HYDROGEN PRODUCTION FROM COAL

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IEA
CLEAN COAL CENTRE

PRESENTATION OUTLINE

- Hydrogen as a fuel
- Hydrogen markets
- Hydrogen production
- Cost and emissions comparisons
- Strategies and supporting policies
- Conclusions

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Technology Collaboration Programme by iea

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HYDROGEN AS A FUEL

HYDROGEN AS A FUEL

- Non-corrosive although can cause embrittlement of metals/alloys
- Typically rise and disperse rapidly, representing a safety advantage
- Leaks in confined spaces can be a concern
- Odorants not readily available
- High mass energy content, but low on volumetric basis
- Ammonia and methanol as a means of transport and storage

PHYSICAL PROPERTIES OF H_2 AND CH_4 (BASED ON DATA FROM IEA 2019C; HANKINSON AND OTHERS 2009)

Property	Hydrogen	Methane
Gas density at 0°C, 0.1 MPa (kg/m^3)	0.090	0.716
Liquid density at boiling point, 0.1 MPa (kg/m^3)	70.85	423
Boiling point (°C)	-252.9	-161.5
Fuel energy content- lower heating value (MJ/kg)	120.1	50.0
Fuel energy content- LHV (MJ/m^3)	10.8	35.6
Laminar flame speed (m/s)	3.46	0.37
Flammability limits (vol % in air)	4-77	4.4-16.4
Auto-ignition temperature (°C)	585	537
Minimum ignition energy (MJ)	0.02	0.3

TYPES OF HYDROGEN

Type	Grey Hydrogen	Blue Hydrogen	Green Hydrogen
'Fuel'	Coal or natural gas	Coal or natural gas	Water + electricity
Production method	Coal gasification or natural gas reforming	Coal gasification or natural gas reforming	Electrolysis
Decarbonisation approach	N/A	CCUS	Renewable electricity

HYDROGEN MARKETS

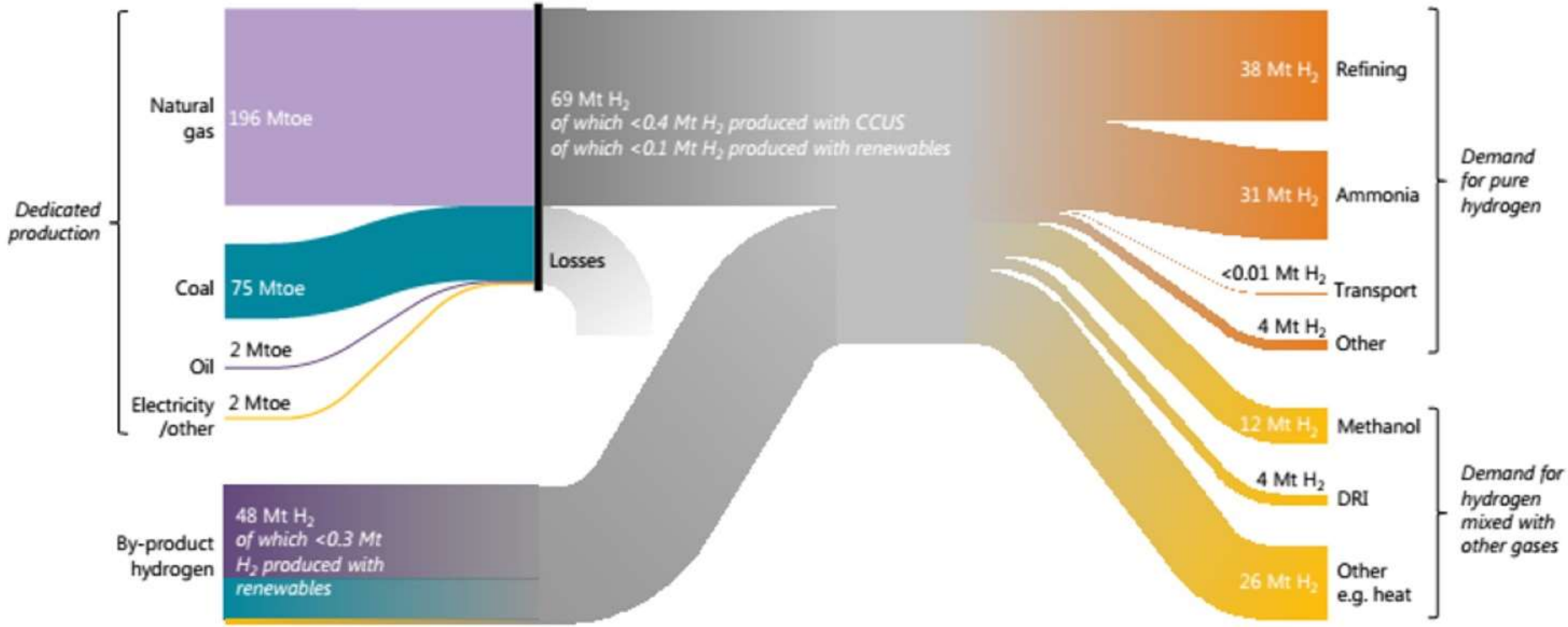
INCREASING INTEREST

Growing interest in hydrogen as a clean energy carrier

- Primary reason is to support the move to limit global temperature rise
- No direct local emissions of air pollutants or GHG
- Made from a diverse range of low-carbon energy sources
- An energy carrier, so can have a role similar to electricity
- Is a chemical energy carrier
- Can be used in existing transportation and utilisation infrastructure
- use business models developed for conventional fossil fuels

