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Hybrid renewable-hydrogen energy systems and their role in the energy transition.

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2024

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Hybrid Renewable-Hydrogen Energy Systems and their Role in the Energy Transition

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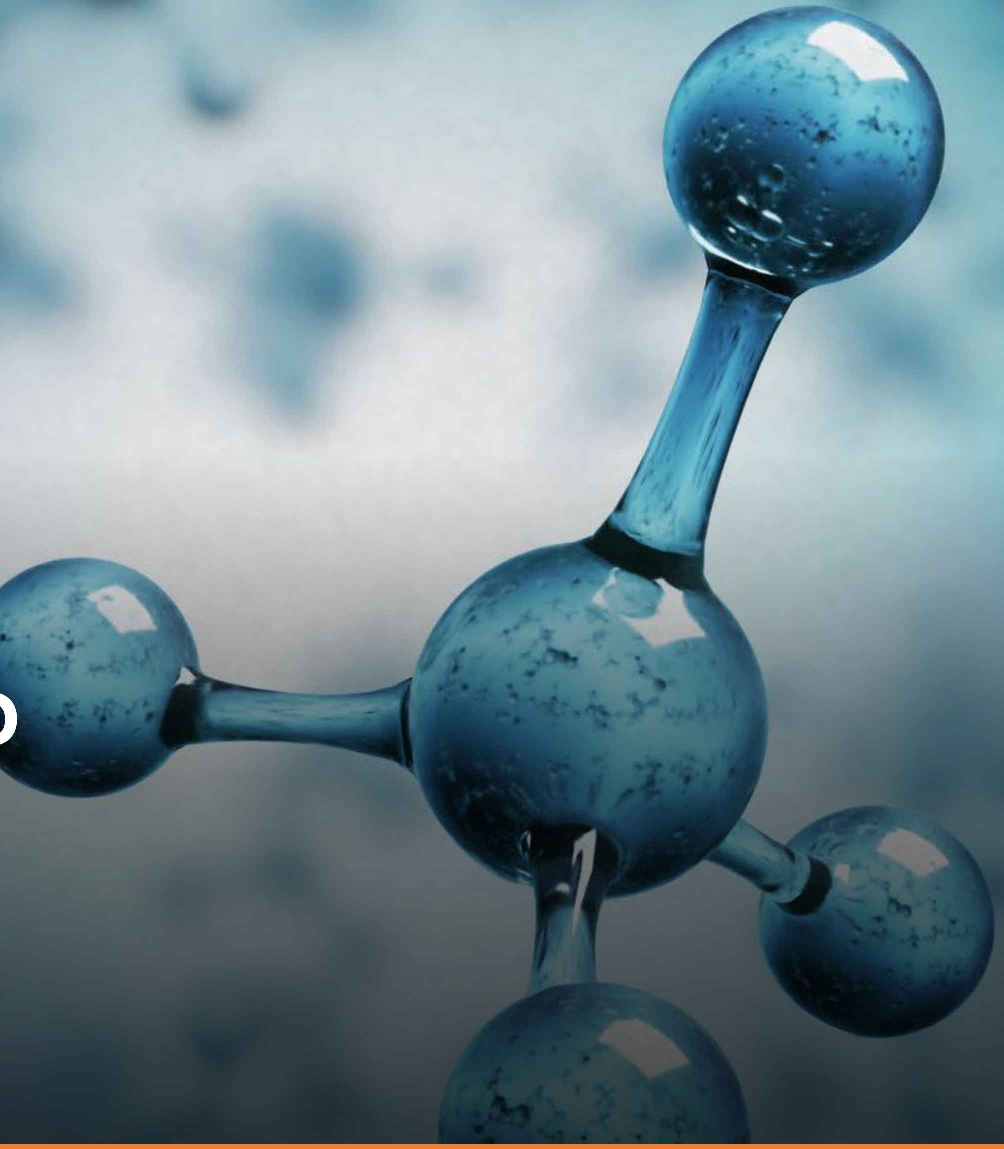
Outline

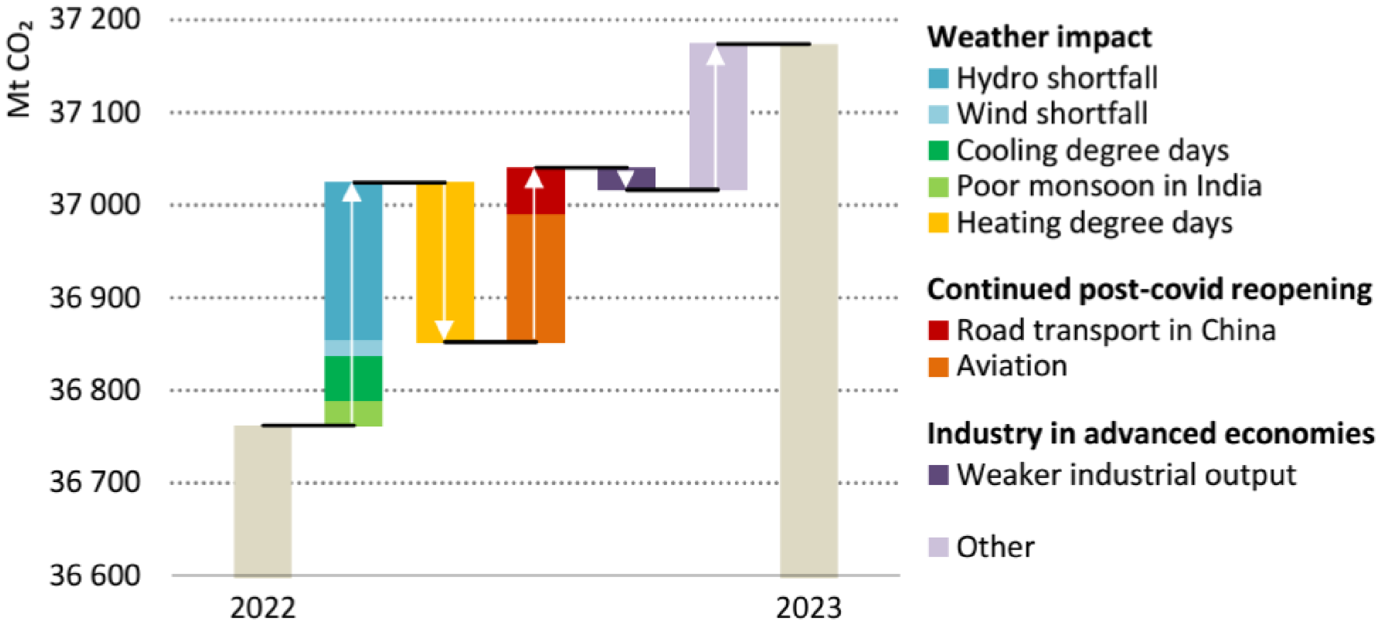
- Why Hydrogen ?
- Hydrogen Production and Color Code Nomenclature
- Hydrogen Potential in Supporting the Scottish Net Zero Energy Transition
- Renewable-Hydrogen Energy Storage Systems
- Hybrid Renewable-Hydrogen Energy Systems – Case Studies
- Conclusion

Why Hydrogen?



Emissions Brief (IEA CO2 Emissions Analysis 2023)

- Global energy-related CO2 emissions grew by 1.1% in 2023, increasing 410 Mt to reach a new record of 37.4 Gt. Emissions from coal accounted for more than 65% of the increase in 2023.
- The global shortfall in hydropower generation due to droughts drove up emissions by around 170 Mt. Between 2019 and 2023, total energy-related emissions increased around 900 Mt.



