into simpler ones.

Infrared analysis showed significant changes in the chemical composition of camel urine after electrolysis.

These changes indicate that electrolysis was effective in decomposing complex compounds into simple gases such as hydrogen and oxygen. The region between 3200-3600 cm^{-1} stands out where there is a significant decrease in water or OH groups, reflecting the production of hydrogen and oxygen. In other regions, changes in the peaks show that chemical reactions have led to shifts in the chemical structure of the compounds

b.4 Analyze the sample before and after the reaction using visible uv

In order to analyze a dromedary camel urine sample using the UV/Vis technique, it is first necessary to dilute it with:

A solution of urine should be prepared with a concentration of 10% of the total volume. To prepare a 50-ml dilute solution, for example, 5 ml of urine (equivalent to 10% of the total volume) should be taken and 45 ml of distilled water (equivalent to 90% of the total volume) added.

The following results were obtained:

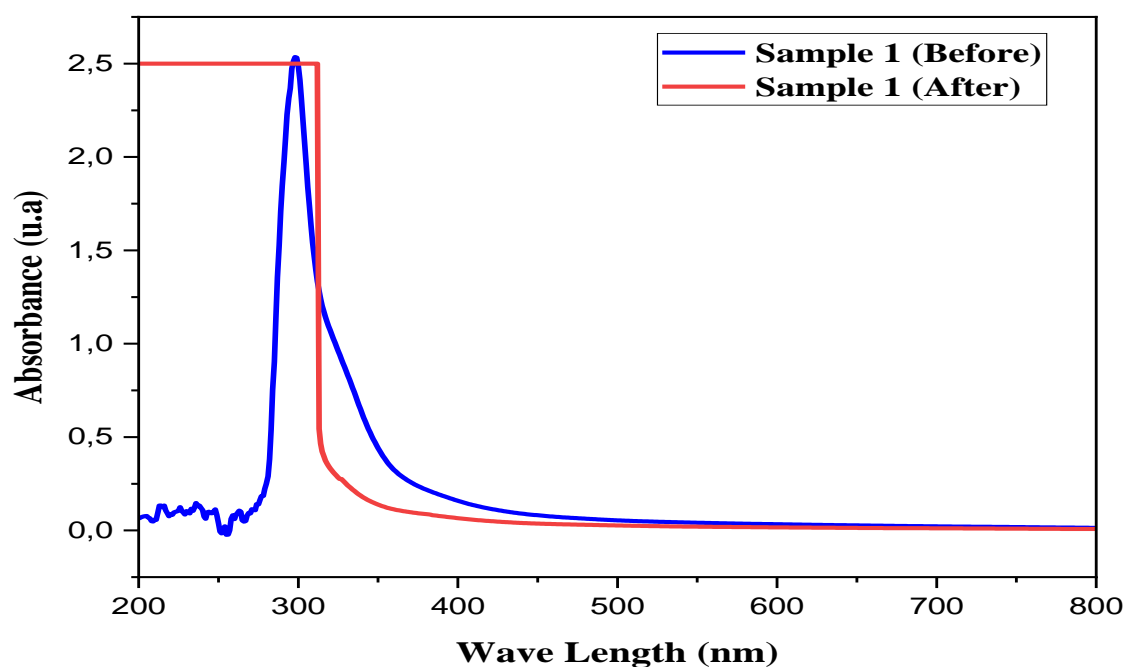


Fig.III.12: UV Spectrum of dromedary Camel Urine Sample Before and After Reaction

- **Spectrum before the reaction (Sample 1 (Before)): “Blue spectrum”**

Maximum wavelength at about 299.08 nanometers.

This wavelength indicates the presence of certain compounds in dromedary camel urine, perhaps complex organic compounds or proteins, that absorb in this band.

The pale-yellow color before the reaction corresponds to the absorption of light in the near ultraviolet (UV-A) range, leaving a pale yellowish visible spectrum.

- **The spectrum after the reaction (Sample 1 (After)) “Red spectrum”**

After electrolysis, showing a decrease in the maximum wavelength to around 280 nm.

The pronounced yellow color after the reaction indicates changes in the chemical composition of the solution. This shift to a shorter wavelength (280 nm) could be the result of the breakdown of larger compounds into smaller ones or the formation of new compounds with different absorption properties.

- ✓ **Explanation of changes**

Before the reaction:

The peak wavelength at 299.08 nm reflects the absorption of natural organic compounds in dromedary camel urine such as proteins, amino acids, and urea. The pale-yellow color appears due to the absorption of light in the near ultraviolet range (UV-A).

After the reaction:

Electrolysis changed the chemical composition of the sample, shifting the peak to 280 nm. This decrease in wavelength indicates the presence of new compounds that absorb in the mid-UV band (UV-B).

The change in color to a more pronounced yellow could be the result of a higher concentration of compounds that absorb in this band, or due to the formation of new compounds that are more effective at absorbing.

finding:

Spectra and colorimetric analysis before and after the reaction show that the electrolysis of camel urine, used to produce green hydrogen, leads to the degradation of the original organic compounds and the formation of new compounds. The transition from the absorption peak at 299.08 nm to 280 nm indicates the decomposition of large compounds into smaller compounds or the formation of new compounds with different absorption properties. These changes in absorbance correspond to a color shift from pale yellow to a more pronounced yellow, indicating changes in the chemical composition of the solution as a result of the reaction.

c. Dromedary Camel Urine Electrolysis

In the experiment, urine was used without any additives, and the montage adopted was Figure III.1. By bringing a flame to the informants, it was possible to ascertain the direction of the

hydrogen gas rise. This resulted in a crackle on the cathode side, while on the anode side, no such phenomenon occurred. This indicates that the hydrogen gas is released on the cathode side.

These are the results obtained:

Table.III.11: the results of using dromedary camel urine

T(min)	VH ₂ (ml)	VAn,gas	E(mv)
0	0	0	-63
10	14	6	-176,5
20	30	10	-173,6
30	44	20	-176,1
40	60	42	-196,1
50	76	80	-181,2
60	94	128	-142,9
70	108	154	-141,2
80	124	184	-130,6
90	142	188	44,1
100	165	196	48,2
110	176	198	49,9
120	196	204	45
130	210	214	46,4
140	230	240	44
150	248	288	50,6
160	268	326	44,9
170	292	364	45,8
180	310	444	45,6

c.1. Analyze the results

c.1.1. Analyze the results of the volume of hydrogen gas released

When the electric current reaches the cathode during urine electrolysis, water reduction occurs, producing hydrogen and hydroxides. In practice, the process can be described as follows:



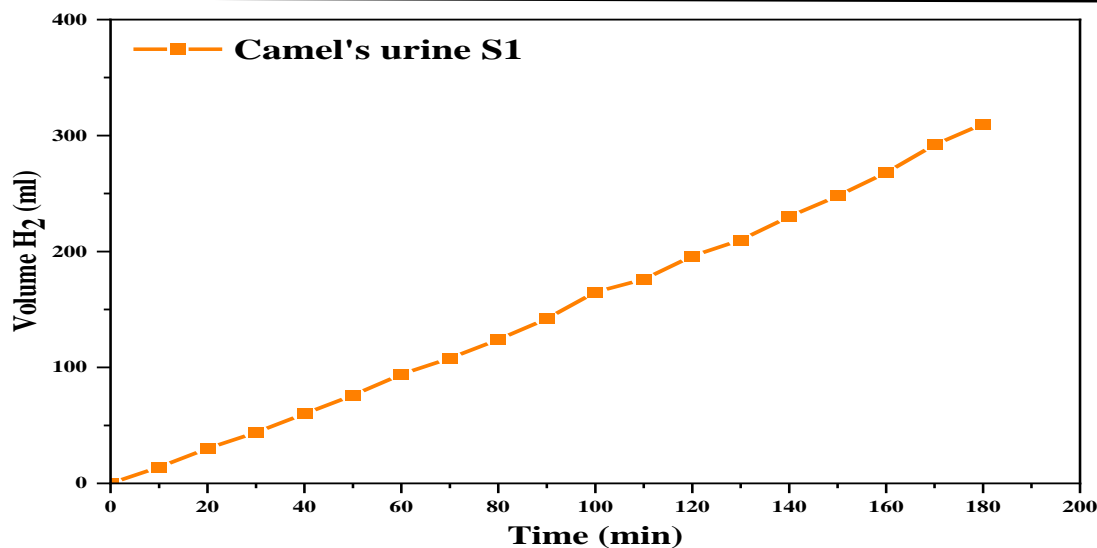


Fig.III.13: Graph representing the volume of hydrogen gas (V) as a function of time (T) of using dromedary camel urine.

➤ **Description of the graph:**

The graph represents the relationship between the volume of hydrogen gas produced (in ml) and time (in minutes) during the camel urine electrolysis process. The curve commences at zero at time 0 minutes and demonstrates a continuous increase in the volume of hydrogen gas until it reaches approximately 300 ml at time 180 minutes. At the outset of the reaction, a gradual increase in the volume of hydrogen gas produced can be observed. This phase reflects the time required for the electrical reaction to be catalyzed and for gas generation to commence. There may be a slight delay at the beginning until the solution is saturated with the ions necessary for the reaction.

