



# REEdI's Guide to Leaving Cert Engineering Prescribed Topic 2025

"Principles and Applications of Hydrogen Energy Technology"

**Prepared by:**

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The REEdI (Rethinking Engineering Education in Ireland) project is proud to present this guide to the 2025 Leaving Certificate Engineering Prescribed Topic, "Principles and Applications of Hydrogen Energy Technology." This study aid has been developed to empower students with the knowledge and skills to understand a critical area in modern engineering—hydrogen energy technology.

## FOREWORD

The REEdI project at MTU Kerry Campus is dedicated to advancing engineering education with a focus on sustainability and emerging energy technologies. Hydrogen energy represents a cornerstone of the global transition to a low-carbon future, and we are committed to helping student engineers to lead in this transformative field. The **Bachelor of Engineering (Hons) in Mechanical and Manufacturing Engineering** (CAO Code: MT834) equips students with cutting-edge knowledge and practical experience in sustainable practices. The programme combines cutting-edge technologies with two years of **paid work placement** at leading manufacturing companies. This innovative structure ensures our student engineers are industry-ready, blending academic excellence with practical application.

Our students benefit from a comprehensive support system to ensure their success, including:

- **Engineers in Residence:** Access to industry experts who provide mentorship and prepare students for work placements.
- **Extra Maths Support:** Addressing specific challenges to enhance technical skills.
- **Mentoring:** Guidance from experienced faculty and industry professionals.

If you're passionate about building a career that tackles global challenges, consider joining the **REEdI Engineering degree at MTU Kerry Campus (CAO Code: MT834)**. Here, you'll gain the skills to become a future engineer, equipped to innovate in sustainable energy and contribute to a better world.

We look forward to welcoming the Student Engineers of the Future to MTU Kerry Campus in September 2025!



**Dr Fiona Boyle**

Head of Department, STEM

Director of the REEdI Project at MTU

# HYDROGEN ENERGY AND THE ENGINEERS OF THE FUTURE



## Introduction to Hydrogen Energy Technology

Hydrogen ( $H_2$ ) energy technology represents a pivotal advancement in the quest for sustainable and clean energy solutions. As the most abundant element in the universe, hydrogen offers immense potential as an energy carrier, capable of bridging the gap between renewable energy sources and current energy demands. This guide provides an overview of hydrogen's role in modern energy systems, its significance in reducing greenhouse gas emissions, and its versatility across various applications. Understanding the fundamentals of hydrogen energy is essential for comprehending its impact on future technological and environmental landscapes.