Environmental Concerns

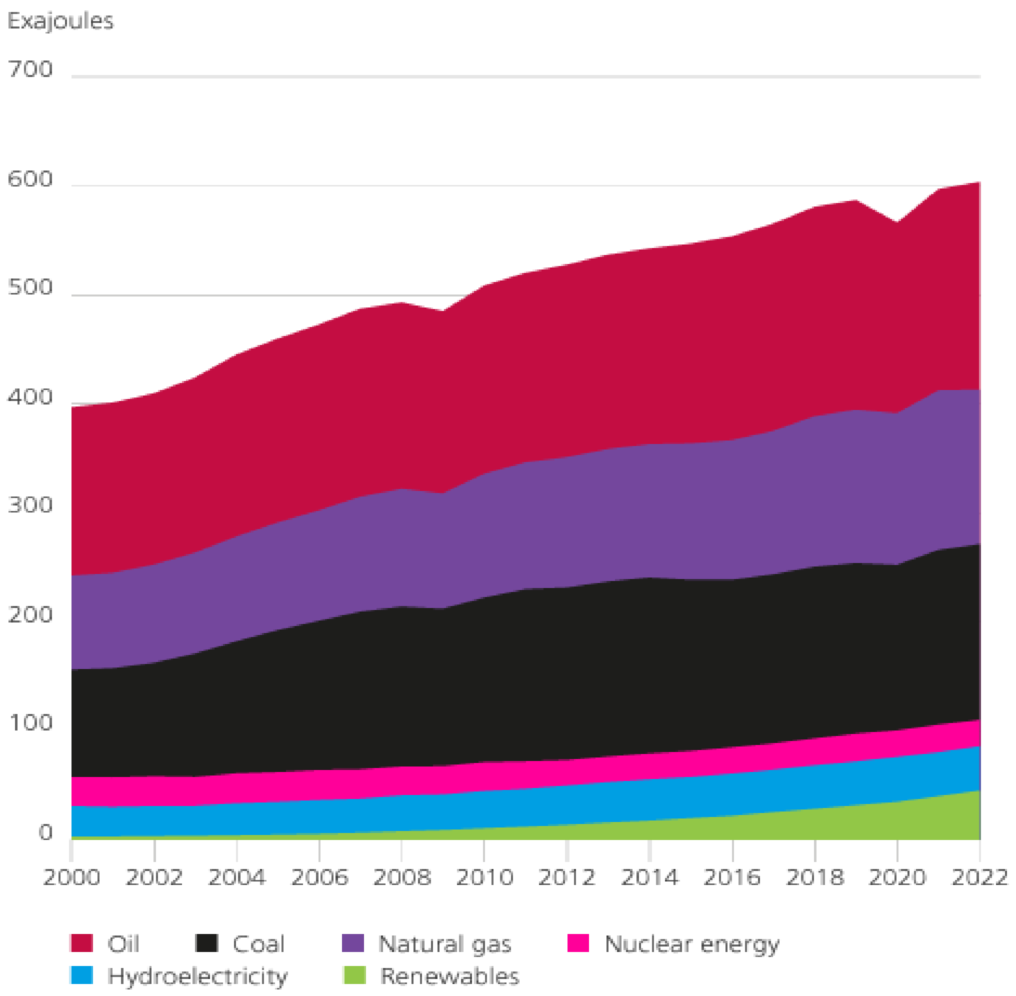
- Air Pollution (causing health issues)
- Water Contamination (affecting humans, animals & plants using it)
- Land Degradation or destruction from human activities. (this lessens the quality and/or productivity of the land for agriculture, forestation, construction, etc.)

  Note that the air, water and soil pollution raise public health issues and require many years to recover.
- Climate Change (destructive impacts include, but are not limited to, melting of polar ice, change in seasons, new illnesses, and change in the general climate situation).
- Global Warming (this results from the fossil fuel GHG emissions)
- Effect on Marine Life (affecting shellfish and microscopic fish)
- Ozone layer Depletion (loss of earth protection from the sun unsafe beams)

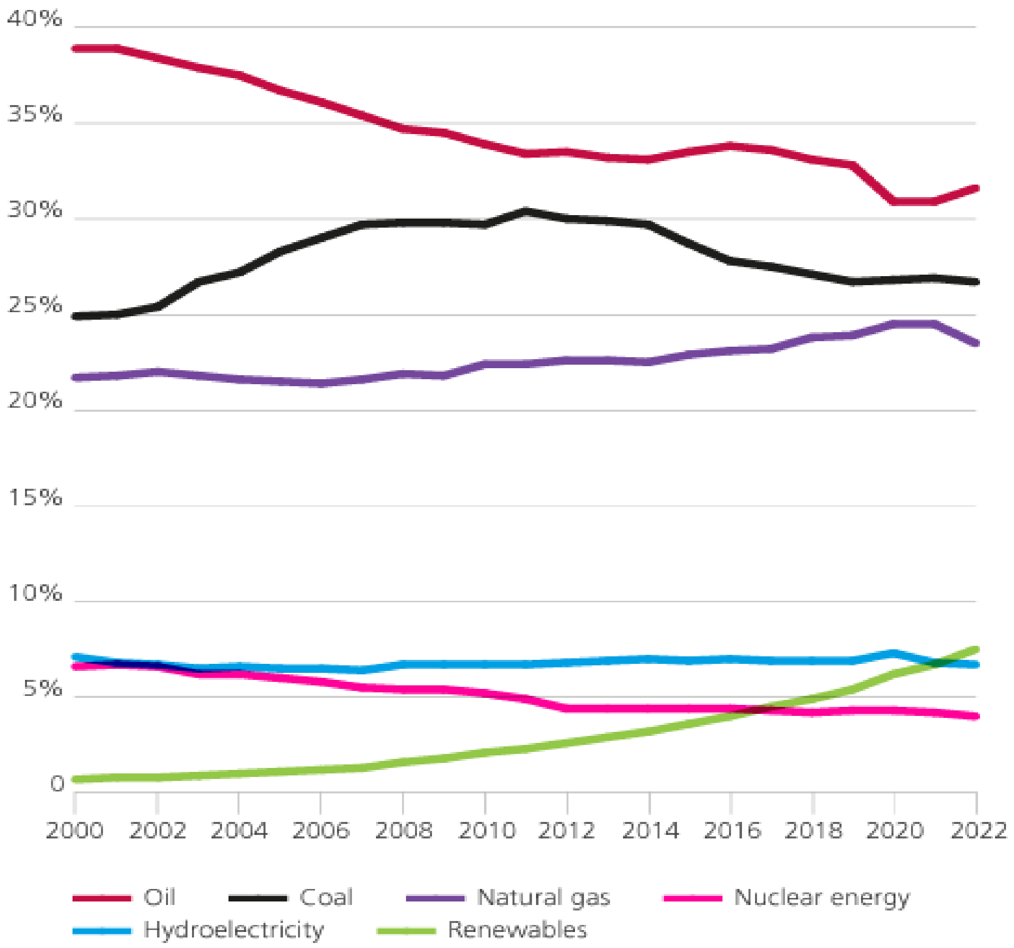

WWF
CLIMATE RISKS: 2°C GLOBAL WARMING
18% of insects
16% of plants
8% of vertebrates
lose over half of their climatically determined range
170% increase in flood risk
2.7 BILLION people exposed to severe HEAT WAVES every 5 years
410 M urban residents exposed to severe drought by 2100
Ice-free summers in the ARCTIC OCEAN every 10 years
Declining ocean productivity substantially lower at 1.5°C than at 2°C
49 M people impacted by 56cm SEA-LEVEL RISE by 2100
>99% loss of the world's CORAL REEFS
Lower economic growth at 2°C than at 1.5°C, particularly low-income countries
Lower yields and nutritional content of cereal crops in tropical regions
Source: IPCC Special Report on 1.5°C global warming (2018)