The intermediate phase (20-120 minutes) is characterized by a steady and stable increase in the volume of hydrogen gas produced. The increase is almost linear during this period.

This phase indicates a high efficiency of the electrolysis process. The ions in camel urine provide an ideal environment for the continuous and constant generation of hydrogen. The ionization and chemical dissociation of organic ions and other compounds in the urine is regular.

The final stage (120-180 minutes) is characterized by a slight slowdown in the rate of increase in the hydrogen volume. The observed slowdown may be attributed to the accumulation of gases on the surface of the electrodes, which impairs the efficiency of the electrolysis process. Additionally, a gradual decline in the reactants necessary for the reaction may occur over time.

✓ Summary

The graph shows a clear stability in the process of hydrogen production from dromedary camel urine, reflecting the high efficiency of the electrolyzer used. The high efficiency in the intermediate stages indicates that camel urine contains suitable components that effectively support the process. However, some challenges may be encountered such as a slight slowdown in the final stages, which could be related to the accumulation of gases on the electrodes or the consumption of active substances in the urine. Overall, the research demonstrates a good and stable performance of the electrolysis process, highlighting the potential of using dromedary camel urine as an efficient source of hydrogen gas production, and the data indicates the effectiveness of the process over a reasonable period of time, with the possibility of overcoming minor challenges to improve the overall efficiency of the process.

c.1.2. Analyze the results of the volume of another gas released

The exact nature of the gases evolved at the anode level has not been determined due to the unavailability of some of the instrumentation needed to analyze the gases. That's why we call them another gas (An, gas). However, based on what has been reported in scientific articles on the electrolysis of urine, both human and animal, the gases that are typically produced at the anode level include

Nitrogen (N₂): Nitrogen is released in the process of urine electrolysis, which is useful in the context of converting the available nitrogen in the urine into other compounds or using it in various applications.

Sometimes **oxygen (O₂):** Oxygen may also be released at the anode, depending on the electrolysis conditions and the chemical composition of the urine.

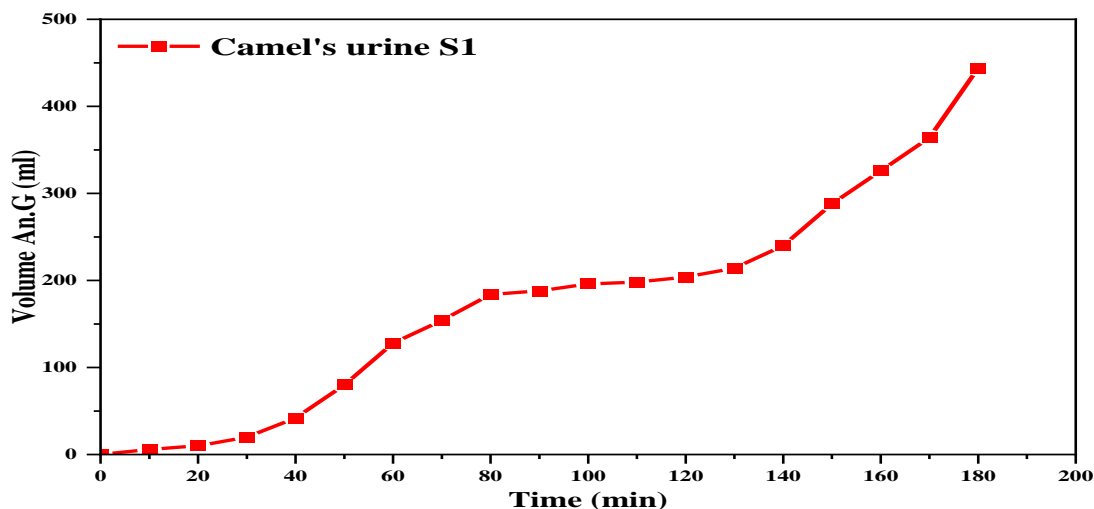


Fig.III.14: Graph representing the volume of another gas (V) as a function of time (T) of using dromedary camel urine.

➤ **Interpretation of the graph**

Start (0-30 minutes): At the beginning, the curve shows a slight increase in the volume of the rising gas. This indicates that the electrolysis reaction is starting slowly, possibly due to the time required to form the first layer of gas on the surface of the anode.

Gradual increase (30-60 minutes): A gradual increase in the volume of evolved gases is observed, indicating that the electrolysis process has become more active and stable. This can be the result of better composition of the gas layer and an improvement in the electrical conductivity of the urine.

Intermediate phase (60-120 minutes): The increase in gas volume continues to increase steadily, indicating that the electrolysis process has stabilized and continues to produce hydrogen efficiently. The high efficiency at this stage indicates that the components of camel urine are effectively supporting the reaction.

Sharp increase (120-180 minutes): A sharp increase in the volume of evolved gases is observed in the final stage, which may indicate that the efficiency of the reaction has increased significantly. This could be due to gas saturation of the electrodes and improved surface interactions.

Possible challenges: A slight slowdown at some points during the downstream phases could be an indication of gas accumulation on the electrodes or consumption of active substances in the urine, temporarily affecting the reaction efficiency.

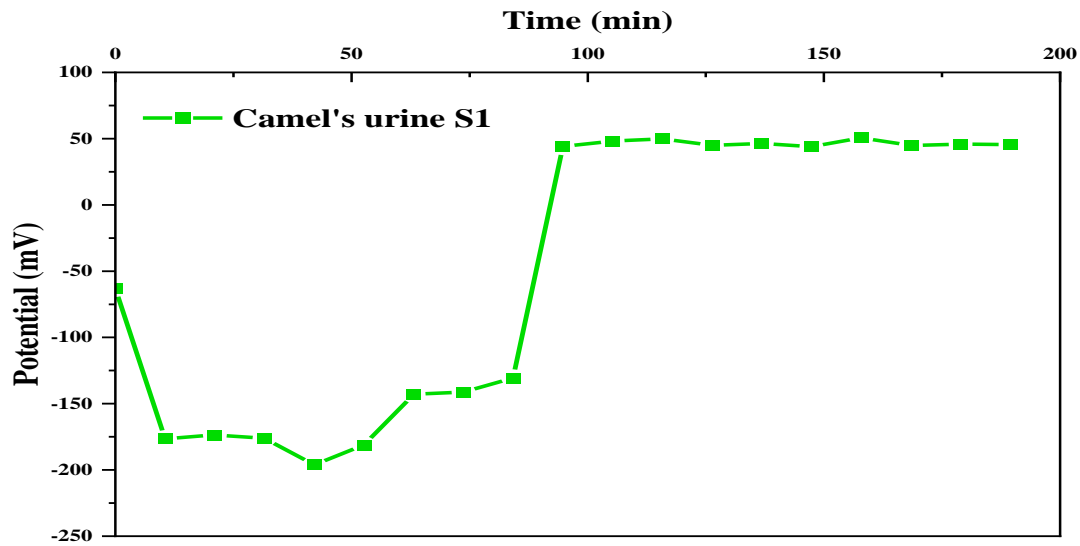
c.1.3. Analyze the measured potential results

Fig.III.15: A graph representing the potential (E) as a function of time (T) of using dromedary camel urine

❖ **Analysis**

Start (0-20 minutes): There is a rapid decrease in the potential difference to negative values.

Reason: When the system is turned on, ions start to move towards the electrodes, leading to the formation of an electric double layer at the electrodes and the initial reaction of the ions.

Middle phase (approximately 20-60 minutes): The potential difference stabilizes at a deep negative value.

➤ Reason: This stabilization is due to a dynamic equilibrium in the chemical reaction where the ions are in equilibrium with the electrodes, resulting in the stable production of hydrogen.

Transition (approximately 60-80 minutes): There is a rapid rise in the potential difference to values close to zero.

➤ Reason: Operational changes such as an increase in ion concentration, a modification in the electrolysis current, or a change in temperature can cause this spike. This reflects the optimization of the reaction efficiency or the removal of some obstacles.

Final Stabilization (80-200 minutes): Stabilization of the potential difference around a value close to zero.

➤ Reason: The system reaches a new equilibrium with improved chemical reaction efficiency and ion distribution, resulting in high efficiency hydrogen production.

❖ **Possible causes of the findings:**

- The composition of dromedary camel urine: Urine contains components such as salts and minerals that affect the potential difference.
- Ion concentration: Changes in ion concentration affect electrical and chemical reactions.
- Side reactions: Side reactions may occur that affect the potential difference.
- Change of electrodes: Accumulation of materials on the electrodes can change their efficiency.

III.4. Conclusion

In this chapter, the method adopted in the study for producing green hydrogen was reviewed, detailing the various stages of the experiment followed meticulously. Starting with the preparation of raw materials and the selection of appropriate equipment, through the process of electrolysis using solar energy, and finally to the collection and analysis of the resulting data. Through these stages, we successfully produced green hydrogen, presenting tangible and reliable results.

