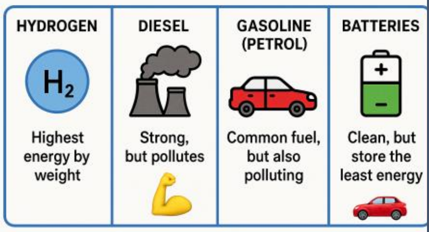

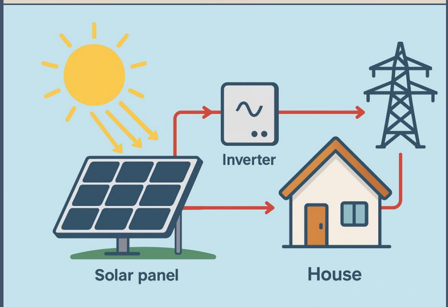

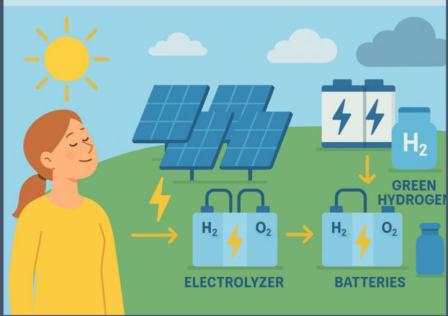

Draft Study Material

Green Hydrogen Plant Technician

(Job Role)

QP: Ref. Id. SGJ/Q0120

Sector: Green Jobs

Textbook for Class XI

PSS CENTRAL INSTITUTE OF VOCATIONAL EDUCATION

(a constituent unit of NCERT, under the Ministry of Education, Government of India)

Shyamla Hills, Bhopal- 462 002, M.P., India

PREFACE

Vocational Education is a dynamic and evolving field, and ensuring that every student has access to quality learning materials is of paramount importance. The journey of the PSS Central Institute of Vocational Education (PSSCIVE) toward producing comprehensive and inclusive study material is rigorous and time-consuming, requiring thorough research, expert consultation, and publication by the National Council of Educational Research and Training (NCERT). However, the absence of finalised study material should not impede the educational progress of our students. In response to this necessity, we present the draft study material, a provisional yet comprehensive guide, designed to bridge the gap between teaching and learning until the official version of the study material is made available by the NCERT. The draft study material provides a structured and accessible set of materials for teachers and students to utilise in the interim period. The content is aligned with the prescribed curriculum to ensure that students remain on track with their learning objectives.

The contents of the modules are carefully curated to provide continuity in education and maintain the momentum of teaching and learning in vocational education. It encompasses essential concepts and skills aligned with the curriculum and educational standards. We extend our gratitude to the academicians, vocational educators, subject matter experts, industry experts, academic consultants, and all other people who contributed their expertise and insights to the creation of the draft study material.

Teachers are encouraged to use the draft modules of the study material as a guide and supplement their teaching with additional resources and activities that cater to their students' unique learning styles and needs. Collaboration and feedback are vital; therefore, we welcome suggestions for improvement, especially by the teachers, in improving the content of the study material.

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Deepak Paliwal
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Date: 20 July 2025

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MODULE 1: INTRODUCTION TO GREEN HYDROGEN

Module Overview

The world is shifting to cleaner energy, with green hydrogen emerging as a key player in this transition. Green hydrogen (H_2), generated from renewable sources like wind and solar, is a clean fuel that produces no harmful emissions and serves as a crucial solution in addressing climate change.

In this module, you will learn why green hydrogen is termed the “fuel of the future.” We will explore its production, storage, transportation, and its significance in industries, transportation, and power generation. Technologies enabling green hydrogen, such as water electrolysis, will also be discussed. The module highlights global investments, especially from India, in developing a green hydrogen economy, alongside the challenges and opportunities it presents.

Finally, we will introduce the role of a Green Hydrogen Plant Technician, outlining the skills and knowledge necessary for this promising field.

Learning Outcomes

After completing this module, you will be able to:

- Explain the role of green hydrogen in ensuring a future based on clean and sustainable energy solutions
- Identify the physical and chemical properties, characteristics, and nomenclature of hydrogen.
- Illustrate the value chain of the green H_2, including generation, storage, transportation, and distribution.
- Analyse the key technological options and challenges associated with green hydrogen systems.
- Describe various end use applications of green hydrogen in industries, transport, and power generation.
- Explore the potential and current developments of the green hydrogen economy in the Indian context.
- Understand the roles, responsibilities, and skills required to work as a Green Hydrogen Plant Technician.

Module Structure
Session 1: Necessity of Green Hydrogen in Sustainable Energy Transition and its Properties
Session 2: Green Hydrogen Mission of the Government of India
Session 3: Colour Code Nomenclature of Hydrogen
Session 4: Green Hydrogen Value Chain
Session 5: Challenges in Green Hydrogen Plant
Session 6: Green Hydrogen Economy in the Indian Context
Session 7: Roles and Responsibilities of a Green Hydrogen Plant Technician.

Session 1: Necessity of Green Hydrogen in Sustainable Energy Transition and its Properties

The world has two big challenges: more energy needs and climate change. Most of our energy still comes from burning coal, gas, and oil, which releases carbon dioxide (CO_2) and makes the Earth hotter. This causes floods, storms, rising sea levels, and harm to nature.

What's the solution? We need clean and green energy, and Green Hydrogen. It's a zero-pollution fuel that can replace petrol, diesel, and coal in cars, factories, and power plants (Fig. 1.1). Using it means less pollution and slower climate change.

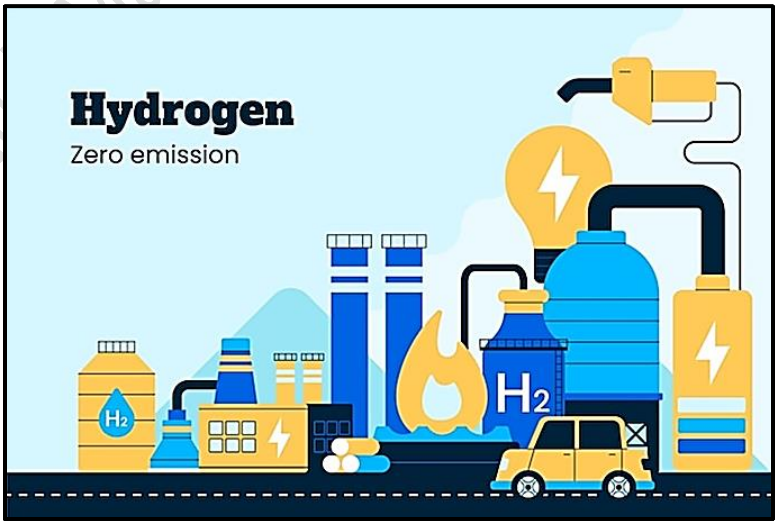


Fig. 1.1: Zero Emission

However, a challenge exists: solar panels cannot generate electricity at night, and wind turbines require the presence of wind to operate. So, how do we keep energy ready 24/7?

Here's the magic: Extra wind or solar energy can be stored as green hydrogen. Thereafter, we can use it to make electricity whenever we need it, just like a rechargeable battery (Fig. 1.2), but better.

Green hydrogen is a decent way of storing renewable energy for later use. It works like a battery but is a type of fuel. This allows us to store energy for a long time with green hydrogen. It helps in balancing the energy demand and supply throughout the day and across different seasons.

Fig. 1.2: Availability of Hydrogen due to Storage

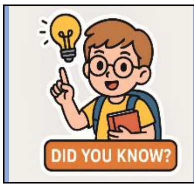
Fig. 1.3: Green Hydrogen for zero emission

High amounts of energy and heat are needed by industries like steel and chemical manufacturing. Fossil fuels are usually used, and large amounts of CO_2 are released. Green hydrogen can be used instead, and harmful emissions can be avoided. Industrial processes can be made cleaner and more eco friendly

Vehicles powered by green hydrogen fuel cells produce only H^2O vapour as a by-product (Fig. 1.3). They are considered a clean alternative to gasoline or diesel vehicles. Hydrogen powered buses (Fig. 1.4), trucks (Fig. 1.5), and trains can be used to reduce air pollution in cities.

Fig.1.4: Bus running on green hydrogen fuel cells

Fig. 1.5: Truck running on green hydrogen fuel cells



"Hydrogen is everywhere. It's the most common element in the entire universe and ranks third in abundance on Earth's surface. No wonder scientists call it the 'fuel of the future.'"

Properties and Characteristics of H_2

Hydrogen, a simplest element in the universe (Fig. 1.7), has just one proton and one electron. It usually teams up in pairs (H_2) and becomes the lightest gas of all. Though it's invisible, has no smell or taste, hydrogen is everywhere around us. It also hidden in water (H_2O) and fuels like natural gas and oil.

So, what are the advantageous properties of hydrogen?

- It can form more compounds than any other element.
- It's a clean energy hero that could solve numerous energy problems of the world.
- It has special properties that make it useful in science, industries, and energy systems.

Are you excited to explore the wonders of hydrogen?

Let us explore its remarkable properties and characteristics in depth.

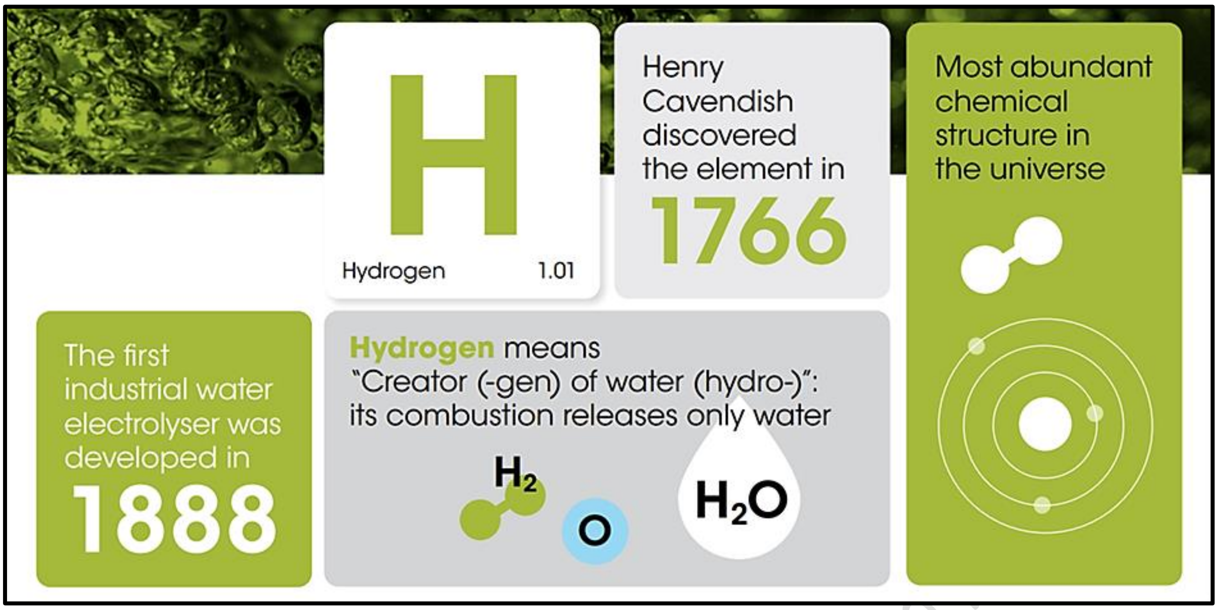


Fig. 1.6: Properties and Characteristics of Hydrogen

1. Physical Properties:

- **Atomic number:** Hydrogen's atomic number is 1, making it the lightest element.
- **State**: At standard temperature and pressure (STP) i.e., 1 atmosphere and 273.15K, hydrogen is an odourless, colourless, and tasteless gas.
- **Molecular form:** In its most common form, H_2 is a diatomic molecule (H_2), means two H_2 atoms are bonded together.
- **Density:** Hydrogen is the least dense gas. Its density is about 0.09 grams per litre at Standard Temperature and Pressure (STP), making it much lighter than air.

  Atomic Structure (Fig. 1.7):
  - Atomic number (AN): 1
  - Hydrogen - the lightest element.
  - Atomic weight: 1.008
  - Density: It is much lighter than air, with a density of 0.08988 g/L, which is about 14 times less dense than air.
  - Boiling point (BP): 252.87°C
  - Melting point (MP): 259.14°C

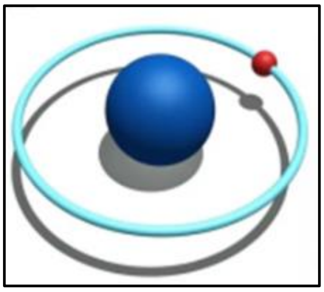


Fig. 1.7: Hydrogen Atomic Structure

2. Chemical Properties:

- **Highly reactive:** Hydrogen is very reactive and readily forms compounds with other elements, especially oxygen, forming water (H_2O), and with carbon to form hydrocarbons. It commonly exists in diatomic form as H_2.

- **Flammability:** Hydrogen is extremely flammable and combusts with a pale blue type flame that is almost invisible.
- **Combustion:** Hydrogen is highly flammable and, when combined with oxygen, burns to produce water while releasing energy in the form of heat. Its combustion reaction is:

  $2H_2 + O_2 \rightarrow 2H_2 0$ + Energy (Heat)

- **Reducing Agent:** Hydrogen is often used as a reducing agent in the chemical reactions, helping to remove oxygen from compounds.

3. Energy Related Characteristics:

- **High Energy Content:** Hydrogen possesses a very high energy content per unit mass. It contains three times more energy per kilogram than gasoline. This makes it attractive as a fuel source, especially in the form of green hydrogen.
- **Clean Energy:** When hydrogen is burned or utilized in fuel cells, the only by-product formed is water, which makes it a clean energy source with zero carbon emissions.

4. Forms of H_2 (Isotopes):

- **Protium (^{1}H):** It is the most common form of hydrogen, with one proton and no neutrons in its nucleus (Fig. 1.8).
- **Deuterium (^{2}H or D):** It is a stable isotope of hydrogen, with one proton and one neutron. Hydrogen is used in nuclear fusion research and also assists as a moderator in nuclear reactors.
- **Tritium (^{3}H or T):** Tritium is a radioactive isotope of H_2 containing one proton and two neutrons; it is used in nuclear fusion reactions and in specific types of luminous paints.

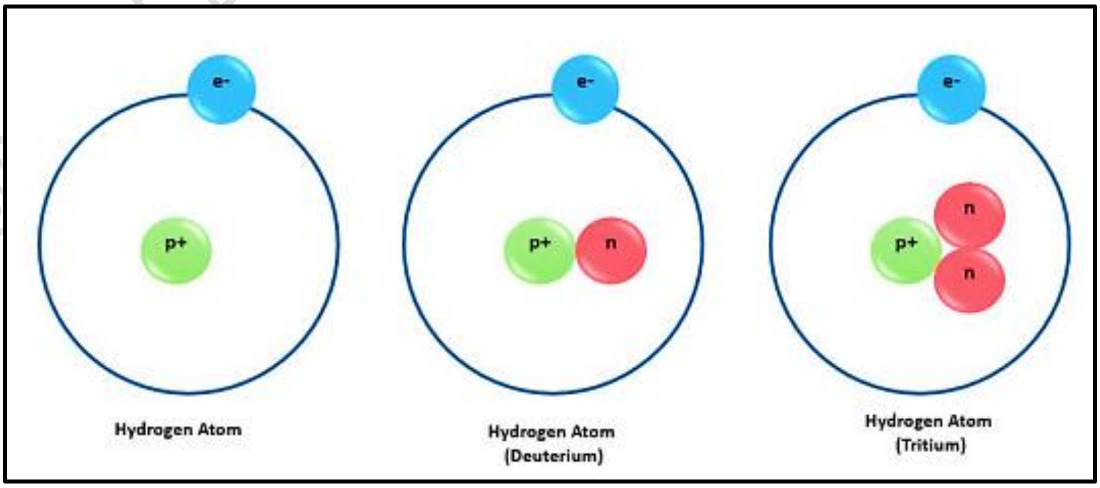


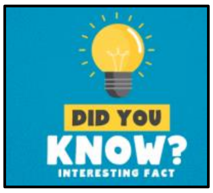
Fig. 1.8: Isotopes of Hydrogen

5. Storage and Transport Challenges:

- **Difficult to Store:** Due to its low density, H_2 gas is considered difficult to store, as large volumes are needed to hold useful energy. It is commonly stored as compressed gas, liquefied at very low temperatures, or absorbed in materials such as metal hydrides.
- **Leakage Risk:** H_2 molecules are very small, leakage is often observed through containers that are normally used to store other gases.

Hydrogen as a Carrier of Energy

Imagine a fuel that is light, powerful, and clean. This source of clean fuel is hydrogen. But hydrogen doesn't just lie around waiting to be used. It is called an energy carrier because we need to make it first, often by breaking water (H_2O) into H_2 and O_2 or by utilizing natural gas. Once produced, hydrogen proves its worth with a stunning energy value of 33.3 kWh per kilogram, more than diesel, CNG, or ammonia. It's like having a small magic box that gives more power than other fuels of the same weight. Hydrogen engines or fuel cells also work with higher efficiency (above 50%), while regular fuels lag behind at less than 40%. Even better, hydrogen is kind to our planet because it produces little or no pollution. However, the real challenge is how to carry it around. To transport it safely, hydrogen has to be compressed like air in a tire or turned into a freezing cold liquid, which requires special technology and extra cost.



By using hydrogen as a clean fuel, we can work towards the global goal of restricting the rise in Earth's temperature to 1.5°C while reducing greenhouse gas (GHG) emissions, and preparing for the challenges of the climate changes. Hydrogen is seen as a bridge to a greener future, as it can replace polluting fossil fuels in many sectors.

The year 2020 marked a turning point for hydrogen, as countries around the world showed unprecedented enthusiasm for this energy source. Governments and industries began setting ambitious targets, launching pilot projects, and making large investments to build a strong hydrogen ecosystem. This global excitement highlights the belief that hydrogen can power a cleaner, safer, and more sustainable world.

Uses of Hydrogen

Hydrogen is primarily used in industries as a raw material for making useful products as follows:

1) It helps oil refineries process crude oil.
2) It is used to make ammonia, which is key for fertilisers.
3) It produces methanol, which is used to make plastics and other products.

4) It can serve as a clean fuel, generating heat above 1,000°C without releasing CO_2.
5) It operates in fuel cells by reacting with O_2 to generate electric current or electricity, producing only water vapour as a by-product without releasing harmful gases.

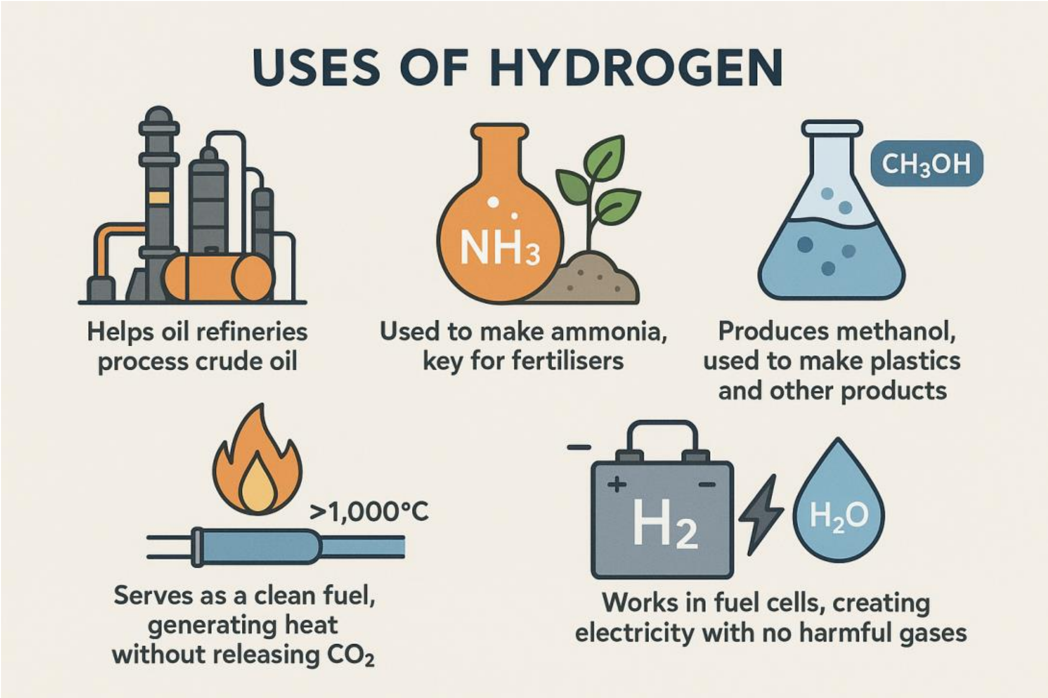


Fig. 1.9: Uses of Hydrogen

Check your Progress

A. Fill in the blanks

1. Hydrogen is the most ________ element in the universe.
2. Green hydrogen is produced using electricity from ________ energy sources.
3. When hydrogen is burned, it produces only ________.
4. Hydrogen has a very high energy content of ________ kWh/kg.
5. Hydrogen burns with a ________ flame.

B. Multiple Choice Questions (MCQs):

1. What is the only by product when hydrogen is burned?

a) Carbon dioxide (CO_2)
b) Methane (CH_4)
c) Water-vapour
d) Nitrogen gas

2. What is the cleanest method to produce hydrogen called?

a) Blue Hydrogen
b) Grey Hydrogen
c) Green Hydrogen
d) Brown Hydrogen

3. What makes hydrogen a clean fuel?
a) High cost
b) Produces CO_2
c) Produces only water
d) Easy to store

4. Which industry uses hydrogen as a feedstock?

a) Education
b) Petrochemical
c) Textile
d) Agriculture

5. Hydrogen's energy conversion efficiency is greater than:
a) 40%
b) 30%
c) 20%
d) 50%

C. Short type answer questions:

1. What is green hydrogen and how is it produced?
2. Why is green hydrogen considering a clean energy source?
3. How can green hydrogen help in industries like steel manufacturing?
4. Why is hydrogen considered an energy carrier?
5. List three uses of hydrogen in industry.

D. Long Answer Questions:

1. Explain how green hydrogen can help in addressing climate change and energy challenges faced by the world today.
2. Describe the benefits of using green hydrogen in the transportation sector.
3. Discuss the role of green hydrogen in attaining sustainable energy transition and India's net zero target by 2070.
4. Discuss the challenges involved in the storage and transportation of hydrogen.
5. Describe how hydrogen can help achieve global climate targets and act as a cleaner source of energy.

Session 2: Green Hydrogen Mission of the Government of India

In 2023, the Indian Government took a big step toward a cleaner future by starting the National Green Hydrogen Mission. Bharat plans to make 5 million metric tons (MMT) of green hydrogen every year by the year 2030. The government has put in about 2.4 billion US dollars (₹19,700 crore). This mission is not only about clean fuel, but it is also about building a stronger economy. The goal is to bring in big investments and create over 6 lakh (600,000) new jobs.

To make this vision a reality, the government has introduced several strong incentives. These include production linked incentives (PLI) for companies that build electrolysers (the machines used to produce green hydrogen), waiving interstate transmission charges for renewable energy used in hydrogen production, and lower GST rates on hydrogen. These forward-thinking policies are designed to accelerate the growing of the green hydrogen industry and lead India towards a cleaner, greener, and self-reliant energy future. With this mission, India aims to become a global leader in green H_2 technology (Fig. 1.10).

Green energy is the energy that is retrieved from natural resources like rain, wind, sunlight and the heat inside the Earth. Unlike fossil fuels, it does not harm the environment and helps keep nature balanced.

Let's say a startup in Gujarat wants to make green hydrogen using solar power from Rajasthan. Thanks to these policies, they won't pay high fees to get the electricity and can even get government help to build their machines. That's a big win for green business.

With these bold moves, India is not just aiming to use green hydrogen it wants to lead the world in it. This is a major step toward becoming Atmanirbhar Bharat (a self-reliant India) in energy.

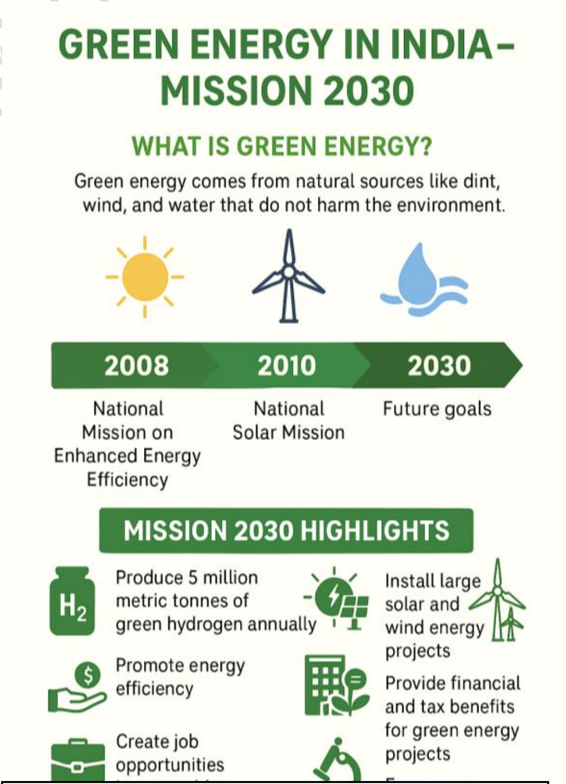


Fig. 1.10: Green Hydrogen Mission of the Government of India

The Government of India has taken several important steps to increase the use of clean energy. In 2008, it launched the National Mission on Enhanced Energy Efficiency (NMEEE) to promote energy savings in industries, transport, and buildings. The PAT scheme (Perform, Achieve, and Trade) rewarded industries for using energy efficiently.

In 2010, the government announced the National Solar Mission (NSM) with a target to produce 20,000 MW of solar power by 2022. India achieved this goal ahead of time in 2019, becoming one of the world's top solar energy producers.

Looking ahead, India's Mission 2030 aims to:

- Generate 5 million metric tonnes (MMT) of green hydrogen every year.
- Generate 40% of electricity from non-fossil fuel sources.
- Install large solar and wind energy projects.
- Promote energy efficiency in industries, transport, and buildings.
- Provide financial support and tax benefits for green energy projects.
- Create job openings in the renewable energy sector.
- Encourage research and innovation in clean energy technologies.

These efforts will reduce pollution, protect the environment, and make India a global leader in green energy.

Check Your Progress

A. Fill in the blanks

1. The Indian government has set target to produce ______________ of green hydrogen by 2030.
2. Green H_2 is generally produced using renewable resources of energy such as ______________ and ______________.
3. The National Solar Mission targeted ______________ MW of solar power by 2022.
4. India aims to attain ______________ of its energy needs from renewable energy by 2030.
5. The offshore wind energy target of India by 2030 is ______________.

B. Multiple Choice Questions

1. What is the target green hydrogen production by India for 2030?

a) 2 MMT
b) 5 MMT
c) 10 MMT
d) 1 MMT

2. Which energy sources are used to produce green hydrogen?

A. Coal and Gas
B. Oil and Nuclear
C. Solar and Wind
D. Diesel and Petrol

3. When was the National Solar Mission launched?

A. 2005
B. 2010
C. 2012
D. 2015

4. What is the offshore wind energy target for India by 2030?

A. 40 GW
B. 20 GW
C. 30 GW
D. 10 GW

C. Short Answer Questions

1. What is the significance of the National Green Hydrogen Mission?
2. Mention two major initiatives under India's Green Energy programme.
3. Explain the objectives and benefits of the National Green Hydrogen Mission of India.
4. Discuss the role of renewable energy in India's energy transition with examples from government missions.
5. Describe the major targets set by the Indian Government under the Green Energy Mission 2030.

Session 3: Colour Code Nomenclature of Hydrogen

Does hydrogen have colours? Let's Find Out.

Yes, it's true. Hydrogen doesn't come in different colours you can see, but scientists and engineers use colour codes to show how hydrogen is made and how clean or polluting it is. This system helps us understand the impact each type of hydrogen has on the environment.

Hydrogen is categorised into five types based on its method of production, and this classification is often represented using different colour codes. These colour codes are often used to designate the production process and the environmental impact associated with each type of hydrogen (Fig. 1.11).

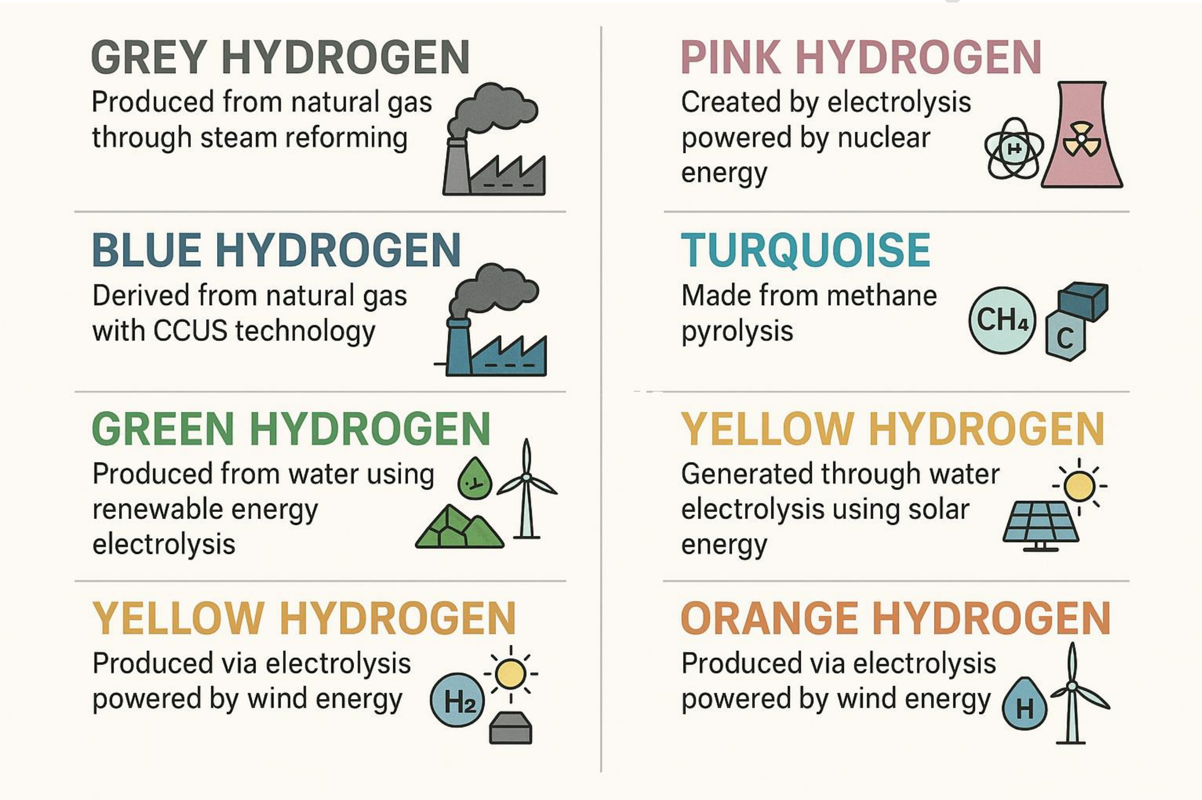


Fig. 1.11: Hydrogen Colour Code Nomenclature

This classification allows us to understand its environmental impact.

- Grey hydrogen is produced using natural gas (NG) via steam reforming, and it does not involve any carbon capture, making it a higher emission option.
- Brown hydrogen is made from coal or lignite gasification and is associated with significant greenhouse gas emissions.

- Blue hydrogen is also derived from natural gas (NG), but its emissions are reduced by using Carbon Capture, Utilization, and Storage (CCUS) technology.
- Green hydrogen is developed from water through electrolysis driven by renewable energy resources, making it the cleanest and most sustainable type of hydrogen.
- Pink hydrogen is generated via electrolysis that is powered by nuclear energy.
- Turquoise hydrogen is prepared through methane pyrolysis, which generates hydrogen with solid carbon as the by-product.
- Yellow hydrogen is generated from water electrolysis using solar energy.
- Orange hydrogen is generated using wind energy to carry out electrolysis.

Check Your Progress

A. Fill in the Blanks

1. _________ hydrogen is produced using renewable electricity for water electrolysis and has zero emissions.
2. _________ Hydrogen is generated from natural gas (NG) using a steam methane reforming (SMR) without capturing CO_2.
3. Blue hydrogen is made like grey hydrogen but includes _________ to reduce carbon emissions.
4. _________ hydrogen is created through methane pyrolysis and emits solid carbon instead of CO_2.
5. Yellow hydrogen is produced using electricity from the _________, which may include fossil fuels and renewables.

B. Multiple Choice Questions

1. Identify the type of hydrogen that is most suitable for environment.

   a) Grey
   b) Blue
   c) Green
   d) Brown

2. Which hydrogen type relies on coal gasification for its production?

   a) Blue
   b) Brown
   c) Yellow
   d) Turquoise

3. What does blue hydrogen use to reduce CO_2 emissions?

   a) Renewable energy
   b) Methane leaks
   c) Carbon capture and storage
   d) Solar panels

4. What is a key disadvantage of grey hydrogen?

   a) Expensive production
   b) Requires rare materials
   c) Produces a lot of CO_2
   d) Cannot be transported

5. Which hydrogen's environmental impact relies on the energy mix of the electric grid?

   a) Green
   b) Yellow
   c) Blue
   d) Brown

C. Short Answer Questions

1. What is the main advantage of green hydrogen over other types?
2. Why is blue hydrogen considered better than grey hydrogen?
3. What makes turquoise hydrogen different in terms of its emission output?

D. Long Answer Questions

1. Explain the differences among grey, blue, and green hydrogen with respect to their methods of production and their impact on the environment.
2. Describe the colour code nomenclature system for hydrogen and its significance.
3. Why is using color codes to classify energy important for climate change and energy policies

Session 4: Green Hydrogen Value Chain

Remember how we talked about hydrogen in earlier sessions? Well, here's the cool part it's one of the most powerful fuels in terms of energy per weight. That means a small amount of hydrogen can give you a lot of energy.

Which Fuel Is Best? Let's Compare.

- Hydrogen: Highest energy by weight
- Diesel: Strong, but pollutes
- Gasoline (petrol): Common fuel, but also polluting
- Batteries: Clean, but store the least energy

Every type of energy, whether it's hydrogen, diesel, petrol, or batteries, has its pros and cons. So, we need to choose the right one depending on what we need it for.

How Much Energy Do They Give?

Let's look at something called specific energy, which means how much energy we get from 1 kilogram of a fuel:

- Hydrogen gives 120 to 140 MJ/kg
- Diesel and Gasoline give only 30 to 45 MJ/kg. That's about 3 to 4 times less than hydrogen
- Batteries store much less about 30 to 90 times less energy than hydrogen.

What About Pollution?

- Diesel and Petrol:
  For every 1 MJ of energy, they produce 7585 grams of CO_2
  ➤ That's a lot of pollution and they release other harmful gases too.
- Hydrogen:
  The only thing it releases is pure water.
  ➤ No CO_2, no smoke, no harm to the environment

▨ Example:

If you had a 1 kg block of fuel:

- Hydrogen could power a space mission
- Diesel could run a truck
- A battery might charge your tablet

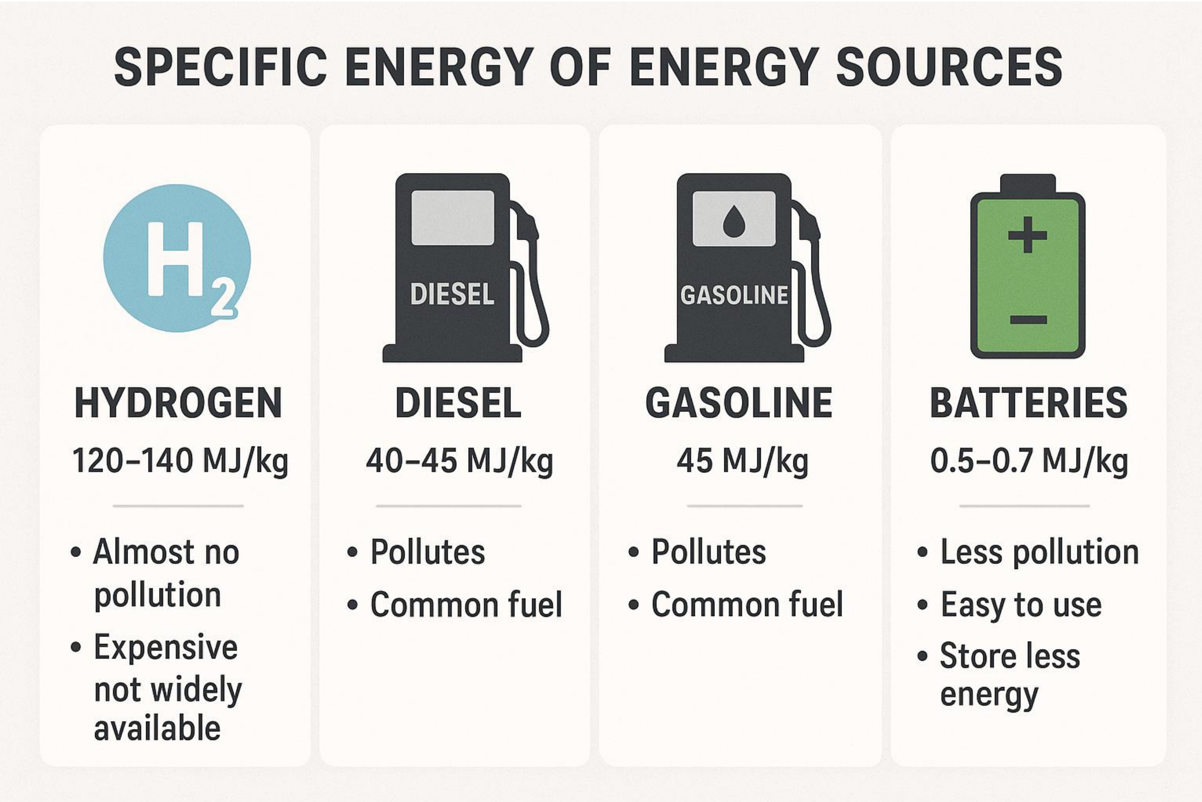


Fig. 1.12: Energy Content per Kg of Fuel

The green hydrogen value chain consists of several interconnected stages that enable the production, processing, storage, use and distribution of hydrogen generated using renewable energy sources.

1. Production
2. Processing
3. Distribution and
4. Storage applications

Main Stages in the Green Hydrogen (GH_2) Value Chain:

1. **Production**: The first step in the production of green hydrogen is taken. Hydrogen gas is created from various sources, mainly through water splitting or natural resources. Several methods are used to produce hydrogen, each offering different benefits.

a) **Electrolysis (Water Splitting)**: Electricity generated using renewable sources like wind or solar is used to split water into hydrogen (H_2) and oxygen (O_2). Pollution is not created by this method, making it a good option for clean energy. However, electrolysis is considered expensive and energy intensive, so it is currently less affordable on a large scale compared to other methods.

b) **Steam Methane Reforming (SMR)**: Hydrogen can be produced cost-effectively through steam methane reforming (SMR), a traditional method that uses natural gas. It is commonly used for large scale industrial needs, but it is not entirely green unless combined with carbon capture.
c) **Partial Oxidation (POX) and Autothermal Reforming (ATR)**: H_2 is also produced using hydrocarbons, like oil and natural gas, and these methods are commonly employed in industrial processes.
d) **Photoelectrochemical (PEC) and Thermochemical Water Splitting**: Hydrogen is produced using new experimental methods that harness sunlight and heat; these methods are currently being researched and hold promise for the future.

2. **Hydrogen Production from Natural Gas (NG) with Carbon Capture and Storage (CCS):** Natural gas (NG) is used as a fuel, while carbon emissions are captured and stored, serving as a transitional solution until greener methods become more widespread
3. **Processing**: After production, hydrogen is purified and refined by the removal of impurities, and sometimes cooled to a liquid state for easier storage, to make it ready for use.
4. **Distribution and Storage**: Once produced, hydrogen is required to be safely transported and stored, typically as a compressed gas or in the liquid form. Reliable storage solutions are required to ensure that a consistent and on demand supply is maintained.
5. **Applications**: Hydrogen is widely used across various industries. Vehicles are powered by it, clean energy is supplied to homes, and manufacturing processes in sectors such as chemicals, metals, and glass are supported by it.

   A cleaner, more sustainable future is enabled by hydrogen due to its versatility and low environmental impact.

Check Your Progress

A. Fill in the Blanks:

1. Green hydrogen is generated through _________, that splits water into H_2 and O_2 using renewable energy."
2. The specific energy of hydrogen is about _________ times more than that of the diesel or gasoline fuel.
3. _________ is a cost effective but carbon intensive method of hydrogen production.
4. Hydrogen may be stored as a _________ or in liquid form for distribution.
5. _________ uses sunlight to produce hydrogen but is still in the research phase.

B. Multiple Choice Questions:

1. What is the main benefit of green hydrogen over fossil fuels?

   a) Lower cost

   b) Higher carbon emissions

   c) Zero carbon emissions when produced via electrolysis

   d) Limited applications

2. Which method of hydrogen generation is the most established but emits CO_2?

   a) Electrolysis

   b) Steam Methane Reforming (SMR)

   c) Photoelectrochemical (PEC)

   d) Thermochemical Water Splitting

3. What is a major drawback of electrolysis for hydrogen production?
   a) High carbon emissions

   b) High energy and cost requirements

   c) Limited hydrogen purity

   d) Only works with fossil fuels

4. Which storage method allows hydrogen to be transported more efficiently?

   a) Solid state storage

   b) Compressed gas

c) Liquid hydrogen

d) Underground reservoirs

5. Which of the following does not represent a stage in the green hydrogen value chain?

   a) Production

   b) Processing

   c) Combustion

   d) Distribution and Storage

C. Short Answer Questions

1. Enlist the main differences between green hydrogen and hydrogen produced via SMR.
2. Why is hydrogen storage challenging?
3. Name one emerging hydrogen production method and its key benefit.
4. Explain the green hydrogen production process using electrolysis. What are its advantages and limitations?
5. Compare Steam Methane Reforming (SMR) and electrolysis methods in terms of environmental impact and scalability.
6. Discuss the role of hydrogen storage and distribution in the value chain. What are the key methods and challenges?

Session 5: Challenges in Green Hydrogen Plant

In this session, we're going to explore the real-world challenges of building and running green hydrogen plants. While the future looks bright, there are still a few hurdles to cross.

Where Are We Now (2025)? Right now, green hydrogen production is still in the pilot stage, which means only small test plants are running. But the government has BIG plans for 2030, aiming to produce millions of tons of green hydrogen every year. Today, green hydrogen prices more than regular hydrogen (made from fossil fuels). But with government support and new technology, the cost is predicted to drop in upcoming years. Think of it like solar panels; they used to be expensive, but now they are much cheaper. To scale up green hydrogen, we need to build Electrolyser units for production, Storage tanks, Pipelines or trucks for transport. This takes money, planning, and time and it's one of the biggest challenges right now.

Producing hydrogen uses a lot of water, which must be managed carefully, especially in dry regions. Land is also needed for building the plants and renewable energy sources (like solar or wind farms). We must warrant that local communities and ecosystems are not harmed in the process.

1. **Production:** As we discussed in previous sessions, green hydrogen is made by splitting H_2O using electricity from the renewable resources like sun, wind, or water. This is done in a process called electrolysis (Fig. 1.13), which does not create CO_2.

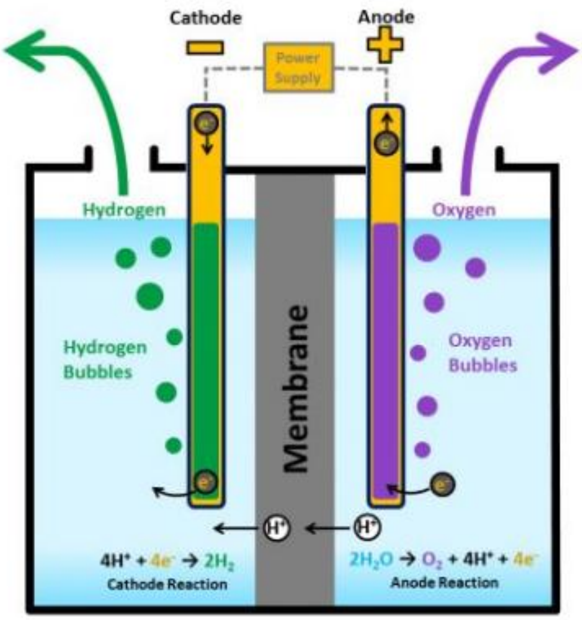


Fig. 1.13: Hydrogen production through electrolysis

2. **Storage**: Hydrogen is required in large amounts for certain applications. In such cases, it is necessary for the hydrogen release time to be kept very short. In addition, a controlled rate of hydrogen storage is needed for specific uses. The capital and operating costs of hydrogen are decided based on the needs of a particular application. In general, hydrogen applications can be classified as either stationary or mobile (Fig. 1.14). Based on the use, the required level of hydrogen purity may be selected.

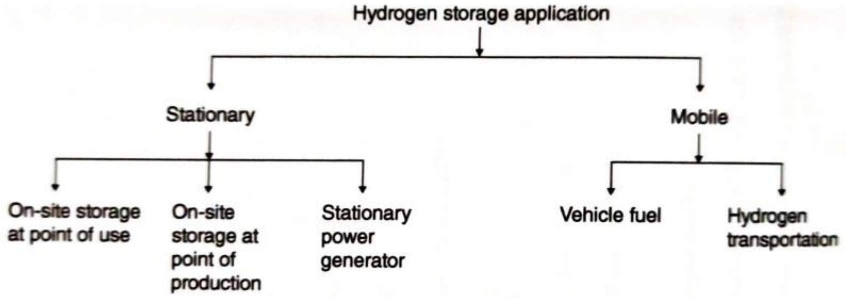


Fig. 1.14: H_2 Storage as per applications

Hydrogen storage is divided into two main types:

(1) Stationary (2) Mobile

In **Stationary storage**, hydrogen is kept at the place where it is made or used. It is also used for making power at those places.

In **Mobile storage**, hydrogen is mainly used as fuel for vehicles. Hydrogen is also moved from one place to another for different uses.

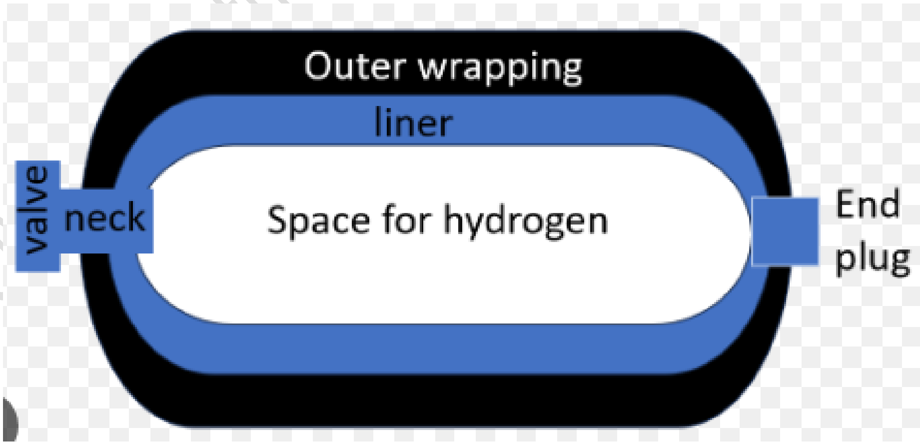


Fig. 1.15: Cylinder for Hydrogen storage

3. **Transportation:** Hydrogen can be sent by pipes, trucks, or ships. Pipes are used for short trips, trucks and ships for long ones. Sometimes hydrogen is mixed with natural gas in pipes, but this must be watched carefully. There are only a few special hydrogen pipes, and building new ones is expensive. Changing old pipes is

tricky because hydrogen can leak easily. Moving hydrogen as a liquid needs costly cooling. Since hydrogen catches fire easily, moving it safely is very important.

4. **Distribution:** Hydrogen distribution means getting hydrogen to users like industries, fuelling stations, and power plants. Local distribution networks and refuelling stations are important for getting more people to use hydrogen, especially in transportation.

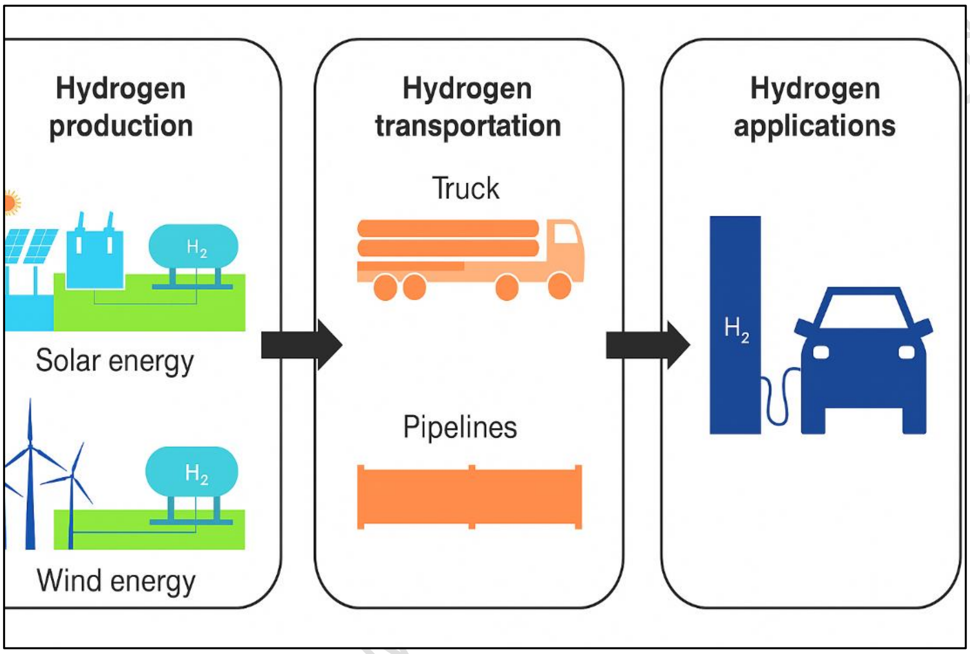


Fig. 1.16: Production, Transportation and Applications of Hydrogen

Hydrogen fueling stations are expensive to build and are currently few, which makes it hard to get people to adopt hydrogen powered vehicles. The cost of distributing hydrogen is high, especially over long distances, affecting its affordability. To ensure safety and efficiency, there needs to be clear standards for hydrogen distribution, which requires coordinating regulations and investment.