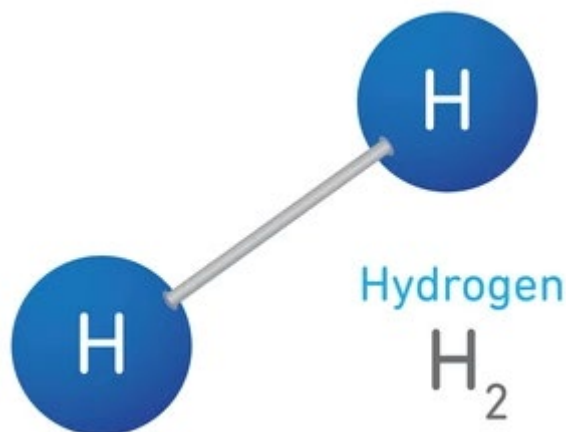


Figure 1: Hydrogen molecule

## Evolution of Hydrogen Usage

The evolution of hydrogen as an energy source spans centuries, marked by significant milestones that have shaped its current role in modern energy systems. In the late 18th century, Henry Cavendish first recognised hydrogen as a distinct element, sparking scientific interest in its properties and potential applications. Throughout the 19th century, researchers laid the foundation for future advancements by exploring hydrogen's versatility. In 1839, Sir William Grove invented the first fuel cell, demonstrating hydrogen's ability to generate electricity through an electrochemical reaction with oxygen. This breakthrough highlighted hydrogen's potential as a clean and efficient energy source. By the 20th century, hydrogen had become integral to industrial processes, such as ammonia production for fertilisers and oil refining, underscoring its economic importance. Its prominence further expanded during the mid-20th century when it became a crucial component in rocket fuel, powering space missions due to its high energy content when combusted with oxygen. In recent decades, hydrogen's role has shifted towards renewable energy integration, addressing the intermittency of sources like wind and solar by enabling energy storage and transport. In the 21st century, increased governmental and private sector investments have accelerated advancements in hydrogen technologies. Policies supporting green hydrogen production and infrastructure development have positioned hydrogen as a cornerstone of the global transition to a low-carbon economy.

## Hydrogen as an Energy Carrier

Hydrogen itself is not a primary energy source but an energy carrier, similar to electricity. This means it stores and delivers energy produced from other sources. Hydrogen can be generated through various processes and subsequently used to produce power, heat, or as a feedstock in industrial applications. Its high energy content per unit mass (approximately 120 megajoules per kilogram) makes it an efficient medium for energy storage, although its low energy density by volume presents challenges for storage and transportation.

## Production of Hydrogen

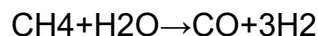
Hydrogen can be produced through several methods, each with distinct processes, efficiencies, and environmental impacts:

### 1. Electrolysis:

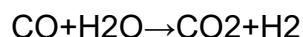
- **Process:** Splits water (H<sub>2</sub>O) into hydrogen (H<sub>2</sub>) and oxygen (O<sub>2</sub>) using electrical energy.
- **Types:**
  - *Alkaline Electrolysis:* Utilises an alkaline electrolyte, offering moderate efficiency and lower costs.
  - *Proton Exchange Membrane (PEM) Electrolysis:* Employs a solid polymer electrolyte, providing higher efficiency and hydrogen purity but at increased costs.
  - *Solid Oxide Electrolysis:* Operates at high temperatures (700-1,000°C), potentially achieving higher efficiencies by utilising waste heat.
- **Advantages:** When powered by renewable energy sources, electrolysis produces green hydrogen with minimal environmental impact.
- **Disadvantages:** Higher costs compared to fossil fuel-based methods and significant electrical energy requirements.

### 2. Steam Methane Reforming (SMR):

- **Process:** Reacts methane (CH<sub>4</sub>) with steam (H<sub>2</sub>O) to produce hydrogen, carbon monoxide (CO), and a small amount of carbon dioxide (CO<sub>2</sub>).



Followed by the water-gas shift reaction:



- **Advantages:** Currently the most widely used and cost-effective method for large-scale hydrogen production.

- **Disadvantages:** Generates significant CO<sub>2</sub> emissions unless coupled with carbon capture and storage (CCS) technologies, contributing to greenhouse gas emissions.

### 3. Biomass Gasification:

- **Process:** Converts organic materials into hydrogen, carbon monoxide, and other byproducts through high-temperature processing in an oxygen-limited environment.
- **Advantages:** Utilises renewable biomass resources, potentially reducing overall carbon emissions.
- **Disadvantages:** Production efficiency and scalability challenges, along with the need for a consistent biomass feedstock supply.

### 4. Photoelectrochemical Processes:

- **Process:** Uses sunlight to directly drive the electrolysis of water, producing hydrogen and oxygen through photoelectrochemical cells.
- **Advantages:** Combines solar energy utilisation with hydrogen production, offering a sustainable and renewable approach.
- **Disadvantages:** Currently experimental with high costs and lower efficiencies compared to established methods.

### 5. Thermochemical Water Splitting:

- **Process:** Utilises high temperatures to drive chemical reactions that split water into hydrogen and oxygen, often using metal oxides as catalysts.
- **Advantages:** Potential for high efficiencies and integration with high-temperature industrial processes.
- **Disadvantages:** Requires substantial thermal energy input and advanced materials to withstand extreme conditions.

