TATA CONSULTING ENGINEERS LIMITED

ENGINEERING A BETTER TOMORROW
SINCE 1962

# Gas Based Economy – Hydrogen and Natural Gas

## Low Carbon Fuels For Energy Transition

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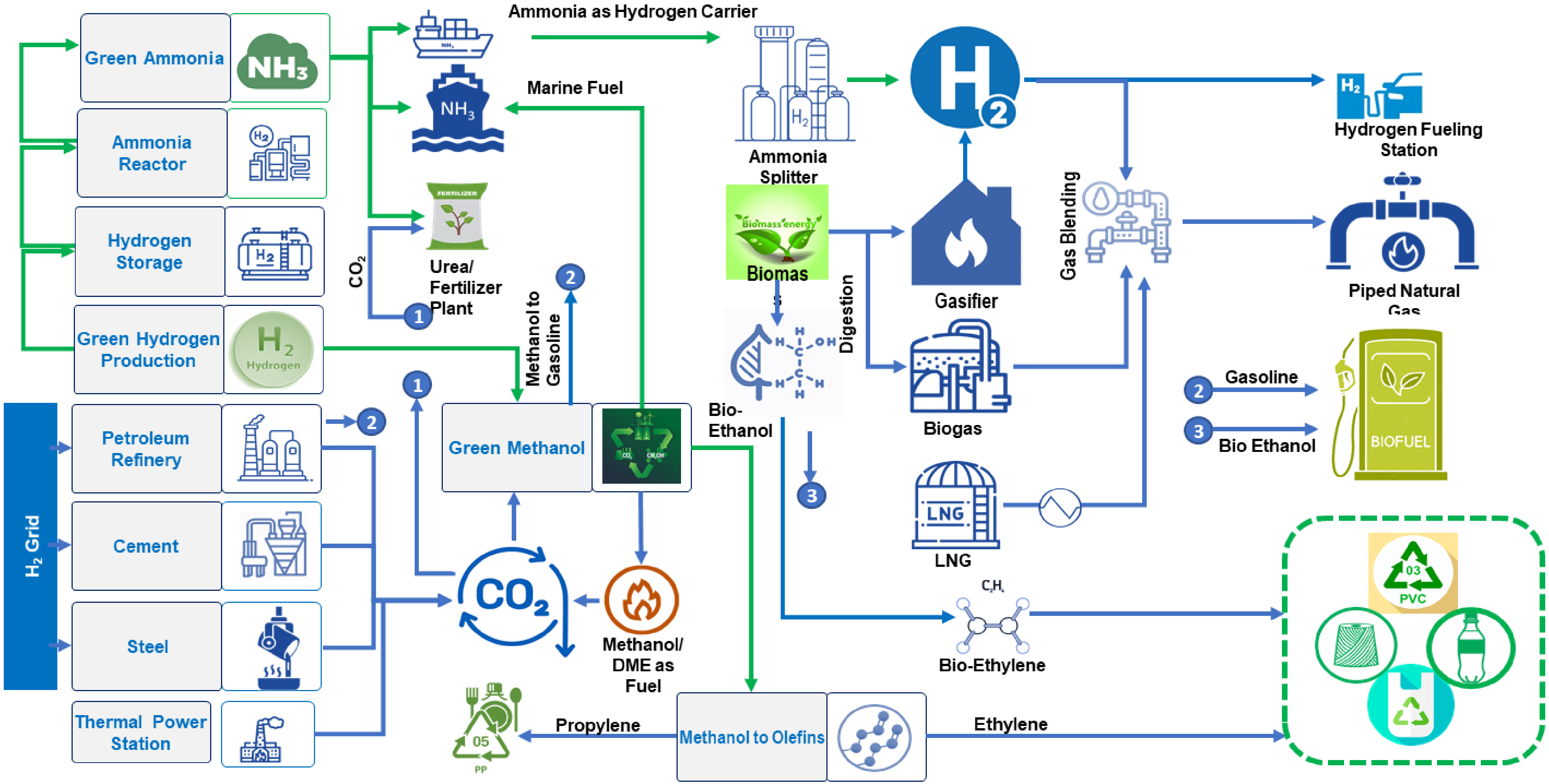
CTO

# Contents

# Green Chemicals and Low Carbon Pathways

## Industrial Approaches For Low Carbon

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# Hydrogen Value Chain

## Key Features

### Water
- Water Source Sustainability
- Purity of Water
- Water Management System.
- Typical requirement of water - SMR- 5.85-13.2 Lit/kg $H_2$
- Electrolyzer: 8.9 DM $H_2O$ Lit/kg $H_2$.

### Renewable Energy
- Energy Source- solar, wind, or hydropower, nuclear etc.
- Grid Integration- smart grid connection
- Energy Storage – batteries, flywheel, Pumped hydro storage, compressed air energy storage, thermal energy storage, hydrogen etc.

### Electrolyser
- Energy Efficiency – typical, Alkaline electrolyser consumes 55-60 kWh/kg-H2
- Energy Source Compatibility
- Energy Management System
- Water Management
- Scale and Modularity.

### Storage
- Storage Capacity
- Energy Density
- Safety Measures
- Hydrogen Purity
- Delivery and Retrieval Efficiency
- In the form storage,
  - Gaseous Storage
  - Liquid Storage
  - Adsorption – Metal Hydrides
  - LOHC s

### Logistics
- Range and Energy Density
- Refuelling Infrastructure
- Safety Measures
- Various type of transport
  - Pipeline Transport,
  - Gaseous Hydrogen in Tubes/Contain
  - Liquid Hydrogen Transport.
  - Rail Transport

