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shaping lives

What is Hydrogen? / Why Hydrogen

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04 Apr 23

AGENDA

1. Why Hydrogen - Climate Change
2. What is Hydrogen
3. Hydrogen Demand
4. Hydrogen Classification – Green, Blue or Gray
5. Typical Sustainable Green Hydrogen Supply Chain
6. Hydrogen Production
7. Challenges – Hydrogen Production, Storage, Transport & Usage
8. Case Study of 100MW power plant – LNG vs Liquid Hydrogen
9. Process Safety aspects

1.0 Why Hydrogen – Climate Change

COP(Conference of the Parties) 26 Goals –

1. **Secure global net zero by mid-century and keep 1.5 degrees within reach**

   Phase-out of coal; curtail deforestation; switch to electric vehicles; invest in renewables.

2. **Adapt to protect communities and natural habitats**

   Protect and restore ecosystems; build defences, to avoid loss of homes, livelihoods and lives

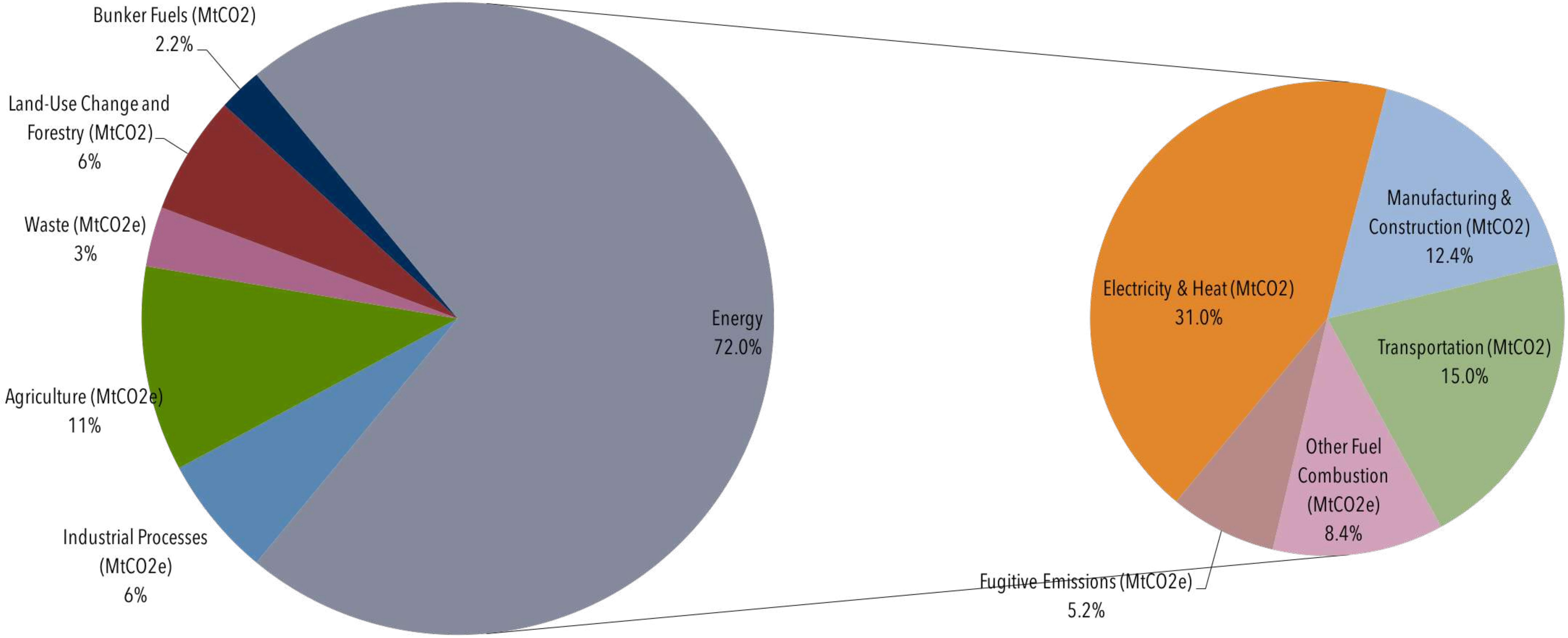
3. **Mobilise finance**

   Developed countries to mobilise at least $100bn in climate finance per year by 2020.

4. **Work together to deliver**

   Finalise the Paris Rulebook; Accelerate action to tackle the climate crisis through collaboration

1.0 Why Hydrogen: Climate Change – Major GHG Contributors



Source: Center for Climate & Energy Solutions

1.0 Why Hydrogen: Climate Change – CO_2E Emissions

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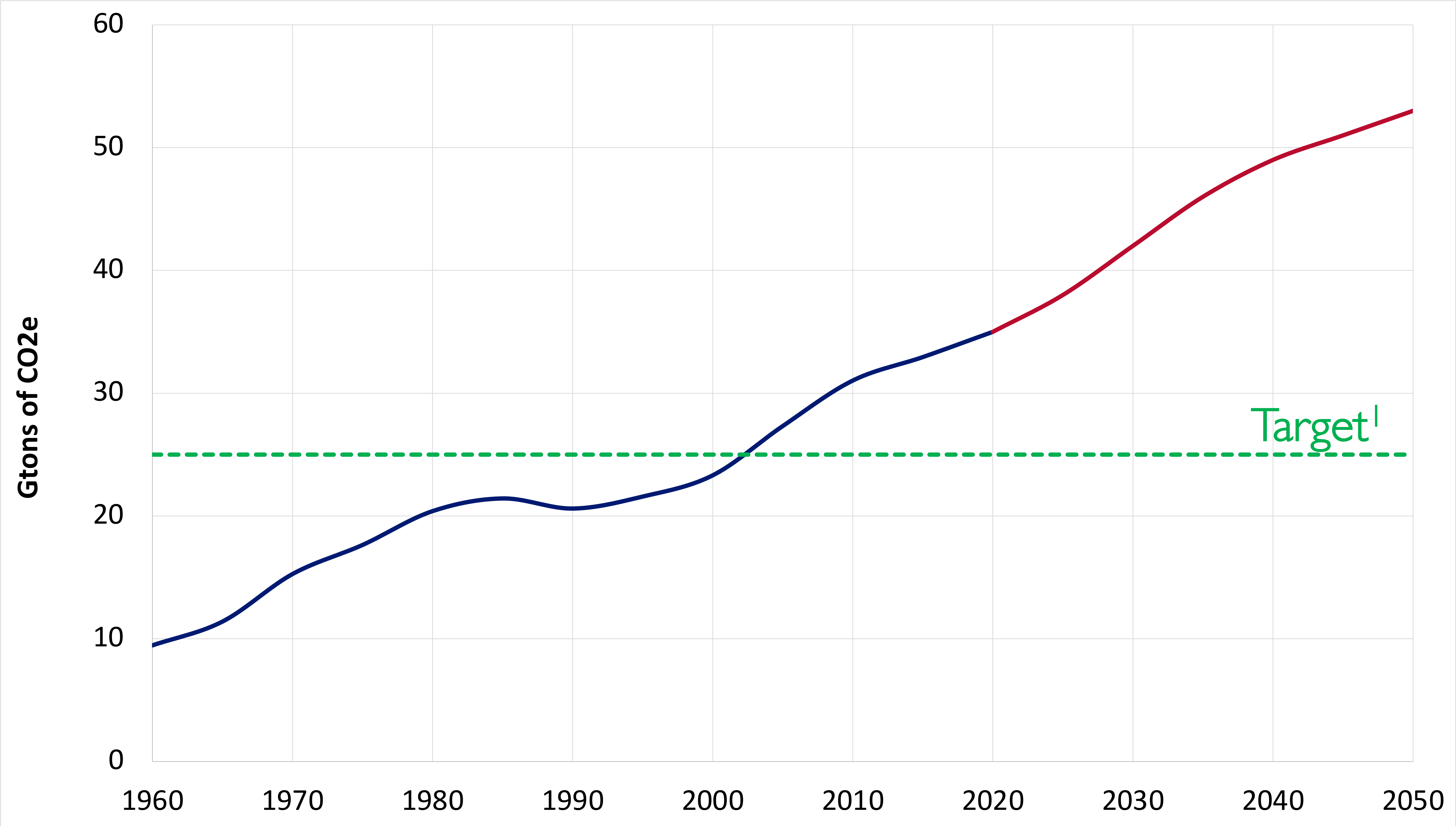