CURRENT HYDROGEN MARKETS

- Coal accounts for 27% of hydrogen demand



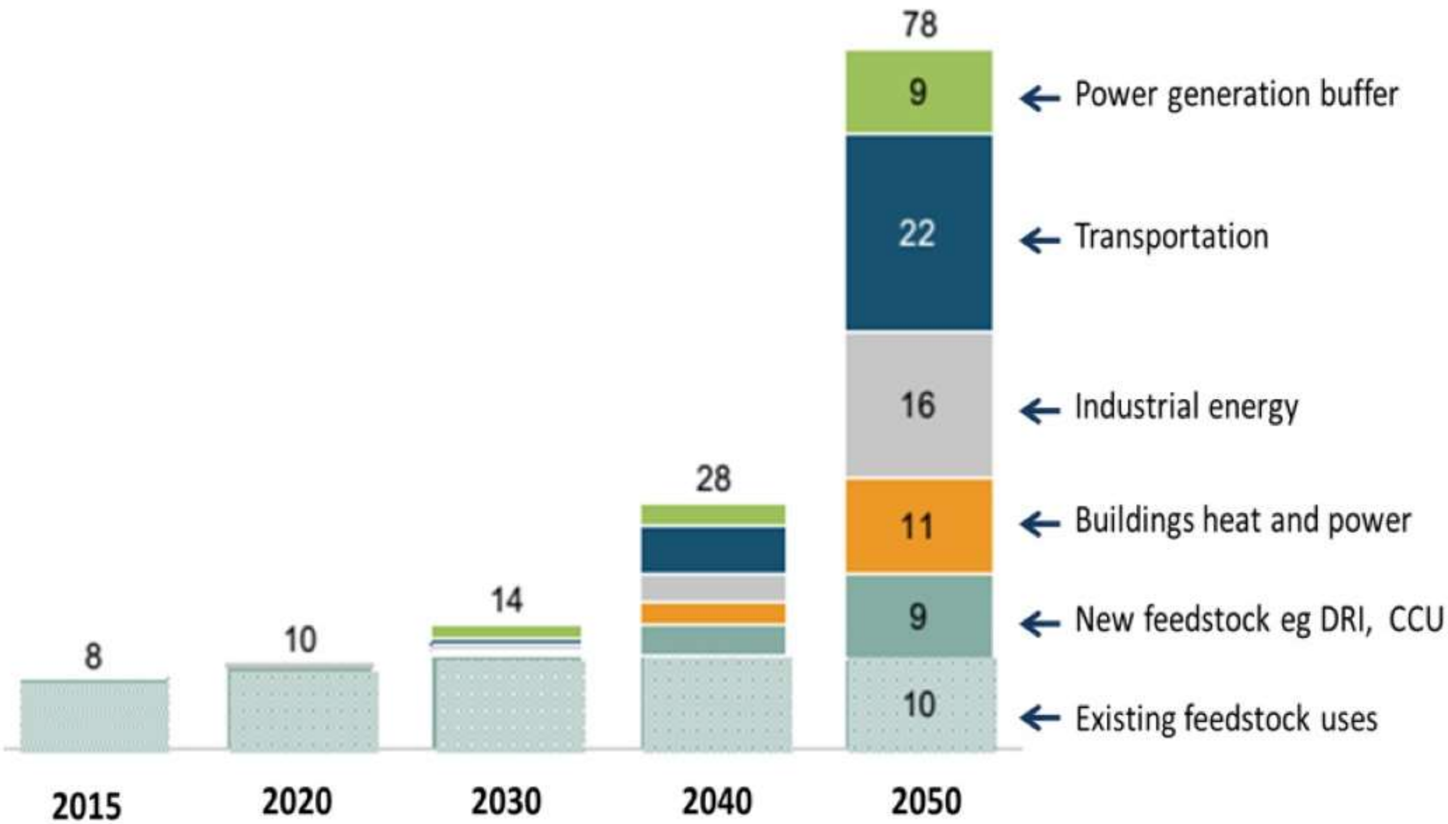
Sankey diagram showing H_2 value chains in 2018 (IEA, 2019)

BREAKDOWN OF HYDROGEN DEMAND

Hydrogen applications fall in to two main categories

- Where it is the only viable decarbonisation alternative
- Where is could become the preferred decarbonisation solution in the future

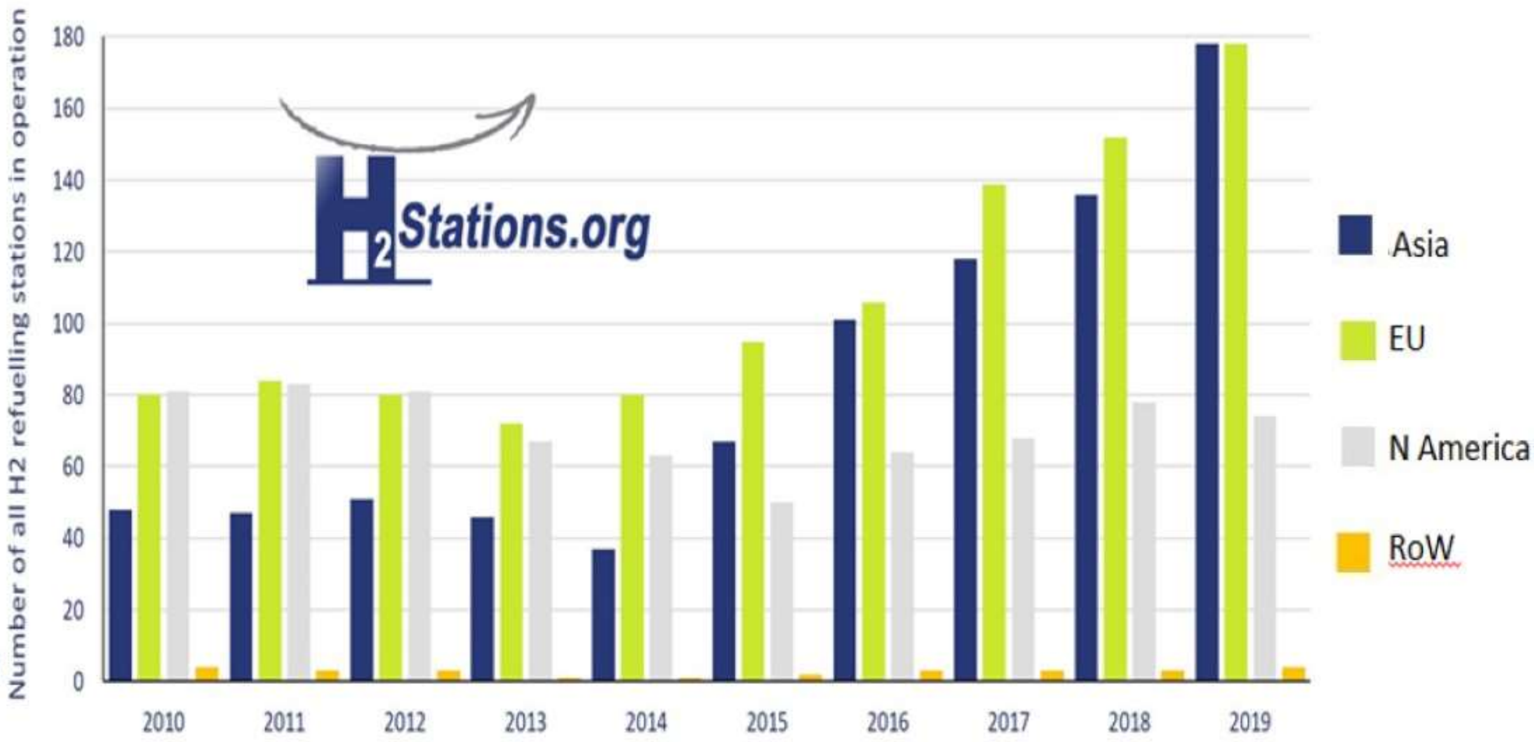
Reasonably uniform potential spread across sectors



