HYDROGEN TRAINS: DRIVING THE FUTURE OF SUSTAINABLE TRANSPORTATION IN INDIA

Abstract

The most abundant element of the world, Hydrogen (H_2) is emerging as a critical solution for sustainable energy. Various production methods of hydrogen such as — grey, blue, and green—determine its environmental impact. Recent developments in hydrogen technologies are enabling the transformation of global energy systems, supporting the transition toward net-zero emissions, and paving the way for a cleaner, sustainable, and more resilient future. Fossil fuel-based transportation systems are the highest contributors of greenhouse gas emission across the world. Railways which are running in non-electrified routes heavily rely on diesel locomotives. Countries across Europe and Asia are investing heavily in hydrogen technology, while India has also initiated initiatives like hydrogen-driven train as a part of the National Green Hydrogen Mission. Still there are challenges such as storage, transportation, and implementation cost. This article explores how hydrogen's fundamental properties combined with modern production methods pave the way for environmentally friendly commercial transportation.

The hydrogen economy will make possible a vast redistribution of power, with far-reaching consequences for society. Today's centralized, top-down flow of energy, controlled by global oil companies and utilities, could become obsolete.

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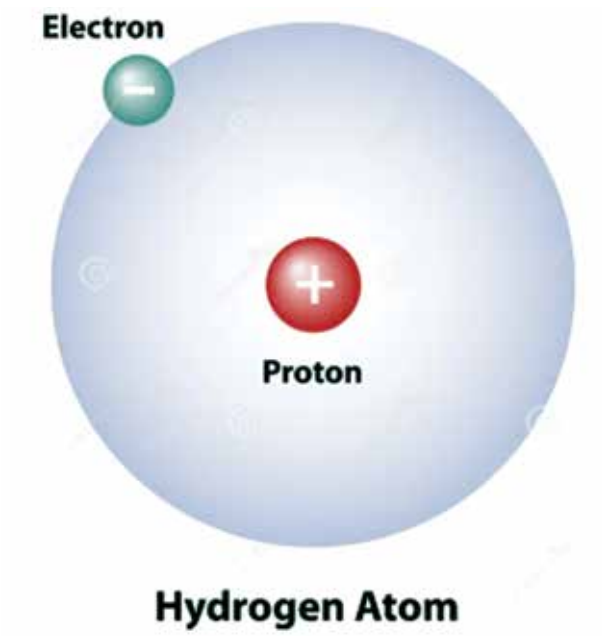
Introduction, Fundamental Properties and Manufacturing of Hydrogen

Hydrogen, the first element in the periodic table, is more than the beginning of chemistry—it is the beginning of a new era of sustainable development. As the lightest and most abundant element in the universe, Hydrogen is emerging as the driving force behind the global energy transition. More than an element of science, it is the element of transformation—decarbonising industries, powering clean mobility, strengthening energy security, protecting the planet and shaping a resilient, sustainable future for generations to come.

Hydrogen is colourless and odourless gas with atomic number 1 and molecular formula H2. Its Density ~0.08988 g/L (much lighter than air) and highly flammable, burns with an almost invisible blue flame.



Methods of manufacturing Hydrogen:

1. Grey hydrogen is produced by methane pyrolysis, a process in which natural gas (methane, CH_4) is heated to very high temperatures (typically 800–1,200°C) in the absence of oxygen. ($CH_4 \rightarrow C+2H_2$)
2. Blue Hydrogen is produced like grey hydrogen as above from natural gas having Carbon Capture Utilisation and Storage (CCUS/CCS) facilities to capture most of the CO_2 instead of venting those directly to air.
3. Green Hydrogen (Most Sustainable) is produced by splitting of Water into hydrogen and oxygen using electricity from renewable sources such as solar, wind or hydropower. ($2H_2O+Electricity \rightarrow 2H_2+O_2$)

Hydrogen is not produced onboard the train. It is manufactured at hydrogen production facilities. It is then compressed and stored in high-pressure cylinders (preloaded) on the roof of the train. The fuel hydrogen is to be refuel at stations, where it is filled into the train's onboard storage tanks, much like diesel is refuelled into conventional locomotives.