Method	Process	Advantages	Disadvantages
<b>Electrolysis</b>	Splits water into hydrogen and oxygen using electrical energy.	<ul style="list-style-type: none"> <li>- Produces green hydrogen with renewable energy.</li> <li>- High hydrogen purity.</li> <li>- Scalable.</li> </ul>	<ul style="list-style-type: none"> <li>- High cost.</li> <li>- Requires substantial electrical energy.</li> </ul>
<b>Steam Methane Reforming</b>	Reacts methane with steam to produce hydrogen and CO <sub>2</sub> (can be mitigated with CCS).	<ul style="list-style-type: none"> <li>- Cost-effective.</li> <li>- High hydrogen yield.</li> </ul>	<ul style="list-style-type: none"> <li>- Significant CO<sub>2</sub> emissions without CCS.</li> <li>- Relies on fossil fuels.</li> </ul>
<b>Biomass Gasification</b>	Converts organic materials into hydrogen and other byproducts through high-temperature processing.	<ul style="list-style-type: none"> <li>- Uses renewable biomass.</li> <li>- Manages agricultural and industrial waste.</li> </ul>	<ul style="list-style-type: none"> <li>- Efficiency depends on feedstock quality.</li> <li>- Requires consistent biomass supply.</li> </ul>
<b>Photoelectrochemical</b>	Uses sunlight to drive electrolysis directly.	<ul style="list-style-type: none"> <li>- Sustainable and renewable.</li> <li>- Directly converts solar to chemical energy.</li> </ul>	<ul style="list-style-type: none"> <li>- High costs.</li> <li>- Limited efficiency.</li> <li>- Requires advanced materials.</li> </ul>
<b>Thermochemical Splitting</b>	Utilises high temperatures to split water into hydrogen and oxygen.	<ul style="list-style-type: none"> <li>- High efficiency potential.</li> <li>- Can use industrial waste heat.</li> </ul>	<ul style="list-style-type: none"> <li>- Energy-intensive.</li> <li>- Requires advanced materials to withstand extreme conditions.</li> </ul>

**Table 1: Production of Hydrogen – Summary Table**

## Harnessing the Power of Hydrogen

Hydrogen’s versatility as an energy carrier allows it to be harnessed in various forms and applications, contributing to a sustainable energy ecosystem. This section explores the primary methods of utilising hydrogen, including combustion and fuel cell technologies, along with their respective advantages and challenges.

# Applications of Hydrogen

Hydrogen's versatility as an energy carrier makes it a cornerstone in the global transition to sustainable energy systems. Its ability to store, transport, and deliver energy from various sources enables its application across diverse sectors, including transportation, power generation, and industry. These applications align with the principles of hydrogen energy technology, which focus on utilising hydrogen to reduce carbon emissions, enhance energy security, and drive technological innovation. This paper explores the key applications of hydrogen energy and connects them to the foundational principles that guide its development and use.

## 1. Transportation

### Overview:

Hydrogen is increasingly used in the transportation sector through fuel cell vehicles (FCVs), hydrogen-powered buses, trains, and even ships and aircraft.

### How It Works:

Hydrogen fuel cells generate electricity through an electrochemical reaction between hydrogen and oxygen, producing water and heat as byproducts. This electricity powers the vehicle's motor, offering a zero-emissions alternative to internal combustion engines.

### Principles in Action:

- **Zero Emissions:** Hydrogen-powered vehicles align with the principle of reducing environmental impact by emitting only water vapour.
- **Energy Efficiency:** Fuel cell vehicles have higher efficiency compared to traditional combustion engines, maximising energy output from hydrogen.
- **Sustainability:** Hydrogen can be produced from renewable energy sources, creating a sustainable transportation ecosystem.

### Challenges:

Despite its benefits, hydrogen transportation faces challenges such as limited refuelling infrastructure, high costs of fuel cell production, and reliance on green hydrogen for maximum sustainability.



