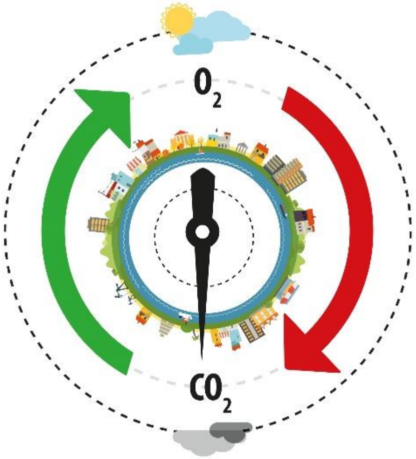
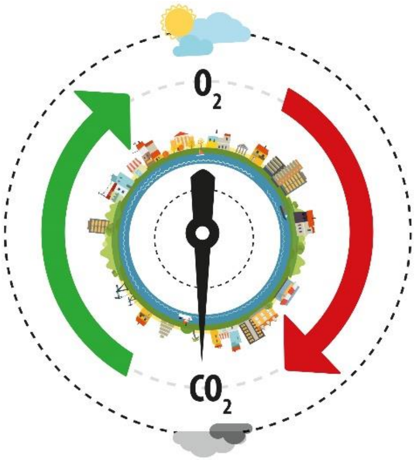


ENERGY

Technical Workshop – UNECE Task Force on Hydrogen

Sustainable Hydrogen Production Pathways in CIS Countries

23 March 2022



We are starting shortly!

10h00 CET

ENERGY

Technical Workshop – UNECE Task Force on Hydrogen

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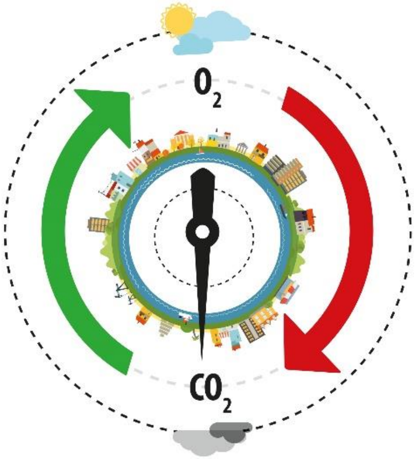
23 March 2022



ENERGY

Technical Workshop – UNECE Task Force on Hydrogen

Sustainable Hydrogen Production Pathways in CIS Countries

23 March 2022

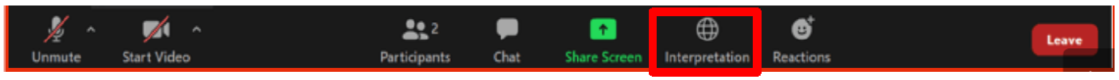
Housekeeping rules

- Select your language channel: English, Russian
- Mute your microphone if you are not speaking
- Switch off your camera if you are not speaking
- Use “Raise hand” function to request the floor
- Use “Chat” function to ask questions and share comments

Instructions to use interpretation in Zoom

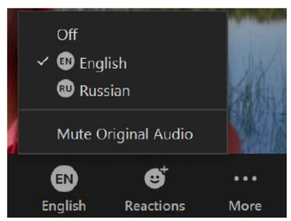
Step 1 – what you see on the screen when you join

Step 2 – select the language channel you wish to listen to



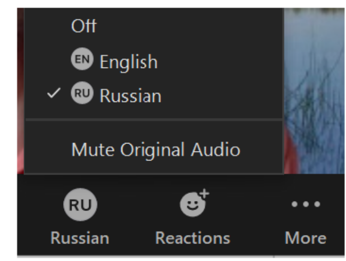
For English speakers:

- During session 1 “Sharing current experience from CEM CCUS countries” for better sound quality DO NOT select any language channel and keep default version. This session will be in English.
- During session 2 “CCUS opportunity in UNECE member countries” click on the “Interpretation” button and choose English language.
- The “Interpretation” button will transform into the “English” button. To change again the language you would like to hear, follow the previous procedure by clicking on the transformed button.
- By default, you will hear the selected language at 80% volume and the original Audio at 20% volume. If you would like to mute/unmute the original audio, click on the corresponding option in the language button.



For Russian speakers:

- Для сессии 1 «Sharing current experience from CEM CCUS countries» и для сессии 2 «CCUS opportunity in UNECE member countries» воспользуйтесь услугами перевода и нажмите кнопку “Interpretation” («Устный перевод») и выберите русский язык.
- Кнопка “Interpretation” («Устный перевод») превратится в кнопку «Russian» («Русский язык»). Чтобы снова изменить язык, который вы хотели бы услышать, выполните предыдущую процедуру и нажмите преобразованную кнопку Interpretation/ Russian.
- Обычно перевод будет звучать на 80% громкости, а исходный звук - на 20%. Если вы хотите отключить / включить исходный звук, нажмите соответствующий параметр на кнопке выбора языка.



Agenda

- **Project update & UNECE work on Hydrogen**

- **Sustainable hydrogen production methods – technology pitch presentations**
  - **Green hydrogen and electrolysis**
  - **Hydrogen from nuclear power**
  - **Hydrogen from natural gas**
  - **Hydrogen from coal**

- **Q&A session with Beneficiary Countries – Discussion on national potential, priorities, identified opportunities and challenges**

Project update & UNECE work on Hydrogen

ENERGY

- Effort by 3 Expert Groups → Group of Experts on Renewable Energy, Gas and Cleaner Electricity Systems
- Carbon neutrality project
  - Role of Hydrogen to Attain Carbon Neutrality
  - Technology Brief on Hydrogen
  - Technology interplay & scenario building
- Subregional project on Sustainable hydrogen production pathways in Eastern Europe and Central Asia
- Guarantees of Origin for Sustainable Hydrogen

UNECE Toolkit for Policy Makers to Attain Carbon Neutrality

UNECE
ENERGY

HYDROGEN VALUE CHAIN

Hydrogen, an innovative solution for achieving carbon neutrality

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PRODUCTION

FUEL-BASED PRODUCTION

Natural gas
Steam methane reforming/ autothermal Reforming with or without CCS

Coal
Gasification of coal with or without CCS

Biomass
Gasification of biomass with or without CCS

CCS
CO_2

Steam reforming and gasification with CCS

ELECTRICITY SYSTEM

Renewable energy
Electricity from wind, solar, hydro or geothermal power

Nuclear
Electricity and heat from nuclear power

O_2 H_2 H_2O

Water electrolysis

H_2

CONVERSION, PROCESSING & TRANSPORTATION

PURE H_2

PROCESSING

- Liquification and regasification of H_2
- H_2 gas compressed

CONVERSION

- **Haber-Bosch process**
  H_2 & N_2 → ammonia;
  standard shipping modes
- **Methanization**
  $H_2 + CO_2 \rightarrow CH_4 + H_2O$
  or $H_2 + CO \rightarrow CH_3OH$ (methanol)
  (synthetic or substitute natural gas)