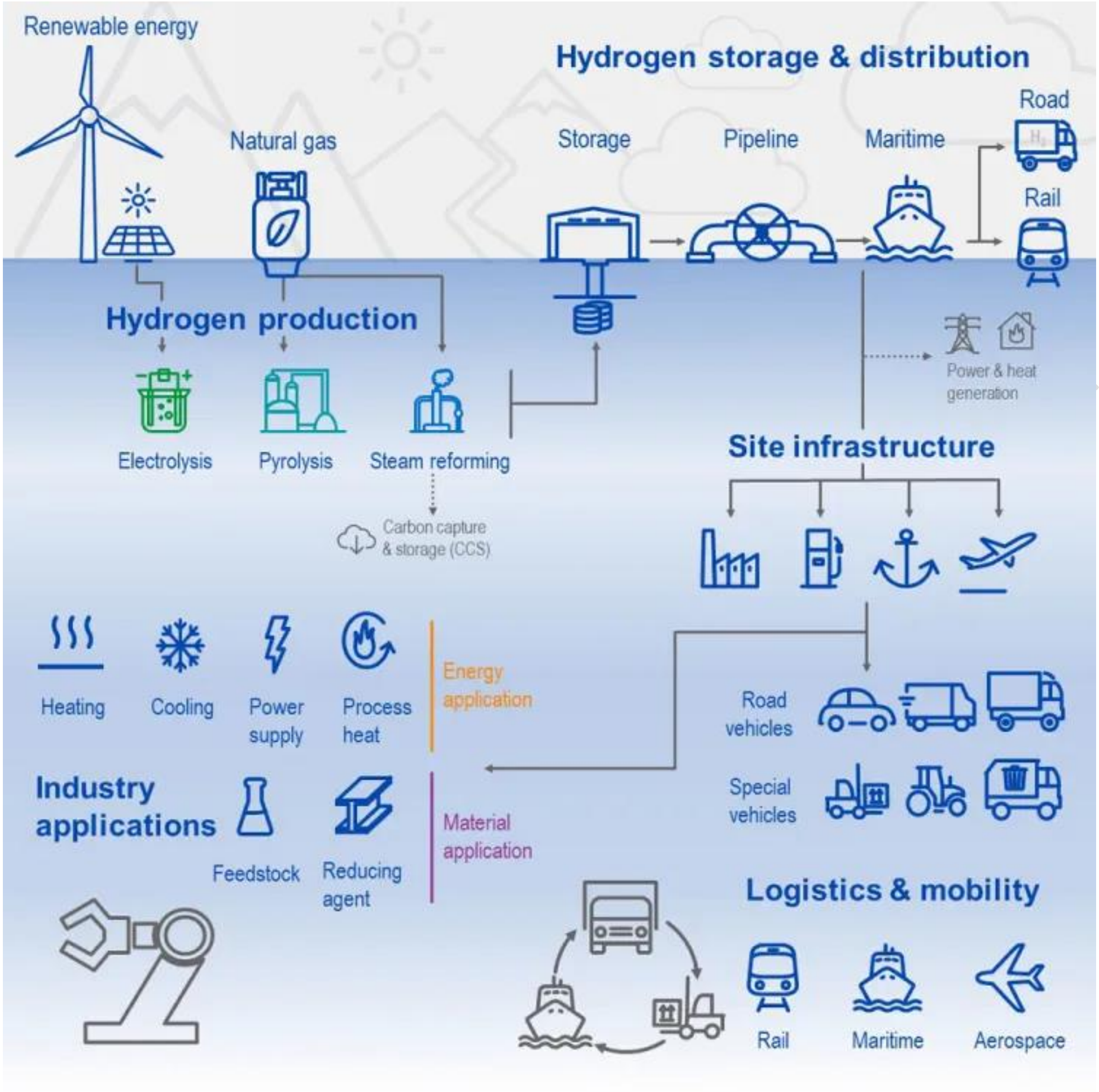


Fig. 1.17: Process of Production, Transformation and Transportation

Advantages and disadvantages of green hydrogen

Green hydrogen is regarded as one of the cleanest energy sources since it generates no harmful emissions either during its production or its use. Unlike many other fuels, it can be stored for later use, making it ideal for industries and transportation. Green hydrogen can also be converted into synthetic gas or electricity, making it a versatile energy option.

However, there are challenges. Producing green hydrogen is expensive because generating energy from renewable sources costs more, and hydrogen production needs more energy than many other types of fuels. It is also highly inflammable, so strict safety measures are necessary to prevent explosions or leaks.

Check Your Progress

A. Fill in the Blanks:

1. Green H_2 is generally produced following a process called ________________ that breaks water into H_2 and O_2 using renewable electricity.
2. Hydrogen is highly ________________ which makes storage and transportation a safety concern.
3. Hydrogen may be stored either as a ________ in pressurised metal tanks or as a ____________ at cryogenic temperatures.
4. The main disadvantage of electrolysis is its ____________________________, which impacts overall efficiency and cost.
5. Currently, there are very few hydrogen ________________, making adoption of hydrogen powered vehicles difficult.

B. Multiple Choice Questions

1. What is the primary method used in green hydrogen production?

   A. Fermentation

   B. Electrolysis

   C. Combustion

   D. Distillation

2. One of the main challenges in hydrogen storage is:

   A. Shortage of pipelines

   B. High cost of labour

   C. Leakage due to small molecule size

   D. Inability to liquefy hydrogen

3. Why is transporting hydrogen in liquid form expensive?

   A. It reacts with metal

B. It requires high temperature conditions

C. It requires cooling to very low temperatures

D. It cannot be stored in tanks

4. What makes hydrogen transportation through existing pipelines difficult?
A. Pipelines are too long

B. Hydrogen is too heavy

C. Hydrogen's small size causes leaks

D. Lack of renewable energy

5. Identify the most important benefit of green hydrogen?

A. It emits CO_2 during use

B. It requires fossil fuels

C. It can be stored and used later

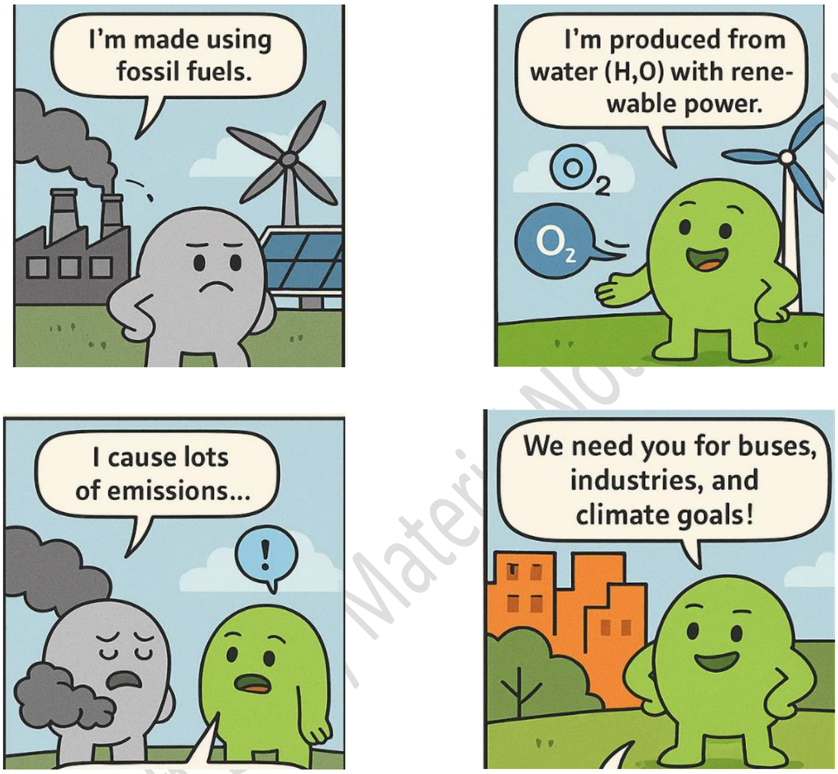
D. It increases energy loss

C. Short Answer Questions

1. Name the two main forms in which hydrogen can be stored.
2. Why is green hydrogen considered environmentally friendly?
3. List two transportation challenges associated with hydrogen.
4. Explain the major challenges in producing green hydrogen using electrolysis.
5. Discuss the safety and cost issues involved in hydrogen storage and transportation.
6. What are the policy and economic barriers to the widespread use of green hydrogen, and how can they be overcome?

Session 6: Green Hydrogen Economy in the Indian Context

As we have discussed in previous sessions, green hydrogen is made by splitting water (H_2O) into hydrogen (H_2) and oxygen (O_2) with electricity that is produced from renewable energy resources like wind or solar. Unlike conventional H_2 produced from fossil fuels that release significant greenhouse gases (GHG), green H_2 is regarded as a clean and sustainable source of energy. This method is seen as important for India's shift to cleaner energy and for meeting its climate goals.



Suitability of Green Hydrogen in the Indian Context

India is blessed with massive wind and solar energy resources. Because of this, green hydrogen can be produced at costs that are competitive worldwide.

The use of green H_2 is expected to reduce India's dependence on imported fossil fuels, which are a major expense for the Indian economy, and energy security can be strengthened.

In important industries such as fertilisers, steel, oil refining, and chemicals, hydrogen is needed and is usually made from fossil fuels. Green hydrogen is now being considered as a cleaner alternative. India has committed to achieve net-zero emission target by the year 2070 and to lower carbon intensity, and green hydrogen is seen as an important way to achieve this.

Major projects of green hydrogen in India

Many Indian companies are helping to develop Green hydrogen (Fig. 1.17).

Fig. 1.18: Indian companies work to develop Green hydrogen in India

NTPC Green Energy is working on hydrogen storage for renewable energy.

Reliance Industries plans to build a huge green hydrogen plant in Jamnagar. Indian Oil Corporation is testing green hydrogen at its refineries to cut emissions. **Larsen & Toubro** is investing in making electrolysers needed for green hydrogen. **Adani New Industries** is joining the global green hydrogen industry with big research and infrastructure projects. These efforts are helping India move toward cleaner energy.

Future Prospects and Economic Impact

The green hydrogen sector is expected to make a major contribution to India's economy by 2030, adding an estimated $1215 billion to the country's GDP and significantly increasing exports of hydrogen and its derivatives. This growth will be supported by the creation of a large number of jobs in both rural and urban areas, helping to boost employment and support local communities. With ambitious targets and strong policy support, India aims to emerge as a global leader in terms of production and export of green H_2, positioning itself as an important contributor to the global shift towards clean energy.

India's green hydrogen economy offers a great chance for sustainable growth, energy self-reliance, and climate protection. By using its huge renewable energy resources and forward-looking policies, India is ready to become a major leader in the world's move towards a cleaner energy future.

Check Your Progress

A. Fill in the Blanks

1) Green hydrogen is prepared by splitting __________using electricity from ____________ sources.

2) India aims to reach__________ emissions by the year____________.

3) Reliance Industries is planning to build a huge green hydrogen plant in ________.

4) The use of green H_2 is expected to reduce India's dependency on ___________________ fossil fuels.

5) The green hydrogen sector is estimated to add $1215 ____________ to India's ___________ by 2030.

B. Multiple Choice Questions

1. Green hydrogen is primarily made by splitting ______
   a) Air
   b) Water (H_2O)
   c) Oil
   d) Gas

2. Which company is working on hydrogen storage for renewable energy?
   a) Reliance Industries
   b) NTPC Green Energy
   c) Larsen & Toubro
   d) Adani New Industries

3. What is one major benefit of green hydrogen for India?

   a) Increases fossil fuel imports
   b) Reduces reliance on imported fossil fuels
   c) Increases pollution levels
   d) Uses coal as the primary source

4. India aims to reach net-zero emissions by ______.

    a) 2026
    b) 2038
    c) 2060
    d) 2070

5. The estimated contribution of the green hydrogen sector to India's economy by 2030 is ______.

    a) $12 billion
    b) $1215 billion
    c) $3040 billion
    d) $100 billion

C. Short Answer Questions

1. What is green H_2, and how is it different from traditional hydrogen?
2. Why is green hydrogen important for India's shift to cleaner energy?
3. Name any two companies in India working on green hydrogen projects and state their roles.
4. What benefits can the green hydrogen sector bring to rural and urban areas of India?
5. How can green hydrogen help India achieve its climate goals?

Session 7: Roles and Responsibilities of a Green Hydrogen Plant Technician.

A Green Hydrogen Plant Technician plays an important role in producing, maintaining, and operating green hydrogen facilities. Their work helps ensure that hydrogen production technologies run smoothly, supporting the global shift to sustainable energy systems. In this session, we will discuss and learn about the roles and responsibilities of a Green Hydrogen Plant Technician and the tasks involved in working at a Green Hydrogen plant.

Fig. 1.19: Green Hydrogen Plant Technician

Role of a Green Hydrogen Plant Technician

1. Support for Hydrogen Production

A Green Hydrogen Plant Technician works with machines that make hydrogen using electricity from the sun, wind, or water. Their job is to run and watch these machines, make sure only clean energy is used, and check that the hydrogen made is of good quality. This helps the world use cleaner and safer energy.

2. Maintenance and Troubleshooting

Machines, equipment, and pipes used in hydrogen production and storage are regularly inspected and maintained. Equipment issues are identified and fixed to reduce downtime and keep operations running smoothly. Broken parts such as pumps, valves, or filters are replaced or repaired as needed.

3. Safety and Compliance

But who makes this amazing fuel work for us?

Meet the ***Green Hydrogen Plant Technician.***

This technician works at special plants (factories) where green hydrogen is produced. They:

- Operate and monitor machines that turn water into hydrogen
- Check and repair equipment to keep everything running safely
- Test the quality of hydrogen and help store or transport it properly

Thanks to these technicians, we can move toward a future with cleaner air, less pollution, and smarter energy systems.

Safety rules are strictly followed when handling hydrogen, which is highly flammable. Systems are continuously monitored to ensure that safety and environmental regulations are met. Team members are regularly trained on emergency procedures, and all legal standards are ensured to be followed by everyone

4. **Monitoring and Reporting Data**

Operational data such as production rates, system performance, and energy use are recorded regularly. Reports are written to help management assess plant efficiency and identify areas for improvement.

5. Energy Efficiency

Hydrogen production processes are improved in collaboration with engineers. Strategies are used to lower energy use while production is maximised.

6. Storage and Distribution

The safe storage of hydrogen in special tanks is carefully overseen. The transportation and distribution of hydrogen to clients or other facilities are managed efficiently.

7. Innovation and Sustainability

New technologies and methods are introduced to improve hydrogen production. Practices that reduce the carbon footprint of plant operations are encouraged.

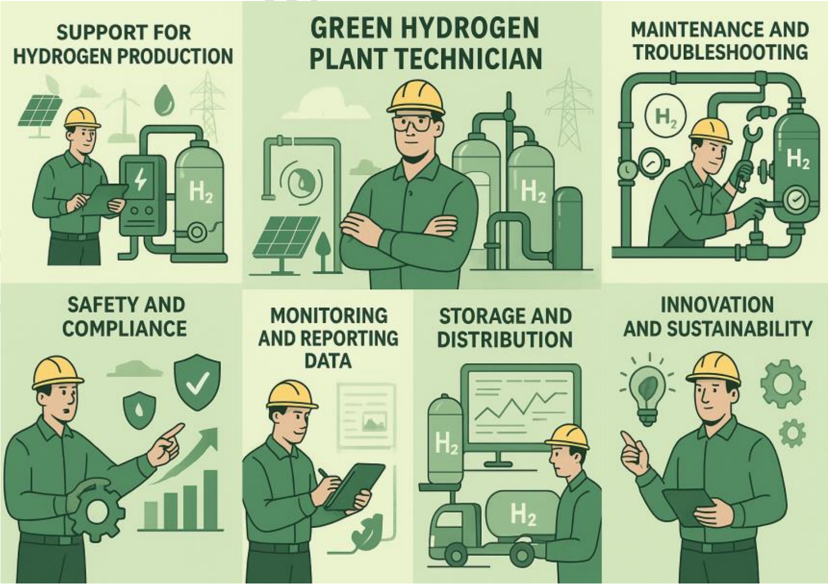


Fig. 1.20: Role of a Green H_2 Plant Technician

Skills and qualities essential for the *Green Hydrogen Plant Technician*

As the role of a Green Hydrogen plant Technician is very important in a green Hydrogen plant so to perform his responsibilities following skills and qualities are desired in a Green Hydrogen plant technician.

1. The Technician should have technical knowledge about electrolysis, renewable energy integration, and plant operations.
2. The Technician should be skilled enough to monitor and ensure the safety and efficiency of equipment and processes.
3. The Technician should be able to identify the issues and fix them quickly.
4. Safety guidelines and protocols are strictly followed by him.
5. Effective collaboration should be maintained with different teams within the plant by the Technician.

Fig. 1.21: Skills and qualities are desired in a Green Hydrogen Plant Technician.

Check Your Progress

A. Fill in the Blanks

1. A Green Hydrogen Plant Technician operates and monitors equipment like ________________ used for hydrogen production.
2. Hydrogen must be produced using ________________ such as solar or wind to be considered green.
3. Technicians ensure safety by following proper _____________ and handling hydrogen with care due to its flammability.
4. One of the technician's key tasks is to ____________________ machines and pipes used in hydrogen systems.

B. Multiple Choice Questions:

1. What is the prime responsibility of a Green Hydrogen Plant Technician in production?

A. Selling hydrogen to customers
B. Mining for natural gas
C. Operating and monitoring electrolysers
D. Designing solar panels

2. Why is it important for technicians to follow strict safety rules?
   A. To increase profit
   B. Because hydrogen is flammable
   C. To reduce the number of staff
   D. To improve the aesthetics of the plant

3. What do technicians do when a valve or pump is damaged?
   A. Paint it
   B. Sell it
   C. Replace or repair it
   D. Ignore it

4. What kind of data do technicians monitor and report?
   A. Employee attendance
   B. Customer reviews
   C. System performance and energy use
   D. Weather forecasts

5. Which of the following is part of a technician's role in sustainability?
   A. Increasing fuel prices
   B. Using non-renewable energy
   C. Promoting low carbon practices
   D. Reducing employee salaries

C. Short Answer Questions:

1. Enlist the role of a technician in maintaining hydrogen equipment?
2. Why is record keeping important for a Green Hydrogen Plant Technician?
3. What does a technician do to support energy efficiency?
4. Describe the safety responsibilities of a Green Hydrogen Plant Technician.
5. Explain how a Green Hydrogen Plant Technician contributes to sustainable energy.
6. What is the role of a technician in hydrogen storage and distribution**?**

MODULE 2 COMPONENTS OF THE GREEN HYDROGEN PLANT AND ITS LAYOUT

Module Overview

This module introduces learners to the essential components, functions, and safety protocols of a Green Hydrogen Plant. It is developed in such a way to provide a clear understanding of how each part of the plant works together to produce, store, and manage green hydrogen efficiently. The sessions will cover the key components of the plant, their functions, and the material, safety codes, technology protocols, and standards necessary for safe and sustainable operation. Learners will gain both theoretical and practical knowledge that is fundamental for working in the green hydrogen industry.

Learning Outcomes

After completing this module, you will be able to:

1. Describe and Identify the main components of a green hydrogen plant, like electrolysers, renewable energy sources, storage units, compressors, and control systems, along with their purposes in production and handling.
2. Understand the overall layout, operations flow, and interconnectivity of these components within the facility.
3. Explain the working principles of key technologies, such as electrolysis for hydrogen production and compression for storage and transportation.
4. Discuss operational challenges related to specific components and propose potential solutions.
5. Recognise materials used in component construction, focusing on the importance of corrosion resistant metals.
6. Apply knowledge of safety codes, operational standards, and protocols (e.g., ISO, BIS) for safe handling, maintenance, and emergency response in hydrogen systems.

Module Structure

Session 1: Key Components of a Green Hydrogen Plant

Session 2: Functions of Key Components of Green Hydrogen Plant

Session 3: Material, Safety Codes, Technology Protocols and Standards

Session 1: Key Components of a Green Hydrogen Plant

Green hydrogen is a super clean fuel made from just water and renewable energy like sunlight and wind. It's created through a process known as electrolysis, in which H_2O is split into H_2 and O_2 using electricity. But have you ever wondered what makes a Green Hydrogen Plant work?

Let's break it down. A Green Hydrogen Plant has three key systems that work together like a team:

1. Electrical System: This brings in clean electricity from wind turbines or solar panel's power to propel the machines.
2. Mechanical System: These are the machines and devices that:
    - Chemically breaks water into H_2 and O_2
    - Compress and store the hydrogen
    - Help transport it safely
3. Civil Infrastructure: This includes the buildings, storage tanks, and support structures that keep everything safe, strong, and in place, even in tough weather.

With the help of these three systems, green hydrogen can be used to:

- Power clean vehicles
- Run factories without pollution
- Provide electricity when the sun or wind isn't available

Learning about these components helps us understand how India and the world are moving toward a cleaner, smarter energy future.

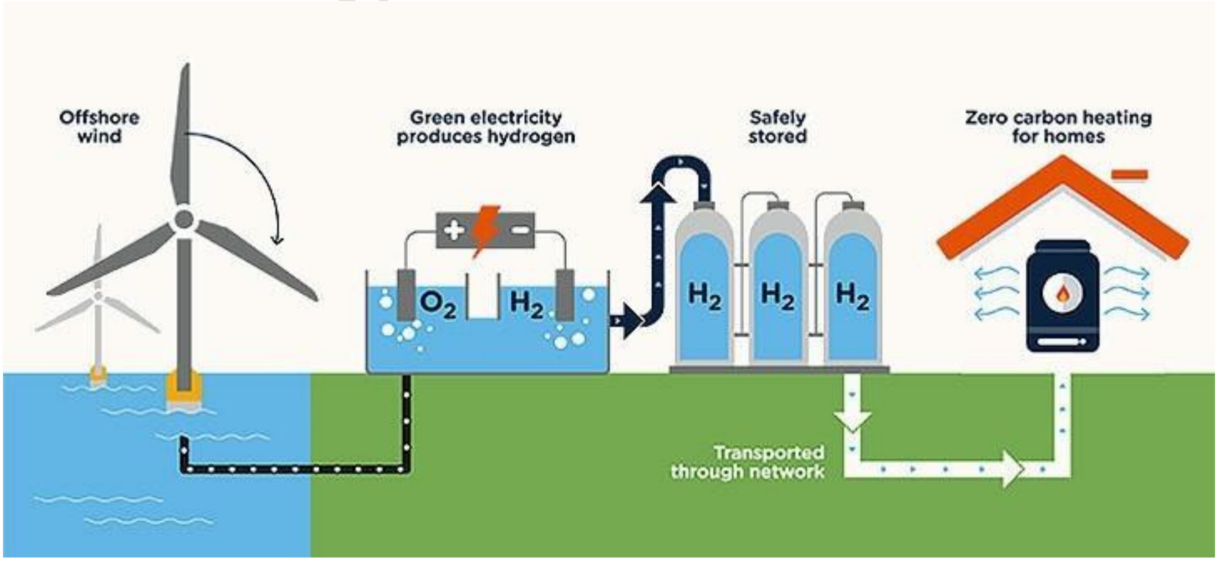


Fig. 2.1: Key Components of a Green Hydrogen Plant

2.1 Renewable Energy Source in a Green Hydrogen Plant

Green hydrogen is made using electricity from renewable sources like sunlight and wind. This electricity is utilized in a process known as electrolysis, which breaks water into H_2 and O_2 (Fig. 2.2). Unlike old methods that use coal or gas and cause pollution, green hydrogen does not release harmful gases. The main purpose of using renewable energy is to make the process clean and safe for the environment. It also helps in reducing pollution and supports the move toward cleaner energy in the future.

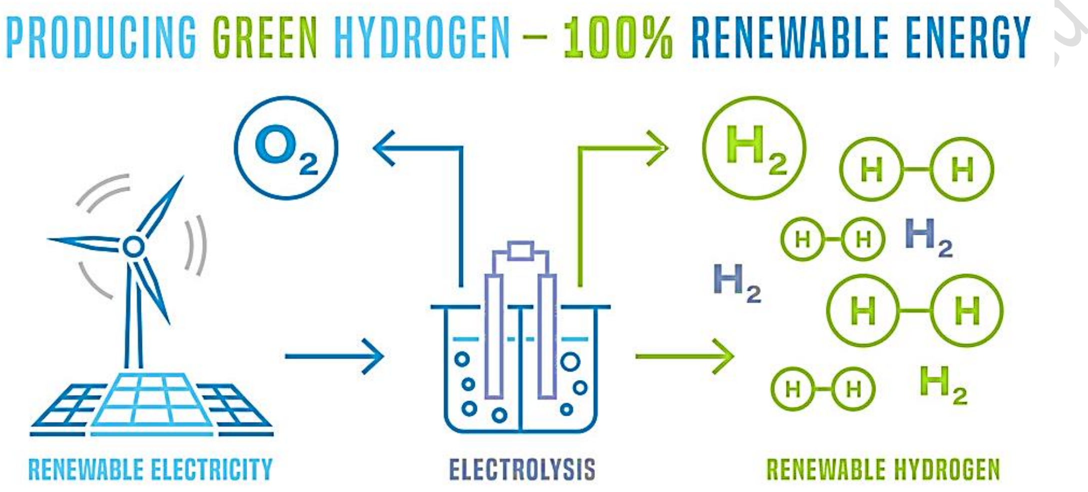


Fig. 2.2: Examples of Renewable Energy Sources

The Components of Renewable Energy Sources are:

a) **Solar Panels:** Solar panels turn sunlight into electricity using materials like silicon. They work best in places with lots of sunlight, generating a good amount of electricity during the day.
b) **Wind Turbines:** Wind turbines use wind to produce electricity. They are effective in areas with steady and strong winds. Wind energy is a cleaner as well as sustainable choice since it does not harm the environment.
c) **Hydropower Systems:** Hydropower systems generate electricity by using the energy of falling or flowing water. These systems are commonly used in areas with plenty of water, like rivers or dams. It is a reliable and renewable source of energy that can ensure a constant power supply to hydrogen plants.

The electricity from renewable sources powers an electrolysers, which breaks water into H_2 and O_2. It also ensures that the hydrogen is free of carbon emissions. However, since sources like wind and solar aren't always available, some hydrogen plants connect to the electrical grid to maintain a steady power supply when renewable energy is low.

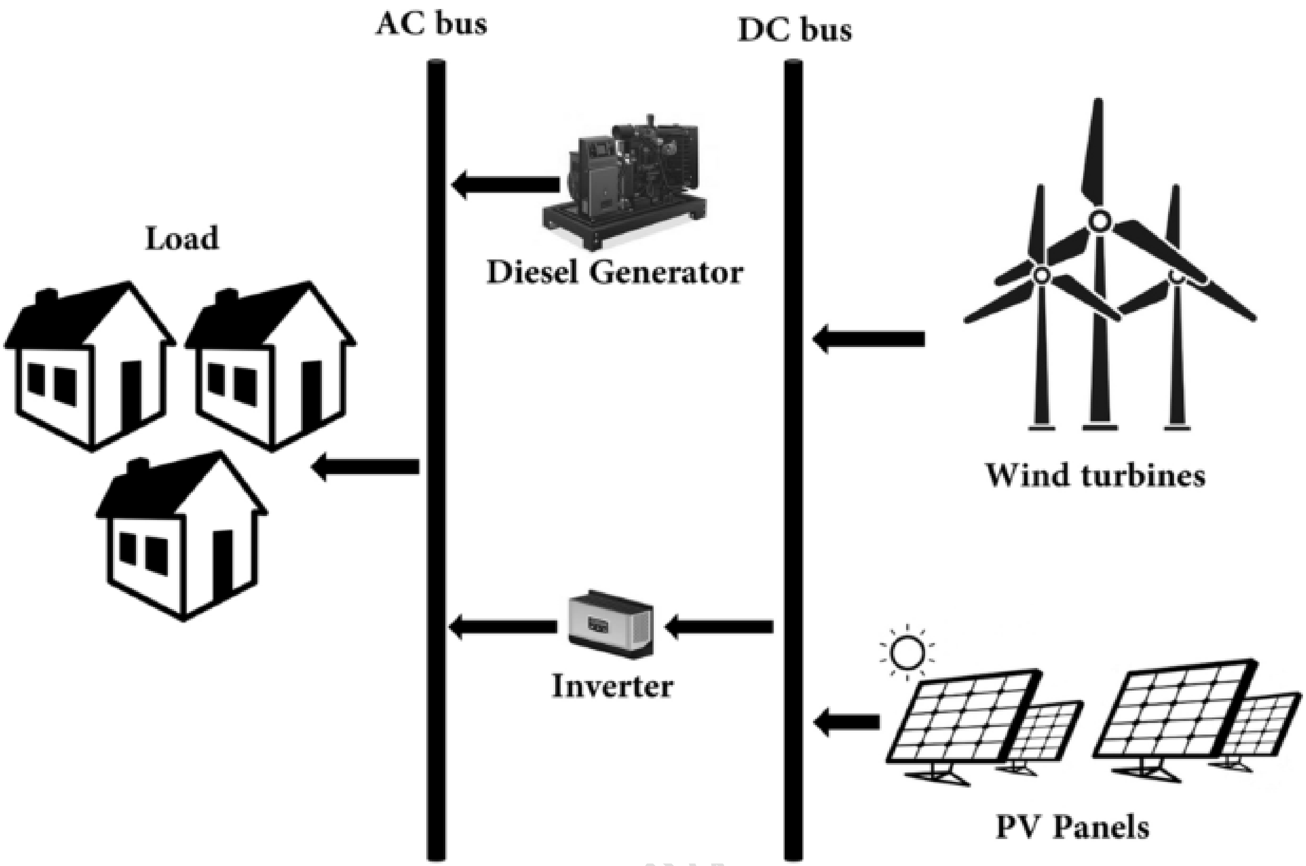


Fig. 2.3: Renewable Energy Sources, converters, load

To work efficiently, renewable energy systems should be located near the hydrogen plant. This reduces energy loss during transmission. If the energy sources are far away, like offshore wind farms, high voltage transmission lines help transport electricity to the hydrogen facility. Good planning and infrastructure are important for smoothly integrating renewable energy into hydrogen production.

Using renewable energy helps green hydrogen plants create a cleaner and sustainable future. It reduces reliance on fossil fuels and supports global efforts to fight climate change.

2.2 Electrolysers in a Green Hydrogen Plant

The electrolyser is a vital part of a green hydrogen plant. It breaks down water (H_2O) into H_2 and O_2 using electricity. When renewable energy is used, the hydrogen produced is completely green, meaning it does not create carbon emissions. The hydrogen can be stored and utilised as a clean fuel, while the oxygen (O_2) can be released in the air or stored for industrial purposes. Types of Electrolysers are discussed in preceding paragraph.

1. **Alkaline Electrolyser (AEL):** This method uses an alkaline solution, such as potassium hydroxide, as the electrolyte. It is cost-effective and durable, which makes it suitable to be widely used for hydrogen generation.

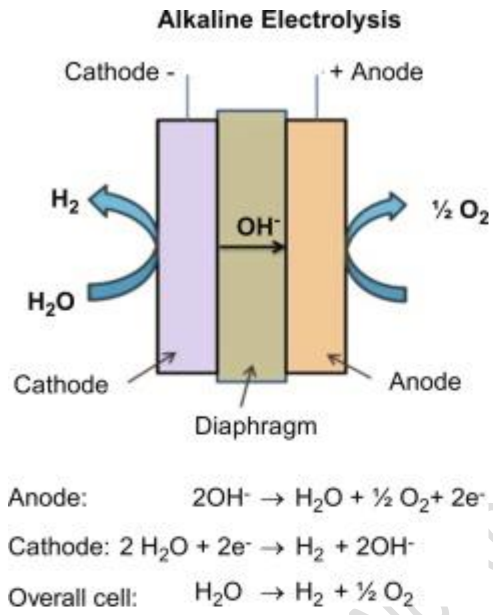


Fig. 2.4: Alkaline Electrolyser

2. Proton Exchange Membrane Electrolyser (PEMEL): This type of electrolyser employs a solid polymer electrolyte. It is highly efficient and can rapidly adapt to fluctuations in power supply, making it well-suited for renewable energy sources such as solar and wind.

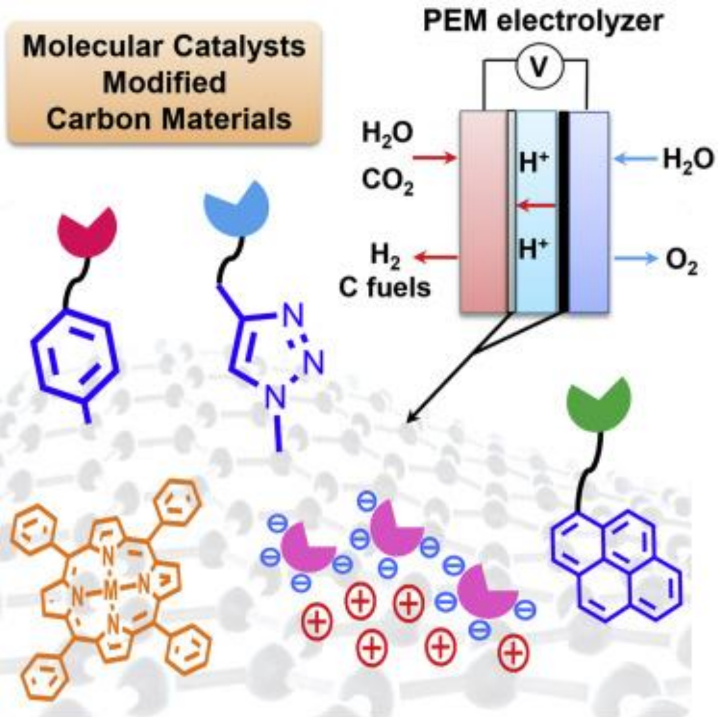


Fig. 2.5: Proton Exchange Membrane (PEM) Electrolyser

3. **Solid Oxide Electrolyser (SOEL):** This type operates at high temperatures (700 900°C) and is very efficient. However, it needs ample amount of heat energy, so it is best for specialised industries that have access to heat.

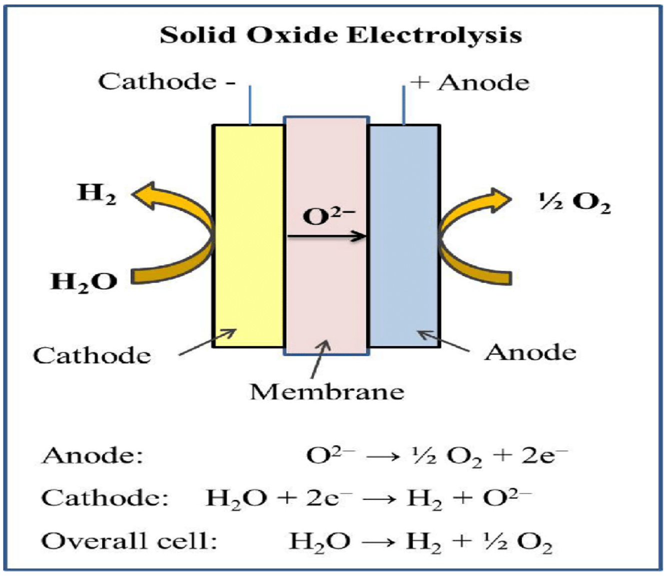


Fig. 2.6: Solid Oxide Electrolyser

The proton electrolyser uses purified water and electricity to create hydrogen and oxygen through electrolysis. It collects, compresses, and stores the hydrogen for later use. The oxygen may either be released in the air or may be captured for industrial uses, like in medicine, steel production, or wastewater treatment.

To operate effectively and safely, the electrolyser should be in a controlled environment where temperature, humidity, and pressure are managed. It should be near the water purification system to ensure a steady supply of clean water and close to the power source to minimise energy losses. Proper placement improves efficiency, reduces costs, and ensures smooth operation in a green hydrogen plant. By adding an electrolyser to a hydrogen production system, industries and energy providers can produce clean and sustainable hydrogen, supporting a greener energy future.

Water Purification System in a Green Hydrogen Plant:

The water purification system is crucial in a green hydrogen plant. It ensures that the water used for electrolysis is free from impurities. Contaminants like particles, dissolved salts, and minerals can lower the electrolyser's efficiency and cause damage over time. High purity water is essential for the electrolysis process to work well and avoid contamination, making an efficient water purification system necessary.

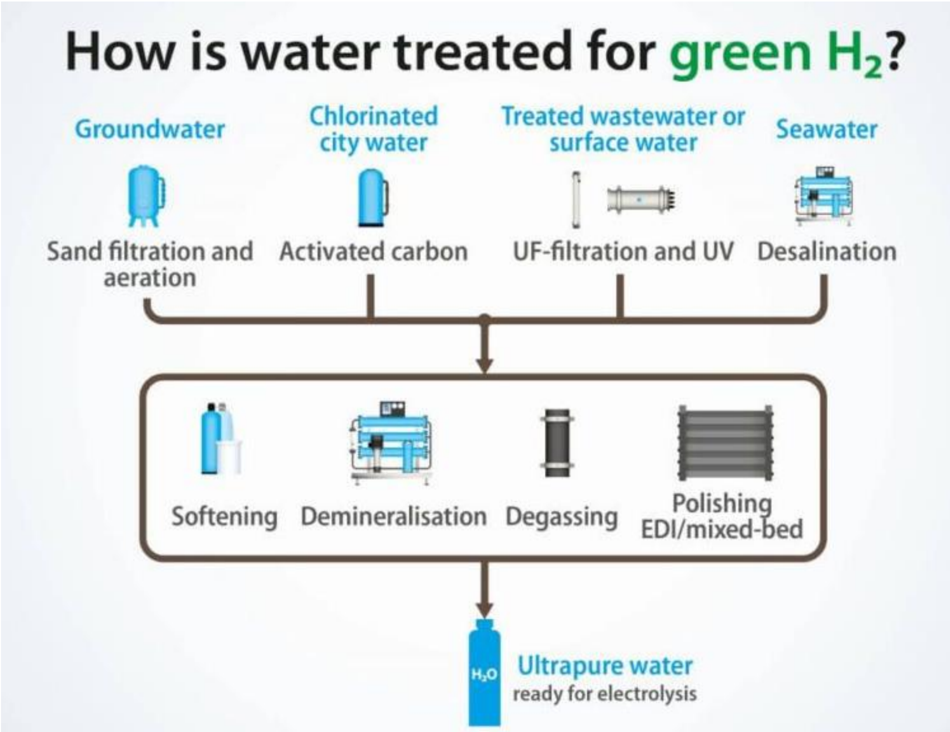


Fig. 2.7: Main components of the Water Purification System

The basic components of a Water Purification System are given below:

1. Filtration Units: These units remove large particles and dirt from the water. They are the primary step in making the water clean enough for the electrolyser.
2. Reverse Osmosis (RO) Systems: RO systems use special membranes to filter out salts, organic materials, and other impurities. This improves water quality and makes it suitable for electrolysis.
3. Deionisation Systems: This system cleans the water even more by removing ions and minerals. It provides ultra-pure water that meets the strict needs of the electrolyser. This step is the last one before the water enters the electrolysis unit.

The water purification system processes raw water to ensure it is clean enough for efficient hydrogen production. If the water is not purified properly, impurities can build up on the electrolyser's electrodes. This can cause lower efficiency, higher maintenance costs, and a shorter lifespan for the equipment. The clean water goes directly into the electrolyser, where it gets splits into H_2 and O_2.

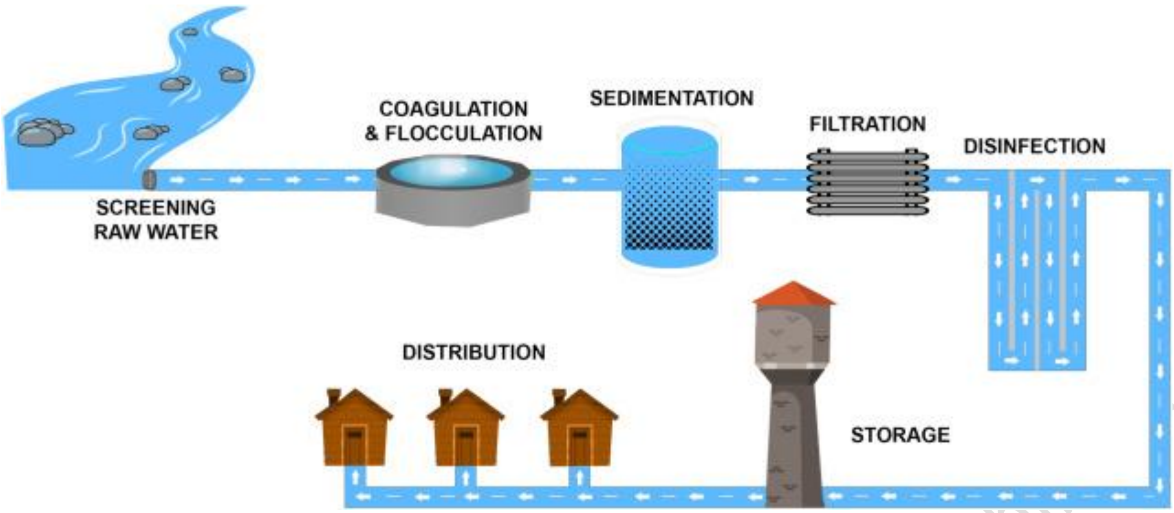


Fig. 2.8: Water Purification System Processes

To continually provide purified water, the system is located upstream of the electrolyser. This means it processes the water before it gets to the electrolysis unit. The system is usually part of the plant's structure to save space and make maintenance easy. A good layout allows the purified water to reach the electrolyser quickly with minimal energy loss. An effective water purification system helps a green hydrogen plant operate efficiently, reduces wear on equipment, and supports sustainable hydrogen production.

Hydrogen storage is important for a green hydrogen plant. It keeps a steady supply of hydrogen for users. Since hydrogen production through electrolysis does not always match immediate demand, a good storage system helps balance supply and demand. Effective storage also simplifies the transport and distribution of hydrogen for several uses, including in industry, energy generation and fuel cells. The method of hydrogen storage is as follows:

a) Compressed Hydrogen Gas: This technique involves storing the H_2 in high pressure metallic tanks that can maintain pressures between 350 and 700 bar. It is often used for transportation, fuel cell vehicles, and industrial purposes because it is easy to handle and allows for quick refuelling.

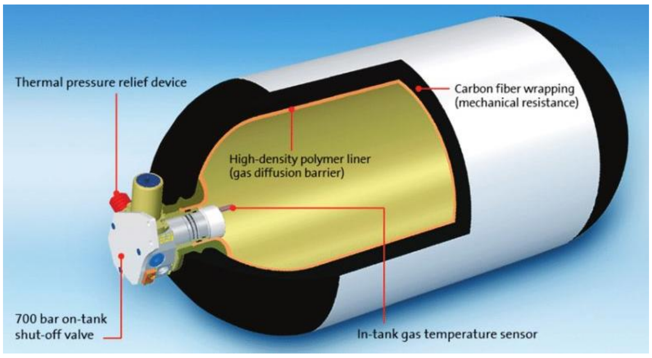


Fig. 2.9: Compressed Hydrogen Storage System

b) Liquid Hydrogen (LH_2): To store hydrogen in the liquid form, it should be essentially cooled to extremely low temperatures (-253°C) and kept in insulated tanks to stop it from evaporating. This method is ideal for large storage needs and long-distance transport, such as in the aerospace sector or hydrogen export facilities.

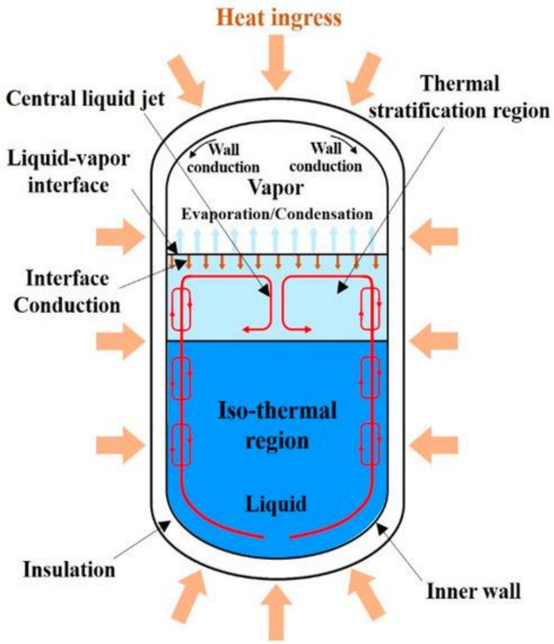


Fig. 2.10: Liquid Hydrogen

c) **Solid State Storage:** This method stores hydrogen by absorbing it into metal hydrides or other materials. It is compact, safe, and very efficient, making it a good option for energy storage. Unlike compressed gas or liquid hydrogen, solid state storage operates at lower pressures and is safer.

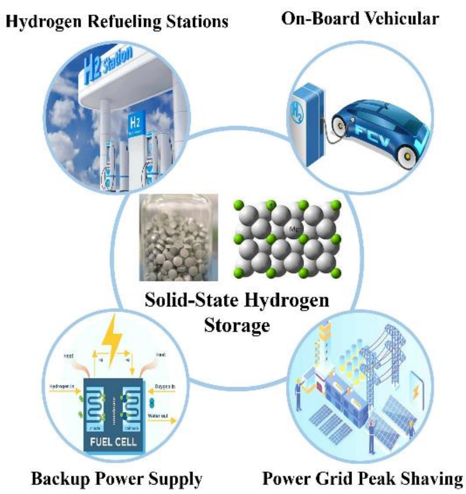


Fig. 2.11: Solid State Storage

The hydrogen storage system stores the hydrogen generated by the electrolyser until it is required for use. It balances supply and demand to ensure there is always enough hydrogen available. This is particularly important for fuel cells, which need a steady hydrogen supply.

To work efficiently and safely, hydrogen storage tanks should be located close to the electrolyser for quick transfer. Because hydrogen is highly flammable, strict safety measures are necessary.

These include leak detection systems, good ventilation, and fire suppression equipment. Careful planning of the layout of the storage area helps to reduce the risks and ensures safe handling of the unit. An effective hydrogen storage system improves energy security, supports large scale hydrogen distribution, and aids in transitioning to clean energy.

2.5 Oxygen Handling in a Green H_2 Plant

In a green H_2 plant, the electrolysis splits water into H_2 and O_2. While the main goal is to produce hydrogen, it is important to manage oxygen safely and efficiently. Oxygen has many industrial uses. If there is no immediate need for it, oxygen must be vented safely into the atmosphere. Proper oxygen handling helps ensure safety and efficiency while reducing environmental impact.

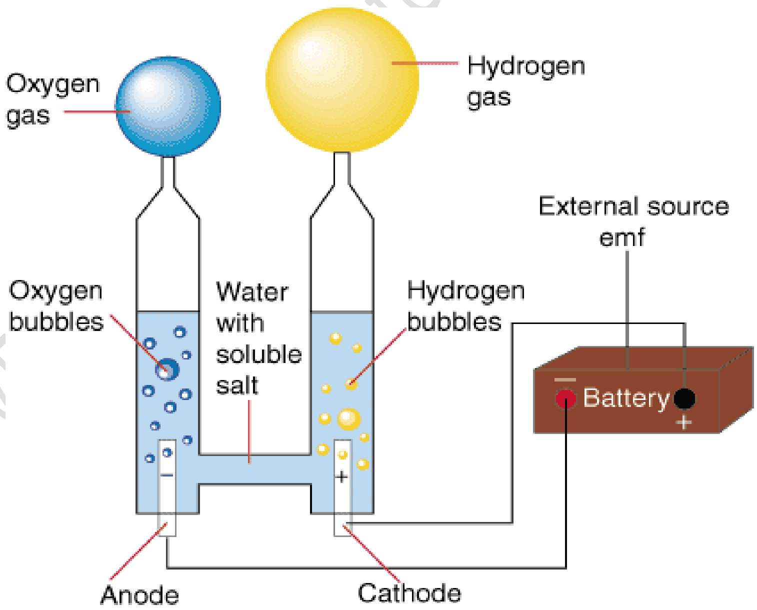


Fig. 2.12: Oxygen Handling in Green Hydrogen Plant

2.5.1 Options for Oxygen Handling

a) Storage for Industrial use: We can collect, purify, and store oxygen in high pressure tanks for various industries. Common uses include:

- Medical applications (like oxygen therapy in hospitals)
- Metal cutting and welding (oxygen assists with combustion)
- Water treatment (oxygen enhances wastewater treatment)

b) Venting into the Atmosphere: If there's no demand for stored oxygen, we can safely release it into the atmosphere. Since oxygen is a natural part of the air, controlled venting does not harm the environment. However, it must follow safety rules to avoid problems, such as creating oxygen rich environments that could increase fire risks.

The oxygen handling system manages oxygen safely and efficiently. It helps to:

i. Use resources effectively by collecting oxygen for those who need it.
ii. Prevent safety hazards by ensuring controlled venting when storage isn't needed.
iii. Maintain plant efficiency by using proper handling methods.

To ensure safety and efficiency, oxygen storage or venting systems should be located near the electrolyser. This allows for direct handling of the produced oxygen. Important safety measures that are used include:

- Pressure relief valves (PRVs) to prevent over pressurisation in storage tanks
- Monitoring systems to check oxygen levels and detect leaks
- Proper ventilation to avoid the buildup of oxygen rich areas that could raise fire risks

By having a well-planned oxygen handling system, a green hydrogen plant can improve safety, reduce waste, and add value from the electrolysis process.

2.6 Power Management System in a Green Hydrogen Plant

The power management system is crucial for a green hydrogen plant. It ensures a steady and efficient electricity supply to the electrolyser. Electrolysis requires a stable power source, so this system manages changes in renewable energy sources like wind and solar. The main components of Power Management System are as follows:

a) Power Converters: These devices regulate the variable electricity generated through solar panels and wind turbines, stabilizing the power to ensure a consistent supply to the electrolyser.
b) Battery Storage: This system stores extra electricity generated during peak times. It also provides backup power when solar or wind energy is low, ensuring continuous electrolysis.
c) Grid Connection: The hydrogen plant can draw power from the grid when renewable energy is insufficient. When there is excess energy, it can feed that surplus back into the grid, benefiting the overall energy system.

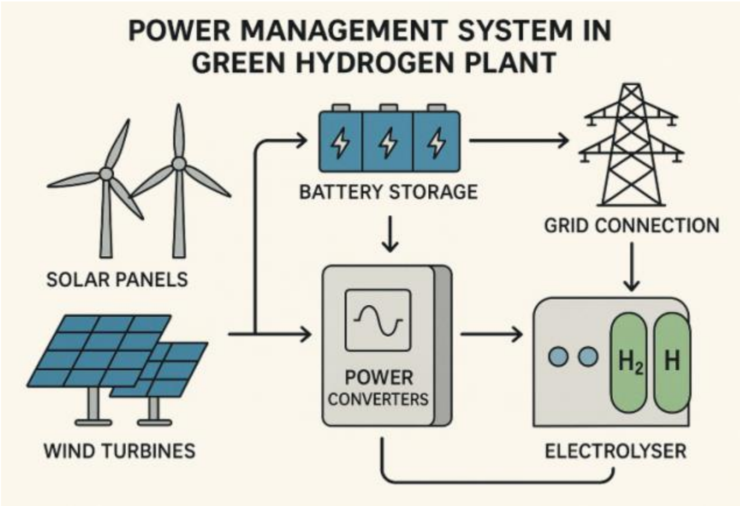


Fig. 2.13: Power Management System in green Hydrogen Plant

The power management system balances electricity supply and demand to keep the electrolyser running efficiently. It maximises renewable energy use, reducing dependency on fossil fuels and making hydrogen production more sustainable. By using battery storage and connecting to the grid, it ensures a reliable power supply, even when renewable energy fluctuates.