Global Energy Consumption

World consumption

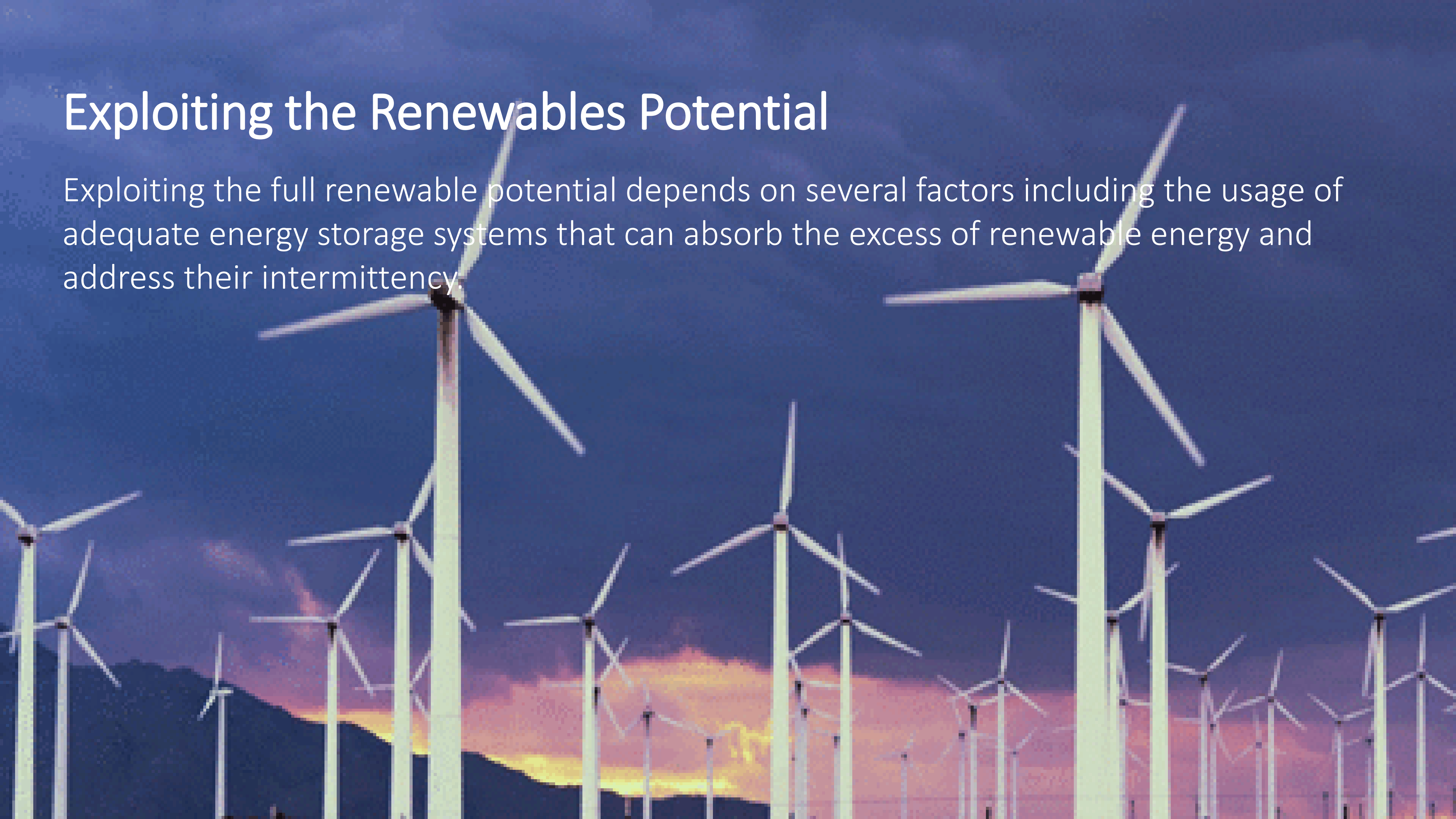


Share of global primary energy



Exploiting the Renewables Potential

Exploiting the full renewable potential depends on several factors including the usage of adequate energy storage systems that can absorb the excess of renewable energy and address their intermittency.



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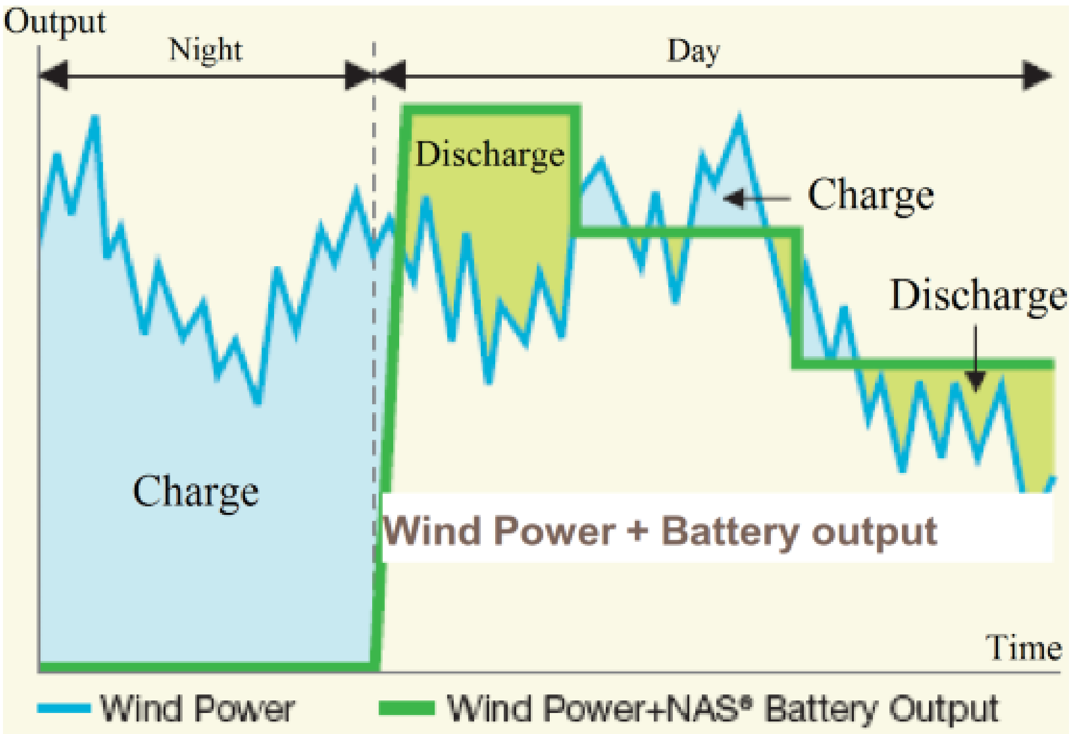
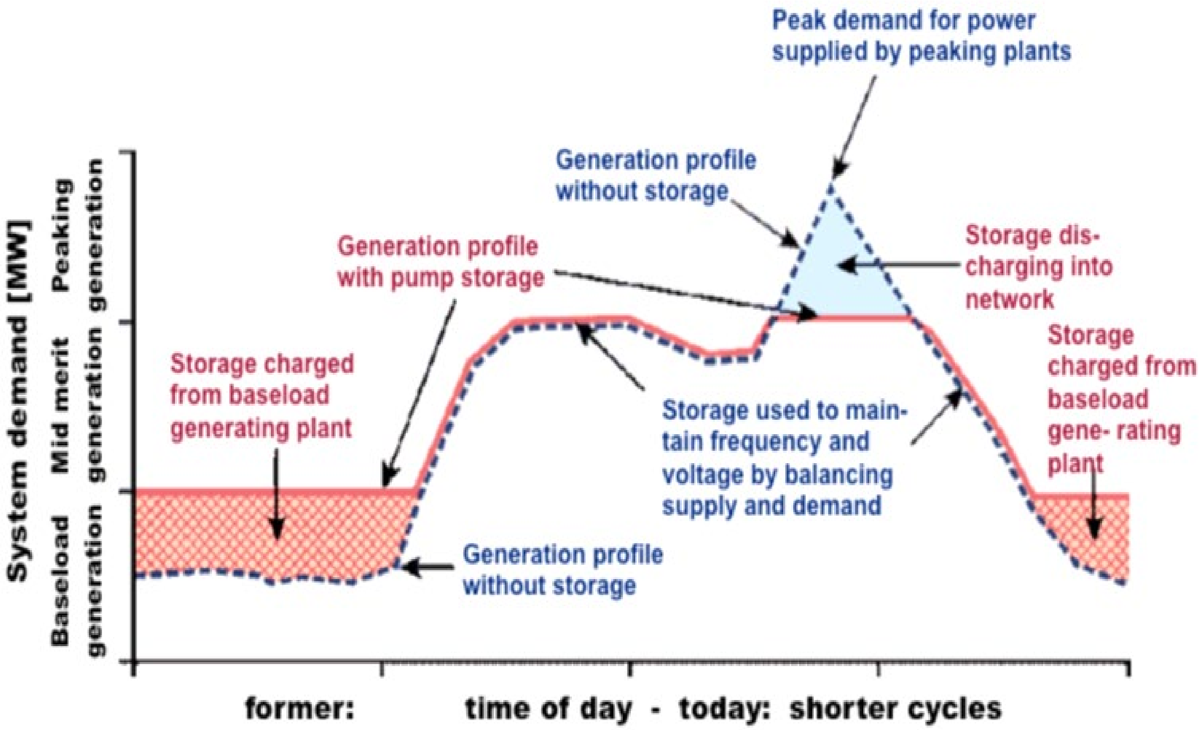
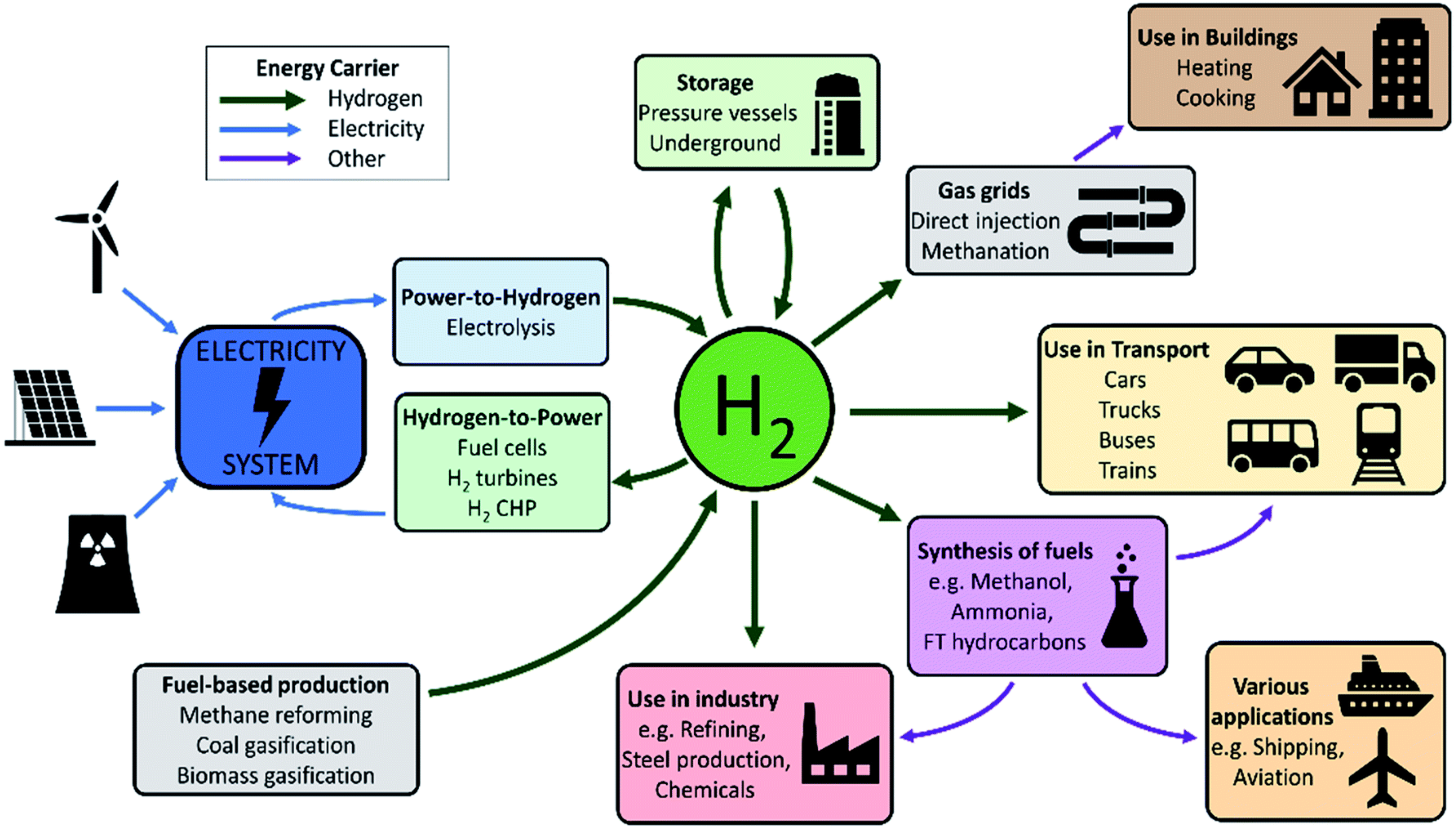
The need for Energy Storage Systems