STORAGE

Liquified H_2 in storage tanks

Geological storage in underground salt caverns

USE

TRANSPORT

- Hydrogen into **fuel cells** for trucks, passanger vehicles
- **Synthetic fuels** for shipping and aviation

INDUSTRY

- Hydrogen as **feedstock** in refining, steel production, chemicals production
- Hydrogen for **heat generation** for industrial processes

BUILDINGS

- Hydrogen for **heating**
- Hydrogen for onsite **power** through fuel cells

POWER

- Fuel cell **electricity**, H_2 turbines and H_2 CHP
- **Energy storage** and system buffer

Awareness
Recognise hydrogen as a viable climate mitigation option

Acceptance
Develop and integrate policies to jumpstart hydrogen economy

Finance
Direct public and private investment into clean hydrogen projects

Project on Sustainable Hydrogen Production Pathways

ENERGY

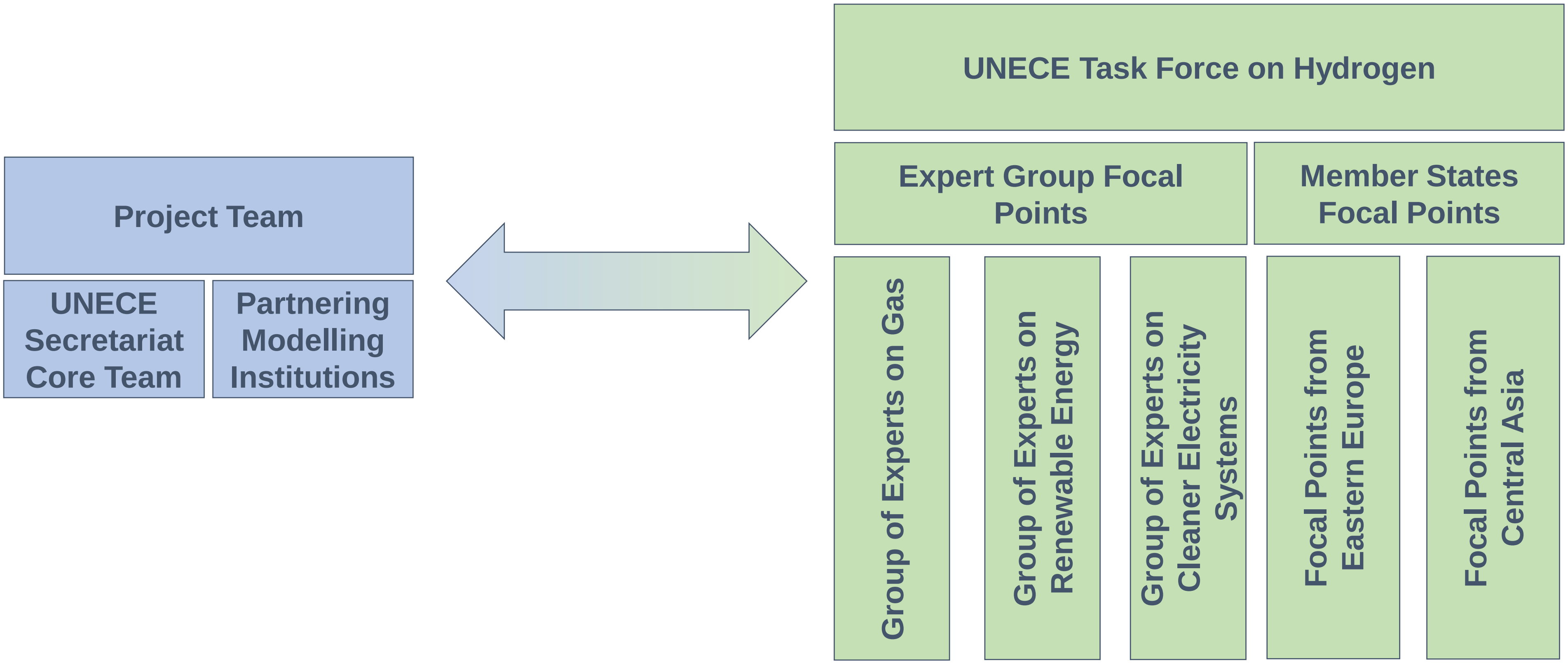
Project Activities as per EXCOM approved document, 15 October 2021		
A 1.1	Conduct an analysis of national potentials to contribute to development of a hydrogen ecosystem and global energy transitions, including the supply of energy to energy-deficient regions of the world	Phase I
A 1.2.	Conduct an analysis of priority areas for the development of national hydrogen potential	Phase I
A 1.3.	Conduct an analysis of hydrogen production potential across CIS countries.	Phase I
A 1.4.	Conduct an analysis of the opportunities for hydrogen export and possible applications in the domestic market	Phase I
A 1.5.	Organize a peer-to-peer dialogue on best practices and lessons learned in developing national hydrogen strategies in the context of the Paris agreement and Agenda 2030 implementation.	Phase I
A 2.1.	Conduct a subregional assessment of cost and technical performance of hydrogen production from fossil fuels, low-carbon energy, and renewable energy across beneficiary countries	Phase II
A 2.2.	Refine existing data and assumptions related to sustainable hydrogen production for the energy model.	Phase II
A 2.3.	Propose the directions for the implementation of pilot projects for the supply of sustainable hydrogen for export	Phase II
A 2.4.	Organize a policy dialogue to identify and overcome existing barriers to development of a hydrogen ecosystem	Phase II
A 2.5.	Develop recommendations for a coherent international system of standardization and certification of hydrogen in the context of the Paris agreement and Agenda 2030 implementation.	Phase III
A 2.6.	Develop recommendations for pilot projects in international cooperation in sustainable hydrogen technologies	Phase III
A 3.1.	Final seminar for representatives of governments, industry, and academia to present and discuss recommendations and discuss how they can be incorporated into draft National Action Plans to meet SDG 7.	Phase III

Project Implementation Phase I & II

ENERGY

- **Timeline: January – June 2022**
- **Analysis on hydrogen potential in Eastern Europe & Central Asia**
  - **National potentials to contribute to development of a hydrogen ecosystem**
  - **Priority areas for the development of national hydrogen potential**
  - **Hydrogen production potential in Eastern Europe and Central Asia**
  - **Subregional assessment of cost & technical performance of various hydrogen production pathways**
  - **Opportunities for hydrogen export potential & domestic applications**
- **Workshops:**
  - **Technical workshop on priority areas and hydrogen production potential,** March 2022 at Annual Meeting of the Group of Experts on Gas
  - **Policy dialogue,** April 2022 at Annual Resource Management Week

Project Governance



Sustainable hydrogen production methods – technology pitch presentations

- Green hydrogen and electrolysis, Constantine Levoyannis
- Hydrogen from nuclear power, Phil Rogers
- Hydrogen from natural gas, Yuriy Melnikov
- Hydrogen from coal, Andrew Minchener