### End users
- Transport
- Fertiliser
- Steel
- SAF
- Refinery
- Cement

# Future Of Hydrogen

**Future of Hydrogen Generation**

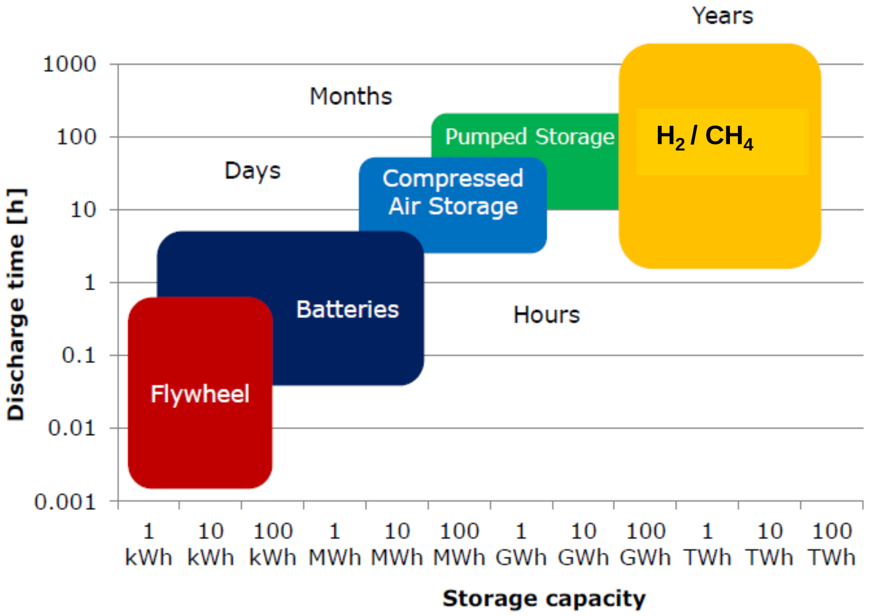
- Green Pathways using Renewable based water electrolysis
- Biomass Gasification
- Coal Gasification
- Steam Methane Reforming with CCU

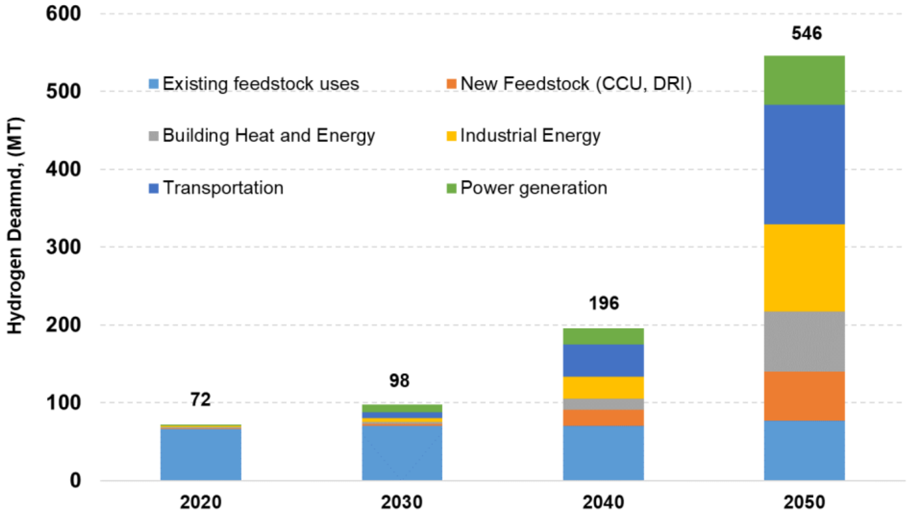
**Future of Hydrogen Storage and Transport**

- Physical Storage- Compressed Gas, Cryogenic Liquid, Caverns
- Material Based Systems
- Ammonia, LOHC