Implementing Energy Storage with Renewables to address their intermittency and facilitate their High Penetration into grid



Implementing Energy Storage with Power plants for balancing the generation profile and avoid running peaking plants


Energy Carrier
Hydrogen
Electricity
Other
Storage
Pressure vessels
Underground
Use in Buildings
Heating
Cooking
Gas grids
Direct injection
Methanation
Power-to-Hydrogen
Electrolysis
ELECTRICITY
SYSTEM
Hydrogen-to-Power
Fuel cells
H_2 turbines
H_2 CHP
H_2
Use in Transport
Cars
Trucks
Buses
Trains
Synthesis of fuels
e.g. Methanol,
Ammonia,
FT hydrocarbons
Fuel-based production
Methane reforming
Coal gasification
Biomass gasification
Use in industry
e.g. Refining,
Steel production,
Chemicals
Various
applications
e.g. Shipping,
Aviation

Hydrogen Production and Colour Code Nomenclature

H2 Production

- H2 gas is currently produced from a variety of primary fossil energy sources such as natural gas, naphtha, heavy oil, coal and water. H2 can be environmentally friendly only if the energy used in its production is clean' renewables.
- Most of the world H2 production comes from steam reforming (SR) of natural gas. Other comes from higher hydrocarbons reforming, coal gasification, and from water electrolysis. CO_2-neutral H2 can be produced by the conversion of biomass via gasification, pyrolysis of bio-oils, SR of biomass-derived higher alkanes and alcohols, and APR of oxygenated hydrocarbons
- Steam reforming of methane and light hydrocarbons involves three reactions, namely, the splitting of hydrocarbons with steam, the water–gas shift, and the formation of methane.
- Gasification of coal and heavy hydrocarbons involves the reaction at high temperatures (1200–1400 K) and moderate pressure (5–10 bar) of the carbon source with a source of hydrogen, usually steam and/or oxygen.
- Water electrolysis is one of the easiest methods for hydrogen production although it is relatively expensive technology. If relatively small quantities of hydrogen are required, on-site electrolysis of water may result more economical than other methods. This technique is very clean and produces more than 99.989% purity of hydrogen gas. In addition, electrolysis can be linked to renewable electricity-producing technologies and hence could become even more important in the future.

White H2 refers to the naturally occurring H2 (rarely) found in underground deposits. Thus, different processes are used to generate H2 artificially.

Grey H2 accounts for most of the production today and emits about 9.3 kg of CO2/kg of H2 production.

Black/Grey Hydrogen

- Black H2 produced from coal gasification; Grey H2: produced via steam reforming of natural gas or methane
- 100% carbon emissions

Blue Hydrogen

- Blue H2 produced from steam reforming of methane or natural gas while utilizing CCS to negate emissions with 85-95% efficiency

Green Hydrogen

- Green H2 produced using renewable energy in electrolysis
- Zero-carbon emissions, ideally suitable for green energy transition

Pink Hydrogen

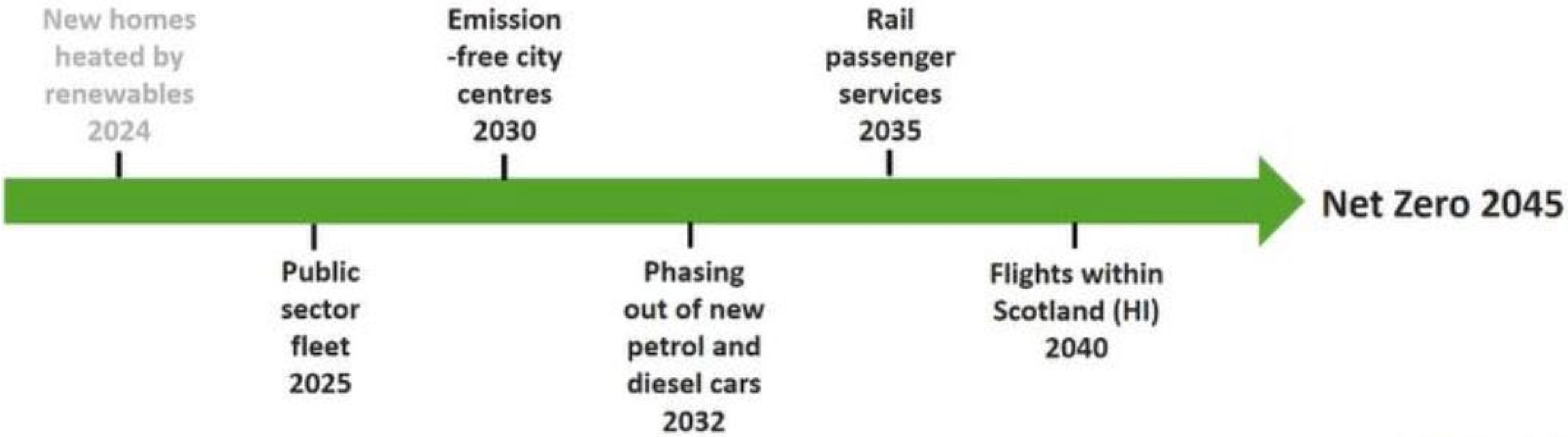
- Pink H2 produced using nuclear energy in electrolysis
- Zero-carbon emissions. Not commercialized yet

Hydrogen Potential in Supporting the Scottish Net Zero Energy Transition

Implementing green H2, as a form of energy storage with renewables, can support the Net Zero transition of many end-users while addressing the renewables' intermittency

Scottish Government Timeline for Decarbonisation

- Scotland set an ambition to support the development of 5GW of renewable and low-carbon hydrogen production by 2030 and 25GW by 2045.
- Scotland's unique selling points to become producer of lowest cost hydrogen in Europe by 2045 are its energy natural resources, infrastructure and skilled energy workforce.
- Scotland supports demonstration, development and deployment of hydrogen for decarbonisation of critical industry functions and processes, transport and heat.



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From Where Scotland can get the Needed H2?