## 2. Power Generation

### Overview:

Hydrogen is used for power generation in stationary fuel cells, gas turbines, and hybrid energy systems. It serves as a clean alternative to fossil fuels for producing electricity.

### How It Works:

- **Fuel Cells:** Stationary hydrogen fuel cells convert hydrogen into electricity and heat, suitable for residential, commercial, and industrial power needs.
- **Hydrogen Turbines:** Hydrogen can be combusted in turbines to generate electricity, similar to natural gas but with lower carbon emissions.

### Principles in Action:

- **Energy Storage and Dispatchability:** Hydrogen acts as a storage medium for excess renewable energy (e.g., from wind or solar) and can be dispatched when needed, ensuring grid stability.
- **Decarbonisation:** Using hydrogen in power generation significantly reduces greenhouse gas emissions compared to fossil fuel-based systems.
- **Technological Integration:** Incorporating hydrogen into hybrid energy systems showcases its adaptability and alignment with advanced energy technologies.

### Challenges:

The efficiency of hydrogen-based power generation and the cost of infrastructure remain barriers to widespread adoption.

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## 3. Industrial Applications

### Overview:

Hydrogen is widely used in industries such as chemical production, refining, and steel manufacturing, and its role is expanding in decarbonising hard-to-abate sectors.

## Key Industrial Uses:

- **Ammonia Production:** Hydrogen is a key feedstock for ammonia synthesis, essential for fertilizers.
- **Refining:** Used in hydrocracking processes to refine crude oil into usable fuels.
- **Steel Production:** Hydrogen can replace coal in reducing iron ore to iron, significantly lowering CO<sub>2</sub> emissions in steelmaking.

## Principles in Action:

- **Emission Reduction:** Replacing traditional carbon-intensive processes with hydrogen reduces industrial greenhouse gas emissions.
- **Versatility:** Hydrogen's adaptability across various industrial processes exemplifies its multifunctional nature as an energy carrier.
- **Resource Efficiency:** Utilising green hydrogen in industrial applications ensures efficient use of renewable energy resources.

## Challenges:

High costs of green hydrogen and retrofitting industrial infrastructure are major obstacles to large-scale adoption.

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## 4. Residential and Commercial Heating

### Overview:

Hydrogen boilers and combined heat and power (CHP) systems are emerging as alternatives to natural gas for residential and commercial heating.

### How It Works:

- **Hydrogen Boilers:** Burn hydrogen to produce heat for space and water heating.
- **CHP Systems:** Use hydrogen fuel cells to generate both electricity and heat, maximising energy efficiency.

## Principles in Action:

- **Environmental Sustainability:** Hydrogen heating systems produce zero CO<sub>2</sub> emissions at the point of use, contributing to cleaner air quality.
- **Energy Efficiency:** CHP systems optimise hydrogen's energy potential by utilising both the electricity and heat produced.
- **Decentralisation:** Distributed hydrogen heating solutions reduce reliance on centralised fossil fuel systems.

## Challenges:

The widespread adoption of hydrogen heating depends on infrastructure development and the affordability of hydrogen fuel.

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## 5. Energy Storage

### Overview:

Hydrogen serves as an effective medium for storing surplus energy generated from renewable sources like solar and wind.

### How It Works:

Excess renewable energy powers electrolysis to produce hydrogen, which can be stored and later converted back into electricity through fuel cells or combustion.

## Principles in Action:

- **Energy Flexibility:** Hydrogen enables the integration of variable renewable energy sources into the grid, addressing intermittency issues.
- **Scalability:** Hydrogen storage systems can be scaled to meet the needs of small communities or large industrial operations.
- **Global Energy Transition:** Hydrogen storage supports the transition from fossil fuel dependence to renewable energy systems.

## Challenges:

High energy losses during conversion processes and the cost of hydrogen storage technologies remain areas for improvement.