To ensure efficient operation and ease of maintenance, the power management system is strategically placed between the renewable energy sources and the electrolyser. It is typically housed in a control room, allowing operators to monitor power flow, detect issues, and optimise energy usage. Effective integration of power converters, battery storage, and grid connections is essential for smooth and reliable hydrogen production. A well-designed PMS (power management system) enhances the overall efficiency and dependability of the hydrogen plant, contributing significantly to a cleaner energy future.

2.7 Hydrogen Compression in a Green Hydrogen Plant

Hydrogen compression (Fig.2.14) is a key process in a green hydrogen plant. It increases hydrogen's energy density, making it easier to store and transport. At normal atmospheric pressure, hydrogen has low density, so we need to compress it to high pressures for effective storage in tanks and transportation through pipelines. Proper compression ensures safe handling, reduces storage space needs, and improves transport efficiency.

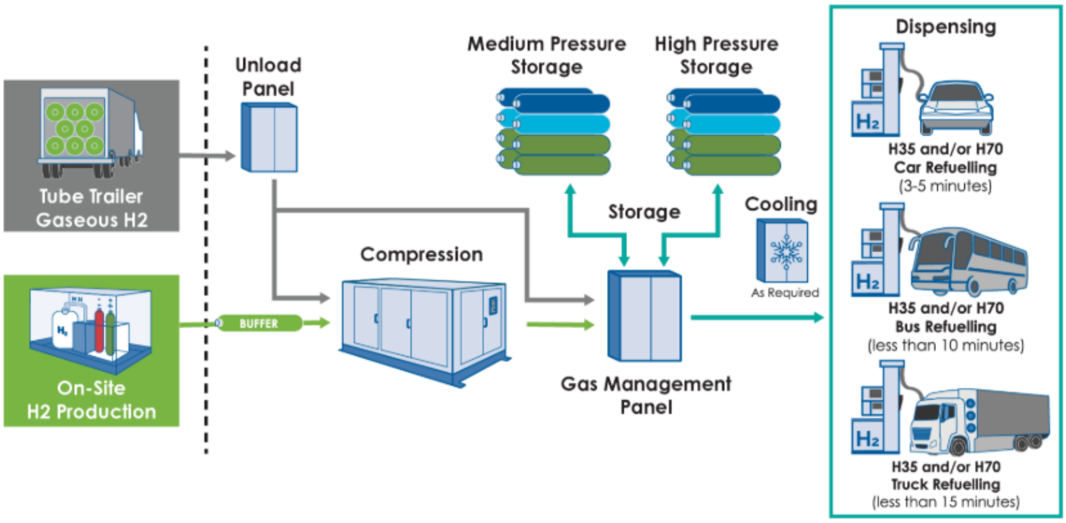


Fig. 2.14: Compression of Hydrogen

2.7.1 Main Components of the Hydrogen Compression System

1) Compressors

  a) These machines raise hydrogen gas pressure to levels between 350 and 700 bar for storage and transport.
  b) They prepare hydrogen for fuel cells, industrial applications and energy distribution.

2) Cooling Systems

  a) These systems remove extra heat produced during compression.
  b) They help prevent overheating and protect equipment, ensuring it lasts longer and operates safely.

Function of the Hydrogen Compression System

  a) The system prepares hydrogen for storage or distribution by increasing its pressure, making it more compact and easier to transport.
  b) Efficient compression allows the plant to store more hydrogen in less space, improving storage and transport logistics.
  c) Cooling systems maintain safe temperatures, helping prevent equipment failures and enhancing overall efficiency.

We place compressors between the electrolyser and the storage tanks to transfer the produced hydrogen directly. Cooling systems are included to keep operating temperatures safe and to prevent overheating and pressure risks. We also have safety features like pressure relief valves and monitoring systems to stop excessive pressure buildup and ensure smooth operation.

2.8 Hydrogen Distribution System in a Green Hydrogen Plant

The hydrogen distribution system moves hydrogen from the production plant to users or distribution points. Hydrogen is a key energy source, so we need to deliver it efficiently and safely for various uses, such as in industries, fuelling stations, and power plants. The distribution method depends on distance, demand, and existing infrastructure.

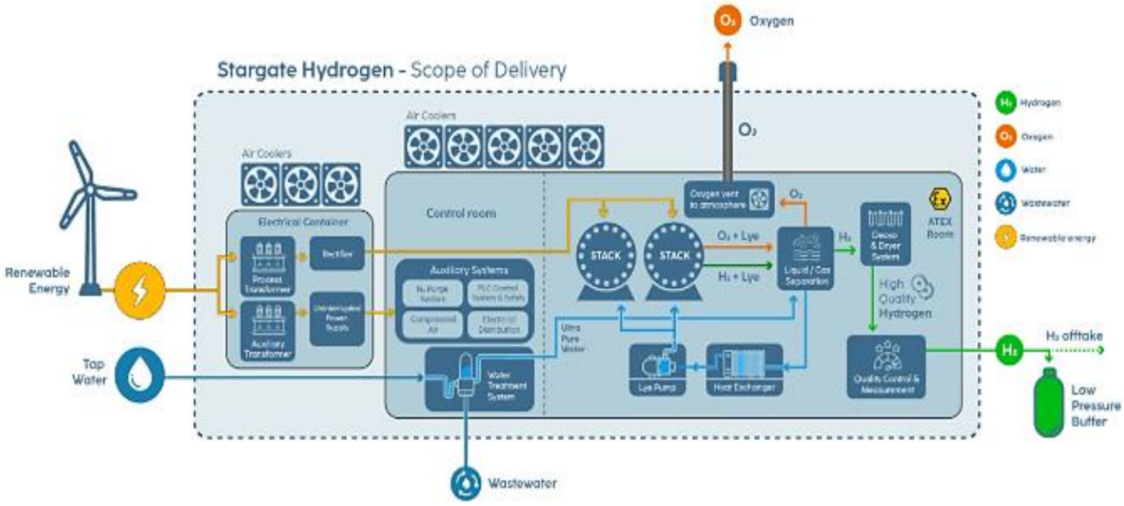


Fig. 2.15: Hydrogen Distribution System

Methods of Hydrogen Distribution

Hydrogen may be transported using various techniques, each suited to specific needs and distances. Hydrogen gas can be transported most effectively across long distances through pipelines. They are particularly suitable for large industrial applications and hydrogen fuelling networks. However, this method requires dedicated infrastructure, similar to natural gas pipeline systems, which can be costly to establish but efficient once in place.

Fig. 2.16: Transportation of Hydrogen Gas through Pipelines

For shorter to medium distances, tube trailers offer a flexible solution. These trailers transport compressed hydrogen gas in high pressure cylinders mounted on trucks, making them ideal for smaller users and regions not connected by pipelines. Tube trailers are commonly used at hydrogen fuelling stations and industrial sites that lack direct pipeline access.

Fig. 2.17: Transportation of Hydrogen Gas in High pressure Cylinder

Cryogenic tankers, on the other hand, are designed to carry liquid hydrogen at extremely low temperatures in insulated tanks. This method is effective for long distance transport and is often used for bulk supply, including the export of hydrogen or delivery to large scale customers. Cryogenic tankers play an important role in the global H_2 supply chain due to their capacity and efficiency in transporting liquefied hydrogen.

Fig. 2.18: Cryogenic tankers

Function of the Hydrogen Distribution System

The system connects to storage tanks and is located near the plant's exit for easy loading and transport. Safety features such as leak detection, emergency shutdowns, and adequate ventilation are essential. The design accommodates different transport methods to ensure a flexible hydrogen supply.

2.9 Control and Monitoring System in a Green Hydrogen Plant

The safe and optimal functioning of a green hydrogen plant requires a reliable control and monitoring system. This system checks, adjusts, and improves the performance of different parts of the plant. It helps prevent problems and increase efficiency by collecting real time data. This allows operators to identify issues early, ensuring smooth and safe operations.

Key Components of the Control and Monitoring System

a) SCADA Systems (Supervisory Control and Data Acquisition): These systems permit real time monitoring and controlling of plant operations. They allow operators to manage processes such as electrolysis, compression, and storage remotely and efficiently.

b) Sensors and Actuators: Sensors continuously monitor critical parameters like pressure, temperature, and flow rate. Actuators respond automatically to sensor inputs, adjusting settings as needed to ensure the safe and smooth plant operation.

c) Safety Systems: Safety systems include features such as leak detection, fire suppression, and emergency shutdown mechanisms. These systems ensure rapid responses to potential safety hazards, safeguarding both personnel and equipment.

Functions of the Control and Monitoring System

- Monitors all plant components to ensure they operate safely and efficiently.
- Offers data analysis to improve processes, troubleshoot problems, and enhance performance.
- Prevents failures by identifying and resolving issues before they become serious.

The control room should be centrally located for easy access to all systems. Position sensors and actuators throughout the plant for comprehensive data collection and automatic adjustments. Design the system to allow for future upgrades and integration of new technology. With an advanced control and monitoring system, a green hydrogen plant can enhance safety, efficiency, and long-term reliability.

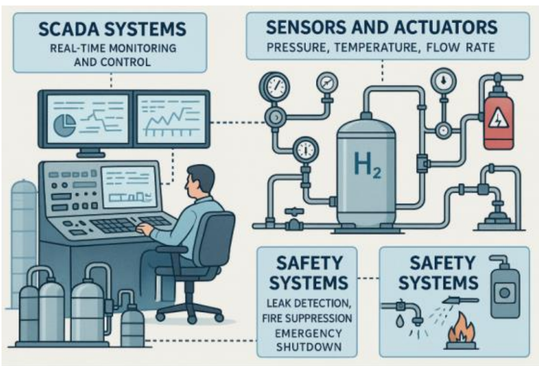


Fig. 2.19: Components of the Control and Monitoring System

2.10 Cooling System in a Green Hydrogen Plant

The cooling system is crucial for keeping the electrolyser, compressors, and other important equipment at the right temperature in a green hydrogen plant. Various processes generate heat, so an effective cooling system is needed to prevent overheating, maintain high efficiency, and extend the lifespan of plant parts. The Key Parts of the Cooling System are given below:

1. Heat Exchangers

- Heat exchangers are used to move excess heat away from important parts to avoid damage.
- They help in keeping temperatures steady for better thermal efficiency.

2. Cooling Towers

- Cooling towers release heat into the air using evaporation or air cooling.
- Cooling towers are commonly used in large hydrogen plants to manage heat from industrial processes.

The cooling system plays an important role in preventing overheating of the electrolyser, compressors, and storage units. It maintains stable operating conditions, thereby enhancing both efficiency and safety. By reducing thermal stress on components, the system helps extend their lifespan and minimize maintenance costs. Cooling systems should be integrated with electrolysers and compressors to manage heat effectively. They must be strategically positioned to reduce energy losses and optimise cooling performance. Additionally, the design should accommodate the specific cooling requirements of different sections within the plant.

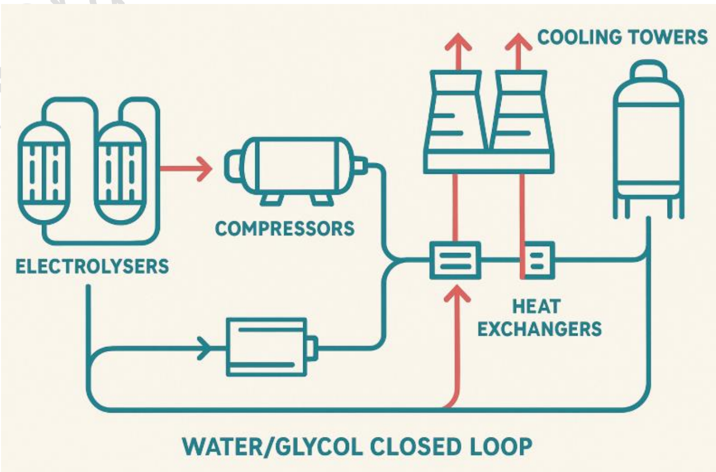


Fig. 2.20: Cooling System in a Green Hydrogen Plant

Check your Progress

A. Fill in the Blanks:

1. _______ energy sources like wind and solar are used to produce the Green H_2.
2. The process of splitting H_2O into H_2 and O_2 via electricity is called _______.
3. A _______ electrolyser uses, potassium hydroxide, which is an alkaline solution, as the electrolyte.
4. _______ systems in a green hydrogen plant help manage changes in power supply from renewable sources.
5. Hydrogen gas is often stored under high pressure ranging from _______ to 700 bar.

B. Multiple Choice Questions:

1. What is the key function of an electrolyser in a green hydrogen plant?
   a) To break water into H_2 and O_2
   b) To compress hydrogen
   c) To store hydrogen
   d) To cool hydrogen gas

2. Which method is **not** a type of hydrogen storage method?
   a) Liquid hydrogen
   b) Solid state storage
   c) Compressed natural gas
   d) Compressed hydrogen gas

3. What does a **Reverse Osmosis (RO)** system remove from water?
   a) Hydrogen
   b) Oxygen
   c) Salts and organic materials
   d) Metal particles only

4. Which type of electrolyser is best suited for quick response to fluctuating renewable energy?
   a) Alkaline
   b) Solid Oxide
   c) Deionisation
   d) Proton Exchange Membrane

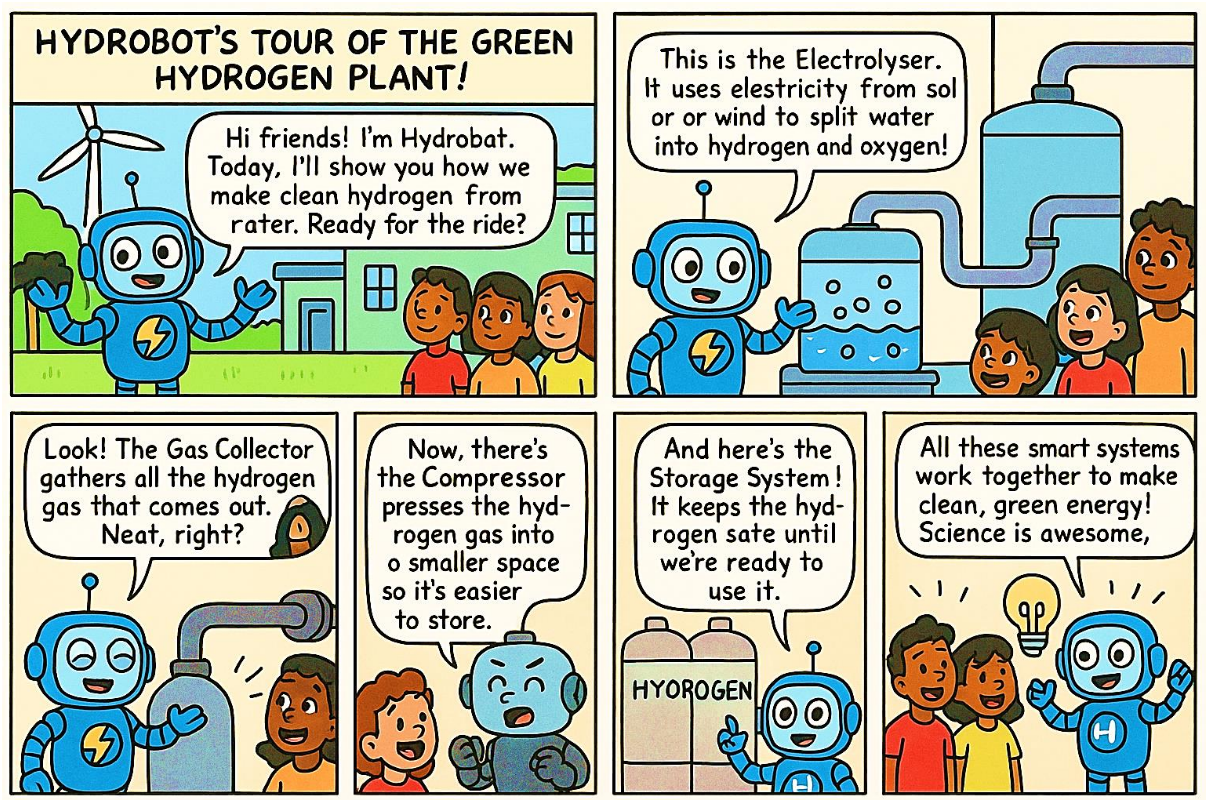
5. Which component helps monitor and control the operation of a green hydrogen plant remotely?
   a) Wind turbine
   b) SCADA system
   c) Electrolyser

d) Cryogenic tanker

C. Short Answer Questions:

1. List three main components of a green hydrogen plant?
2. Why is purified water necessary in the electrolysis process?
3. What is the purpose of H_2 compression in a green H_2 plant?
4. Describe the role of renewable energy sources in green H_2 production. Include examples and why proximity to the plant matters.
5. Explain the importance and components of the water purification system in a green H_2 plant.
6. Discuss the function and safety measures of the hydrogen storage and distribution systems.

Session 2: Functions of Key Components of Green Hydrogen Plant



A green Hydrogen (H_2) plant operates on several fundamental scientific and engineering principles that enable the efficient production, purification, storage, and distribution of H_2 gas. Each major component, such as the Electrolyser stack, gas collector, power source, gas compression unit, and storage system. Understanding these principles helps in optimising the efficiency, safety, and sustainability of H_2 production.

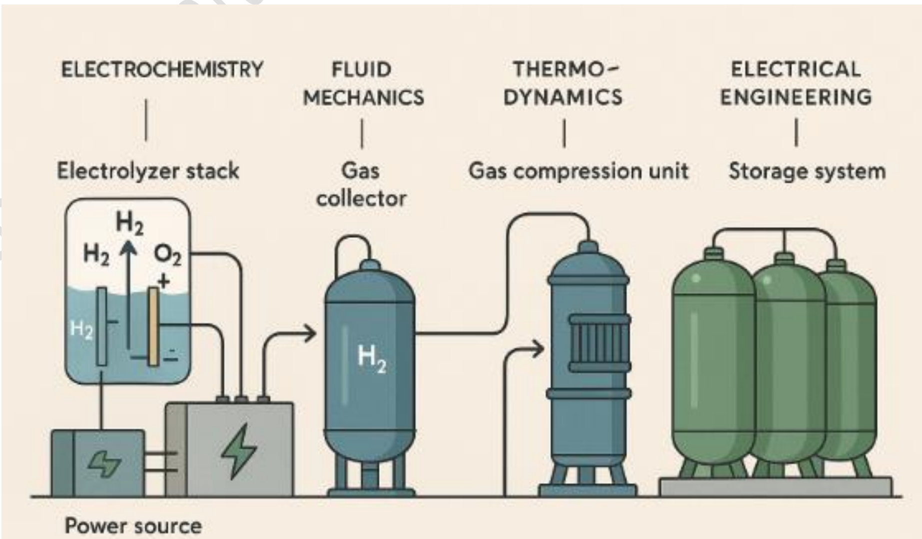


Fig. 2.21: Green Hydrogen plant

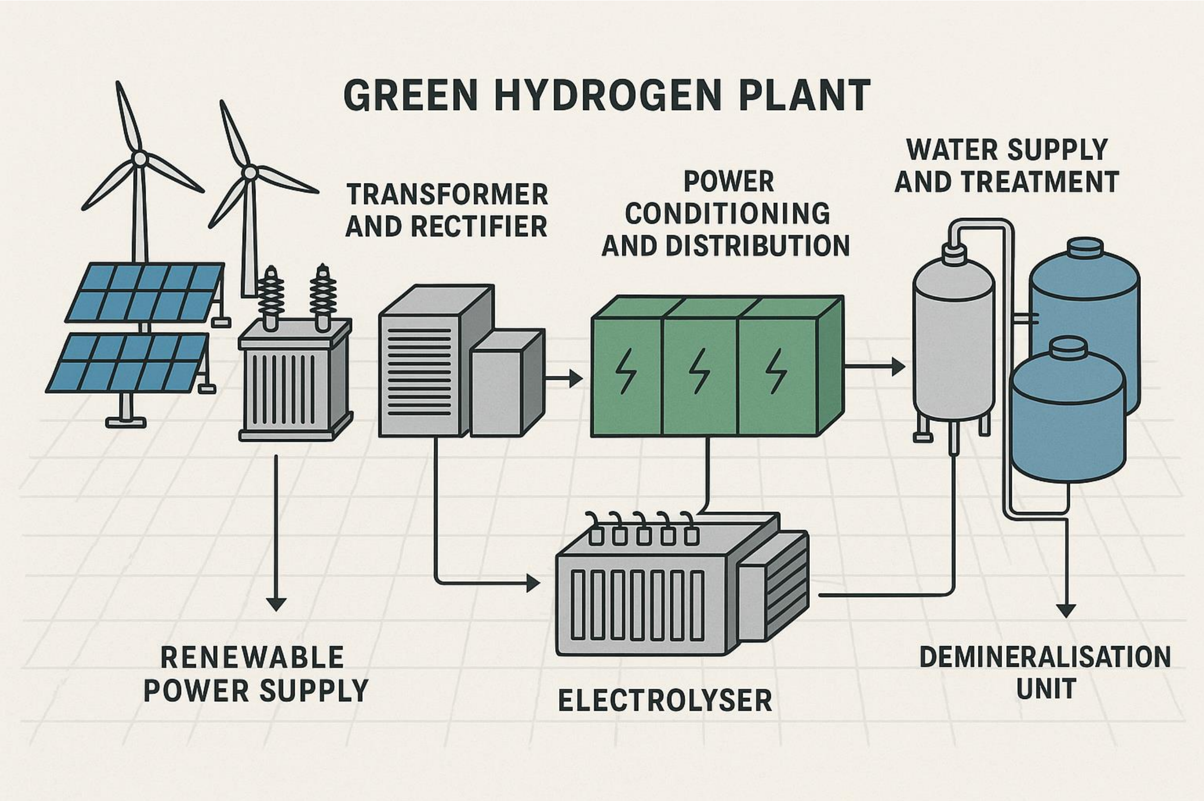


Fig. 2.22: Main components of the Green Hydrogen plant

A typical green H_2 plant is designed with a logical layout to maximise efficiency and functionality. The process begins with the Renewable Power Supply System, where sources like solar panels, wind turbines, or hydro-electric generators generate clean electricity. This electricity is routed through transformer and rectifier units that adjust the voltage and convert AC to DC required for electrolysis. Following this, the Power Conditioning and Distribution section ensures the electricity is stable and conditioned for optimal performance by the Electrolyser. Next to it is the Water Supply and Treatment System, which includes a feedwater intake, a demineralisation unit to remove impurities, and storage tanks to maintain a continuous supply of purified water for hydrogen production.

At the heart of the plant is the Electrolyser Unit, where electricity is used to break the H_2O into H_2 and O_2. This central unit also includes cooling and safety mechanisms to control temperature and pressure. Adjacent to the Electrolyser is the Gas Separation and Purification Unit, where the produced gases are separated using gas separators, filtered through membranes, and dried to remove moisture and impurities. The purified hydrogen is then directed to the Compression and Storage System, where it is compressed for storage using high pressure tanks or stored in cryogenic tanks if liquefied hydrogen is required. This section is equipped with several safety features like pressure relief valves and monitoring systems to prevent accidents.

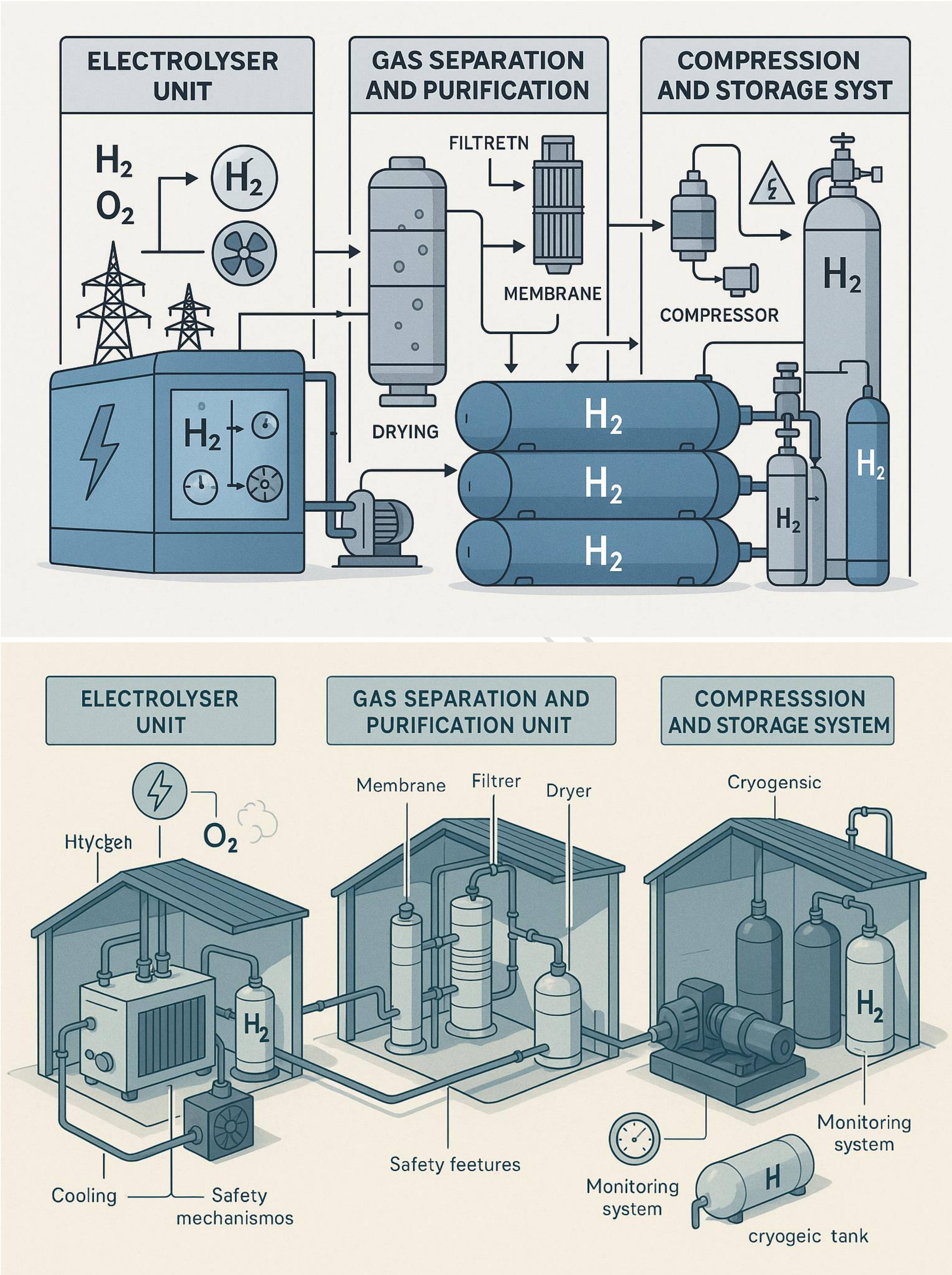


Fig. 2.23: Electrolyser Unit

Finally, the Hydrogen Distribution and Utilisation section manages the delivery of hydrogen for various uses. Hydrogen may be supplied via pipelines, transported in cylinders or tankers, or utilised directly in fuel cells to generate electricity. Complementing all these operations are the Safety and Control Systems, which include a centralised control room for monitoring, an emergency shutdown system (ESD), ventilation and cooling systems to prevent overheating, and hydrogen sensors and suppression systems to address fire or explosion risks.

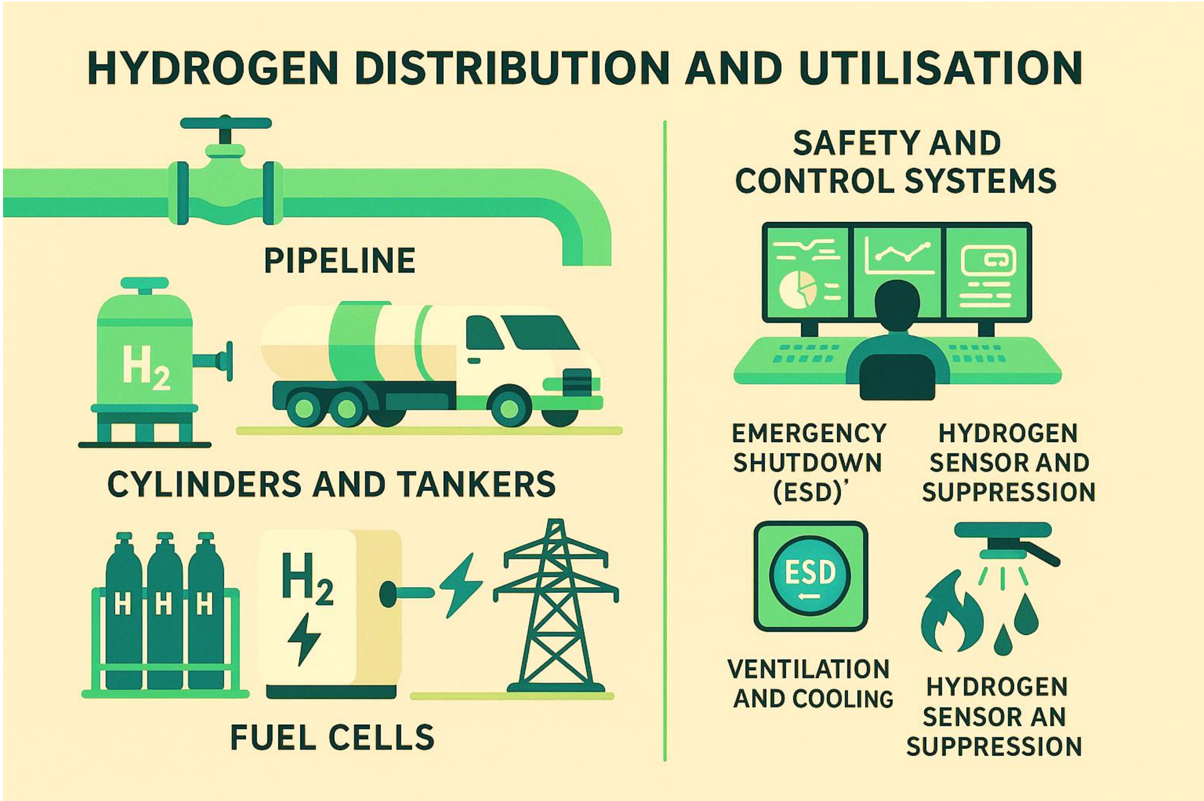


Fig. 2.24: Hydrogen Distribution and Utilization

Let us now discuss the details of the Main Components of the Green Hydrogen Plant.

1. Electrolyser Stack Principle of Electrolysis

The Electrolyser stack operates based on electrolysis, a process that uses electrical energy to split H_2O into H_2 and O_2. This is governed by Faraday's Laws of Electrolysis, which states that the amount of substance liberated at an electrode is directly proportional to the amount of electricity passed through the electrolyte.

Working Mechanism:

- Electric current is passed through water using electrodes (cathode and anode).
- At the anode (i.e., the positive electrode): Water molecules gets split, releasing O_2 gas and hydrogen ions (H^+).

- At the cathode end (i.e., the negative electrode): The hydrogen ions gain electrons and form the hydrogen gas (H_2).
- Membranes or separators ensure that the produced gases do not mix, preventing safety hazards.

Key Formula (Electrolysis):

$$2H_2O \rightarrow 2H_2 + O_2$$

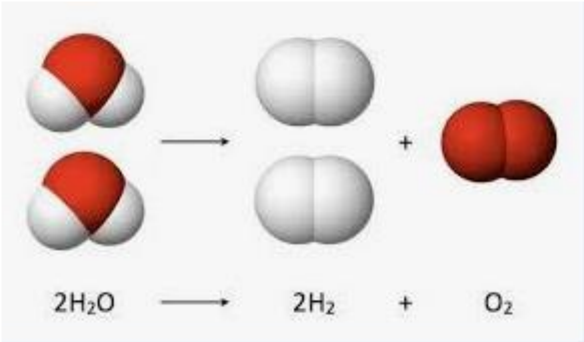


Fig. 2.25: Electrolysis process

This reaction requires energy input, which is provided by renewable electricity.

2. Gas Collector Principle of Gas Separation and Density Differences

The gas collector works by taking advantage of the different densities of hydrogen and oxygen produced when water is split in the electrolyser. These gases can easily be separated using physical barriers or membranes, allowing them to rise or settle in distinct areas. This method makes the collection of hydrogen and oxygen efficient and safe.

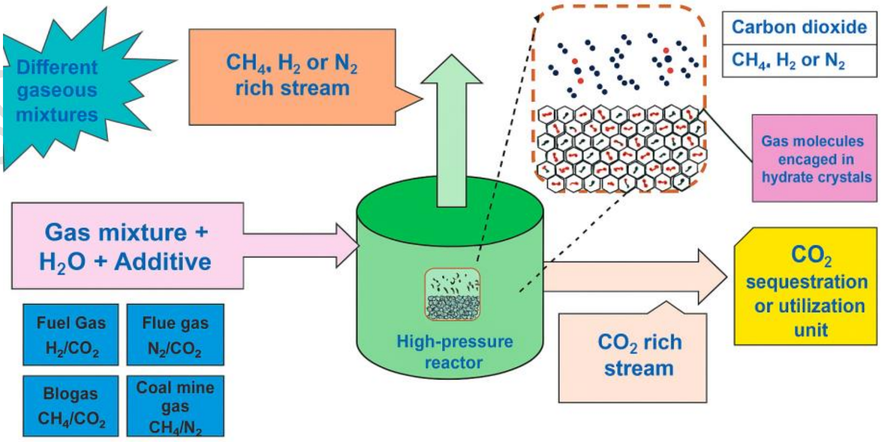
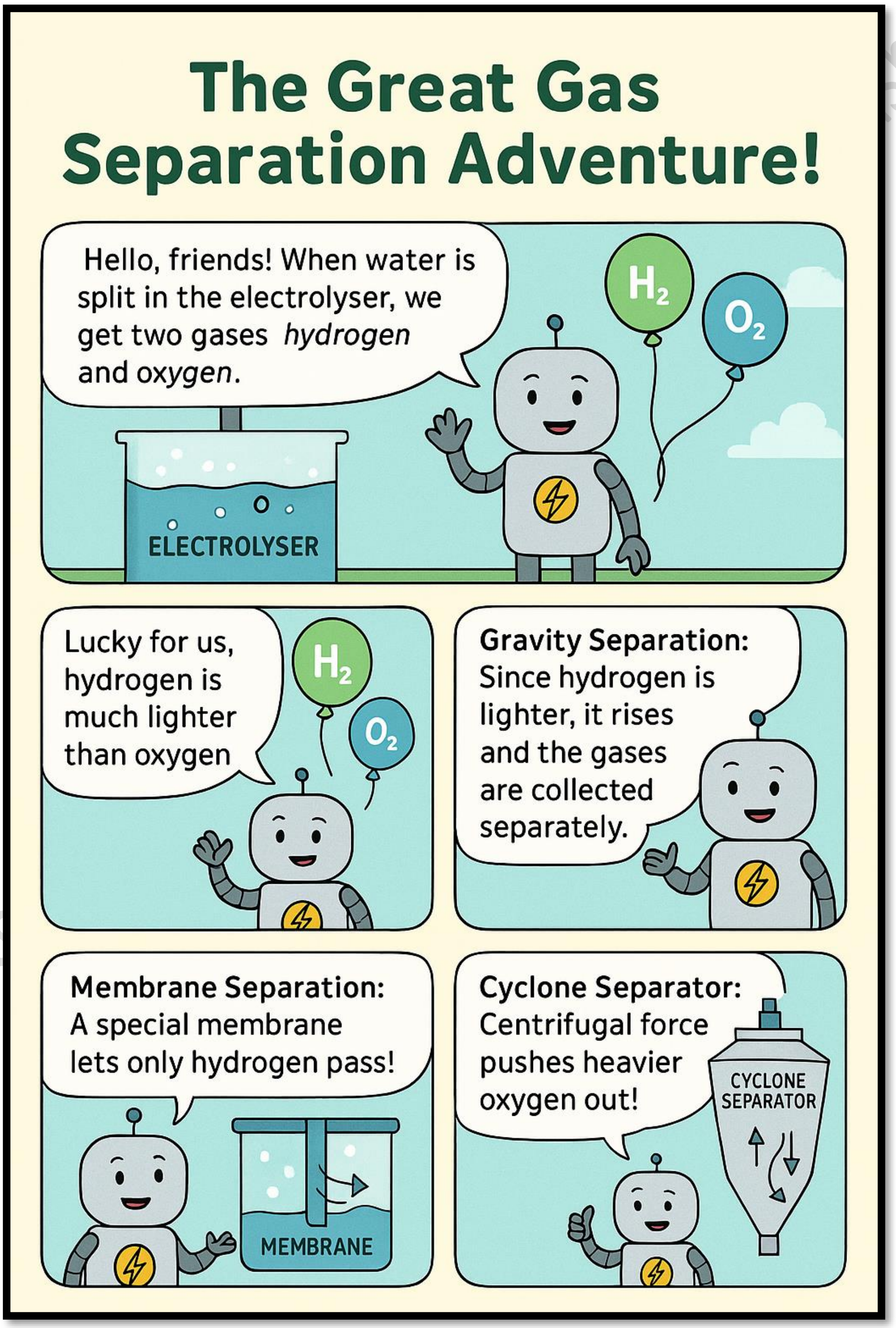


Fig. 2.26: Hydrate based gas Separation

Working Mechanism:

- **Membrane Separation:** Allows only hydrogen molecules to pass through while blocking oxygen.
- **Gravity Separation:** Since hydrogen is much lighter than oxygen, it naturally rises and can be collected separately.
- **Cyclone Separators:** Use centrifugal force to separate gases based on their molecular weight.



Importance of separation:

- Prevents hydrogen and oxygen from mixing, reducing explosion risks.
- Ensures high purity of hydrogen, which is necessary for industrial applications.

3. Power Source

The power source for a green hydrogen plant relies on energy conversion principles such as the photovoltaic effect (solar panels), kinetic energy conversion (wind turbines), and electromagnetic induction (hydropower systems). These principles govern how renewable energy is converted into electrical energy.

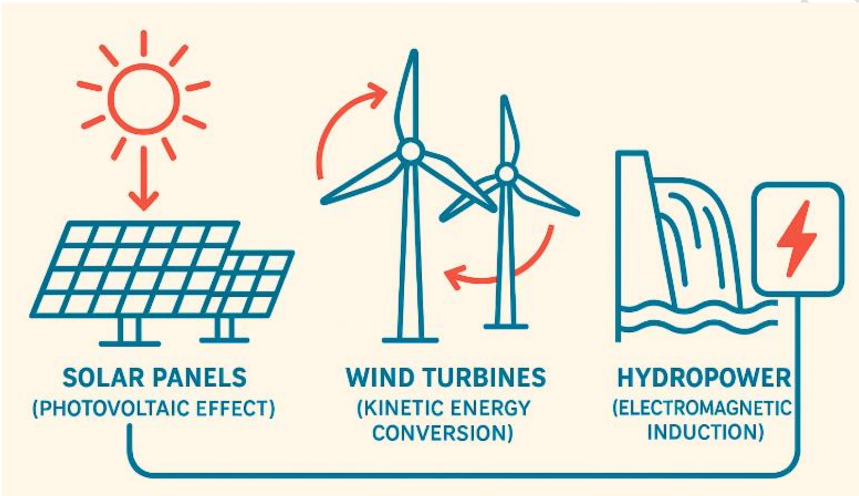


Fig. 2.27: Renewable Energy Conversion

Fig. 2.28: Green Hydrogen plant layout

Working Mechanism for Different Renewable Sources

Solar Panels (Photovoltaic Effect):

- Photons from sunlight excite electrons in a semiconductor material (such as silicon), generating electricity.
- Formula: P = Voltage (V) x Current (I)

  Where, P represents the power, V represents the voltage, and I represents the current.

- **Wind Turbines (Kinetic Energy to Electrical Energy):**
  - The motion of wind spins the blades of a turbine, which in turn, drives a generator that produces electricity.
  - Governed by Betz's Law, which states that the maximum energy that can be extracted from wind is 59.3% of its kinetic energy.
- **Hydropower (Electromagnetic Induction):**
  - The turbine, connected to a generator, which produces electricity through electromagnetic induction, is operated by moving water.

4. Transformer and Rectifier

- Transformer operation is based on Faraday's Law of Electromagnetic Induction, which states that a change in magnetic flux induces an electromotive force (EMF).
- Rectifiers convert AC to DC using diodes, which allow the flow of current in one direction only.

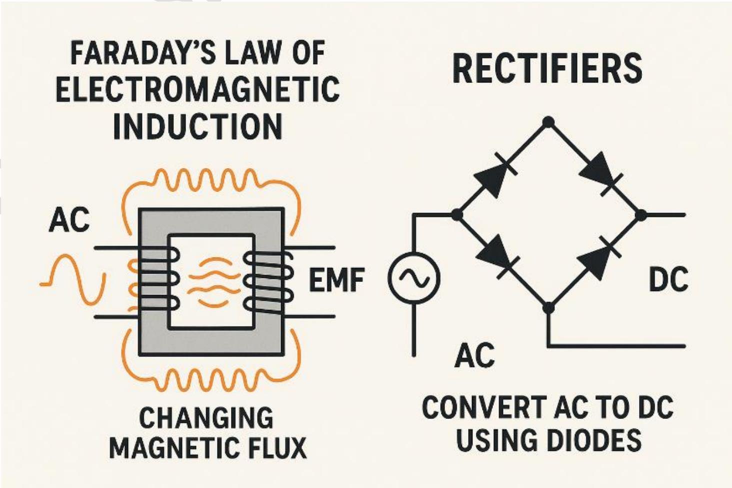


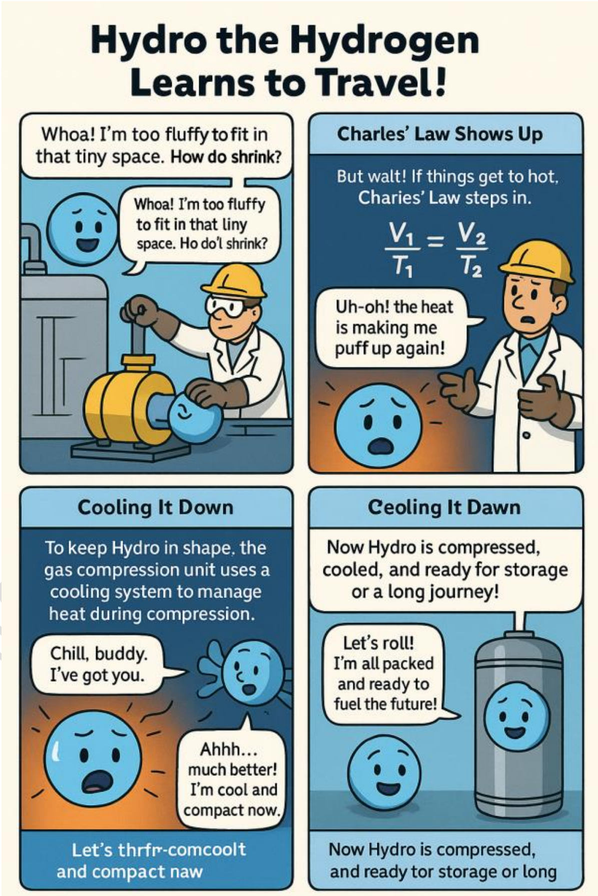
Fig. 2.29: Transformer and Rectifier

Working Mechanism:

- **Transformer:** Adjusts voltage levels from high voltage AC power (from a renewable source or grid) to the required level for electrolysis.
- **Rectifier:** Converts AC into DC, which is needed for Electrolyser operation.

5. Gas Compression Unit

The gas compression unit operates based on Boyle's Law and Charles' Law, which describe how gases behave under pressure and temperature changes.



- **Boyle's Law:** States that as pressure increases, the volume of gas decreases, assuming temperature to be constant. This implies that $P_1V_1 = P_2V_2$
- **Charles' Law:** States that as temperature increases, gas expands, assuming pressure is constant. $V_1/T_1=V_2/T_2$

Working Principle:

- The hydrogen gas is compressed using mechanical piston or diaphragm compressors.
- Compressors reduce the gas volume, making it easier to store and transport.
- Cooling systems prevent excessive heating during compression.

6. Hydrogen Storage

Hydrogen is stored based on high pressure gas storage and cryogenic liquefaction principles.

- **High Pressure Storage:** It works on Pascal's Law, which states that pressure exerted on a confined fluid is transmitted equally in all directions without reduction.
- **Cryogenic Storage:** Uses the Joule Thomson Effect, where gas cools upon expansion, allowing hydrogen to be stored in liquid form at 253°C.

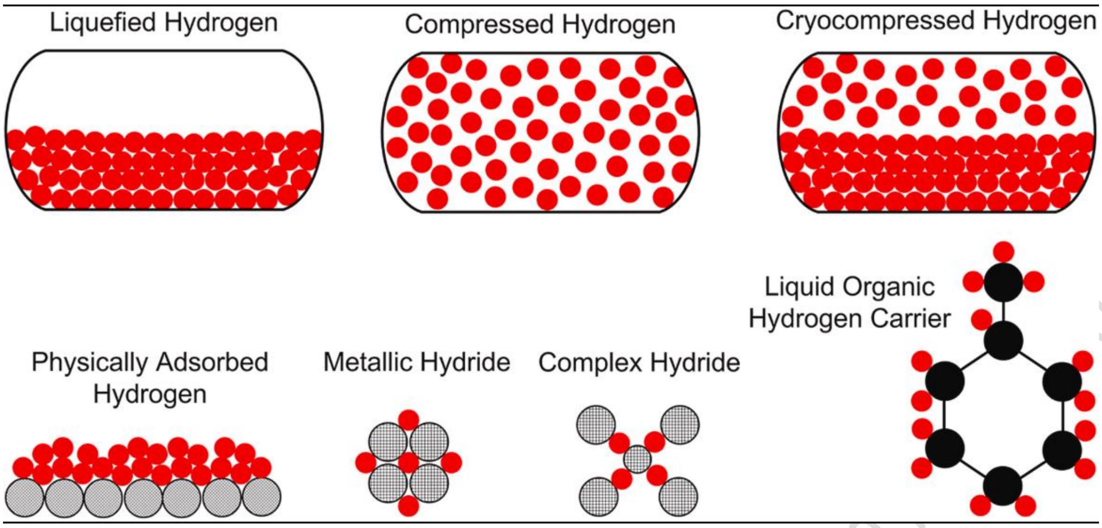


Fig. 2.30: Methods of Hydrogen Storage

Working Mechanism:

- **High pressure storage:** Hydrogen is stored in reinforced carbon fiber or metal tanks at 350 700 bar.
- **Cryogenic storage:** H_2 is cooled and stored in liquid form in insulated tanks to prevent evaporation.

Check Your Progress

A. Fill in the Blanks

1. ____________________ of Electrolysis govern the relationship between the amount of matter produced and the amount of electricity used.
2. Membrane separation in gas __________________ allows only hydrogen to pass through, blocking oxygen.
3. The gas compression unit uses ________________ and Charles' Law to manage hydrogen volume and temperature during compression.
4. In _______________________, hydrogen is stored at a temperature of approximately 253°C in liquid form.

B. Multiple Choice Questions

1. Which law explains the voltage induction in a transformer?
   A. Boyle's Law
   B. Faraday's Law
   C. Newton's Law

D. Ohm’s Law

2. What is the purpose of the rectifier in a green hydrogen plant?
   A. To cool hydrogen gas
   B. To compress hydrogen gas
   C. To convert AC into DC
   D. To increase gas pressure

3. Which principle is used in cryogenic hydrogen storage?
   A. Bernoulli’s Principle
   B. Joule Thomson Effect
   C. Newton's Third Law
   D. Betz’s Law

4. Which of the following renewable sources uses the photovoltaic effect?
   A. Wind
   B. Biomass
   C. Hydropower
   D. Solar power

5. Why are gas separation units important in a green hydrogen plant?
   A. To improve cooling efficiency
   B. To prevent the mixing of hydrogen and oxygen
   C. To store more water
   D. To increase temperature

C. Short Answer Questions

1. Explain the role of the transformer and rectifier in the electrolysis process.
2. State Boyle’s Law and explain its relevance in hydrogen gas compression.
3. Why is it necessary to purify water before electrolysis in a hydrogen plant?
4. Explain the working principle of the Electrolyser stack and the role of electrochemistry in hydrogen production.
5. Describe the components and layout of a green hydrogen plant and how they are interconnected.
6. Discuss the importance of integrating different renewable energy sources in hydrogen production. Provide examples.

Session 3: Material, Safety Codes, Technology Protocols and Standards

The iridium and platinum used in PEM electrolysers are hard to get materials. Iridium is corrosion resistant and is used as a catalyst, which is added in thin layers to anodes. Platinum can also be used to coat the electrodes of PEM electrolysers. A thin layer of platinum is often applied to bipolar plates to lower their surface resistance. Bipolar plates separate cells in a stack, conduct electricity between them, supply water for electrolysis, remove heat, and transport the products of the reaction.

Various materials presently used in electrolysers are summarised in the following table.

Did you know?