Developments in Electrolyser sector

Constantine Levoyannis,
Nel Hydrogen

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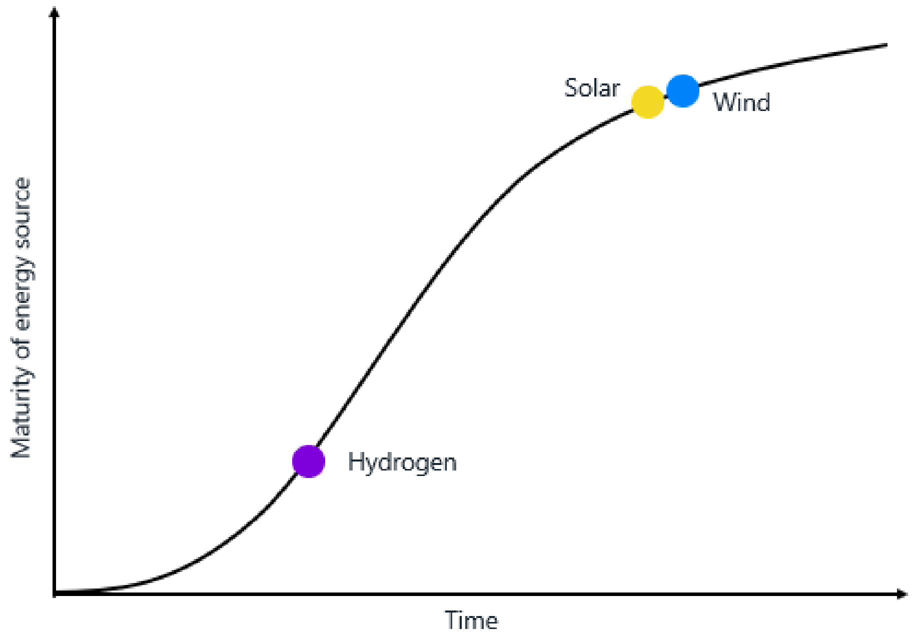
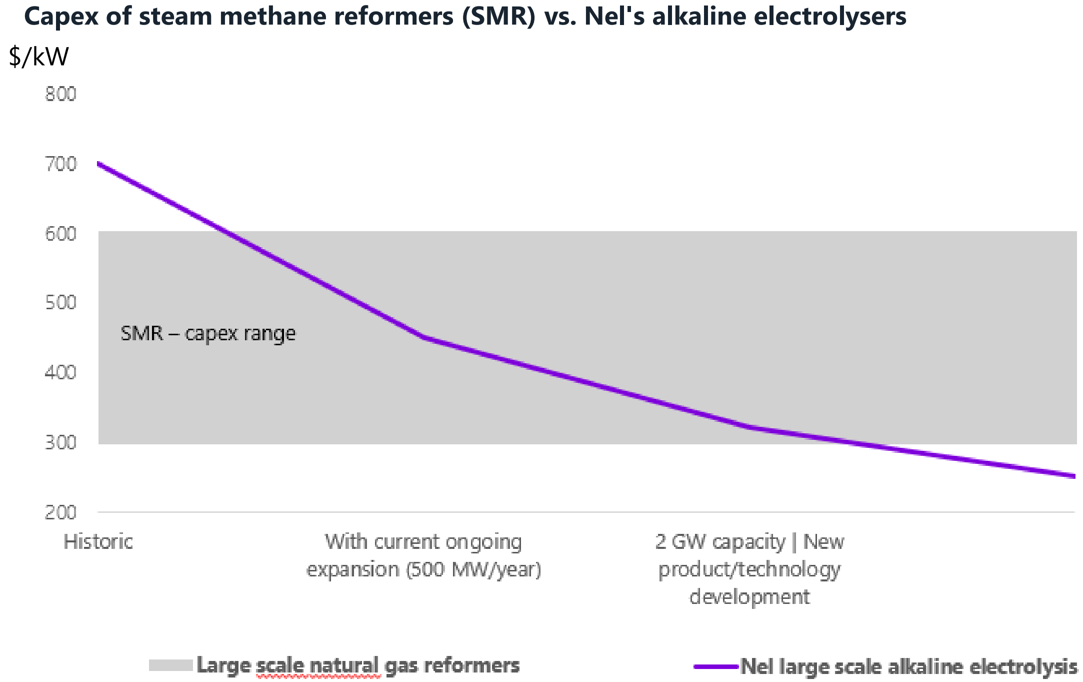
AND COOPERATION
IN THE REGION

Hydrogen technology catching up on maturity curve



Growth in renewable hydrogen will accelerate with reduced capex for electrolysers



Source: Company analysis and projections, hydrogen production plant excluding installation, civil works and building.