Forecast increase in global hydrogen demand (EJ) through to 2050 (Hydrogen Council, 2017)

HYDROGEN DEMAND- TRANSPORT

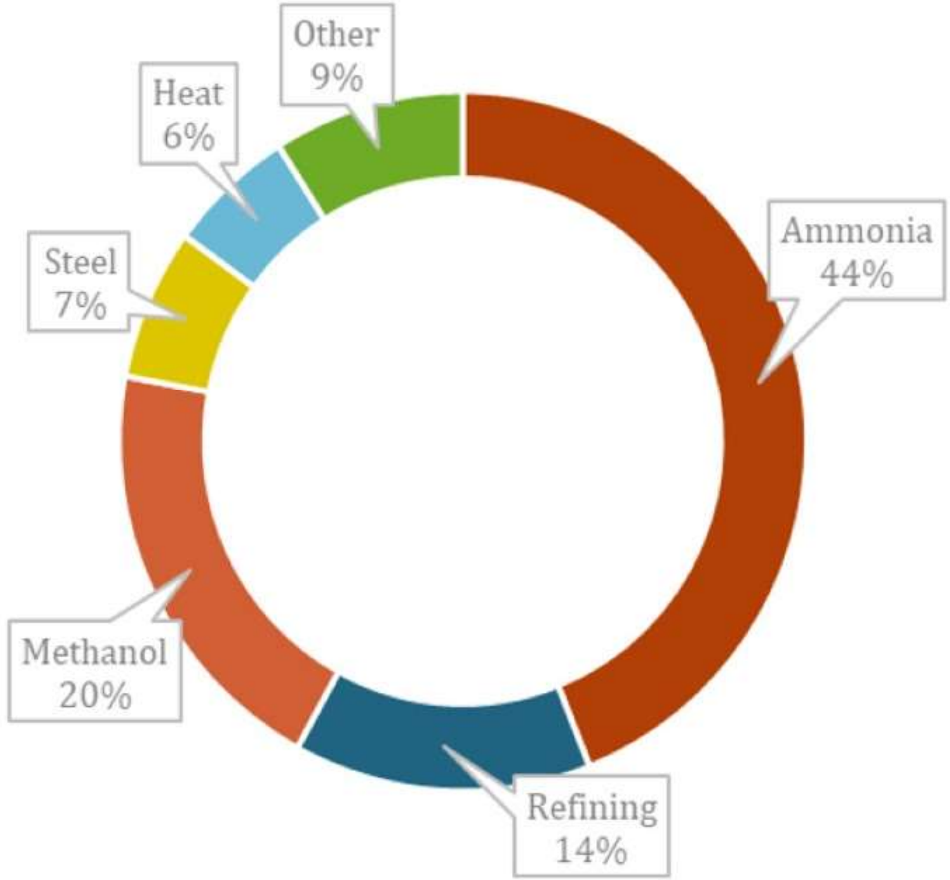
- Transport market could be around 185 MtH_2/y; almost 30% of H_2 demand
- Mainly FCEV's for large vehicle segment
- FCEV's are commercially available now and will be available for all applications with 5 years
- Hydrogen refuelling stations need to be deployed in parallel- more than doubled in last 5 years



Hydrogen refuelling stations by region (H2 stations, 2020)

HYDROGEN DEMAND- INDUSTRY

- Industrial sector could be around 190 MtH_2/y; almost 30% of H_2 demand
- Ammonia manufacture at 44%, Methanol at 20% and refinery applications at 14% continue as the main uses
  - 1-4% growth rate to 2030 with China, N America and Europe as key regions
- Hydrogen use in steel manufacture could develop as a DRI fuel
- Industrial process heat and space heating could also develop, particularly for high grade heat



Projected industrial uses of H_2 in 2050 (Aarnes and others, 2018)