Scotland has:

- Significant offshore wind resources to produce Green H2 from Renewables by electrolysis at scale (Timeframe 5-20 years)
- Industrial Carbon Capture, Utilization and Storage (CCUS) for producing Blue H2 from methane reforming (Available now)

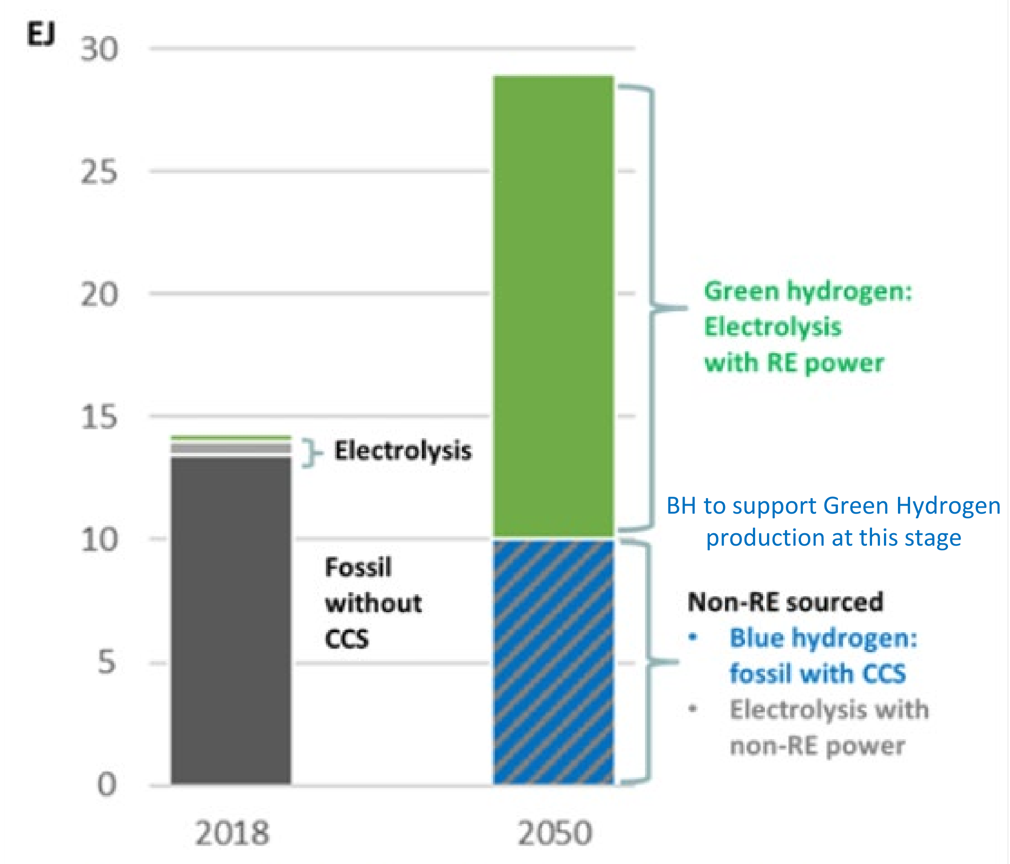


Figure – Role of clean hydrogen in IRENA Remap scenario. Source: IRENA

H2 Potential in decarbonizing the hard-to-abate sectors

- H2 holds a great potential in decarbonizing hard-to-abate sectors such as heavy industry and heavy-duty transport (Transport accounted for 34% of the UK CO2 emissions in 2019).

Aberdeen City Council continues to grow their hydrogen vehicle fleet

H2 trains allow hybrid configurations of batteries and fuel cells thus increasing performance & range

Hydrogen tank and Ballard fuel cell system on CRRC-Sifang light rail - https://blog.ballard.com/fuel-cell-trains

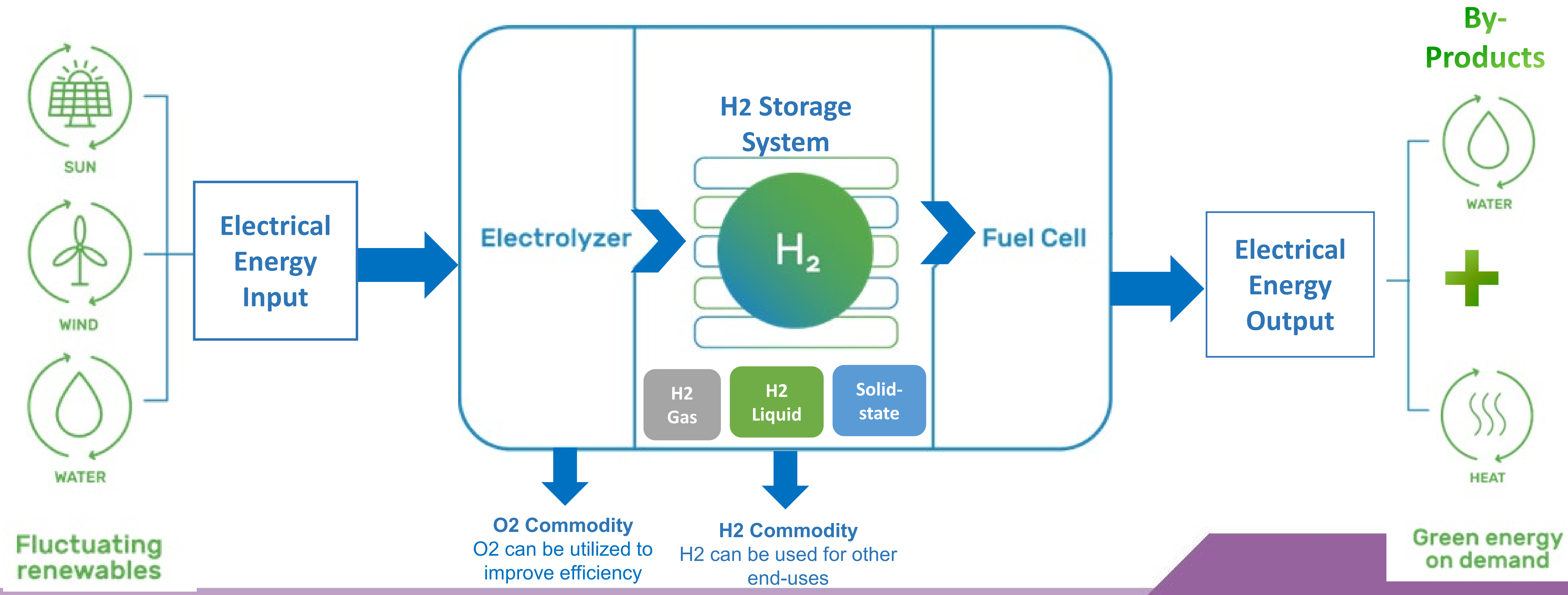
- Fuelling a H2 train is faster than charging a battery-based train.
- H2 trains demonstrated in Europe high-performance and adaptability as diesel-powered trains of similar range while eliminating emissions.
- Electric cars & trains are not essentially clean (electricity source).
- Railway Electrification has high CAPEX and visual impact.
- Deploying Renewable-H2 trains can support the electrical network when integrating large-scale renewables, and help creating new jobs.

Future H2 Markets

- **Market 1 – Ammonia**
  - $48 billions of ammonia sales in 2016 and will reach over $76 billion in 2025
  - Green ammonia by using green H2
- **Market 2 – Methanol**
  - Methanol generates $55 billion/year and creates 90,000 jobs globally.
  - Green methanol by using green H2
- **Market 3 – H2 Trains**
  - The market for H2 trains for the next 30 years is €44 billion for the CAPEX alone
  - H2 trains use fuel cells
- **Market 4 – H2 Boats**
  - Using H2 fuel cell boats
  - Using H2 internal combustion engines
  - New H2 production systems to supply fuel for boats