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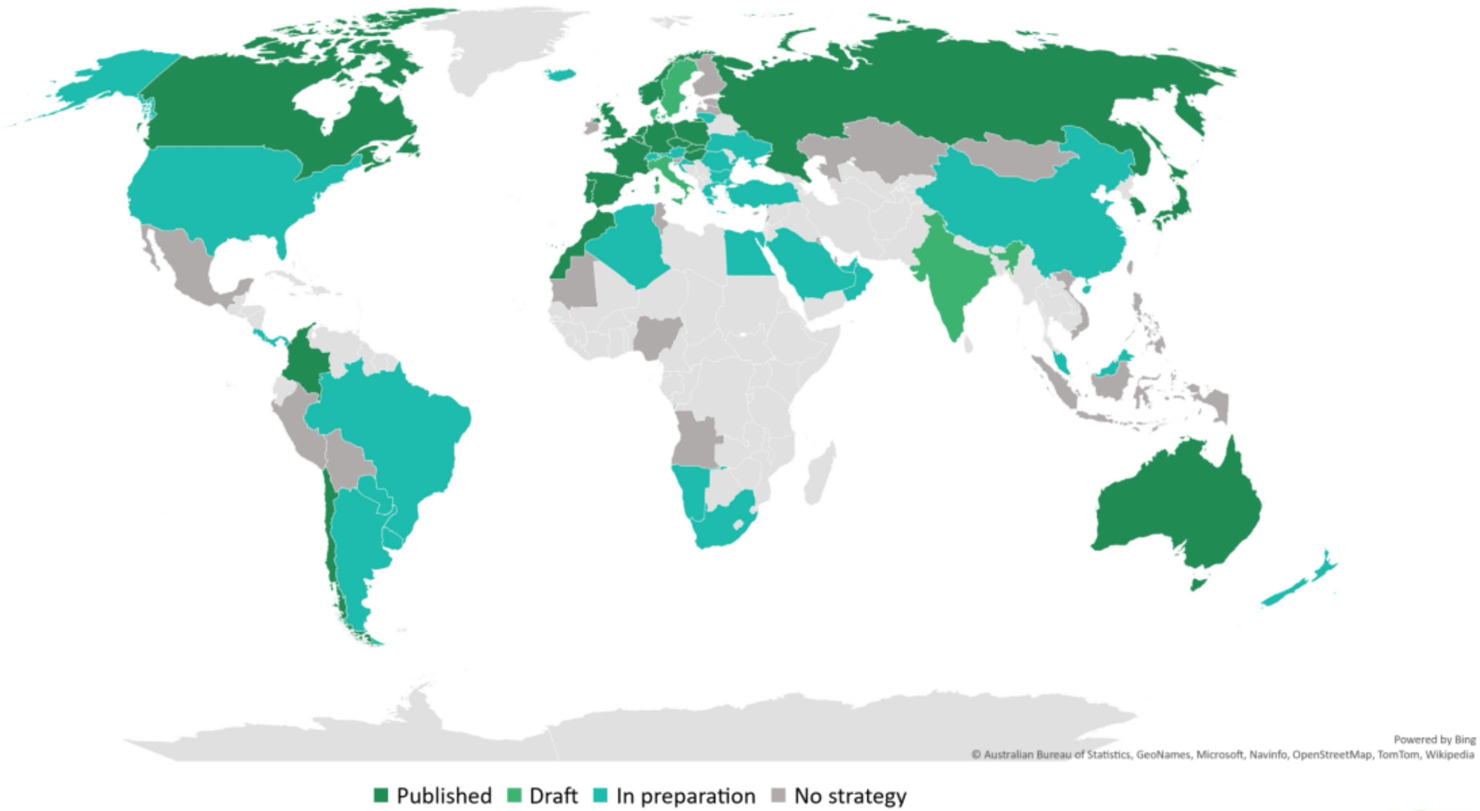
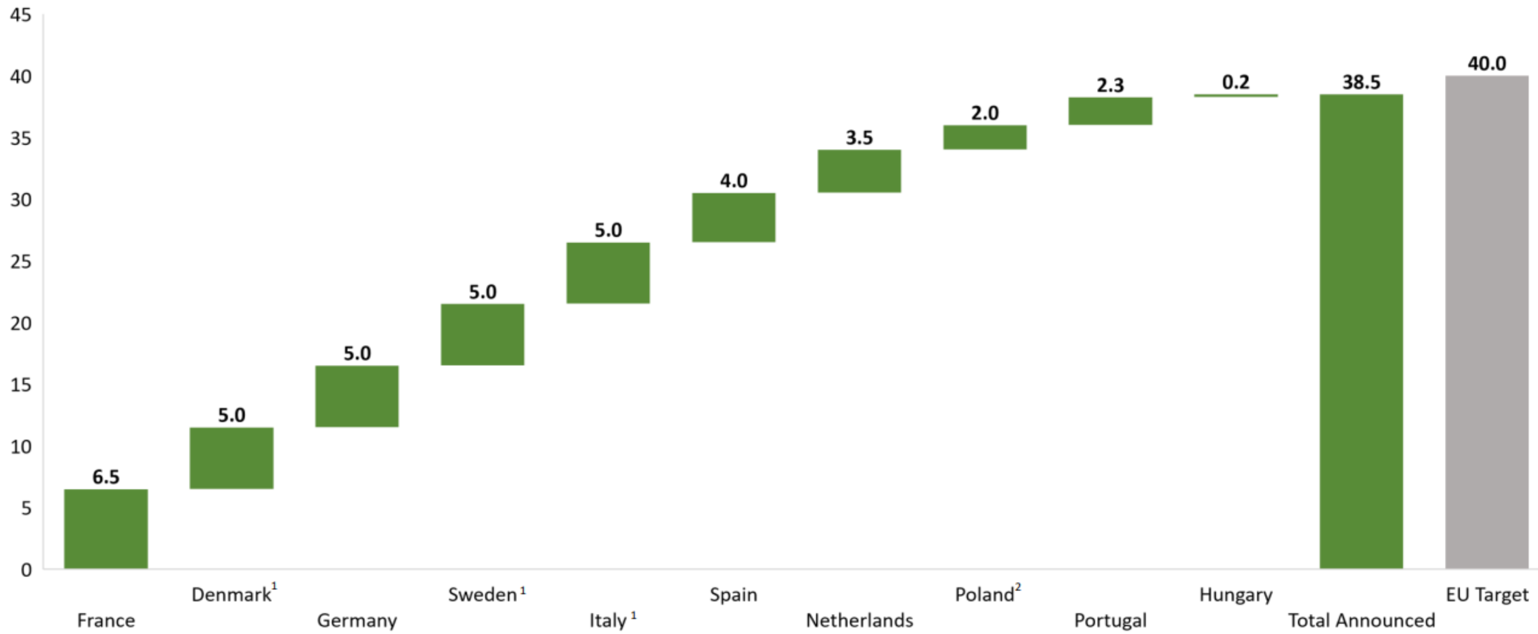
21 countries have published a hydrogen national strategy



Electrolyser capacity commitments by 2030 amount to 38.5 GW



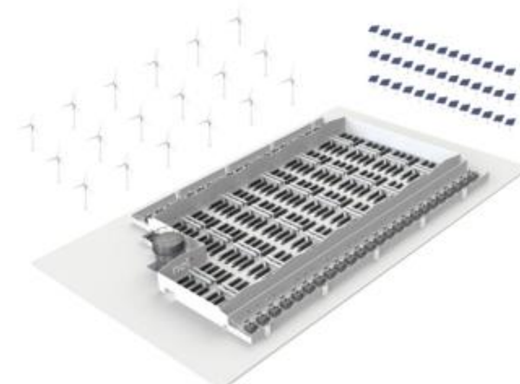
Included countries are the only ones with specific targets for planned electrolyser capacity.
When the target is a range, the median value of that range was used.
[1] Target is provisional and subject to change in the final version of the national H2 strategy.
[2] Polish target is for low-carbon emission sources, including electrolysers.

Electrolyser technology evolving

Wide proven experience
Alkaline electrolysers since 1927 and
PEM electrolysers since 1996

Scalable design
from <1 to >8,000 kg/day production
able to deliver 100+ MW systems

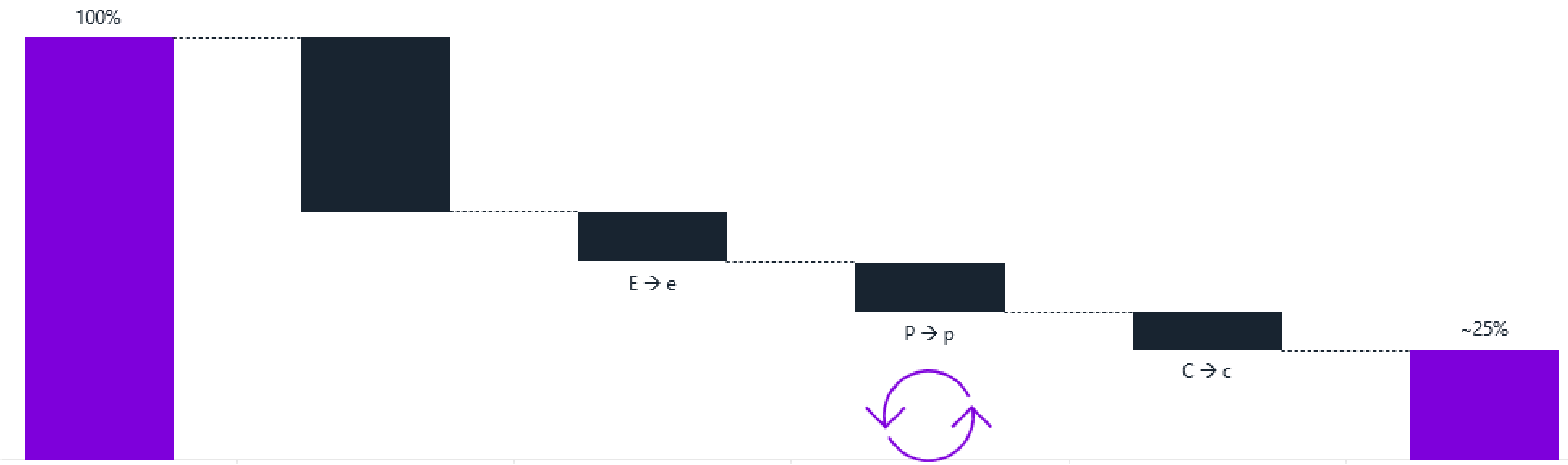
Designed for high volume manufacturing
to achieve large scale plants
with fossil price quality