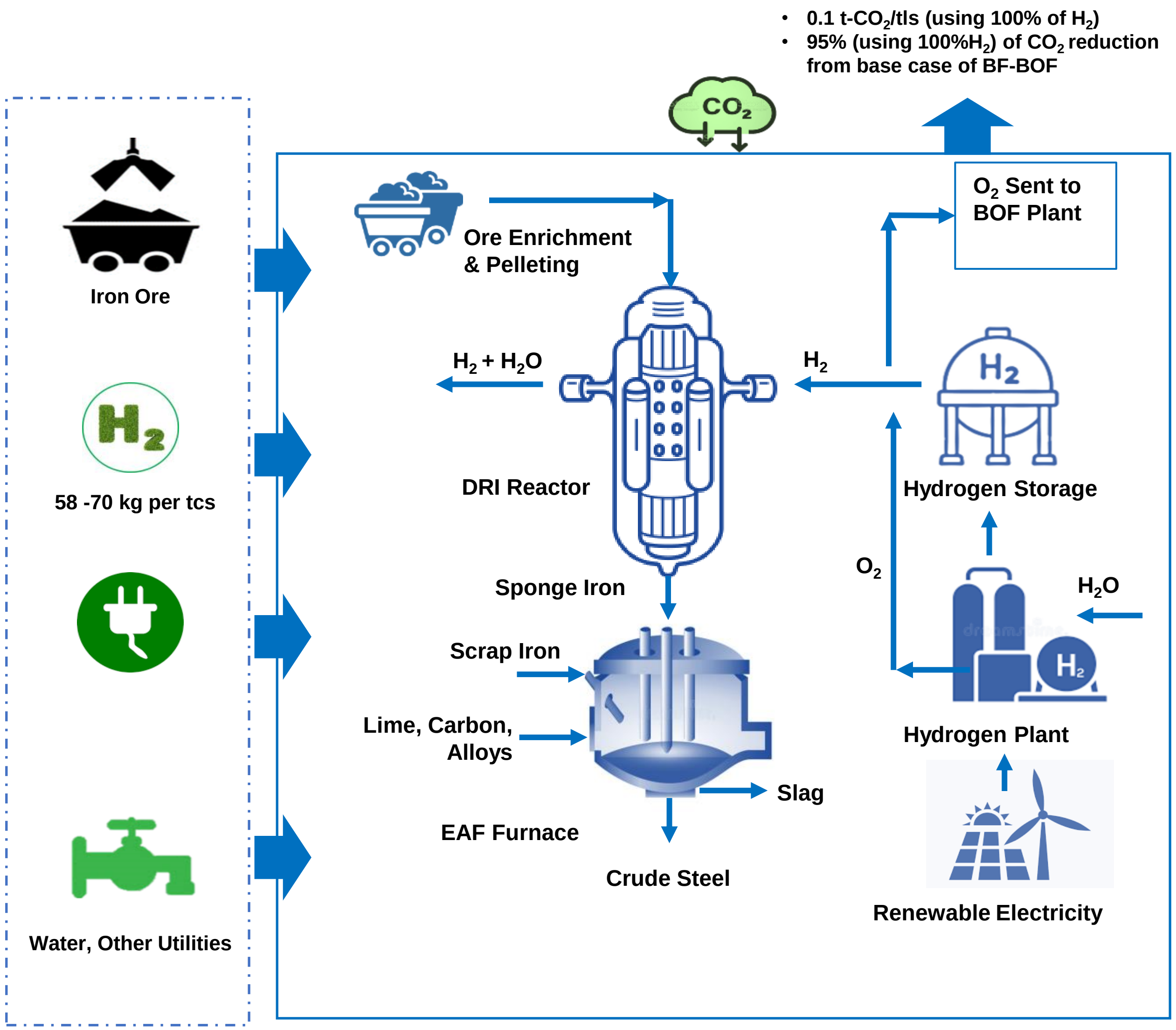
**Future of Hydrogen Applications**

- Transport Sector: Aviation, Marine, Road and Rail
- Feedstock: Ammonia, Methanol, Steel
- Alternate Fuel: Cement, Steel, Power



# Hydrogen for Green Steel

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### Economic Analysis

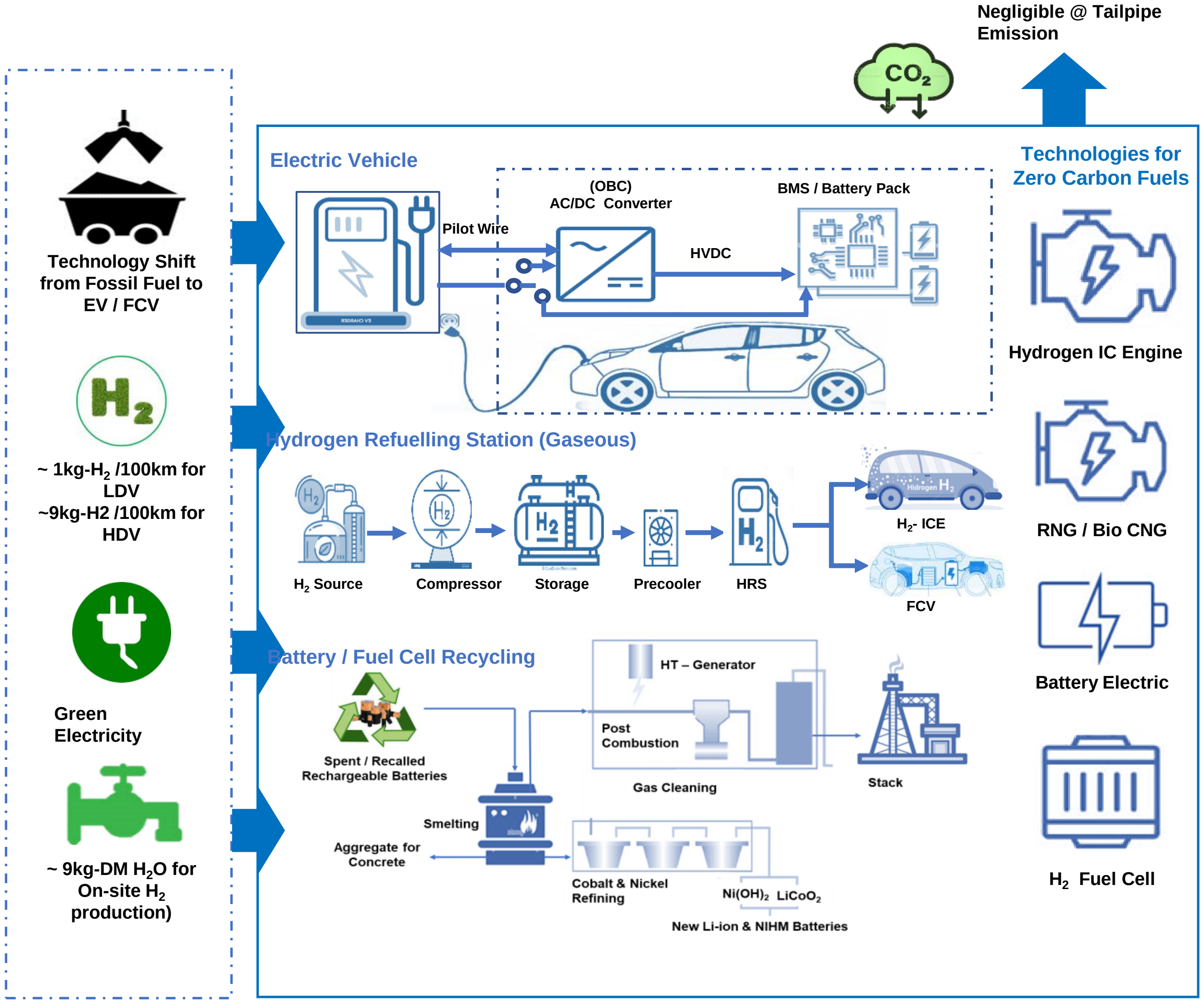
| Hydrogen Cost, $/kg-$H_2$ | 1 | 2 | 3 | 4 | 5 |
|---|---|---|---|---|---|
| DRI production cost, $/t-DRI | 230 | 310 | 380 | 460 | 540 |

### Green Steel Technology Options

- BF-BOF with CCUS
- DRI-EAF-BOF
- Biomass Blending as Fuel
- HYBRIT Process -H2based DRI
- HYFOR -H2 based reduction without sintering or Pelletizing
- Plasma Direct Steel

| Challenges | Mitigation |
|---|---|
| High Carbon Emissions | $H_2$-based direct reduction, electric arc furnaces powered by renewable energy, and CCUS. |
| Resource Intensive | To increase steel recycling rates, use alternative raw materials like scrap steel, and explore sustainable sourcing of raw materials. |
| Energy Intensity | Improve waste heat recovery, and the use of energy-efficient equipment. |
| Financial Support | Governments and financial institutions can provide incentives, subsidies, or financing options to encourage the adoption of sustainable steel practices. |