## Hydrogen consumption: Industry applications

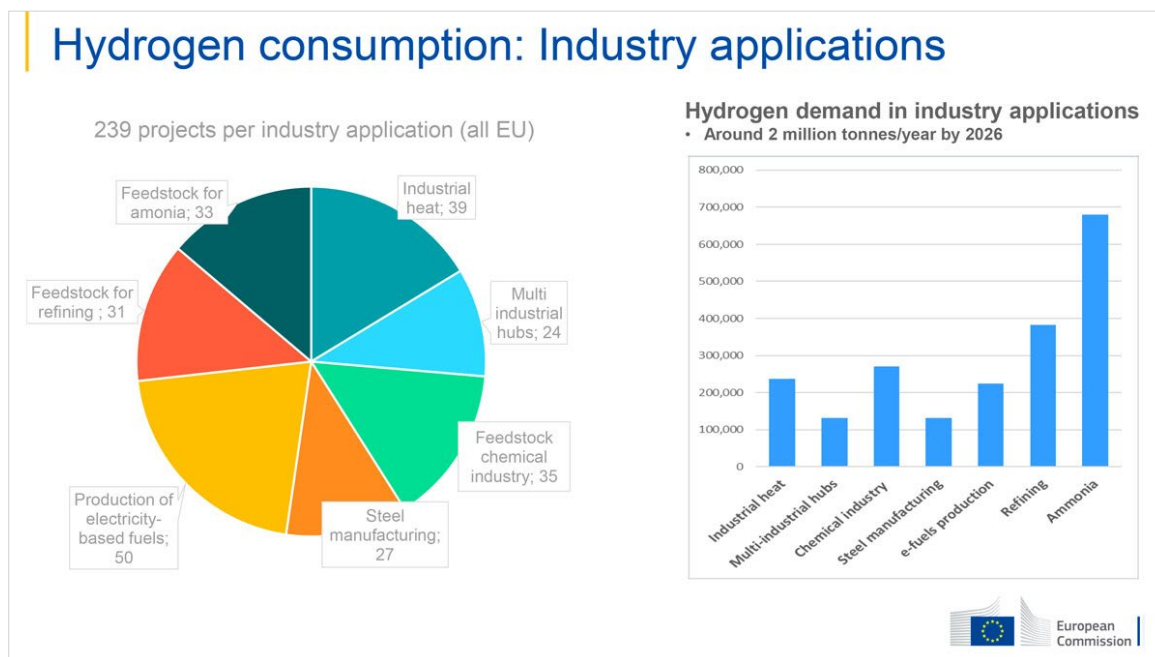


Figure 2: Hydrogen use by industrial applications across Europe)Source: European Commission)

### Advantages and Disadvantages of Hydrogen Over Other Energy Technologies

Hydrogen is increasingly regarded as a key component of the global transition to sustainable and low-carbon energy systems. As an energy carrier, hydrogen offers unique benefits that distinguish it from traditional fossil fuels and other renewable energy technologies. However, its adoption is not without challenges. This piece explores the advantages and disadvantages of hydrogen compared to other energy technologies, such as fossil fuels, solar, wind, and batteries, highlighting its potential and limitations.

Here is a graph comparing hydrogen to other energy technologies based on three key attributes: emissions (g CO<sub>2</sub>/kWh), efficiency (%), and energy density (MJ/kg).

- **Emissions:** Hydrogen and renewable energy sources like solar/wind produce zero emissions at the point of use, while fossil fuels emit high levels of CO<sub>2</sub>.
- **Efficiency:** Batteries lead in efficiency, followed by hydrogen, solar/wind, and fossil fuels.
- **Energy Density:** Hydrogen has the highest energy density per unit mass, making it suitable for applications like aviation and heavy-duty transport.

Figure 3 highlights hydrogen's strengths and the areas where it complements or competes with other technologies.