1: 25 Gtons of CO2e to limit global warning to 1.5 degC per Paris Agreement 2016

Source: Center for Climate & Energy Solutions

1.0 Why Hydrogen: Climate Change – Pathways for Decarbonization

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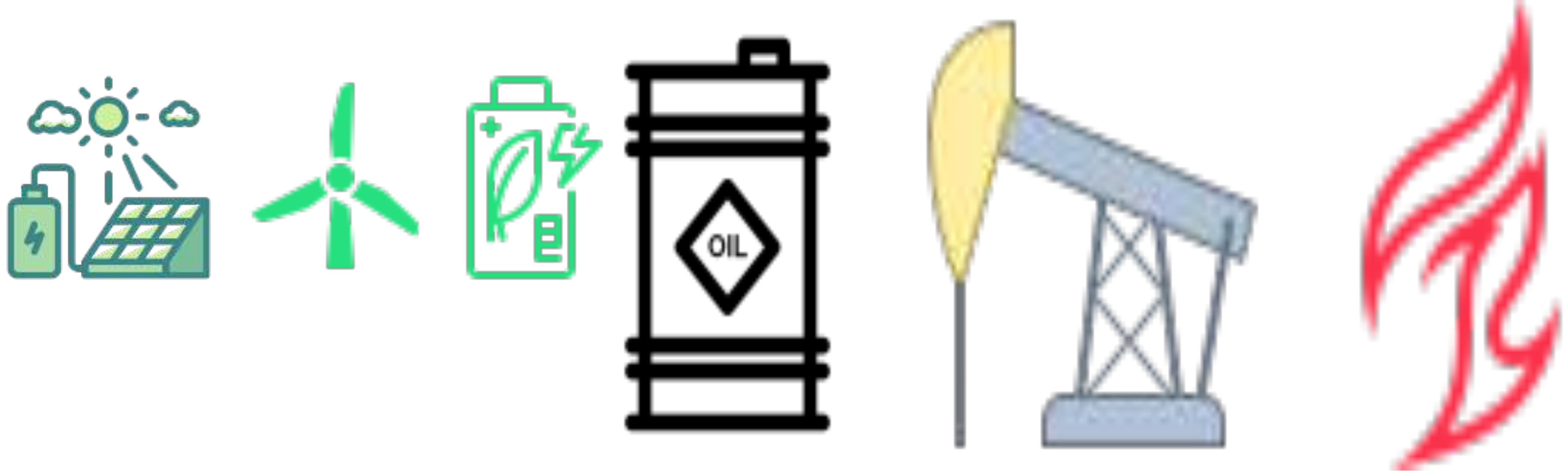
- ❑ Reduce dependence on fossil fuels
- ❑ Shift to zero carbon source of energy



- ❑ Using Energy Efficient Technologies
- ❑ Minimizing the usage of energy

- ❑ Carbon Capture and storage

2.0 What is Hydrogen

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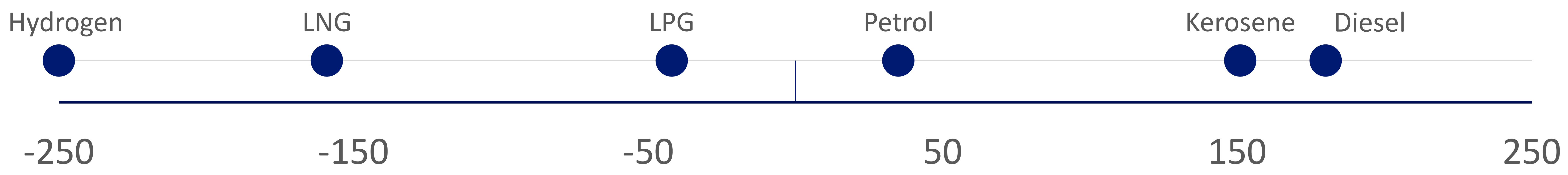
- ❑ Colourless, odourless, non-toxic, and most abundant element on earth.
- ❑ Emits only water when combusted
- ❑ Needs to be cooled down to - 253 C at atmospheric pressure to liquefy.

Boiling Point of Major Fuels (^{0}C)



- ❑ High Energy Density

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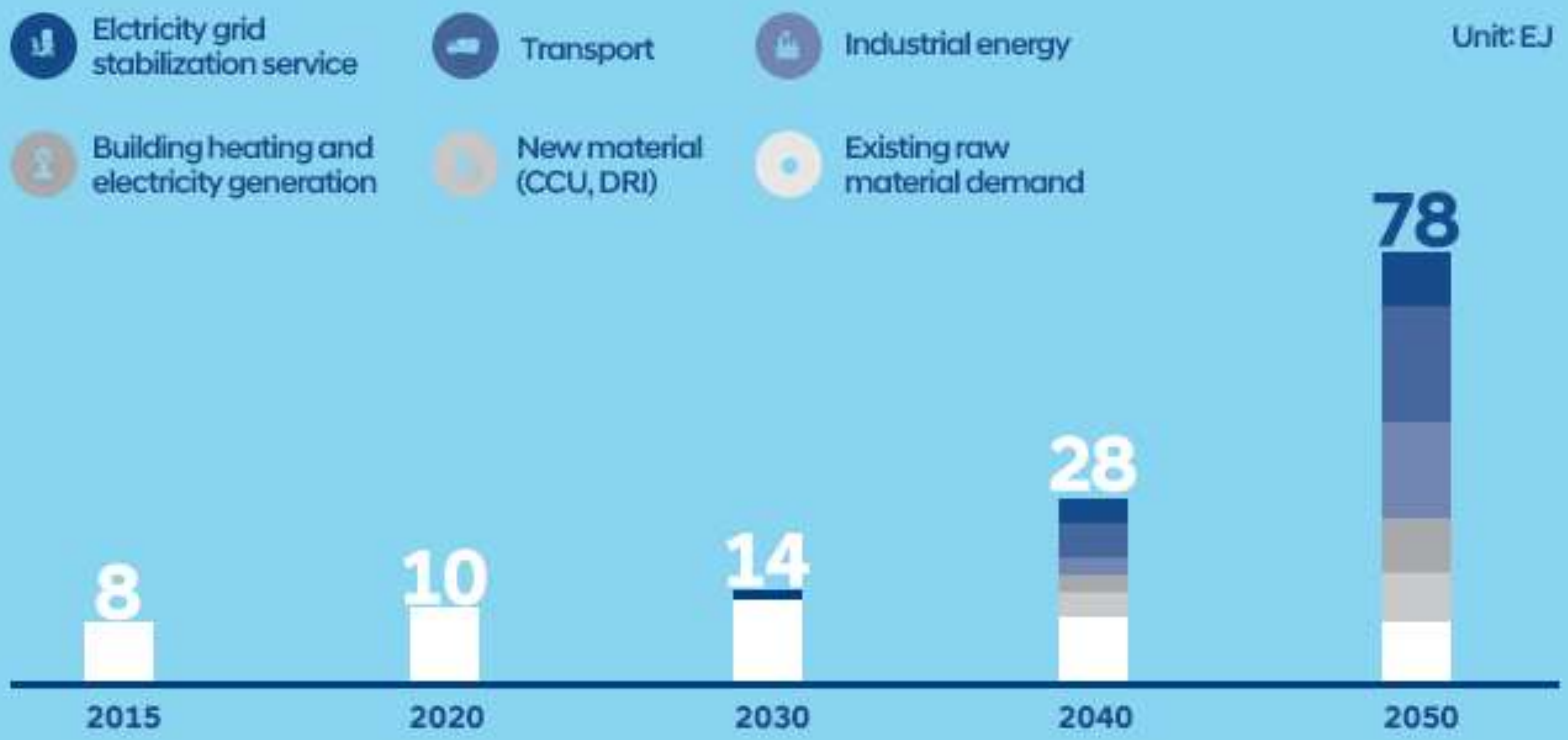
	Transportation Applications	Chemicals and Industrial Applications	Stationary and Power Generation Applications	Integrated/Hybrid Energy Systems
Existing Growing Demands	• Material-Handling Equipment • Buses • Light-Duty Vehicles	• Oil Refining • Ammonia • Methanol	• Distrubuted Generation: Primary and Backup Power	• Renewable Grid Integration (with storage and other ancillary services)
Emerging Future Demands	• Medium-and Heavy-Duty Vehicles • Rail • Maritime • Aviation • Contruction Equipment	• Steel and Cement Manufacturing • Industrial Heat • Bio/Synthetic Fuels	• Reversible Fuel Cells • Hydrogen Combustion • Long-Duration Energy Storage	• Nuclear/Hydrogen Hybrids • Gas/Coal/Hydrogen Hybrids with CCUS • Hydrogen Blending