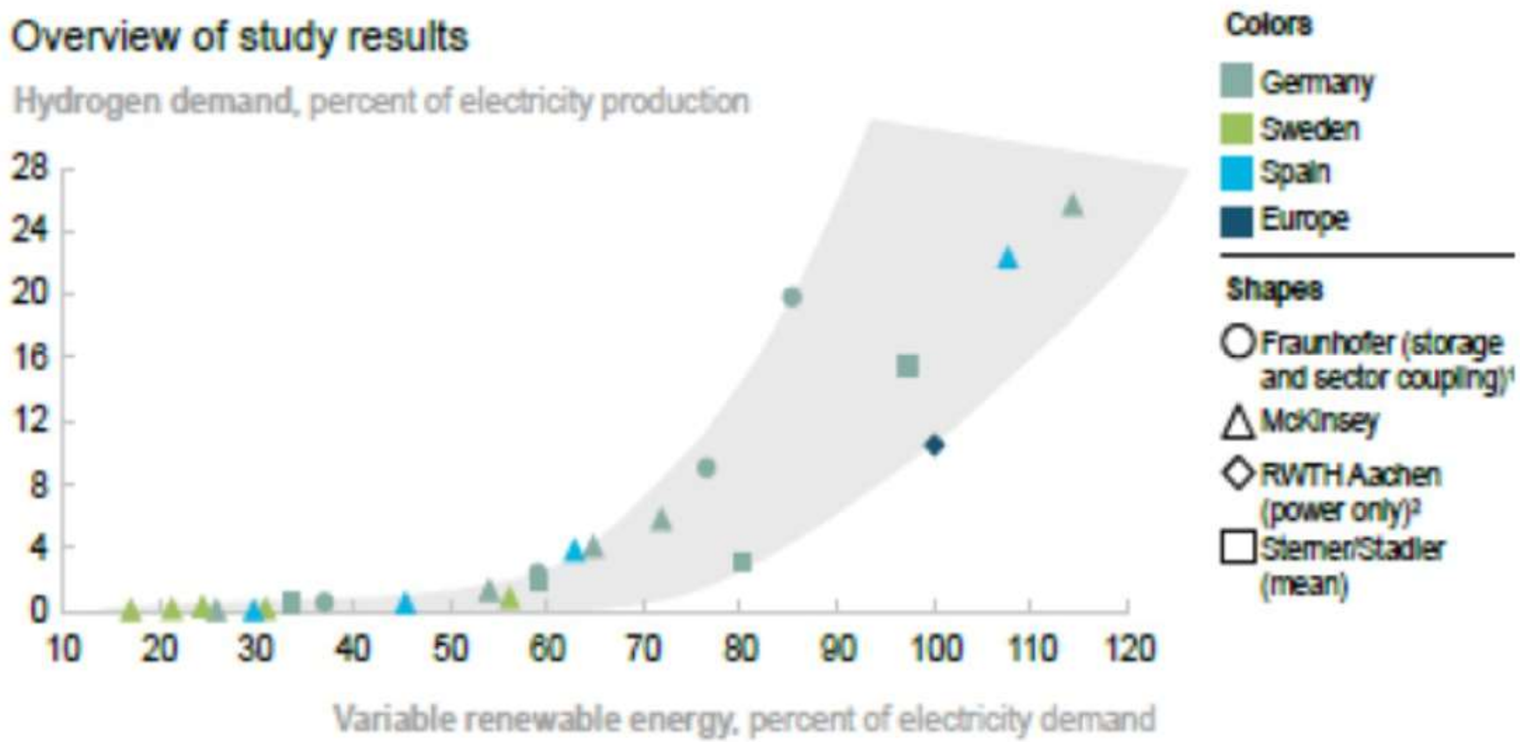
HYDROGEN DEMAND - BUILDINGS

- Heating and power could account for ~ 92 MtH_2/y by 2050
  - Australia, Canada, the Netherlands, S Korea, UK and USA will be leading
- Hydrogen can be stored to cope with seasonal heating demand
- Existing gas infrastructure can be used for blending or potentially repurposed for 100% hydrogen

Potential leading countries for H_2 based space heating of buildings (Hydrogen Council, 2017)

HYDROGEN DEMAND- POWER GENERATION

- Power generation could account for ~75 MtH_2/y by 2050
- Hydrogen can be an enabler for high levels of renewables
- Hydrogen can also be used to provide clean dispatchable power

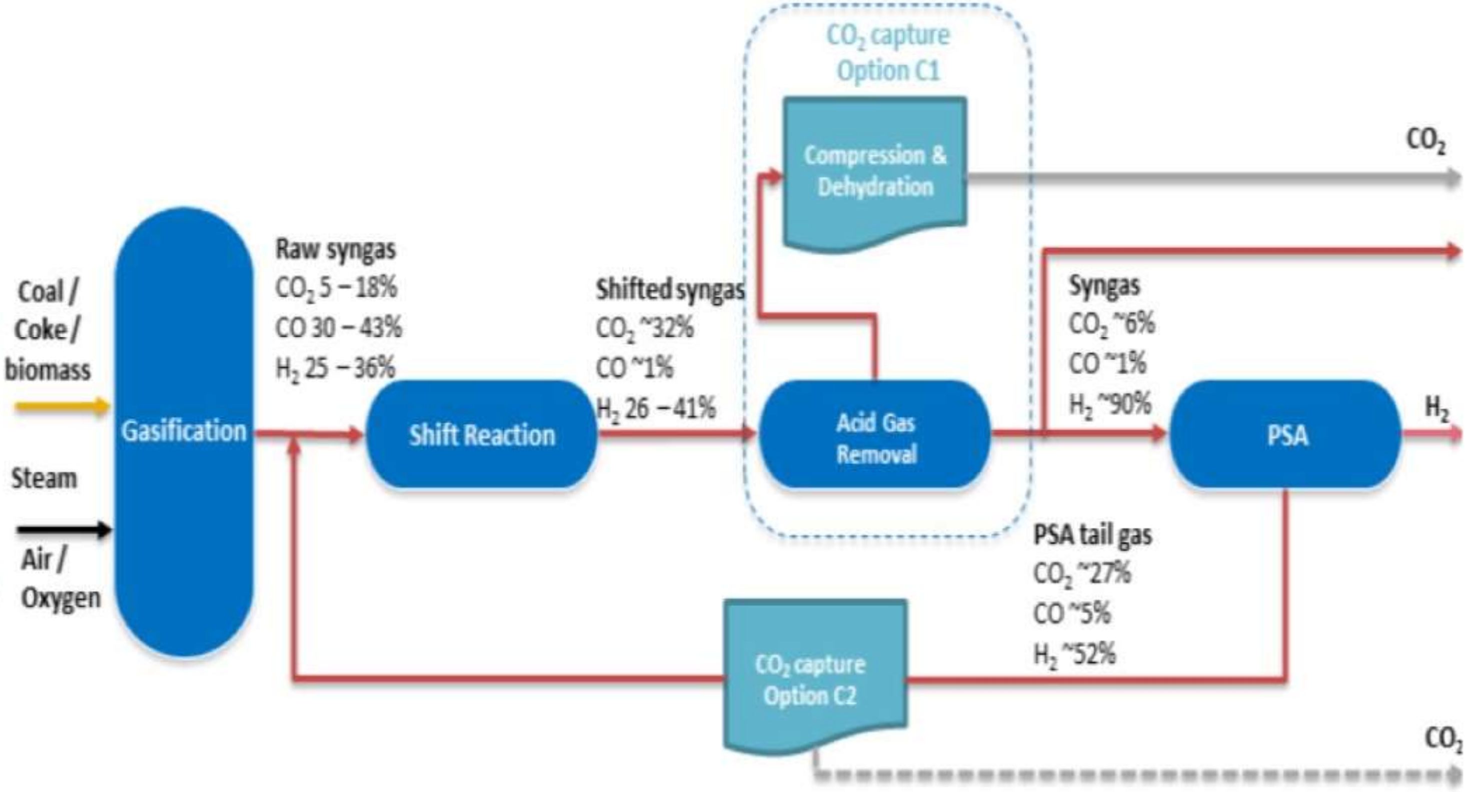


Increasing demand for H_2 with renewable electricity penetration (Hydrogen Council, 2017)

HYDROGEN PRODUCTION

HYDROGEN PRODUCTION-COAL GASIFICATION

- Gasification process used where coal is heated at high temperature, typically with oxygen to produce syngas
- Syngas then 'upgraded' through water gas shift (WGS) reaction
  - $CO + H_2O \leftrightarrow CO_2 + H_2$
- CO_2 next captured using physical adsorption techniques of Selexol/ Rectisol
- 99.8% purity hydrogen achieved with pressure swing absorption (PSA)



H_2/syngas production with CCUS (Zapantis and Zhang, 2020)

HYDROGEN PRODUCTION FROM COAL

A Hydrogen Production from Coal/Coke Including CCUS - Author prepared based on (Zapantis and Zhang, 2020)				
Facility	H_2 production capacity	Process	H2 Use	Operation Date (with CCUS)
Great Plains Synfuel, USA	1,300 tonnes/day in syngas	Lignite gasification	SNG and fertiliser production	2000
Coffeyville, USA	200 tonnes/day	Petroleum coke gasification	Fertiliser production	2013
Sinopec Qilu, China	100 tonnes/ day	Coal/coke gasification	Fertiliser production	2021 (planned)
Latrobe Valley, Australia (CCUS not included in pilot phase)	5 tonnes/year (<0.1 tonnes/day)	Lignite gasification	Export to Japan for power generation	2021
Pouakai, New Zealand	600 tonnes/day (proposed)	Natural gas fired Oxyfuel/Super-critical CO_2	Fertiliser production	2024

COAL GASIFICATION EXAMPLE - GREAT PLAINS

- H_2 production since 1988, capturing 3 Mt/CO_2/y since 2000
- Cost for design and construction of plant was around US$ 2 billion
- 14 Lurgi Mark IV gasifiers
  - Bottom fed operating at 1200°C
  - Oxygen blown
- Plant uses syngas to make SNG
- Modified to also produce ammonium sulphate for fertiliser manufacture
- CCUS added in 2000 capturing 50% of CO_2 used for EOR.