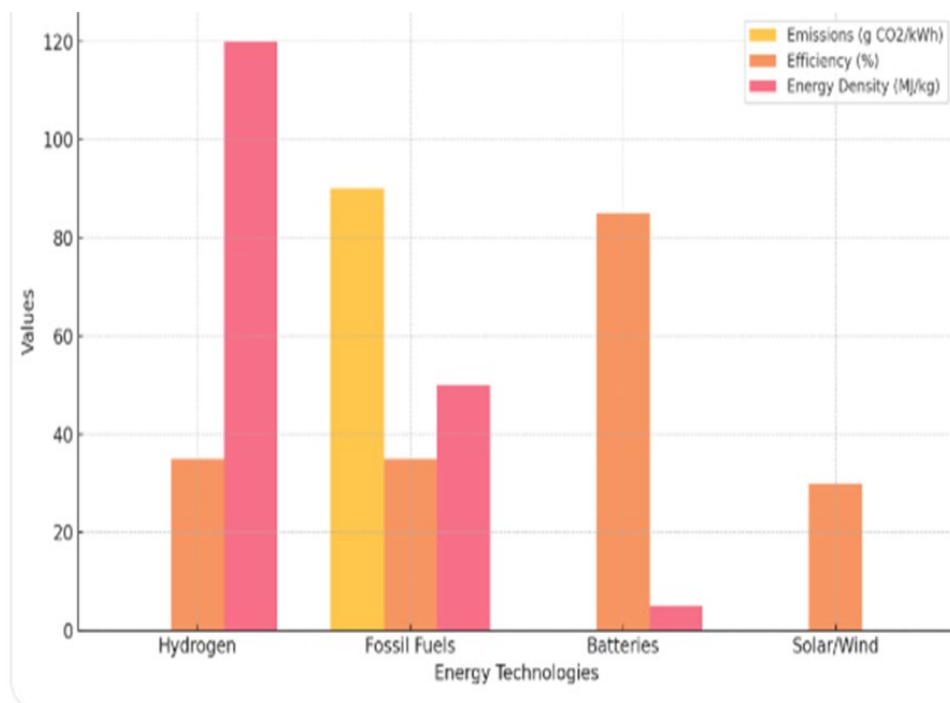


Figure 3: Hydrogen Vs other energy technologies

Energy density is typically a measure of the amount of energy stored per unit mass or volume, and it applies to energy carriers like fuels (e.g., hydrogen, batteries, fossil fuels) that store energy for later use. Solar and wind energy are sources of energy, not carriers. They generate electricity directly and don't involve storage in the traditional sense of energy density.

- **Hydrogen, Fossil Fuels, and Batteries:** These are energy carriers that store energy and release it when needed, making energy density a relevant metric.
- **Solar and Wind:** These technologies produce electricity directly from natural resources and don't store energy inherently. Instead, they often require separate storage systems (e.g., batteries or hydrogen) to handle intermittency.

## Advantages of Hydrogen

- **Zero Emissions at the Point of Use**

Hydrogen, when utilised in fuel cells or burned with oxygen, produces only water vapour and heat as byproducts. Unlike fossil fuels, it does not release carbon dioxide (CO<sub>2</sub>), particulate matter, or other harmful pollutants during use, making it an ideal energy source for reducing air pollution and combating climate change.

- **High Energy Density**

Hydrogen has a high energy content per unit mass (120 megajoules per kilogram), surpassing that of fossil fuels and batteries. This makes it particularly advantageous for applications requiring lightweight and high-energy storage, such as aviation, shipping, and heavy-duty transportation.

- **Versatility**

Hydrogen can be utilised across various sectors, including transportation, power generation, industrial processes, and residential heating. It serves as a bridge between different energy systems, enabling sector coupling and improving overall energy system efficiency.

- **Energy Storage and Grid Balancing**

Hydrogen can store surplus energy generated by intermittent renewable sources like wind and solar. It can be converted back into electricity or used in other applications, addressing the issue of renewable energy intermittency and

ensuring grid stability.

