ALL INDIA SEMINAR ON "**GREEN HYDROGEN GENERATION, STORAGE, AND SAFETY ASPECTS**"

The Institution of Engineers (India)

# Challenges and Innovations in Green Hydrogen

## A Pathway to Sustainable Energy Transition

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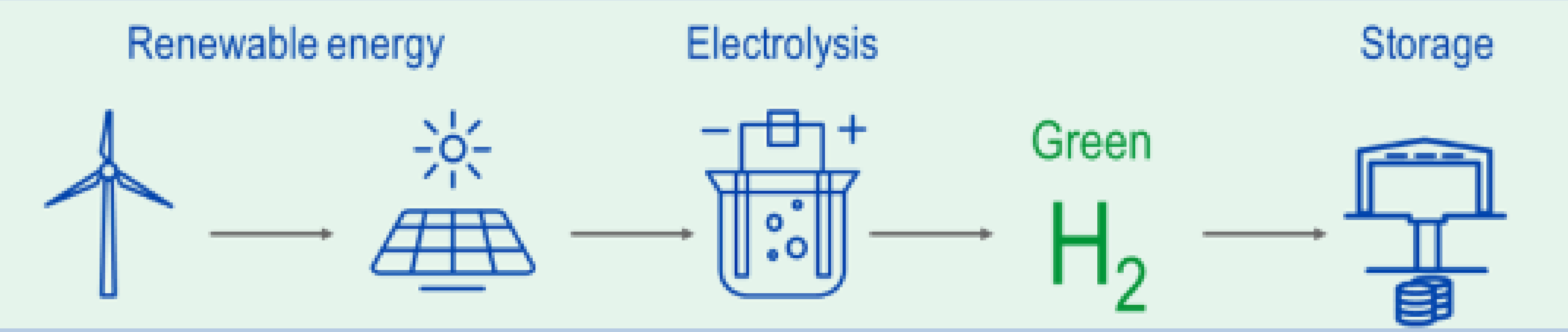
# Green Hydrogen: Energy Resource of the Future

- Green or low-carbon hydrogen is a potential energy resource integral to drive energy transition to achieve global net-zero ambitions.
- An integrated approach to drive sustainable development goals opens new pathways in green hydrogen applications in industries, utilities and transport sector.
- Innovations in green hydrogen can help us provide a green fuel alternative, and build long-term energy security.




Hydrogen is one of the most promising energy vectors to assist the low-carbon energy transition.

# Why is Green Hydrogen important for our economy?

- **Power Generation**: Green hydrogen can be used as a fuel for low-carbon power generation by blending with natural gas in gas turbines.
- **Industry feedstock**: Green $H_2$ can be used as an industrial feedstock in the production of green ammonia and nitrogenous fertilizers.
- **Transportation**: In transportation, green hydrogen can be used as zero-emission fuel for fuel-cell electric vehicle (FCEV).
- **Heating**: It can be used as a clean energy substitute for fossil fuels in heating applications.

**Challenges**: High cost of infrastructure for production, storage and transportation of green hydrogen.

**Actions needed**: Policy and regulatory support for green hydrogen infrastructure, promoting green H2 technologies, e.g. fuel cells, electrolyzers, safe storage and transportation

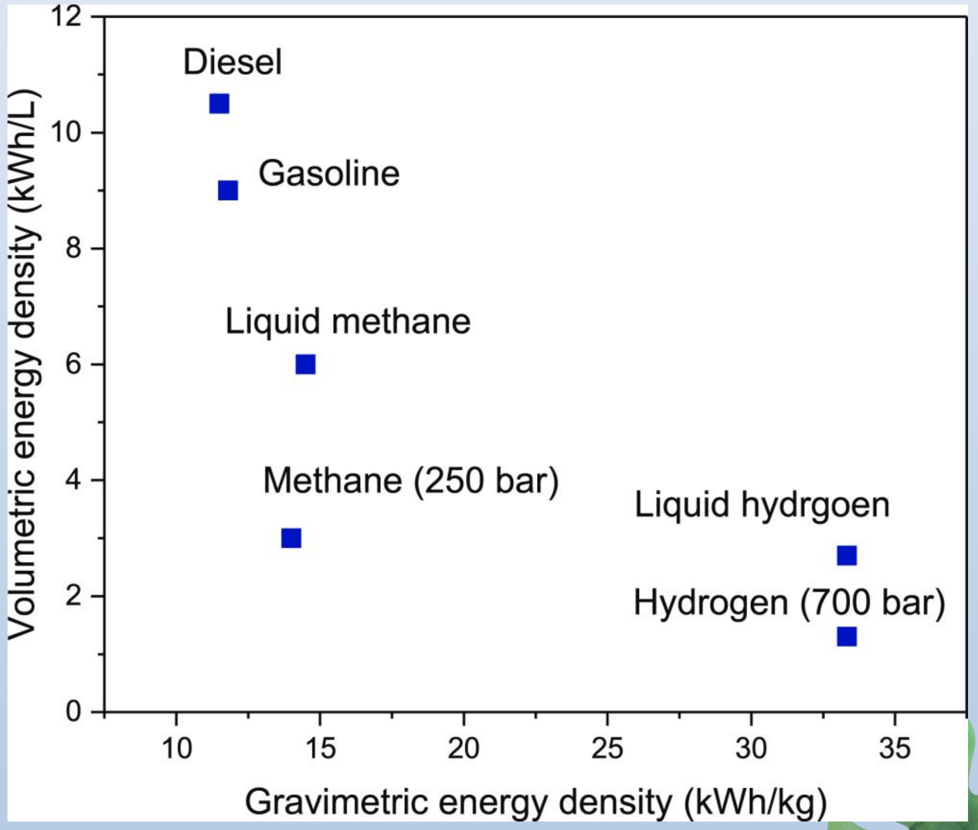
# Green Hydrogen production technologies