Fuel Cell Chemistry (Electrochemical not Combustible)

Hydrogen fuel Train use a Proton Exchange Membrane fuel cell (PEM). The overall reaction looks very simple, but it happens in two separate half-reactions across a membrane:

Overall reaction:

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

At the anode side (negative electrode): Hydrogen gas is split by a platinum catalyst.

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

Each hydrogen molecule loses its electrons and breaks into protons (H^+).

Journey across the membrane: The protons pass through the polymer membrane (which only allows H^+ through, not electrons) toward the cathode. The electrons, blocked by the membrane, are forced to travel through an external circuit instead — and that flow of electrons is the electric current that powers the motor.

At the cathode (positive electrode): Oxygen from the air combines with the arriving protons and electrons.

$$O_2 + 4H^+ + 4e^- \rightarrow 2H_2O$$

Hence, unlike conventional fossil fuel engines, hydrogen trains emit only water vapour during conversion to energy, making them one of the most environmentally friendly modes of transport available today.

Hydrogen fuel technology is therefore attracting global attention not only because it provides clean transportation but also because it aligns with sustainability goals (SDGs) and international climate commitments. As countries move towards achieving

Net Zero emissions, hydrogen is increasingly being recognised as the fuel of the future.

Hydrogen Trains Supports Sustainable Mobility and ESE

Hydrogen train that supports the three pillars of sustainability - Environment, Social and Economic. From the environmental perspective, it does not contribute to greenhouse gas emissions during its action and helping countries to meet climate targets. From the social perspective, hydrogen trains improve public health by reducing harmful pollutants. Which resulted into lower healthcare costs and a better quality of life for communities living near railway corridors. Its quieter operation also reduces noise pollution, creating a more environment friendly for passengers and nearby residents. From an economic perspective, hydrogen trains have a long-term benefit though its initial investment is high. It will reduce dependency on fossil fuel which will improve energy security and will create new opportunities. Advantages over lowering the emission causes reduction of environmental cost. By evolving effective technology to produce less costly hydrogen will be an economically sustainable solution for the future of rail transport.

Global Developments

Germany's adoption of the Coradia iLint has inspired other nations to explore hydrogen-powered rail systems as part of their sustainable strategies. The Coradia iLint offers operational advantages like quiet and better performance compared to conventional diesel trains and its ability to use existing railway tracks reduces the infrastructural cost. This pioneering innovation marks a significant milestone in the evolution of green rail transport an alternative to conventional diesel-powered trains. Several countries like France, Italy, Austria, China, Japan, and South Korea are also investing heavily in hydrogen railway technology. Many country's railway operators view hydrogen as an economical solution for regional railway lines where electrification costs are extremely high.

India's Journey Towards Hydrogen Transportation

India is one of the largest railway networks in the world. Although electrification has progressed rapidly, many sections still rely on diesel locomotives. Realising the importance of clean energy, the Government of India launched the National Green Hydrogen Mission. India's first indigenous hydrogen-powered train, the "*NaMo* Green Rail," was flagged off on July 17, 2026, by Prime Minister Narendra Modi in Haryana. It operates on the 89 km Jind-Sonipat route, carrying up to 2,600 passengers and reaching operational speeds of 75 km/h with zero emissions. This 10-car train utilised a 1,200-kilowatt hydrogen fuel cell system. (A 1.2 MW hydrogen fuel cell system means the train can deliver a maximum continuous electrical power output of 1.2 megawatts to its traction motors). These successful journey aim to reduce carbon emissions and encourage domestic manufacturing of hydrogen technologies under the Make in India initiative.

India possesses enormous renewable energy potential through solar and wind power. This makes the country well positioned to become the largest producers of green hydrogen.

Its success will play an important role not only in railways but also in roadway transport, shipping, aviation, heavy industries and power generation.

Economic Opportunities

Hydrogen technology represents far more than an environmental solution. It also offers significant economic opportunities.

- **Energy Security:** It will reduce the huge dependency on imported fuel by domestically produced green hydrogen as well as will reduce Foreign Exchange Outflow.
- **Job Creation:** Will generates employment across hydrogen production, storage, transportation, refuelling infrastructure, fuel cell manufacturing and maintenance. Which will be resulted to creation of high-skilled jobs in manufacturing, engineering, construction, operations, maintenance, research and development and off course for Cost and Management Accountants (CMAs).
- **Industrial Growth:** This will stimulate investment in renewable energy, electrolyser manufacturing, fuel cells, hydrogen storage systems and railway technology. Which will accelerate the growth of domestic industries by producing high tech equipment under

initiatives such as 'Make in India'.