Renewable-Hydrogen Energy Storage Systems

Renewable-Hydrogen Energy Storage Systems

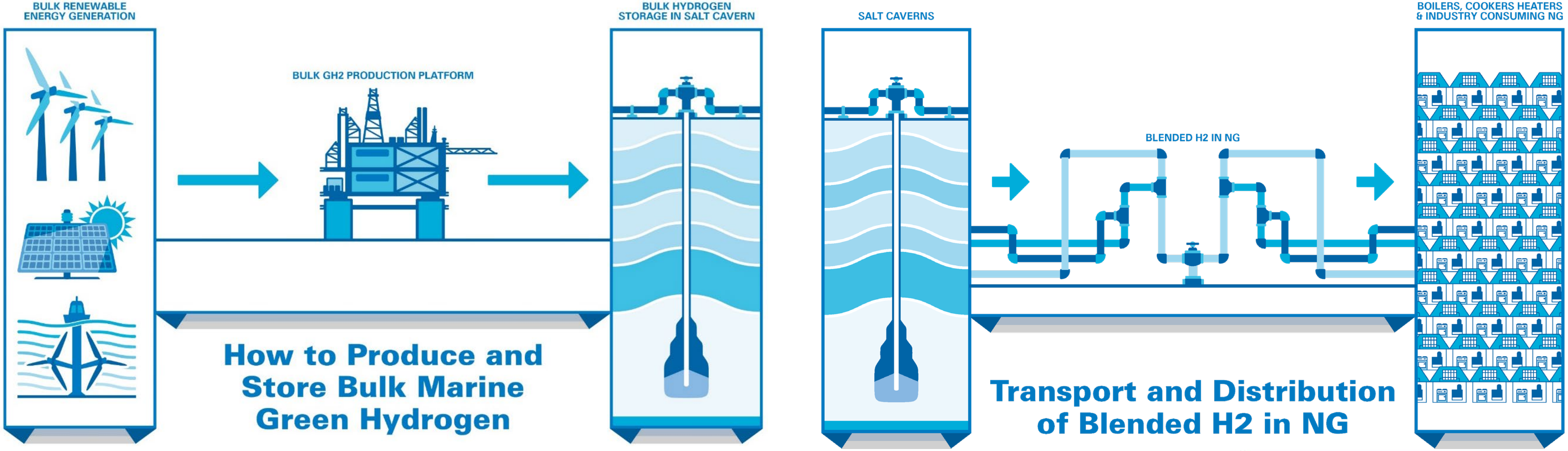


Cost of Renewable/Green Hydrogen

- **Green H2** is **currently more expensive** than conventional H2 produced from fossil fuels
- **Cost of green H2 is falling rapidly** due to combined effects of **reduced electrolyzer cost** and **reduced renewable power costs**
- **Costs associated with CO2 emissions** from fossil fuels could be considered to further **improve the competitiveness of green H2**
- Renewable-H2 **will compete in the next 5 years** with fossil fuels
- Wind-H2 will allow **wind farms with expiring feed-in tariffs/incentives to identify new revenue streams.** Integrating Electrolysers into wind farms will:
    - **Allow CAPEX reduction** by replacing high cost HV infrastructure with pipes network
    - **Increase system efficiency** due to lower HV electrical loses
    - **Increase plant load factor** as electrolyzer load is more flexible than electrical network requirements

Large-Scale Renewable-Hydrogen Production & Storage

- **To fully unlock the potential of renewable-hydrogen, costs of hydrogen technology should be reduced through large-scale implementations**.



Hybrid Renewable-Hydrogen Energy Systems Case Studies

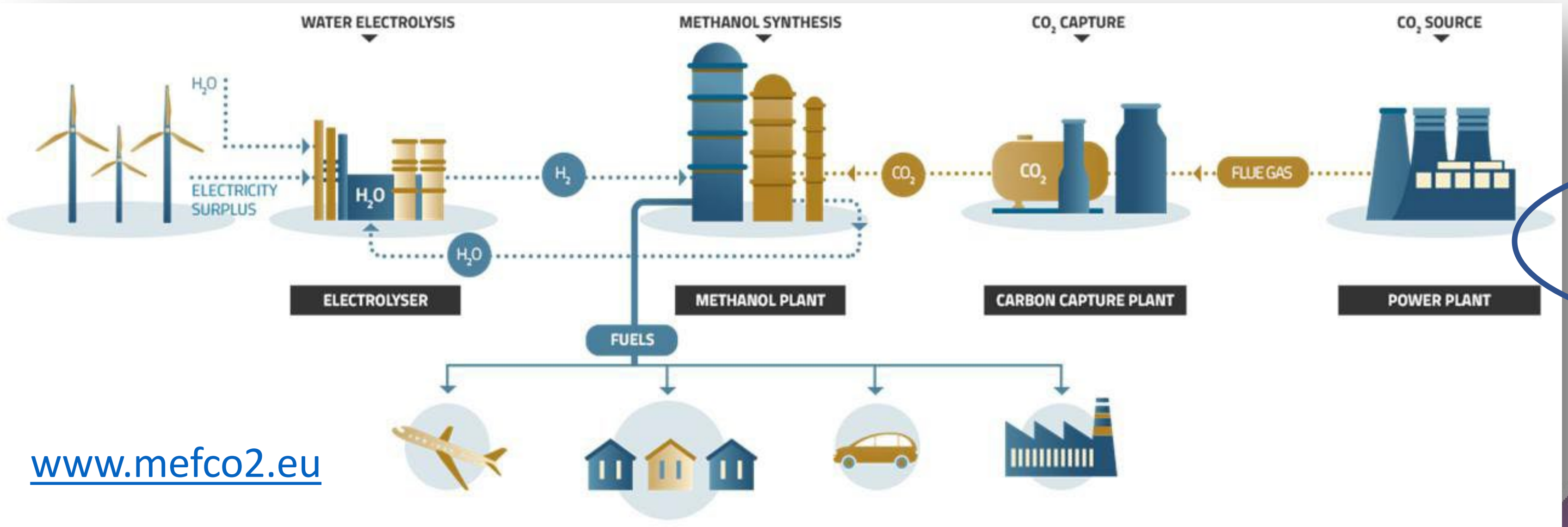
Case Study 1 (Power to Power): Lam Takhong Wind Hydrogen Hybrid Project - Thailand

- Use the curtailed energy from 24 MW wind farm with limited injection capacity
- Implement 1 MW PEM electrolyzer, 3 MWh (10 hours) of compressed hydrogen storage (250 bar), and 300 kW PEM fuel cell
- Use the hydrogen through a 300-kW fuel cell to power the new energy center

Case Study 2 (Power-to-Methanol): Niederaußem - Germany

- Produce **green methanol** as energy vector from captured CO_2 and the hydrogen produced using surplus renewable energy.

- Implement 1x HyLYZER®-200-30 (PEM, single cell stack design) with all peripherals to produce 200 Nm^3/h H_2 (power: 1 MW)



www.mefco2.eu

1MW PEM Electrolyser
CO2 Capture Plant
Methanol Plant

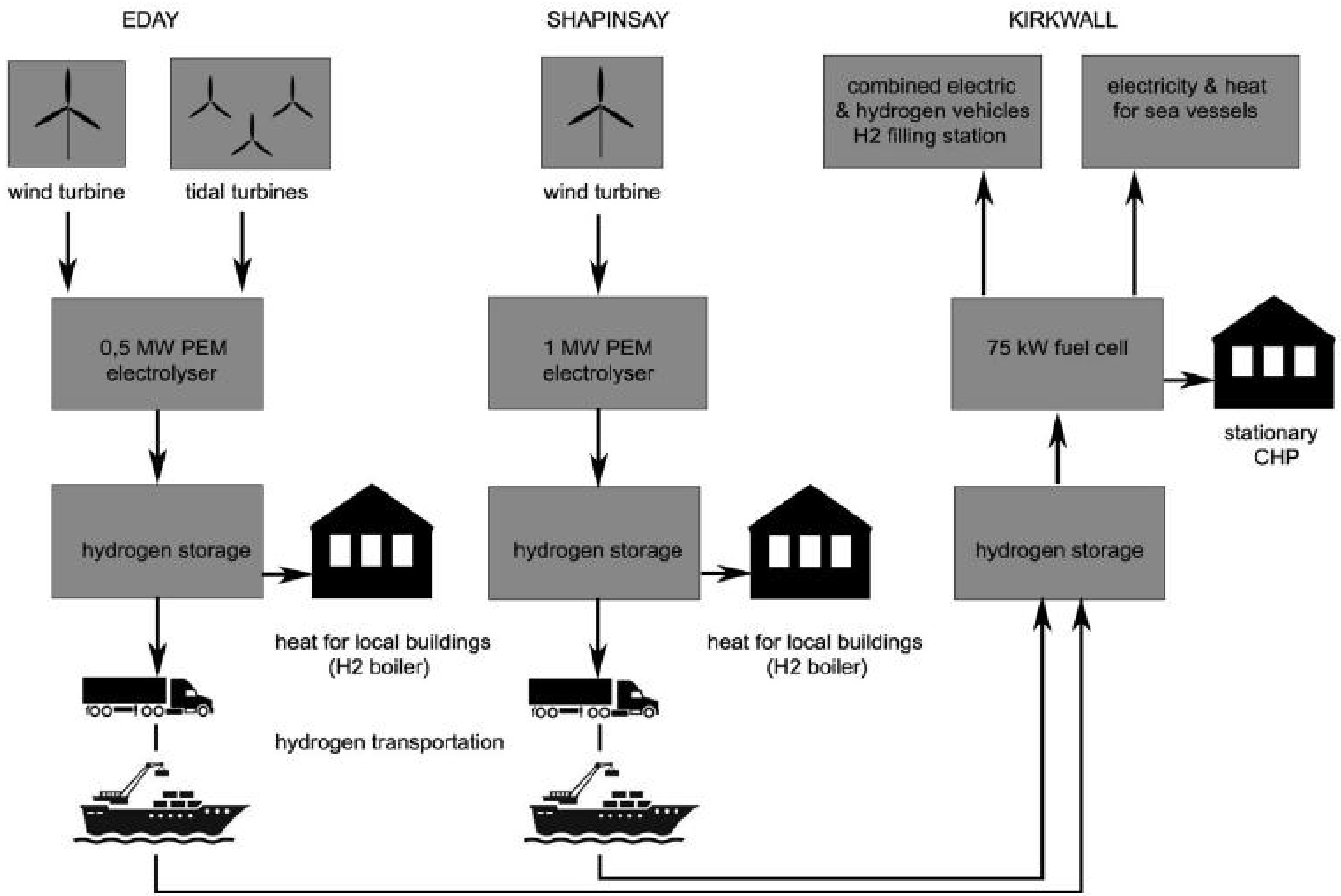
Case Study 3 (Remote operation): Highly flexible Electrolysers - Norway