Great Plains Gasification Plant
(https://lignite.com/mines-plants/poly-generation-plants/great-plains-synfuels-plant/)

COAL GASIFICATION EXAMPLE - HESC PROJECT

- Hydrogen Energy Supply Chain (HESC) project in Victoria State with support from Japan
- AU$ 500 million (US$ 390 million) project supported by Japanese government/ industry, with Australian and Victorian governments
- Lignite gasification plant at LaTrobe Valley, Australia
- The pilot phase will produce 5 ktH_2/y which is planned to increase to 10 MtH_2/y by 2030, together with 125 MtCO_2/y of storage
- Key project challenge is cyogenic H_2 shipping to Kobe

LaTrobe Valley Gasifier (KHI, 2021)

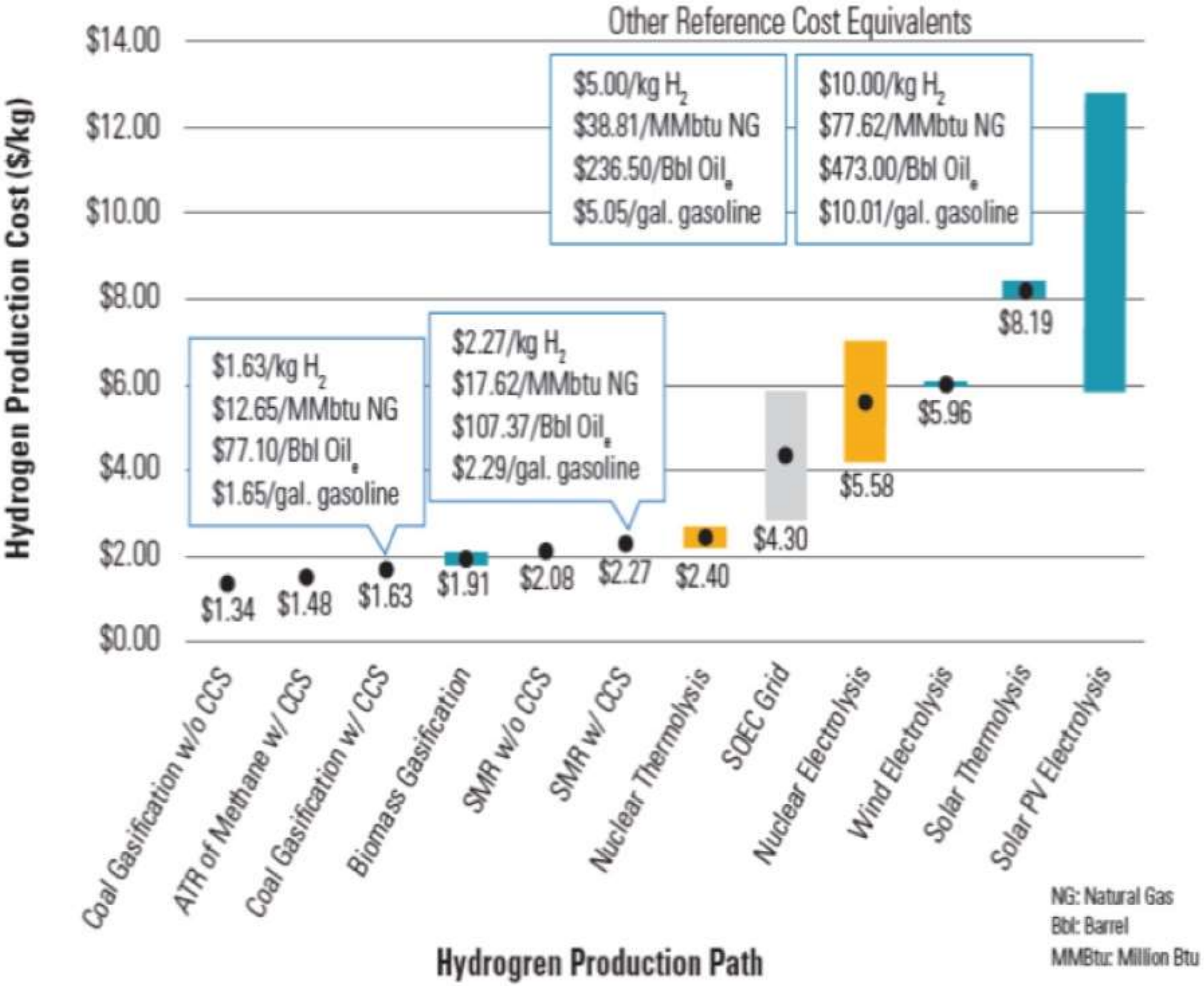
Liquid H_2 ship (KHI, 2019)

COST AND EMISSIONS COMPARISONS

HYDROGEN COST

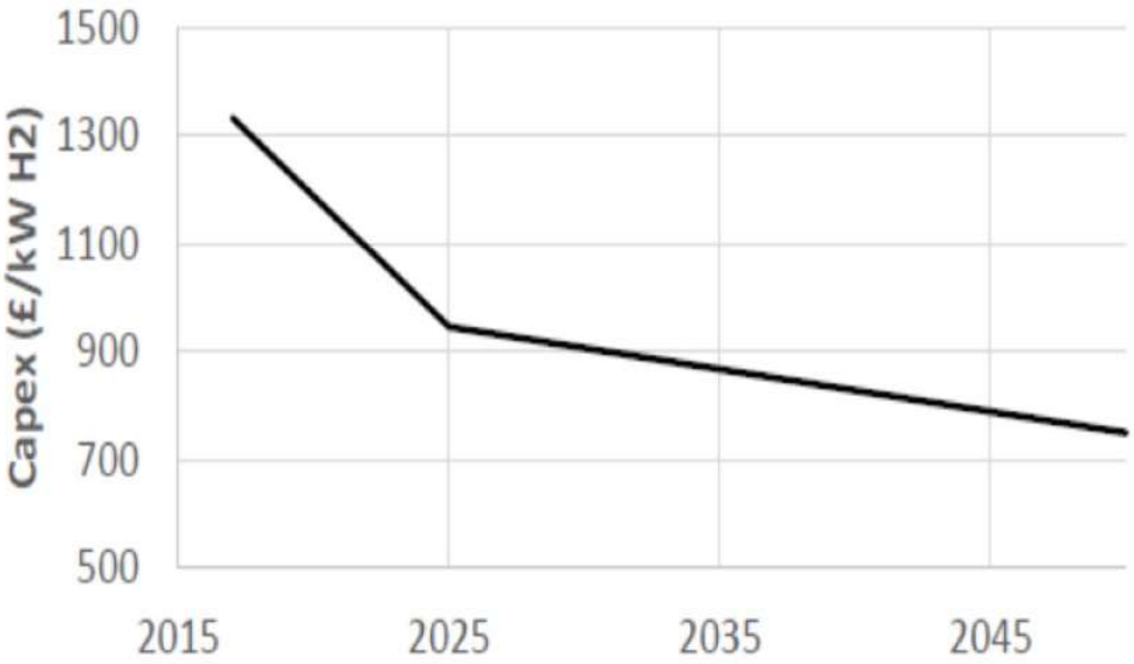
- Costs vary due to local factors, fuel price, renewable electricity price, load factor, learning rates and carbon taxes
- Blue-H_2 is typically 3 times cheaper than Green-H_2
  - H_2 from coal gasification with CCUS as low as US$1.6/kg to US$2.4/kg
- Large unabated fossil fuel fleet of hydrogen production should be retrofitted with CCUS