# Hydrogen for Road Transport

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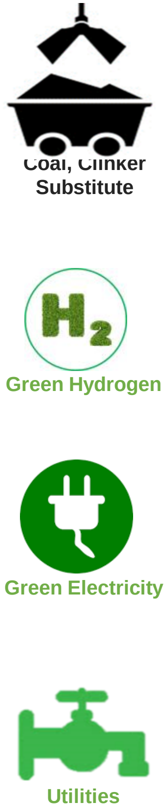
## Enablers

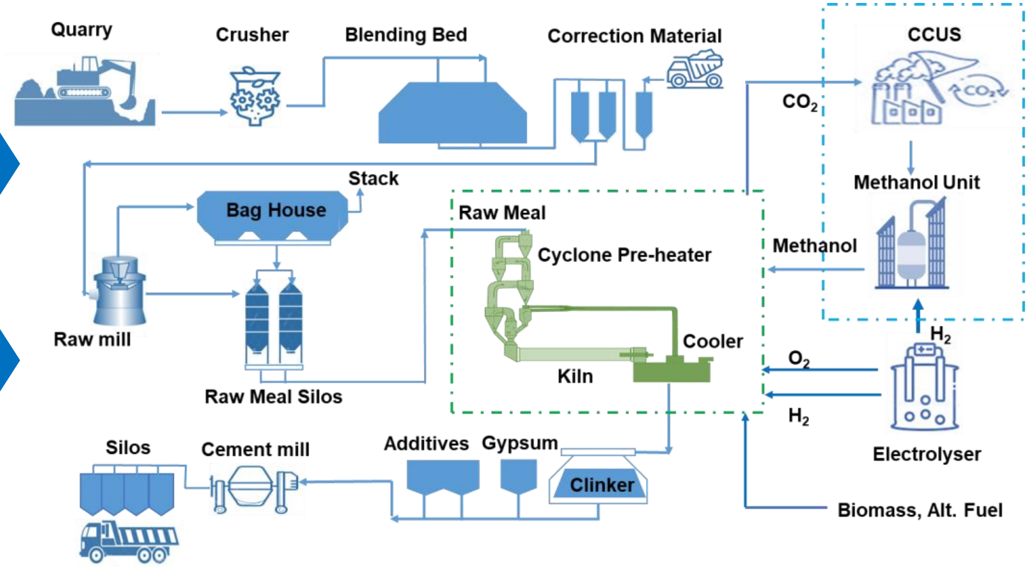
- Thrust on Renewable Energy
- Biofuels
- Mass Rapid Transportation (MRT)
- Improved Battery/ Fuel Cell Technology
- Vehicular Efficiency
- Charging Infrastructure
- Battery Swapping
- Non-motorised modes

| Challenges | Mitigations |
|---|---|
| **Limited $H_2$ Infrastructure** | Focus needs in the development of a comprehensive and accessible HRS network. |
| **$H_2$ Production Costs** | Focus in R&D to reduce the cost of H2 production, including renewable energy technologies. |
| **Energy Efficiency** | Improve the energy efficiency of the entire hydrogen supply chain. |
| **Hydrogen Storage** | Focus in R&D on advanced hydrogen storage materials, such as solid-state hydrogen storage or advanced composite tanks, to increase energy density and safety. |
| **Safety Concerns** | Develop and implement stringent safety standards and technologies, including leak detection and emergency shutdown systems, to ensure safe hydrogen handling. |

# Hydrogen for Cement Industry




Reduction by 50 %




- Hydrogen As Raw Material for Utilization of Captured Carbon: Methanol Production
- Hydrogen As combustion Fuel In Calcinators:

| Process | MJ/t Clinker | GJ/t Clinker | H2 kg required /t clinker | Required Capacity of Electrolyser, MW |
|---|---|---|---|---|
| Wet | 5800 | 5.8 | 40.9 | 2.3 |
| Dry | 4600 | 4.6 | 32.4 | 1.8 |

- Hydrogen Flame properties- Temperature profile- May call for using it in combination with Biomass
- Considering scale and amount of energy required, complete replacement to existing fuels may not be possible as the demand on renewable electricity to produce green hydrogen will be huge.

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## Enablers

- Reducing the clinker to cement ratio
- Supplementary Cementitious Materials (SCM)
- Using emerging and innovative technologies such as EHR to generate electricity
- Alt. Fuel (MSW, PMCG Waste, Pulp and Papers Mill Residue, Automotive Waste), Hydrogen and Bio-Mass

| Challenges | Mitigations |
|---|---|
| High Carbon Emissions | Utilize alternative materials, Adopt CCS, transition to low-carbon or carbon-free fuels. |
| Energy Intensity | Improve energy efficiency through process optimization |
| Waste and Emissions Management | Implement advanced emissions control technologies, reduce waste generation, and recycle or repurpose waste materials. |
| Water Consumption | Implement water recycling systems, optimize water use, and explore alternative sources of water, such as treated wastewater. |