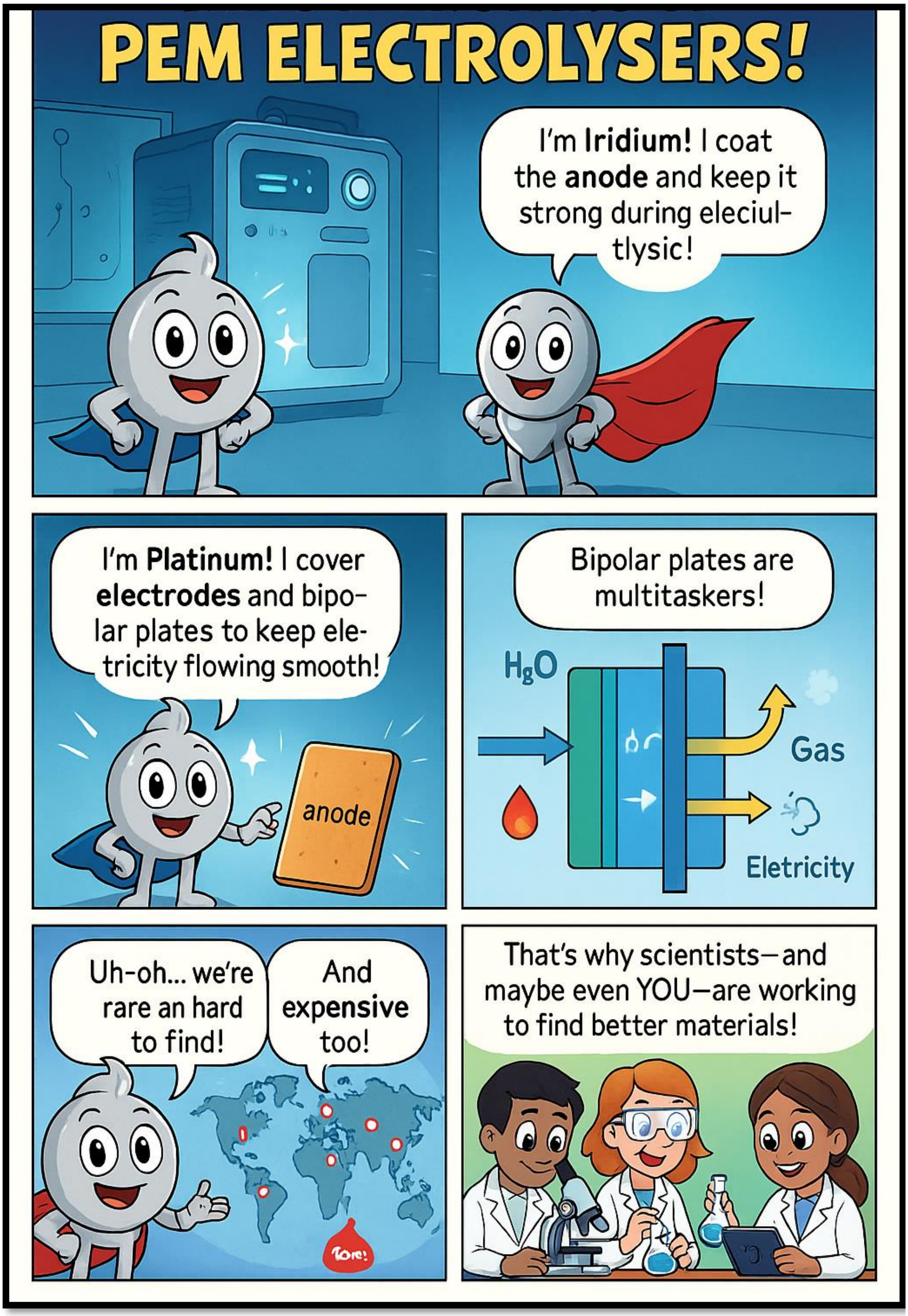
Some metals used in **PEM electrolysers** are so rare, they're like hidden treasures.

Meet Iridium and Platinum.

- **Iridium** is a **special metal** that doesn't get rusty or damaged easily. That's why it's used in **thin layers** on the **anode** (the positive side) of PEM electrolysers. It helps accelerate the water-splitting process.
- **Platinum** is another **Special metal** used to **coat the electrodes**. It also covers the **bipolar plates,** which are thin plates inside the electrolyser stack.

Why? To help electricity flow smoothly by reducing resistance, like making the road less bumpy for electrons.

Item	Alkaline	PEM (Proton Exchange Membrane)	Solid Oxide
Electrolyte	30% KOH + DM water	Solid polymer membrane + DM water	Solid oxide or ceramic
Cathode	Ni with catalytic coating such as Pt	Pt nanoparticles on carbon	Ni doped YSZ (yttria stabilised zirconia)
Anode	Ni based	Titanium (Ti) mesh	A cermet of Ni and YSZ
Membrane/ Diaphragm	Zircon / ZrO_2	Nafion (Du Pont)	Solid oxide or ceramic
Bipolar/Separator Plate	Stainless Steel (SS)	Ti is the base material used for bipolar plates	Graphite or metal
Catalyst (Anode)	Ni / Co	Pt, Iridium oxide	Pt
Catalyst (Cathode)	Stainless steel mesh	Pt	Pt


PEM ELECTROLYSERS!
I'm Iridium! I coat the anode and keep it strong during eleciul-tlysic!
I'm Platinum! I cover electrodes and bipo-lar plates to keep ele-tricity flowing smooth!
anode
Bipolar plates are multitaskers!
H₉O
Gas
Eletricity
Uh-oh... we're rare an hard to find!
And expensive too!
That's why scientists—and maybe even YOU—are working to find better materials!

Hydrogen Safety Challenges

Right now, safety guidelines mainly focus on industries that use hydrogen, but they do not adequately protect the general public. As hydrogen use expands into everyday life, it's crucial to understand the hazards it poses and how to control them.

You need to learn about safe storage, handling, labelling, transportation, waste disposal, training for workers, personal protective equipment, first aid, and firefighting procedures. It's also important to be aware of the relevant safety standards.

Hydrogen is a gas that has no colour, smell, or taste, making it hard to detect. Although it remains stable at normal temperatures and pressures, it can react violently or ignite when mixed with air. Certain metals like platinum can act as catalysts in these reactions.

Indian Standards on Hydrogen

We need clear rules, safety codes, and quality standards for the hydrogen ecosystem. Regulations should support industries that utilise new technologies, and we must simplify and update the process for obtaining approvals and permissions. To improve the 'Ease of Doing Business,' we should make processes easier and speed up approvals. It's crucial to align our rules with international standards.

Right now, hydrogen is mainly used in industries at low pressure. As we seek new energy solutions, the use of H_2 is growing rapidly in the transportation sector. We are setting up H_2 fuelling stations to meet this demand. Therefore, we are reviewing and updating India's existing hydrogen standards.

India has a background in creating standards for other gases like CNG and LPG, both for homes and transport. We should review and upgrade these standards to fit the unique properties of hydrogen. We also need to develop new standards specifically for hydrogen.

Safety is critical for hydrogen. Many organisations have created strict codes based on their experiences. Over the past decade, countries have studied the entire supply chain for H_2 production, distribution, storage, and use.

The manufacturer of equipment producing H_2 needs to follow standards for construction, safety, and performance requirements of the equipment. The following table list some of the existing Indian standards on hydrogen.

Indian Standards on Hydrogen	Description
IS 15201 (2002)	Hydrogen Code of Safety
IS 1090 (2002)	Compressed hydrogen

IS/ISO 11114 4	Transportable Gas Cylinders – Part 4: Test methods for evaluating the compatibility of the cylinders and valve metallic materials (with gas contents), focusing on resistance to hydrogen embrittlement.
IS 16749:2018	Fundamental aspects of ensuring safety in hydrogen systems
IS 17445: 2020	Testing preloaded fasteners to detect hydrogen effects

Interprets Signs, Notices, and Cautions at Green Hydrogen Project Site

A Green Hydrogen Production Facility involves high voltage electrical systems, pressurised gases, flammable materials, and hazardous chemicals. Therefore, understanding and interpreting safety signs, notices, and caution indicators is critical for safe operations and emergency response.

I. Types of Safety Signs and Their Meanings

At a green hydrogen project site, safety signs are classified into the following four categories (A D):

(A) Warning Signs (Yellow Triangle, Black Border)

These indicate potential hazards and warn workers to take precautions.

Symbol	Meaning
⚠ **General Warning**	Beware of hazards in the area.
⚡ **High Voltage**	Risk of electrical shock.
Flammable Gas	Hydrogen is highly flammable and explosive.
☠ **Toxic Gas**	Exposure to harmful gases like oxygen or impurities.
Slippery Floor	Risk of slipping due to water leaks.

Fig. 2.31: Warning Signs

(B) Prohibition Signs (Red Circle with Diagonal Line)

These indicate restricted activities to prevent accidents.

Symbol	Meaning
🚭 No Smoking	Strictly prohibited due to fire risk.

No Open Flames	No welding or open flames near hydrogen storage.
No Mobile Phones	Avoid static electricity or sparks in sensitive areas.
No Unauthorised Entry	Only trained personnel allowed.

Fig. 2.32: Prohibition Signs

(C) Mandatory Signs (Blue Circle, White Symbol)

These indicate necessary protective measures for safety.

Symbol	Meaning
Wear Safety Vest	High visibility vests required.
Wear Safety Goggles	Eye protection is required due to gas exposure.
Use Ear Protection	Required in high noise areas (e.g., compressors).
Wear Safety Gloves	Protect hands from chemicals or burns.

Fig. 2.33: Mandatory Signs

(D) Emergency & Safety Signs (Green Rectangle, White Symbol)

These indicate safety equipment locations and emergency exits.

Symbol	Meaning
Emergency Exit	Follow the route in case of evacuation.
Fire Extinguisher	Firefighting equipment available.
First Aid Station	Medical help available in case of injury.
Emergency Shower / Eye Wash	For chemical exposure incidents.

Fig. 2.34: Emergency and Safety Signs

Check Your Progress

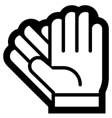
A. Fill in the Blanks

a. Iridium is used as a catalyst in PEM electrolysers because it is _________ resistant.

b. In PEM electrolysers, _________ is often used to coat electrodes and reduce surface contact resistance.

c. The base material for bipolar plates in PEM electrolysers is _________.

d. Hydrogen is _________, _________, and _________, making it hard to detect.

e. The safety sign  indicates the use of _________ for hand protection.

B. Multiple Choice Questions

1. Which out of the following materials acts as a catalyst at the anode in a PEM electrolyser?
   A. Nickel
   B. Iridium oxide
   C. Graphite
   D. Zirconium

2. Which material is used in solid oxide electrolysers as the cathode?
   A. Stainless steel mesh
   B. Platinum
   C. Ni-doped YSZ
   D. Titanium

3. What does the symbol  represent in a hydrogen facility?
   A. No entry
   B. Fire hazard
   C. General warning
   D. Toxic gas

4. Which of the following Indian standards relates to compressed hydrogen?
   A. IS 15201
   B. IS 1090
   C. IS 16749
   D. IS 17445

5. What is the purpose of bipolar plates in PEM electrolysers?
   A. Generate electricity
   B. Remove impurities

C. Separate cells and supply water
D. Store hydrogen gas

C. Short Answer Questions

1. Why is hydrogen difficult to detect without sensors?
2. Mention two mandatory safety signs and their meaning in a hydrogen facility.
3. What is the role of the membrane in an electrolyser?

D. Long Answer Questions

1. Explain the materials used in different types of electrolysers (Alkaline, PEM, and Solid Oxide) and compare their key components.
2. List and explain the key hydrogen safety challenges and measures required to ensure public and worker safety.
3. Describe the importance of safety signs in a green hydrogen facility and explain the four categories of safety signs with examples

MODULE 3 ELECTRIC POWER SOURCE FOR GREEN HYDROGEN PLANT

Module Overview

This module focuses on the critical function of electric power in green hydrogen production. It explains how renewable and hybrid power plants serve as the backbone of sustainable hydrogen generation. Learners will explore key factors influencing power generation, the importance of cost effective and reliable electricity, and the need for stable power supply to ensure efficient electrolyser performance. The sessions will also highlight challenges such as power fluctuations and cell switching, along with practical solutions for optimising energy use in hydrogen plants.

Learning Outcomes

After completing this module, you will be able to:

1. Understand the importance of electric power for green hydrogen generation through electrolysis and the relationship between energy consumption and production efficiency.
2. Recognise how power quality affects electrolyser performance and identify suitable renewable energy sources for hydrogen production.
3. Describe hybrid power systems and evaluate factors influencing renewable power generation, including cost and environmental considerations.
4. Analyse strategies for reliable power generation and discuss energy storage technologies to support efficient operations.
5. Explain the significance of power stability and cell switching techniques for electrolysers and propose solutions to manage power fluctuations.

Module Structure

Session 1: Importance of Electric Power in Green Hydrogen Production

Session 2: Cost-Effective and Reliable Renewable Power

Session 3: Flexible System Operation

Session 4: Sizing Renewable Power & Storage for Hydrogen Demand

Session 5: Functions of Transformers and Rectifiers

Session 6: Maintaining Stability of Power Supply for Green Hydrogen Plant

Session 1: Importance of Electric Power in Green Hydrogen Production

Have you ever wondered how we can turn sunshine, wind, and flowing water into electricity? Welcome to the exciting world of renewable and hybrid power plants. These power plants use natural sources such as solar energy, wind energy, and water (hydropower) to generate electricity. Since these sources are available freely and can be replenished naturally, they are called renewable resources.

To produce green hydrogen, we need clean electricity, and that electricity must come from renewable energy sources like the sun, water or wind. Why? Because we want to make hydrogen in a way that's safe for the environment and do no cause pollution to the planet.

Let's explore one of the most popular sources of renewable energy used in green hydrogen plants.

A. Solar Power

Have you ever felt the sun's warmth on your face? That same sunlight can be captured and turned into electricity using solar panels, which is then used to run machines called electrolysers to produce green hydrogen.

But here's the thing: solar energy depends on sunny days and daylight hours. So, to make sure hydrogen is produced all the time, even on cloudy days, solar power plants often use batteries to store the extra energy generated during sunny hours.

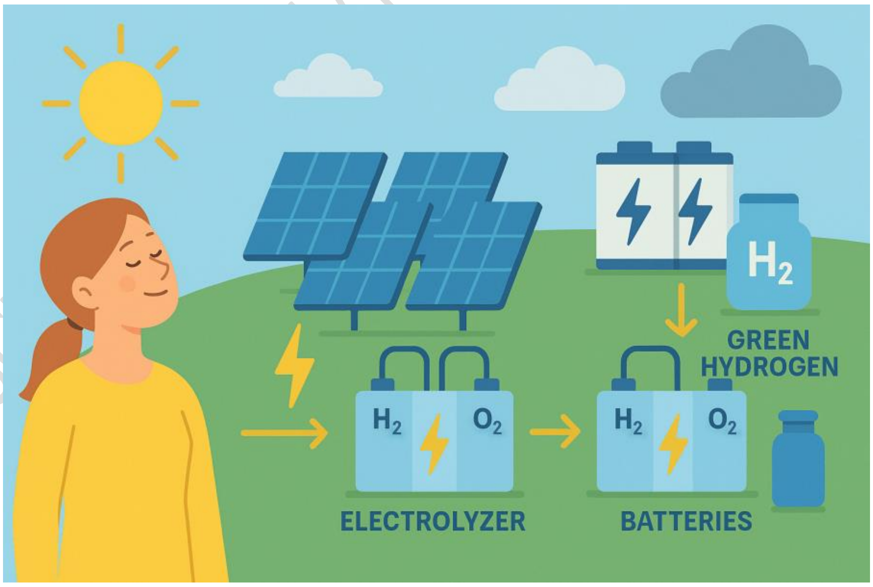


Fig. 3.1: Solar Energy

What are Photovoltaic (PV) System?

A PV system is a setup that converts sunlight directly into electricity using a technology called photovoltaics. The main part of this system is the solar panel.

These panels use the photovoltaic effect, a special process that turns sunlight into electrical energy. It's clean, renewable, and doesn't cause pollution.

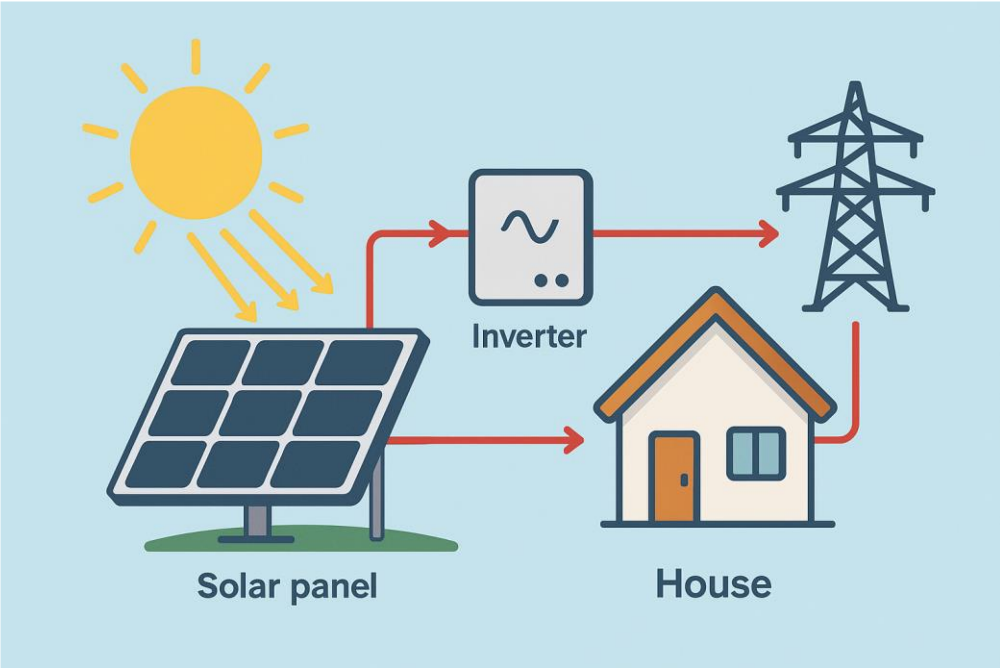


Fig. 3.2: Photovoltaic System

Let's Learn About Solar Panel Parameters

Each solar panel comes with its own "report card," telling us how it performs. These are called technical parameters:

Parameter	What it Tells Us
Wattage (Power Rating)	Maximum power the panel can produce (in W or kW)
Efficiency	How much sunlight is turned into electricity (shown in %)
Voltage & Current	Amount of electricity (in DC) the panel generates
Temperature Coefficient	How performance changes with temperature (higher heat = lower efficiency)
Open Circuit Voltage (Voc)	Voltage when no electricity is being used (no load)
Short Circuit Current (Isc)	Current when panel wires are directly connected
Maximum Power Voltage (Vmp)	Voltage at which the panel produces max power
Maximum Power Current (Imp)	Current at which the panel produces max power
Size/Dimensions	Physical space the panel takes up

What Affects Solar Panel Output?

There are many things that can impact how much power a solar panel can produce. Let's look at some important ones:

Factor	How It Affects Output
Irradiance Level	More sunlight = more electricity
Module Mismatch	If one panel in the group works poorly, the whole system slows down
Soiling (Dirt on Panels)	Dust or bird droppings reduce sunlight absorption
Module Cell Temperature	Hotter panels can lose efficiency
STC Watts (Power Tolerance)	Shows if the panel can produce slightly more or less than rated power
Array Shading	Even a little shadow can greatly reduce output
Wiring Losses	Long or thin wires can waste energy
Inverter Inefficiency	Converting DC (from panels) to AC (for use) can lead to small energy losses

How Do We Calculate Energy from a Solar Panel?

There's a simple formula to calculate the energy output retrieved from a solar PV panel:

$$E = A \times H \times r \times PR$$

Where:

- E = Energy produced (in kilowatt hours, kWh)
- A = Solar Panel Area (in m^2)
- r = Panel Efficiency (as a decimal)
- H = Annual average solar radiation on the panel ($kWh/m^2/year$)
- PR = Performance Ratio (a value between 0.5 and 0.9; standard = 0.75)

Example:

Let's calculate the efficiency of a solar panel.

Question: What is the efficiency of a 250 Wp (Watt peak) solar panel that has an area of 1.6 m^2?

Solution:
Efficiency = (250 / 1600) × 100 = 15.6%

This means the panel can convert 15.6% of the sunlight it receives into electricity.

Note: These values are based on standard test conditions:
Solar radiation = 1000 W/m^2
Cell temperature = 25°C
Air mass ratio (AM) = 1.5

Let's Do It Together: Activity Time

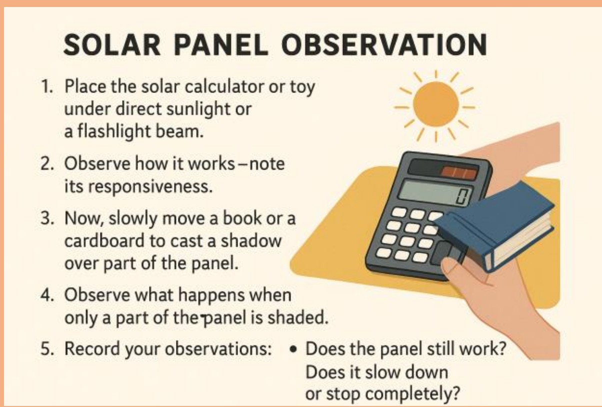
Here's a fun activity to understand solar panel performance.

Activity: Measure the Shadow Effect

Objective: To observe how shading affects the performance of a solar panel.

Materials Needed:

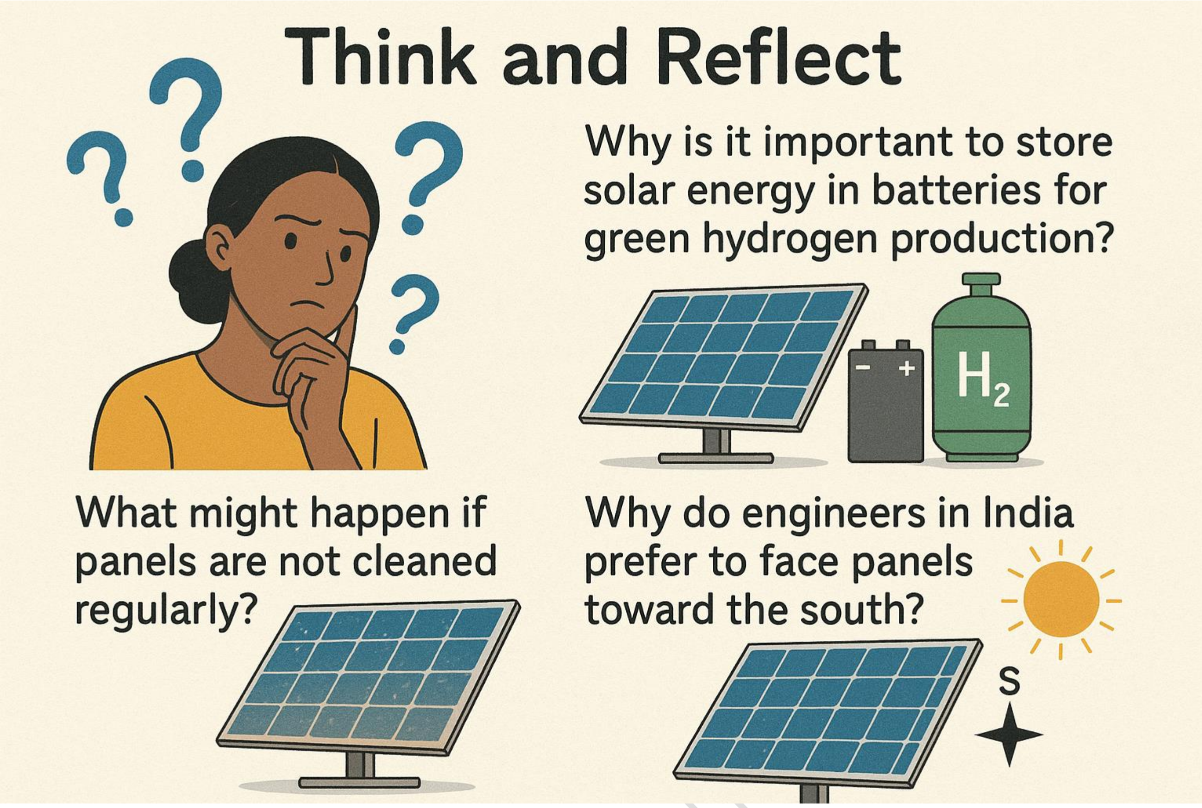
- A small solar powered calculator or solar toy
- A flashlight or access to sunlight
- A notebook and pen
- A book or piece of cardboard (for shading)



Steps:

1. Place the solar calculator or toy under direct sunlight or a flashlight beam.
2. Observe how it works note its responsiveness.
3. Now, slowly move a book or a cardboard to cast a shadow over part of the panel.
4. Observe what happens when only a part of the panel is shaded.
5. Record your observations:
   - Does the panel still work?
   - Does it slow down or stop completely?

Conclusion:
Even partial shading can significantly reduce the output of solar panels. That's why installation needs careful planning to avoid shadows from trees, buildings, or poles.



2. Wind Power

Did you know that wind can help us make hydrogen? Yes. Just like the sun, the wind is another powerful natural force that we can use to produce green hydrogen.

Here's how it works: Wind turbines spin when the wind blows, and that spinning generates electricity. Electrolysers, driven by this electricity, split water molecules to produce hydrogen and oxygen.

Why Wind Power?

As a clean energy source, the wind power produces no pollutants, which in turn contributes to the reduced air pollution and climate change mitigation. It generates a significant amount of power when wind speeds are favorable, utilizing modern turbines that can convert wind into electricity effectively. Also, it often has lower operating costs, especially in regions that experience consistent and strong winds, which may lead to savings on energy bills for consumers and businesses alike.

Wind is not always steady. Sometimes it's breezy, and sometimes it's calm. To keep hydrogen production consistent, many green hydrogen plants use both wind power and solar energy or other sources.

Key Parameters of Wind Power Plants

Wind turbines come in many shapes and sizes. To design a wind power system, engineers look at several important factors:

Parameter	What It Means
Turbine Capacity	Max Power output of one wind turbine (in kW or MW)
Rated Power	Wind speed at which the turbine gives its best performance
Cut Out Speed	Wind speed at which the turbine stops to avoid damage
Cut in Speed	Minimum wind speed needed to start the turbine
Rotor Diameter	Diameter of the spinning blades; more area means more energy
Hub Height	The height of the turbine's centre is higher means more wind
Wind Resource	Average wind speed and reliability at the site
Capacity Factor	How much power a turbine produces vs. what it *could* produce if it worked all the time
Grid Integration	How do we connect variable wind energy to the power system?
Environmental Impact	Effects on birds, animals, noise levels, and local communities
Turbine Type	Horizontal Axis (HAWT) or Vertical Axis (VAWT) design matters.

Let's Do Some Wind Math.

To figure out how much power can be generated using a wind turbine, we use this formula:

$P_w = \frac{1}{2} \times \rho \times A \times v^3$ (in Watts)

Where:

- Pw = Wind power (Wat)
- ρ = Density of Air (typically 1.225 kg/m^3 at sea level)
- A = Swept area = $\pi \times r^2$ (r = radius of blade in meters)
- v = Wind speed (in m/s)

Now, not all wind power turns into useful electricity. Some of it is lost due to friction and system limitations.

To find how much power the turbine gives us, we use:

$P_t = \eta_t \times P_w$

Where:

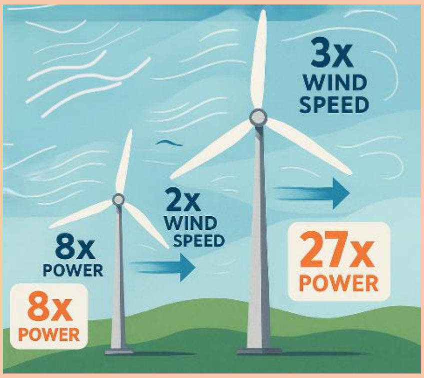
- Pt = Turbine output power (Watts)
- ηt = Turbine efficiency (maximum = 59%, based on Betz's Law)

Did You Know?

The power from wind increases as the cube of wind speed. That means:

- If the wind speed gets doubled, the power output gets increased by 8 times (i.e., $2^3 = 8$).
- If the wind speed triples, the power gets increased by 27 times (i.e., $3^3 = 27$).

That's why taller turbines are more powerful they reach higher into the atmosphere, where the wind is stronger and steadier.



How does Wind Energy convert into Power Energy?

The transformation of wind energy into electrical energy, and ultimately into green hydrogen, involves a series of carefully coordinated steps. Wind hits the turbine blades, which are made to capture its energy. With faster wind speeds, lift is created, causing the blades to spin around a central hub. The spinning blades connect to a rotor and shaft, changing linear motion into rotational motion. This creates torque, which moves through gears to the generator shaft, allowing us to efficiently convert mechanical energy into electricity. The rotating shaft powers the generator, where it uses electromagnetic induction to turn mechanical energy into alternating current (AC) electricity. This electricity may be used or may be sent to the grid for further distribution. Powering the Electrolyser for Green Hydrogen Production: The electricity generated powers an electrolyser that splits water into H_2 and O_2 using electrolysis. This process produces green hydrogen from renewable energy, supporting a sustainable energy future.

To find how much power the generator gives us, we use:

$$P_g = \eta_g \times Pt$$

Where:

- P_g = Generator power output (Watts)
- η_g = Generator efficiency (usually between 9098%)

Did You Know?

Betz's Law states that a wind turbine can extract at most 59% of the kinetic energy available in the wind. This is due to physical limitations; some air must continue to flow past the blades, or the wind would stop altogether.

Try This Fun Activity.

Activity: Make Your Wind Turbine Model
Objective: Understand how turbines use wind to rotate and generate torque.
Materials:

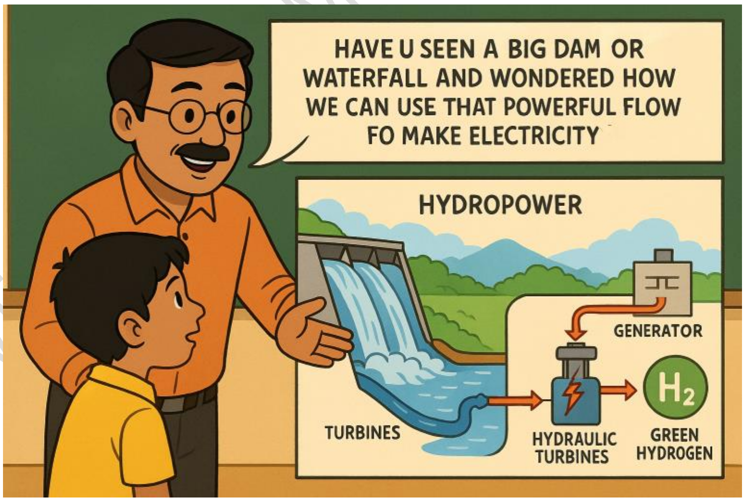
- Paper or cardboard
- Pencil with eraser
- Pin or paperclip
- Fan or natural breeze

Steps:

1. Cut a pinwheel shape from cardboard.
2. Attach it to the eraser end of a pencil using a pin.
3. Place the setup in front of a fan or breeze.
4. Observe the rotation speed with different fan speeds or wind sources.

Conclusion: Faster wind = faster rotation. This shows how wind speed affects turbine power.

3. Hydropower



Why Use Hydropower?

Hydropower has many benefits that make it an attractive energy source. As a renewable option, it uses the natural flow of water without draining any limited resources. This makes it a sustainable choice for the environment. Hydropower plants provide a steady supply of electricity, which can meet changing energy needs at all times. This is important for both homes and businesses.

By using flowing water to create energy, hydropower greatly reduces greenhouse gas emissions compared to fossil fuels, helping to keep the air cleaner. These power plants are usually built near rivers, streams, or reservoirs to take full advantage of natural water sources. They work best in hilly or mountainous areas where water can move easily. However, in dry regions, there may not be enough water flow, making it tough to set up these plants.

How Does Hydropower Work?

Hydropower begins by storing water in a high reservoir created by a dam. This reservoir collects rainwater and river flow for controlled water release based on energy needs. When released, water flows down due to gravity, moving through penstocks where it speeds up and gains energy. Rapidly flowing water causes the turbine blades to rotate, converting the kinetic energy of the water into the mechanical energy. The turbine is engineered to withstand high forces, ensuring optimal efficiency. As it turns, the turbine drives a generator that converts mechanical energy into electricity, which may be alternating current (AC) or direct current (DC), depending on the hydropower plant's configuration. This electricity can then be used for green H_2 production, where electrolysis separates water into H_2 and O_2, contributing to sustainable energy solutions

Key Parameters of a Hydropower Plant

Parameter	What It Means
Capacity	Maximum electricity the plant can produce (in MW or GW)
Head	The height from which water falls. Higher head = more energy.
Flow Rate	How much water flows per second (m^3/s)
Turbine Type	Depends on head and flow common types: Francis, Kaplan, Pelton
Generator Type	Converts turbine movement into electricity
Efficiency	How well the plant turns water energy into electricity
Environmental Impact	Effects on river life and habitats
Reservoir Capacity	How much water can be stored for use later
Run of River vs Storage	Some plants use river flow directly; others store water in reservoirs
Regulation and Control	Used to manage flow and ensure grid stability

Grid Interaction	Making sure the power reaches where it's needed safely and efficiently

Let's Do Some Hydropower Math.

To calculate the power output of a hydro unit, we use this equation:

$$P_g = \eta_o \times \rho \times g \times Q \times H_n$$

Where,

- P_g = Power output (Watts)
- η_o = Overall efficiency (turbine × generator efficiency), usually around 0.9
- ρ = Water Density (1000 kg/m^3)
- g = Acceleration due to gravity (9.81 m/s^2)
- Q = Flow rate of water (m^3/s)
- H_n = Net head (in meters)

Note: The higher the head and the stronger the flow, the more energy we can generate.

Example Time.

Let's say:

- Efficiency (η_o) = 0.86
- Flow rate (Q) = 2.5 m^3/s
- Net head (H_n) = 200 m

Now let's calculate the output:

Pg = 0.86 × 1000 × 9.81 × 2.5 × 200
Pg = 4,218,000 Watts = 4218 kW = 4.218 MW

That's enough to power a small town.

In some hydropower plants, the turbine and generator are connected directly, but smaller plants may use a gearbox to increase speed with only about 2% energy loss.

Hydropower is very efficient, but some energy is lost. Turbine efficiency is between 90% and 95%. Losses happen due to friction in the water flow and turbulence in the spiral casing or draft tube. Generator efficiency is between 90% and 99%. Losses in generators come from friction in bearings and fans, copper losses from resistance in coils, and iron losses in the magnetic core. Small generators are less efficient than large ones. Overall, hydropower remains one of the most energy efficient systems available.

In the design of hydropower plants, several important factors are considered. First, the source of water is at a high elevation because the higher the water is, the more energy it can generate as it falls. Second, the place of the power unit is at a lower elevation, so it can fully capture the force of the falling water. The geography of the area also plays a significant role in the design. In steep locations, vertical axis turbines are placed below ground level to take advantage of maximum height, increasing energy output. By positioning the water source high and the generator unit low, they effectively maximise the energy produced by the plant.

Let's Do It Together: Activity.

Activity: Observe Water Energy

Objective: Understand the potential energy in falling water.
You Need:

- A bottle filled with water
- A small pinwheel or waterwheel model
- A tray or bucket

Steps:

1. Make a small opening at the lower side of the bottle.
2. Let the water pour onto the pinwheel.
3. Watch how the force of water spins it.
4. Try the same with water from a higher height. What do you observe?

Conclusion: The higher the fall, the greater the force, resulting in more power.

4. Hybrid Power

Have you ever thought about how we can use *more than one* energy source to ensure electricity is available even when sunlight and wind are not present? That's exactly what a hybrid power system does.

A hybrid power plant is like a *team of energy sources* working together. It combines two or more types of power, usually a mix of renewable sources like solar, wind, hydro, or biomass, and sometimes conventional sources like diesel or natural gas. These different sources support each other to make sure we always have electricity even when one of them isn't working at full power.

Think of it like this: just like having a backup plan when your mobile battery dies, hybrid power plants have different sources of power to rely on. This makes the system more reliable, more stable, and sometimes even cheaper.

Hybrid Power System

A hybrid power system combines multiple energy sources to enhance efficiency and reliability. Common combinations include:

a. Solar Panels and Wind Turbines: Utilizes sunlight and wind energy, balancing electricity generation throughout the day and seasons.
b. Solar and Hydro Power: Harnesses both solar energy and flowing water, ensuring a consistent power supply regardless of weather fluctuations.
c. Wind Power and Hydrogen Fuel Cells: Uses excess wind energy to generate hydrogen that can be stored and reconverted into electricity whenever required at later stage.
d. Solar with Battery Storage: Stores excess solar energy for utilisation during less production times, like at night.
e. Wind and Diesel Backup: A diesel generator acts as a backup when renewable sources fall short.
f. Solar PV + Power Grid + Battery: Generates solar energy, stores it, and provides flexibility to draw from the grid as needed.

The selection of combinations is influenced by geographical location, energy needs, and resource availability. Hybrid power systems promote energy resilience, lower carbon emissions, and support a sustainable energy future.

Key Features of a Hybrid Power Plant

Let's understand the most important parts of a hybrid power plant:

Key Parameter	What it Means
Energy Sources	Types of energy used: solar, wind, hydro, diesel, gas, etc.
Capacity	Total power it can produce (usually in kW or MW).
Load Profile	How much power is needed and at what time of the day.
Storage Capacity	How much energy can be stored for later use (e.g., in batteries or hydrogen).
Control System	The brain of the plant. It decides which source to use and when.
Conversion Efficiency	How well each source turns raw energy (like sunlight or wind) into electricity.
Grid Integration	How the plant connects to and works with the main power grid.
Economic Viability	Whether the plant is affordable to build and maintain.
Environmental Impact	How much pollution it prevents by using clean sources.
Resilience	The plant's ability to keep running even during bad weather or outages.
Fuel Availability	For conventional parts, whether the fuel (like diesel) is easily available.

Let's Learn with an Example

Imagine a remote village in a hilly area. There is plenty of sunlight during the day, and strong winds in the evenings. But there's no reliable connection to the main electricity grid. What can be done?

A hybrid power system using solar panels for daytime and wind turbines for the evening would be perfect. Add a battery storage system, and you can even have electricity on cloudy days or at night. This setup confirms the village always has light, even when one energy source isn't available.

Now, if we also add a green hydrogen system, we can store extra electricity by converting water into hydrogen. Later, we can turn that hydrogen back into electricity using a fuel cell. That's a smart and clean solution.

Did You Know?

- The world's largest hybrid power plant is being developed in India. It will use solar, wind, and battery storage to supply power to thousands of homes.
- In some islands, hybrid systems are replacing diesel generators to reduce fuel costs and carbon emissions.

Activity Time

◈ Draw and Label a hybrid power system that uses solar panels, wind turbines, and batteries.

◈ Group Activity: Design a hybrid power plant for your school using any two renewable energy sources. Discuss how it will work and where you would install the parts.

Check Your Progress

A. Fill in the Blanks

1. The process of converting sunlight directly into electricity is called the ___________.
2. The formula fro the calculation of energy from a solar panel is _____ **= A × r × H × PR.**
3. In wind power, the formula for power is ___ **= ½ × ρ × A × v³.**
4. In hydropower, the falling height of water is known as the ________.
5. A system that combines more than one source of power is called a _______________ system.

B. Multiple Choice Questions

1. Which direction do solar panels in India usually face for maximum sunlight?
   a) East
   b) West
   c) North
   d) South

2. Which principle explains that a wind turbine cannot harness more than 59% of the wind's energy?
   a) Ohm's Law
   b) Betz's Law
   c) Faraday's Law
   d) Boyle's Law

3. Which parameter in hydropower refers to the volume of water flowing per second?
   a) Head
   b) Flow rate
   c) Capacity factor
   d) Efficiency

4. In a hybrid power plant, the "control system" works as:
   a) The backup fuel source
   b) The brain that manages power sources
   c) The storage unit for energy
   d) The device that measures load

5. Identify the non-renewable energy source from the following.
   a) Solar energy
   b) Wind energy
   c) Diesel generator
   d) Hydropower

C. Answer the following Questions

1. Explain in detail how solar energy is converted into electricity and then used in green hydrogen production. Include the photovoltaic effect, storage methods, and parameters affecting output.
2. Describe the principle of working of a wind power plant and how wind speed influences energy output. Include relevant formulas and examples.

3. Discuss the process of hydropower generation from water storage to electricity production for hydrogen plants. Explain the role of head, flow rate, and efficiency.
4. What is a hybrid power system? Explain different combinations of energy sources and their advantages for green hydrogen production.
5. Compare solar, wind, and hydropower in terms of efficiency, reliability, and environmental impact.
6. Explain the formula for calculating the energy output of a solar panel ($E = A \times r \times H \times PR$) and describe each term in detail.
7. Why is it important for green hydrogen plants to use renewable energy sources?
8. What is the cut in speed of a wind turbine and why is it important?
9. Define the term "capacity factor" in wind power plants.
10. How does partial shading affect solar panel performance?

Session 2: Cost-Effective and Reliable Renewable Power

Why Renewable Energy is Economical and Helpful for Green Hydrogen Production

Using more renewable energy in our power grid is good for the environment. It helps reduce our dependence on fossil fuels like coal, oil, and gas. Fossil fuel prices often go up and down due to global market changes, making electricity expensive. But renewable energy sources, such as hydro, wind and solar, give us more stable and affordable power.

Hydroelectric power (produced from water) has consistently been one of the lowest-cost options within renewable energy. Do you know Why? Most of the hydroelectric plants were built long ago, and their infrastructure is already in place. They just need flowing water to generate electricity. Water, unlike fossil fuels, doesn't need to be bought or imported. It is freely available in nature and not affected by market prices. That makes hydro power a reliable and cost-effective source of energy.

Like hydro power, solar and wind energy are also affordable because sunlight and wind are available for free. These resources don't need to be mined, transported, or imported from other countries. Another big advantage of solar and wind power projects is that they can be built quickly. This helps us start generating electricity sooner, which saves time and money. Also, solar panels and wind turbines work at lower temperatures and speeds. That means they don't wear out easily and cost less to maintain each year.

Although hydroelectric power is cheap in the long run, building a new hydro project can be expensive and take several years, sometimes up to a decade. Because of this, hydroelectric power may not be cheaper than fossil fuels right away. But over time, once the setup cost is recovered, it becomes very economical.

Trends in Solar PV, Wind and hybrid energy in India

Solar PV, wind, and run-of-the-river hydroelectricity are effective and cost-efficient power sources in India. The ***'must run'*** policy gives these sources priority for supplying the essential electricity needed, known as the base load. This ensures a reliable and steady energy supply.

As a result, coal fired power is changing its role. Instead of focusing on continuous energy needs, it is now better suited for peak load demands when

What is the 'Must-Run' Policy?

India has a special rule called the 'must-run' policy. This means that electricity from sources like solar, wind, and run-of-the-river hydro must be used first to supply power. These sources are given priority because they are clean and renewable. They help meet the base load, which is the minimum amount of electricity needed at all times.

electricity use is highest. This shift helps reduce pollution and reliance on imports.

Economical Solar PV Energy

On November 23, 2020, India set a new record by achieving a low solar power tariff of Rs. 2 per kilowatt hour during an auction by the Solar Energy Corporation of India (SECI). This auction selected solar power developers to set up 1,070 megawatts of solar photovoltaic (PV) projects connected to the grid in Rajasthan. The developers were chosen through a bidding process based on tariffs, allowing them to build, own, and operate the projects. Fourteen developers participated in this competitive auction, which attracted significantly more interest than expected, with a total bid of 3,280 megawatts, showing strong demand for these solar projects.

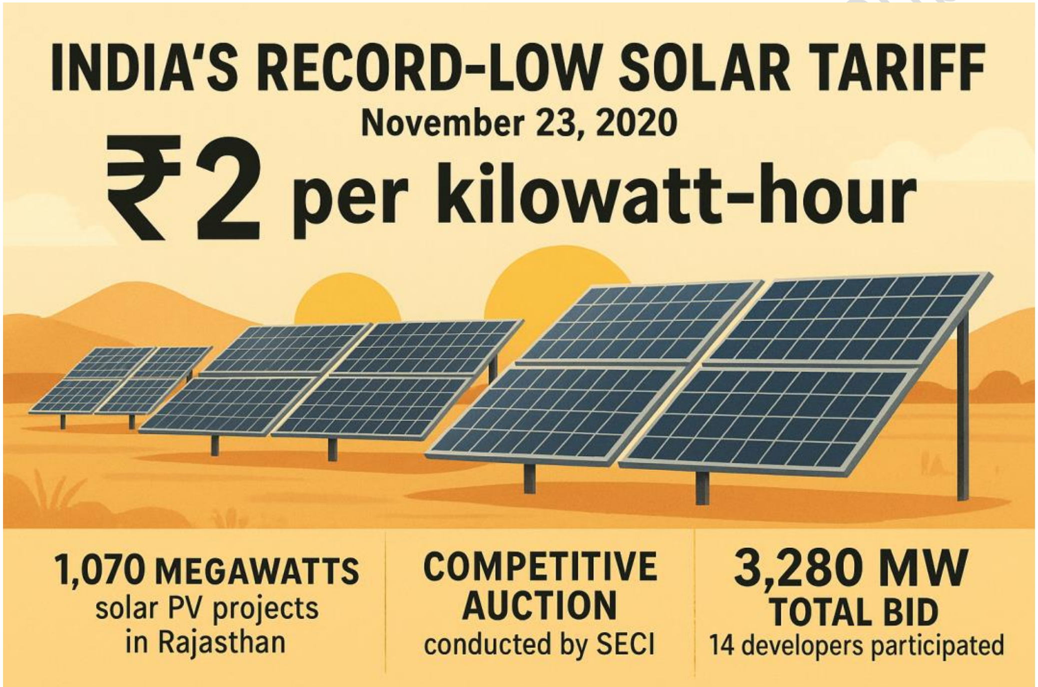


Fig. 3.3: Achievements of India

Factors for Affordable and Reliable Renewable Power for Green Hydrogen Production

To produce green hydrogen efficiently, we need a mix of advanced technologies, energy storage, smart grid management, government support, efficient conversion methods, and ongoing innovation. This approach helps manage the natural ups and downs of renewable energy sources. It also supports a sustainable and cost-effective shift to cleaner energy.

The image shows important factors that help produce affordable and reliable renewable power for green hydrogen:

- Advanced Technologies: Use efficient technologies like solar panels, wind turbines, and advanced systems to optimise energy conversion.
- Hybrid Systems: Combine renewable sources like wind and solar to balance energy supply and ensure consistency.
- Energy Storage: Use batteries to stock extra energy generated during peak hours and use it when generation is less.
- Smart Grids: Set up intelligent grid systems that monitors and manages energy distribution in real time to match supply and demand.
- Predictive Analytics: Use weather forecasts and past data to predict renewable energy availability and plan for hydrogen production.
- Efficient Electrolysis: Use effective processes to convert electricity into hydrogen, minimising energy loss.
- Economies of Scale: Increase production to lower costs by boosting efficiency and technology improvements.
- Government Support: Take advantage of subsidies, incentives, and policies that promote renewable energy as well as green hydrogen production.
- Research and Innovation: Invest in developing new technologies and methods to improve efficiency and lower costs.
- Demand Response: Adjust energy use to match renewable energy supply and reduce grid strain.
- Infrastructure Investment: Build strong energy infrastructure, including transmission and distribution systems, to effectively deliver renewable power.

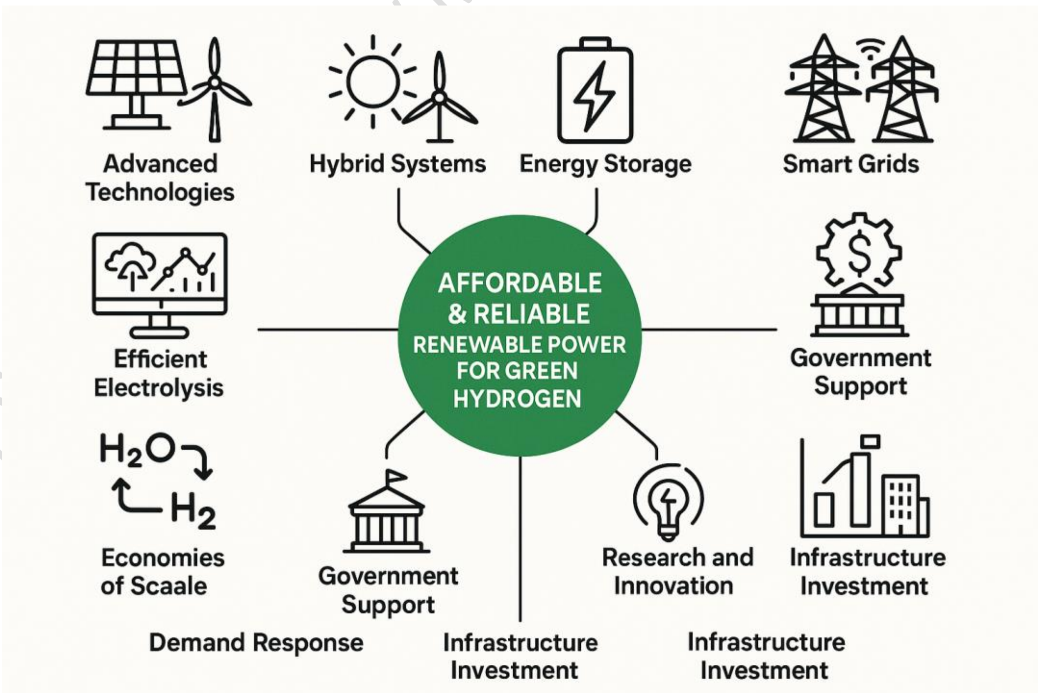


Fig. 3.4: Factors produce affordable and reliable renewable power for green hydrogen

Check Your Progress

A. Fill in the Blanks:

1. The price of the fossil fuels such as oil, coal and gas often go up and down due to ____________ changes.
2. Water used for hydropower generation is _________ in nature.
3. On November 23, 2020, India achieved a record low solar power tariff of ______________.
4. A system that combines renewable sources like solar and wind to balance supply is called a ____________.
5. ______________ systems like batteries help store extra renewable energy for later use.

B. Multiple Choice Questions

1. **Why is hydroelectric power cost effective in the long run?**
   a) Water is free and infrastructure is already built
   b) It requires no maintenance
   c) It uses fossil fuels
   d) It produces energy instantly

2. **Which policy gives solar PV, wind, and hydro priority in supplying electricity?**
   a) Peak load policy
   b) Must run policy
   c) Base load policy
   d) Grid stability policy

3. **Which factor helps predict renewable energy availability for hydrogen production?**
   a) Energy storage
   b) Smart grids
   c) Predictive analytics
   d) Economies of scale

4. **The record breaking Rs. 2/kWh solar tariff in 2020 was achieved in which Indian state?**
   a) Gujarat
   b) Rajasthan
   c) Tamil Nadu
   d) Maharashtra

5. **What is the main advantage of hybrid power systems for green hydrogen production?**
   a) Lower upfront cost
   b) Consistent and balanced energy supply
   c) No need for infrastructure
   d) Use of fossil fuels

C. Answer the following Questions

1. Explain why renewable energy sources like hydro, wind and solar are economical for green hydrogen production. Include long term cost benefits, resource availability, and maintenance aspects.
2. Discuss the trends in solar PV, wind, and run of the river hydroelectricity in India, including the role of the must run policy and its impact on coal fired power plants.
3. Describe the important factors that make renewable power affordable and reliable for green hydrogen production. Use examples where possible.
4. What was significant about the 2020 SECI solar auction in India, and what does it indicate about the renewable energy sector?
5. Compare the cost structure and reliability of hydroelectric, solar, and wind energy for hydrogen production.
6. Explain how hybrid power systems improves the overall stability and consistency of the renewable energy supply.
7. Why are solar and wind power considered affordable energy sources?
8. What is meant by "economies of scale" in renewable power production?
9. Define the term "smart grid" and explain its importance in renewable energy integration.
10. Why can hydropower projects take many years to become cost effective?

Session 3: Flexible System Operation

Flexibility in a power system means its ability to quickly and effectively adjust to changes in electricity demand and supply. A flexible power system can respond promptly to changes in energy needs, generation levels, and unexpected events. This helps maintain stability and ensures that electricity is reliably delivered to consumers. This is especially important in modern power grids that use a lot of renewable energy sources like wind and solar, which can cause the fluctuation in power generation.