Comparison of H_2 costs (USDOE, 2020)



COSTS OF COAL GASIFICATION

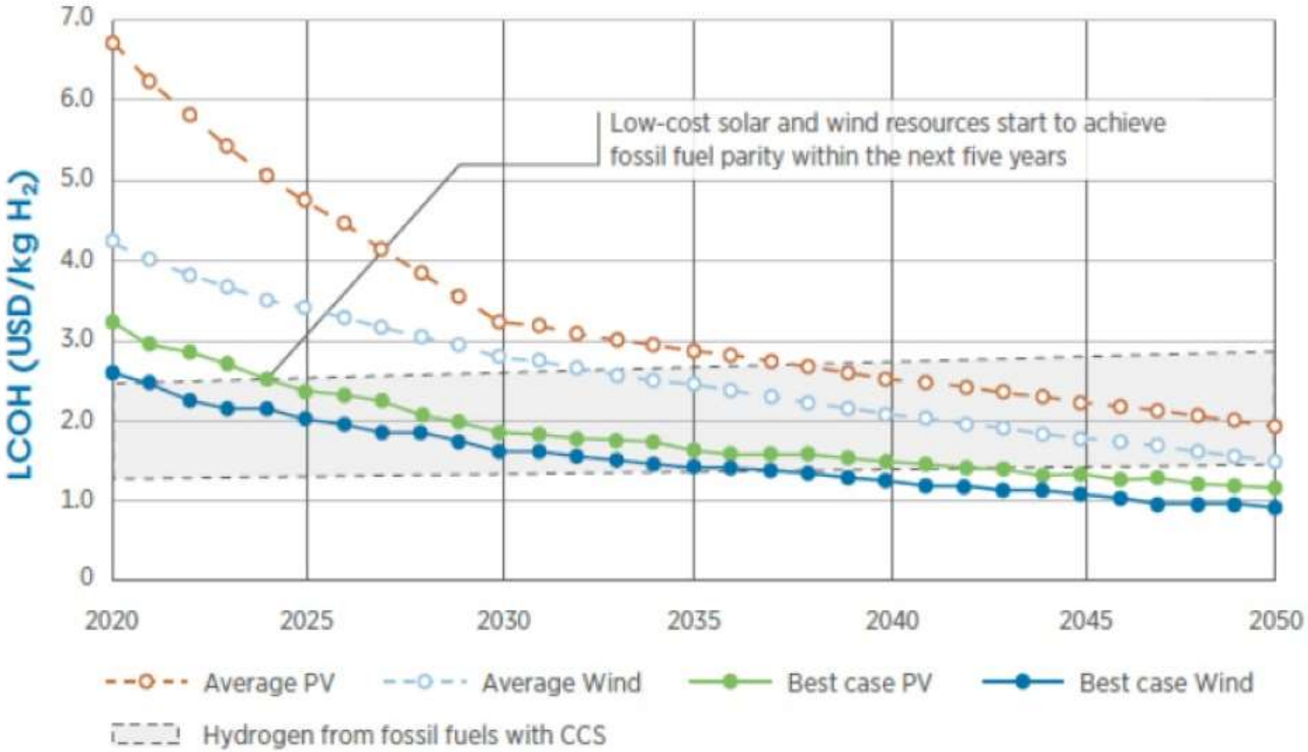
- Capex/Opex accounts for 80-85%, with balance being fuel cost (China basis)
- CCUS adds around 5% to Capex and 130% to Opex
- Analysis for the UK Government showed capex could be reduced by perhaps 45-50% by 2050
- Future cost of H_2 could be reduced by perhaps 10-15% by 2050
    - Inclusive of carbon tax cost rising to £227/tCO_2



Coal gasification Capex reduction potential (Element Energy, 2018)