# Hydrogen for SAF

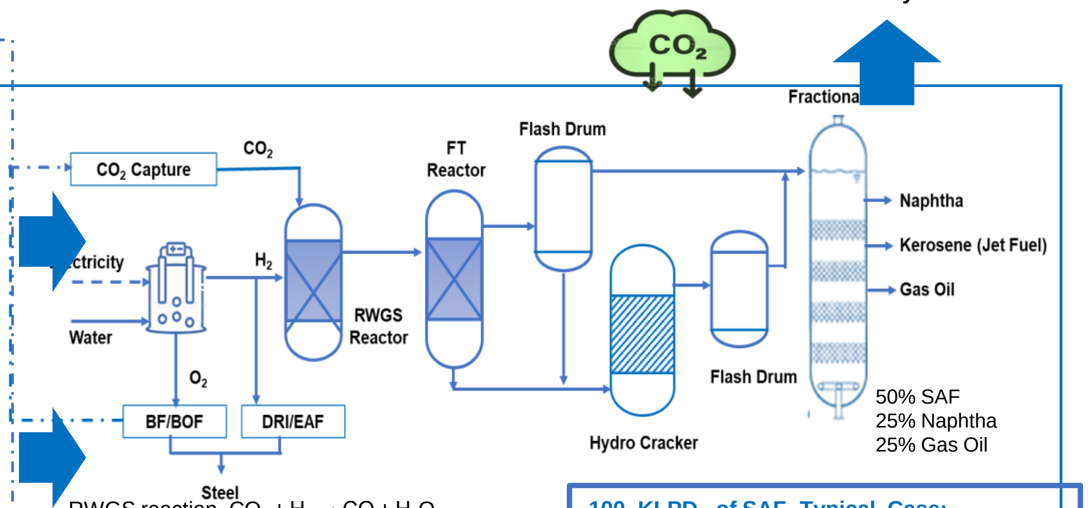
Captured $CO_2$

Green Hydrogen

Clean Power

Utilities

Reduction by 80 %




RWGS reaction, $CO_2 + H_2 \rightarrow CO + H_2O$

FT reactions, $CO + H_2 \rightarrow C_nH_m + H_2O$

Overall reaction, $CO_2 + 3H_2 \rightleftarrows (\text{-}CH_2\text{-}) + 2H_2O$

**100 KLPD of SAF- Typical Case:**

- $CO_2$ required: ~475 to 500 tpd
- $H_2$ required: ~80-90 tpd

**Electricity Required:**

- For SAF plant: ~3.5 - 4MWh
- For $H_2O$ electrolysis:~160 -180 MWh
- For Carbon Capture: ~6-7 MWh

**Key features**

- SAF achieve a significant $CO_2$ reduction versus their equivalent fossil-based fuels.
- Estimated GHG emissions intensity was found to be 49 $gCO_2$-eq./MJ for steel mill gas (SMG-FT route), far lower than the 88 $gCO_2$-eq./MJ-jet fuel average for the conventional benchmark.
- SAF can be used as a direct replacement (drop-in) for fossil jet fuel.
- SAF reduces emissions in aviation by up to 80% (life-cycle analysis).
- This process is at TRL 6-7.

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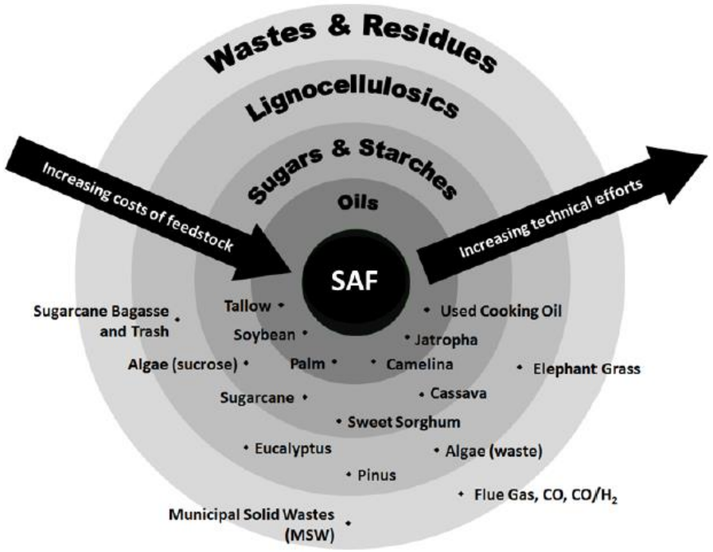
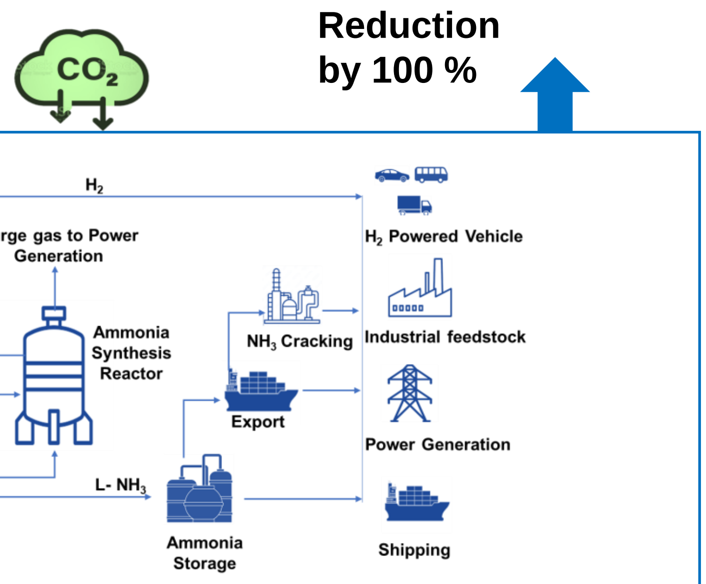
## Enablers

- 12 % more energy than conventional Jet Fuel
- Sustainable feed stocks for SAF production
- Proven Technology
- $CO_2$ from carbon capture of existing BF/BOF plants and / or coal gasification
- Improves environmental boost aircraft performance
- SAF can be produced vis various technologies.