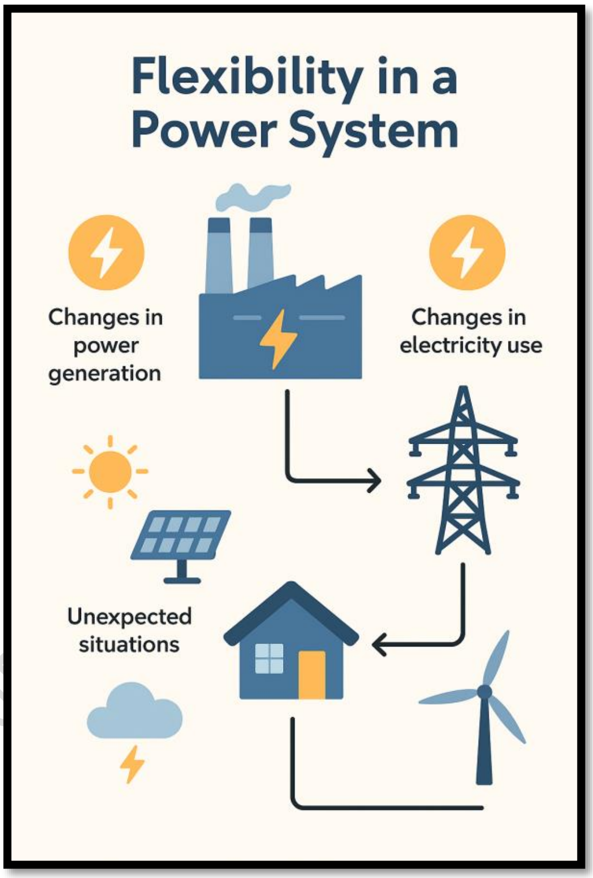


Fig. 3.5: Flexibility in a Power System

Flexibility in a power system refers to electricity sources that can be delivered on demand and supplied as needed by power grid operators. These sources can increase or decrease their output over a specified period to meet requirements within set parameters.

The International Energy Agency (IEA) defines "electrical flexibility" is defined as the power system's ability to cope with variable and uncertain demand and supply while ensuring reliability and cost efficiency. This is essential to ensure the short-term stability of power systems and to safeguard the long-term security of supply.

Need for Flexibility

Modern power systems increasingly use renewable energy sources like wind and solar. However, these sources not always provide a steady amount of electricity. Things like clouds can block sunlight, and changes in wind speed can affect power generation. This leads to fluctuations in supply.

To keep our lights on and machines running, we need the amount of electricity generated to match the amount consumed at all times every second, everywhere. If this balance is disrupted, the system's frequency (50 Hz in India) can change, which may lead to instability or power outages.

Flexibility is crucial in this system. A flexible power system can quickly adjust to:

- Sudden increases or decreases in electricity demand
- Sudden increases or decreases in power generation

Dispatchable power plants like gas turbines, diesel generators, and hydropower dams help maintain this balance. They can be turned on, off, or adjusted to meet demand, especially during peak hours, ensuring that the grid stays stable and reliable.

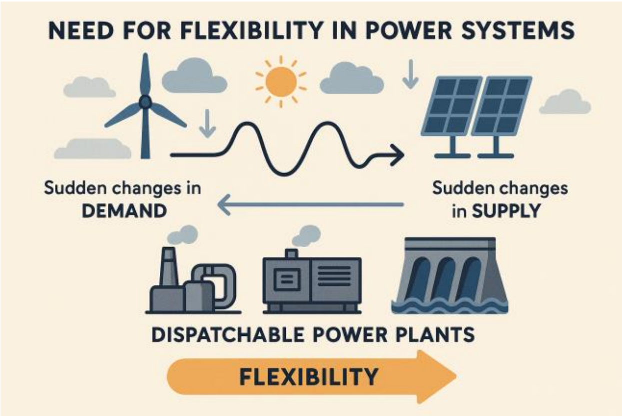


Fig. 3.6: Need for Flexibility in a Power System

Flexibility Options

Traditional power generation methods, such as fossil fuels and nuclear plants, can adapt to changing demand. However, the rise of renewable energy sources necessitates a more flexible power system. This transition requires new technologies, operating practices, and enhanced staff training for nuclear plants, including clear safety procedures. Key considerations include ramp rates, power reduction depth and duration, and frequency of changes. For hydroelectric power, flexible operation presents challenges, necessitating better materials for turbine runners and effective maintenance strategies to ensure reliability and performance.

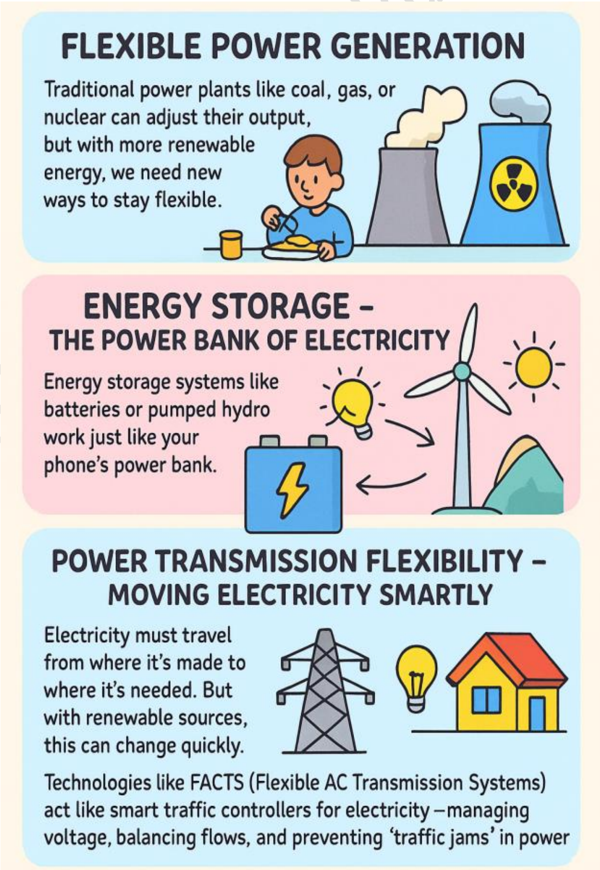


Fig. 3.6: Flexibility Options in a Power System

Using Storage to Improve Flexibility

"Using storage to improve flexibility" means using energy storage systems to make our power system more adaptable and stable. Technologies like batteries and pumped hydro storage can hold extra energy and provide it when needed. This helps manage the ups and downs of renewable energy sources.

Energy storage serves as a buffer, ensuring a steady power supply and increasing grid flexibility. It helps manage peak demand, controls frequency, and keeps voltage steady. These systems can quickly respond to the changes in electricity demand and supply, easing congestion in Transmission and Distribution networks by balancing power flow during times of low and high demand.

Power Transmission Flexibility

Power Transmission Flexibility refers to the capacity of a power system to adapt to variations in electricity generation and demand across different times and locations. This flexibility is important for delivering electricity from generation sites to where it is needed, while also managing fluctuations, especially with renewable energy sources. As we use a wider variety of power sources that can be unpredictable, it is essential for the transmission system to keep up with these changes. Technologies like Flexible AC Transmission System (FACTS) help balance supply and demand, improve stability, and make electricity transmission more efficient by regulating voltage and reducing energy losses.

Modelling and Simulation

The main goal of power system operation is to maintain a balance between electricity generation and consumption at all times. Power system operators rely on the flexibility of their current power system. In today's power systems, modelling and simulation are important tools for studying and analysing operational flexibility.

The following figure shows different flexibility options:

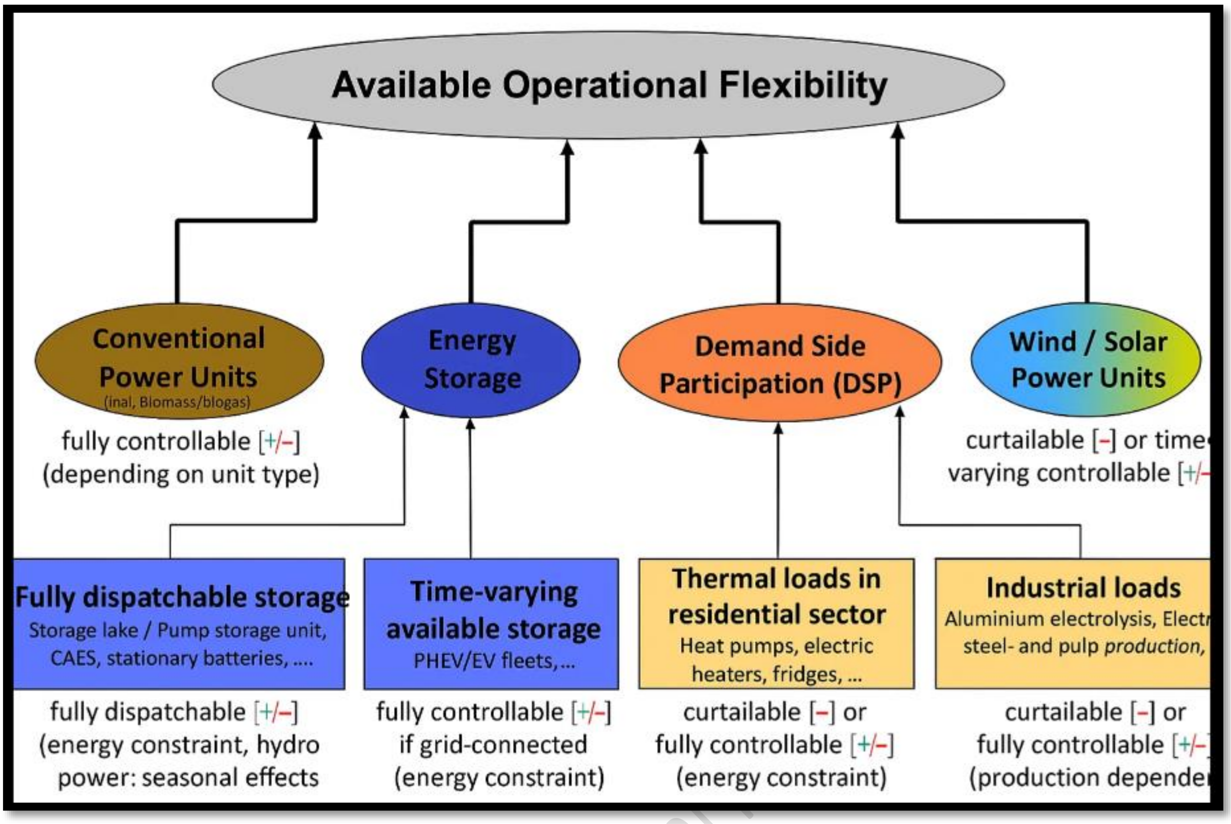


Fig. 3.7: Operational flexibility in power systems

In this figure, the [+/] sign indicates that power can be imported (+) or exported (), which helps integrate renewable energy sources. When there is too much electricity generation from solar or wind energy, the following options can help maintain balance:

- Conventional generation units can reduce their power output.
- Excess or extra energy can be stored in pump storage reservoirs, batteries, or as heat energy in thermal storage (like electric water or space heaters).
- Extra electricity can be exported.
- Some electricity production can also be limited.

If there is a shortage of electricity generation, these options are available:

- Conventional generation units can increase their power output.
- Pump storage reservoirs or batteries can provide extra power.
- Shortages can be covered by importing electricity.
- We can reduce or shift electricity demand.

Operators prioritise actions with the lowest operational costs within technical constraints. Demand side management, including electric vehicles and thermal loads, can also help maintain the power balance.

Check Your Progress

A. Fill in the Blanks:

1. The capability of a power system to quickly adjust to changes in electricity demand & supply is called ________________.
2. In India, the standard power system frequency is ________.
3. A ________________ power generator can be turned ON or OFF to match electricity demand.
4. FACTS stands for ______________________________.
5. ___________________ systems act as a buffer to balance variations in electricity generation and consumption.

B. Multiple Choice Questions

1. What does the International Energy Agency (IEA) define as "electrical flexibility"?
   a) The ability to produce electricity at low cost
   b) The ability to manage the variability as well as uncertainty of demand and supply
   c) The use of renewable energy resources only
   d) The utilisation of diesel generators during peak demand

2. Identify the example of a dispatchable power source from the following options.
   a) Solar PV system
   b) Wind turbine
   c) Gas turbine peaking plant
   d) Rooftop solar panel

3. Which technology helps regulate voltage, enhance stability, and reduce losses in transmission networks?
   a) Smart meters
   b) Flexible AC Transmission System (FACTS)
   c) Energy efficient transformers
   d) Grid interactive inverters

4. Which of the following is NOT a flexibility option when there is excess renewable generation?
   a) Exporting electricity
   b) Storing energy in batteries
   c) Increasing conventional generation output
   d) Limiting electricity production

5. What is one main benefit of energy storage in flexible power systems?
   a) Reduces the number of renewable plants needed
   b) Stores excess energy and releases it when needed
   c) Eliminates the need for grid infrastructure
   d) Increases fossil fuel usage

C. Answer the following Questions

1. Define power system flexibility and explain why it is essential in grids with a high share of renewable energy.
2. Discuss the different flexibility options available in power systems to handle both excess generation and shortages. Include storage, export/import, and demand side management.
3. Explain the role of energy storage systems in providing flexibility. Describe types, benefits, and their contribution to grid stability.
4. What is a dispatchable power generator? Give examples and explain its importance in maintaining grid stability.
5. Describe the function of Flexible AC Transmission Systems (FACTS) in improving transmission flexibility.
6. Explain how modelling and simulation help power system operators ensure operational flexibility.
7. What happens if the power system frequency in India deviates from 50 Hz?
8. Why do renewable heavy grids require higher flexibility compared to conventional grids?
9. Give two examples of situations where electricity demand fluctuates.
10. How does pumped hydro storage help in balancing supply and demand?

Session 4: Sizing Renewable Power & Storage for Hydrogen Demand

Introduction

Sizing means deciding the right capacity or size for a system so it works efficiently and meets demand without waste. Accurate sizing in green hydrogen systems allows excess energy from high solar or wind availability to be stored for use during low-production times. This keeps the plant running smoothly and supports a clean, sustainable energy system.

For example, imagine a green hydrogen plant in Rajasthan. On a bright sunny day, the solar panels produce more power than the plant needs. With proper sizing, the extra power is stored and used at night or on cloudy days. The same applies to wind energy on windy nights; turbines can produce extra power, which can be stored for calm days.

Solar PV and wind are the prime renewable sources for such plants, but they are variable their output changes with the weather. That's why correct sizing and storage systems are essential.

Considering this, the following two potential approaches can be adopted to secure a dependable power supply:

- Approach 1: To average out the variable power: Based on data on daily power generation from solar and wind resources in different seasons, the average renewable power generation can be calculated. The difference in maximum renewable power and average renewable power as well as average renewable power and minimum renewable power may be calculated. It would provide the basis to decide the capacity of storage system. This combination of renewable power and energy storage will ensure availability of continuous power. The electrolyser capacity will have to be decided on the basis of the availability of such average power. Accordingly, it will ensure uniform production of hydrogen.

- Approach 2: To average out hydrogen production: On the basis of availability of variable renewable power, an economical production of hydrogen and its averaging may have to be done. The hydrogen production above average will have to be stored for supply of green hydrogen when its production falls below average. In this approach, the rated capacity of electrolysers will have to be kept above average production rate to create hydrogen storage for its supply during low production period. This approach, due to higher capacity of electrolysers i.e. above average capacity may work out to be costlier compared to approach 1 given above.

Energy Storage

Today, for reducing the emissions of the carbon dioxide, a large number of renewable power projects are already in operation in India. Considering the uncertainty of solar and wind resources, the energy storage systems are still needed for balancing and stabilizing the power system. Among different existing energy storage systems, the hydrogen storage systems have the highest energy density and are important for the integration of variable renewable resources.

In the future, the integration of both hydrogen and battery storage is expected to emerge as a crucial component of electric power systems; as shown in the following figure.

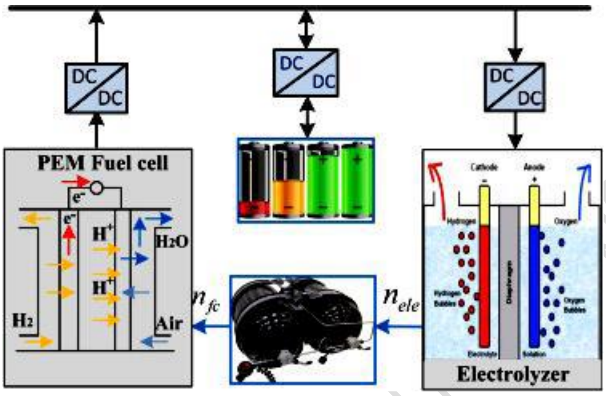


Fig. 3.8: Hydrogen and battery storage system for electric power generation

The electrolyser functions to convert excess renewable energy into hydrogen (H_2), which is subsequently compressed and stored in hydrogen tanks. The fuel cell is responsible for converting hydrogen into electricity when needed. Additionally, battery storage can handle rapid changes in load conditions. The overall energy storage capacity relies on the capacities of the compressed hydrogen tanks.

The power capacity of the plant or system is determined by the electrolyser rated power. When sufficient hydrogen is stored in compressed tanks, electricity or heat can be generated for an extended period through fuel cells. In cases of excess electricity, the electrolyser can transform the remaining energy into hydrogen, which is then stored in compressed tanks for future utilisation.

Check Your Progress

A. Fill in the Blanks:

1. ____________________ refers to determining the appropriate capacity or dimensions of a system for optimal performance and efficiency.
2. In ____________________, the electrolyser capacity is decided based on the availability of ____________________.

3. ______________________ requires the electrolyser capacity to be kept ____________________ production rate to store hydrogen for low production periods.
4. Among existing energy storage systems, ____________________________ have the highest energy density.
5. The _________________ converts excess renewable energy into hydrogen for storage.

B. Multiple Choice Questions:

1. **What is the prime goal of proper sizing in a renewable power plant for hydrogen production?**
   a) To ensure optimal performance and efficiency
   b) To reduce water usage
   c) To eliminate the need for electrolysers
   d) To increase fossil fuel backup

2. **Which approach generally works out to be costlier?**
   a) Approach 1: Average out variable power
   b) Approach 2: Average out hydrogen production
   c) Both are equally costly
   d) None of the above

3. **What is the function of a fuel cell in the hydrogen storage system?**
   a) Store hydrogen
   b) Regulate voltage
   c) Convert electricity into hydrogen
   d) Convert hydrogen into electricity

4. **What determines the overall energy storage capacity in a hydrogen-based storage system?**
   a) Electrolyser efficiency
   b) Hydrogen tank capacity
   c) Solar panel wattage
   d) Wind turbine rotor size

5. **Which storage technology can handle rapid changes in load conditions effectively?**
   a) Hydrogen storage tanks
   b) Pumped hydro storage
   c) Battery storage

d) Flywheel storage

C. Answer the following Questions

1. Explain the importance of proper sizing of renewable power plants with storage to meet hydrogen load demand. Discuss both Approach 1 and Approach 2 in detail.
2. Describe how hydrogen and battery storage systems can be integrated in renewable power systems to enhance flexibility and stability.
3. Discuss the role of electrolysers, compressed hydrogen tanks, and fuel cells in a renewable hydrogen energy storage system.
4. Compare Approach 1 and Approach 2 in terms of cost, efficiency, and hydrogen production reliability.
5. Why is hydrogen storage considered to have the highest energy density among existing storage systems?
6. Explain how battery storage complements hydrogen storage in managing power system load variations. Define "sizing" in the context of renewable power plants for hydrogen production.
7. In Approach 1, why is the electrolyser sized according to average renewable power?
8. What happens when excess electricity is available in a hydrogen storage-based system?
9. Give two advantages of integrating both hydrogen and battery storage in renewable systems.

Session 5: Functions of Transformers and Rectifiers

Transformers

A transformer is an electrical device that alters the voltage of electricity without moving parts. It can increase the voltage (step up) or decrease it (step down). The size of a transformer depends on how much electrical power (in kVA or MVA) it can handle.

At a power station, transformers step up the voltage in the switchyard so electricity can travel long distances with less loss. Before it reaches homes, factories, or offices, transformers step down the voltage to safer levels. Most consumers use electricity at 415 V, 6.6 kV, or sometimes 11 kV.

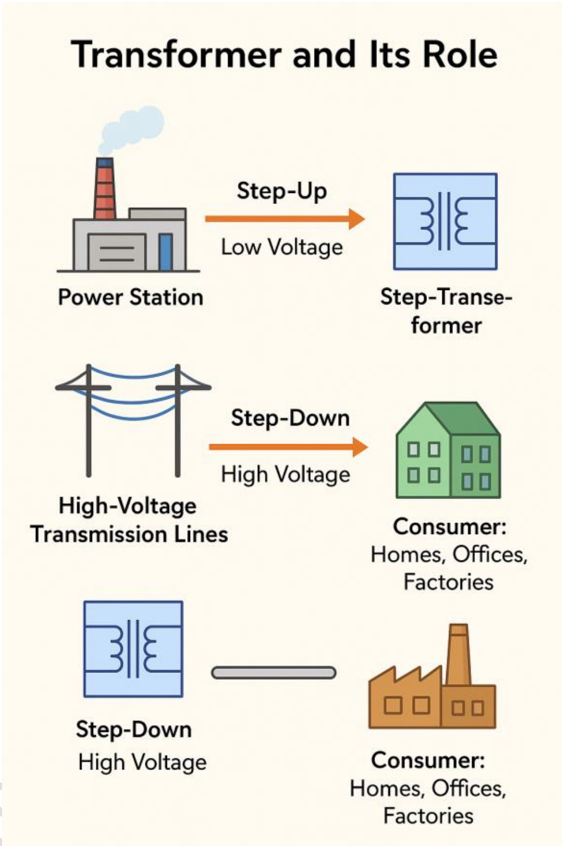


Fig. 3.9: Role of Transformer

Transformers have built in sensors to measure oil temperature and winding temperature (usually on the low voltage side). They also have a terminal box, often with separate insulated sections for power cables and control wires.

For safety, the transformer core must be earthed (connected to the ground) and checked during maintenance.

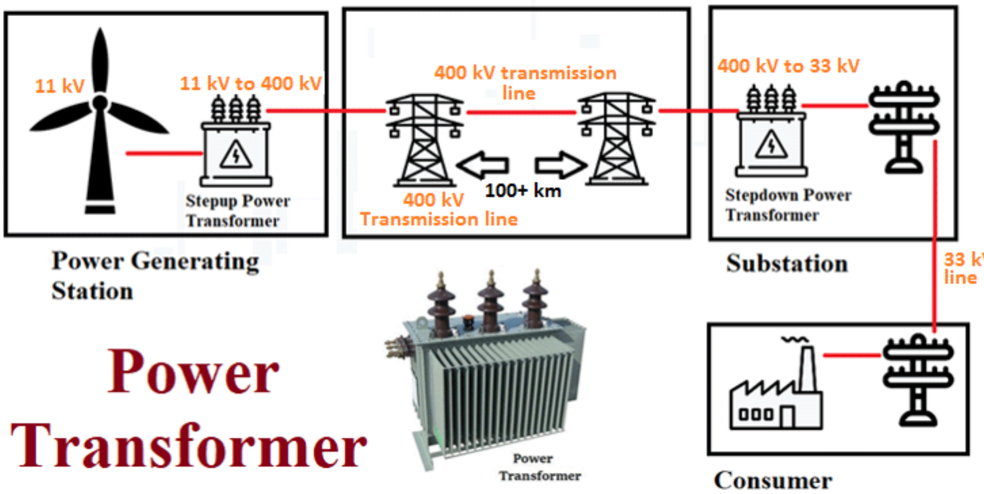


Fig. 3.10: ***Transformers in power transmission and distribution systems***

Thus, the main functions of an electrical transformer are:

- Voltage Transformation: Transformers modify the voltage of an AC electrical circuit without altering its frequency, either increasing (step-up) or decreasing (step-down) the voltage as needed.
- Current Transformation: Transformers can also modify the current level while maintaining power conservation in an AC circuit.
- Isolation: The transformers maintain isolation between the primary and secondary sides, thereby protecting the circuit from direct electrical linkage.
- Impedance Matching: By providing impedance matching, transformers ensure maximum efficiency in power transfer across various parts of a circuit.
- Voltage Regulation: By responding to variations in input voltage and load, transformers regulate the output voltage, ensuring steady power delivery.
- Power Distribution: Transformers are essential in power distribution as they allow electricity to be transmitted efficiently over long distances at high voltages and then reduce it to lower voltages for local use.
- Coupling and Decoupling: The transformers facilitate signal coupling and decoupling in communication networks by transferring energy between circuits while maintaining electrical isolation.
- Instrumentation: Transformers are often used in instrumentation to provide accurate measurement and control of AC voltages and currents.
- Inductive Coupling: Transformers enable inductive coupling between circuits, allowing energy transfer through mutual inductance.
- Isolation from DC: Transformers can block the flow of direct current (DC) while allowing AC to pass, which is useful in various applications.
- Voltage Conversion: Transformers are utilised in voltage conversion for various electronic devices, ensuring compatibility with different power sources.
- Reactance Control: Transformers help in controlling reactance in electrical circuits, which affects the flow of current in response to voltage changes.

Rectifier

A rectifier is a device used to change alternating current (AC) into direct current (DC). It is used to supply DC power from an AC source. The input voltage is usually 415 VAC or 1000 VAC. The main component of a rectifier is a thyristor, which has positive (+), negative (), and control terminals to adjust the DC output voltage. To make the DC power smooth and stable, other components like capacitors, resistors, and inductors are used. Rectifiers also have built in protection devices to guard against problems like overvoltage, overcurrent, short circuits, and DC leakage. On the front panel, you will usually find control switches and indicator lamps for operation and monitoring.

The diagram below shows a 3-phase thyristor-controlled rectifier.

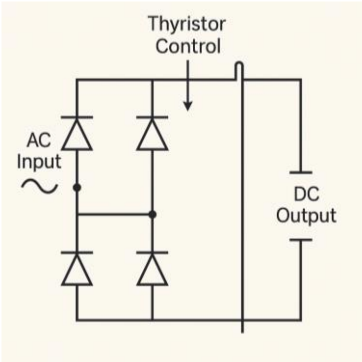


Fig. 3.11: *Thyristor controlled rectifier*

A load controller (also called a demand controller) can be provided to regulate DC electrical loads (connecting/disconnecting a number of electrolysers) as per the availability of variable input wind/solar power.

Thyristor Control

Thyristors provide more precise control of current than diodes. They can be triggered to conduct at a chosen instant, allowing current flow in a controlled manner by adjusting the conduction or firing (switching on the thyristor) angle. Actually, thyristor regulates DC voltage by cutting AC voltage cycle. The DC voltage variation controls DC current to the electrolysers.

The following figure represents the waveforms obtained from thyristor-controlled rectifier.

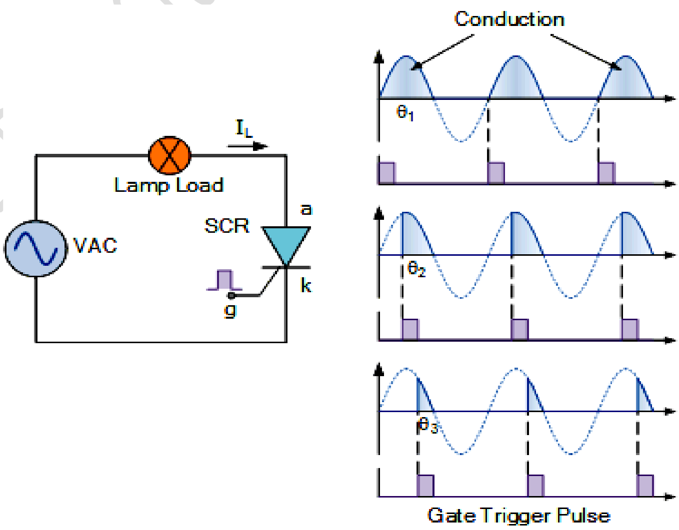


Fig. 3.12: Waveform obtained by thyristor switching of SCR

The primary functions of a rectifier are:

- **Conversion of AC to DC**: Rectifiers are used to convert AC into DC, which is mandatory for powering many electronic devices and systems.
- **Power Supply**: Rectifiers provide a stable or consistent DC voltage source for various electronic devices, ensuring a consistent and reliable power supply.
- **Voltage Regulation**: Rectifiers can be employed to regulate the output voltage, thereby maintaining a steady DC voltage level irrespective of the changes in input or load conditions.
- **Rectification**: Rectifiers rectify the AC voltage waveform by permitting only one half of the AC cycle to pass through, resulting in unidirectional current flow.
- **Signal Detection**: Rectifiers are used in signal detection and demodulation processes, extracting useful information from modulated AC signals.
- Charging Batteries: Rectifiers are employed to change alternating current into direct current for use in battery chargers.
- Electroplating and Electrolysis: Rectifiers provide controlled DC current for applications like electroplating and electrolysis, where precise current control is crucial.
- Motor Drives: Rectifiers are used in motor drives and variable speed control systems to convert AC power to DC power for controlling the speed and direction of electric motors.
- Voltage Multiplier Circuits: In voltage multiplier circuits, rectifiers help convert AC into elevated levels of DC voltage.
- Power Transmission: Rectifiers serve in high-voltage direct current (HVDC) networks by transforming alternating current into direct current for long-distance transmission efficiency.
- DC-DC Converters: Rectifiers serve as the front end of many DC-DC converters, which step down or step up DC voltage levels for various applications.
- Protection: Rectifiers protect sensitive electronic devices from reverse voltage by permitting current flow in one (single) direction only.
- Lighting Applications: Rectifiers are used in lighting applications, such as LED drivers, to change AC power to the suitable DC voltage for illuminating LEDs.

- Photovoltaic Systems: In solar photovoltaic systems, rectifiers are employed to convert the DC output of the solar panels into usable AC power for residential or commercial use.

Check Your Progress

A. Fill in the Blanks:

1. A transformer is a ___________ used to step-down or step-up the voltage.
2. The size of a transformer depends on _______________ to be handled.
3. Earthing of the ____________ is essential for safety and reliability.
4. A rectifier is an electronic device that changes (or converts) _______________.
5. In thyristor control, the _______________ determines when the thyristor starts conducting.

B. Multiple Choice Questions

1. **Identify the function that a transformer does not carry out.**
   a) Voltage transformation
   b) Impedance matching
   c) AC to DC conversion
   d) Isolation

2. **In a rectifier, which component is used to regulate the DC output voltage?**
   a) Diode
   b) Capacitor
   c) Thyristor
   d) Resistor

3. **Why is stepping up voltage done at the switchyard?**
   a) To reduce transmission losses
   b) To match consumer voltage levels
   c) To increase current
   d) To regulate frequency

4. **Which protection is usually built into a rectifier?**
   a) Lightning arrestor
   b) Overvoltage and overcurrent protection
   c) Arc suppression
   d) Oil temperature relay

5. **Which application requires precise DC control from a rectifier?**
   a) Street lighting
   b) Electroplating
   c) Transmission of AC power
   d) Loudspeaker operation

C. Short Answer Questions

1. Define a transformer and state its primary purpose in power systems.
2. Why is earthing important in transformers?
3. What is the main function of a rectifier in an electrolyser based hydrogen plant?
4. How does a thyristor control the DC voltage output of a rectifier?
5. List two common consumer voltage levels supplied after the transformer step down operation.

D. Long Answer Questions

1. Explain the role of a transformer in voltage regulation and power distribution.
2. Describe the function of a thyristor-controlled rectifier and its advantage over diode rectifiers.
3. Discuss the applications of rectifiers in renewable energy systems.

E. Very Long Answer Questions

1. Describe the working principle and multiple functions of the transformer, including isolation, voltage transformation and impedance matching.
2. Explain in detail the operation of a thyristor-controlled rectifier, including firing angle control and waveform shaping.
3. Compare transformers and rectifiers in terms of function, application, and role in renewable powered hydrogen plants.

Session 6: Maintaining Stability of Power Supply for Green Hydrogen Plant

A green hydrogen plant's hydrogen production capacity is usually measured in kilograms per hour or per day. This hydrogen is produced using one or more electrolysers. Each electrolyser is made up of many cells, with each cell containing an anode and a cathode. The production capacity of each electrolyser depends on the size of the electrodes and the amount of electrolyte it can hold.

To address the issues with variable resources, hybrid power projects have been developed, sometimes including energy storage and sometimes not. A green hydrogen production plant uses several electrolysers for electrolysis. It is important to run these electrolysers at their highest efficiency for the best results. The key to this is switching the electrolysers when needed. The table below shows when to switch electrolysers for different combinations of renewable energy sources, both with and without energy storage.

Renewable source	Nature of electrical output	Switching of electrolysers
Solar thermal/hydro	Consistent. Reliable	Not required
Solar PV	Variable, Power output is unreliable. Predictable with high accuracy	Required
Wind	Variable. Power output is unreliable. Accurate prediction is not possible.	Required
Wind solar hybrid	Less variable. Power output is more reliable than wind or solar PV alone.	Required
Hybrid: Wind-hydro or wind-solar PV-hydro solar PV hydro	Consistent. Fully reliable	Not Required
Wind solar hybrid with energy storage	Consistent power output. Fully reliable.	Not required

It is to be ensured that instead of operating all the electrolysers at part load and low efficiency, it will be preferred to operate some electrolysers at or near full load and the best efficiency whereas the remaining electrolysers are switched off.

Case Study: Concept of Switching of Electrolysers

Let us understand the concept of switching of electrolysers with the help of a case of wind resource which fluctuates due to irregular wind speed fluctuations that have a strong impact on power system stability.

Assumptions: The assumptions are as given below:

- The wind farm under consideration uses variable-speed wind turbines coupled with permanent magnet synchronous generators. These generators are characterized by large air gaps (between stator and rotor) which reduce flux linkage in generators having large number of magnetic poles. As a consequence, generators with low rotational speed can operate directly, eliminating the requirement for a gearbox.
- The electrolysers with ON/OFF control by switching: 10 nos.
- Switching algorithm considered: FIFO (First in - first out), i.e. an electrolyser unit started (switched ON) first, also stops (switched OFF) first, and vice versa.

Approach: To maintain steady line power in a wind farm, the reference power is chosen as the farm's average output. The switching process manages the fluctuations that occur above or below this level. With this method, every electrolyser unit runs at full load, which improves its efficiency and durability, and removes the requirement for an energy storage system.

How Does Switching Work?

When solar or wind energy is high, we can run more electrolyser cells at full capacity to maximise hydrogen production. When the power supply drops, we turn off some cells while the remaining ones operate efficiently with the available electricity. Automated controllers monitor the power supply and adjust the number of active electrolyser cells accordingly.

Activities

1. Model Battery Demonstration (Hands on Activity)

- Objective: Show how batteries store and release energy.
- Materials: Small solar panel, rechargeable battery, LED bulb, wires, switch.
- Steps:
    1. Connect the solar panel to charge the batteries during the day.
    2. Use the switch to connect the battery to the LED bulb at "night" (cover the panel).
    3. Observe how stored solar energy powers the bulb when there's no sunlight.

Discussion: How does this mimic grid scale battery storage?

Check Your Progress

1. Fill in the Blanks:

1. A green hydrogen plant's hydrogen production capacity is usually measured in ______________________________.
2. In a wind solar hybrid system with energy storage, switching of electrolysers is ______________
3. Instead of operating all electrolysers at part load, it is preferred to operate some electrolysers at or near ______________________________.

2. Multiple Choice Questions

1. **What determines the production capacity of each electrolyser?**
   a) Number of turbines
   b) Size of the electrodes and the amount of electrolyte it can hold
   c) Type of gearbox used
   d) The height of the wind tower
2. **Which renewable source requires switching of electrolysers?**
   a) Solar thermal/hydro
   b) Wind solar hybrid with energy storage
   c) Wind
   d) Hybrid: Wind hydro
3. **What is the main benefit of the switching strategy for electrolysers?**
   a) Increases water usage
   b) Requires more energy storage
   c) Operates electrolysers at full load to improve efficiency and life
   d) Increases fluctuations in power

3. Short Answer Questions

1. Why is switching of electrolysers important when using variable renewable energy sources?
2. What does the FIFO (First in, first out) switching algorithm mean in the context of electrolysers?

4. Long Answer Questions

1. Explain the concept of switching electrolysers in a green hydrogen plant powered by variable renewable sources like wind energy.
2. Describe the case study of a wind powered hydrogen production system using the FIFO switching algorithm.

MODULE 4 | TOOLS AND SAFETY EQUIPMENT

Module Overview

This module covers the basic tools, equipment, and safety practices needed to install electrolysers and handle hydrogen safely. Learners will learn about the tools used to build and maintain electrolysis systems, as well as important safety measures for safe operations. The module highlights the need for personal protective equipment (PPE), following safety rules, and following hydrogen specific safety guidelines to avoid accidents and keep the plant running reliably.

Learning Outcomes

After completing this module, you will be able to:

1. Identify and understand the use of hand tools, power tools, and measuring instruments for electrolyser installation, ensuring proper assembly and selection for specific tasks.
2. Implement safety precautions, including the use of PPE kit and safety practices, while recognizing hazards associated with hydrogen (flammability, leakage, and explosions).
3. Follow standard hydrogen safety codes and emergency procedures, utilizing gas detection tools, fire safety equipment, and proper ventilation to maintain a safe working environment.

Module Structure

Session 1: Tools and Equipment Used for the Installation of the Electrolyser

Session 2: Safety Measures for the Installation of Electrolyser

Session 3: Safety Measures in Hydrogen Handling;

Installing an electrolyser requires special tools and safety gear. Using the right tools helps put the parts together correctly, which reduces mistakes and improves how the system works. Safety gear, such as gloves, goggles, and protective clothing, protects workers from electric shocks, gas leaks, and chemical spills. The right tools make the system strong and reliable, while safety gear prevents injuries. When both tools and safety gear are used correctly, the work is done safely and follows important safety rules.

Session 1: Tools and Equipment Used for the Installation of the Electrolyser

When we set up an electrolyser to create green hydrogen, we need various mechanical tools. These tools help us safely and correctly assemble, connect, lift, and measure different parts of the electrolyser. Common tools we use include spanners, wrenches, pliers, screwdrivers, and hammers. These are for basic tasks like tightening nuts and bolts or holding parts in place.

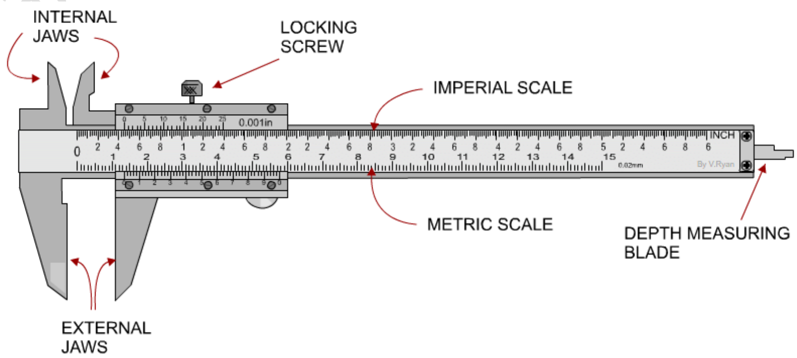
We also use special tools, like torque wrenches, to ensure bolts are tightened properly and to prevent leaks. For working with pipes that carry gas or water, we use pipe cutters, tube benders, and threading tools.

To lift heavy parts like tanks or the electrolyser unit, we use lifting tools such as chain blocks, hydraulic jacks, and slings. Measuring tools like vernier calipers, measuring tapes, and spirit levels are also important to ensure all parts are fitted correctly in terms of position and size. Using the right tools is crucial for the electrolyser to work safely and properly. That's why technicians need to know how to use these tools correctly during the installation.

A. Mechanical Tools and Equipment

Tool/Equipment	Definition
Torque Wrench	A wrench is used to apply a specific amount of torque over a fastener, so as to ensure appropriate tightness. 
Spanners (Open End & Ring)	Hand tools used to grip and turn nuts and bolts of specific sizes.

	
Socket Set	A collection of sockets of various sizes used with a ratchet to tighten or loosen fasteners. 
Allen Keys (Hex Keys)	L shaped tools used to drive bolts and screws with hexagonal sockets. 
Hammer / Mallet	Used to apply impact force for fitting or removing parts. Mallets are softer and used to avoid surface damage. 

Bench Vice	A clamping device fixed to a workbench to hold materials firmly during cutting, drilling, or assembly. 
Measuring Tape /	A measuring tape is used for general measurements. 
Vernier Caliper	A Vernier Caliper provides precise measurements of components. 

B. Electrical Tools and Devices

Tool/Equipment	Definition

Multimeter	An electronic tool used to measure voltage, current, and resistance in electrical circuits. 
Clamp Meter	A type of multimeter that measures current without direct contact with the wire. 
Insulation Resistance Tester (Megger)	A device used to test the insulation resistance of an electrical wiring system to prevent leakage currents. 
Cable Stripper & Cutter	These tools are used to remove the insulation applied over the electrical wirings and cut them to size.

	
Crimping Tool	Used to attach lugs or terminals securely to the ends of wires. 
Soldering Iron	A tool used to join wires and components using melted solder. 
Cable Glands	Devices used to secure and seal cables entering an electrical panel or enclosure.

	
Continuity tester	Confirms electrical connections are properly made. 
Earth resistance tester	Ensures proper grounding of the system. 

C. Fluid Handling Tools

Tool/Equipment	**Definition**
Pipe Cutter	A tool used to cut pipes cleanly and accurately.

	
Tube Bender	A tool used to bend metal pipes or tubes without flattening them. 
Threading Kit	Used to cut threads on the ends of pipes to connect them with fittings. 
Flaring Tool	Used to widen the end of a pipe to allow for a secure, leak proof joint.

	
PTFE Tape (Thread Seal Tape)	A thin white tape wrapped around pipe threads to ensure a watertight or gas tight seal. 
Pressure Gauge	An instrument used to measure the pressure in gas or liquid lines. 

D. Gas and Hydrogen Safety Tools

Tool/Equipment	Definition
Hydrogen Leak Detector	A device that detects hydrogen gas leaks in the installation area. 
LEL Monitor	An LEL monitor is an instrument used to measure unsafe levels of flammable gases or solvent vapors in air, expressed in percentage of the Lower Explosive Limit (%LEL). It is also commonly called an LEL gas detector, an LEL gas detection system, or a fixed gas detection system 
Ventilation Fan	Equipment used to circulate air and prevent gas buildup in confined spaces.

	
Explosion Proof Lamp	A lighting device that is safe to use in environments where explosive gases may be present. 
Earthing Rod and Cable	Used to safely discharge static electricity or faults to the ground. 

E. Lifting and Handling Equipment

Tool/Equipment	Definition
Chain Pulley Block / Hoist	A mechanical lifting device used to raise or lower heavy objects. 
Pallet Jack / Trolley	A wheeled device used to move heavy components around the installation site. 
Forklift / Crane	Motorised equipment is used to lift and transport heavy machinery or parts. 

Hydraulic Jack	A lifting device that operates on hydraulic pressure to move heavy loads upward. 

F. Commissioning and Calibration Tools

Tool/Equipment	**Definition**
Gas Flow Meter	Measures the flow rate of hydrogen or oxygen gas produced by the electrolyser. 
Gas Purity Analyser	Determines the purity level of the gases generated (usually hydrogen or oxygen).

	
Water Quality Meter	Checks parameters like pH, conductivity, and TDS (Total Dissolved Solids) of input water. 
Data Logger	An electronic device that records data over time, used for performance monitoring. 
Thermal Imager	Captures heat patterns to detect hotspots or overheating in the system.

B. Personal Protective Equipment (PPE)

Standard operating procedures should clearly specify the personal protective equipment (PPE) required for each task.

Examples of PPE application include:

People working with liquid hydrogen, where cryogenic vapors may be present, should wear protective gear for their eyes and hands. Systems must be managed carefully to avoid the possibility of anyone without protection touching uninsulated pipes or vessels that contain cryogenic hydrogen.

If clothing is exposed to chemicals through spraying or soaking, it should be safely removed and substituted with uncontaminated attire.

Workers should not wear nylon, silk, or wool garments, as these fabrics can generate static electricity capable of igniting flammable gas mixtures. Instead, ordinary cotton, flame-retardant cotton, or Nomex clothing is recommended. Gauntlet gloves, tight-fitting clothes, or garments that can retain liquids against the skin should also be avoided.

Appropriate PPE for use in hydrogen-related workplaces consists of:

During the operation of hydrogen systems under pressure, and when attaching or removing lines or parts, the use of face shields is recommended to prevent injury from debris.

1. When dealing with objects that have been in contact with cryogenic liquids or vapors, insulated gloves should be used to avoid frostbite. Gloves should not be tight and must be easy to take off quickly.

2. Workers should wear proper footwear, keeping trousers outside the boots or work shoes to stay safe from spills and dropped materials. Shoes that are open or made of porous material must not be used.
3. Workers may need to wear hard hats to stay safe from objects that could fall from above
4. Hearing protection should be used in areas where noise levels are high
   Special protective clothing may be required when performing cleaning or decontamination tasks.

Equipment	Definition
Safety Goggles	Protects the eyes from dust, chemical splashes, and flying debris. 
Flame Resistant Gloves	Protect the hands from heat, sparks, and chemicals. 
Helmet with Chin Strap	Protects the head from falling objects or accidental bumps.

	
Anti-Static Shoes	Footwear is designed to prevent static electricity buildup. 
Face Shield / Mask	Protects the face and respiratory system from harmful exposure. 
Flame resistant clothing	Shield the body from electrical arcs or heat during hydrogen handling.

	
Electrical insulating gloves	Insulated gloves should be worn to protect hands from electric shock when working with live circuits. 
Ear protection	Prevents hearing damage in noisy installation environments. 
Respiratory protection	Used if there is a risk of inhaling fumes or gas leaks.

Check Your Progress

A. Fill in the Blanks:

1. _________ and safety gear is essential for the correct and safe installation of an electrolyser.
2. A _________ is used to apply a specific amount of torque to fasteners. _________ gloves are used to protect workers from electric shock.
3. The _________ detects hydrogen gas leaks during installation.
4. A _________ measures the flow rate of hydrogen or oxygen gas.

B. Multiple Choice Questions:

1. What is the purpose of using a torque wrench during installation?

    A. To measure voltage
    B. To hold pipes in place
    C. To apply correct tightness to bolts
    D. To cut wires

2. Which device is used to test the insulation resistance in electrical circuits or wiring?

    A. Multimeter
    B. Clamp Meter
    C. Insulation Resistance Tester (Megger)
    D. Crimping Tool

3. What is used to safely lift heavy equipment like tanks during installation?

A. Flaring Tool
B. Chain Pulley Block
C. Pipe Cutter
D. Crimping Tool Answer:

4. Which of the following PPE is used to prevent hearing damage?
   A. Face Shield
   B. Anti-Static Shoes
   C. Respiratory Protection
   D. Ear Protection

5. What does a Water Quality Meter check?
   A. Gas purity
   B. Torque levels
   C. pH and TDS of input water
   D. Wire insulation

C. Short Answer Questions

1. Why is it important to use the correct tools during the installation of an electrolyser?
2. Name any three mechanical tools used for assembling electrolyser parts.
3. What is the function of a Hydrogen Leak Detector?

D. Long Answer Questions

1. Explain the role of personal protective equipment (PPE) during the installation of a green hydrogen electrolyser.
2. Describe the various tools used under mechanical, electrical, and fluid handling categories for installing an electrolyser.
3. How do lifting and calibration tools contribute to the safe and efficient commissioning of a hydrogen electrolyser?

Session 2: Safety Measures for the Installation of Electrolyser

Ventilation

When we work with hydrogen, proper ventilation is very important to keep the area safe.

Hydrogen gas is very light, so it can collect in spaces like false ceilings, closed covers, or pockets in the structure. These areas should be avoided or kept well ventilated so the gas does not build up.

In a laboratory, if hydrogen is released, it should be trapped inside safe enclosures (like a fume hood) and then released outside into the open air. This prevents the gas from reaching any spark or flame, which could cause a fire or explosion.

Normal room ventilation is not enough for getting rid of hydrogen from pressure relief lines, purging, or cryogenic boil off. For such cases, there should be a special vent system made only for hydrogen.

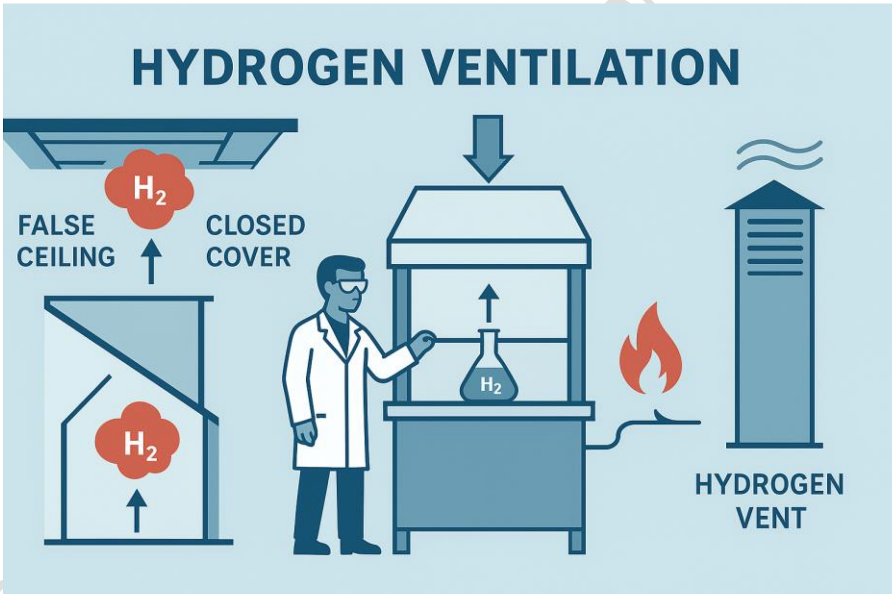


Fig. 4.1: Hydrogen Ventilation

▯ **Pressure relief lines** Pipes or tubes that safely release extra gas or pressure from equipment.

▯ **Purging** Cleaning out pipes or equipment by pushing gas or liquid through them.

▯ **Cryogenic boil off** Gas that escapes when very cold liquids (like liquid hydrogen) slowly turn back into gas.

Basic Requirements

For working safely with hydrogen, ventilation must meet certain basic requirements. The airflow should be strong enough to dilute any hydrogen leak to less than 25% of its Lower Flammability Limit (LFL), which for hydrogen is about 1% by volume in air. If natural or passive ventilation is used, air inlets must be placed at the floor level on outside walls, and air outlets must be placed at the highest point (peak point) of the room on outside walls or at the roof. The total size of these openings should be at least 0.003 square metres for every cubic metre of room volume (or 1 sq. foot for every 1,000 cubic feet of the room volume). The normal air exchange rate should be 0.3 cubic metres of air per minute for every square metre of solid floor space (or 1 cubic foot per minute for every square foot of the floor space). Laboratories and fume hoods where hydrogen is present must have continuous ventilation under normal operating conditions. The minimum ventilation rate should be enough to prevent hydrogen buildup from small leaks, and the ventilation system should never be turned off in an emergency.