- **Decarbonisation of Hard-to-Abate Sectors**

Hydrogen provides a pathway to decarbonise sectors that are difficult to electrify, such as steel production, chemical manufacturing, and long-haul transportation. In these industries, hydrogen can replace fossil fuels without compromising process efficiency.

- **Diverse Production Pathways**

Hydrogen can be produced from a variety of sources, including water electrolysis powered by renewable energy (green hydrogen) or from fossil fuels with carbon capture and storage (blue hydrogen). This flexibility enhances energy security by reducing dependence on a single energy source.

- **Long-Term Storage**

Unlike batteries, which are suited for short-term energy storage, hydrogen can be stored for extended periods in various forms, such as compressed gas, liquefied hydrogen, or chemical carriers. This makes it a valuable resource for seasonal energy storage.

## Disadvantages of Hydrogen

- **High Production Costs**

Green hydrogen, produced via electrolysis using renewable energy, remains significantly more expensive than fossil fuel-based hydrogen (grey hydrogen). The high capital and operational costs of electrolyzers and renewable energy integration hinder the economic viability of hydrogen on a large scale.

- **Energy Inefficiency**

Hydrogen production, storage, transport, and conversion involve energy losses at each stage. For example, producing hydrogen through electrolysis and converting it back into electricity via fuel cells can result in an overall efficiency of 30-40%, compared to the direct use of electricity in batteries, which exceeds 80%.

- **Infrastructure Limitations**

Widespread adoption of hydrogen requires substantial investments in production facilities, distribution networks, and refuelling infrastructure. The current lack of hydrogen pipelines, storage facilities, and refuelling stations poses a significant barrier to scalability.

- **Safety Concerns**

Hydrogen is highly flammable and requires strict safety measures for handling, storage, and transport. Its low density and tendency to escape through small leaks can create challenges in maintaining safe and efficient systems.

- **Environmental Concerns of Non-Green Hydrogen**

Most hydrogen today is produced through steam methane reforming (SMR), which generates significant CO<sub>2</sub> emissions unless coupled with carbon capture and storage (CCS). Grey hydrogen, in particular, undermines the environmental benefits of hydrogen as a clean energy carrier.

- **Competition with Batteries**

In sectors like passenger vehicles and short-term energy storage, batteries often outperform hydrogen in terms of energy efficiency, cost, and existing infrastructure. Hydrogen's advantages are more pronounced in heavy-duty transport, industrial processes, and long-term storage, where batteries face limitations.

- **Water Resource Dependency**

Electrolysis requires significant amounts of water to produce hydrogen, which can be a concern in regions facing water scarcity. Balancing the demand for water resources with hydrogen production needs is a challenge that must be addressed.



Aspect	Advantages of Hydrogen	Disadvantages of Hydrogen
<b>Emissions</b>	Zero emissions at the point of use; produces only water vapour and heat.	Environmental concerns with grey hydrogen due to CO <sub>2</sub> emissions from fossil fuel-based production.
<b>Energy Density</b>	High energy content per unit mass, suitable for aviation, shipping, and heavy-duty transport.	Low energy density by volume; requires compression or liquefaction for storage.
<b>Versatility</b>	Applicable across transportation, power generation, industrial processes, and heating.	Less efficient than direct electrification (e.g., batteries) in certain applications like passenger vehicles.
<b>Energy Storage</b>	Stores surplus renewable energy for long-term use, addressing intermittency of solar and wind power.	Energy losses during production, storage, and conversion reduce overall efficiency (30-40%).
<b>Decarbonisation</b>	Enables emission reduction in hard-to-abate sectors like steel, chemicals, and long-haul transport.	Infrastructure for hydrogen production, transport, and refuelling is limited and expensive to develop.
<b>Production Flexibility</b>	Can be produced from various sources, including renewables (green hydrogen) and fossil fuels with CCS.	Green hydrogen is expensive; grey hydrogen undermines environmental benefits if CCS is not implemented.
<b>Safety</b>	Produces no harmful pollutants and is safe to use when managed properly.	Highly flammable and prone to leaks, requiring stringent safety measures.
<b>Water Resource Usage</b>	Renewable hydrogen from electrolysis can support sustainable energy goals.	Electrolysis requires significant water, which may strain resources in water-scarce regions.
<b>Competition with Batteries</b>	More effective for heavy-duty transport, long-term energy storage, and industrial uses.	Batteries are more efficient and cost-effective for passenger vehicles and short-term energy storage.