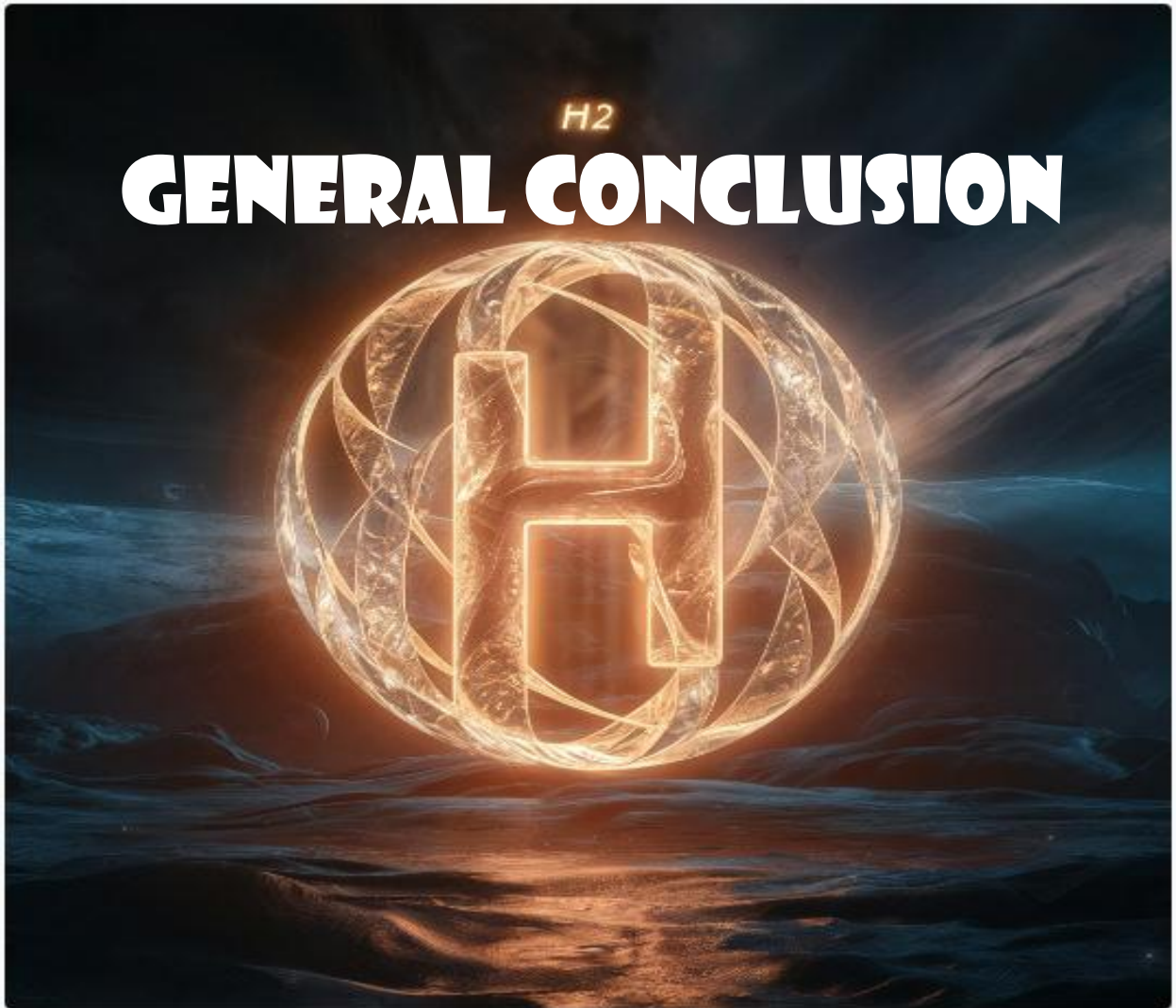
The main findings of this study involved improving the efficiency of hydrogen production by experimenting with two different methods. The first method, using distilled water with sodium hydroxide and potassium hydroxide, yielded impressive results in terms of production efficiency. The second method utilized dromedary camel urine, and although the production results were relatively low, the ability of urine to produce hydrogen without additives was a remarkable finding. These results were discussed in detail, highlighting the factors influencing production efficiency and providing scientific explanations for them.

Throughout the study, several challenges were encountered, particularly with the electrodes (cathode and anode). Two types of electrodes were tested: graphite electrodes and steel electrodes. When using steel electrodes, the anode, where oxygen gas is released, corroded, turning the solution in the cell orange. With graphite electrodes, the anode eroded at high electrolyte concentrations, while the cathode remained intact. Based on these observations, the recommendation is to use electrodes made from different materials: an anode made from a corrosion-resistant material such as platinum or titanium coated with ruthenium or iridium, and a cathode made from platinum, graphite, nickel, or steel. Additionally, it was observed that using graphite electrodes resulted in better production efficiency compared to steel.

By addressing these challenges and implementing the proposed solutions, the efficiency and reliability of green hydrogen production can be significantly enhanced.

H2

GENERAL CONCLUSION



General Conclusion

In this compelling study, we successfully produced green hydrogen using a simple electrolysis technique powered entirely by solar energy. What makes this achievement significant is the use of manually fabricated equipment, demonstrating the potential to maximize the efficiency and efficacy of the process in generating this clean and sustainable fuel.

At the outset of this study, we reviewed the history of green hydrogen and underscored its importance as an environmentally clean fuel. This was followed by a thorough discussion of production methods employing modern and efficient technologies that achieve the highest levels of efficiency. The second chapter focused on the challenges of hydrogen storage in its liquid, solid, and gaseous states, accompanied by a comprehensive analysis of the advantages of each type and their potential applications. Furthermore, we examined the impact of various storage technologies on the efficiency and safety of green hydrogen utilization.

In the experimental section of the study, we highlighted key results obtained. The methods employed, including the use of water with sodium hydroxide and potassium hydroxide, yielded remarkable outcomes in hydrogen production. Additionally, we successfully produced hydrogen from dromedary camel urine, emphasizing diverse analyses conducted on the sample before and after the reaction, indicating significant progress toward developing a sustainable and efficient production system.

Throughout the study, several challenges were encountered, particularly with the electrodes (cathode and anode). Two types of electrodes were tested: graphite electrodes and steel electrodes. When using steel electrodes, the anode, where oxygen gas is released, corroded, turning the solution in the cell orange. With graphite electrodes, the anode eroded at high electrolyte concentrations, while the cathode remained intact. Based on these observations, the recommendation is to use electrodes made from different materials: an anode made from a corrosion-resistant material such as platinum or titanium coated with ruthenium or iridium, and a cathode made from platinum, graphite, nickel, or steel. Additionally, it was observed that using graphite electrodes resulted in better production efficiency compared to steel.

This study represents not just an experiment but a promising start toward a bright future. We are dedicated to improving and advancing these technologies, exploring novel approaches to establish green hydrogen as a primary energy source globally. We hope this study contributes to

GENERAL CONCLUSION

enriching scientific and technological knowledge, serving as a cornerstone for future research aimed at enhancing and developing these pioneering technologies.

Our advancements in the field of green hydrogen present extensive opportunities for a more sustainable and plentiful future of clean energy, reinforcing our aspirations to build a safer and more prosperous world for future generations.



1. Calculate the rate of production of hydrogen gas

➤ **NaOH 5%**

Production rate for each time period:

Time period 0-10 minutes: $PR = \frac{150 - 0}{10 - 0} = 15.00ml/min$	Time period 90-100 minutes: $PR = \frac{1800 - 1650}{100 - 90} = 15.0ml/min$
Time period 10-20 minutes: $PR = \frac{350 - 150}{20 - 10} = 20.0ml/min$	Time period 100-110 minutes: $PR = \frac{2000 - 1800}{110 - 100} = 20.0ml/min$
Time period 20-30 minutes: $PR = \frac{550 - 350}{30 - 20} = 20.0ml/min$	Time period 110-120 minutes: $PR = \frac{2140 - 2000}{120 - 110} = 14.0ml/min$
Time period 30-40 minutes: $PR = \frac{750 - 550}{40 - 30} = 20.0ml/min$	Time period 120-130 minutes: $PR = \frac{2290 - 2140}{130 - 120} = 15.0ml/min$
Time period 40-50 minutes : $PR = \frac{950 - 750}{50 - 40} = 20.0ml/min$	Time period 130-140 minutes: $PR = \frac{2440 - 2290}{140 - 130} = 15.0ml/min$
Time period 50-60 minutes : $PR = \frac{1100 - 950}{60 - 50} = 15.0ml/min$	Time period 140-150 minutes: $PR = \frac{2590 - 2440}{150 - 140} = 15.0ml/min$

Appendix

Time period 60-70 minutes : $PR = \frac{1300 - 1100}{70 - 60} = 20.0ml/min$	Time period 150-160 minutes: $PR = \frac{2740 - 2590}{160 - 150} = 15.0ml/min$
Time period 70-80 minutes: $PR = \frac{1450 - 1300}{80 - 70} = 15.0ml/min$	Time period 160-170 minutes: $PR = \frac{2840 - 2740}{170 - 160} = 10.0ml/min$

And we rely on the same method for all concentration ratios of each electrolyte.