Source: US DOE

3.0 Hydrogen Demand



Source: Global Hydrogen Council

4.0 Hydrogen Classification – Green, Blue Or Grey

Raw Material	Energy Source	Process	Product
Biomass, Water	Renewables	Electrolysis, Bio-Gasification	H_2
Fossil Fuel	Non - Renewables	Reforming, Gasification Carbon Capture	H_2 + CO_2
Fossil Fuel	Non -Renewables	Reforming, Gasification	H_2 + CO_2

5.0 Typical Sustainable Green Hydrogen Supply Chain

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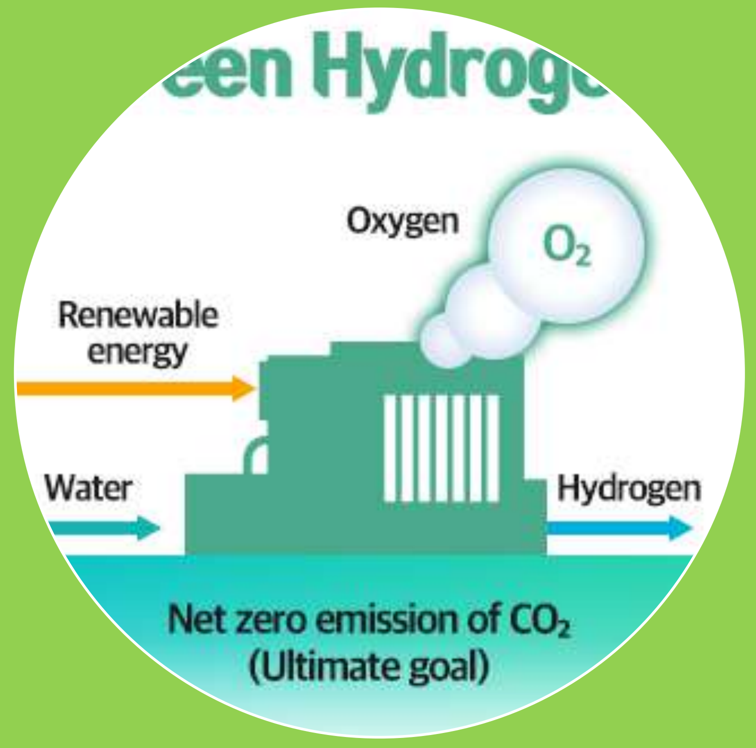
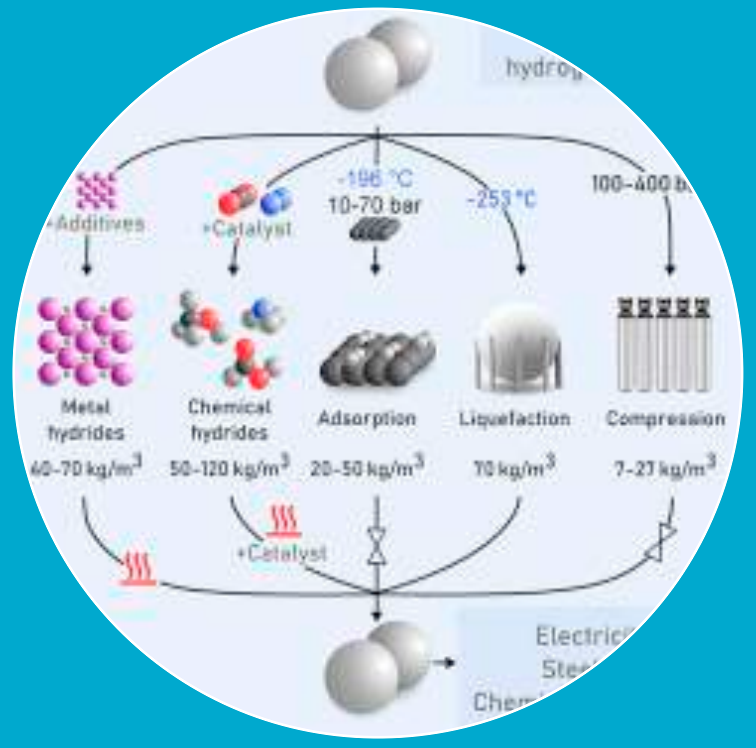
Primary Renewable Source

- Wind
- Solar
- Tidal
- Biomass



Green Hydrogen Generation

- Electrolysis
- Gasification

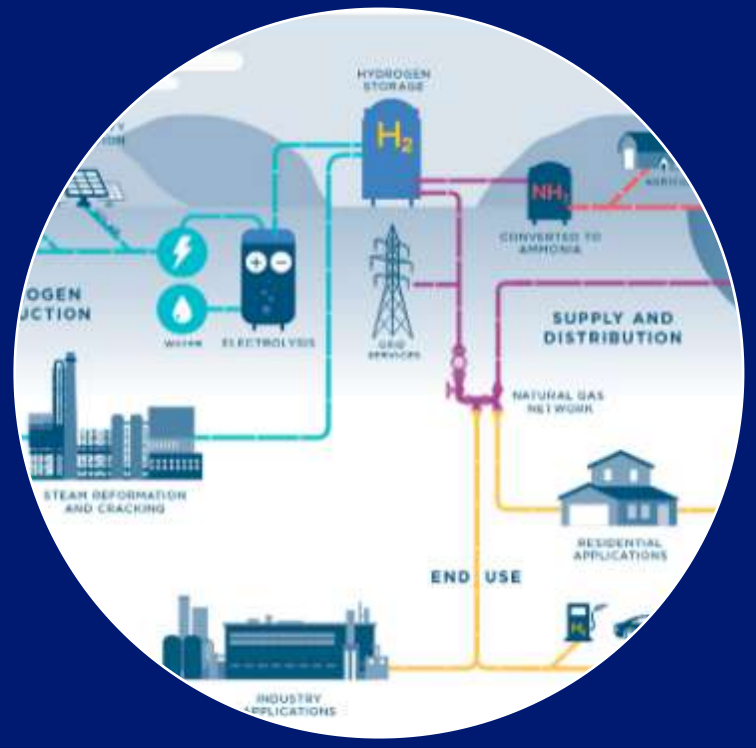


Hydrogen Storage

- Liquid hydrogen
- Compressed Hydrogen Storage
- Metal & Chemical Hydrides
- Ammonia
- Adsorption on solids
- Liquid Organic Hydrogen Carrier(LOHC)