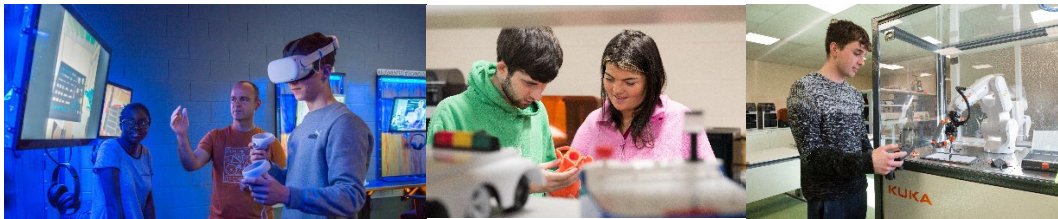
**Table 2: Summary Table of Advantages & Disadvantages of Hydrogen Energy**

## Conclusion

Hydrogen's diverse applications across key sectors illustrate its potential to revolutionise global energy systems. By adhering to the principles of hydrogen energy technology, these applications contribute to decarbonisation, energy efficiency, and sustainability. However, challenges such as cost reduction, infrastructure development, and technological efficiency must be addressed to unlock hydrogen's full potential. As research and investment in hydrogen energy continue to grow, its role as a clean, versatile, and sustainable energy carrier will become increasingly central to achieving global climate goals.

## Study at Munster Technological University









Munster Technological University is a multi-campus technological university, contributing to the region through the provision of academic programmes that support student development and opportunities, education and research. MTU has an extensive and impressive regional footprint with six campuses across the South-West region in Cork and Kerry, and a student body of 18,000. MTU offers the full range of higher education qualifications, including Bachelor degrees, Honours Bachelor degrees, and post-graduate Masters and PhD. For a full list of courses Available at MTU visit: <https://www.mtu.ie/courses/>



## The 'REEdI' Bachelor of Engineering (Honours) in Mechanical & Manufacturing Engineering

The REEdI (Rethinking Engineering Education in Ireland) BEng (Honours) in Mechanical and Manufacturing Engineering is a blended degree that brings in the best of manufacturing and mechanical engineering, culminating in flexible and adaptable engineers to meet industry needs. The REEdI student engineer learn about the design and development of processes whilst also gaining an equally strong knowledge of the design, development and operation of products and equipment.

Students learn “just-in-time” not “just-in-case”. The course is delivered using cutting edge technologies such as augmented and virtual reality. In addition, students get to learn from top lecturers in the field, study and work with emerging technologies, work with world-class companies, learning using a blended approach, through classroom-based, as well as hands-on experience. The goal of the REEdI programme is to turn curious, creative, innovative and adaptable people into the engineers of the future.

 <b>TYPE OF PROGRAMME</b> Full-time	 <b>NUMBER OF PLACES</b> 30
 <b>DURATION</b> 4 Years	 <b>COURSE CODE</b> MT 834
 <b>ENTRY REQUIREMENTS</b> Portfolio submission + CAO Points (50/50 weighting - max 600 each). Minimum 648 combined in 2024. See the minimum entry requirements for CAO listed below.	 <b>APPLICATION DEADLINE</b> See CAO for details
 <b>LOCATION(S)</b> MTU Kerry North Campus, MTU Kerry South Campus, Kerry	 <b>COURSE NFQ LEVEL</b> Level 8

For more information on this programme visit:

<https://www.mtu.ie/courses/mt834/>

<https://reedi.ie/>