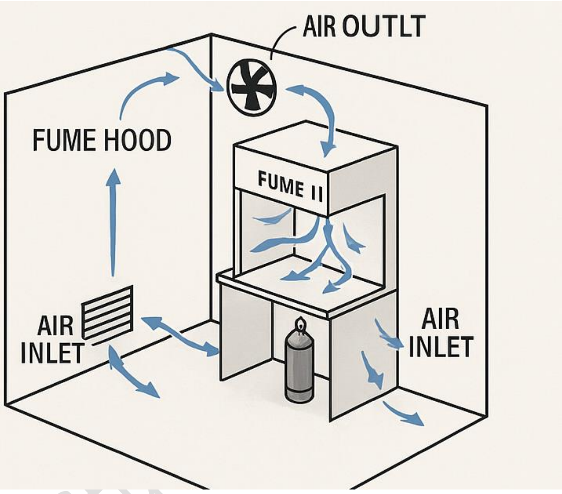


Fig. 4.2: Air Exchange from small leaks

Supply Systems

Laboratory ventilation systems should be designed so that the air coming into the laboratory is clean and free from flammable gases or other dangerous materials that might have been re circulated from another exhaust system. The air pressure inside the laboratory should be lower (negative pressure) compared to corridors and other non-laboratory areas, so that hazardous air from the lab does not leak out. Air supply outlets and diffusers should be placed in positions that do not create air currents which could disturb the proper working of fume hoods and exhaust systems.

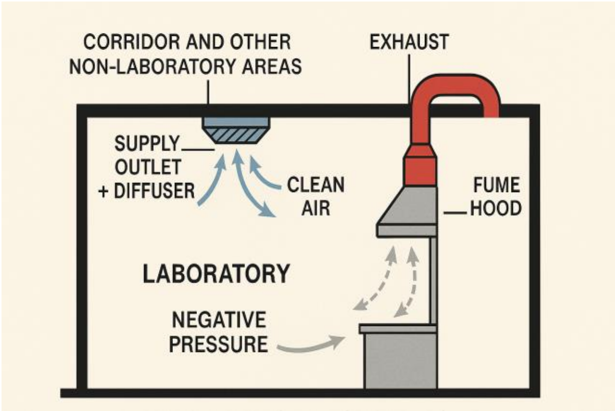


Fig. 4.3: Supply systems

Exhaust Systems

Let's imagine you're in a hydrogen lab. Hydrogen is super light, invisible, and can catch fire easily. So, the way air moves in and out of the lab is a big deal for safety.

1. Where does the used air go?

When the fume hood (that big box pulling away dangerous gases) sucks in air, it sends it up above the roof far away from any place where it could get pulled back into the building's fresh air system.

2. What if hydrogen escapes in the lab?

In hydrogen labs, the air is always pulled out through ducts that keep a slightly lower pressure than other rooms. Think of it like a vacuum cleaner it's always sucking air in so hydrogen doesn't wander into hallways.

3. Sealing the system

Some parts of the exhaust system like fans or flexible pipes have to be airtight or kept in a room that's constantly ventilated, so no hydrogen can sneak out.

4. Making sure the fume hood works well

   The fume hood needs to pull in air fast enough to grab any hydrogen and send it outside before it can spread in the lab.

5. Small jobs need small tools

   For certain tasks, there are special exhaust arms called snorkels that pull hydrogen away right at the source. They also need to be strong enough to "catch" the gas.

6. Keeping hydrogen levels safe

The ducts must always have enough airflow so hydrogen stays well below the danger limit (called the LFL Lower Flammable Limit).

7. Some tools are a "maybe"

Canopy hoods (the kind hanging like an umbrella) aren't normally used unless experts test and prove they can safely trap hydrogen.

8. A big "No" for safety

Automatic fire dampers devices that shut off air during a fire aren't used in hydrogen fume hood exhaust systems, because they could trap dangerous hydrogen inside.

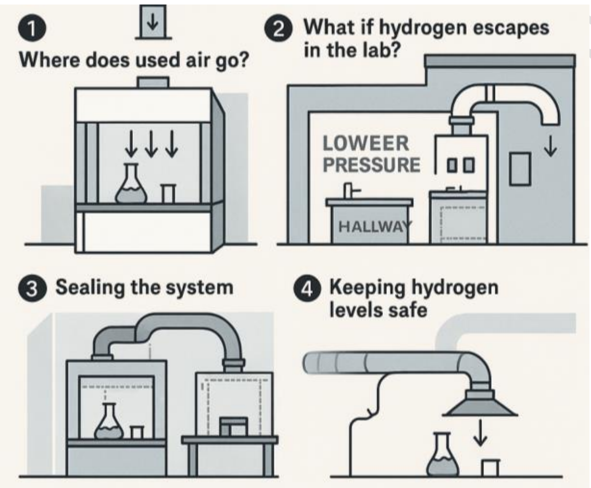


Fig. 4.4: Exhaust Systems

Fans

1. Choosing the right fan: In a hydrogen lab, not just any fan will do. The fan has to be strong enough to handle fire, explosions, and even rust from chemicals.

2. What if hydrogen passes through the fan?

If hydrogen flows right through the fan, the spinning blades must be made from non-sparking materials. That means, even if the blades touch something, they won't create a spark that could cause an explosion.

4. Materials that don't spread flames
   Parts made from nonferrous (non-iron) or spark resistant materials also have to pass a special test they must have a flame spread index of 25 or less. In simple words, this means if they ever catch fire, the flames won't spread quickly.

Addressing Laboratory Spaces Where Hydrogen Leaks Might Accumulate

Hydrogen is the lightest gas in the world so light it can slip through even the tiniest crack in a pipe or fitting. This makes it tricky to handle, because if it escapes, it can rise quickly and collect in high or hidden spots where it becomes dangerous.

Places where hydrogen can get trapped:

- Up near the ceiling
- Between ceiling beams
- Inside suspended ceilings
- In tight spaces with hydrogen pipes, like inside walls, covered floor drains, pipe trenches, or sealed boxes

Best practices to prevent problems:

A. Find where leaks could happen: Engineers should figure out the most likely spots for hydrogen leaks and how the gas might spread. They can use computer (PC) simulations known as Computational Fluid Dynamics (CFD), or follow rules from international safety standards like IEC 60079 10, along with building codes for ventilation.
B. Reduce leaks at the source: The safest option is to design piping so it has fewer joints where leaks could occur for example, using continuous pipes or welded fittings instead of parts that screw together. But in real life, this isn't always possible everywhere.
C. Use detectors to catch leaks early: Many hydrogen labs have H_2 gas detectors or even H_2 flame detectors to spot leaks or flames quickly. Placing these sensors in the right spots is important especially where leaks are most likely to happen. How many sensors you need depends on:
   - How fast hydrogen might leak
   - How quickly air is replaced (ventilation rate)
   - The size of the lab space

D. Design smart from the start

In new labs, it's easier to avoid enclosed spaces and set up good ventilation from the beginning.

In older labs being upgraded for hydrogen, some parts like suspended ceilings, enclosed drains, or covered piping may need to be removed or fitted with extra ventilation and gas monitors.

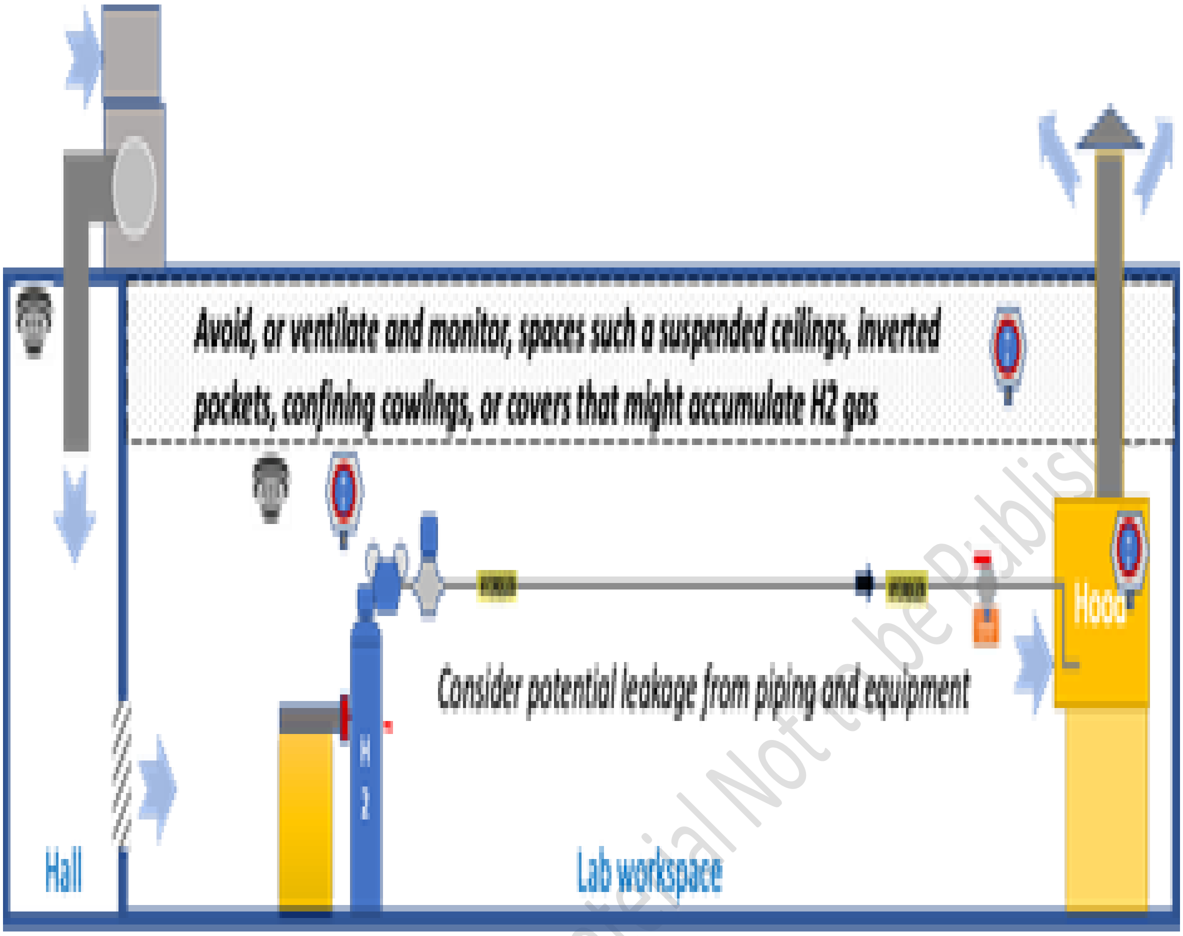


Fig. 4.5: H_2 leak and flame detection systems

Check Your Progress

A. Fill in the Blanks:

1. Hydrogen is the lightest and most ________ of gases, making it prone to leak through even small piping defects.
2. Ventilation systems should not be used for the disposal of hydrogen but instead should have a separate ________ system.
3. Face shields are required when operating hydrogen systems under ________ to protect against debris.
4. Clothing made of ________, silk, or wool should be avoided as it can generate static electricity.
5. Duct airflows must be sufficient to keep hydrogen concentrations below the ________ during probable release scenarios.

B. Multiple Choice Questions

1. What is the preferred clothing material in hydrogen environments to prevent static electricity?

   A. Nylon
   B. Silk
   C. Wool
   D. Cotton

2. Which of the following should **not** be used in fume hood exhaust systems?

   A. Automatic fire dampers
   B. Airtight ductwork
   C. Spark resistant fans
   D. Nonferrous materials

3. What is the main function of hydrogen gas detectors in laboratories?

   A. Filter hydrogen
   B. Increase gas flow
   C. Detect leaks
   D. Ventilate air

4. Where should the **outlet openings** of passive ventilation be located?

   A. At floor level
   B. On internal walls
   C. Highest point of the room
   D. At basements

5. Which type of gloves is recommended when handling cryogenic hydrogen?

   A. Cotton gloves
   B. Insulated gloves
   C. Rubber gloves
   D. Leather gloves

C. Short Answer Questions

1. Why should hydrogen not be disposed of through general ventilation systems?
2. Mention two confined spaces where hydrogen leaks are most likely to accumulate.
3. What are two PPE items essential when handling cryogenic hydrogen?

D. Long Answer Questions

1. Explain the basic ventilation requirements in laboratories where hydrogen is used and why they are important.
2. Describe how supply and exhaust systems should be designed to handle hydrogen safely in laboratory settings.
3. List and explain the personal protective equipment (PPE) recommended for working in hydrogen environments, and why each is important.

Session 3: Safety Measures in Hydrogen Handling

Purging

Before we put hydrogen into any system, we need to make sure that air, oxygen, and other oxidisers are removed. if hydrogen mixes with these gases, it can create an explosive mixture, which is extremely dangerous. So, before introducing hydrogen, we purge the system. *Purging* means flushing out the unwanted gases using another safe gas.

Purging Before Maintenance

If a hydrogen system needs to be opened for repair or maintenance, the hydrogen inside must be removed first. This is because when hydrogen escapes into the air, it can easily reach its flammable range and catch fire.

Inert Gases to the Rescue

To safely purge, we use inert gases, which means gases that don't react easily. For hydrogen gas systems, we usually use nitrogen and for liquid hydrogen systems, we use helium. At extremely cold liquid hydrogen temperatures, nitrogen freezes into a solid, so helium is the better choice. Apart from purging, inert gases are also used to pressurise the system to check if it is leak tight before operation.

When working with hydrogen systems, we use purging to make sure no dangerous gases remain inside. There are three main purging methods:

1. Flowing Gas Purge

- **How it works:** An inert gas (like nitrogen or helium) is made to flow into one part of the system and out from another.
- This pushes the unwanted gas out of the system.
- Works best for simple systems with fewer branches.
- In complex systems (with many side pipes), the flow may not reach every corner.
- The vent gases are released in a safe location (like a tall vent stack) so they don't cause asphyxiation.

💡 *Example:* Imagine flushing out dirty water from a straight pipe by running clean water through it.

2. Pressurising Venting Cycle Purge

- **How it works:**
    1. Pressurize the system with inert gas.
    2. Vent it to atmospheric pressure.

3. Repeat several times.

- Each cycle dilutes the unwanted gases until the mixture is safe.
- Useful for systems with long dead ends (areas where gas can get trapped).
- Often used for Type IV cylinders and other parts that cannot handle vacuum purging.
- Needs short pauses after pressurizing so gases can mix properly.

💡 *Example:* Like adding clean water, shaking the bottle, pouring it out, and repeating until no dirt is left.

3. Vacuum Purging

- **How it works:**
  1. Vent the system to atmospheric pressure.
  2. Use a vacuum pump to remove most of the gas.
  3. Fill it with inert gas to a positive pressure limit.
  4. Vent it again to the atmospheric pressure.
- May need several cycles depending on how clean you need it.
- The vacuum pump must be able to handle hydrogen, air, and inert gas safely.

💡 *Example:* Like sucking all the air out of a bottle with a pump, then filling it with clean air.

💡 **Did You Know?**

Vacuum purging is the most effective method for removing gases, but not all equipment can handle it because of the pressure difference it's like how not every bottle can be vacuum sealed without collapsing!

Hydrogen Leaks

Hydrogen gas is made of very small molecules, so tiny leaks are very common. In a well-designed system, these types of small leaks usually don't cause danger, because the amount of hydrogen is too little to form a flammable mix.

The real danger happens when hydrogen builds up in a confined space over time. This can cause:

- Fire/Explosion risk (if it reaches its flammable concentration)
- Asphyxiation (lack of oxygen to breathe)

How to Detect Hydrogen Leaks

1. Listen High pressure leaks make a loud *hissing* sound.
2. Portable detectors Small handheld devices to check for leaks.
3. Permanent detectors installed in facilities with alarms (sound or flashing lights) for safety.

Liquid Hydrogen (LH_2) Leaks Different Behaviour

Liquid hydrogen is extremely cold (cryogenic).
When it leaks:

- It forms a white cloud this is not hydrogen gas, but water vapour from the air that has condensed because of the extreme cold.
- The cloud is heavier than air at first, so it stays near the ground and may transfer sideways.
- Once the hydrogen gets warm, it turns into gas and rises rapidly.

Did You Know?
Even in very dry deserts, an LH_2 leak will still make a visible cloud because the extreme cold freezes whatever tiny amount of water vapor is in the air.

Fig. 4.6: An LH_2 leak will still make a visible cloud

A release of liquid hydrogen looks much like a liquid nitrogen leak. These leaks can mix with air to create flammable conditions, which may lead to flames or explosions.

Hydrogen Flames

Hydrogen is flammable when its concentration in air is between 4% and 75%, which is much broader than for other fuels. In a closed area without ventilation, a leak could quickly reach the 4% lower flammability limit. In open air, the gas rises and spreads quickly, reducing the risk of ignition.

Hydrogen flames are pale blue and almost invisible in daylight, so they are hard to see. They also emit little heat, making it difficult to notice the fire until you are very near. Hydrogen alone cannot burn; oxygen or air, along with a spark or flame, is needed for combustion.

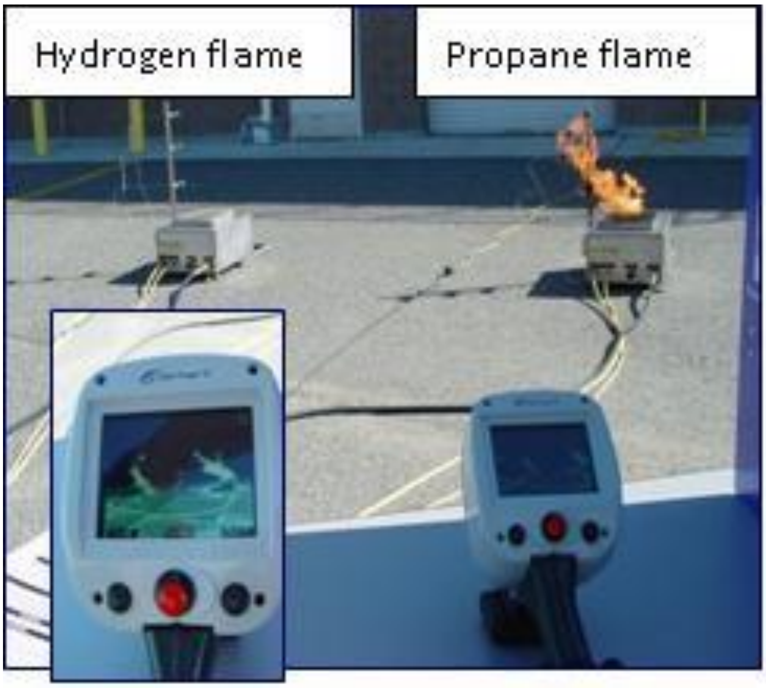


Fig. 4.7: Hydrogen and Propane Flames in Daylight

Fig. 4.8: Hydrogen and Propane Flames at Night

Hydrogen Flame Detection

Fig. 4.9: Thermal Imaging Camera in Use

Because hydrogen flames are hard to see, a portable flame detector like a thermal imaging camera may be the safest way to spot them. Alternatively, a flammable tool such as a broom can be used: if it comes into contact with a hydrogen flame, it will light up, making the fire visible.

When flame detectors are not available, listen for the hissing of venting hydrogen and look for heat patterns that show a nearby flame.

Note: Keep in mind that hydrogen venting from stacks often ignites, but vent stacks are designed to safely handle these flames

Hydrogen Explosions

A large release of hydrogen can create dangerous overpressure, which may cause harm directly or indirectly through building damage or flying objects. Such overpressure can occur either from unignited pressurized hydrogen escaping or from the ignition of a hydrogen-air mixture.

Overpressure from Unignited Releases

When any cryogenic liquid turns into gas as it warms, it takes up far more space. Liquid hydrogen expands about 850 times from its liquid to gaseous form, so a closed vessel, pipe, or sealed area can easily experience overpressure.

Gas cylinders (containers) can be over-pressurized if they are operated unintentionally, exposed to heat like fire, or affected by other causes.

All hydrogen equipment should have pressure relief devices, such as rupture disks or relief valves, to avoid overpressure. The PRDs must be directed to a safe venting area.

Overpressure from Ignited Releases

Besides the risk of overpressure from stored gas, flammable gases like hydrogen can burn. If a cloud of released hydrogen ignites, it can produce rapid combustion and create an explosion or overpressure.

Precautions: It is important to keep ignition sources away from areas where hydrogen clouds could form, such as sparks from electrical equipment or static electricity.

Examples: Places where hydrogen clouds may appear are called 'exclusion zones,' and safe distances are often set for buildings, vehicles, and equipment.

Types of hydrogen combustion: Deflagration verses Detonation

Deflagrations are explosions in which a flame moves slower than the speed of sound through a mixture of hydrogen and air.

Detonations are explosions in which a flame travels faster than the speed of sound through a mixture of hydrogen and air, creating shock waves. They are usually more damaging than deflagrations.

Sometimes, deflagrations can speed up such as when the flame moves across small repeated obstacles or through long pipes resulting in a deflagration-to-detonation transition (DDT). DDT usually does not happen at hydrogen concentrations near the flammable limits and is more likely in large equipment, long pipelines, or big hydrogen releases in partly confined areas.

NFPA 68 states that venting can protect against deflagrations, but it is not effective if a deflagration accelerates into a detonation (DDT).

NFPA 67 provides guidance on preventing detonations and managing detonation pressure in pipelines carrying gaseous mixtures. A person nearby would probably see both deflagrations and detonations as explosions.

Fig. 4.10: Controlling over Hydrogen Explosion

Hydrogen Characteristics & Leak Detection Considerations

To better understand hydrogen, consult So You Want to Know More About Hydrogen. The comparison in Hydrogen Compared with Other Fuels is particularly helpful for designers. Understanding hydrogen's properties is crucial for designing safe workspaces, as it helps in arranging the facility to reduce hazards based on hydrogen's characteristics.

Hydrogen is Highly Flammable and Easily Ignitable

Those designing or operating hydrogen systems should know that hydrogen can burn over a much wider range of concentrations than other fuels. At an ideal mixture of about 29% hydrogen in air, it takes very little energy, just a small spark, to ignite the hydrogen.

In most cases of hydrogen fires or explosions, the exact source of ignition is unknown. Because hydrogen requires very little energy to ignite and there are many possible ignition sources, any leak should be treated as potentially ignitable. Mixtures close to ideal combustion conditions are especially likely to ignite. Typical ignition sources include:

- Electrical
- Mechanical
- Static electricity
- Impact
- Electrical charge from equipment
- Friction
- Open flame

- Metal fracture
- Thermal
- High velocity jet heating
- Vehicle exhaust
- Hot surfaces
- Chemical reactions

A large release of hydrogen under high pressure can spontaneously ignite due to the formation of shock waves.

According to NFPA standards, hydrogen storage tanks must be kept at a safe distance from flammable materials, including buildings, plants, and vehicles.

A good safety practice is to ensure that no grass or shrubs are planted near locations where hydrogen might leak. This prevents the use of powered garden tools, which could act as ignition sources

Fig. 4.11: Flame Detection Systems

Flames are too Hard to Visualise (See)

Hydrogen flames are pale blue and almost invisible in daylight. They may look yellow if the air contains impurities like dust or salt from the ocean. Pure hydrogen flames do not create smoke and give off very little heat, so you might not notice the flame until you are very near it. Some best safety practices are:

- Flame detectors should be permanently installed in areas where hydrogen is handled or dispensed."
- Portable flame detectors, such as thermal imaging cameras, can also be used for monitoring."
- Pay attention to the sound of venting hydrogen and observe thermal patterns that may indicate the presence of a flame.

- Use a combustible probe made of materials that will easily ignite if they contact a flame (e.g., a broom).

Hydrogen has Buoyant features

Hydrogen is much lighter than other gases, so it rises quickly when it leaks into the air. This helps outdoor systems because the gas disperses fast. In indoor areas, hydrogen can gather near the ceiling, creating a risk of explosion. Proper ventilation should be installed to avoid such buildup.

Check Your Progress

A. Fill in the Blanks:

1. To avoid creating an explosive mixture, ___________ must be purged from the system before introducing hydrogen.
2. ___________ is typically used as an inert gas for hydrogen gas systems, while ___________ is used for liquid hydrogen systems.
3. Hydrogen combusts with a ___________ flame that is nearly invisible in daylight.
4. A deflagration is a combustion explosion with ___________ flame propagation, while a detonation has ___________ flame propagation.
5. Hydrogen is ___________ times less dense than air, making it highly buoyant.

B. Multiple Choice Questions

1. **Which method is NOT suitable for purging Type IV cylinders?**
   A. Flowing gas purge
   B. Pressurizing venting cycle purge
   C. Vacuum purging
   D. All of the above

2. **Which inert gas becomes solid at liquid hydrogen temperatures?**
   A. Argon
   B. Nitrogen
   C. Helium
   D. Oxygen

3. **Which out of the following is a potential ignition source for hydrogen?**
   A. Static electricity
   B. Open flame
   C. Friction

D. All of the above

4. **Which device is commonly used to detect invisible hydrogen flames?**
   A. Smoke detector
   B. Thermal imaging camera
   C. Pressure gauge
   D. CO_2 sensor

C. Short Answer Questions:

1. Why is helium used instead of nitrogen in liquid hydrogen systems?
2. How can small hydrogen leaks be detected?
3. What are two differences between deflagration and detonation?

D. Long Answer Questions:

1. Explain the three general approaches to purging a hydrogen system.
2. Describe the properties of hydrogen that make it a unique fire and explosion hazard.
3. What precautions should be taken to prevent hydrogen explosions in confined areas?

MODULE 5 — INSTALLATION OF ELECTROLYSER FOR GREEN HYDROGEN PRODUCTION I

Module Overview

This module provides a detailed understanding of electrolysers, their types, and their role in green hydrogen production. Learners will explore the structure and components of Proton Exchange Membrane (PEM) electrolysers, along with the essential inputs and outputs of an electrolyser system. The module also covers the basic operation and maintenance (O&M) activities required for the efficient and safe performance of the system. By the end of the module, learners will have a solid foundation in both the theoretical and practical aspects of electrolyser installation and functioning.

Learning Outcomes

After completing this module, you will be able to:

1. Understand the principles of electrolysis, key components, and operation of different electrolyser technologies (PEM, alkaline, solid oxide) for hydrogen production.
2. Compare their advantages, limitations, energy efficiency, and maintenance needs while recognizing essential inputs and outputs (hydrogen, oxygen, heat) and handling methods.
3. Identify common operational issues and troubleshooting techniques.

Module Structure

Session 1: Electrolysers and their types

Session 2: Components of PEM

Session 3: Inputs/Outputs of an Electrolyser System

Session 4: Operation and Maintenance (O&M) Activities

Session 1: Electrolysers and their types

As discussed in previous sessions, Electrolysis is a process that uses DC to trigger a chemical reaction. One common use of electrolysis is to split water (H_2O) into hydrogen (H_2) and oxygen (O_2) gas:

$$H_2O = H_2 + \frac{1}{2} O_2$$

This reaction occurs in a device known as an electrolyser. Electrolysers are found in various sizes, from small units suitable for localised hydrogen production to large facilities that can connect directly to renewable energy sources like solar or wind. When renewable energy is used to generate electricity for hydrogen production, the hydrogen is called green hydrogen because it does not create carbon emissions.

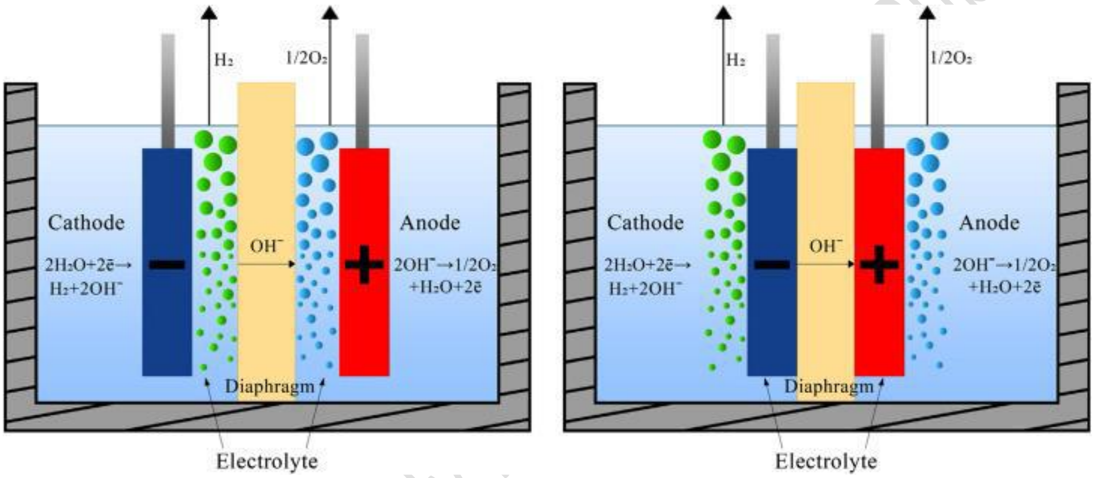


Fig. 5.1: Electrolyser

Working principle of an Electrolyser

The simplest type of electrolyser has two electrodes placed in water, separated by a membrane. When you apply a DC voltage, the water breaks down, producing H_2 gas at the cathode (the negative electrode) and O_2 at the anode (the positive electrode). The gases continue to form as long as electricity flows. In a single electrolysis cell, for initiating the reaction, the voltage required depends on factors such as temperature and the conductivity of the water. Commercial electrolysers have several cells connected together, called a stack. Depending on how many cells are in a stack.

Large scale electrolysers need extra equipment to function properly. This includes a water purifier, often using reverse osmosis (RO), to make sure the water meets the electrolyser's requirements. It also needs a purifier to clean the hydrogen gas produced, ensuring it meets quality standards for its intended use.

All electrolysers have some inefficiency, meaning the energy contained in the hydrogen produced is lesser than that of the energy used to create it. The energy that doesn't turn into hydrogen is released as heat, so cooling systems are necessary to prevent overheating. These cooling systems can be a significant investment, especially for large installations.

Types of electrolysers

Electrolysis works on the same principle in all systems, though the technologies vary in terms of chemical, physical, and electrochemical features. At present, four main types of electrolysis technologies are commonly used.

1. **Alkaline Electrolysers**

Alkaline type of electrolysers operate by applying direct current (DC) electricity to metal electrodes placed in a liquid solution, usually made of 20 40% potassium hydroxide. This process releases H_2 gas at the cathode and O_2 gas at the anode. At the cathode, water breaks down, producing hydroxide ions (OH) and H_2 gas. The ions move towards the anode side, where they react to create O_2, H_2O, and electrons. The DC voltage pulls electrons from the anode side to the cathode side.

In traditional industrial electrolysers, a space between the electrodes is filled with a diaphragm or membrane, keeping the two sides of the cell separate. The electrodes touch the diaphragm, which makes the system more compact and allows for a higher current density. Most modern electrolysers use flat cells arranged together in a filter press setup. Each cell is separated by bipolar plates that connects the cells in series. Although, there are some technical downsides to this filter press design, and the assembly of cell stacks can differ by manufacturer.

Typically, the anode and the cathode are made from porous metals, like Raney nickel. While they can degrade over time due to impurities in the water, they are less expensive than the precious metals used in PEM electrolysers, making alkaline electrolysers a cost-effective choice for many commercial uses.

These cells usually operate below 100°C, since higher temperatures can shorten the separator's lifespan and affect hydrogen's purity. They also tend not to exceed current densities of 400-500 mA/cm^2. While higher current densities can lower the capital costs, lower densities provide better efficiency in H_2 production per kWh of electricity used. Therefore, finding the right current density ensures a balance between the performance and the cost, similar to what is seen in fuel cells.

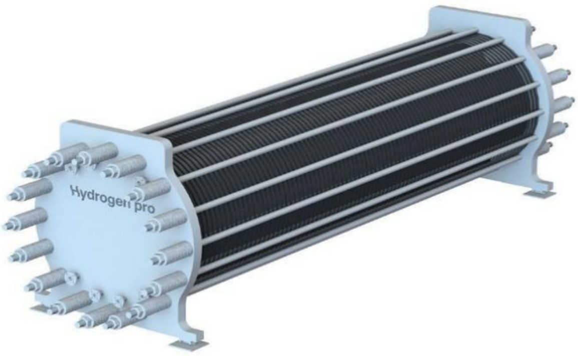


Fig. 5.2: Alkaline electrolyser

Fig. 5.3: Small packaged alkaline electrolyser

It is not accurate to think of an electrolyser as just a stack of electrolysis cells. A modern alkaline electrolyser needs several components, shown in Fig. 5.4. These parts include pumps to feed and circulate the liquid electrolyte and H_2O, as well as heaters, filters, and vessels that separate H_2 and O_2 from the circulating electrolyte (i.e.' H_2O).

Most electrolysers also need water purification, typically through a reverse osmosis (RO) system. This removes minerals and substances that could harm the electrodes inside the cells. The manufacturers generally specifies a minimum level of purity for the cells, depending on their design. Additionally, the hydrogen produced by an alkaline electrolyser must be purified for water removal and oxygen clean up.

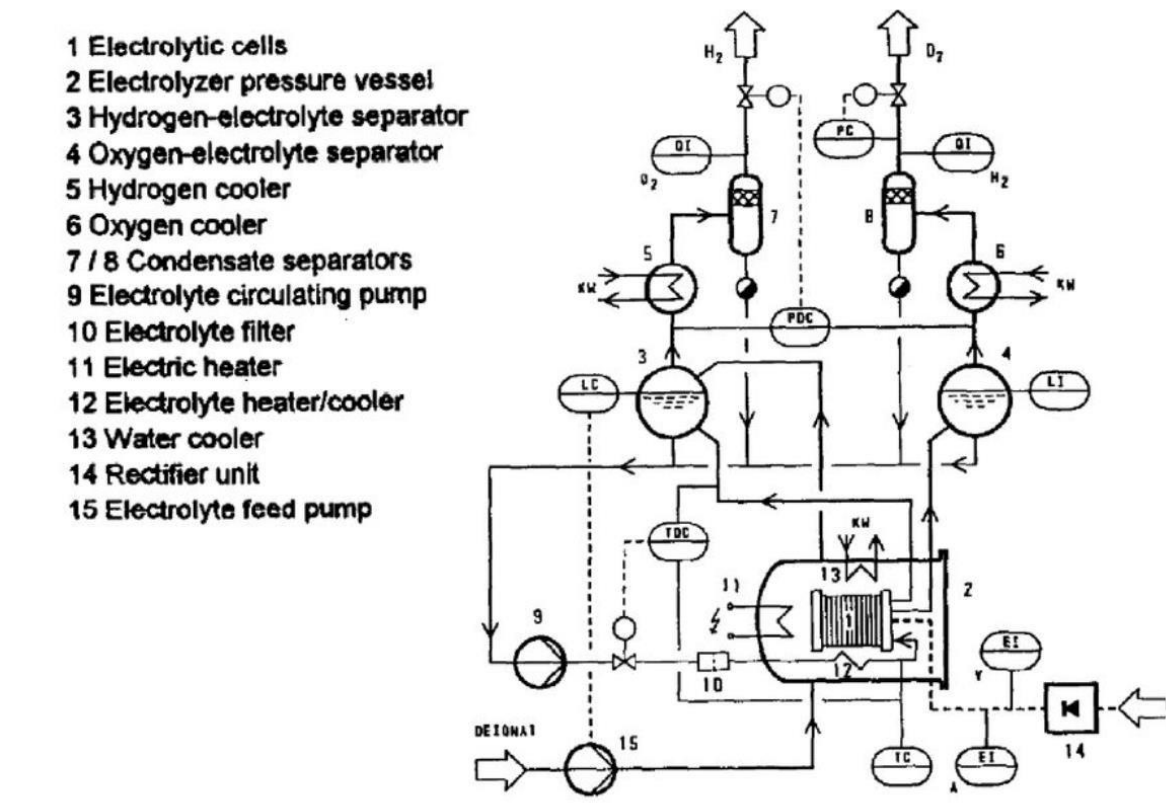


Fig. 5.4: Modern alkaline electrolyser (Process flow diagram)

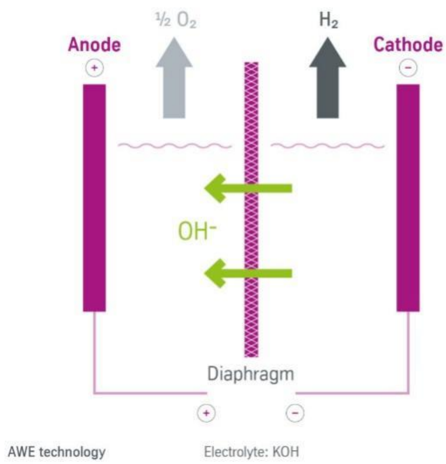


Fig. 5.5: Alkaline Water Electrolysis process

Structure of Alkaline Water Electrolysis (AWE):

In Alkaline Water Electrolysis, the electrodes are placed in an alkaline solution, like potassium hydroxide (KOH), that helps move ions and enables the process of electrolysis. The electrodes are held in separate half cells that are divided by a special membrane. The membrane allows ions to pass through but keeps oxygen and hydrogen gases from mixing.

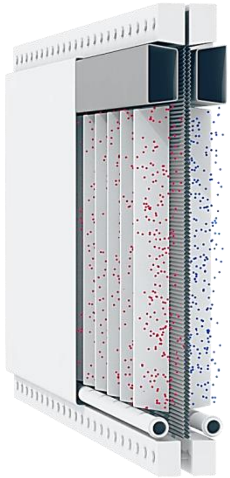


Fig. 5.6: One of the cells

The process of AWE:

At the cathode, the electrons react with H_2O, producing H_2 and hydroxide ions (i.e.; OH).

$$2H_2O + 2e \rightarrow H_2 + 2OH$$

The OH ions pass through the diaphragm, and H_2 gas leaves the cell. At the anode, these ions react to form O_2 and H_2O, giving off electrons.

$$2OH \rightarrow ½O_2 + H_2O + 2e$$

Characteristics of AWE:

- AWE operates at high pressure and high temperature.
- It is Known for strong long-term stability and comparatively lower setup costs.
- Presently, AWE achieves the highest efficiency levels.
- Ready for industrial usage.

2. Proton Exchange Membrane (PEM) Electrolysers

A PEM (Proton Exchange Membrane) electrolyser has a solid polymer membrane between its electrodes. Unlike an alkaline electrolyser, which uses OH^- ions, a PEM electrolyser moves protons (H^+) from the anode to the cathode through the membrane. The membrane conducts hydrated protons and must stay hydrated, so the cell operates below 100°C at atmospheric pressure to prevent drying.

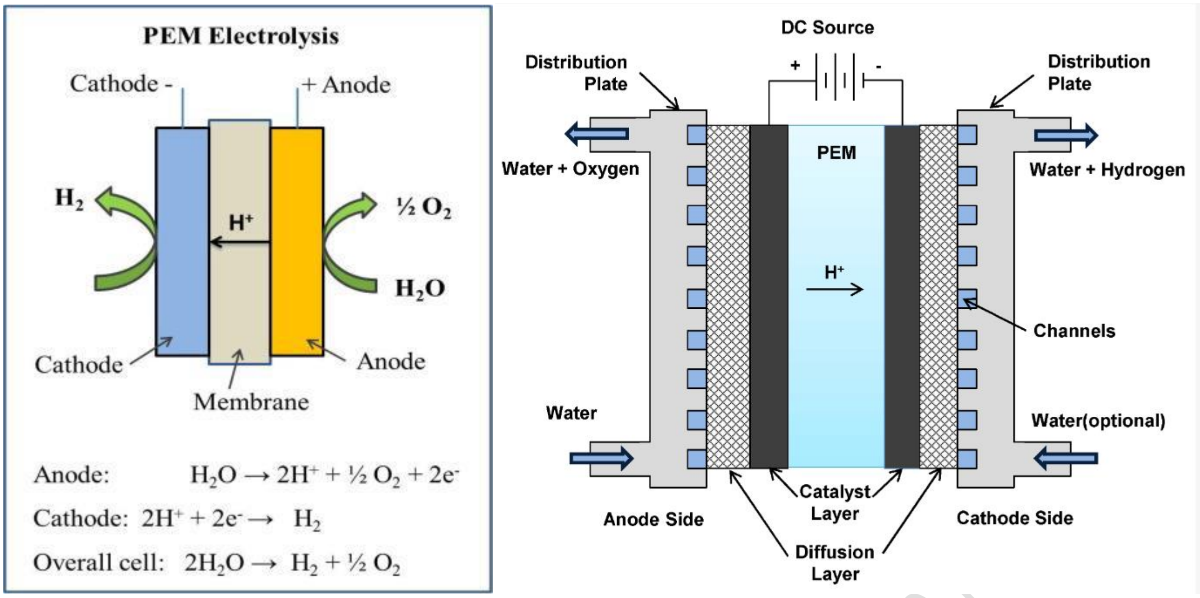


Fig. 5.7: Working principle of the PEM electrolyser

PEM electrolysers have slightly different chemistry compared to alkaline electrolysers (see Fig. 5.7). One main benefit is that they can handle high current densities, enabling smaller, high-power stacks that may reduce costs. Their thin membrane (100–200 microns) reacts quickly to load changes, making them ideal for solar or wind energy, which are intermittent. At the start, the membrane does not allow gases to pass through, which results in very pure hydrogen production.

However, several factors contribute for the higher costs of the PEM electrolyser:

1. The polymer electrolyte has acidic properties, which means it cannot use base metal catalysts for the electrodes. As a result, only platinum group metals can provide the necessary longevity for the stacks.

2. Platinum-on-carbon catalysts may lose activity over time, which restricts the guaranteed lifespan of the stacks.

3. In PEM electrolysers, stainless steel cannot be used for the cell and stack housing. Titanium or its alloys are generally used for the bipolar plates and housing instead.

4. The fabrication of the membrane is costly, and the material can degrade during the application, potentially leading to holes. This can allow oxygen to mix with hydrogen, further limiting the operating life of the stack.

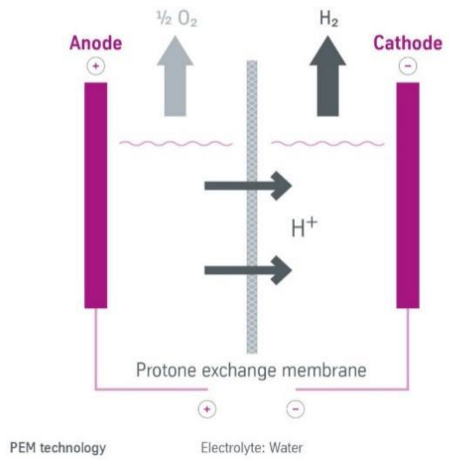


Fig. 5.8: Simplified PEM Electrolysis process

Structure of PEM:

PEM electrolysers work in an acidic medium and do not use liquid electrolytes. They have a solid membrane that lets protons pass but blocks electrons, which is essential for the proper conduction of protons during the process.

PEM detailed process:

Water enters the anode, and as electrons are released, it is oxidized to form oxygen (O_2) and hydrogen protons (H^+).

$$H_2O \rightarrow ½O_2 + 2e + 2H^+$$

Protons of hydrogen move through the membrane to the cathode, and there they react with electrons to produce hydrogen gas (H_2).

$$4H^+ + 4e \rightarrow 2H_2$$

PEM Characteristics:

- PEM electrolysers work at low temperatures and can also operate under higher pressures.
- PEM electrolysis has been used in scientific research for many years and is currently being developed for larger-scale industrial use.

Table 1. Characteristics of PEM and Alkaline electrolysers

Type →	**Alkaline**	**PEM**
Electrolyte	KOH solution (30 wt. %)	Solid polymers like Dupont Nafion
Operating pressure	< 3.2 MPa	< 5 MPa
Operating temperature	80- 90 °C	50-80 °C
History	Long history of industrial use	Relatively new technology
Operational Characteristics	Best suited for steady-state operation, responds slowly to load changes, and operates at constant pressure (isobaric).	The system can operate over a wide range to meet large changes in demand. It supports black start, responds within 10 seconds, and can handle high differential pressures.
	The system uses a highly corrosive KOH electrolyte, and the hydrogen generated over 99.8% pure needs additional purification.	The electrolyser uses a safe solid electrolyte without harmful materials and generates hydrogen over 99.99% pure, needing only minor purification to remove water.
	Moderate current density.	High current densities and more compact designs.
	Capability to operate at high pressures (i.e., 10 - 34 MPa).	Operating pressure is constrained by the requirement to contain liquids.
	Significant O and M cost, including the replacement of electrolyte.	Very low O and M cost.
Manufacturing cost	Low.	High.
Life-span	10 years before rebuild.	3-5 years before the stack replacement.

Figure 5.9 illustrates a PEM electrolyser consisting of three integrated cell stacks. Unlike alkaline electrolysers, which are typically stacked horizontally, the cells in a PEM electrolyser are arranged vertically. This vertical configuration takes advantage of gravity to help maintain gas-tight seals between the cells.

Fig. 5.9: Packaged PEM electrolyser system

3. **Anion exchange membrane (AEM) electrolysers**

Alkaline electrolysers have some disadvantages compared to proton exchange membrane (PEM) electrolysers. One benefit of PEM is that it uses membranes that move hydroxide ions (OH^-) instead of hydrogen ions (H+). This means it can use cheaper electrode materials, such as those used in alkaline electrolysers, in a design that has no gap, similar to modern PEM electrolysers.

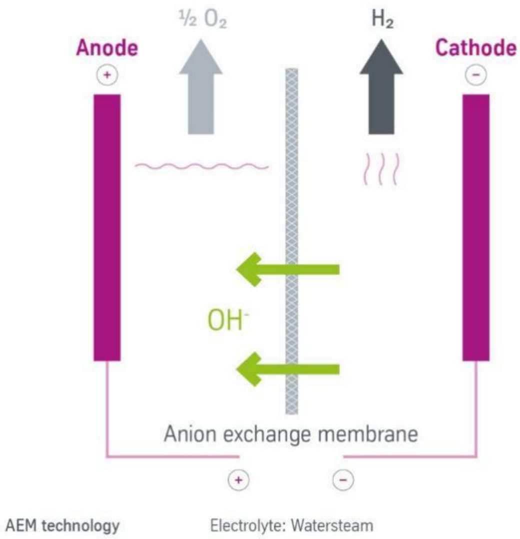


Fig. 5.10: Simplified Anion Exchange Membrane Electrolysis Process

Anion Exchange Membrane (AEM) cells use a lower concentration of alkaline electrolyte compared to conventional alkaline electrolysers. In AEM cells, the membrane that conducts anions takes the place of the liquid alkaline electrolyte, which reduces corrosion problems. This design can also be more compact than traditional alkaline methods. However, making anion exchange membranes is more complicated than making the commonly used perfluorinated sulfonic acids found in PEM systems. This complexity is why AEM technology is not commercially developed as much yet.

Setup for AEM electrolysis:

In AEM cells, the anode and cathode are divided by an anion exchange membrane

AEM process:

When electric current passes through H_2O, it soaks into the anion exchange membrane and moves from the anode to the cathode. Water at the cathode splits into hydrogen gas (H_2) and hydroxide ions (OH^-) with the help of electrons.

The reaction is:

$$2H_2O + 2e \rightarrow H_2 + 2OH$$

As hydrogen gas exits the cell, the hydroxide ions travel towards the anode side. There, hydroxide ions react with electrons to produce O2 gas and H_2O.

The reaction is:

$$2OH \rightarrow \frac{1}{2}O_2 + H_2O + 2e$$

Important Characteristics of AEM:

AEM uses alkaline solutions and can operate at high current densities. It is still being developed and researched.

When we take a closer look, we see some differences. Even though All four main types of water electrolysis technologies have a similar basic structure, their processes differ. These differences come from the materials needed for charge transfer and the temperatures used to split H_2O. The operating conditions as well as the choice of electrolyte influence the materials used.

4. **Solid Oxide Electrolysers (SOEC)**

A solid ceramic material, like zirconia, is used as the electrolyte in Solid Oxide Fuel Cells (SOFCs). These fuel cells run at high temperatures, usually above 800°C, and at normal air pressure. Running electrolysis at these high temperatures is comparatively more efficient than using low temperature systems because it doesn't require cooling.

In Solid Oxide Electrolysis Cells (SOEC), water becomes steam at these high temperatures. The method for splitting H_2O into H_2 and O_2 is different from that used in other electrolysers, like alkaline and proton exchange membrane (PEM) types. In SOEC, water splits into hydrogen and O_2 ions at the cathode. These O_2 ions then move through the solid type electrolyte. At the anode electrode, they release their electrons, producing oxygen gas. When SOEC are connected with current industrial processes, they can achieve efficiencies of nearly 90%.

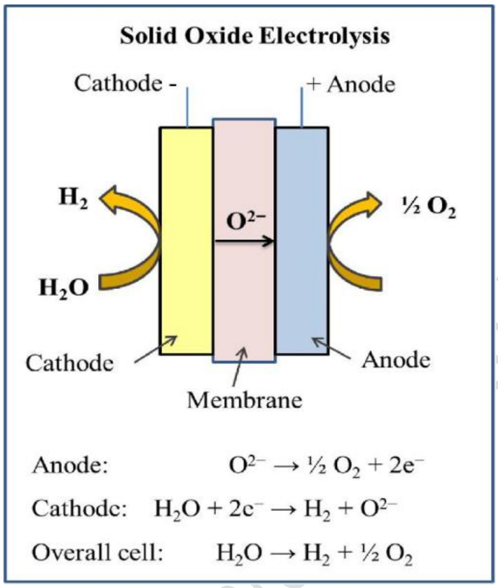


Fig. 5.11: Principle of operation of the Solid Oxide Electrolyser

SOECs (Solid Oxide Electrolyser Cells) can break water into hydrogen and oxygen, and they can also turn carbon dioxide (CO_2) into carbon monoxide (CO) and oxygen (O_2). The carbon monoxide can be mixed with hydrogen to make syngas, which is used to produce green fuels like methanol, kerosene, and diesel. SOECs can convert both steam and carbon dioxide into syngas at the same time in the same stack. This co-electrolysis process is attracting attention in Europe for making e-kerosene, a synthetic jet fuel from renewable energy.