الجمهورية الجزائرية الديمقراطية الشعبية

وزارة التعليم العالي والبحث العلمي

جامعة محمد خيضر بسكرة

عنوان المشروع

الهيدروجين الأخضر

مشروع لنيل شهادة مؤسسة ناشئة في إطار القرار

الوزاري 1275

العلامة التجارية



الاسم التجاري

Green Hydrogen

بطاقة معلومات

حول فريق الاشراف وفريق العمل

1- فريق الاشراف:

فريق الاشراف	
المشرف الرئيسي (01): جاني فيصل	التخصص: كيمياء المواد
المشرف الرئيسي (02): أواس كمال	التخصص: هندسة الطاقة والمواد

1- فريق العمل:

فريق المشروع	التخصص	الكلية
الطالبة: رحموني أم هاني	كيمياء المواد	العلوم الدقيقة وعلوم الطبيعة والحياة

الفهرس

المحور الأول: تقديم المشروع

المحور الثاني: الجوانب الابتكارية

المحور الثالث: التحليل الاستراتيجي للسوق

المحور الرابع: خطة الإنتاج والتنظيم

المحور الخامس: الخطة المالية

المحور السادس: مخطط نموذج العمل BMC

المحور السابع: النموذج الاولي التجريبي

مشروع الهيدروجين الأخضر

المقدمة

يعد مشروع الهيدروجين الأخضر مبادرة رائدة تهدف إلى إنتاج الهيدروجين باستخدام مصادر الطاقة المتجددة مثل الرياح والطاقة الشمسية. يُطلق على هذا النوع من الهيدروجين "أخضر" لأنه لا ينتج عنه انبعاثات كربونية ضارة، مما يجعله خيارًا مستدامًا وصديقًا للبيئة.

يمثل المشروع استجابة ملهمة للتحديات العالمية المتعلقة بتغير المناخ، ويتطلع إلى أن يكون ركيزة أساسية في البنية التحتية للطاقة المستقبلية. يمتلك الهيدروجين الأخضر القدرة على تخزين الطاقة بشكل فعال واستخدامه في مجموعة متنوعة من التطبيقات الصناعية والنقل والكهرباء. علاوة على ذلك، يُتوقع أن يسهم المشروع في تعزيز النمو الاقتصادي من خلال خلق آلاف فرص العمل الجديدة ودعم الصناعات المحلية.

في ظل سعي العالم لتحقيق أهداف الاستدامة وتقليل البصمة الكربونية، يمثل الهيدروجين الأخضر حلاً مبتكرًا يمكنه تحويل مشهد الطاقة العالمي، مما يعزز مكانة المناطق ذات الظروف المناخية المثالية. مثل الجزائر كمراكز رئيسية لإنتاج الهيدروجين الأخضر.

مشروع الهيدروجين الأخضر

المحور الأول: تقديم المشروع

1. فكرة المشروع (الحل المقترح)

يتناول مشروع الهيدروجين الأخضر مجالات الطاقة المتجددة، حيث يهدف إلى إنتاج الهيدروجين باستخدام تقنيات التحليل الكهربائي المعتمدة على مصادر الطاقة النظيفة مثل الرياح والطاقة الشمسية، مع التركيز على إنتاج بديل وقود طبيعي صديق للبيئة. بدأت الفكرة من الحاجة الملحة لتقليل الاعتماد على الوقود الأحفوري وتخفيض انبعاثات الكربون لمكافحة التغير المناخي. مع تقدم تقنيات التحليل الكهربائي وزيادة الكفاءة، تطورت الفكرة لتشمل استخدام مصادر متجددة متنوعة. بالإضافة إلى ذلك، جاءت فكرة استخدام بول الجمل كمصدر للهيدروجين نتيجة أبحاث متقدمة ودراسات حول استخدام النفايات البيولوجية لإنتاج الطاقة النظيفة، مما أضاف بُعدًا بيئيًا واقتصاديًا للمشروع.

سنقوم بإنتاج بديل وقودا طبيعيا صديقا للبيئة ويتم ذلك بإنجاز خلايا التحليل الكهربائي للماء وبول الجمل بالاعتماد على أحدث التقنيات و المواد الأولية اللازمة لسير المشروع.

سيتم إنجاز المشروع في المناطق الصحراوية المعزولة عن السكان، مستفيدين من الموارد الطبيعية الغنية بالطاقة الشمسية والرياح المتوفرة في البلاد. ستقام منشآت الإنتاج في مناطق مختارة بعناية توفر الظروف المثالية للإنتاج الكبير والمستدام للهيدروجين الأخضر. كما سيتم إقامة منشآت تجريبية لاختبار تقنية التحليل الكهربائي لبول الجمل في مناطق توفر المواد الأولية المطلوبة. هذا النهج الشامل والمبتكر يضمن تحقيق أهداف المشروع ويعزز مكانة الجزائر في مجال الطاقة النظيفة والمستدامة.

2. القيم المقترحة

- ✓ استدامة بيئية: يسهم المشروع بشكل كبير في تقليل انبعاثات الغازات الدفيئة، مما يساعد في مكافحة التغير المناخي وتحسين جودة الهواء.
- ✓ تنوع مصادر الطاقة: يعزز المشروع تنوع مصادر الطاقة ويحد من الاعتماد على الوقود الأحفوري، مما يزيد من أمن الطاقة واستقرارها.

مشروع الهيدروجين الأخضر

- ✓ خلق فرص عمل: تطوير صناعة الهيدروجين الأخضر يفتح أبواباً جديدة للتوظيف في مجالات متعددة مثل الهندسة والتصنيع والبناء والصيانة.
- ✓ الاستقلالية الطاقوية: يمكن للجزائر تحقيق استقلالية طاقوية أكبر من خلال استغلال مواردها الطبيعية الوفيرة من الرياح والشمس لإنتاج الهيدروجين الأخضر.
- ✓ جذب الاستثمارات: يمكن للمشروع جذب استثمارات دولية ومحلية في قطاع الطاقة المتجددة، مما يعزز الاقتصاد المحلي.
- ✓ تشجيع البحث والتطوير: مثل تحفيز البحث العلمي حيث ان مشروع الهيدروجين الأخضر يدفع المؤسسات الأكاديمية ومراكز البحث إلى التركيز على تطوير تقنيات جديدة في مجالات التحليل الكهربائي وإنتاج الطاقة المتجددة. يمكن أن يؤدي هذا إلى اكتشافات تكنولوجية جديدة وتحسينات في العمليات القائمة.

3. أهداف المشروع

نسعى من خلال هذا المشروع إلى إنتاج بديل وقود طبيعي صديق للبيئة مستخرج من موارد طبيعية، وإنشاء بنية تحتية لتخزينه، وتعزيز الابتكار والتطوير المستدام لتحقيق هذه الأهداف. وفي المراحل التالية، نسعى لاستغلال مياه الصرف الصحي أو بول الإنسان كجزء من استراتيجية شاملة لإدارة الموارد المائية بفعالية لإنتاج الهيدروجين الأخضر. هذا المشروع ليس فقط خطوة نحو تأمين احتياجاتنا الطاقوية، بل هو أيضاً مساهمة في مكافحة التغير المناخي وتعزيز استخدام الطاقة النظيفة.

مشروع الهيدروجين الأخضر

المحور الثاني: الجوانب الابتكارية

نقدم مشروعًا مبتكرًا وجديدًا في الجزائر، حيث يعتمد على استخدام بول الجمل لإنتاج الهيدروجين الأخضر، مما يمثل خطوة هامة نحو مستقبل أكثر استدامة ونظافة في الطاقة. يتم توليد الكهرباء الضرورية لعملية التحليل الكهربائي، سواء للماء أو لبول الجمل، باستخدام موارد الطاقة المتجددة المتاحة بوفرة في منطقة بسكرة، مثل الطاقة الشمسية. يهدف المشروع إلى تحقيق كفاءة عالية وتقليل التكاليف، مع التركيز على الحد من الأثر البيئي السلبي. هذه الخطوة ليست فقط مبتكرة بل أيضًا تحدث تغييرًا إيجابيًا في مجتمعنا وتساهم في تعزيز استدامة مواردها الطبيعية.

مشروع الهيدروجين الأخضر

المحور الثالث: التحليل الاستراتيجي للسوق

1. السوق المحتمل للسوق

- ✓ شركات النفط والغاز الموجودة على مستوى مدينة بسكرة وضواحيها
- ✓ محطات توليد الطاقة: التي يمكن أن تستخدم الهيدروجين كوقود لتوليد الكهرباء.

2. السوق المستهدف

- ✓ شركات النقل العام
- ✓ مصانع الصلب والكيماويات في الجزائر: لاستخدام الهيدروجين في العمليات الصناعية.

3. مبررات اختيار السوق المستهدف

الطلب المتزايد على الطاقة النظيفة: هناك اتجاه عالمي ومحلي نحو استخدام الطاقة النظيفة للحد من التلوث البيئي، مما يجعل شركات النقل العام ومصانع الصلب والكيماويات أهدافاً رئيسية.

السياسات الحكومية الداعمة: الحكومة الجزائرية تشجع مشاريع الطاقة النظيفة وتقدم حوافز وتشريعات داعمة.

التفرد والابتكار: المشروع يقدم حلاً فريداً باستخدام بول الجمال، مما يعزز الابتكار ويجذب اهتمام الجهات المستهدفة.