Game-changer in industrial decarbonisation
Case study: Heroya, Norway

- Fully automated and designed according to **lean manufacturing and industry 4.0 principles**
- Industrial scale production of most efficient electrolysers in the market, at a **game-changing cost**
- Large scale production line, name plate capacity of **more than 500 MW**
- Room to expand to **~2 GW** annually
- CO_2 reduction potential in line 1 (pilot) of **1.000,000 tonnes** – with 2 GW, **4-5 million tonnes**
- Production for **Nikola and Everfuel** will commence in Q4

Standardization reducing system cost to enable $1.5/kg



Electrolyser system cost today	Herøya expansion	Engineering	Procurement	Construction	Reduced cost
Excludes Civil/Building	Increased capacity with Herøya expansion	Standardizing large-scale offerings: 20 MW, 50 MW, 100 MW, 250 MW	Continuous improvement of supply chains and framework agreements	Standardised design and pre-fabricated skids reduce time and cost for commissioning and installation	

Key drivers for large scale commercialisation & deployment

- One standardised and universally applied certification system classifying the different types of hydrogen with common LCA methodology.

- Flexible and workable rules for the sourcing of renewable electricity from the grid.

- Clear demand signals promoted via regulation e.g.
    - Targets for the use of renewable hydrogen in industry / transport segments.
    - No double grid fees for renewable h2 production.
    - Distance targets for h2 refuelling stations.

- Contracts for difference.

- Developing a broader concept for the use of the term "efficiency". What about system efficiency? Cost-efficiency? Resource efficiency?

Nuclear enabled Hydrogen Production

Dr Philip Rogers
Technology Leader
National Nuclear Laboratory, UK

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- Nuclear can deliver low carbon hydrogen on a large scale
- Low carbon, excellent sustainability
- Only feedstock is water
- Proven, commercialised technology: today's nuclear with electrolysis
- Combing low carbon electricity and heat from nuclear can improve efficiencies and reduce costs
- Future technologies could further improve efficiencies and reduce costs
- Complimentary to renewables
- Diverse supply chains
- Improved security of supply

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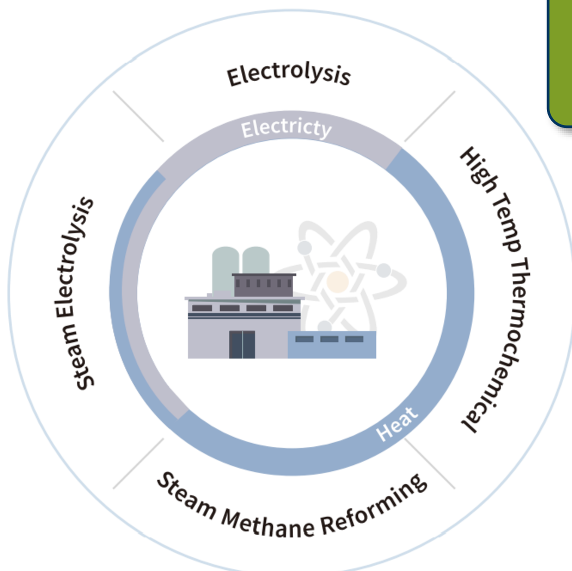
Nuclear enabled Hydrogen Production

Available today

Current nuclear technology coupled with commercial electrolysers

Current and future nuclear technology Commercial technologies in development

Available 2030's



Available 2040's

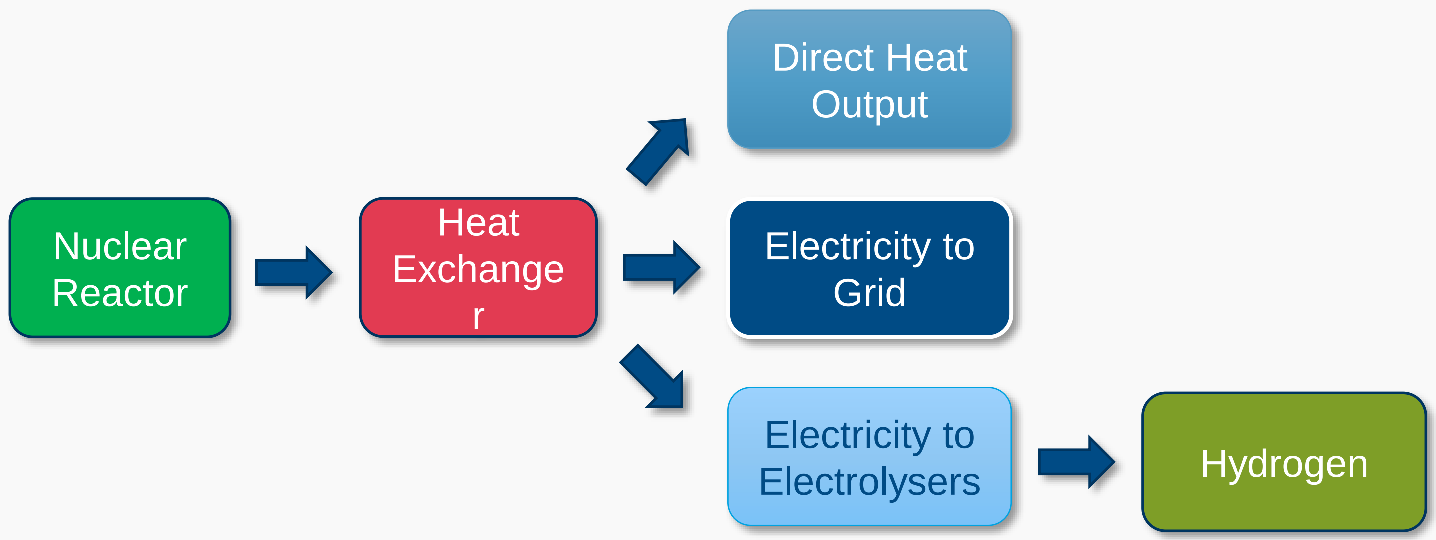
Future Advanced Nuclear Thermo-chemical R&D