Hydrogen Transport

- Hydrogen Carrier Ships
- Hydrogen Tanker
- Hydrogen Trucks
- Pipelines

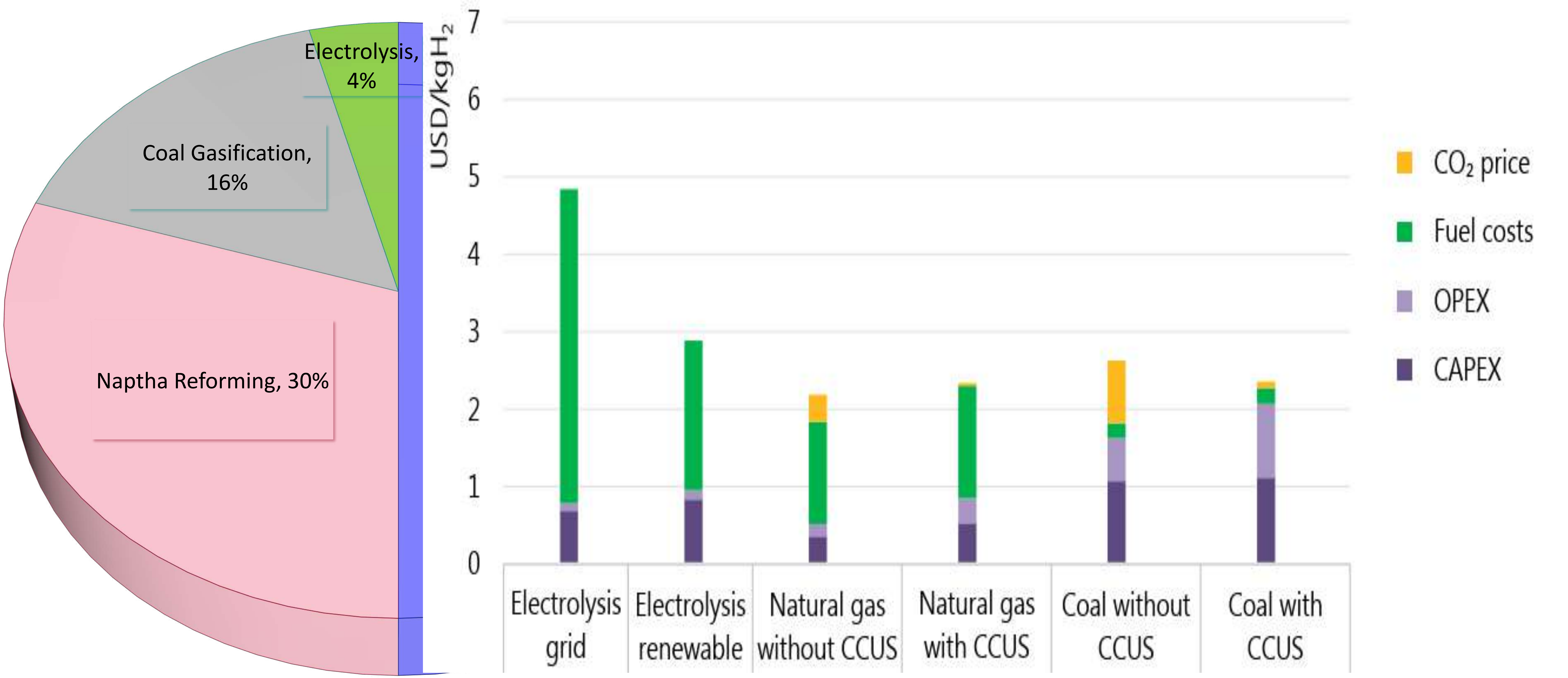


Hydrogen Usage

- Power Generation
- Ammonia production
- Synthetic Fuels
- Hydrogen Fuel Cell Powered Vehicles
- Maritime Fuel