4. تحليل PESTEL

تحليل PESTEL يساعد في فهم البيئة الخارجية التي يمكن أن تؤثر على مشروع إنتاج الهيدروجين الأخضر. يتضمن التحليل العوامل التالية:

مشروع الهيدروجين الأخضر

الجدول 1: تحليل PESTEL

العوامل	التأثير الإيجابي	التأثير السلبي
السياسية	الدعم الحكومي والسياسات المشجعة للطاقة المتجددة يمكن أن توفر تمويلاً وإعفاءات ضريبية	قلة الدعم الحكومي وغياب السياسات المشجعة للطاقة المتجددة
الاقتصادية	زيادة الاستثمارات في الطاقة المتجددة يمكن أن يدعم النمو المستدام للمشروع	التكاليف: كالتنقل والتخزين
الاجتماعية	زيادة الوعي البيئي ودعم المجتمع لمشاريع الطاقة النظيفة يمكن أن يعزز قبول المشروع	نقص الوعي أو المعارضة من بعض الفئات المجتمعية قد يعوق تنفيذ المشروع
التكنولوجية	التقدم التكنولوجي يمكن أن يحسن كفاءة الإنتاج ويقلل التكاليف	الاعتماد على التكنولوجيا المتقدمة قد يتطلب استثمارات عالية وتدريب مستمر
البيئية	الامتثال للمعايير البيئية يمكن أن يعزز سمعة المشروع ويساهم في حماية البيئة	التحديات البيئية مثل توافر الموارد الطبيعية والمخاوف البيئية قد تعرقل المشروع

5 . تحليل PORTER

تحليل قوى بورتر الخمس يساعد في تقييم قوة السوق والمنافسة:

الجدول 2: تحليل PORTER

العنصر	الوصف	التأثير
الموردون	<ul style="list-style-type: none"> مربي الجمال: يوفرون بول الجمال كمواد خام أساسية للمشروع. مزودي المعدات: يقدمون المعدات اللازمة لعملية التحليل الكهربائي. 	نجاح المشروع يعتمد على بناء علاقات قوية ومستدامة مع الموردين لضمان توافر المواد الخام بجودة عالية وتكاليف معقولة.
المنافسون	<ul style="list-style-type: none"> مشاريع الهيدروجين الأخضر الأخرى: نظرًا لأن إنتاج الهيدروجين الأخضر باستخدام بول 	يجب مراقبة التقدم في المشاريع الأخرى والتقنيات

مشروع الهيدروجين الأخضر

البديلة لضمان القدرة على التكيف والتطوير المستمر.	الجمال هو فكرة جديدة في الجزائر، فإن المنافسة المحلية المباشرة قد تكون ضئيلة.	
توفر الحواجز العالية للدخول ميزة تنافسية، لكن من الضروري الاستمرار في الابتكار والبقاء في الطليعة.	<ul style="list-style-type: none"> التكاليف الرأسمالية الكبيرة: سوق إنتاج الهيدروجين الأخضر قد يجذب أصحاب رؤوس الأموال الكبيرة الذين يمكنهم تمويل مشاريع مماثلة. التقدم التكنولوجي: التطورات التكنولوجية قد تقلل من حواجز الدخول وتزيد من المنافسة. 	تهديدات من دخول منافسين جدد
يجب أن يقدم الهيدروجين الأخضر مزايا بيئية واقتصادية مقارنة بالبدائل الأخرى ليكون جذابًا للزبائن، وذلك من خلال تحسين الكفاءة وخفض التكلفة.	<ul style="list-style-type: none"> الوقود الأحفوري: يشمل النفط والغاز الطبيعي. 	المنتجات البديلة

6. تحليل SWOT

الجدول 3: تحليل SWOT

الوصف	العنصر
<ul style="list-style-type: none"> الابتكار والتفرد: استخدام بول الجمل لإنتاج الهيدروجين الأخضر، الأول من نوعه في الجزائر. الدعم الحكومي محتمل: السياسات الحكومية الداعمة للمشاريع البيئية والتكنولوجيا النظيفة. الموارد الطبيعية المتاحة: توفر مصادر متجددة لتوليد الكهرباء اللازمة لعملية التحليل الكهربائي. 	نقاط القوة
<ul style="list-style-type: none"> قلة الخبرة والتطبيق: قلة الخبرة في تكنولوجيا الهيدروجين الأخضر في الجزائر. تكاليف بداية عالية: الحاجة إلى استثمارات كبيرة للتأسيس والتشغيل. 	نقاط الضعف

مشروع الهيدروجين الأخضر

<ul style="list-style-type: none"> ● التوعية المحدودة: نقص الوعي بفوائد الهيدروجين الأخضر بين المستهلكين والشركات. 	
<ul style="list-style-type: none"> ● زيادة الطلب على الطاقة النظيفة: الطلب المحلي والدولي المتزايد على الطاقة النظيفة والمستدامة. ● الدعم الدولي: الحصول على التمويل والدعم 	الفرص
<ul style="list-style-type: none"> ● منافسة محتملة: دخول منافسين جدد إلى السوق مع تقنيات إنتاج مشابهة. ● تقلبات أسعار الطاقة: التغيرات في أسعار الطاقة العالمية التي قد تؤثر على التكاليف والربحية. 	التحديات

7. دراسة المزيج التسويقي لمشروع إنتاج الهيدروجين الأخضر

1.7. المنتج (Product)

❖ الوصف: الهيدروجين الأخضر المنتج باستخدام بول الجمل من خلال عملية التحليل الكهربائي.
❖ الخصائص:

- صديق للبيئة وخالي من الانبعاثات الكربونية.
- يمكن استخدامه في مجموعة متنوعة من التطبيقات بما في ذلك النقل والصناعة وتوليد الطاقة.
- أول منتج من نوعه في الجزائر، مما يمنحه ميزة فريدة.

❖ الفوائد:

- يساهم في تقليل التلوث البيئي.
- يوفر مصدر طاقة مستدام.
- يدعم الاستقلال الطاقوي للجزائر من خلال استخدام موارد محلية..

2.7 السعر (Price)

❖ استراتيجية التسعير:

- التسعير التنافسي: تقديم الهيدروجين الأخضر بسعر تنافسي مقارنة بالوقود التقليدي والهيدروجين المستورد.
- التسعير القيمي: التركيز على الفوائد البيئية والصحية للهيدروجين الأخضر لتبرير سعر أعلى نسبيًا إذا لزم الأمر.

مشروع الهيدروجين الأخضر

❖ الاعتبارات:

- التكاليف الأولية للإنتاج والتكنولوجيا.
- التسعير الترويجي في المراحل الأولى لتحفيز الاعتماد المبكر.

3.7. الترويج (Promotion)

❖ استراتيجية الترويج:

- التسويق المباشر: التواصل مع الشركات الصناعية وشركات النفط والغاز ومؤسسات الحكومة المحلية لتقديم المنتج والفوائد.
- التسويق الرقمي: استخدام وسائل التواصل الاجتماعي والمواقع الإلكترونية للتعريف بالهيدروجين الأخضر وفوائده.
- العلاقات العامة: عقد مؤتمرات وندوات حول أهمية الهيدروجين الأخضر والابتكار في استخدام بول الجمل.
- العروض الترويجية: تقديم عروض تجريبية وأسعار مخفضة في المراحل الأولى لجذب العملاء.

4.7. مكان التسويق (Place)

إنشاء شبكة توزيع مباشرة مع الشركات الصناعية وشركات النقل ومحطات توليد الطاقة. التعاون مع الموزعين المحليين وشركات النفط والغاز لتوسيع نطاق التسويق.

5.7. المستهلك (Customer)

الشركات الصناعية: يمكن استخدام الهيدروجين الأخضر كبديل نظيف للوقود الأحفوري في العمليات الصناعية. شركات توليد الطاقة: استخدام الهيدروجين الأخضر كمصدر للطاقة المتجددة في محطات توليد الكهرباء.

مشروع الهيدروجين الأخضر

6.7. الأفراد (People)

المسؤول:

مسؤول المشروع الذي يتولى إدارة المشروع.

المهندسون:

مهندس كيميائي: متخصص في تكنولوجيا التحليل الكهربائي وإنتاج الهيدروجين الأخضر.

مهندس طاقة وكهرباء: متخصص في تصميم وتنفيذ عملية التحليل الكهربائي وإنتاج الهيدروجين.

7.7. العلامة التجارية (Brand)



الشعار: يعبر عن الطاقة المتجددة والهيدروجين الأخضر.

الألوان: استخدام ألوان العلم الجزائري مع رموز الطبيعة والطاقة.

الالتزام بالاستدامة البيئية.

استخدام موارد محلية مبتكرة (بول الجمل).

التميز: المنتج الأول من نوعه في الجزائر.

8. تحليل السوق

❖ الزبون: شركات النفط والغاز.

❖ تحليل المنافسين المتوقعين:

مشروع الهيدروجين الأخضر

1. شركة سوناطراك (Sonatrach)

المميزات:

- خبرة واسعة: تمتلك خبرة طويلة في مجال الطاقة والإنتاج.
- دعم حكومي قوي: تحظى بدعم كبير من الحكومة الجزائرية.
- بنية تحتية متطورة: تمتلك شبكة بنية تحتية قوية في قطاع الطاقة.

العيوب:

- التوجه نحو النفط والغاز: تركز بشكل رئيسي على النفط والغاز التقليدي، وليس على الطاقات المتجددة.
- بيروقراطية معقدة: تعاني من بطء العمليات والإجراءات بسبب البيروقراطية.