Heat and electricity to reduce carbon intensity of Blue H2

Available today

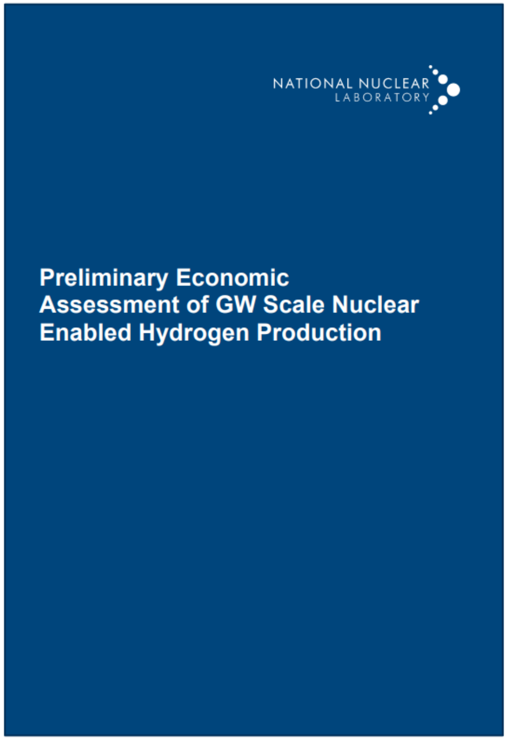
Nuclear enabled Hydrogen Production

- Flexible electricity to grid provided by electrolyser coupling
- Off-grid, standalone hydrogen production



Nuclear enabled Hydrogen Production

- Cost is highly dependent on financing arrangement
- High capacity factor offers high electrolyser utilization
- Electrolysers driven by nuclear heat and electricity could be 40% more efficient
- Nuclear enabled hydrogen could be equivalent cost to off-shore wind according to UK Government data
- Other organisations predict that nuclear could become the lowest cost form of low carbon hydrogen production


NATIONAL NUCLEAR LABORATORY

Preliminary Economic Assessment of GW Scale Nuclear Enabled Hydrogen Production

- UK example:
  - Policies are being put in place now to deliver nuclear enabled hydrogen in the 2030's
  - Long term thinking drives positive investments that deliver secure, low cost, low carbon energy
  - Including nuclear in energy system strategies can unlock carbon neutrality in new ways
  - International markets could enable cross border trade of nuclear enabled hydrogen (similar to cross border electricity trades), potentially providing nuclear enabled hydrogen options for countries not seeking domestic nuclear deployment

Thank you

phil.rogers@uknnl.com

Hydrogen from natural gas: technologies and prospects

Yuriy Melnikov

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IN THE REGION

«Low-carbon hydrogen from natural gas: global perspective and possibilities for Russia» – the new open study by SKOLKOVO School of Management

- The hydrocarbons role in the hydrogen production according to the international think-tanks forecasts
- *Hydrogen production technologies from fossil fuels*
- *Competitiveness of hydrogen from natural gas: cost, carbon footprint*
- Areas for development: energy policy, investments, individual projects
- **The study will be published in spring 2022**

Hydrogen production technologies from fossil fuels: steam methane reforming with CCUS

- Steam methane reforming by itself (without CCUS) is the most commercially proven technology for large-scale hydrogen production (TRL 11, 10-200 Nm3/h, distributed worldwide)
- Methane in a mixture with water vapor is converted into hydrogen and CO2 - when thermal energy is supplied from the outside (due to the combustion of the methane part)
- A key challenge is to achieve a high proportion (>90%) of CO2 capture across all outlet streams
- in 2021, there were no more than 5 commercial-scale installations with a CO2 capture rate of 60%

Source: Energy Centre, SKOLKOVO School of Management (2022)

Hydrogen production technologies from fossil fuels: autothermal methane reforming with CCUS

- the process does not use air, but oxygen (which requires electricity to produce), and thermal energy is generated inside the reactor, resulting in a single exhaust gas stream with a high concentration of CO2
- Easier to organize CO2 capture
- Autothermal reforming has long been used to produce syngas in the chemical industry
- its use in the production of blue hydrogen will require refinement (ATR c CCUS technical readiness level, according to the IEA - 8-9)

Source: Energy Centre, SKOLKOVO School of Management (2022)

Hydrogen production technologies from fossil fuels: CCUS as a necessary element for reforming

- to achieve climate goals in the SDS scenario by 2050, CO_2 capture and storage should reach 4.6 $GtCO_2$-eq. per year, which is comparable to the scale of the modern oil industry (IEA)
- The peculiarity of CCUS for blue hydrogen is that it is possible to provide the necessary volumes of hydrogen production only with long-term storage of captured CO_2 (and not its useful use)
- 20% of the 40 million tons of CO_2 captured today is sent to long-term storage - the rest is used for enhanced oil recovery (EOR)
- Cautious attitude of the public and investors VS the need that analytical agencies talk about

Source: Energy Centre, SKOLKOVO School of Management (2022)

Hydrogen production technologies from fossil fuels: pyrolysis (decomposition) of methane

- conversion of methane to hydrogen and solid carbon without direct CO_2 emissions. The process proceeds at high temperatures (more than 800 °C; the optimum level for a non-catalytic process is 1100-1300 °C)
- Pyrolysis technologies have long been used to produce carbon black (hydrogen is a by-product, its quality is not regulated)
- the problem of useful use or long-term storage of emitted carbon (the world carbon market is 16 million tons, which corresponds to 5 million tons of hydrogen from pyrolysis)
- The IEA rates the average TRL of pyrolysis technologies in the range of 3 to 6, so there are no reliable cost estimates for them yet.

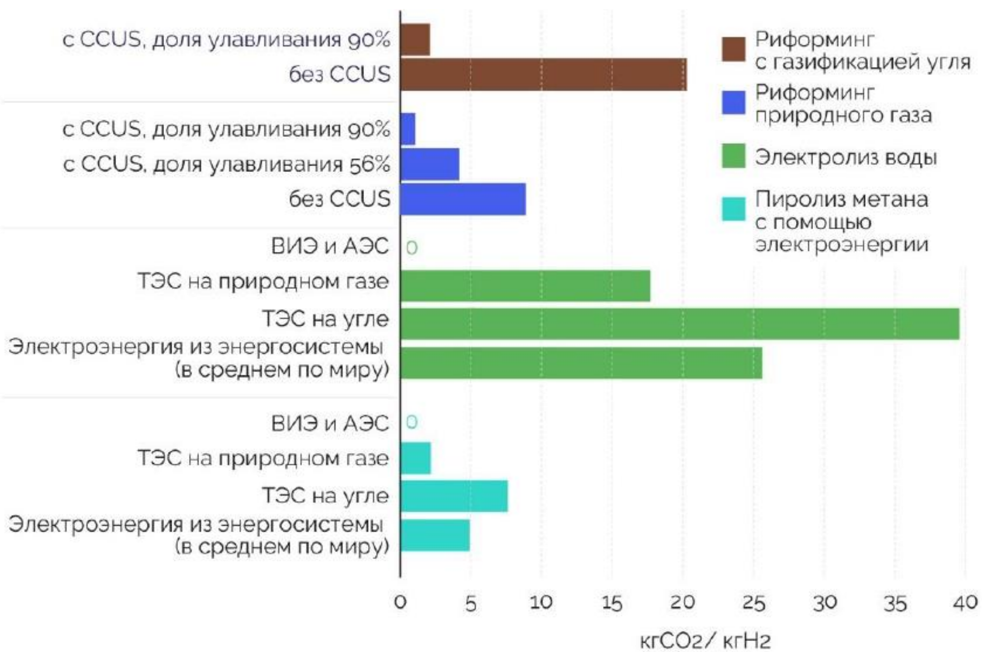
Source: Energy Centre, SKOLKOVO School of Management (2022)