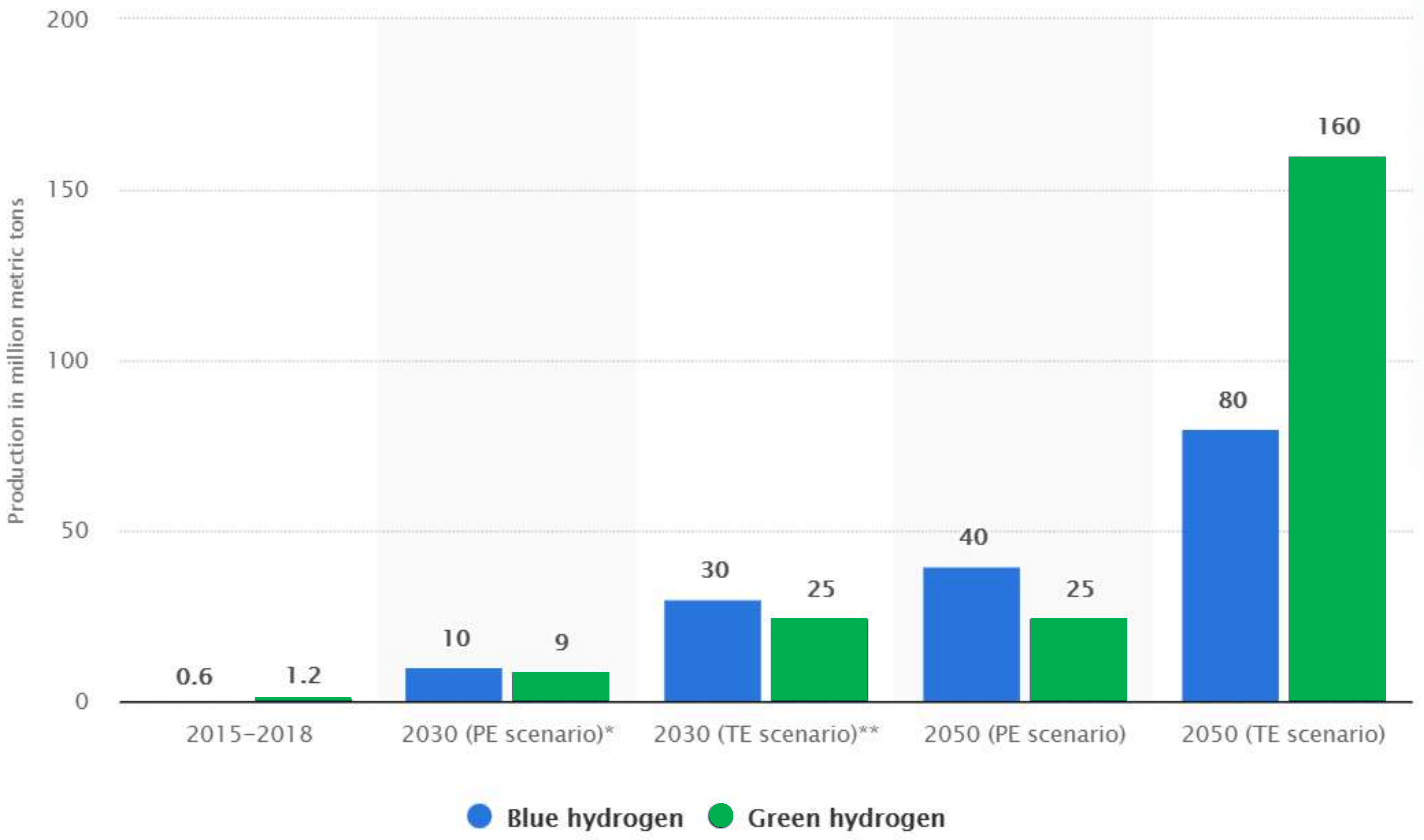
6.0 Hydrogen Production

Hydrogen Production Trends



Source: IEA

6.0 Hydrogen Production



PE – Planned Energy Scenario

TE – Transforming Energy Scenario

Source: Statista.com

7.0 Hydrogen Production - Challenges

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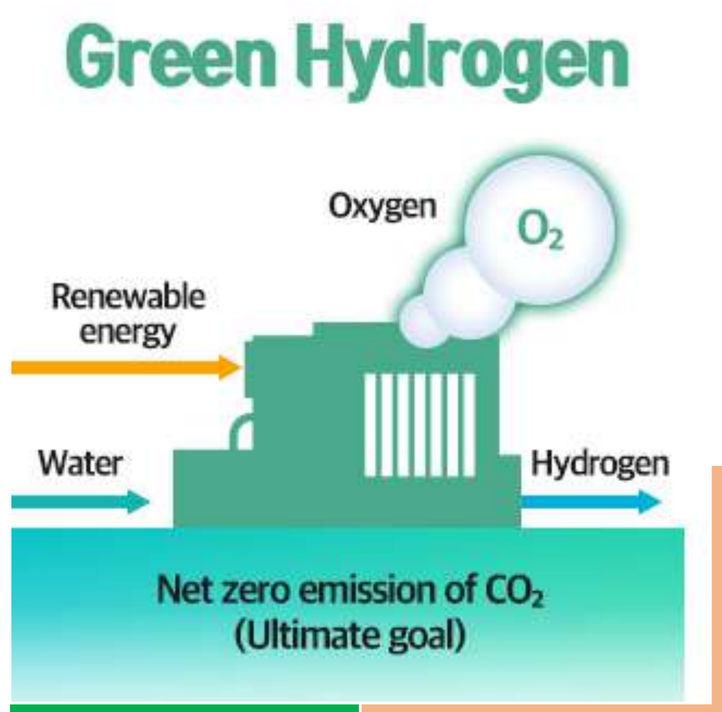


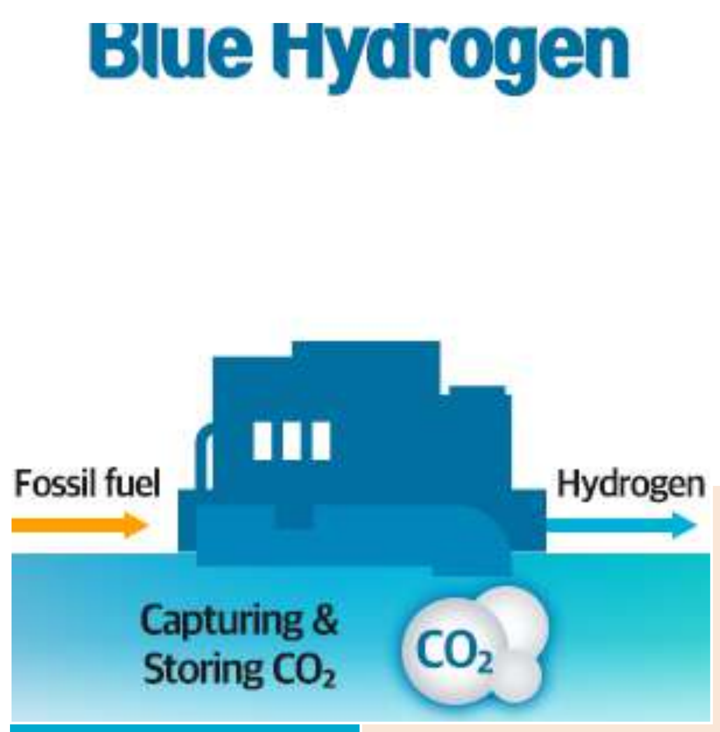
Green Hydrogen Production

➢Electrolysis of Water

- Higher overall scale up cost
- Cost and durability of membranes
- Cost and feasibility of novel and durable thermochemical & photoelectrochemical materials
- Lower efficiency and reliability of electrolysers
- Higher electricity production cost

➢Biomass/Waste Gasification

- Lower Conversion efficiency
- Separation of hydrogen after conversion
- Catalyst activity and performance
- High Pre-treating cost
- Higher transportation cost
- Lower Percentage yield of hydrogen



Blue Hydrogen Production

➢Natural Gas Conversion with CCUS

- High Cost of Hydrogen production with CCUS
- High Capex for carbon capture facilities
- Process Control challenges
- CO2 storage & utilization
- High energy & balance of plant requirements

➢Coal Gasification with CCUS

- High Cost of Hydrogen production with CCUS
- High Capex for carbon capture facilities
- Process Control Challenges
- CO2 storage and utilization
- High energy & balance of plant requirements
- Coal quality and pre-treatment costs
- Waste Disposal and environmental impact

7.0 Hydrogen Storage - Challenges

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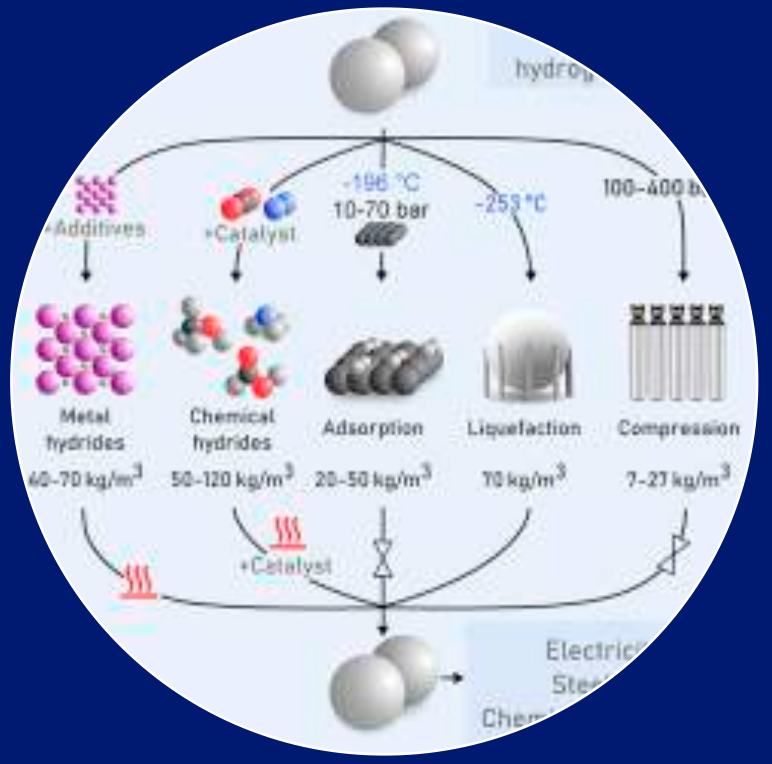
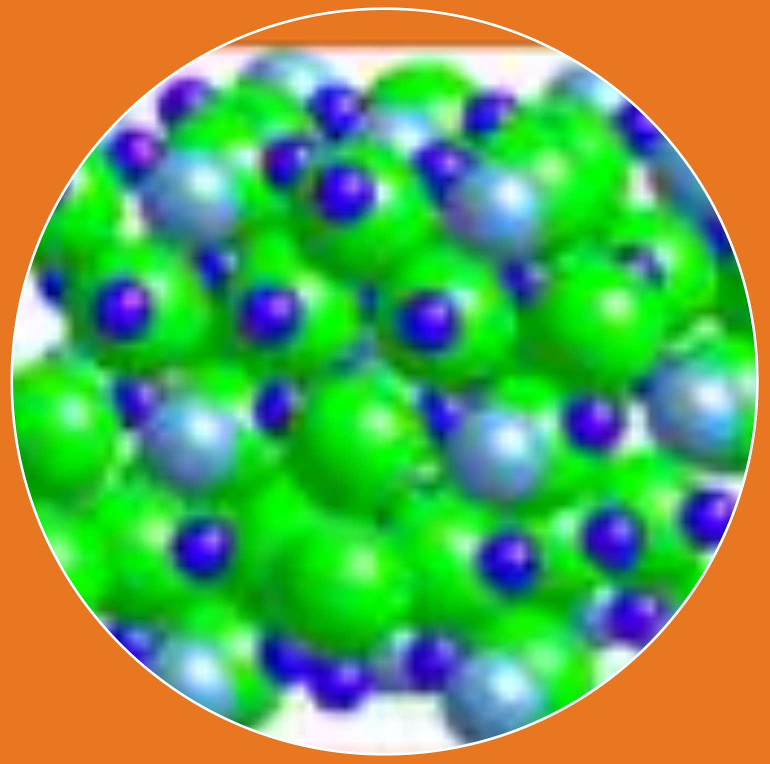