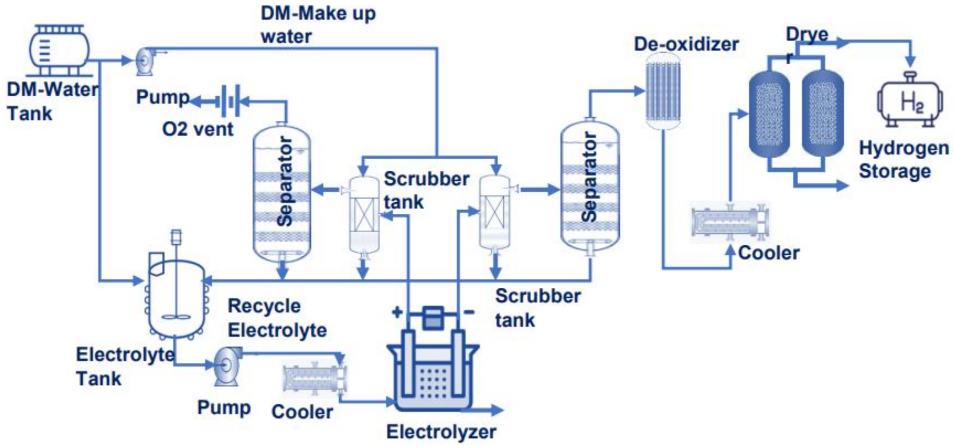
## Cost of feedstock and processing effort for SAF production



# Hydrogen for Green Ammonia




## Alkaline Water Electrolyser – PFD




## Key Driver(s)

- Demand for long term storage of renewable energy
- Obligations to reduce GHGs emission from traditional ammonia methods
- Increased agricultural production and subsequent rise in fertilisers consumption

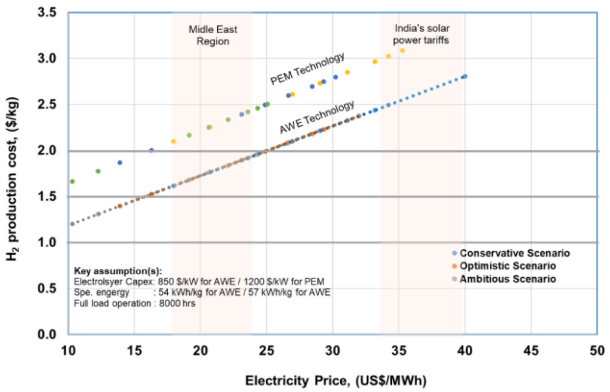
## Opportunities

- Ammonia as future maritime fuel
- Increasing focus on $H_2$ based economy.

## Challenges

- Higher initial capital requirements for green ammonia plant infrastructure
- High renewable price and $H_2$ price

## Economic Analysis

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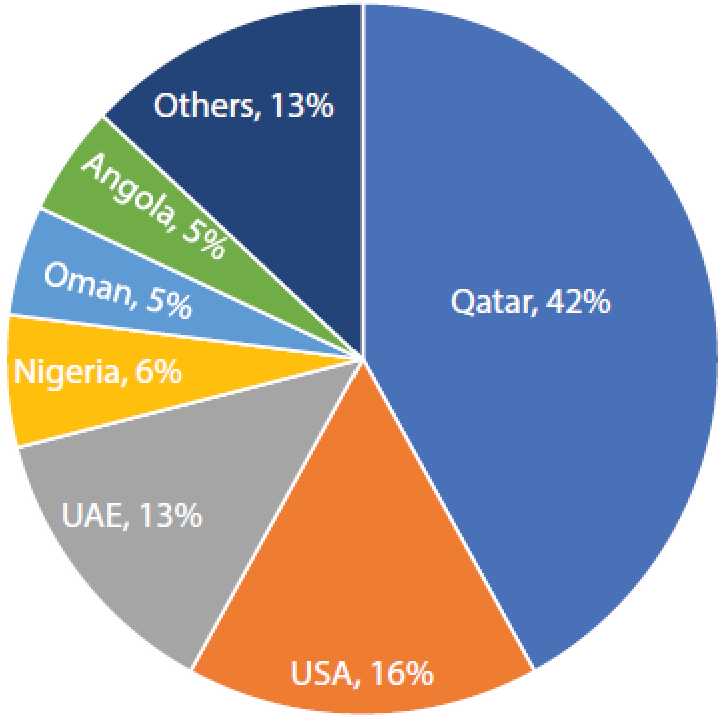
# Natural Gas

- Natural Gas (NG) is a versatile and efficient source of energy. It is commonly used fuel for heating applications in residential, commercial, and industrial sectors.
- It is also used as a fuel for electricity generation in power plants.
- Natural gas provides a reliable and continuous source of energy supply, contributing to energy security.
- India aims to increase the share of natural gas in the primary energy mix from ~ **6 per cent to 15 per cent by 2030** to make a gas-based economy.




*Distribution of LNG Import into India in 2021, by Country of Origin*

To achieve this target by:

a) Expanding the City Gas Distribution (CGD) network, installing LNG terminals.