- A 45 MW wind park implementing 1x HyLYZER®-500-30 (PEM) with all peripherals to produce 400 Nm^3/h H2 (power: 2.5 MW).
- Demonstrate enhanced wind integration through hydrogen storage
- Demonstrate multiple control systems and remote operation (difficult access to grid and upgrading the existing grid infrastructure is very expensive)

More information: www.haeolus.eu

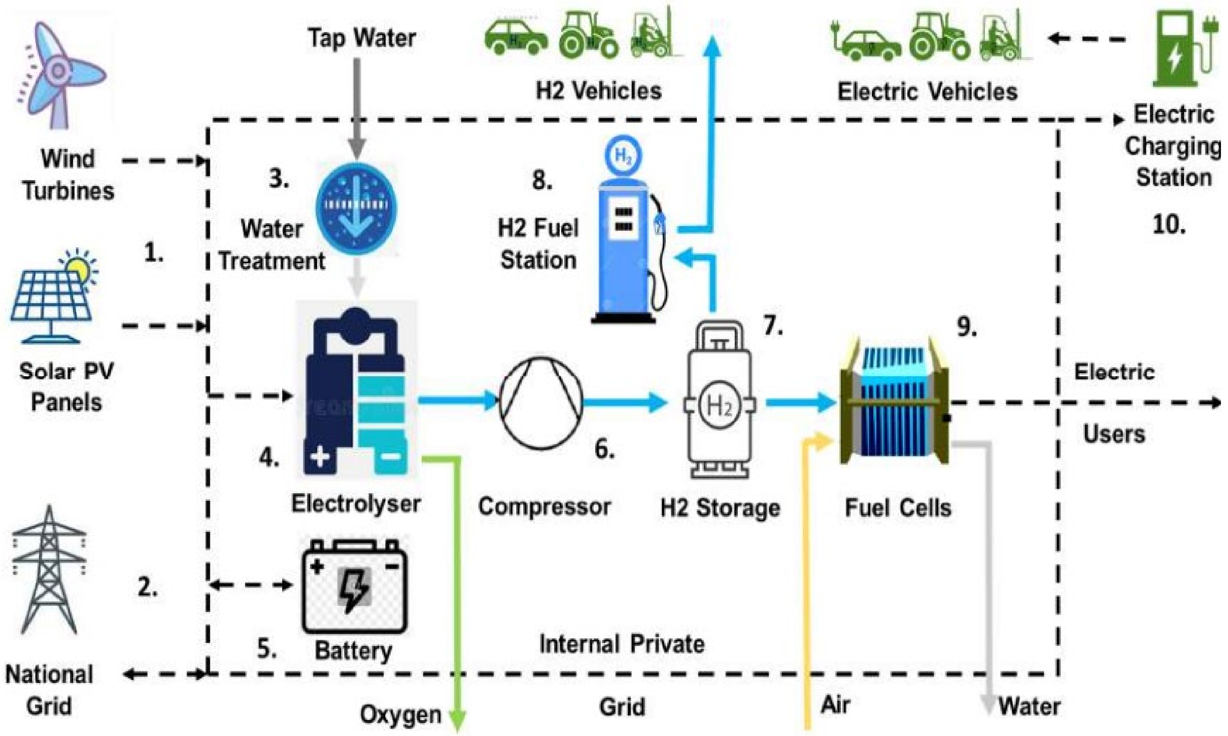
Case Study 4 (Utilizing Curtailed Renewable Capacity): The BIG HIT Project, Orkney/Scotland

- The Orkney Islands have over 50 MW of installed wind, wave and tidal capacity and produce over 100% of their electricity demand from renewables on an annual basis.
- Two PEM electrolysers are used in the islands of Eday and Shapinsay to produce H2 that can be transported to mainland Orkney, or consumed locally, or can be stored to be converted later into heat and power.
- A 75-kW fuel cell is used to convert the stored H2 to heat and power for several harbour buildings and 3 ferries in Kirkwall.



Case Study 5 (Power-to-Power and Fuel): The HydroGlen Project (Glensaugh Aberdeenshire)

- Renewable Generators (Solar PV and Wind)
- Grid Connection with import/export
- Battery (for short term storage of renewables electricity and grid-balancing)
- PEM Electrolyser producing H2 at higher pressure (30 bar)
- H2 Compressor (to 200 bar)
- H2 Storage (modular and scalable, 200 bar gas bottles)
- Hydrogen refuelling station typically operating at 900 bar discharging to vehicle fuel tank at 700 or 350 bar. Refuelling a Hydrogen Fuel Cell Electric Vehicle (FCEV) takes 3-5 minutes like petrol or diesel.
- Hydrogen fuel cells for additional power generation by reconverting hydrogen back to electricity.

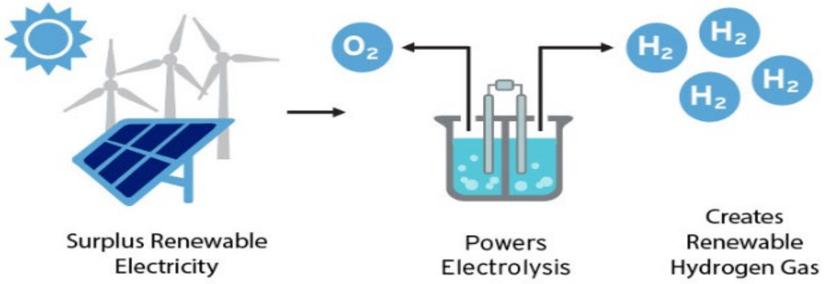


ERM Dolphyn and Source Energie announce plans to develop Gigawatt scale "green hydrogen" floating wind sites in the Celtic Sea

Case Study 7 (Solar Power-to-Power Small-Scale Grid-Connected Building Decarbonization): The Farmhouse Research Project, Scotland

This project aimed decarbonising a grid-connected farmhouse while avoiding its grid power import/export.

- A 24kW/h Solar PV capacity is installed to supply the farmhouse power needs during summer, and the excess in its summer generation is stored in the form of Green H2 to be utilized during winter to reduce/eliminate grid power import/export.
- An electrolyser was sized based on the excess in solar generation during summer for the given PV size and location. H2 storage tanks are sized based on the generated H2 from electrolyser, the storage pressure, and on the storage period.
- The proposed PV-H2 system was simulated to demonstrate the H2 production over the different months based on the PV excess supplied to the electrolyser.