HYDROGEN STORAGE CHALLANGES

- Low Volumetric energy density
- High energy requirement for Liquefaction

Cryogenic Pressurised/ Atmospheric Storage

- Low capacity
- High Cost
- Insulation technology to reduce BOR
- Material durability & Safety
- Low cost technology options for high pressure tanks



Material Based Storage

- Storage materials to meet weight, volume, kinetics, and other performance requirements
- Round-trip efficiency using chemical hydrogen carriers
- Low TRL for dehydrogenation efficiency and catalyst activity
- Purity of Liberated hydrogen to be used in Fuel cell

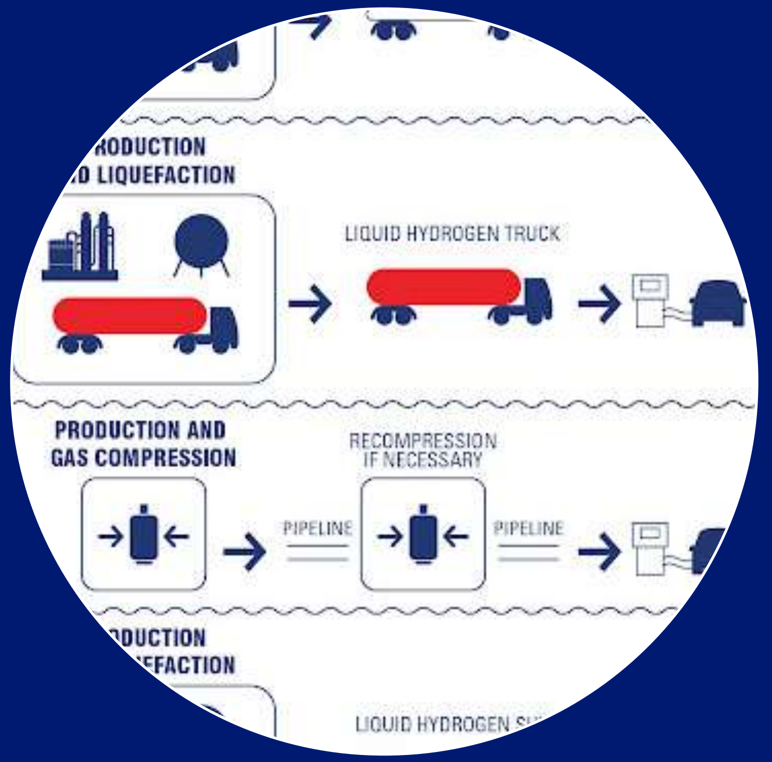
Ammonia Based Storage

- Ammonia Cracking is Low TRL Technology
- High Energy requirement for cracking process
- High Capex for Hydrogen separation after decomposition
- Toxic nature of ammonia and safety requirement for handling ammonia in urban areas

Methanol Based Storage

- Existing production method is Carbon Intensive
- Synthetic Green Methanol Production is low TRL technology
- High Capex

7.0 Hydrogen Transport - Challenges



HYDROGEN TRANSPORT CHALLANGES

- Low Volumetric energy density
- Cost & Safety

Liquid Hydrogen Transport

- Low capacity & high capex
- High Liquefaction Cost
- Insulation technology to reduce BOR during transport
- Material durability & safety for cryogenic storage
- Low cost carbon fibre technology options for high pressure tanks
- Infrastructure cost & Safety

Other forms of Transport

- Storage materials to meet weight, volume, kinetics, and other performance requirements
- Large Scale transport deployment yet to be tested
- Large Capex with increasing hydrogen transport volumes

Ammonia Based Transport

- Environmental and safety risks for handling and transporting ammonia

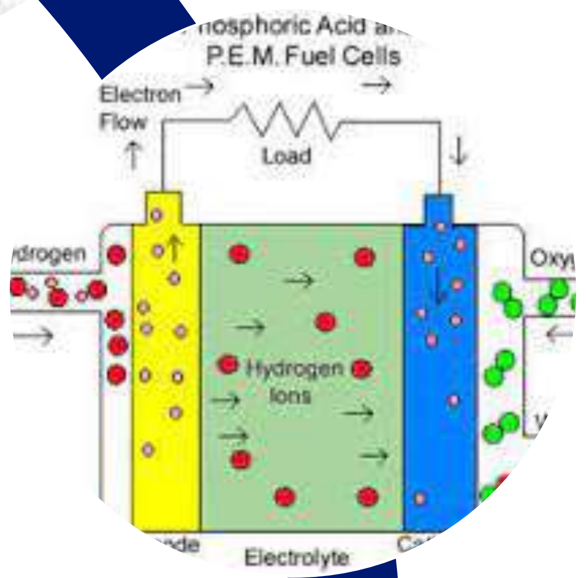
Methanol Based Transport

- Environmental and safety risks for handling and transporting methanol

7.0 Hydrogen Usage - Challenges

Hydrogen Usage Challenges

Power Generation (CCGT)
- Potential uncertainty in 100% H2 CCGT technology commercialisation timeline
- CAPEX associated with turbine due to higher combustion temperatures



Fuel Cells (Vehicles)
- High Capex requirement
- Large Footprint for heavy vehicles
- Hydrogen Filling System
- Safety & Robustness

Maritime Fuel
- High Cost of Green Hydrogen
- Fuel and bunkering needs infrastructures investments
- Novel power generation system requirement to burn hydrogen
- High Capex to store liquid hydrogen
- Material Challenges for storage

Ammonia & Synthetic Methanol
- LOW TRL for Ammonia decomposition technology
- HIGH Capex for Synthetic fuel like methanol from green hydrogen and CCUS cost involved

8.0 Case Study: 100 MW Power Generation

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Basis for Study:

Comparison between LNG & Liquid Hydrogen Fuel for a 100 MW power generation facility

	LNG	Liquid Hydrogen
Storage Temperature	-160 ^{0}C	-253 ^{0}C
Storage Pressure	Ambient	Ambient
Composition (mol%)	Methane – 99.86 % Ethane – 0.01%, Nitrogen – 0.13%	Hydrogen – 99.0 % Nitrogen – 1.0 %
Boil Off Rate	0.04 volume%/day	0.2 volume%/day
Lower Heating Value	55 MJ/kg	120 MJ/kg
Recirculation Return Temperature	5˚C	5˚C
Ambient Air temperature	37˚C	
Relative Humidity	85%	