Comparison of technologies by energy and resource intensity

Technology	Specific consumption per 1 kg H2			Production of by-products per 1 kg H2	
	Electricity (kWh)	Methane (kg)	Water (kg)	CO2 (kg)	Solid carbon (kg)
SMR + CCUS	1,91	3,71	13-18	2,3-5,8 (в атмосферу), всего около 12	0
Methane pyrolysis	11-15, up to 35	4	-	-	3
Water electrolysis	55	-	9	-	-

Source: Energy Centre, SKOLKOVO School of Management (2022)

Comparison of technologies by carbon footprint



- CCUS reforming and pyrolysis provide a low carbon footprint under certain conditions (methane emissions are an important factor)
- Electrolysis provides a low carbon footprint only when using renewables and nuclear power plants
- Carbon footprint needs to be certified

Source: Energy Centre, SKOLKOVO School of Management (2022)

Intermediate findings

- Steam methane reforming is the most commercially developed technology for large-scale hydrogen production. Requires integration with CCUS (including through autothermal reforming)
- The scope and effectiveness of CCUS needs to be scaled up
- Pyrolysis is a promising technology, but there are issues with technological readiness, scaling, cost and carbon utilization
- Hydrogen from natural gas can be low-carbon under certain conditions and its certification

Source: Energy Centre, SKOLKOVO School of Management (2022)

Coal to Hydrogen

Dr Andrew Minchener, General Manager
International Centre for Sustainable Carbon

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IN THE REGION

PRESENTATION OUTLINE

- Who we are and what we do
- Current hydrogen markets
- Hydrogen production
- Costs and emissions comparisons
- Strategies and supporting policies
- Regional context

INTERNATIONAL CENTRE FOR
SUSTAINABLE CARBON

Technology Collaboration Programme
by iea

DR ANDREW MINCHENER OBE

General Manager

INTERNATIONAL CENTRE FOR
SUSTAINABLE CARBON

Technology Collaboration Programme
by iea

- **We are dedicated to providing independent information and analysis** on how biomass, coal and other carbon sources can become cleaner sources of energy, compatible with the UN Sustainable Development Goals

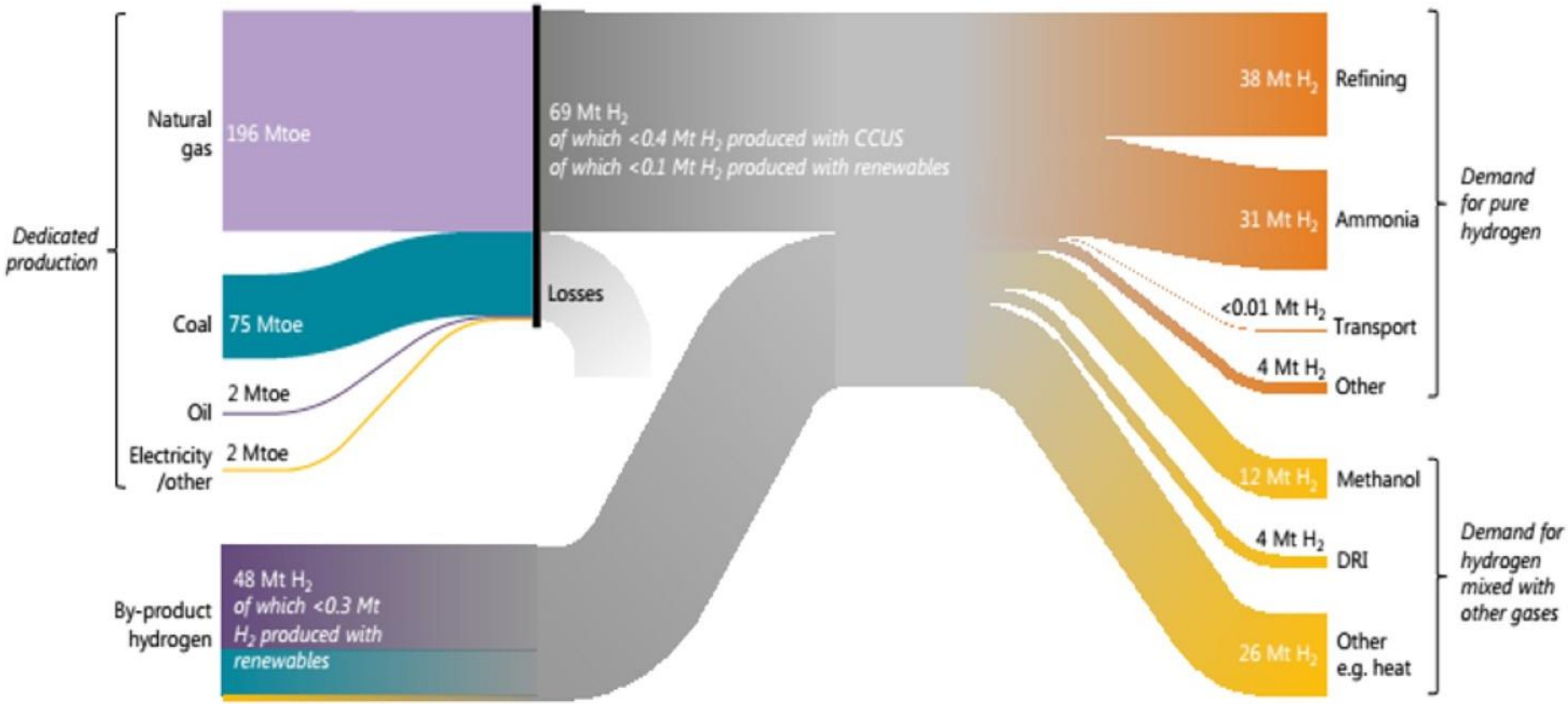
- **The International Centre for Sustainable Carbon (ICSC)** is part of a network of autonomous collaborative partnerships focused on a wide range of energy technologies known as Technology Collaboration Programmes (TCPs)

- The TCPs are organised under the auspices of the International Energy Agency (IEA) but are functionally and legally autonomous