- **Infrastructure Development:** Will encourages the establishment of hydrogen production plants, refuelling stations and distribution networks, boosting regional economic development. Green hydrogen plants located near renewable energy projects can stimulate economic activity, infrastructure development and employment in rural areas.
- **Lower Operating Costs:** Considering the high initial investment at present, the advancements in hydrogen technology and economies of scale are expected to reduce lifecycle operating and maintenance costs.
- **Innovation and Research:** The technological innovation will attract investment in research, development and advanced manufacturing. Since it will lower the greenhouse gas emissions the green financing, sustainability-linked investments and ESG-focused capital flow will increase.
- **Export Potential:** The countries which can developing improved technologies can become global suppliers of hydrogen equipment, fuel cells and green hydrogen, enhancing export earnings to boost economy.

Challenges

Despite its many advantages, hydrogen technology still presently has several challenges.

- Green hydrogen production is highly expensive because renewable electricity and electrolysers require significant investment.
- Hydrogen storage is technically demanding due to its low density. It must either be compressed at very high pressures or stored in liquid form at extremely low temperatures, which is again costly.
- Building hydrogen refuelling stations requires substantial costly infrastructure development.
- Safety is another very important aspect. Hydrogen is highly flammable and requires strict engineering controls, advanced sensors and robust operating procedures.

Hopefully continued research, technological innovation and economies of scale are expected to reduce these challenges over the coming years.

Hydrogen and the Future of Fuel Consumption

Human civilisation has experienced several major fuel transitions. The revolution in the usage of wood as fuel from the Stone Age was replaced by Charcoal in the Bronze/ Iron Age, during the Industrial Revolution it replaced by Coal, so it is called as Coal Age also. Coal gradually gave way to petroleum products, while natural gas emerged as a cleaner alternative for many applications. Now, the world is entering another major transition, where renewable electricity and hydrogen are expected to become dominant energy carriers. Hydrogen is especially valuable for sectors where usage of electricity is either difficult or very costly which includes heavy transportation, long-distance railways, shipping, aviation and steel/ cement manufacturing. Till date most of the countries rely on Coal for generation of electricity. Many experts therefore describe hydrogen as the missing link in achieving a fully renewable energy system. As hydrogen production becomes cleaner and more affordable, it is expected to transform global energy markets just as petroleum transformed the twentieth century.

Linkage with the Sustainable Development Goals (SDGs)

The deployment of hydrogen-powered trains aligns closely with India's commitment to the United Nations Sustainable Development Goals (SDGs). The adoption of green hydrogen in rail transport advances SDG 7 (Affordable and Clean Energy) by promoting cleaner energy sources and reducing dependence on fossil fuels. Expansion of the hydrogen value chain encourages industrial investment, innovation and high-skilled employment, thereby contributing to SDG 8 (Decent Work and Economic Growth) and SDG 9 (Industry, Innovation and Infrastructure). The replacement of diesel locomotives with zero-emission alternatives improves air quality and supports sustainable urban transport, reinforcing SDG 11 (Sustainable Cities and Communities). Furthermore, efficient resource utilisation and cleaner production practices promoted through green hydrogen are consistent with SDG 12 (Responsible Consumption and Production), while the reduction of greenhouse gas emissions supports SDG 13 (Climate Action). Collectively, these contributions demonstrate that hydrogen-powered railways are

not merely a technological innovation but an integrated strategy for achieving sustainable and inclusive development.

Role and Scope of Cost and Management Accountants (CMAs)

Cost and Management Accountants play a strategic role in ensuring the financial and operational sustainability of hydrogen train projects. Their expertise in life-cycle costing, capital budgeting, investment appraisal, cost optimisation and performance evaluation assists decision-makers in assessing the long-term economic feasibility of hydrogen technology. CMAs also contribute through risk assessment, financial modelling, sensitivity analysis and the application of techniques such as Net Present Value (NPV) and Internal Rate of Return (IRR). In addition, they facilitate ESG reporting, Business Responsibility and Sustainability Reporting (BRSR), carbon accounting and sustainability performance measurement, thereby strengthening governance, transparency and value creation in green infrastructure projects.