2. شركة سونلغاز (Sonelgaz)

المميزات:

- استثمارات في الطاقة المتجددة: بدأت في الاستثمار في مشاريع الطاقة المتجددة مثل الطاقة الشمسية والرياح.
- شبكة توزيع واسعة: تمتلك شبكة توزيع واسعة للطاقة الكهربائية في الجزائر.

العيوب:

- تكاليف تشغيل مرتفعة: تواجه تكاليف تشغيلية عالية تؤثر على قدرتها التنافسية.
- اعتماد كبير على الطاقة التقليدية: تركز بشكل أكبر على مصادر الطاقة التقليدية مقارنة بالمتجددة.

3. شركة نفطال (Naftal)

المميزات:

- شبكة توزيع قوية: تمتلك شبكة واسعة لتوزيع الوقود في جميع أنحاء الجزائر.
- توجه نحو الطاقة النظيفة: بدأت في استكشاف مصادر طاقة أنظف لتلبية الطلب المتزايد.

العيوب:

مشروع الهيدروجين الأخضر

- بنية تحتية قديمة: بعض منشآتها تحتاج إلى تحديث لتتماشى مع المعايير الحديثة.
- محدودية التركيز على الهيدروجين: لا تركز بشكل كبير على إنتاج وتوزيع الهيدروجين الأخضر.

❖ تحليل الموردين

الموردون

مربي الجمال:

- مميزات: توفر مورد مستدام (بول الجمال) وسهل الحصول عليه.

- الموقع: لوطاية، الحاجب، طولقة، الحوش , لقنطرة

- المادة: بول الجمال، مصدر متجدد وغير مكلف.

محطات تحلية المياه لتوفير الماء المقطر، ومزودي المواد الكيميائية:

المميزات: توفر المواد الأولية بشكل محلي، انخفاض تكلفة النقل، ودعم الاقتصاد المحلي

الموقع:

9. الاستراتيجية التسويقية

لضمان نجاح استراتيجية التسويق لمشروع الهيدروجين الأخضر في الجزائر، يتعين علينا الحرص على توازن المزيج التسويقي بشكل متناسق. يجب أن نركز على تطوير التقنيات المستعملة في إنتاج الهيدروجين الأخضر لجعله يتميز بالجودة والاستدامة، وتلبية احتياجات السوق المحلية بشكل فعال. بالإضافة إلى ذلك، ينبغي لنا تحديد سياسات تسعير مناسبة تعكس القيمة المضافة للمنتجات مع الأخذ في الاعتبار التنافسية وتوفير قيمة اقتصادية للعملاء. علاوة على ذلك، يتطلب الأمر بناء شبكة توزيع فعالة تضمن توفر المنتجات بشكل مستمر وفي الأماكن المناسبة بالتعاون مع شركاء محليين موثوقين. استخدام وسائل التواصل الاجتماعي والتسويق الرقمي يعزز من وعي العلامة التجارية ويسهم في زيادة التفاعل مع العملاء المحتملين، في حين يتطلب تطوير الاستراتيجيات الدعائية المبتكرة لتسليط الضوء على فوائد ومزايا الهيدروجين الأخضر بطريقة جذابة. وأخيراً، يجب أن تتميز الخدمة العملاء بالتميز لتعزيز رضا العملاء وبناء علاقات دائمة ومستدامة، مما يساهم في نجاح المشروع واستقراره في السوق الجزائرية.

مشروع الهيدروجين الأخضر

10. تقدير المبيعات لمشروع الهيدروجين الأخضر:

لقد استندت في إعداد جدول الإنتاج اليومي على التجربة الصغيرة التي أجريتها باستخدام بول الجمل كمصدر طبيعي. في هذه التجربة الأولية، تم تحقيق إنتاج محدود من الهيدروجين الأخضر على مدى فترة زمنية قصيرة، مما سمح لنا بفهم العملية وتقييم كفاءتها. ومع ذلك، فإن الإمكانيات الحقيقية للمشروع تبرز عند النظر إلى التوسع والتطوير المستمرين.

في الواقع، مع الاستثمارات المناسبة في البنية التحتية والمعدات، فضلاً عن تحسين العمليات وزيادة الكفاءة، يمكن للمشروع تحقيق إنتاج أكبر بكثير. نهدف إلى مضاعفة الإنتاج من خلال زيادة ساعات العمل اليومية باستخدام الطاقة الشمسية والطاقة المخزنة، بالإضافة إلى تحسين تقنيات الاستخراج والتخزين. هذا التوسع لن يؤدي فقط إلى زيادة الكميات المنتجة، بل سيسهم أيضاً في تحقيق استدامة أكبر للمشروع وتوفير طاقة نظيفة بأسعار تنافسية.

بالتالي، فإن الجدول الحالي للإنتاج اليومي يعتبر نقطة انطلاق تعتمد على النتائج الأولية، بينما نعمل جاهدين على توسيع نطاق العمليات وتحقيق إمكانيات إنتاجية أكبر بكثير في المستقبل القريب.

الجدول 4: تقدير الإنتاج اليومي من الهيدروجين الأخضر المنتج من بول الجمل

البند	القيمة
كمية بول الجمل اليومية	2.67 لتر
حجم ساعات العمل	16 ساعة (8 بالطاقة الشمسية + 8 بالطاقة المخزنة)
سعة الإنتاج في اليوم	16.28 كيلوغرام
أيام العمل في الشهر	25 يوم
أيام العمل في السنة	300 يوم
نسبة الهدر	نسبة الهدر غير معروفة حالياً

بناءً على المقال المنشور حول مشروع وهران ارزيو للهيدروجين الأخضر، قمت بإجراء حسابات دقيقة لتقدير الإيرادات المتوقعة للمشروع. استناداً إلى الإنتاج المتوقع والسعر المحدد للهيدروجين، وصلت إلى النتائج التالية:

مشروع الهيدروجين الأخضر

تم حساب الإيرادات السنوية بالدينار الجزائري بناءً على إنتاج سنوي يبلغ 2,442 كيلوغرام من الهيدروجين الأخضر. بفضل السعر المقرر للهيدروجين بمقدار 2 دولار لكل كيلوغرام، فإن الإيرادات المتوقعة للمشروع بلغت حوالي 1,316,502.48 دينار جزائري سنويًا.

الجدول 5: تقدير مبيعات الهيدروجين الأخضر المنتج من بول الجمل.

البند	القيمة
الإنتاج السنوي للهيدروجين (كيلوغرام)	4884
كمية المخزون خلال السنة (كيلوغرام)	لا يوجد مخزون متبقي
الوزن الصافي للإنتاج (كيلوغرام)	4884
عدد الوحدات المباعة (كيلوغرام)	4884
ثمن الكيلوغرام الواحد (دينار جزائري)	269.22
إيرادات المبيعات خلال السنة (دينار جزائري)	1,316,502.48

وعند استعمال الماء المقطر بإضافة الالكترووليت اللازم لإتمام عملية التحليل الكهربائي لإنتاج الهيدروجين الأخضر نجد ان:

الجدول 6: تقدير الإنتاج اليومي للهيدروجين الأخضر باستعمال الماء والالكترووليت

البند	القيمة
كمية المحلول اليومية	6 لتر
حجم ساعات العمل	16 ساعة (8 بالطاقة الشمسية + 8 بالطاقة المخزنة)
سعة الإنتاج في اليوم	100 كيلوغرام
أيام العمل في الشهر	25 يوم
أيام العمل في السنة	300 يوم
نسبة الهدر	نسبة الهدر غير معروفة حاليًا

مشروع الهيدروجين الأخضر

الجدول 7: تقدير مبيعات الهيدروجين الأخضر المنتج من الماء المقطر بإضافة بعض من الالكتروليت.

القيمة	البند
30000	الإنتاج السنوي للهيدروجين (كيلوغرام)
لا يوجد مخزون متبقي	كمية المخزون خلال السنة (كيلوغرام)
30000	الوزن الصافي للإنتاج (كيلوغرام)
30000	عدد الوحدات المباعة (كيلوغرام)
336.53	ثمن الكيلوغرام الواحد (دينار جزائري)
10,095,900,00	إيرادات المبيعات خلال السنة (دينار جزائري)

مشروع الهيدروجين الأخضر

المحور الرابع: خطة الإنتاج والتنظيم

خطة الإنتاج

1. اختيار الموقع الجغرافي

تبلغ المساحة التقريبية المطلوبة لإنشاء المصنع بالكامل 10 هكتار للإنتاج الجيد، حيث نحتاج الى ارض تكون مبنية جزئيا الجزء المبني سيكون خاص بالمخبر والجزء الاخر سيخصص للبنية التحتية للتخزين ولتنبيت الألواح الشمسية. من المتوقع أن يكون المبنى للإيجار. ويكون الموقع قريب من مدينة بسكرة وبتحديد قريب من موقع الموردن (لوطاية...)