| Green $H_2$ Production | Pros | Cons |
|---|---|---|
| **Proton Exchange Membrane (PEM)** | High efficiency, clean production | High initial and production costs, membrane durability issues |
| **Alkaline Water Electrolysis** | Lower cost, well-established technology | Lower efficiency compared to PEM |
| **Solid Oxide Electrolysis Cells (SOEC)** | High efficiency | High operating temperatures, material challenges |
| **Photo electro-chemical (PEC) water splitting** | Utilizes solar energy | Poor efficiency, sluggish reaction rates |
| **Biological and Microbial Electrolysis** | Sustainable, can use organic waste | Lower production rates, complex processes |

Green hydrogen is an important vector to promote decarbonization and tackle climate change.

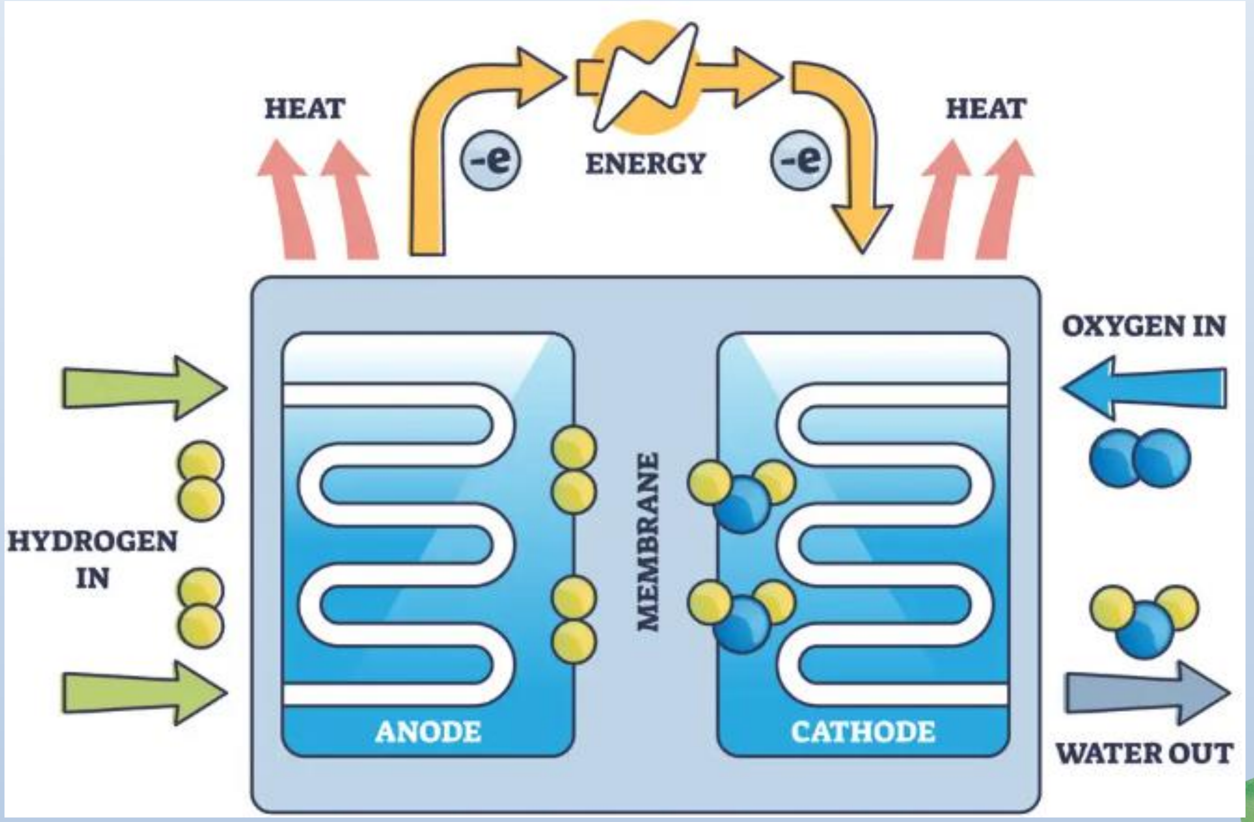
# Green $H_2$ storage and transportation