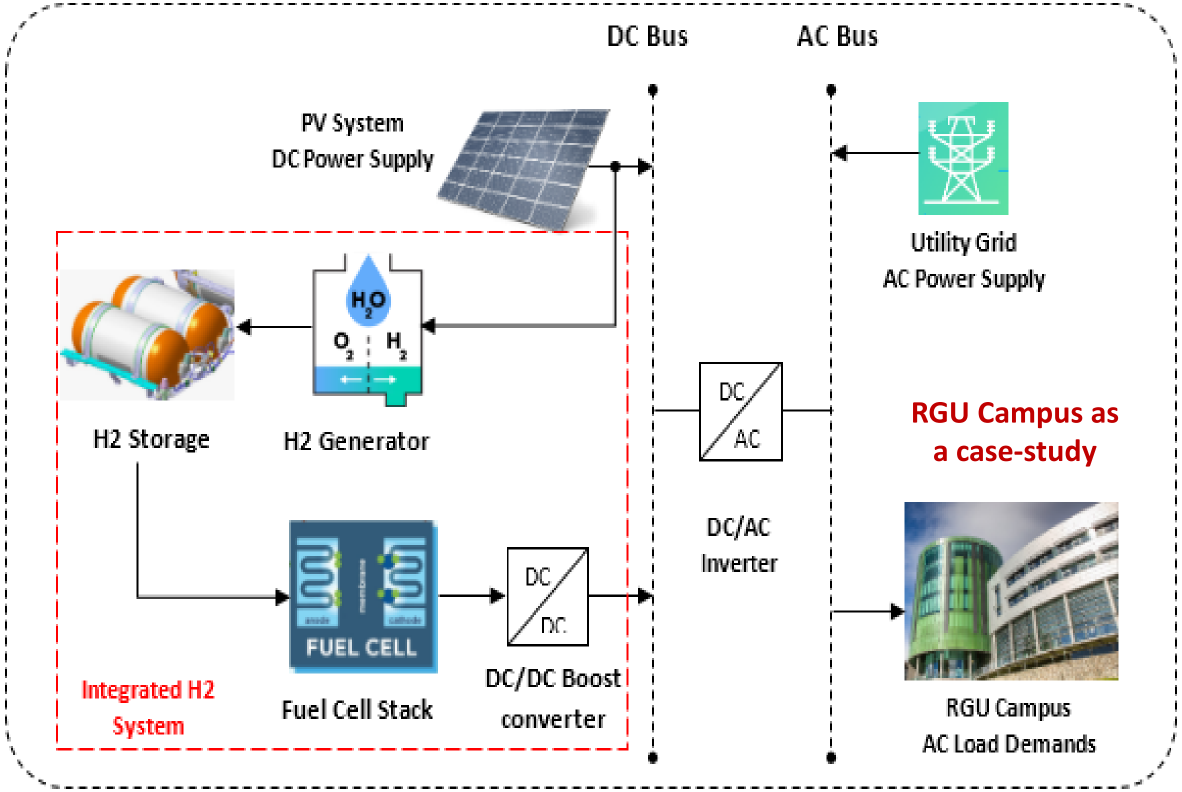


Case Study 8 (Solar Power-to-Power Large-Scale Grid-Connected Building Decarbonization): RGU Campus Research Project, Scotland

This project aims developing an energy optimization tool for realizing a Zero-Carbon Hydrogen-Based Grid-Connected Building-Scenario to be implemented on any grid-connected building

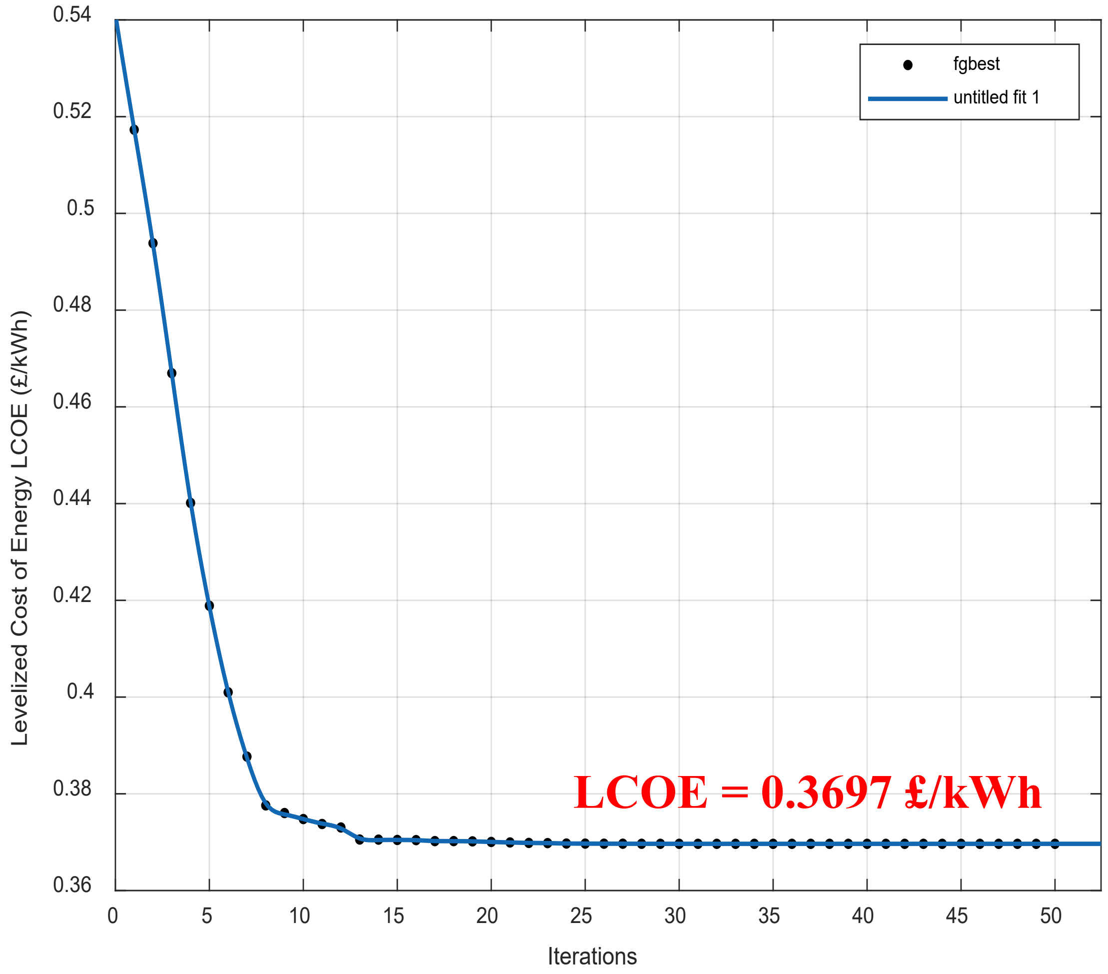
Research Project Objectives:

- Size the PV capacity needed to minimize the building GHG based on the building annual energy demands together with the electrolyzer and fuel cell needed to complement the Solar capacity and mitigate its intermittency
- Develop a precise dynamic model for simulating the dynamic generation and consumption of renewable H2
- Address the optimal sizing of system components from economic and environmental prospects.
- Develop a GUI tool for the optimal design, sizing, energy management and simulation of Real-World PV-H2 energy systems within grid-connected buildings (Disclosed).

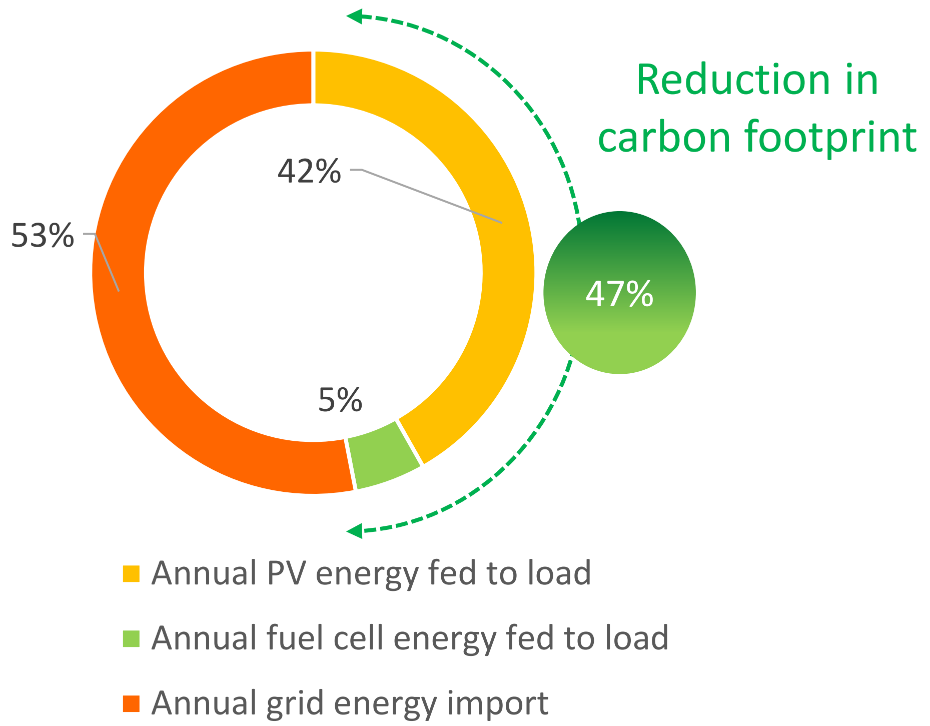


Proposed Zero-Carbon Hydrogen-based Grid-connected Building Scenario

Case Study 8 (Solar Power-to-Power Large-Scale Grid-Connected Building Decarbonization): RGU Campus Research Project, Scotland



PV System	Electrolyser	H2 Storage tank	Fuel Cell
4.0 MW	1.083 MW	80 kg	607 kW



Conclusion

Hydrogen is a key player in the world clean energy transition and major contributor to the UK Net Zero Future. H2 will play a pivotal role in achieving an affordable, clean and prosperous economy.

For Hydrogen to play such a key role, the following is needed:

- Technology breakthroughs to reduce costs across the entire supply chain
- Favourable Government Policies for the widespread of hydrogen implementation
- Development of Local Skilled Workforce and Service Infrastructure
- Further Research, Analysis and Modelling that allows the effective deployment of hydrogen across different sectors

THANK YOU!