COST COMPARISON WITH ELECTROLYSIS

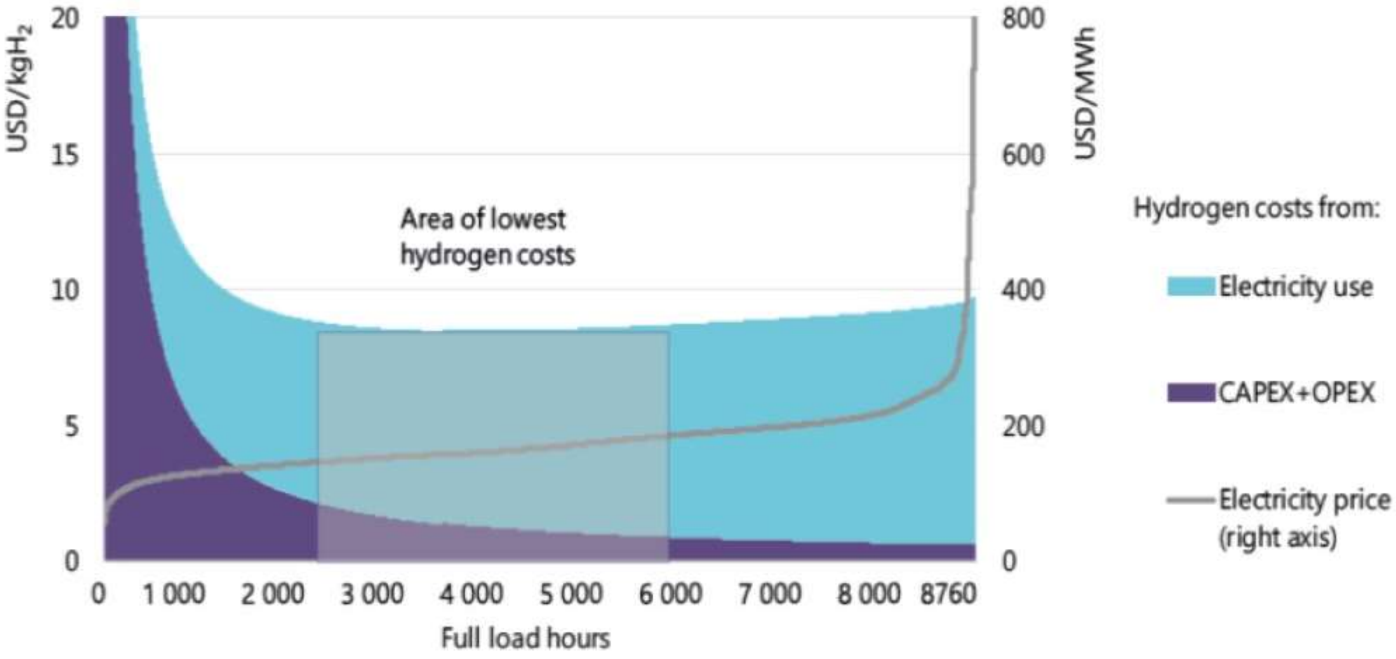
- Green-H_2 could in time compete with Blue-H_2
  - Low-cost renewable electricity
  - Australia and China
- Could be 2025-35 timeframe for best locations
- Later than 2035 for 'average' PV and wind resource locations
- Points to continuing role for fossil-fuel based H_2 with CCUS in the medium term



Cost of Green-H_2 compared with Blue- H_2 (IRENA, 2019)

COST DETAILS OF ELECTROLYSIS

- Renewable electricity costs dominate at higher operating hours
- Surplus renewable electricity is lowest cost but only available occasionally
- Operating at higher load may be preferable
  - Optimum at 35-70% capacity factor
- May not be compatible with some applications



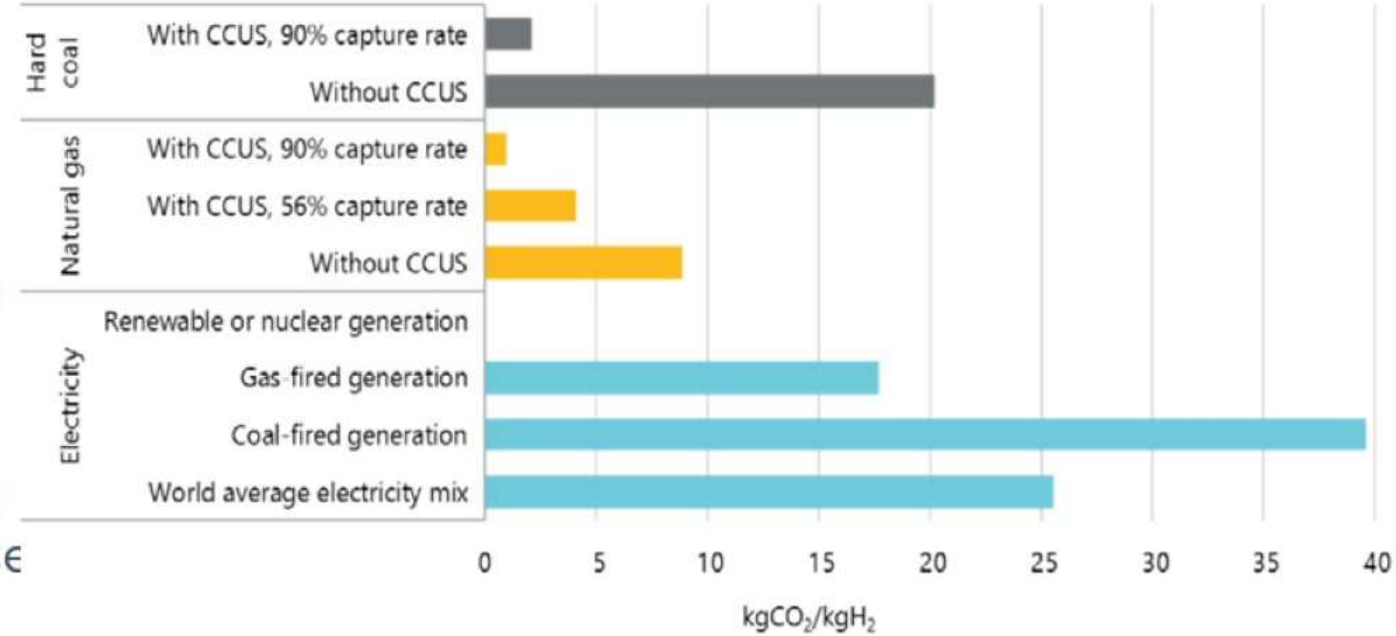
otes: CAPEX = USD 800/kW$_{e}$; efficiency (LHV) = 64%; discount rate = 8%.

ource: IEA analysis based on Japanese electricity spot prices in 2018, JEPX (2019), *Intraday Market Trading Results 2018*.

Hydrogen costs for water electrolysis using grid electricity (IEA, 2019)

EMISSIONS COMPARISON

- Carbon intensity of grey-H_2 from coal is 19 $kgCO_2/kgH_2$
- Adding CCUS (90% capture) can reduce this to 3 $kgCO_2/kgH_2$
- Higher capture rate of co-fire with biomass/waste can reduce further
- Water electrolysis can be detrimental to net zero targets unless low capacity factor to use mainly RE, or significant increase in RE on grid



CO2 intensity of H_2 production (IEA, 2019)