| Green $H_2$ Storage & Transportation | Pros | Cons |
|---|---|---|
| **Compressed Gas Storage,** in high-pressure tanks at pressures up to 700 bar | Simple and widely used method | Requires strong, heavy tanks and high energy for compression |
| **Liquid $H_2$ Storage,** cooled to cryogenic temperatures and stored in insulated tanks | Higher energy density compared to compressed gas | Requires significant energy for liquefaction and to maintain low temperatures |
| **Metal Hydrides,** absorbed into metal alloys, forming metal hydrides | Safe and compact storage method | High cost of metal hydrides and slower release rates |
| **Chemical Storage,** as in chemical compounds such as ammonia and hydrocarbons | High storage density and ease of transportation | Requires chemical processing to release hydrogen |
| **Underground Storage,** in caverns or depleted oil and gas fields | Large-scale storage capacity | Requires suitable geological formations and infrastructure |



# Innovative use cases of Green Hydrogen…1

1. **Hydrogen Fuel Cells**:
   - HFCs can fill the gaps in electricity demand during intermittent generation from renewable energy systems.
   - HFCs can be used in sustainable transport operations by sea, land, or air, minimizing carbon footprint and promoting a green economy.
2. **Renewable Hydrogen**: Production of green hydrogen from renewable energy sources eliminates carbon emissions.
3. **Hydrogen intermediates**: Hydrogen intermediates e.g. e-methanol can be used in internal combustion engines by blending with motor fuels, to reduce emissions



# Innovative use cases of Green Hydrogen…2

1. **Combined Heat & Power (CHP):**
   - Green hydrogen blended with natural gas acts as low carbon fuel for gas turbines in power generation.
   - Termed cogeneration, the exhaust heat from gas turbines is then fed to the boiler to produce steam, for electricity generation and heating.
2. **Hydrogen Propulsion**:
   - Green hydrogen is used as a clean propulsion fuel (liquid oxygen-hydrogen systems) in transport, aviation and space application.
   - Blending it with other fuels provide a low-carbon alternative to fossil fuels.

# Role of Technology in Green $H_2$ transition

## Artificial Intelligence and Machine Learning (AI/ ML)

1. **Optimizing Operations**: Analyze real-time data from sensors and adjusting parameters such as temperature, pressure, and current to improve efficiency, performance and green hydrogen production
2. **Predictive Maintenance**: Monitor asset health and detect potential issues in electrolyzers, compressors, pumps, and other components of green hydrogen production, storage and distribution
3. **Optimizing RE sources**: Optimize resources of green hydrogen production using data forecast of weather, grid demand, available capacity and energy prices
4. **Supply Chain Optimization**: Optimize logistics, transportation, storage and supply of green hydrogen, apart from managing resources in supply chain

# Role of Technology in Green $H_2$ transition

## Industrial Internet of Things (IIoT)

1. **Real-Time Monitoring and Control**: IIoT devices, such as sensors and telemetry, provide real-time data on energy consumption, plant performance, hydrogen production and storage
2. **Enhanced Efficiency**: IIoT systems facilitate the integration of RE sources to power electrolyzers for green hydrogen production, with real-time data of availability, production and storage
3. **Data-Driven Decisions**: IIoT enables data-driven decisions by providing accurate forecasts of variable RE generation and energy demand, thus optimizing resources and cost of production

# Role of Technology in Green $H_2$ transition

## Blockchain technology

1. **Certificates of Origin**: Certification process by providing a secure and immutable digital ledger to store transactions and ensure traceability of green hydrogen to clean energy sources.
2. **Smart Contracts**: Automated execution of smart contracts among parties for transacting in green hydrogen, without a central authority or intermediaries.
3. **Transparency and Security**: Transparent and secure way to track emissions along the value chain from production to consumption, ensuring that investments in green hydrogen are appropriately credited.

# Role of Technology in Green $H_2$ transition

## Digital Twin & Advanced Analytics

**Digital twin (DT)**:  DT can be used for modeling & simulation of variables in green $H_2$ production e.g. weather, demand, cost, etc. to maximize returns and minimize risks

a) **Modelling:** Calibrate optimal configuration of RE systems and electrolyzer capacity, based on hydrogen production demand and storage capacity

b) **Simulation**: monitors the operations of electrolyzer and associated equipment to predict potential failures, reduce downtime and maximize production efficiency.

**Advanced analytics**: Analytics can transform data into business intelligence with actionable insights, during green $H_2$ production

a) **Data analytics**: Timely action to maximize yields during green hydrogen production

b) **Business intelligence**: Root cause analysis of operational failures to increase electrolyzer uptime, reduce losses and improve revenues


# ACKNOWLEDGEMENT

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# Thank you!

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