الشكل.1: تخطيط افتراضي للمشروع

مشروع الهيدروجين الأخضر

2. طبيعة الإنتاج:

انتاج الهيدروجين الأخضر

3. الطاقة الإنتاجية:

4. المواد الأولية

1.4. عند استعمال بول الجمل

المادة	المصدر	الكمية	السعر
بول الجمل	مربي الجمال	800 لتر	1600.00 دج

2.4. عند استعمال الماء المقطر بإضافة الالكتروليت

المادة	المصدر	الكمية	السعر
الماء المقطر	بائعين المواد الكيميائية	2190 لتر	5475.00
الالكتروليت (KOH، NaOH)	بائعين المواد الكيميائية	300 كلغ	90000.00 دج

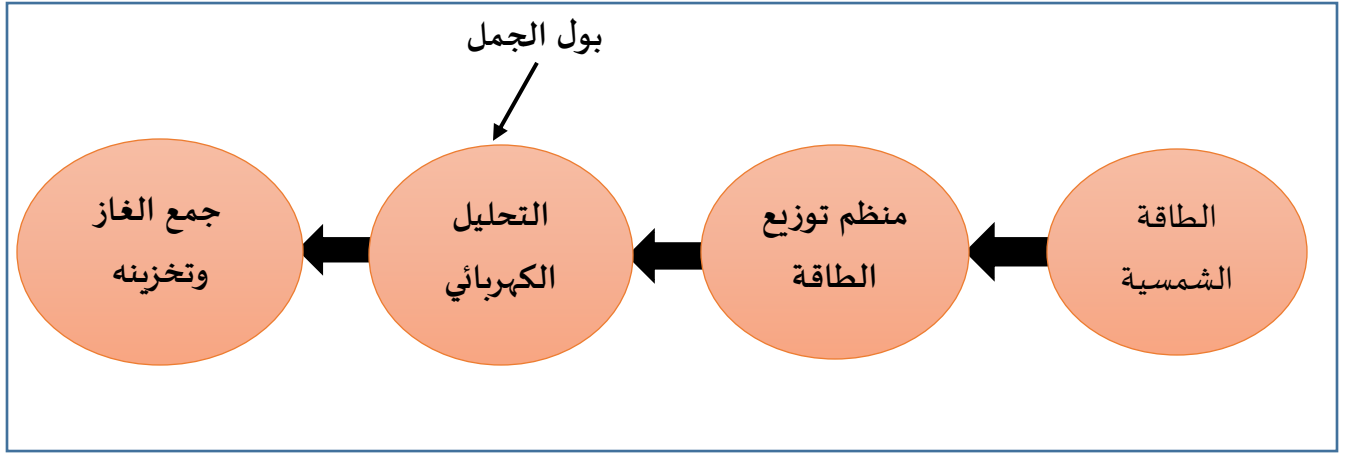
5. عدد العمال:

العامل	العدد	المهام	الاجر الشهري لكل عامل دج
مهندس الكيمياء	1	تصميم وتنفيذ عمليات إنتاج الهيدروجين، تطوير تكنولوجيا التحليل الكهربائي.	80000.00
مهندس كهرباء والطاقة	1	إدارة أنظمة الطاقة الكهربائية المستخدمة في الإنتاج، تحسين كفاءة الطاقة.	70000.00

ملاحظة ستكون الأجور خام وصافية تشمل الضمان الاجتماعي والضريبة عند الدخل الإجمالي

مشروع الهيدروجين الأخضر

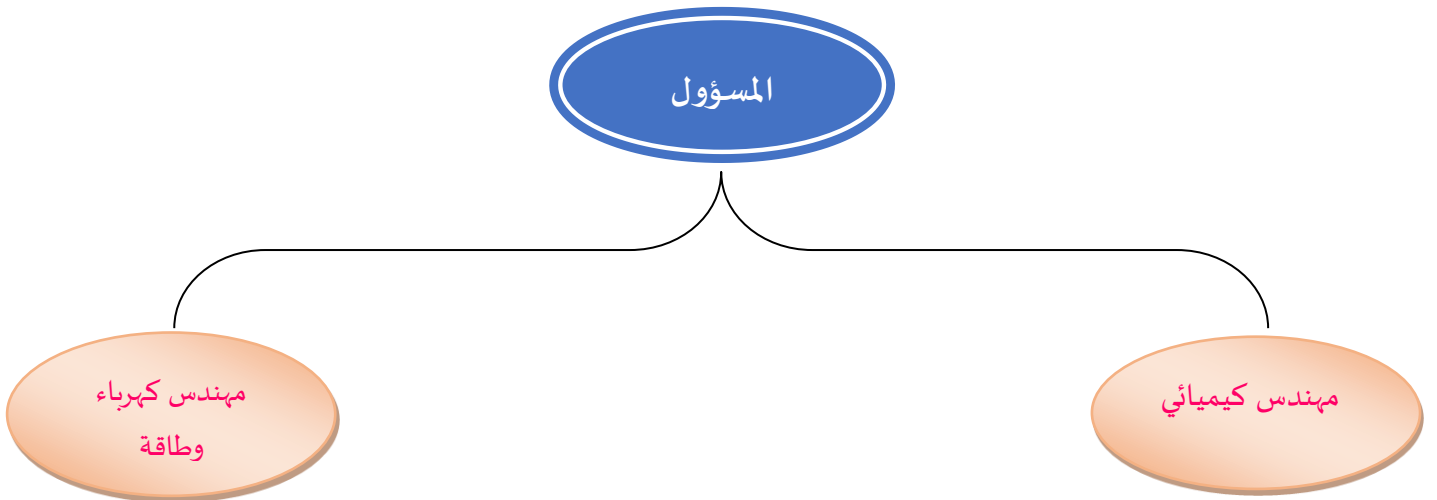
1.5. خطة الإنتاج



الشكل 2: خطة إنتاج الهيدروجين الأخضر

2.5. خطة التنظيم

يمثل هذا المخطط هيكلًا تنظيميًا بسيطًا وواضحًا يعكس التنظيم الهرمي لمشروع إنتاج الهيدروجين الأخضر، مع تدرج من الإدارة العامة إلى الفنيين الذين يقومون بالعمل اليومي في المشروع.



الشكل 3: مخطط تنظيمي مبسط يوضح الهيكل التنظيمي لمشروع إنتاج الهيدروجين الأخضر

مشروع الهيدروجين الأخضر

المحور الخامس: الخطة المالية PLAN FINANCIER

1. المصاريف التأسيسية

التكلفة (دج)	
200.00	السجل التجاري
500.00	مصاريف حماية العلامة التجارية
700.00	اجمالي المصاريف

2. المصاريف الاستثمارية

السعر (دج)	الكمية	
3000000.00	قطعة ارض مساحتها 1000 متر مربع وتكون مبنية جزئيا الجزء المبني سيكون خاص بالمخبر والجزء الاخر سيخصص لتثبيت الالواح الشمسية و وضع خزانات الغاز ولإنشاء البنية التحتية من المتوقع اننا سنشتري المبني	الموقع
36100.00	2	الالواح الشمسية 190 واط
1746495.40	1	مخبر كيميائي كامل التجهيز
27,000,00	2	خزانات جمع الغاز
140000.00	2	أجهزة كومبيوتر مبرمجة على اظهار نتائج أجهزة التحليل
3,375,000	1	جهاز كروماتوغرافيا الغاز (GC)
47250.00	1	جهاز التحليل الطيفي بالأشعة تحت الحمراء (Infrared Spectroscopy)

مشروع الهيدروجين الأخضر

80000.00	1	كاشفات الأمونيا الإلكترونية (Electronic Ammonia Detectors):
75000.00	1	مبرد جمع وتبريد البول
2025000 .00	1	خلايا التحليل الكهربائي بجميع التجهيزات
11.174.24	2	نظام الكتروني يعمل بالاستشعار لقياس حجم الغاز المنتج مستشعر غاز الهيدروجين اردوينو نظام مبرمج على جهاز الحاسوب للتسجيل كمية الغاز
50000.00	1	نظام الشبكة والانترنات
80000.00	1	مكيفات هوائية
7351769.64		اجمالي المصاريف

3. التكاليف التشغيلية

التكلفة دج	
500.00 شهريا	المادة الأولية
150000.00 شهريا	اجمالي الأجور
1806000.00	المجموع السنوي

مشروع الهيدروجين الأخضر

4. الإيرادات المتوقعة

أ. الهيدروجين المنتج الماء المقطر

الأصول	التكلفة
الإنتاج السنوي (كيلو غرام)	300000
ثمن الكيلو غرام الواحد	336.55 دج
إيرادات المبيعات السنوية	10,095,900.00 دج

ب. الهيدروجين المنتج من بول الجمل

الأصول	التكلفة
الإنتاج السنوي (كيلو غرام)	4884
ثمن الكيلو غرام الواحد	269.22 دج
إيرادات المبيعات السنوية	1,316,502.48 دج