HYDROGEN STRATEGIES AND SUPPORTING POLICIES

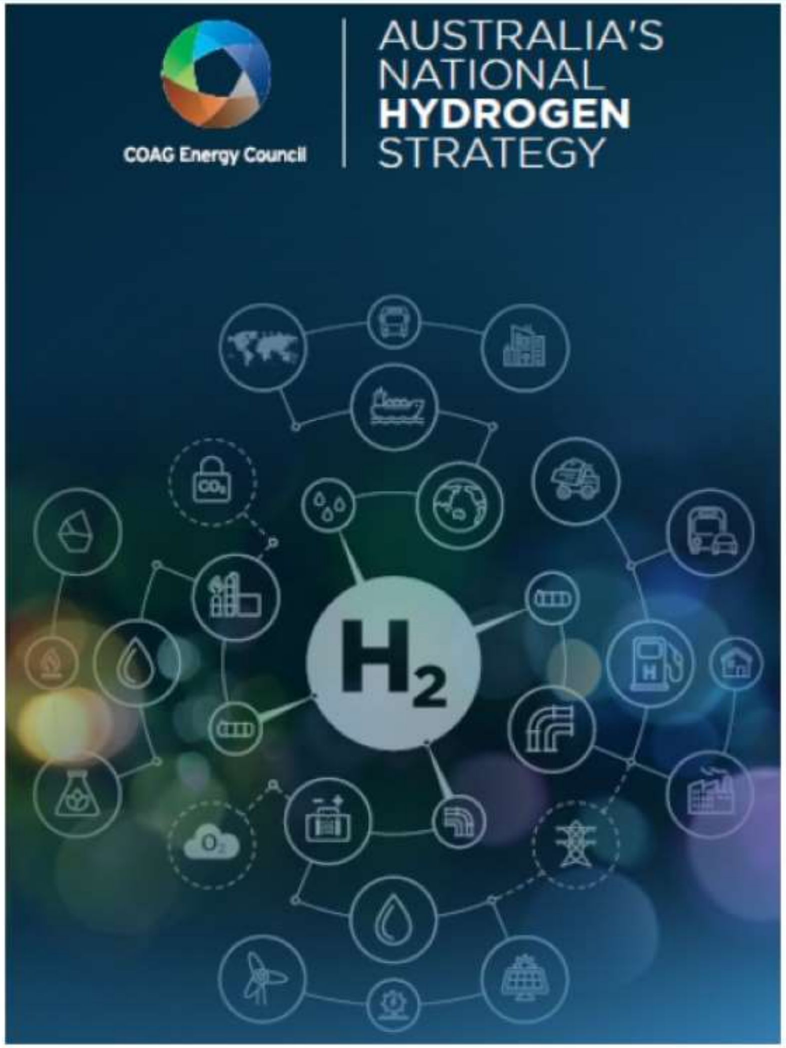
HYDROGEN STRATEGIES

Number of countries producing H_2 strategies/ roadmaps and the scale of ambition is increasing

- Australia, Austria, Belgium, EU, France, Germany, Italy, Japan, Korea, The Netherlands, Norway, UK

Example: Australia

- Published strategy in Nov 2019
- AU$370m committed
- Council of Australian Government's Energy Council established Hydrogen Project Team in March 2020
- CSIRO published technical roadmap for hydrogen in Australia



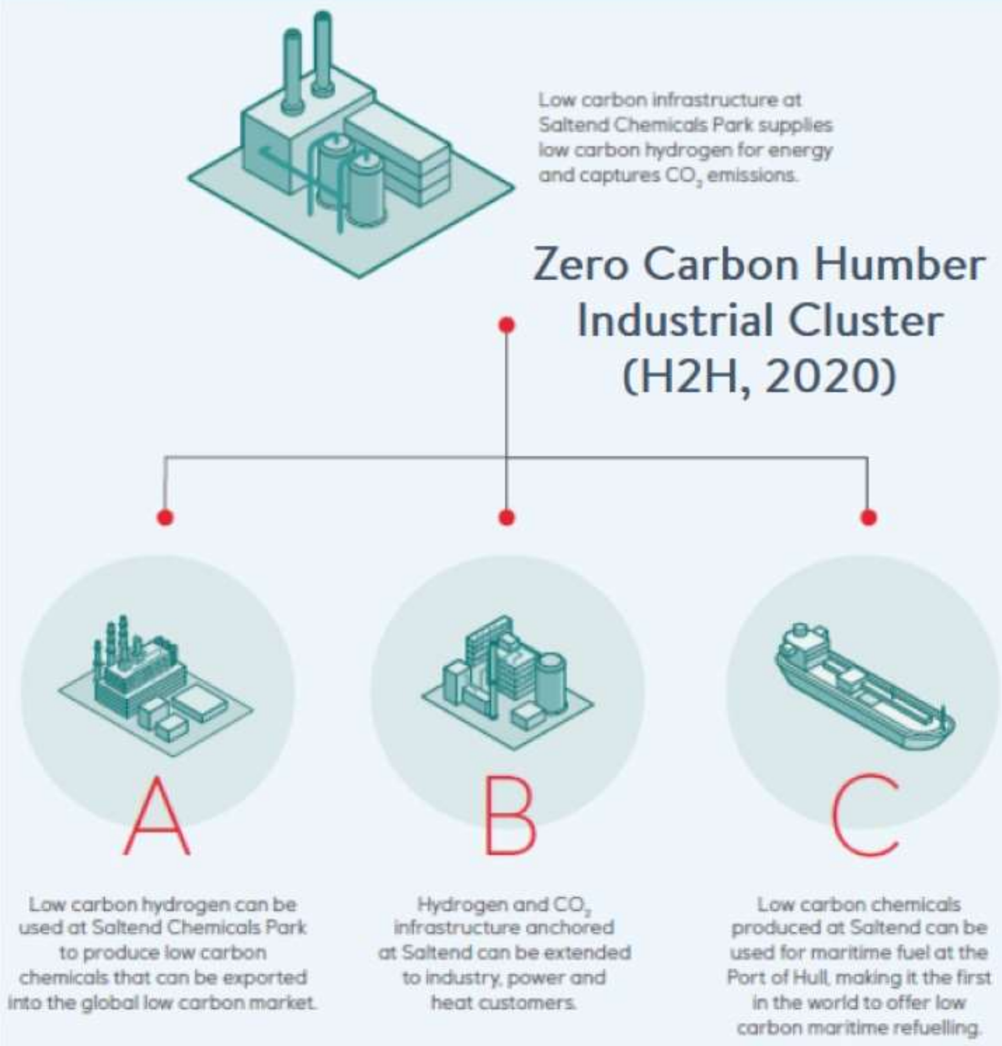
SUPPORTING POLICY ACTIONS

Policy actions to 2030

- Establish longer term signals to promote investor confidence
- Stimulate commercial demand
- Mitigate first mover risk
- Promote R&D and knowledge share
- Harmonise standards and remove barriers

Deployment at scale in clusters

- Examples: Zero Carbon Humber, Porthos, Northern Lights, HyNet



CONCLUSIONS

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- 115 MtH_2/y global demand in 2018, produced local to point of use, almost entirely from fossil fuels
- Forecast up to 650 MtH_2/y by 2050, representing around 14% of the expected world total energy demand in 2050
- Coal gasification with CCUS costs 1.9-2.4 US$/$kgH_2$ and as low as US$ 1.6/kgH_2 in China
- CCUS can reduce carbon intensity <3 $kgCO_2/kgH_2$
  - Explore further reduction with near 100% capture or cofire with waste/biomass for zero or negative emissions
  - help to 'future proof' the gasification plant
- Near term actions are required to overcome barriers and reduce costs

Sinopec Refinery, China

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THANK YOU FOR LISTENING

ANY QUESTIONS?

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