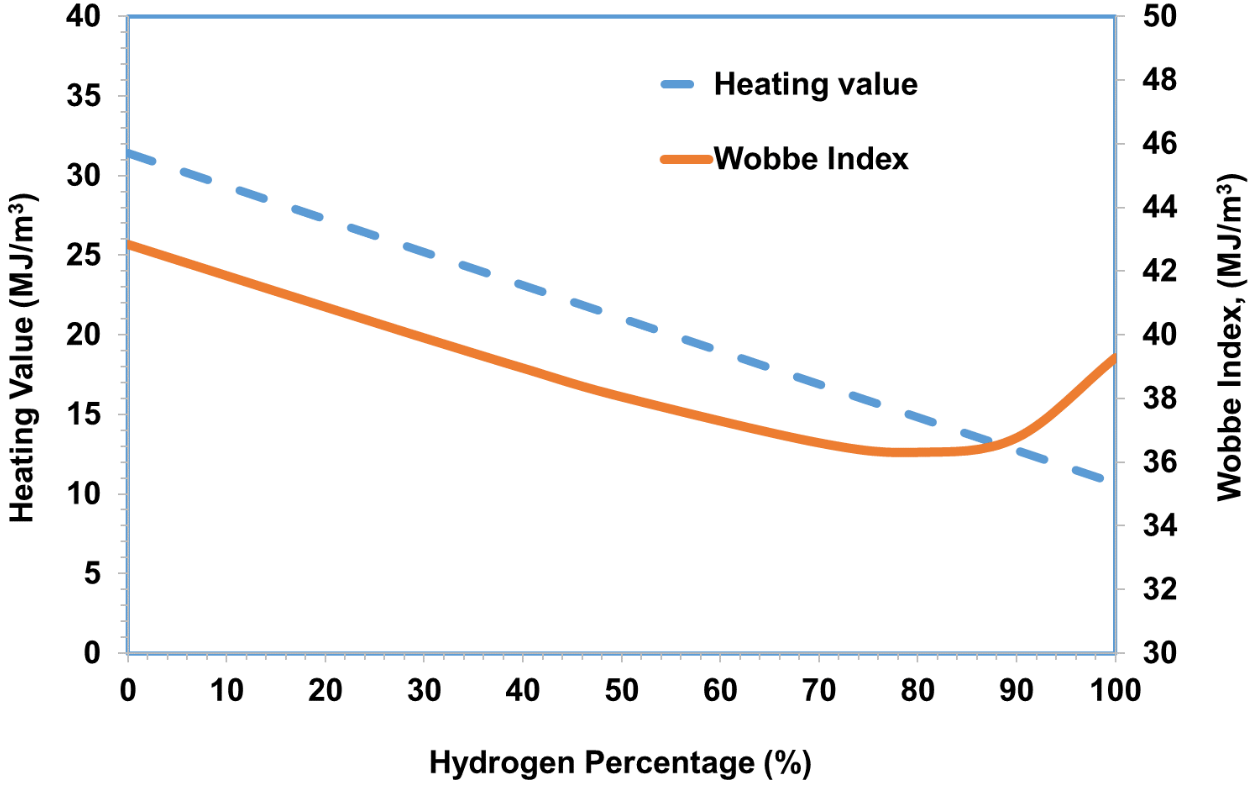
b) Allocating domestic gas to compressed natural gas (transport) and piped natural gas (domestic)

c) Allowing marketing and pricing freedom for gas produced in certain areas like deep water and ultra-deep water, as well as from coal seams.

d) Programmes to promote Bio-CNG under the Sustainable Alternative Towards Affordable Transportation umbrella.

# Heating Value Vs $H_2$ content

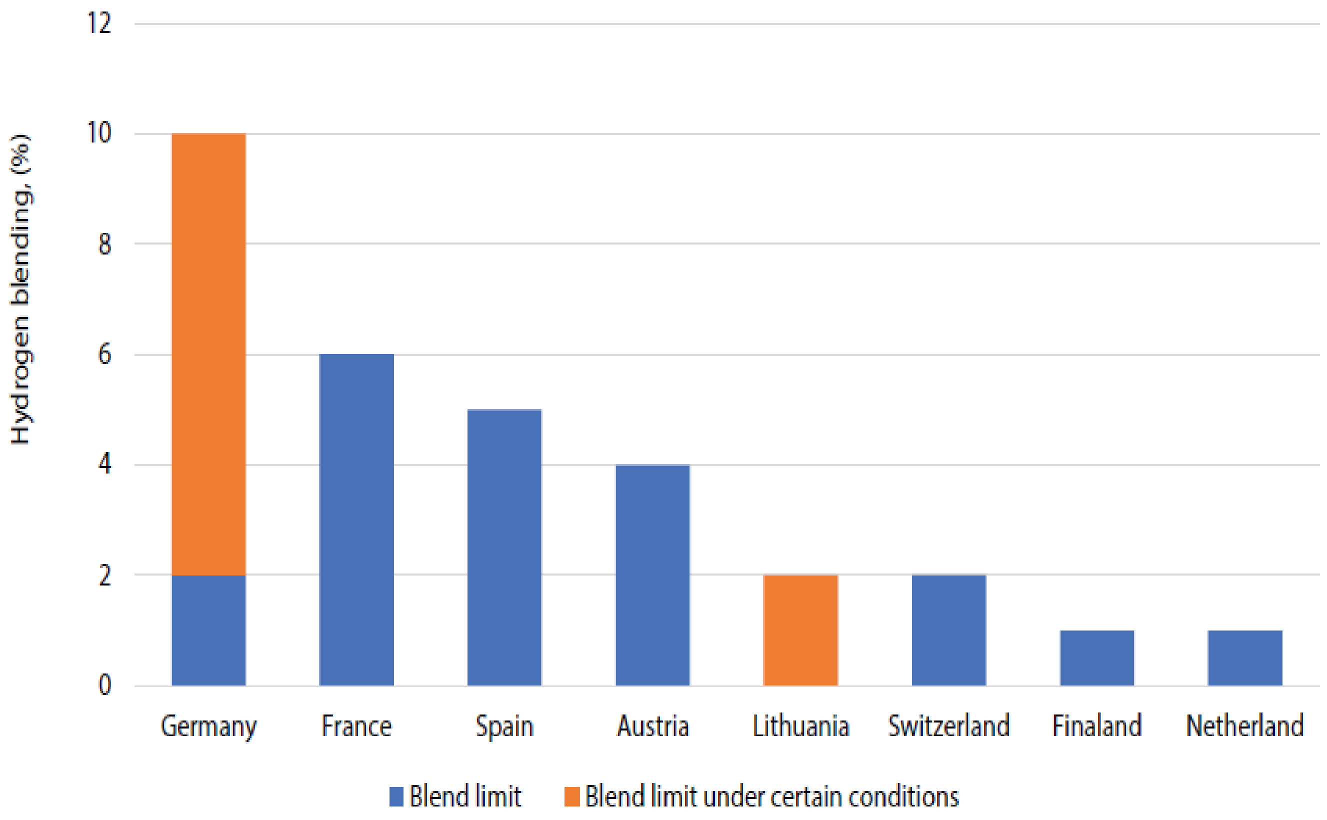
- The Wobbe index of $H_2$ is typically lower than that of natural gas.
- $H_2$ blends will have a lower heating value than pure natural gas.
- Increasing the $H_2$ concentration in the gas mixture can compensate for the lower heating value of hydrogen.
- The amount of $H_2$ blended into natural gas without affecting the Wobbe index depends on the specific gas mixture.
- However, in general, the amount of $H_2$ that can be blended into natural gas is limited to about 20%.