مشروع الهيدروجين الأخضر

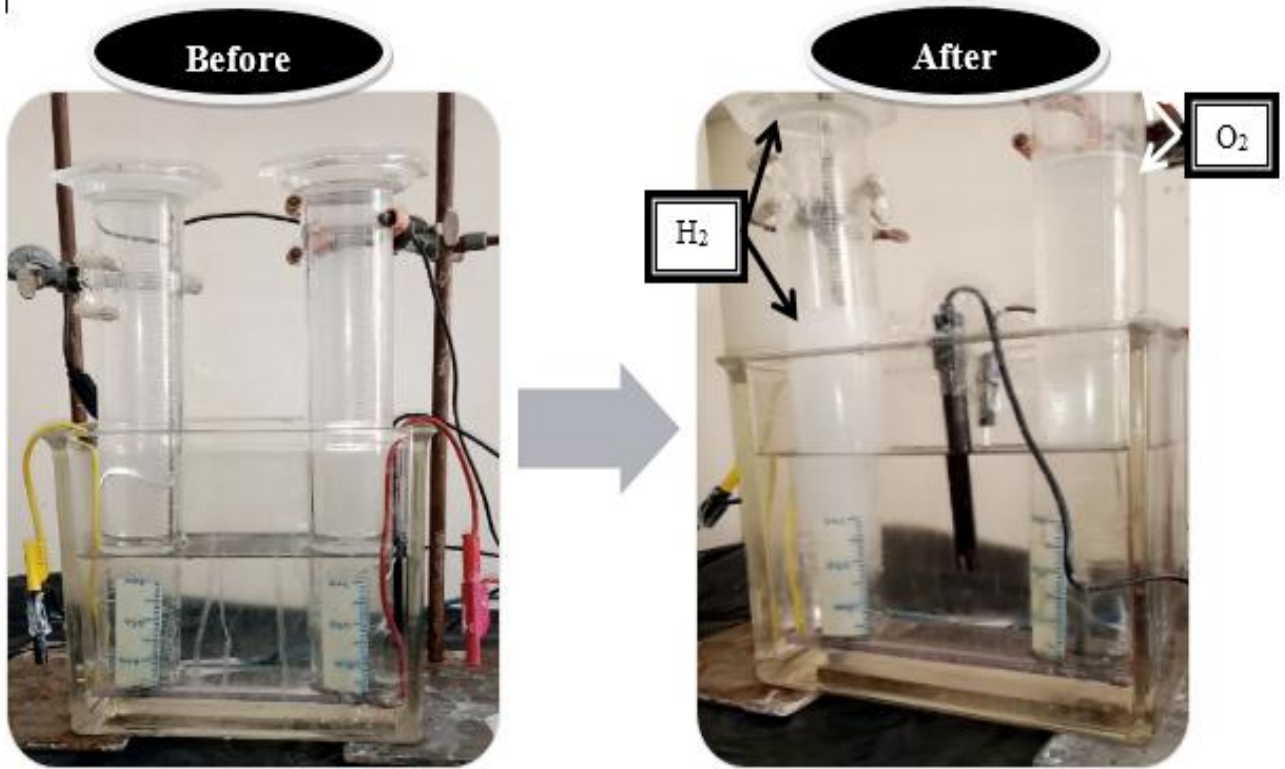
المحور السادس: مخطط نموذج العمل BMC

<p><u>الشراكات الرئيسية</u></p> <p>شركة التوصيل</p>	<p><u>النشاطات الرئيسية</u></p> <p>انتاج الهيدروجين الأخضر انتاج طاقة</p> <p><u>الموارد الرئيسية</u></p> <p>الموارد الطبيعية "الكهرباء من الطاقة الشمسية والمواد الأولية" الموارد البشرية "العمال" الموارد المادية "الأجهزة والمعدات"</p>	<p><u>القيمة المقدمة</u></p> <p>مصدر نظيف للطاقة وخال من الانبعاثات الضارة. تقديم حلا بيئيا ومستداما لمشاكل التلوث وتغير المناخ. الابتكار: استغلال بول الجمل لإنتاج الهيدروجين.</p>	<p><u>العلاقات مع الزبائن</u></p> <p>علاقة مباشرة: - تقديم الدعم والتوجيه للوكلاء.</p> <p><u>القنوات</u></p> <p>حملات إعلانية للترويج للمشروع. توصيل المنتج عن طريق شركات التوصيل</p>	<p><u>شرائح العملاء</u></p> <p>-B to B:</p> <p>شركات النفط والغاز المستشفيات ومراكز الصحة</p>
<p><u>هيكل التكاليف</u></p> <p>تكاليف البنية التحتية والمعدات تكاليف المواد الخام تكاليف العمالة مصاريف النقل البحث والتطوير</p>		<p><u>الإيرادات</u></p> <p>مبيعات المنتج</p>		

مشروع الهيدروجين الأخضر

المحور السابع: النموذج الاولي التجريبي

ان هدف هذه الدراسة انتاج الهيدروجين الأخضر باستخدام بول الجمل، والأهم من ذلك هو طريقة انتاجه و الوصول الى اكتشاف افضل الشروط للإنتاج الجيد. حيث تم في هذه الدراسة الاعتماد على تقنية التحليل الكهربائي البسيط، وذلك بواسطة خلية زجاجية واستعمال اقطاب من مادة الغرافيت . النموذج كالتالي:



الخلية الموضحة في النموذج تحتوي داخلها أقطابا من الغرافيت. يتضمن الإعداد مخبرين مقلوبين لقياس كمية الغاز المتصاعد. يتم ملء المخبرين بالمحلول المراد تحليله، ثم يتم قليهما لغمر كل من القطبين على حدا. عند بدء التفاعل، تبدأ فقاعات الغاز (الهيدروجين على مستوى الكاثود القطب السالب وغاز الأكسجين على مستوى الأنود القطب الموجب) بالتصاعد، مما يؤدي إلى نزول مستوى المحلول داخل المخبر المدرج، والجزء الفارغ يمثل حجم الغاز المتصاعد. استخدمت هذه الطريقة نظرا لعدم توفر إمكانات تقدير كميات الغازات بدقة، ولكن في المستقبل سنعتمد على تقنية مبتكرة ومطورة لقياس حجم غاز الهيدروجين والأكسجين وأيضا مختلف الغازات التي ينتجها بول الجمل. هذا النهج سيساهم في جمع بيانات أكثر دقة.

مشروع الهيدروجين الأخضر



اقطاب الغرافيت.

الشكل التالي يوضح المنتج الأخير مخزن في خزان ضغط عالي للغازات مرفق بالعلامة التجارية، في المستقبل سيتم توزيع الهيدروجين الأخضر بهذا الشكل



الجمهورية الجزائرية الديمقراطية الشعبية

وزارة التعليم العالي والبحث العلمي

جامعة محمد خيضر - بسكرة

الكلية: العلوم المؤقتة وعلوم الصحة والبيئة
الميدان: علوم الصيدلة
التخصص: كيمياء المواد
القسم: علوم المواد
الشعبة: كيمياء
المستوى: ليسانس ماستر

ترخيص بمناقشة مشروع تخرج في إطار القرار 1275

للسنة الجامعية 2023/2024

نوع المشروع: شهادة جامعية/مؤسسة ناشئة شهادة جامعية/مؤسسة مصغرة
 شهادة جامعية/براءة اختراع

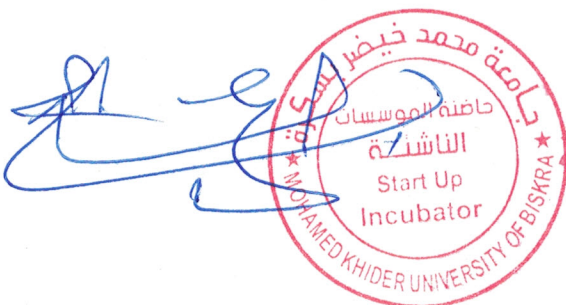
عنوان المشروع: Green Hydrogen

الطلبة: 1/ محمد بن أم حادي
2/
3/
4/
5/
المشرفون: 1/
2/
3/
4/

بسكرة في: 2024/06/13

إمضاء مدير الحاضنة

امضاء المشرفين



جاني في حادي
كمال أراسي

مسؤول حاضنة المؤسسات الناشئة
د/ محمد جلاب

République Algérienne Démocratique et Populaire

Ministère de l'Enseignement Supérieur et de la Recherche Scientifique

Université Med Khider Biskra

Faculté des Sciences Exactes et des Sciences de la Nature et de la Vie

Département des Sciences de la Matière

Filière de Chimie



الجمهورية الجزائرية الديمقراطية الشعبية

وزارة التعليم العالي و البحث العلمي

جامعة محمد خيضر بسكرة

كلية العلوم الدقيقة و علوم الطبيعة و الحياة

قسم علوم المادة

شعبة الكيمياء

تصريح شرفي

خاص بالالتزام بقواعد النزاهة العلمية لإنجاز بحث

(ملحق القرار 1082 المؤرخ في 2021/12/27)

أنا الممضي أسفله،

السيدة(ة): **رحموني أم هاني**

الصفة: طالب سنة ثانية ماستر كيمياء تخصص: كيمياء المواد

الحامل(ة) لبطاقة التعريف الوطنية رقم: 03876854 الصادرة بتاريخ: 2018/12/27

المسجل بكلية: العلوم الدقيقة و علوم الطبيعة و الحياة قسم: علوم المادة

والمكلف بانجاز أعمال بحث : مذكرة ماستر في الكيمياء

عنوانها: **Green Hydrogen**

أصرح بشرفي أنني ألتزم بمراعاة المعايير العلمية والمنهجية ومعايير الأخلاقيات المهنية والنزاهة الأكاديمية المطلوبة في إنجاز البحث المذكور أعلاه وفق ما ينص عليه القرار رقم 1082 المؤرخ في 2021/12/27 المحدد للقواعد المتعلقة بالوقاية من السرقة العلمية ومكافحتها.

التاريخ:

إمضاء المعني بالأمر