8.0 Case Study: 100 MW Power Generation

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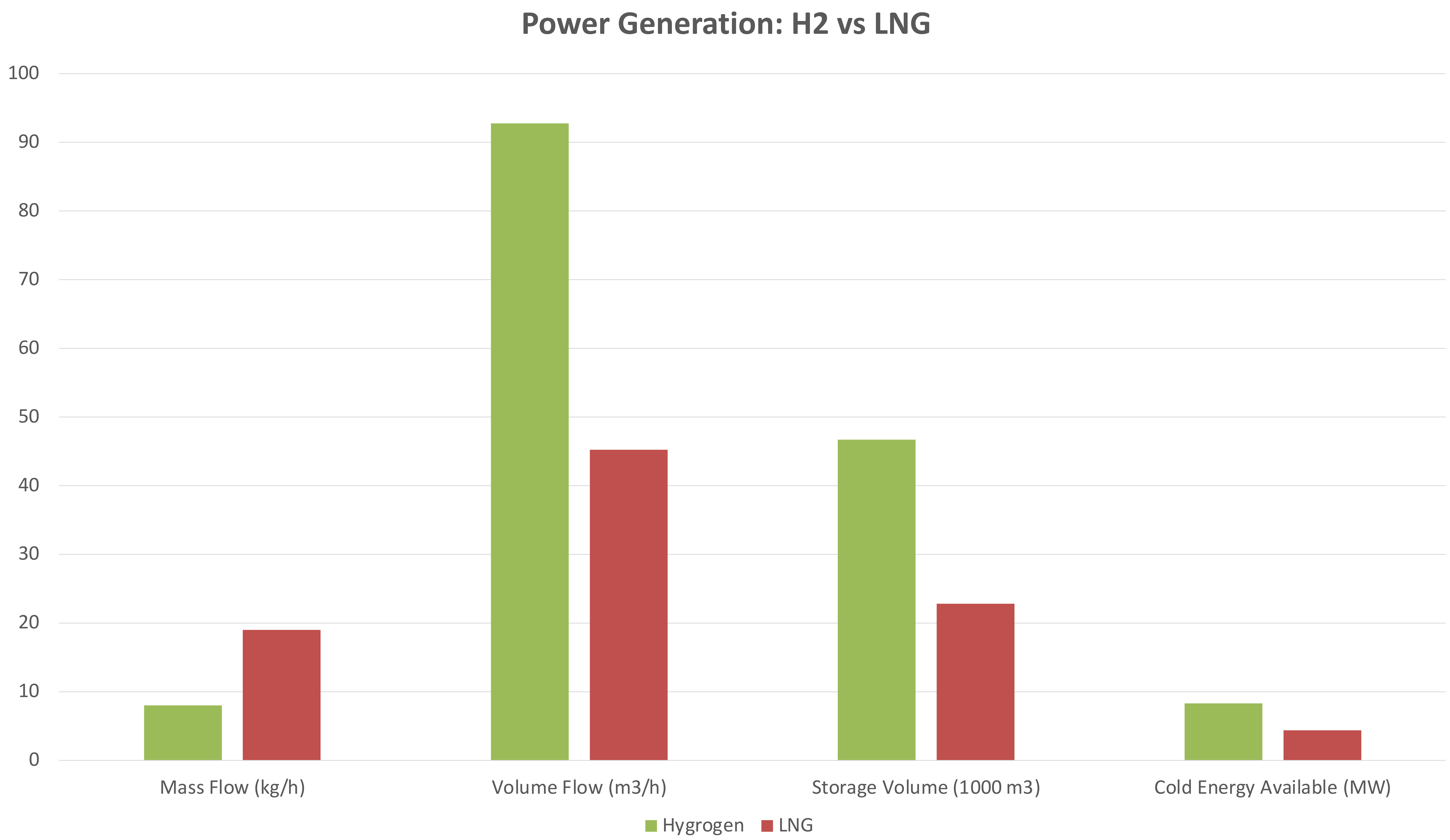


8.0 Case Study: Transportation Comparison

Liquid Hydrogen (LH2) Carrier – 160,000 m^3

Additional Trips – 2.5

LNG Carrier – 160,000 m^3

Additional Trips – 1.75

Ammonia as Hydrogen Carrier – 160,000 m^3

Green/Blue Hydrogen cost to come down to 5 times of existing price i.e. < 2 USD/kg

Green/Blue Ammonia cost to come down to 3.8 times of existing price i.e. < 250 USD/kg

9.0 Process Safety

KEY CONSIDERATIONS:

- Hydrogen is highly flammable and burns with invisible flame, therefore it is difficult to detect the fire with CCTV
- Very wide range of flammability (LFL = 4%, UFL = 74%)
- Adequate Ventilation is required for Storage and Handling
- For purging requirements, Helium gas is recommended over Nitrogen.

HAZARDS ASSOCIATED WITH H_2 FIRE:

- Fire
- Explosion
- Asphyxiation
- Exposure to extremely low temperature (Cold Burns)

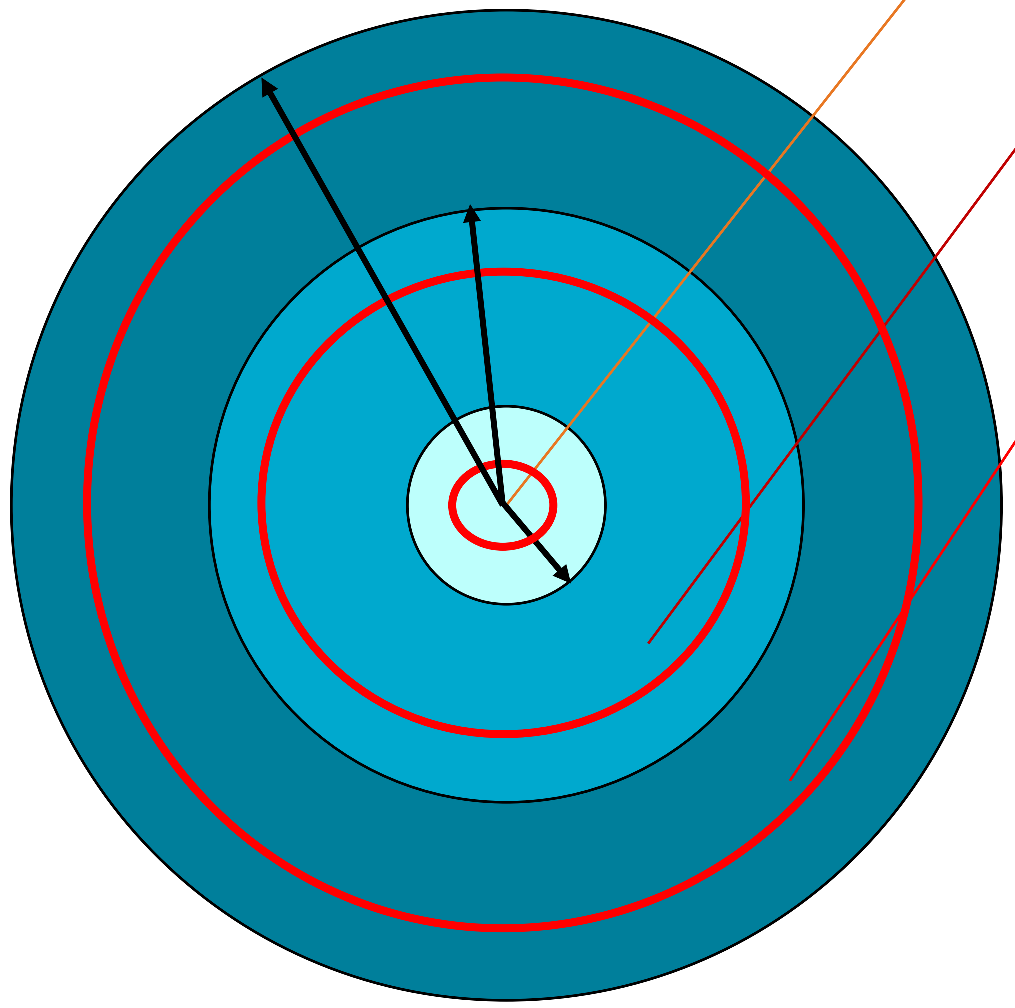
FIRE FIGHTING MEASURES:

- The most effective way to fight a hydrogen fire is to shut off the flow of gas.
- Dry Chemical Powder can be used to extinguish the fire

9.0 Process Safety- Typical Safety Distance

- DISPERSION LIMITS:

10 MM Leak

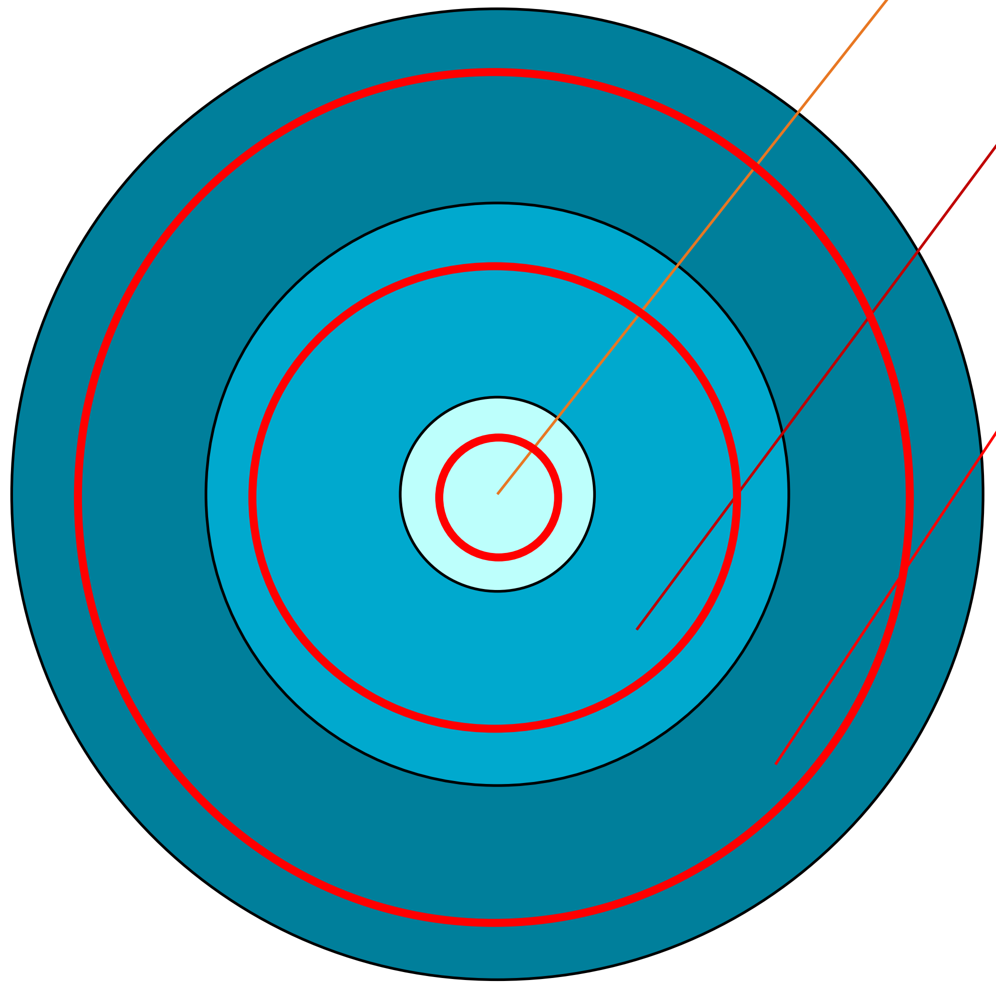


Category 1F
- Distance to UFL (m)= 2
- Distance to LFL (m)= 25

Category 2B
- Distance to UFL (m)= 2
- Distance to LFL (m)= 27

Category 3 C
- Distance to UFL (m)= 2
- Distance to LFL (m)= 28

25 MM Leak

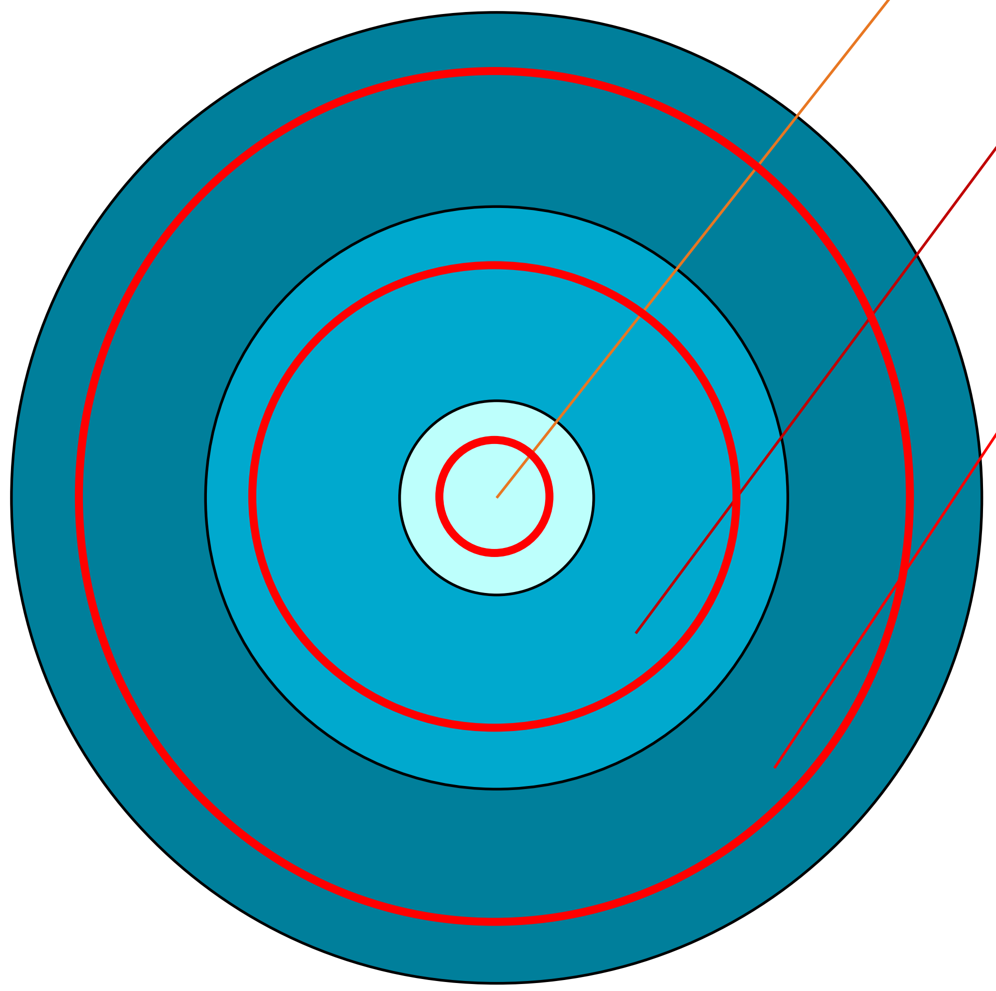


Category 1F
- Distance to UFL (m)= 6
- Distance to LFL (m)= 49

Category 2B
- Distance to UFL (m)= 5
- Distance to LFL (m)= 52

Category 3 C
- Distance to UFL (m)= 5
- Distance to LFL (m)= 54

75 MM Leak



Category 1F
- Distance to UFL (m)= 18
- Distance to LFL (m)= 119

Category 2B
- Distance to UFL (m)= 16
- Distance to LFL (m)= 120

Category 3 C
- Distance to UFL (m)= 16
- Distance to LFL (m)= 121