*No policy regulation or restriction on hydrogen blending with natural gas.*

# Global Status on Blending Ratio

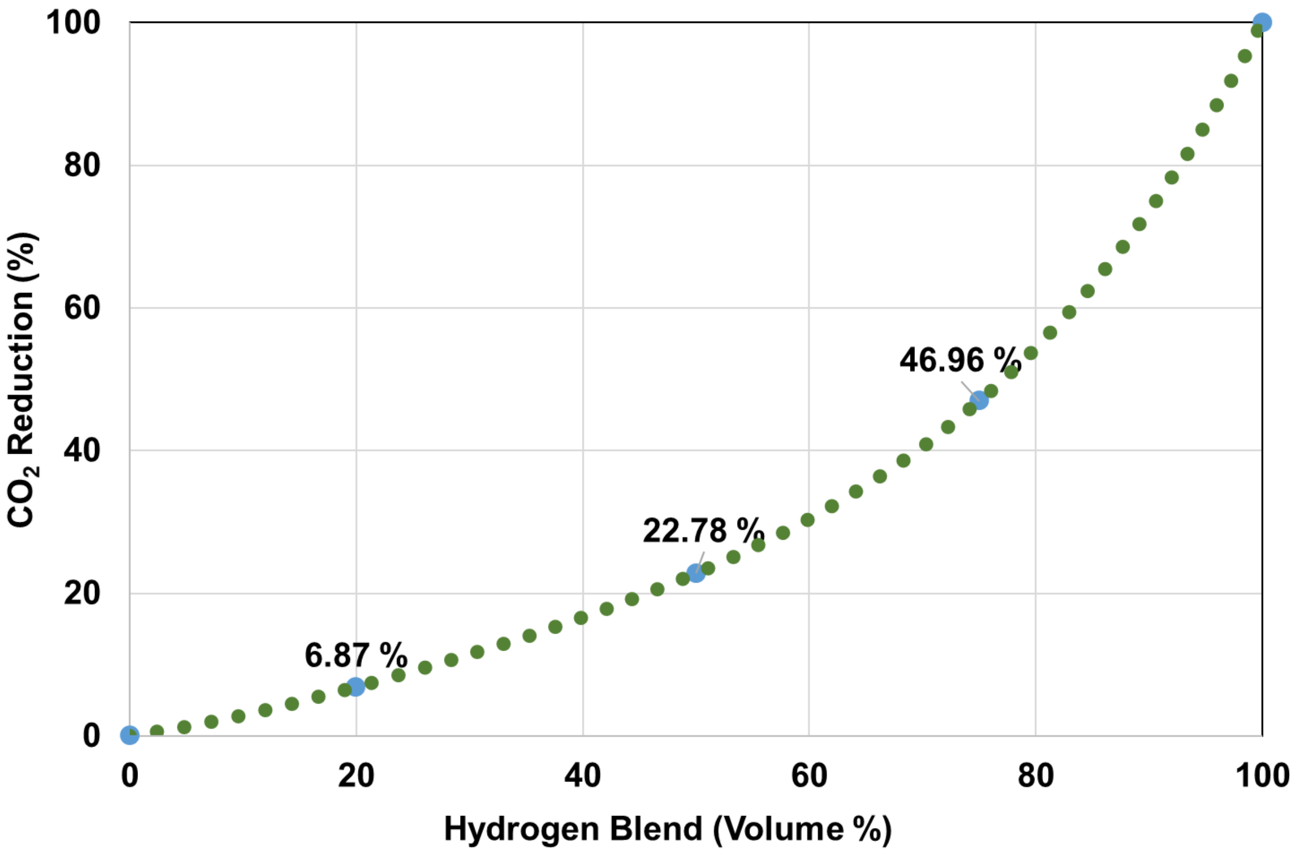
- European countries (like Germany, France, Spain, and Austria) preferred a 10% or below 10% blending ratio.
- The lower blending ratio involves mixing a small percentage of hydrogen (up to 10%) with natural gas.
- This ratio allows for a relatively easier integration of hydrogen into existing natural gas infrastructure, as it requires minimal modifications to the existing systems.




*The blending ratio would vary with applications, varying to the distribution and transmission lines.*

*If $H_2$ concentrations exceed 20% in the distribution line, the increase in overall risk is more significant than for distribution mains.*

# $CO_2$ Reduction with Blending Hydrogen Content




- < 20% can be tolerated without a significant change in performance and infrastructure.
- Increasing the hydrogen content in the blend generally leads to **higher CO2 reductions** but may also require infrastructure upgrades to ensure safe and efficient operation.
- $H_2$ has a lower volumetric energy density than methane; volumetric blending of hydrogen with methane **does not provide a linear reduction of carbon emissions** per unit of energy.
- CO2 reduction will increase the concentration of hydrogen in the natural gas grid.

# Effect of Embrittlement

- Embrittlement of materials due to hydrogen blending with natural gas is an important concern in the energy industry.
- **Hydrogen Embrittlement Mechanism**: Hydrogen embrittlement occurs when atomic hydrogen penetrates the crystal lattice of materials, weakening their structural integrity.
- **Material Susceptibility**: Certain materials, such as high-strength steels and some polymers, are more susceptible to hydrogen embrittlement than others.
- **Operating Conditions**: The degree of embrittlement depends on operating conditions, such as temperature, pressure, and hydrogen concentration.

# Challenges in $H_2$ blending with existing NG grid network

### Operational Perspective

- Compatibility and material concerns
- Leakage
- Gas quality consideration & metering
- Pressure fluctuations and management
- Hydrogen purity and Impurities
- Infrastructural flexibility or system upgrades
- Regulatory and standards compliance

### Safety Perspective

- Metal embrittlement and material compatibility
- Leak detection
- Combustion properties
- Risk of explosion
- Public awareness and education

### Economic Perspective

- Infrastructure upgrades
- Hydrogen production cost
- Storage and transportation costs
- Regulatory and policy frameworks
- Market demand and pricing
- Transition costs

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# THANK YOU

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