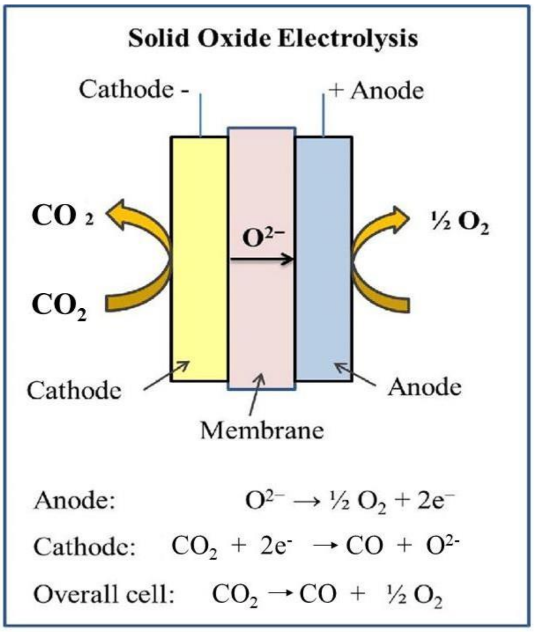


Fig. 5.12: Operating principle of CO_2 electrolysis using a solid oxide cell

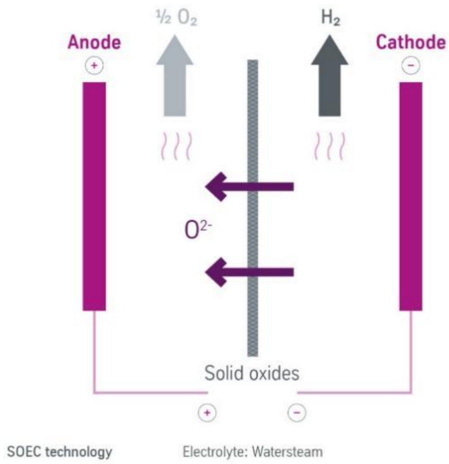


Fig. 5.13: Simplified SOEC Electrolysis process

Structure of SOEC:

In an SOEC, the solid electrolyte is usually a ceramic material like yttrium-stabilized zirconia (YSZ) and separates the anode from the cathode.

How the SOEC Works

At elevated temperatures between 500°C and 1,000°C, water vapor is introduced at the cathode. When a voltage is applied, the water vapor at the cathode–electrolyte interface decomposes into hydrogen and oxygen ions.

The reaction is:

$$H_2O + 2e \rightarrow H_2 + O^2$$

Hydrogen (H_2) gas escapes from the cathode, while the electrolyte allows O_2 ions to move from the cathode side to the anode side. At the anode side, the oxygen ions combine with electrons to form O_2 gas.

The reaction is:

$$O_2 \rightarrow \frac{1}{2}O_2 + 2^e$$

Key Features of SOEC:

- SOEC uses ceramics to handle high temperatures.
- Higher temperatures speed up reactions, increasing efficiency.
- SOEC technology is sensitive for temperature changes.

SOEC, like Proton Exchange Membrane (PEM), was mainly used in research and specialised areas and is now being tested for industrial use.

Table 1: Specifications of Electrolysers

	Alkaline	PEM	SOE	AEM
Electrolyte	Aqueous potassium hydroxide	PFSA membranes (e.g., Nafion)	Yttria Stabilises Zirconia (YSZ)	Anion exchange ionomer
Cathode	Nickel, Nickel - Molybdenum alloy	Platinum, Platinum - Palladium alloy	Nickel/YSZ	Nickel and Nickel alloys
Anode	Nickel, Nickel - Cobalt alloys	Ruthenium oxide, Iridium oxide	YSZ	Nickel, Ferrous, Cobalt oxides
Operating Temperature (°C)	60-80	50-80	500-850	50-60
Operating Pressure (Bar)	30	70	1-25	1-30
Stack Lifetime (h)	60-100k	20-60k	<10k	-
Technology Readiness	Matured	Commercialised	Demonstration	Large prototype
Cost	USD 500-1400/kW	USD 1100-1800/kW	USD 2800-5600/kW	

Check Your Progress

A. Fill in the Blanks

1. The process of electrolysis uses ___________________ electricity to trigger the chemical reactions.
2. In an __________________________, H_2 gas is produced at the cathode side and O_2 gas is produced at the anode side.
3. The electrolyte used in ___________________ is usually a potassium hydroxide (KOH) solution.
4. PEM electrolyser uses a ________________________ membrane to allow protons to pass through from anode to cathode.
5. The Solid oxide electrolysers (SOEs) operates at very high temperatures, usually above 800°C and use _______ materials as electrolytes.

B. Multiple Choice Questions:

1. **Choose the key advantage of PEM electrolysers.**
   a) Low current density
   b) Use of inexpensive electrodes
   c) Ability to handle high current densities
   d) Use of liquid electrolyte

2. **Which type of electrolyser operates at the highest temperature?**
   a) Alkaline
   b) PEM
   c) AEM
   d) SOEC

3. **What is the primary reason for using reverse osmosis in electrolysers?**
   a) To purify water
   b) To cool the system
   c) To remove gases
   d) To reduce electricity use

4. **Which of the following technologies is still in the research and development phase?**
   a) Alkaline electrolysers
   b) PEM electrolysers
   c) SOEC
   d) AEM electrolysers

5. **In a SOEC, what material is commonly used as the solid electrolyte?**
   a) Potassium hydroxide
   b) Platinum
   c) Yttrium stabilised zirconia (YSZ)
   d) Sulfuric acid

C. Short Answer Questions

1. What is green hydrogen and how is it produced?
2. List two key advantages of alkaline electrolysers.
3. Why are cooling systems important in electrolysers?

D. Long Answer Questions

1. Explain the working principle of an Alkaline Water Electrolyser (AWE), along with its structure and characteristics.
2. Compare the characteristics of Alkaline and PEM electrolysers.
3. Describe the structure and process of a Solid Oxide Electrolyser Cell (SOEC). What makes it different from low temperature electrolysers?

Session 2: Components of PEM

PEM (Proton Exchange Membrane) electrolysers are widely used because they efficiently produce hydrogen from water. Here, we look at the key parts of a PEM electrolyser, such as the compression plate, bipolar plates, gas diffusion layer, anode and cathode processes, and the membrane electrode assembly. By examining a dismantled PEM electrolyser, we can learn about the materials and roles of each component, helping us understand this modern technology and its importance for clean energy.

The Compression Plate

The compression plate is made of aluminum alloy and is used to fix the whole electrolysis cell.

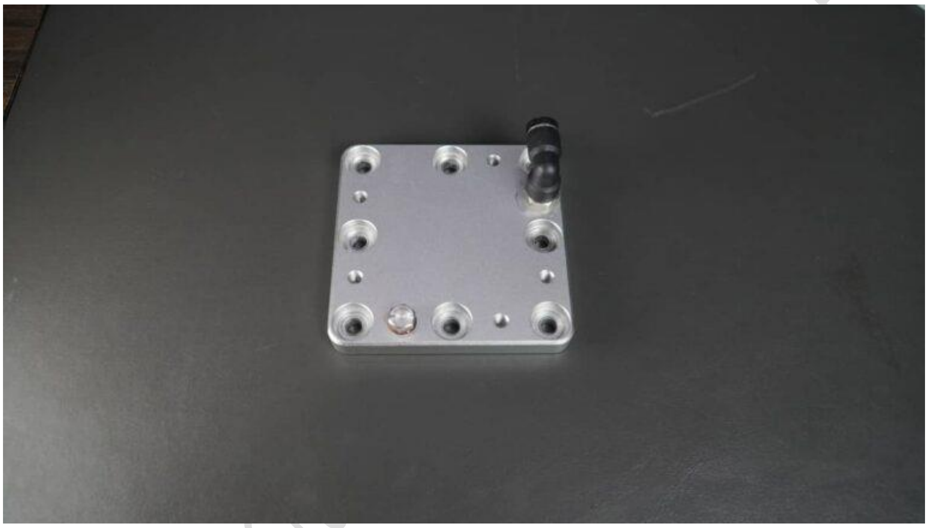


Fig. 5.14: The Compression Plate

Bipolar Plate (BPPs)

The Bipolar plates (BPPs) are flat separator plates, made using metal mesh, laminated screens, or etched flow channels, that stack multiple electrolysis cells in series to match the power supply voltage. They separate adjacent cells electrically and provide mechanical support. Bipolar plates need low electrical resistance, good mechanical and chemical stability, proper fluid distribution, and high thermal conductivity to help heat transfer. Titanium is commonly used because it is strong, has low resistivity, good thermal conductivity, and low hydrogen permeability. However, it can corrode at the anode, where voltages may exceed 2 V, leading to surface oxides that increase resistance and reduce heat transfer. A thin platinum coating can be added to reduce this surface resistance.

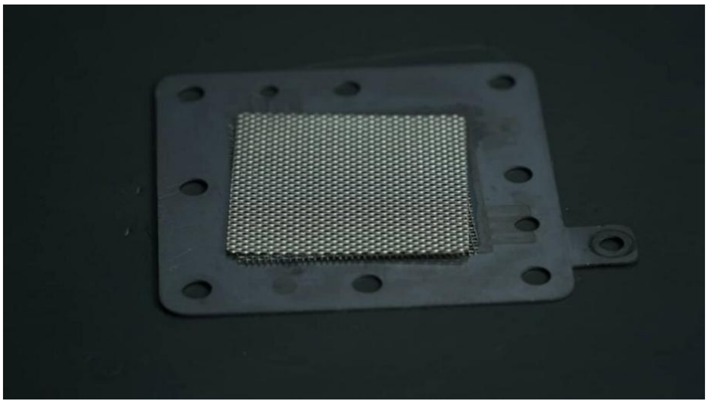


Fig. 5.15: Bipolar Plates (BPP)

Gas Diffusion Layer (GDL)

The gas diffusion layer (GDL), also called the porous transport layer (PTL) or current collector, connects the Membrane Electrode Assembly (MEA) and the BPP and helps liquids and gases move efficiently between the electrodes and the bipolar plate.

At the anode side, the H_2O moves from the BPP passages to the catalyst layer on the membrane via the current collector, where it splits into O_2 and protons. The O_2 then diffuses back through the collector to the BPP flow passages.

At the cathode side, the H_2O and H_2 travel from the membrane to the BPP passages through the current collector. Electrons travel from the anode catalyst layer, through the collector and BPP, to reach the cathode. Because the anode voltage is high enough to oxidize carbon, titanium is often used for the anode current collector

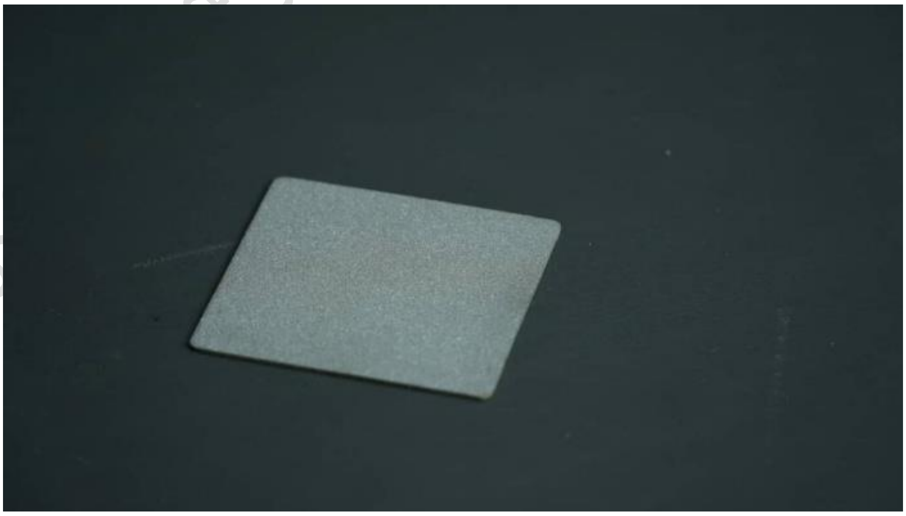


Fig. 5.16: Diffusion Layer (GDL)

Membrane Electrode Assembly (MEA)

The MEA consists of a proton-conducting membrane coated with porous catalyst layers on both the anode and cathode sides. This is the central part of the electrolyser, where H_2O is split into H_2 and O_2 using electric current. At the anode side, water is oxidized to produce O_2 and protons. These protons move through the membrane to the cathode, and the electrons flow to the cathode through the external circuit.

Protons at the cathode gain electrons and form H_2 gas. Iridium oxide (IrO_2) is considered the best catalyst for PEM water electrolysis. Although RuO_2 has the highest oxygen evolution reaction (OER) activity among single transition oxides, it is not stable under electrolyser conditions. IrO_2 has slightly lower activity but is more resistant to corrosion, making it more reliable for long-term use.

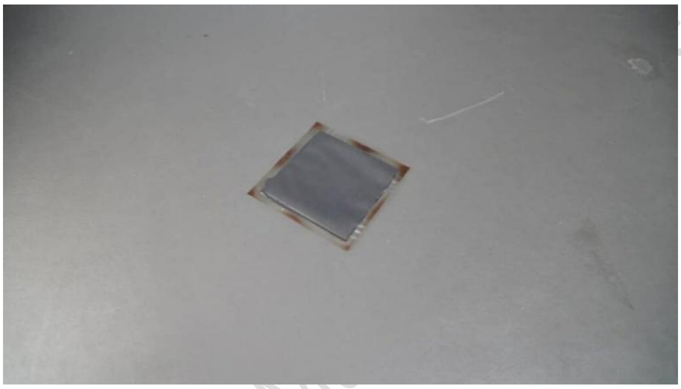


Fig. 5.17: Membrane Electrode Assembly

Installation of Electrolysers

To install an electrolyser, you should have to following:

Tools/Tackles	Description
1. Drawings from Suppliers	The drawings from the Supplier include the following: • Single line/block diagram, • General layout of the plant. Observe the orientation of each equipment. Check civil drawings for their matching with the general layout drawings. • Layout of piping and electrical cables • Individual assembly diagrams • Drawings of fasteners, gaskets, seals, 'O' rings etc. • Civil foundation and embedment drawings • Earthing pits (electrical and electronic), etc.

2. Installation Manual from Supplier	The installation manual from the supplier includes the specific instructions, drawings, safety standards etc.
3. General tools	General installation tools such which are easily available in market such as spanners, screw drivers etc.
4. Special tools & tackles	Listed in drawings/manuals along with the instructions for their use. Generally, in the supplier's scope of supply.

As long as hydrogen is not filled or produced, the tools needed are similar to those used in other projects. Special tools are only necessary when working in a hydrogen environment. The equipment supplier provides all necessary information, manuals, special tools, and instructions for their use. If needed, the plant contract may include training for the customer's technicians on installation, operation, and maintenance of the ordered plant.

This text aims to give a general overview of the activities involved and the skills required. However, according to the contract and warranty clauses, the actual work must strictly follow the plant supplier's manuals, which may differ between plants and suppliers.

During the installation of a hydrogen production plant, the technician must be able to identify each component, including fasteners (nuts, bolts, washers, etc.), and confirm their quantities according to the bill of materials. The assembly drawings are simple and can be learned from more experienced workers. A critical task is to check the bill of materials against the received materials, noting their condition and how to store them, including temperature, humidity, and shelf life.

Proper sealing of various joints is crucial. Use the sealing rings, gaskets, and other sealing materials that come with the equipment as needed. Handle them carefully to prevent issues like looseness or cracking due to over tightening. Always check gaskets and sealing rings for cracks, folds, or cuts. Keep them clean and free from dust and particles.

To tighten the electrolyser cover, follow the supplier's guidelines. Generally, nuts and bolts should be tightened in a specific sequence, such as diagonally opposite, over three to four rounds without full tightening in the first round. Pipe fittings require appropriate sealing tapes, such as Teflon tape, to achieve a 100% leak proof seal. The equipment supplier will provide any special tools needed along with an instruction manual for their use. Typically, torque wrenches are used for accurate and even tightening.

Initially, test the sealing with pressurised helium or a mixture of 5% H_2 and 95% N_2 for a specified duration. This pressure should be 50 to 100% higher than the actual hydrogen pressure during operation.

Remember, any faults or wrong actions can lead to increased temperature, noise, or vibrations. For daily monitoring, use a remote temperature sensing device, a portable vibration meter, or special wooden sticks to detect any changes in these key measurements.

Check Your Progress

A. Fill in the Blanks

1. _________ is made up of aluminium alloys and is used for fixing the whole electrolysis cell.
2. _________ is generally used as the coating on titanium bipolar plates to reduce surface resistance.
3. The _________ helps liquids and gases move efficiently between the electrodes and the BPP.
4. In a PEM electrolyser, _________ oxide is widely used as a corrosion resistant catalyst at the anode.
5. During installation, _________ wrenches are used to ensure accurate and even tightening of nuts and bolts.

B. Multiple Choice Questions:

1. What is the primary function of the compression plate in a PEM electrolyser?

   A. Electrolyte storage
   B. Fixing the entire electrolysis cell
   C. Gas flow control
   D. Proton transfer

2. Which of the following materials is commonly used for bipolar plates due to its strength and conductivity?

   A. Aluminium
   B. Copper
   C. Titanium
   D. Carbon

3. Why is a platinum coating applied to titanium bipolar plates?

A. To increase flexibility
B. To reduce cost
C. To reduce surface resistance
D. To add color

4. What is the role of the Membrane Electrode Assembly (MEA)?

A. Distribute gases
B. Conduct electrons externally
C. Separate hydrogen and oxygen physically
D. Decompose water into hydrogen and oxygen

5. Which gas mixture is commonly used to test the sealing of PEM electrolysers?

A. 5% hydrogen and 95% nitrogen
B. 50% oxygen and 50% nitrogen
C. 100% oxygen
D. 100% helium

C. Short Answer Questions:

1. What are the key properties required for a material to be used in bipolar plates of PEM electrolysers?
2. Why is titanium preferred as a material for the current collector at the anode side in PEM electrolysers?
3. What precautions should be taken while handling gaskets and sealing materials during installation?
4. Explain the working of a Membrane Electrode Assembly in a PEM electrolyser.
5. Describe the structure and role of the Gas Diffusion Layer (GDL) in a PEM electrolyser.
6. List the tools and procedures necessary for the safe and proper installation of a PEM electrolyser.

Session 3: Inputs/Outputs of an Electrolyser System

"Imagine a machine that can take something as simple as water and electricity and turn it into clean hydrogen fuel is key to a sustainable energy future. How does this work? What exactly goes into such a system, and what comes out? Today, we'll break down the essential inputs and outputs of an electrolyser, the heart of green hydrogen production."

As the world moves towards renewable energy, hydrogen made through electrolysis is becoming important. It is used in fuel cells, industrial processes, and energy storage. Understanding how an electrolyser works is essential for future engineers, scientists, and policymakers. By learning about its inputs and outputs, you will understand the basics of hydrogen technology.

The following figure represents the inputs to an electrolyser.

DC electric power supply (from renewable sources of energy)
Water
Electrolyte (in case of alkaline electrolyser

Fig. 5.18: Inputs to an Electrolyser

Connect the electric cables for each pair of electrodes using the correct cable sizes to prevent overheating and sparking. Use proper lugs with solid and even soldering on the cable conductors. Avoid dry soldering. Attach the lugs to the electrodes with the specified bronze nut bolts, washers, and heat sinks. Ensure all connections are tight to prevent overheating and sparking from high currents.

When laying and fixing cables, avoid mechanical stress and twisting. Use cable holders, mild steel wire, or strips to support the cables properly. Make sure there is no leakage or seepage of electrolyte from drain valves or fittings. These connections should be leak proof, so pressure test them as specified in the supplier's manuals.

All these points should be taken care of for all the electrical equipment or their components.

Outputs from electrolysers

Hydrogen is the output and oxygen is the by product from electrolysers. Oxygen after separation from water droplets or vapour can be let out in the atmosphere or stored for other uses. Working with oxygen is quite safe similar to working with inert gases. However, care has to be taken to avoid its mixing with hydrogen. The physical layout takes care by keeping oxygen outlet quite apart from hydrogen outlet.

Hydrogen needs to be handled very carefully right from its outlet from the electrolyser to high pressure storage tanks. In between, hydrogen passes through a water separator, a hydrogen gas holder, a hydrogen drier and finally the inlet of the high-pressure compressor system. Strict monitoring is required at all such places or terminals

Calculate Losses and Equipment Efficiency

Tests are conducted on a specific model of electrolyser at an authorised laboratory to check its efficiency and other important factors. If the model passes these tests, the manufacturer becomes an approved supplier for that electrolyser.

The initial tests are done to verify the design, and signed certificates are provided with the offers. Customers usually place orders based on these certificates.

For the customer's facility, routine tests are carried out at the manufacturer's workshop for all electrolysers, and the customer's representatives can observe these tests.

Typically, tests check the efficiency, pressure, and temperature resistance of each piece of equipment.

After the plant is assembled, a test is performed to measure the overall energy input, the demineralised water used, and the amount of hydrogen collected after the high or medium pressure hydrogen compressors. Special arrangements are needed to weigh the hydrogen stored in high or medium pressure tanks.

Calculations must consider the efficiencies of each piece of equipment, which are recorded during their efficiency tests.

In a broad sense:

- Plant efficiency = Gross input energy (with due corrections for meters, CT/PT errors and calibrations and permissible tolerances) Energy consumed by each equipment e.g. dryer, compressor (again with due corrections)
    - o = Energy required for production of dry hydrogen.
- Hydrogen produced = Weight of hydrogen filled cylinder weight of empty cylinder with errors corrections allowed as per the applicable standards.

Above will give energy required for hydrogen production by the electrolyser.

All these calculations should be essentially performed before acceptance of the plant. It avoids future disputes to a great extent.

Electrolyser Efficiency

Water electrolysis works in the opposite way to a fuel cell. Many PEM and solid oxide fuel cells can switch between operating as a fuel cell or as a water electrolyser, depending on the direction of the electric current.

The following figure represents the equation for the water electrolysis reaction, which is simply reversal of the fuel cell equation.

$$H_2O \text{ (liquid)} + 237.2 \text{ kJ/mole electricity} + 48.6 \text{ kJ/mole heat} \rightarrow H_2 + \tfrac{1}{2} O_2$$

Thus, efficiency can be calculated in the opposite way as well. The efficiency of a water electrolysis system is given by the heating value of the hydrogen produced divided by the electrical energy input, as shown in the following formula:

- Electrical efficiency (HHV) = $HHV\ of$ the $H_2\ produced/\ Eletricity\ used$

where,

HHV is the higher heating value.

HHV (Higher Heating Value) is the amount of heat released when a unit of fuel, starting at 25°C, is fully burned and the resulting products are cooled back to 25°C. This value includes the heat required to condense (Latent heat) the water vapor.

- A voltage of 1.23 V represents the higher heating value (HHV) of hydrogen
- HHV of hydrogen/kg = 141.9 MJ = 39.4 kWh
- LHV of hydrogen/kg = 120.1 MJ = 33.3 kWh
- The Electrical efficiency (based on LHV) = $LHV\ of\ H_2\ produced/\ Eletricity\ used$

Other efficiency measures are usually mentioned in electrolyser brochures, with the most common being the electricity used in kilowatt-hours for each normal cubic meter (kWh/Nm^3) of dry hydrogen produced.

Computation of Efficiency by Simulation

The efficiency of the PEM electrolyser plant can be computed, for which the input data has to be carefully worked out with accuracy. The following figure represents the schematic diagram that shows the components of the PEM electrolyser plant.

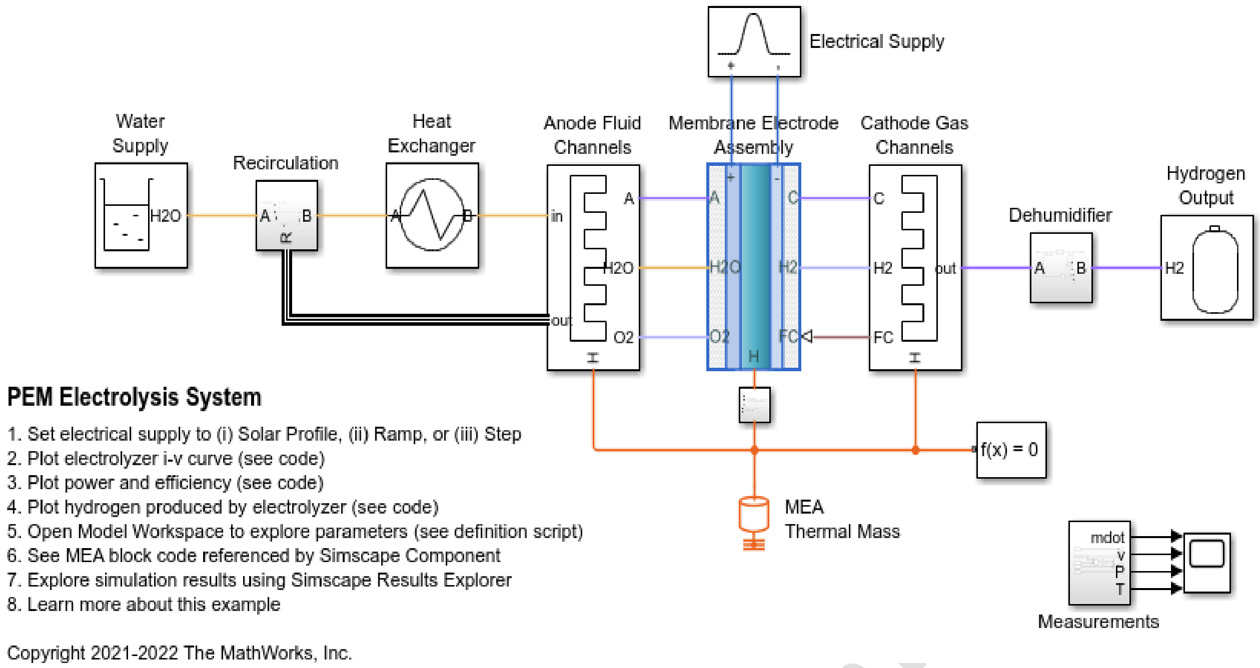


Fig. 5.19: Mathematical model of PEM electrolyser plant.

TIPS:

❖ Special tools & tackles are mentioned in the drawings/manuals along with the instructions for their use. These are generally in the supplier's scope of supply.

❖ Drawings from Supplier:

- Single line/block diagram,
- General layout of the plant. Observe the orientation of each equipment. Check the civil drawings for their matching with the general layout drawings.
- Layout of piping and electrical cables
- Individual assembly diagrams
- Drawings of fasteners, gaskets, seals, 'O' rings etc.
- Civil foundation and embedment drawings
- Earthing pits (electrical and electronic) etc.

❖ Installation/O&M manuals of supplier:

- Specific instructions for the use of special tools/tackles are given in drawings/manuals.

Check Your Progress

A. Fill in the Blanks:

1. The two main inputs to an alkaline electrolyser are _______ and _______.

2. Oxygen produced in an electrolyser must be kept separate from hydrogen to avoid _______.
3. The _______ value of hydrogen comprises the latent heat (LH) of vaporisation of water.
4. The standard potential for water electrolysis is _______ volts.
5. After hydrogen leaves the electrolyser, it passes through a _______ and _______ before compression.

B. Multiple Choice Questions:

1. What is the primary output of an electrolyser?
   A. O_2
   B. CO_2
   C. H_2
   D. N_2

2. Which among the following is NOT an input to an electrolyser?
   A. Demineralized water
   B. AC electric power
   C. Electrolyte (for alkaline electrolysers)
   D. Natural gas

3. **Why must electrical connections in an electrolyser be tightly secured?**
   A. To improve hydrogen purity
   B. To prevent overheating and sparking
   C. To reduce water consumption
   D. To increase oxygen production

4. **How is electrolyser efficiency (HHV) calculated?**
   A. (LHV of H_2) / (Electricity used)
   B. (HHV of H_2) / (Electricity used)
   C. (Oxygen output) / (Water input)
   D. (Voltage supplied) / (Current drawn)

5. **What is the purpose of a hydrogen drier in the system?**

A. To eliminate water vapor from hydrogen
B. To remove oxygen traces
C. To cool down the electrolyser
D. To increase electrolyte concentration

C. Short Answer Questions

1. List three safety precautions when handling hydrogen from an electrolyser.
2. What is the difference between HHV and LHV in hydrogen production?
3. Why are routine tests conducted on electrolysers before delivery?
4. Explain the step by step process of hydrogen production in an electrolyser, from inputs to final storage.
5. Describe how electrolyser efficiency is calculated and why it matters in industrial applications.
6. What are the key checks during electrolyser installation, and why are supplier manuals critical?

Session 4: Operation and Maintenance (O&M) Activities

The main operational activities include the following tasks:

- To monitor the temperatures of electrolyte, electrolyser terminals, cables etc., with remote temperature sensing devices.
- Further, noise levels, vibrations of rotating equipment, such as compressors, are to be monitored by portable vibration meters, and noise levels by special wooden sticks.
- To monitor the leakages of electrolyte and its level, hydrogen/oxygen leakages, condition of electrolyte filters. Monitor the gas holder for any leakages of hydrogen.
- To monitor hydrogen temperatures and pressure at the inlet and outlet of high high-pressure compressor.

The maintenance activities include the following tasks:

- Before any maintenance, purging of hydrogen is to be done with nitrogen or carbon dioxide.
- As per the observations, recorded by the operation staff, check the tightness of the electrolyser terminals, seal cover, electrode seals, membrane, and valve seals.

Operation Safety

A water electrolysis cell stack comprises multiple electrochemical cells linked in series. After stopping, these stacks can retain considerable electrical charge due to leftover hydrogen and oxygen in cells. This charge takes hours to dissipate naturally. Extreme care is needed for maintenance or replacement right after the operation. A metal tool bridging current terminals could cause damage or injury through a large current or electrical arc. Lack of proper insulating gear poses risks to personnel.

The following are the Best Practices for Handling Water Electrolysis Cell Stacks:

Pre Check	Maintenance and service personnel should ensure no significant electric charge remains in the cell stack before proceeding.
Safety Measures	Before removing safety guards and electrical connections, confirm that the cell stack is free from substantial electrical charge.
Voltage Verification	Personnel are recommended to check the voltage of the cell stack to guarantee discharge
Additional Safeguard	In certain situations, service personnel can use a purpose designed service tools with high current shorting resistor across the discharged cell stack for added protection.

Cleaning of Electrolyser

Cleaning of electrolyser includes the following tasks:

- Cleaning of filter mesh by raw water followed by DM water.
- Compressor maintenance: Change of filters, checking of bearings, filing, greasing etc. Note that all these compressor maintenances should be carried out after purging of hydrogen.
- Maintenance of dryer: Cleaning, change of moisture absorbing chemicals e.g. silica gel. To check the valve operation and leakage test.
- Recharging of hydrogen as specified in the manual. Normally it is done with purging of nitrogen or carbon dioxide. After checking the pressure withstand, it is filled with hydrogen.

Checking Instruments

It includes the following tasks:

- Zero position of instruments must be checked every six months.
- Instruments must be calibrated every year by authorised laboratories only.
- When checking the dismantled instruments, parts contacting medium shall be oil free before they are installed.

Note: These are indicative and instruments may vary from one manufacturer to another

Start-up Sequence:

- Turn on the general power switch and the instrument switch.
- Switch on the air source.
- Start the DM feed pump until the DM water reaches about 50% in the separators or as specified.
- Start the electrolyte circulation pump.
- Set the current regulating knob on the rectifier panel to zero. Power the control circuit; the relevant indicator will light up. Press the 'run' button; the 'run' indicator will light. Slowly turn the current regulating knob clockwise to start the electrolysis process. The liquid level in the separator and cell temperature will rise. Increase the current to the rated value by turning the knob clockwise.
- When the cell temperature reaches 50°C (or as specified), set the temperature. Adjust the set point to between 75°C and 85°C or as specified by the manufacturer.
- After the plant has been running for a few hours and the gas is vented before the catalyst column, check the purity of the hydrogen gas. If it meets the standard, close the vent valve and direct the hydrogen gas to the catalyst column.

Routine Operation and Maintenance

- After starting the plant, operators should closely monitor its operation and follow the parameters set by the equipment supplier. Take readings regularly, at least once an hour.
- Pay attention to process values and quickly address any unusual situations. You can use a remote sensing thermometer or a vibration meter to detect issues, such as excessive noise or changes in sound.
- When adjusting the DC output of the rectifier panel, turn the potentiometer knob gently. Do not change the selection switch unless the current regulating potentiometer is at the '0' position.
- Clean the filters if you notice a sudden drop in the amount of circulating electrolyte.

Filter Cleaning

Whenever there is a flow drop or an abrupt variation in the flow of electrolyte, the time arrives for the cleaning of the filters. However, before refilling the electrolyte, the filters are to be cleaned.

Safety Precautions

When operating or maintaining the facility, follow these safety guidelines:

- If the plant shuts down for a long time, like six months, drain the electrolyte solution from the electrolyser and fill it with demineralised water.
- Since oxygen and hydrogen are produced under pressure, operators must follow all operating regulations carefully.
- Install explosion proof lights and fixtures in the electrolyser room. Ensure the room is well ventilated and has a gas detector for safety.
- Do not carry out repairs while the plant is running.
- Before welding in the electrolyser room, check the hydrogen concentration to ensure it is below the explosion limit. Avoid welding if possible; if necessary, do it under strict supervision.
- Purge the plant and pipelines to remove hydrogen and oxygen simultaneously.
- No smoking is allowed in the electrolyser room. Operators should wear suitable shoes and avoid synthetic or woollen clothes. Tools that can create sparks, like metal colliding together, are not allowed.
- Keep fireproof equipment, such as extinguishers, sand, and asbestos clothing, ready for use in the electrolyser plant.
- Have protective glasses and a 2% boric acid solution in the electrolyser room.

Wear rubber gloves when handling potassium hydroxide (KOH) solution.

- Do not vent hydrogen and oxygen suddenly at high rates, as this can cause burning and explosions. If oxygen is vented too quickly, it can create sparks from the oxidation layer in the pipes. Reduce pressure in the system slowly.
- Do not let grease or oil touch parts that come into contact with oxygen. Keep hands and clothes oil free while operating and maintaining the plant.
- Do not let alkaline solution drop into the gaps between bolts and electrode plates, as this can cause short circuits and lower current efficiency. Keep the surface of the electrolyser clean and free from any conductors.
- In case of an accident, like a gas or electrolyte leak, immediately cut-off the main supply and the power of the rectifier panel. Release pressure in the plant slowly. Analyse the cause of the accident and take necessary remedial actions.
- Do not store flammable or explosive materials in the electrolyser room. Only authorised personnel should enter.

Check Your Progress

A. Fill in the Blanks:

1. Before the maintenance, purging of hydrogen must be done using _______ or _______.
2. The _______ and _______ of rotating equipment like compressors must be monitored using portable meters.
3. After shutdown, electrolyser cell stacks may retain residual charge due to leftover _______ and _______.
4. For safety, welding in the electrolyser room should only be done if hydrogen concentration is below the _______ limit.
5. The electrolyte solution should be drained and replaced with _______ if the plant is idle for six months.

B. Multiple Choice Questions:

1. **What is the primary purpose of purging with nitrogen before maintenance?**
   a) Increase hydrogen production
   b) Prevent electrical arcing
   c) Remove residual hydrogen to avoid explosions
   d) Cool down the electrolyser

2. **Which tool is used to ensure a cell stack is discharged before maintenance?**
   a) Thermocouple
   b) High current shorting resistor
   c) Pressure gauge

d) Vibration meter

3. **Why must grease/oil be kept away from oxygen handling parts?**
a) To prevent fire hazards (spontaneous combustion)
b) To improve electrolysis efficiency
c) To reduce electrolyte contamination
d) To avoid voltage fluctuations

4. **What should be done if an electrolyte leak is detected during operation?**
a) Increase current supply
b) Immediately shut off power and slowly release pressure
c) Vent hydrogen rapidly
d) Ignore minor leaks

5. **How often should instrument calibration be performed?**
a) Monthly
b) Every 6 months
c) Annually
d) Only after failures

C. Short Answer Questions

1. List three safety precautions for handling potassium hydroxide (KOH) in electrolysers.
2. Why must hydrogen and oxygen outlets be kept apart?
3. What is the correct start up sequence for an electrolyser?
4. Explain the risks of residual charge in electrolyser cell stacks and how to mitigate them.
5. Describe the routine maintenance tasks for an electrolyser compressor.
6. Outline the safety protocols for welding in an electrolyser room.

Module 6 — Installation of Electrolyser for Green Hydrogen Production -II

Module Overview

This unit expands on the basics of electrolyser systems by focusing on practical skills in installation and operation. Learners will examine essential requirements for installing an electrolyser, such as site preparation, technical details, and safety protocols. The course also includes assembling and installing components, with emphasis on proper alignment and integration. Additionally, learners will explore criteria for selecting settings that maximize performance and the importance of keeping detailed daily logs to track efficiency, identify problems, and maintain safe operation.

Learning Outcomes

After completing this module, you will be able to:

- Identify essential site requirements for electrolyser installation, including space, ventilation, and utilities.
- Understand technical specifications, safety prerequisites, and the importance of thorough planning.
- Follow a step by step process to assemble and install key components, using the right tools and techniques while ensuring alignment and sealing integrity.
- Select components based on capacity, efficiency, and durability.
- Maintain a daily operational log to track data and analyse it for trends to optimise performance and prevent failures.

Module Structure

Session 1: Installation Requirements

Session 2: Assembly/Installation of Parts and Components of Electrolyser

Session 3: Selection Parameters and Maintaining the Log for Daily Operation of Electrolysis

Session 1: Installation Requirements

Installing a green hydrogen plant requires several important details and checks:

- Availability of renewable electricity and its specifics
- Daily and hourly hydrogen needs
- Water supply
- Space for the plant
- Any transport limitations
- Plans for hydrogen transport, if needed

Before issuing the tender, discuss the specifications with the plant supplier or manufacturer. Create the specifications based on proven commercial data for the following components:

- Electrolyser
- Water separator
- Low pressure water ring compressors
- High pressure compressor
- Storage cylinders
- Various types of valves
- Demineralised water preparation
- Pumps
- Filters
- Electrolyte preparation

If the plant is small, a turn key offer may be best. For larger plants, it might be more cost effective to get separate offers for electrolysers, compressors, and other parts.

Before starting the installation, complete these tasks:

1. Review the block/single line diagram to understand the process and sequence.
2. Check that the general layout shows a logical order for the equipment.
3. Examine civil foundation drawings to ensure they match general arrangement drawings before approval. Look for embedment needs, cable/pipe entry points, and foundation plates for panel installation.
4. Study the assembly drawings for each equipment piece, including required fasteners, cable/piping details, installation procedures, and testing requirements.
5. Examine the layout for cables and pipes, ensuring they connect properly to the equipment. Prepare cable terminals, installation arrangements, and do the same for piping.

Engineering Drawing

Drawings/documents: During the construction of a project, various drawings and documents are required during installation, operation and maintenance of a plant as listed in the following figure. Such are listed below:

1. Assembly and Components Drawings
2. Installation Manual
3. O&M Manual
4. Factory test certificates
5. Bill of materials from drawings
6. Material Verification

An engineering drawing is a technical illustration that shows how to build or assemble a part. Its main goal is to provide clear details about the shape and size of a component for manufacturing or construction. The drawing includes different views, such as plans, elevations, and side views, along with measurements, material specifications, and the quantity of each item needed for the assembly. A bill of materials is also included, listing the quantity, weight, and size of specific materials required.

Language of Engineers

Engineering drawing helps us visualize, calculate, and interpret these illustrations, which is essential for engineers in construction and industry. Every construction project requires drawings to guide the work. Engineering drawings are crucial documents for engineers and are often called the "language of engineers." Therefore, it is important to read them carefully and understand the information they convey.

These drawings apply to various fields, such as civil, mechanical, electrical, and electronic engineering, and use standard symbols. Symbols are usually the starting point for reading and understanding the drawings. The following figures show some common electrical and electronic symbols used in these drawings.

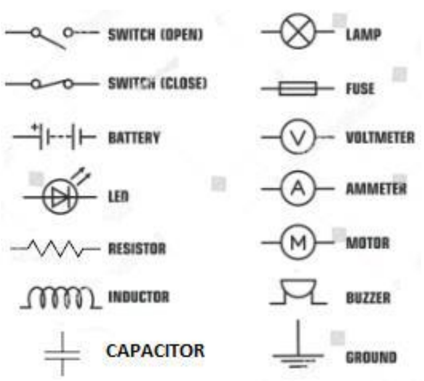


Fig. 6.1: Electrical circuit symbols.

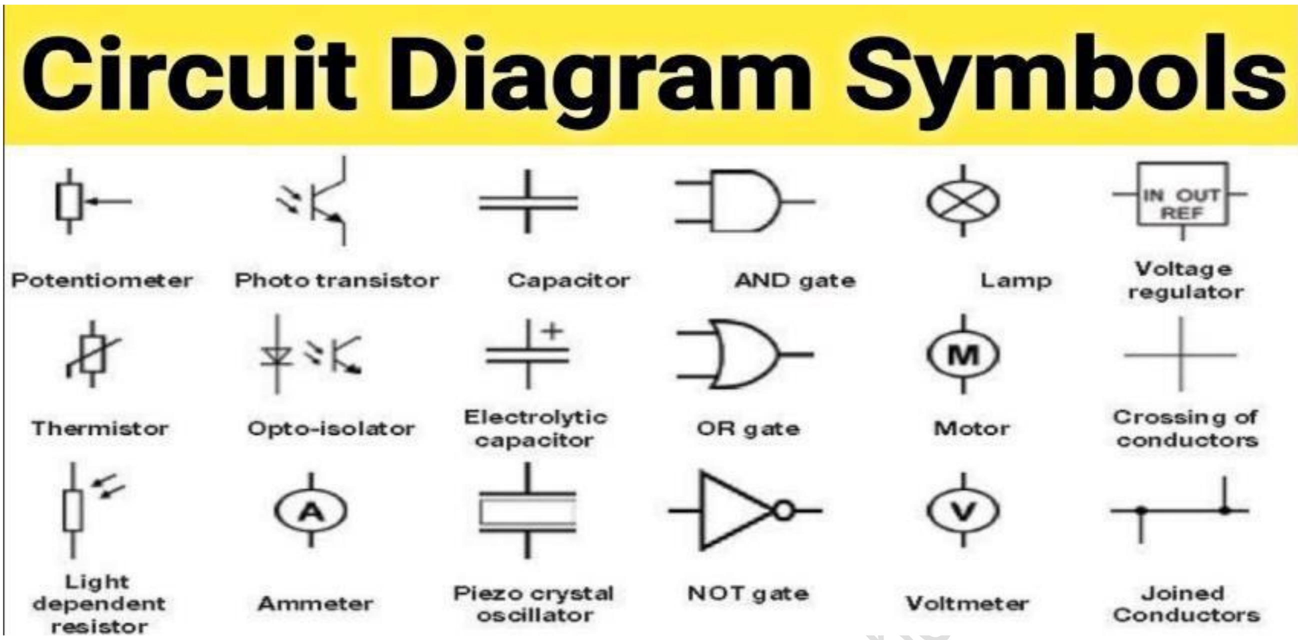


Fig. 6.2: Electronic circuit symbols.

Installation Procedure for Green Hydrogen Production Plant Using Drawings and Manuals

For installing the Green H_2 plant using the design drawings and documents, follow these basic steps:

- Review the block or single line diagram. Understand the entire process and sequence of operations.
- Examine the general layout drawing of the plant. This shows the access road to the office and the positioning of each piece of equipment. It includes dimensions for each equipment area, spacing between equipment, and the routing of cables and pipelines, as well as space for moving around the plant.
- Look at the civil foundation drawings. Check the embedment required for each piece of equipment, their front and back orientation, cable and pipe entry points, and any mild steel plates needed for securing panels.
- Study the assembly drawings and instruction manuals. Familiarize yourself with the standards and codes related to each piece of equipment, including fasteners, cable and pipe details, installation procedures, and testing of individual equipment.
- Lay out the cables and pipes according to their layout drawings. Make the necessary connections to the respective equipment. Prepare the cable terminals and secure them to the equipment. Repeat this process for the water and hydrogen pipelines.

Check Your Progress

A. Fill in the Blanks:

1. Before issuing a tender for a green hydrogen plant, discuss specifications with the _______ or _______.
2. For large hydrogen plants, it may be cost effective to procure _______ and _______ separately.
3. Engineering drawings include _______, _______, and material specifications.
4. The _______ lists the quantity, weight, and size of materials required for assembly.
5. Before installation, verify that civil foundation drawings match the _______ drawings.

B. Multiple Choice Questions

1. What is the first step in installing a green hydrogen plant?

   A. Lay cables and pipes
   B. Review the block/single line diagram
   C. Begin electrolyte circulation
   D. Calibrate instruments

2. Which document provides fastener details and installation procedures?

   A. Factory test certificate
   B. Bill of Materials
   C. Assembly drawing
   D. P&ID diagram

3. Why are engineering drawings called the "language of engineers"?
   A. They use universal symbols
   B. They replace verbal instructions
   C. They are written in multiple languages
   D. They include cost estimates

4. What must be checked in civil foundation drawings before installation?

A. Hydrogen purity levels
B. Embedment requirements and cable entry points
C. Electrolyte concentration
D. Compressor noise levels

5. **What is included in a turn key offer for small plants?**
A. Only electrolyser supply
B. Separate procurement of compressors
C. Complete system from a single supplier
D. Manuals without drawings

C. Short Answer Questions

1. List three pre installation checks for a green hydrogen plant.
2. Why is a Bill of Materials (BOM) critical for installation?
3. What are the key components of an engineering drawing?
4. Explain the role of engineering drawings in installing a hydrogen plant, with examples.
5. Compare turn key and modular procurement approaches for hydrogen plants.
6. Describe the safety checks needed during pipeline and cable installation.

Session 2: Assembly/Installation of Parts and Components of Electrolyser

Assembly of Electrolyser

Most electrolysers are made in sizes from 1 Nm3/hour to 100 Nm3/hour and come pre assembled from the factory. It is common to buy these readymade electrolysers based on the desired production capacity. It is also smart to get an extra unit for backup.

Assembling an electrolyser stack requires expert knowledge, special tools, and careful testing. This is usually only practical for larger hydrogen plants. For small to medium sized plants, it's more cost effective to buy factory assembled electrolysers.

Other equipment, like gas holders, water separators, pump motors, valves, and compressors, can be purchased separately. You can assemble this equipment by following standard procedures, and it doesn't require special skills, except for high level sealing in high pressure compressors. Most electrolyser assembly happens in controlled factory environments to ensure proper sealing, membrane integrity, and accurate oxygen and hydrogen outputs.

Some manufacturers say that hydrogen produced by an electrolyser may be used right away in numerous processes, including in the food industry, as long as it is dried properly, so there is no need for separate storage.

The following figure shows the stack assembly of a PEM electrolyser along with parts of a single cell.

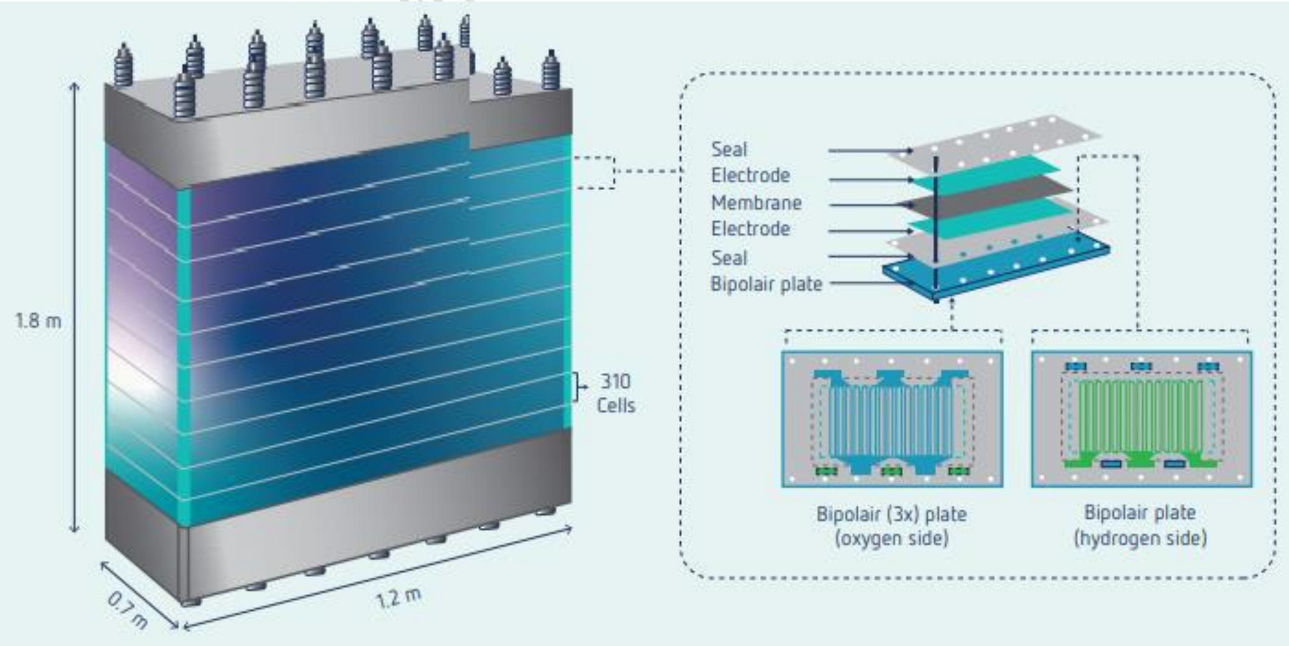


Fig. 6.3: Schematic illustration of PEM electrolyser stack and a cell

The factory makes a machine called an electrolyser, which is a bit like a sealed part of a refrigerator. The pictures show two types of electrolysers that can make 2 kilograms of hydrogen every hour. This is part of a green energy project by NTPC in a place called Leh in Ladakh.

Fig. 6.4: PEM and Alkaline electrolyser assemblies

PEM Electrolyser/Fuel Cell Assembly

The PEM electrolyser can work as fuel cell and vice versa. Here is the step by step assembly of PEM electrolyser/fuel cell is given.

Steps

Step 1: Place end plate (aluminium) on flat surface. Assemble bolts vertically, as shown in Fig. 6.5.

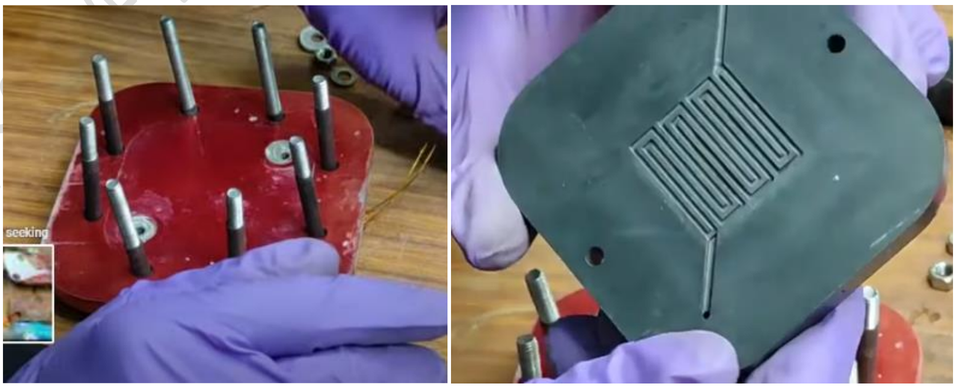


Fig. 6.5: Assembly of PEM fuel cell/electrolyser Fig. Gas flow channel

Step 2: Place Teflon cloth insulation to prevent short circuit of current collector with end shield

Step 3: Place current collector of copper (it has integral terminal)

Step 4: Assemble silicon 'O' seal rings to prevent gas leakage.