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Role of the ICMAI

The ICMAI can strengthen the implementation of hydrogen-powered railway projects by promoting standardised sustainability measurement, reporting and assurance practices. Its contribution includes developing guidance for sustainability disclosures, supporting ESG and BRSR reporting, encouraging carbon accounting and life-cycle performance measurement, facilitating sustainability assurance and enhancing professional capacity through research and training. These initiatives can improve transparency, accountability and evidence-based decision-making, thereby supporting India's transition towards a resilient and low-carbon railway system.

Epilogue

HYDROGEN – The Fuel of the Future

H – Harnessing Clean Heat

Hydrogen delivers high-efficiency, carbon-free heat, replacing fossil fuels in industries and transport.

Y – Yielding Sustainable Power

Hydrogen fuel cells generate exceptional energy output with water as the only by-product, ensuring maximum efficiency with minimum environmental impact.

D – Driving Decarbonisation

Hydrogen is a cornerstone of the global transition to a low-carbon economy, significantly reducing greenhouse gas emissions across hard-to-abate sectors.

R – Revolutionising Renewable Energy

Green hydrogen transforms surplus renewable electricity into a storable, transportable and versatile clean fuel, enabling a resilient energy future.

O – Optimising Energy through Oxidation

In fuel cells, hydrogen undergoes electrochemical oxidation to produce electricity silently, efficiently and without harmful emissions.

G – Green Gas for Global Progress

The lightest element in the universe is becoming one of the most powerful enablers of sustainable mobility, clean manufacturing and energy security.

E – Empowering the Energy Transition

Hydrogen bridges the gap between renewable energy generation and reliable energy demand, creating a flexible, clean and circular energy ecosystem.

N – Navigating Towards Net-Zero

Hydrogen is a strategic pathway to achieving global Net-Zero commitments, supporting climate resilience, energy independence and sustainable economic growth.

Hydrogen trains have the potential to become an important part of India's transition towards cleaner and more efficient transportation. Their adoption can reduce dependence on fossil fuels, support the growth of the green hydrogen economy, and contribute to national goals relating to climate action and sustainable development. However, the long-term success of this initiative will depend on more than technological progress. Affordable hydrogen production, reliable refuelling infrastructure, supportive policy measures, and continued investment in research and skill development will all play an equally important role. In this transition, Cost and Management Accountants (CMAs) can contribute by supporting project costing, investment appraisal, carbon cost assessment, sustainability reporting, performance measurement, and strategic decision-making. Their expertise in resource optimization and value creation can help ensure that hydrogen rail projects remain financially viable while achieving environmental objectives. As these efforts gather momentum, hydrogen-powered railways can create new opportunities for industry, researchers, educational institutions, and management professionals to contribute to a low-carbon future. Although the transition will take time, the initiative has the potential to reshape India's railway sector in a manner that is both economically beneficial and environmentally responsible. MA

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Congratulations!!!

Heartiest congratulations to CMA Sheel Kumar Mittal, Director (Finance), UPMRC and the entire Uttar Pradesh Metro Rail Corporation (UPMRC) on being honoured with the prestigious Enterprise Sustainability Transformation Award at the Times Internet Ecopreneur Awards 2026 in a ceremony held in New Delhi. This distinguished national recognition is a testament to UPMRC's exemplary commitment to sustainable urban mobility and environmental conservation. It acknowledges the Corporation's consistent efforts in seamlessly integrating sustainability with operational excellence across Lucknow, Kanpur, and Agra Metro networks. Guided by its inspiring vision of "Green Metro, Clean Metro" UPMRC continues to set new benchmarks by adopting innovative technologies and environmentally responsible practices, thereby creating one of India's most sustainable urban transport systems.

We extend our heartfelt congratulations to CMA Sheel Kumar Mittal and the entire UPMRC team on this remarkable achievement and wish them continued success in all their future endeavours. May they continue to inspire excellence in sustainable infrastructure and contribute significantly to India's journey towards a greener and more sustainable future.