Step 5: Place cathode electrode.

Step 6: Assemble membrane with silicon gaskets on its both to stop leakage

Step 6A: Assemble anode electrode.

Step 7: Assemble bottom flow channel (graphite, of 2.8 cm x 2.8 cm size).

Step 8: Assemble current collector

Step 9: Assemble silicon 'O' ring seals to stop gas leakage

Step 10: Teflon insulating cloth to prevent short circuit between current collector and end plate.

Step 11: Assemble end plate.

Note: Check that there is no gap between various layers of the cell assembly.

Step 12: Assemble Teflon washer before assembling the nuts to protect against electrical short

Step 13: Tighten the nuts hand.

Note: A 25 W heater is fitted on the end plate to heat the fuel cell for improving its performance.

Step 14: Tighten the bolts with the concept of differential tightening i.e. tighten opposite bolts.

Step 15: Finally tighten the nuts using torque wrench uniformly by applying torque of 2 Newton metre.

Test:

- **Electrolyser mode:** Check the production of hydrogen and oxygen by water bubbles.
- **Fuel cell mode:** Input: Hydrogen and air. Check voltage & current at no load and load using electronic load. (fuel cell mode).

❖ Stack Assembling, Testing, Operation, Maintaining and Troubleshooting of an Electrolyser

Testing of Electrolyser

An electrolyser is an electrical device. Therefore, the tests used for other electrical devices also apply to testing an electrolyser. The testing of an electrolyser includes these key tests:

Insulation Test:

Use a 500 V megger for testing.

The insulation resistance must be over 1 Mega ohm.

The Polarization Index (PI) should be greater than 2.

High Voltage Withstand Test

- Conduct this test at 2.5 kV for 60 seconds. Connect the outer metal body to the electrical earth, and connect the cathode and anode to the high voltage terminal. After the test, ground the anode and cathode to discharge any leftover voltage.

Low Resistance Requirement: The electrolyser needs to have a resistance below 5 milli ohms due to the high DC it uses, to prevent excessive heating.

Leak Proof Tests:

- Perform a leak proof test at a pressure of 2 3 bar, since the electrolyser works with water and electrolytes.
- For the gas leak proof test, block all outlets and increase the pressure to 3 5 bars.
- Monitor the pressure drop with a gauge; it should not exceed 0.1% in one hour.

Probable Problems and Troubleshooting of Electrolyser

The following table represents the indicative probable problems in an alkaline electrolyser plant and the respective troubleshooting mechanisms.

S.No.	Problem	Probable reasons	Troubleshooting
1	The plant stops suddenly	• Power failure • Trouble with rectifier panel. • Break down because of lack of cooling water • Break down because of over current • Break down because of blowing of quick break fuse • Cell pressure too high causing rectifier panel to tripped off	• Inspect the power supply system • Eliminate the trouble of cooling water system. Check if at any point short circuit has taken place • Replace the fuse • Reduce cell temperature that is to increase cooling water flow rate
2	Total cell voltage is too high	• Electrolyte contains excessive dirt which blocks the inlet of cell causing the increase in cell resistance • Cell temperature is too low • Electrolyte concentration is too high or too low • DC current is too high	• Wash off the blocking material by frequently increase and reduce DC current and circulation amount; wash the cells after shutdown; replace filter gauze • Increase cell temperature to 90±20°C. Measure electrolyte concentration and make it to specific value • Reduce DC current to its rated valve
3	There is no water	• Feed water pump stops • There is no water in water tank	• Check the pump circuit elements and pump • Fill DM water tank fully

4	Gas purity falls down	• Levels in two separators are too low • Analysers are not accurate • Concentration of electrolyte is too high or too low. • DM water quality does not meet requirement • Electrolyte in electrolyser contains excessive dirt	• Shut down the plant and overhaul electrolyser, DM water and recalibrate the analysers. • Make the concentration to specific range. Improve the concentration to specific range. Wash the electrolyser
5	Containing oxygen cannot reach the required parameters	• Air is leaking in the system • The activity of catalyser falls	• Check the air tightness of the system and attend the leakage if any • Increase temperature or change the catalyzer properly
6	Dew point cannot reach the required value	• Short heating time of molecule sieve, incompletion regeneration • Great resistance of system, uneven gas • Quality of molecular sieve falls	• Adjust heating time • Check system gradually reinstall molecular sieve and make its density even • Change molecule sieve

Manifolds in Electrolyser Plant

Manifold is a pipe with several openings for taking gas or liquid in and out. The following figure represents the manifold pipes and manifolds in flow arrangement respectively.

Fig. 6.6: Manifold pipes

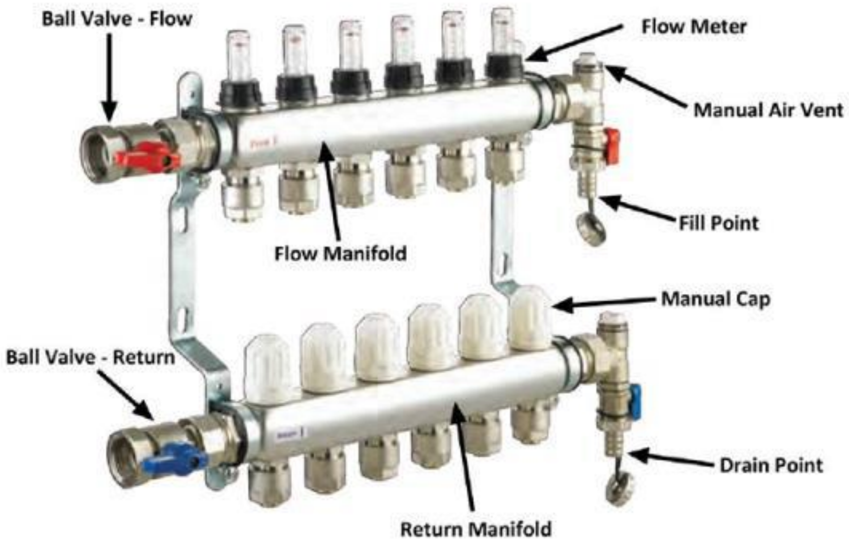


Fig. 6.7: Manifolds in flow arrangement

Because hydrogen is highly reactive and flammable, it's important to use leak proof joints. Sealing hydrogen is more complicated than sealing other liquids. These joints have one or more openings for gas or liquid to enter or exit. You may also need to add a pressure relief device. Valves can be included for easier control of the gas or liquid flow.

In a hydrogen production plant, the hydrogen produced by each electrolyser goes into a manifold. This manifold collects hydrogen from all the electrolysers and connects to a water separator and gas holder. The plant uses several manifolds to manage the flow of electrolyte, water, hydrogen, and oxygen.

Sealing in an Electrolyser

Leakage of hydrogen poses a serious safety hazard. Given that this sealing plays a critical role in a hydrogen environment. Generally, sealing is used in the following components of the electrolyser:

- Thermoplastic frames
- Metal frames
- Seal on titanium bipolar plate
- Loose gaskets

Sealing

To produce electrolysers on a large scale, we need a new and innovative approach that fits with automated manufacturing processes and suitable sealing technologies. This involves using sealing materials that are easy to assemble, ensure high production efficiency, prioritize safety with special materials, and meet the durability requirements for harsh environments. These factors are important for producing green hydrogen on a large scale. The Fig. 6.8 shows flat FKM gaskets used to seal the space between the monopolar plates and the cell frame.

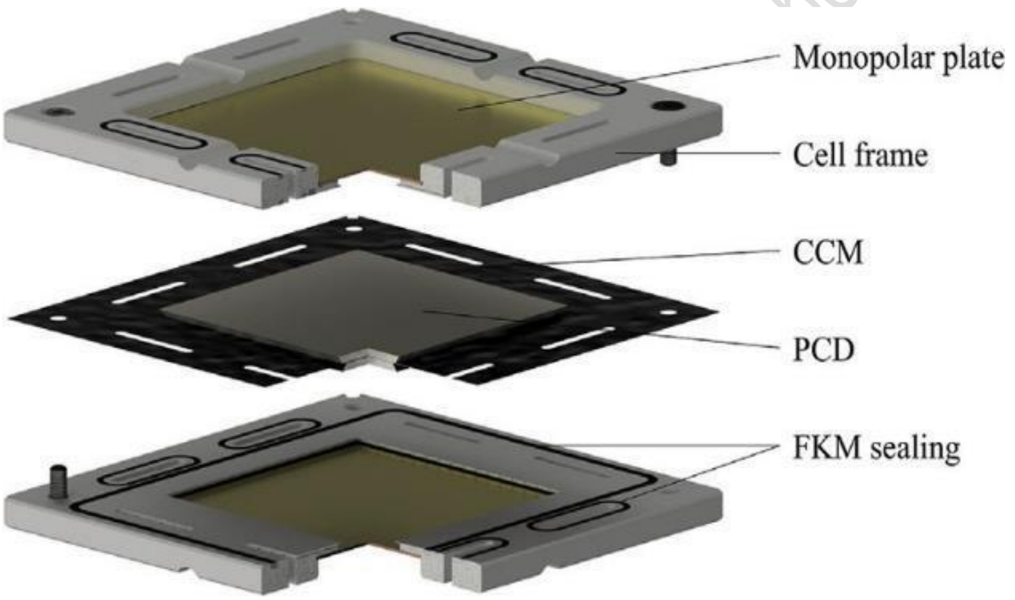


Fig. 6.8: Plastic cell frames with integrated media channels

Important: The factory assembled and tested finished products are preferable due to the availability of full-fledged workshop/industrial facilities, skilled workforce, designers etc.

Check Your Progress

A. Fill in the Blanks:

1. Assembling an electrolyser stack requires ____________, ________________ & careful testing.
2. For small to medium-sized plants, it is more cost-effective to buy _______________

electrolysers.

3. In high pressure compressors, special care is needed for ________________
4. The _____________ can also work as a fuel cell.
5. A ____________ is fitted on the end plate to improve fuel cell performance.
6. A manifold is a pipe with several openings for taking _________________ in and out.

B. Multiple Choice Questions

1. Electrolysers are commonly purchased in what size range?
   a) 10–500 Nm^3/hour
   b) 1–100 Nm^3/hour
   c) 100–1000 Nm^3/hour
   d) 0.1–1 Nm^3/hour

2. Which material is used as insulation between current collector and end plate?
   a) Copper cloth
   b) Graphite sheet
   c) Teflon cloth
   d) Aluminium foil

3. Which test checks the insulation resistance of an electrolyser?
   a) Insulation Test
   b) High Voltage Test
   c) Load Test
   d) Leak Test

4. In an electrolyser, resistance must be kept below:
   a) 50 milli ohms
   b) 10 milli ohms
   c) 5 milli ohms
   d) 1 milli ohm

5. What is used to check hydrogen and oxygen production in electrolyser mode?
   a) Multimeter
   b) Flow meter
   c) Pressure gauge
   d) Water bubbles

6. Which of the following is used as sealing material in electrolysers?
   a) PVC

b) FKM gaskets
c) Nylon rings
d) Glass seals

7. Why are manifolds important in hydrogen plants?
   a) They reduce electricity use
   b) They provide cooling
   c) They increase electrode life
   d) They collect and distribute gases/liquids

C. Answer the following Questions

1. Why is sealing important in an electrolyser?
2. Mention two key tests performed during electrolyser testing.
3. What is the role of manifolds in an electrolyser plant?
4. Why is it advisable to purchase an extra electrolyser unit?
5. Explain the step-by-step process of PEM electrolyser assembly.
6. Discuss the different types of tests carried out on an electrolyser and their purpose.
7. Describe the troubleshooting procedure when the total cell voltage becomes too high.
8. Discuss the role of factory assembly in maintaining the quality and safety standards of electrolysers.
9. Write in detail about the probable problems in an alkaline electrolyser plant and the respective troubleshooting mechanisms.
10. Describe the role of sealing and manifolds in an electrolyser plant. Discuss how these contribute to safety, durability, and efficient hydrogen production.

Session 3: Selection Parameters and Maintaining the Log for Daily Operation of Electrolysis

Selection parameters for electrolysis are crucial in finding the best method and conditions for producing hydrogen. Here are some key points to consider when choosing an electrolysis method:

1. **Density, Volume, and Weight**: Hydrogen is the lightest element. One kilogram of hydrogen occupies 11 cubic meters (m^3) at normal temperature and 1 bar pressure. Thus, we need to compress hydrogen gas either at high pressure or very low temperatures. These parameters are interconnected; as density increases, volume decreases. Higher pressure allows us to store or transport more hydrogen in the same space.
2. **Pressure**: Pipelines are the fastest and cheapest way to transport and distribute hydrogen. For fuel cells, especially in vehicles where space is limited, hydrogen needs to be pressurised between 100 to 700 bars. Normally, the pressure in the electrolyser is only a few bars, which helps move hydrogen through pipes to gas holders and water separators. The operating temperature for alkaline electrolysers typically ranges from 70 to 90°C.
3. **Temperature:** Alkaline and PEM electrolysis processes operate at low temperatures (below 100°C). In contrast, solid oxide electrolysis occurs at high temperatures (above 700°C) and produces a lot of waste heat. This waste heat can be useful if harnessed for industrial processes. Alternatively, we can save renewable energy by using waste heat from other sources to preheat.
4. **Purity of Hydrogen:** During the planning phase of a hydrogen production plant, it's important to consider how the hydrogen will be used. The required purity of hydrogen affects the choice of electrolysis method and other plant components. Hydrogen from electrolysis is usually over 99.99% pure and can be used for general purposes after drying, except in cases like the semiconductor industry that require higher purity.
5. **Export Component:** If green hydrogen needs to be exported, transportation is crucial. This usually involves shipping by sea, and liquid hydrogen or ammonia may be used. Customers can use ammonia directly or convert it back to hydrogen. At normal temperature (T) and pressure (P), one kilogram of H_2 occupies 11 m^3, so for transportation, it must be compressed to pressures of 100, 200, or 700 bars.

The benefits of using pressurized hydrogen for transporting more quantity can be illustrated in the following tables.

Pressure (Bar)	Sizes (Meters) (L X D)	Storage Volume (M^3)	Storage Capacity (Kg)
250	9 X 1	7.1	125
250	12 X 1	9.4	146
250	16 X 1	12.6	222
Density @ 250 Bar = 17.58 Kg/M^3			

Cylinder size and storage volume Table

Pressure (Bar)	Sizes (Meters) (L X D)	Storage Volume (M^3)	Storage Capacity (Kg)
250	9 X 1	7.1	125
250	12 X 1	9.4	146
250	16 X 1	12.6	222
Density @ 250 Bar = 17.58 Kg/M^3			

Hydrogen pressure and storage density

Maintaining the Log for Daily Operation of Electrolyser

Daily logs are kept for four main areas: electrical, mechanical, water, and hydrogen. For small plants that produce about 100 kg of hydrogen each day, operators can record data manually every hour, as outlined in the operations and maintenance manual for the electrolysers.

Now, let's look at how to log these four components.

A. Electrical

Log the hourly readings of current, voltage, power, and energy. Also, note any instances of electrolysers, pumps, dryers, or other equipment tripping. The following table shows an example format for logging the electrical parameters of an electrolyser plant.

Department: ....

Electrolyser No. & location	....	**Technician Supervisor**	**Name/sign.................** **Name/sign.................**	**Date**

Time	Current, A	Voltage, V	Power, W	Energy, kWh
06:00 AM				
07:00 AM				
08:00 AM				
09:00 AM				
10:00 AM				

An indicative log sheet of electrical parameters of electrolyser plant

B. Mechanical

Take hourly readings of compressor pressure at the inlet and outlet, temperature, drier temperature, and how long the water pump runs or stops.

a) Water

The log notes the following:

- Water level
- Quantity used
- Temperature
- Electrolyte consumption

Hydrogen

The log notes the following:

- Pressure at the electrolyser
- Pressure after the water separator
- Pressure at the inlet and outlet of the high/medium pressure compressor
- Total running time
- Pressure at the storage tank

You can calculate hydrogen weight, storage tank volume, and hydrogen weight at different pressures from these readings. In large plants, data logging is done using specific software for online recording. Benefits of computerised logs include:

- Access from any location
- Alerts for missing data
- Automatic calculations

Setting this up requires appropriate sensors, hardware, and software. The cost of a hydrogen plant's IT setup may be less than 1% of the total project cost. Ongoing costs for maintenance are usually minimal.

The following figure shows the basic layout of a system for soft logging data, remote communication, and data collection.

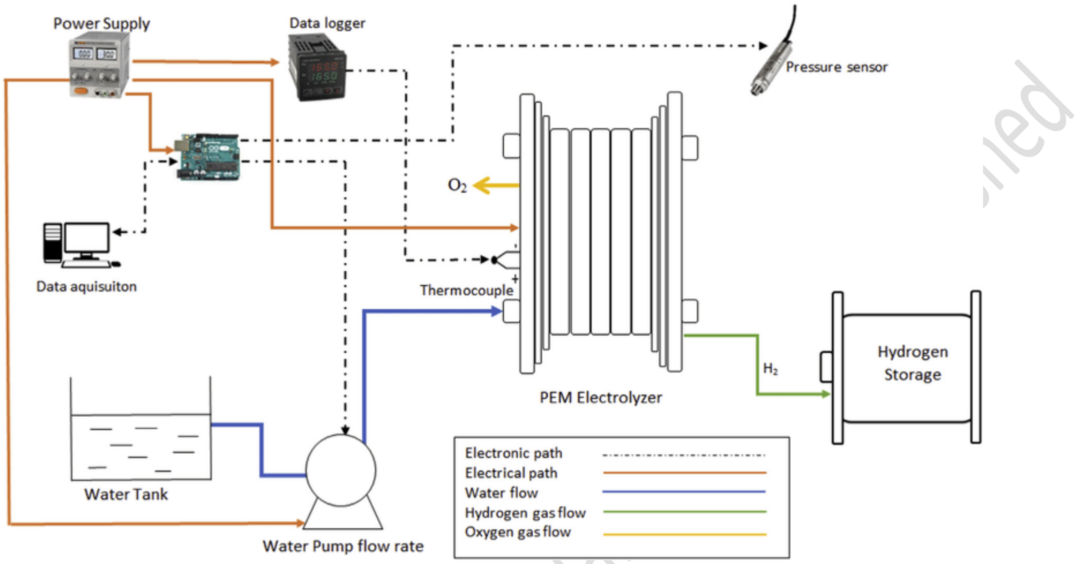


Fig. 6.9: Arrangement of soft logging of a PEM electrolyser data

The following table represents a sample log sheet for recording the performance data of PEM-type electrolyser.

Department: ....

Electrolyser No. & location	………… ……………	**Technician Supervisor**	**Name/sign……………… Name/sign………………**	**Date Time**

STACK			
Operating Temperature	T	[°C]	85
Operating Pressure	p	[bar]	30
Diameter	D	[m]	1.6
Current Density	i	[mA/cm^2]	200
Number of Cells	N_C	[-]	480
Conductivity	C	[S/m]	134.75
Surface Area	A	[m^2]	2.01
Resistance Anode	R_A	[Ohm cm]	2.0
Resistance Cathode	R_C	[Ohm cm]	2.0
MEMBRANE			
Membrane Thickness	y	[m]	0.003
Porosity	P	[%]	50
Permeability for H_2	P_{H_2}	[-]	2E-7
Permeability for O_2	P_{O_2}	[-]	1E-7
ELECTROLYZER PARAMETER			
Applied Cell Voltage	V_{app}	[V]	1.809
Total Stack Voltage	V_{Stack}	[V]	868.35
Current	I	[A]	4021.12
Power	P	[kW]	3491.72
Efficiency	η_d	[%]	81.81
Hydrogen Production Mass Rate	m_{H_2}	[kg/hr]	72.02
Hydrogen Production Volumetric Rate (STP)	V_{H_2}	[m^3/hr]	806.58
Purity of H_2	x_{H_2}	[%]	97.32
Purity of O_2	x_{O_2}	[%]	98.66

- An indicative log sheet of electrolyser plant
- Start up, Shutdown, and Operate the Production Processes
- Operating the Hydrogen Production Process

The following figure represents an indicative operation sequence of PEM electrolyser.

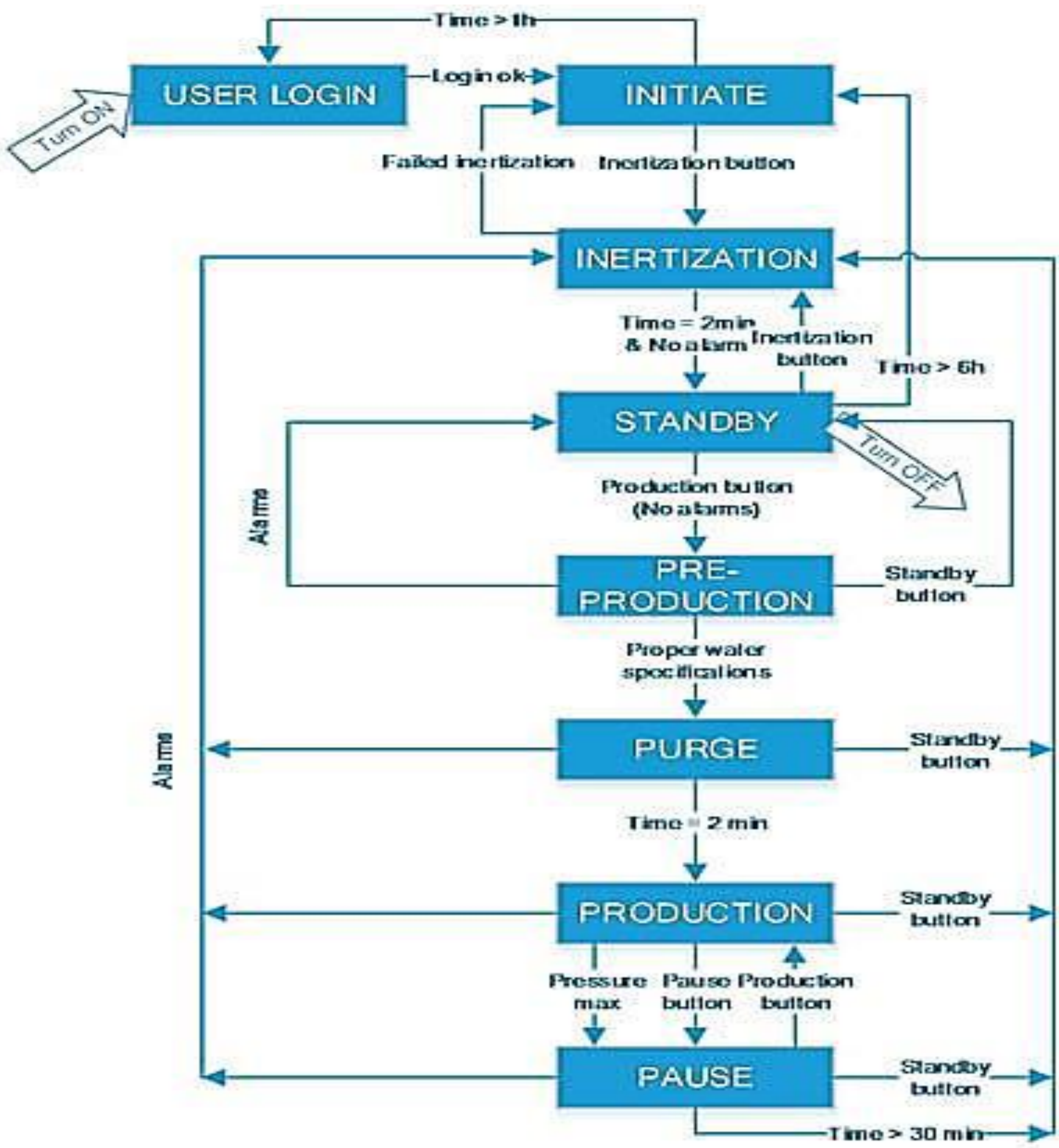


Fig. 6.10: Indicative operation sequence of PEM electrolyser

Starting Up the Plant

When the plant is operating, operators must watch the situation closely and follow the equipment supplier's parameters. Check readings regularly, at least once an hour.

Monitor process values carefully and quickly address any unusual situations. Use remote sensing thermometers and vibration meters to spot issues, such as loud noises or changes in noise patterns.

When adjusting the DC output of the rectifier panel, avoid turning the potentiometer knob violently. Make sure the selection switch is not turned if the current regulating potentiometer is not at the '0' position.

Clean the filters if the circulating electrolyte level drops suddenly.

Shutting Down the Plant

To shut down the plant, complete these steps:

- Reduce the current and voltage to zero in the rectifier.
- Lower the pressure in the PLC and open the vent valves.
- Remove the filter cover. Take out the filter element and gently brush it; rinse with clean water.
- Reinstall the filter element and tighten the cover.
- Keep the levels in the hydrogen and oxygen separators at mid-level (or as specified). Check that the auto compensating water system works properly.
- For effective instrument operation, ensure the compressed air supply is clean and dry. Regularly open the water valve at the bottom of the air filtering pressure reducer to drain water and oil.
- Regularly check the air tightness of pipelines and connectors.

Normal Shut Down

For a normal shut down, do the following:

- First, stop the feed water compensating pump/valve. Keep the separator level at its low limit, as the manufacturer directs.
- Turn the current regulating potentiometer counterclockwise (or as specified) to '0'. Switch-off the power of the main circuit.
- Fully open the cooling water valve to maximum.
- Once the cell temperature is below 50°C, set the pressure controller to '0'. Slowly open the oxygen valve to lower the cell pressure. Keep the differential pressure between the two separators below 150 mm of water or as specified by the manufacturer.
- After the cell pressure drops to zero, shut down the circulation pumps and cut off power to the power distribution panel. Stop the compressed air supply.

Shutting Down Under Abnormal Conditions

If you need to shut down the plant under abnormal conditions, take these steps (these steps may vary):

❖ Switch-off the power supply to the rectifier panel main circuit. Manually stop the feed water pump.
❖ Quickly vent hydrogen and oxygen while following safety regulations. Monitor the levels in both separators, ensuring hydrogen and oxygen do not mix. Close all valves

when the system pressure drops to zero.

- Switch-off the general power supply to the power distribution panel. Cut off the air supply. Document the emergency stop and notify all relevant departments of necessary actions.

Note: If the plant needs to restart after an abnormal shutdown, the electrolyser, auxiliary equipment, and accessories must be checked by the responsible person. Inspect the instruments to ensure everything is in order before starting as directed by the authorised individual.

Check Your Progress

A. Fill in the Blanks:

1. At 1 bar pressure and normal temperature, 1 kg of hydrogen occupies ___ **m^3**.
2. Alkaline electrolysers generally operate between ___**°C to** ___**°C**.
3. For fuel cell vehicles, hydrogen is typically compressed to ___ **to** ___ **bars**.
4. The purity of hydrogen from electrolysis is usually above ___**%**.
5. During abnormal shutdowns, hydrogen and oxygen must be vented while ensuring they ____________.

B. Multiple Choice Questions:

1. **What is the primary benefit of high-pressure hydrogen storage?**
   A. Reduced energy consumption
   B. Higher volumetric density for transport
   C. Lower electrolyser temperature
   D. Increased hydrogen purity

2. **Which electrolysis method operates above 700°C and produces waste heat?**
   A. Alkaline
   B. PEM
   C. Solid oxide
   D. Anion exchange membrane

3. **What must be logged hourly in the electrical component of an electrolyser plant?**
   A. Electrolyte pH
   B. Current, voltage, and power
   C. Ambient humidity

D. Compressor lubrication levels

4. **Why is computerised data logging beneficial for large plants?**
    A. Provides remote access and automatic alerts
    B. Reduces hydrogen purity requirements
    C. Increases electrolyte consumption
    D. Eliminates the need for sensors

5. **What is the first step in a normal plant shutdown?**
    A. Vent hydrogen explosively
    B. Disassemble the electrolyser
    C. Increase rectifier voltage
    D. Stop the feed water pump/valve

C. Short Answer Questions

1. List three parameters logged under "Mechanical" in daily operations.
2. Why is hydrogen compressed for transportation?
3. What precautions are needed during abnormal shutdowns?
4. Compare alkaline, PEM, and solid oxide electrolysis methods in terms of temperature, pressure, and applications.
5. Explain the steps to safely restart a plant after an abnormal shutdown.
6. Describe the key considerations for selecting an electrolysis method based on hydrogen end use.

Answer Key

MODULE 1: INTRODUCTION TO GREEN HYDROGEN

Session 1: Necessity of Green Hydrogen in Sustainable Energy Transition and its Properties

E. Fill in the blanks	F. Multiple Choice Questions
1. Abundant 2. Renewable 3. Water vapour 4. 33.3 5. Pale blue	1. C 2. C 3. C 4. B 5. D

Session 2: Green Hydrogen Mission of the Government of India

Fill in the blanks	Multiple Choice Questions
1. 5 million metric tonnes 2. Solar, Wind 3. 20000 4. 50% 5. 30GW	1. B 2. C 3. B 4. C

Session 3: Colour Code Nomenclature of Hydrogen

Fill in the blanks	Multiple Choice Questions
1. Green 2. Grey 3. Carbon capture and storage (CCS) 4. Turquoise 5. Electric grid	1. C 2. B 3. C 4. C 5. B

Session 4: Green Hydrogen Value Chain

Fill in the blanks	Multiple Choice Questions
1. Electrolysis 2. 3 to 4 3. Steam Methane Reforming (SMR) 4. Gas	1. C 2. B 3. B 4. C 5. C

5. Photoelectrochemical (PEC) Water Splitting)	

Session 5: Challenges in Green Hydrogen Plant

Fill in the blanks	Multiple Choice Questions
1. Electrolysis 2. Flammable 3. Gas, liquid 4. High Energy requirement 5. Fuelling station	1. B 2. C 3. C 4. C 5. C

Session 6: Green Hydrogen Economy in the Indian Context

Fill in the blanks	Multiple Choice Questions
1. Water (H_2O), Renewable 2. **Net Zero, 2070** 3. **Jamnagar** 4. **Imported** 5. **billion, GDP**	1. B 2. B 3. B 4. D 5. B

Session 7: Roles and Responsibilities of a Green Hydrogen Plant Technician.

Fill in the blanks	Multiple Choice Questions
1. Electrolysers 2. Renewable energy sources 3. Safety rules 4. Inspect and maintain	1. C 2. B 3. C 4. C 5. C

MODULE 2 COMPONENTS OF THE GREEN HYDROGEN PLANT AND ITS LAYOUT

Session 1: Key Components of a Green Hydrogen Plant

Fill in the blanks	Multiple Choice Questions
1. Renewable 2. Electrolysis 3. Alkaline 4. Power management 5. 350	1. A 2. C 3. C 4. D 5. B

Session 2: Functions of Key Components of Green Hydrogen Plant

Fill in the blanks	Multiple Choice Questions
1. Faraday's laws 2. Collectors 3. Boyle's law 4. Cryogenic storage	1. B 2. C 3. B 4. D 5. B

Session 3: Material, Safety Codes, Technology Protocols and Standards

Fill in the blanks	Multiple Choice Questions
1. Corrosion 2. Platinum 3. Titanium 4. Colourless, odourless, tasteless 5. Safety gloves	1. B 2. C 3. C 4. B 5. C

MODULE 3 ELECTRIC POWER SOURCE FOR GREEN HYDROGEN PLANT

Session 1: Importance of Electric Power in Green Hydrogen Production

Fill in the blanks	Multiple Choice Questions
1. photovoltaic effect. 2. E 3. P_w 4. Head 5. Hybride power	1. D 2. B 3. B 4. B 5. C

Session 2: Cost-Effective and Reliable Renewable Power

Fill in the blanks	Multiple Choice Questions
1. Global Market 2. Freely available 3. Rs. 2 per kilowatt hour 4. Hybrid System 5. Energy Storage	1. A 2. B 3. C 4. B 5. B

Session 3: Flexible System Operation

Fill in the blanks	Multiple Choice Questions
1. Flexibility 2. 50 Hz 3. Dispatchable 4. Flexible AC Transmission System 5. Energy storage	1. B 2. C 3. B 4. C 5. B

Session 4: Sizing Renewable Power & Storage for Hydrogen Demand

Fill in the blanks	Multiple Choice Questions
1. Sizing 2. Approach 1, average renewable energy 3. Approach 2, above average 4. Hydrogen storage system 5. Electrolyser	1. A 2. B 3. D 4. B 5. C

Session 5: Functions of Transformers and Rectifiers

Fill in the blanks	Multiple Choice Questions
1. Static electrical device 2. kVA or MVA 3. Transformer core 4. AC to DC 5. Firing angle	1. C 2. C 3. A 4. B 5. B

Session 6: Maintaining Stability of Power Supply for Green Hydrogen Plant

Fill in the blanks	Multiple Choice Questions
1. Kilograms per hour or day 2. Not requires 3. Full load and best efficiency	1. B 2. C 3. C

MODULE 4 TOOLS AND SAFETY EQUIPMENT

Session 1: Tools and Equipment Used for the Installation of the Electrolyser

Fill in the blanks	Multiple Choice Questions

1. Tools 2. Torque wrench 3. Electrical insulating 4. Leak detector 5. Gas flow meter	1. C 2. C 3. B 4. D 5. C

Session 2: Safety Measures for the Installation of Electrolyser

Fill in the blanks	Multiple Choice Questions
1. Buoyant 2. Vent 3. Pressure 4. Nylon 5. LFL (Lower Flammable Limit)	1. D 2. A 3. C 4. C 5. B

Session 3: Safety Measures in Hydrogen Handling;

Fill in the blanks	Multiple Choice Questions
1. air, oxygen, and other oxidisers 2. Nitrogen, Helium 3. pale blue 4. subsonic, supersonic 5. 14	1. C 2. B 3. D 4. B

MODULE 5 INSTALLATION OF ELECTROLYSER FOR GREEN HYDROGEN PRODUCTION I

Session 1: Electrolysers and their types

Fill in the blanks	Multiple Choice Questions
1. Direct Current 2. Electrolyser 3. Alkaline water electrolysis 4. Solid polymer 5. Ceramic	1. C 2. D 3. A 4. D 5. C

Session 2: Components of PEM

Fill in the blanks	Multiple Choice Questions
1. Compression Plate 2. Platinum 3. Gas Diffusion Layer (GDL)	1. B 2. C 3. C

4. Iridium 5. Torque	4. D 5. A

Session 3: Inputs/Outputs of an Electrolyser System

Fill in the blanks	Multiple Choice Questions
1. DC electric power, Water 2. Mixing (or explosion) 3. Higher Heating Value (HHV) 4. 1.23 5. Water separator, Hydrogen drier	1. C 2. D 3. B 4. B 5. A

Session 4: Operation and Maintenance (O&M) Activities

Fill in the blanks	Multiple Choice Questions
1. Nitrogen, Carbon dioxide 2. Noise levels, Vibrations 3. Hydrogen, Oxygen 4. Explosion 5. Demineralised water	1. C 2. B 3. A 4. B 5. C

MODULE 6 INSTALLATION OF ELECTROLYSER FOR GREEN HYDROGEN PRODUCTION -II

Session 1: Installation Requirements

Fill in the blanks	Multiple Choice Questions
1. Plant supplier, Manufacturer 2. Electrolysers, Compressors 3. Plans, Elevations 4. Bill of Materials (BOM) 5. General arrangement	1. B 2. C 3. A 4. B 5. C

Session 2: Assembly/Installation of Parts and Components of Electrolyser

Fill in the blanks	Multiple Choice Questions
1. Expert knowledge, Special tools 2. factory-assembled 3. high-level sealing 4. PEM electrolyser	1. B 2. C 3. A 4. C

5. 25W heater 6. Gas or Liquid	5. D 6. B 7. D

Session 3: Selection Parameters and Maintaining the Log for Daily Operation of Electrolysis

Fill in the blanks	Multiple Choice Questions
1. 11 2. 70,90 3. 100,700 4. 99.99 5. Do not mix 6.	1. B 2. C 3. B 4. A 5. D

Glossary

Term	Meaning
Alkaline Electrolyser (AEL)	A type of electrolyser that uses an alkaline solution (like potassium hydroxide) as the electrolyte. It is durable and cost-effective.
Alkaline Electrolyser (AWE)	type of electrolyser that uses an alkaline solution (usually potassium hydroxide) as the electrolyte to produce hydrogen and oxygen.
Allen Keys (Hex Keys)	L-shaped tools used to drive bolts and screws with hexagonal sockets.
Alternating Current (AC)	An electric current that changes direction periodically, commonly used in power transmission.
Ammonia (NH_3)	A chemical compound made using hydrogen, widely used in fertilisers.
Anion Exchange Membrane (AEM) Electrolyser	An electrolyser that uses a membrane to move negatively charged ions (OH), combining features of alkaline and PEM designs.
Anode	The positive electrode in an electrolyser or battery where oxidation occurs.
Anti-Static Shoes	Footwear designed to prevent static electricity buildup, reducing fire risk in hydrogen environments.
Atmospheric Pressure	The pressure exerted by the weight of air in the atmosphere, used as a reference in purging and venting cycles.
Autothermal Reforming (ATR)	A hydrogen production method that combines partial oxidation and steam reforming of hydrocarbons.
Battery Storage	A system that stores extra electricity from renewable sources and provides backup when solar or wind energy is low.
Bench Vice	A clamping device fixed to a workbench to hold materials firmly during cutting, drilling, or assembly.
Bipolar Plate	A component in an electrolyser stack that separates individual cells, provides electrical conduction, and helps manage water and heat.
Bipolar Plates (BPP)	Plates used in PEM electrolysers to connect individual cells in series, distribute gases, and conduct electricity.
Blue Hydrogen	Hydrogen produced from natural gas with carbon capture, utilisation, and storage (CCUS) to reduce emissions.
Boil-Off (Cryogenic)	Gas that escapes when very cold liquids (like liquid hydrogen) slowly warm and turn into gas.
Brown Hydrogen	Hydrogen produced from coal or lignite gasification, with high greenhouse gas emissions.
Cable Glands	Devices used to secure and seal cables entering an electrical panel or enclosure.
Cable Stripper & Cutter	Tools used to remove insulation from wires and cut them to size.
Capacitor	An electrical component that stores and releases energy to smooth out fluctuations in voltage.
Carbon Capture, Utilization, and Storage (CCUS)	A technology to capture and store carbon dioxide emissions to reduce environmental impact.
Carbon-Free Hydrogen (Green Hydrogen)	Hydrogen produced using renewable energy without releasing carbon emissions

Catalyst	A material (like platinum or iridium) that speeds up chemical reactions in the electrolyser without being consumed.
Cathode	The negative electrode in an electrolyser or battery where reduction occurs.
Chain Pulley Block / Hoist	A lifting device used to raise or lower heavy objects using a chain mechanism.
Chemical Properties of Hydrogen	Characteristics such as high reactivity, flammability, and its ability to form compounds like water and hydrocarbons.
Civil Infrastructure	Physical structures of the plant such as buildings, tanks, and foundations that provide support and safety.
Clamp Meter	A type of multimeter that measures current without direct contact with the conductor.
Climate Change	Long-term changes in Earth's temperature and weather patterns caused mainly by greenhouse gas emissions.
Colour Code Nomenclature of Hydrogen	A classification system that identifies hydrogen types based on production methods and environmental impact (e.g., green, blue, grey, brown).
Commissioning	The process of testing and ensuring that the electrolyser system and its safety measures function correctly before use.
Compressed Gas Storage	A common method to store hydrogen under high pressure in cylinders or tanks.
Compressed Hydrogen Gas	Hydrogen stored at high pressure (350-700 bar) in reinforced tanks for use in vehicles or industries.
Compression Plate	A plate, usually made of aluminium alloy, used to hold and fix the electrolyser cell together.
Compressor	A machine that increases the pressure of hydrogen gas to make storage and transportation easier.
Computational Fluid Dynamics (CFD)	A computer simulation technique used to predict how gases (like hydrogen) move and accumulate in confined spaces.
Continuity Tester	A device used to check if an electrical connection is properly made.
Control and Monitoring System	The "brain" of the plant that uses SCADA, sensors, and safety systems to check, adjust, and optimise operations.
Control System	The set of devices and software that monitor and regulate the operation of a hydrogen plant.
Cooling System	Equipment (like heat exchangers and cooling towers) that removes excess heat from electrolysers, compressors, and storage units.
Cotton (Flame-Resistant)	Preferred clothing fabric in hydrogen environments to avoid static electricity.
Cryogenic Tanker	A specially insulated tanker that carries liquid hydrogen at very low temperatures (−253 °C)
Current (I)	The flow of electric charge in a circuit, measured in amperes (A).
Data Logger	An electronic device that records data over time for performance monitoring of systems.
DC Electricity (Direct Current)	The type of electricity required for electrolysis, where current flows in one direction only.
Deflagration	A type of explosion where flame spreads at subsonic speed through a gas mixture.
Deionisation System	Part of water purification that removes ions and minerals to make

	ultra-pure water for electrolysis.
Detonation	A violent explosion where flame spreads at supersonic speed, creating destructive shock waves.
Deuterium (^2H or D)	A stable isotope of hydrogen with one proton and one neutron, used in nuclear research.
Diesel and Gasoline Fuels	Conventional fossil fuels that release large amounts of CO_2 when used, unlike green hydrogen.
Direct Current (DC)	An electric current that flows in one direction only, required by electrolysers.
Ear Protection	Equipment used to prevent hearing damage in noisy working environments.
Earthing Rod and Cable	Used to safely discharge static electricity or electrical faults into the ground.
Electrical Insulating Gloves	Special gloves that protect workers from electric shocks.
Electrodes	Conductive plates (anode and cathode) in an electrolyser where the electrochemical reaction takes place.
Electrolyser Stack	The core unit made up of many electrolysis cells working together to produce hydrogen.
Electrolyser	A device that uses electrolysis to produce hydrogen and oxygen from water.
Energy Carrier	A substance like hydrogen that stores and delivers energy, though it must first be produced.
Energy Storage System (ESS)	Technology such as batteries used to store excess power from renewable sources.
Explosion Proof Lamp	A lighting device designed for use in environments with explosive gases.
Faraday's Laws of Electrolysis	Scientific laws stating that the amount of substance produced at an electrode is proportional to the amount of electricity passed through water.
Filtration Unit	The first step in water purification, removing dirt and large particles.
Flowing Gas Purge	A purging method where inert gas is flowed through the system to flush out oxygen or air.
Frequency	The number of cycles of alternating current per second, measured in hertz (Hz).
Fuel Cell	A device that generates electricity by combining hydrogen with oxygen, with water vapour as the only by-product.
Fuel of the Future	A phrase often used to describe hydrogen due to its potential as a clean energy source.
Gas Collector	Equipment that separates hydrogen and oxygen gases after electrolysis.
Gas Diffusion Layer (GDL)	A porous layer in PEM electrolysers that allows gases and water to move efficiently between the electrodes and the membrane.
Gas Purity Analyser	A device that checks the purity of hydrogen or oxygen gases.
Gauntlet Gloves	Loose-fitting gloves used for handling cryogenic liquids to protect from frostbite.
Green Energy	Energy generated from natural renewable sources such as sunlight, wind, and geothermal heat, without environmental harm.
Green Hydrogen Economy	An economic system based on large-scale production, storage,

	distribution, and use of green hydrogen.
Grey Hydrogen	Hydrogen produced from natural gas without carbon capture, leading to high CO_2 emissions.
Grid Connection	Linking the hydrogen plant to the main electricity grid for backup power or supplying surplus electricity back to the grid.
Grounding	The process of connecting equipment to the earth to prevent static buildup or electrical hazards.
Heat Exchanger	A device that transfers heat from one medium to another to keep equipment cool.
High-Pressure Hydrogen Storage	Storage of hydrogen gas in special tanks at very high pressures for easy use and transport.
Higher Heating Value (HHV)	The total amount of energy released when hydrogen is burned, including the heat recovered from condensing water vapour.
Hydrogen Density	At STP, hydrogen has a density of about 0.09 g/L, making it the least dense gas.
Hydrogen Distribution System	The system that delivers hydrogen from the plant to industries, fueling stations, or pipelines.
Hydrogen Isotopes	Variants of hydrogen atoms: Protium (^1H), Deuterium (^2H), and Tritium (^3H).
Hydrogen Leak Detector	A device that detects hydrogen gas leaks at the installation site.
Hydrogen Purifier	A system used in electrolysers to remove water, oxygen, and other impurities from hydrogen gas to meet quality standards.
Hydrogen Safety Codes	Rules and standards (e.g., IS 15201, IS 16749) that ensure safe handling, storage, and transport of hydrogen.
Hydropower	Electricity generated using the energy of flowing or falling water.
Ignition Source	Any spark, flame, heat, or friction that can ignite hydrogen.
Indian Oil Corporation (IOC)	A major Indian company testing green hydrogen in its refineries to reduce emissions.
Inductor	An electrical component that resists changes in current and helps smooth DC output.
Industrial Applications of Hydrogen	Includes refining crude oil, making ammonia, producing methanol, and serving as a clean fuel.
Inert Gas	Non-reactive gas (e.g., nitrogen, helium) used for purging hydrogen systems.
Insulation Resistance Tester (Megger)	A device used to test the insulation resistance of electrical wiring.
Inverter	A device that converts DC into AC for grid use or equipment operation.
Kilowatt (kW)	A unit of power equal to 1,000 watts.
Larsen & Toubro (L&T)	An Indian company investing in electrolyser manufacturing for green hydrogen production.
LEL (Lower Explosive Limit)	The lowest concentration of hydrogen in air (4% by volume) at which it can ignite.
Lifting Slings	Straps used with cranes or hoists for lifting equipment safely.
Liquid Hydrogen (LH_2)	Hydrogen stored at cryogenic temperatures (−253 °C), appearing as a clear liquid.
Liquid Hydrogen Storage	A method of storing hydrogen in liquid form at extremely low temperatures.
Load	The total power consumed by devices or systems at a given time.

Lower Heating Value (LHV)	The energy released when hydrogen is burned, excluding the heat from condensing water vapour.
Measuring Tape	Tool for general measurement of distances or lengths.
Megawatt (MW)	A unit of power equal to 1,000 kilowatts.
Membrane Electrode Assembly (MEA)	The core of a PEM electrolyser, consisting of a proton-conducting membrane with catalyst layers where water is split into hydrogen and oxygen.
Methane Pyrolysis	A method for producing turquoise hydrogen with solid carbon as a by-product.
Multimeter	An electronic tool that measures voltage, current, and resistance in circuits.
National Green Hydrogen Mission (NGHM)	A strategic initiative by the Indian government to boost hydrogen production, reduce imports, and create jobs.
National Solar Mission (NSM)	An Indian government programme launched in 2010 to promote solar power, with a target of 20,000 MW by 2022.
Negative Terminal (-ve)	The terminal of a device where current flows out in a DC circuit.
Nomex Clothing	Flame-resistant clothing commonly used in hydrogen environments.
NTPC Green Energy	A company working on hydrogen storage solutions for renewable energy in India.
Overpressure	A Dangerous condition where gas pressure exceeds safe limits, potentially causing explosions.
Oxygen Handling System	Equipment and methods for safely venting or storing oxygen produced during electrolysis.
Oxygen Outlet	The part of the electrolyser system where oxygen gas exits as a by-product of electrolysis.
Partial Oxidation (POX)	A method of hydrogen production using hydrocarbons such as oil and natural gas.
Petrochemical Industry	A sector that uses hydrogen as a raw material for refining processes and chemical production.
Photoelectrochemical (PEC) Water Splitting	An experimental hydrogen production method using sunlight to split water.
Photovoltaic (PV) Cell	A solar cell that converts sunlight directly into electricity.
Pink Hydrogen	Hydrogen produced through electrolysis powered by nuclear energy.
Pipe Cutter	A tool used to cut pipes cleanly.
Positive Terminal (+ve)	The terminal of a device where current enters in a DC circuit.
Power Converter	A device that changes the variable output of solar panels or wind turbines into stable electricity for the electrolyser.
Power Management System	A system that balances electricity supply and demand, using converters, batteries, and grid support.
Pressurising-Venting Purge	A purging method using cycles of pressurising with inert gas and venting to remove oxygen.
Protium (^1H)	The most common isotope of hydrogen with one proton and no neutrons.
Reducing Agent	Hydrogen's role in removing oxygen from compounds during chemical reactions.
Renewable Energy	Energy derived from natural, replenishable sources like solar and wind, used to produce green hydrogen.

Rupture Disk	A safety device that bursts at a set pressure to prevent overpressurisation.
SCADA (Supervisory Control and Data Acquisition)	A computerised system for real-time monitoring and remote control of plant operations.
Sizing of System	The process of calculating the required power capacity of a renewable energy plant.
Solid Oxide Electrolyser (SOEL)	A high-temperature electrolyser (700-900 °C) that is very efficient but used mainly in specialised industries.
Solid Oxide Electrolyser Cell (SOEC)	A high-temperature electrolyser (500-1000°C) that uses a solid ceramic electrolyte to produce hydrogen, often achieving very high efficiency.
Solid-State Hydrogen Storage	A storage method where hydrogen is absorbed into materials like metal hydrides, making it compact and safer.
Steam Methane Reforming (SMR)	A common and cost-effective method of hydrogen production from natural gas, but carbon-intensive.
Storage Challenges of Hydrogen	Difficulties due to low density, leakage risks, and the need for high-pressure or cryogenic systems.
Syngas	A mixture of hydrogen and carbon monoxide produced by SOECs when they co-electrolyse steam and carbon dioxide, used for making fuels.
Thyristor	A semiconductor device used in rectifiers to control DC voltage output.
Transportation of Hydrogen	Movement of hydrogen through pipelines, trucks, or ships, often expensive and technically challenging.
Tritium (^3H or T)	A radioactive isotope of hydrogen with one proton and two neutrons, used in nuclear fusion and luminous paints.
Turquoise Hydrogen	Hydrogen produced from methane pyrolysis with solid carbon as the by-product.
Vacuum Purging	A purging method that uses a vacuum pump to remove gases from a system before filling it with inert gas.
Vent Stack	Tall exhaust pipe where gases (including hydrogen) are safely released.
Ventilation Fan	A fan used to circulate air and prevent hydrogen buildup.
Ventilation System	Airflow system designed to dilute and remove hydrogen from workspaces.
Vernier Caliper	Precision measuring tool for checking thickness or dimensions.
Voltage (V)	The electrical potential difference between two points, measured in volts.
Water Purification System	A system that filters, demineralises, and prepares water to the purity needed for electrolysis.
Water Quality Meter	Instrument used to check pH, conductivity, and TDS of input water for the electrolyser.
Water Separator	A device used to remove water droplets and vapour from hydrogen before it enters storage or compression systems.
Watt (W)	The unit of power, equal to one joule per second.
Wind Turbine	A machine that converts the kinetic energy of wind into electricity for hydrogen production.
Wrenches	General category of hand tools used to grip and turn objects like nuts and bolts.
Yellow Hydrogen	Hydrogen produced from water electrolysis using solar power.