- We are funded by national governments (contracting parties) and by corporate industrial organisations (sponsors)

Current Hydrogen Markets

- Coal currently accounts for 27% of hydrogen demand



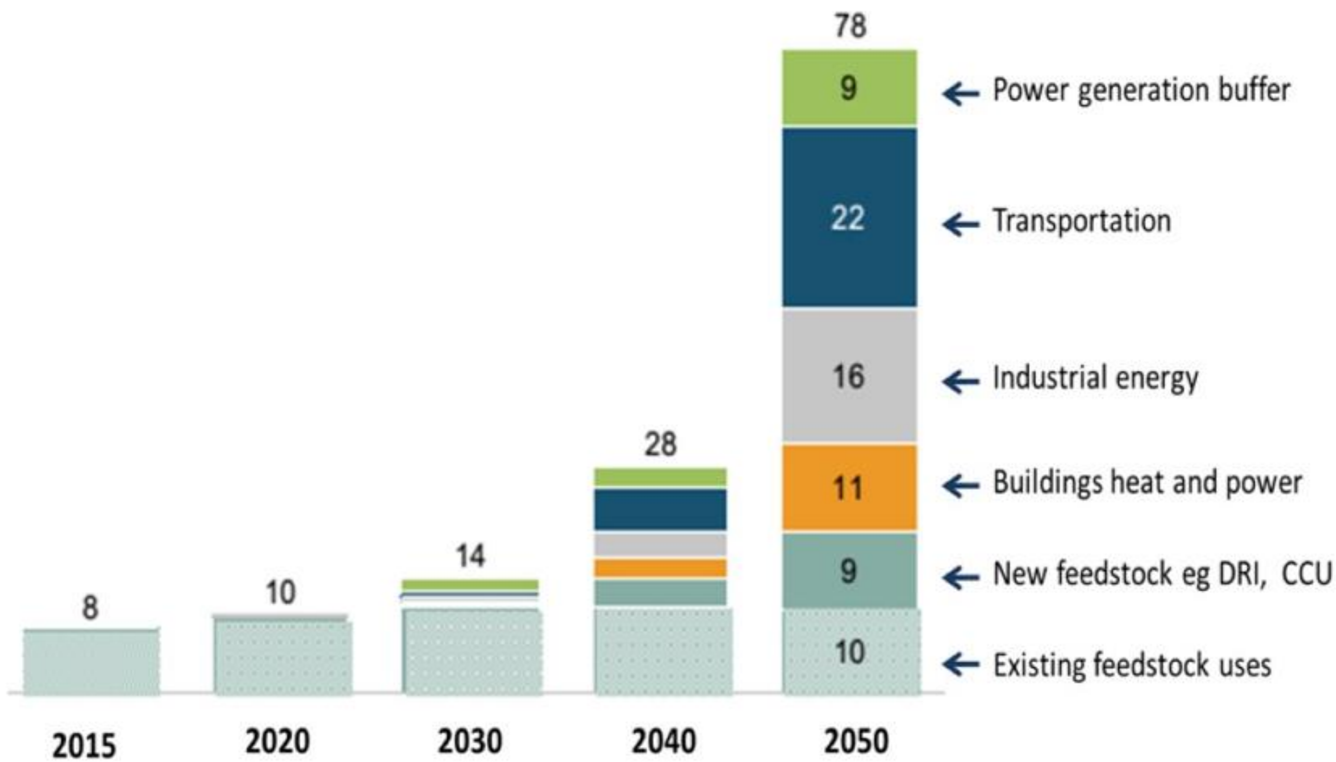
Sankey diagram showing H_2 value chains in 2018 (IEA, 2019)

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

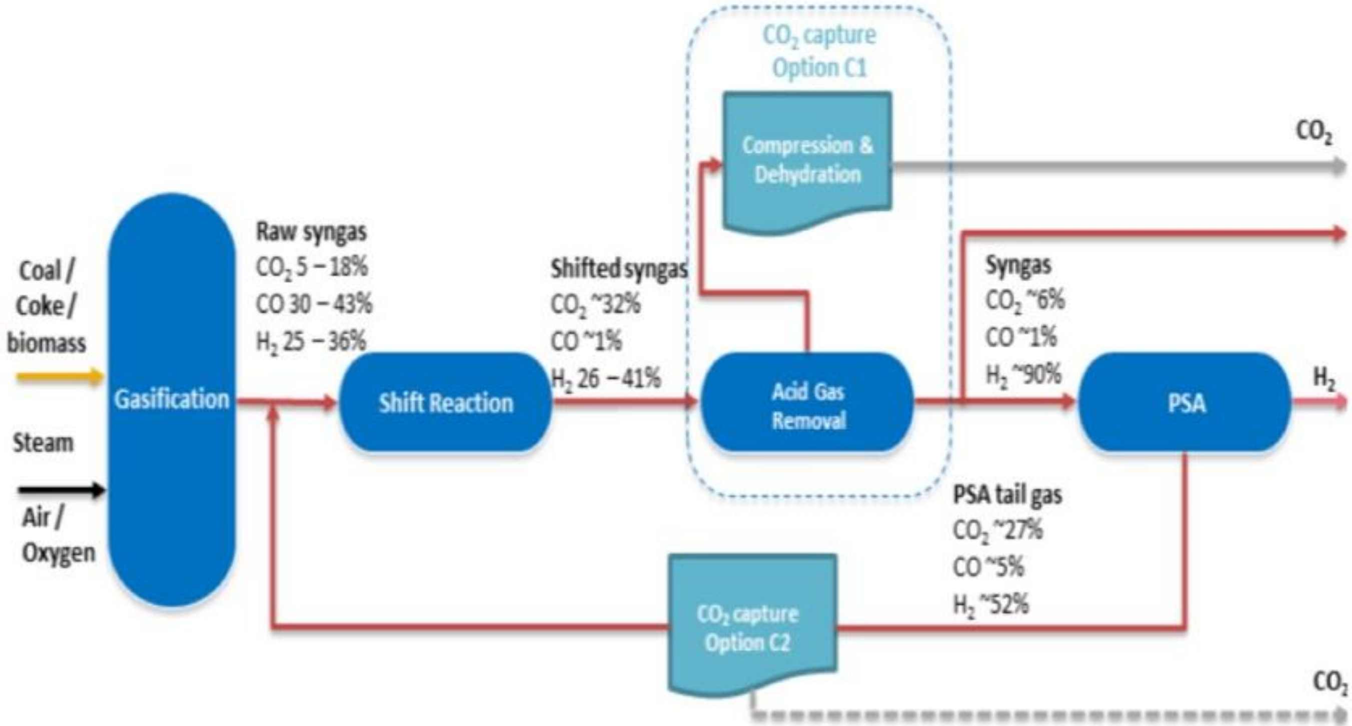
Reasonably uniform potential spread across sectors



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

Coal to Hydrogen Production via 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)



H2/syngas production with CCUS (Zapantis and Zhang, 2020)

Coal to Hydrogen Production with CCUS

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

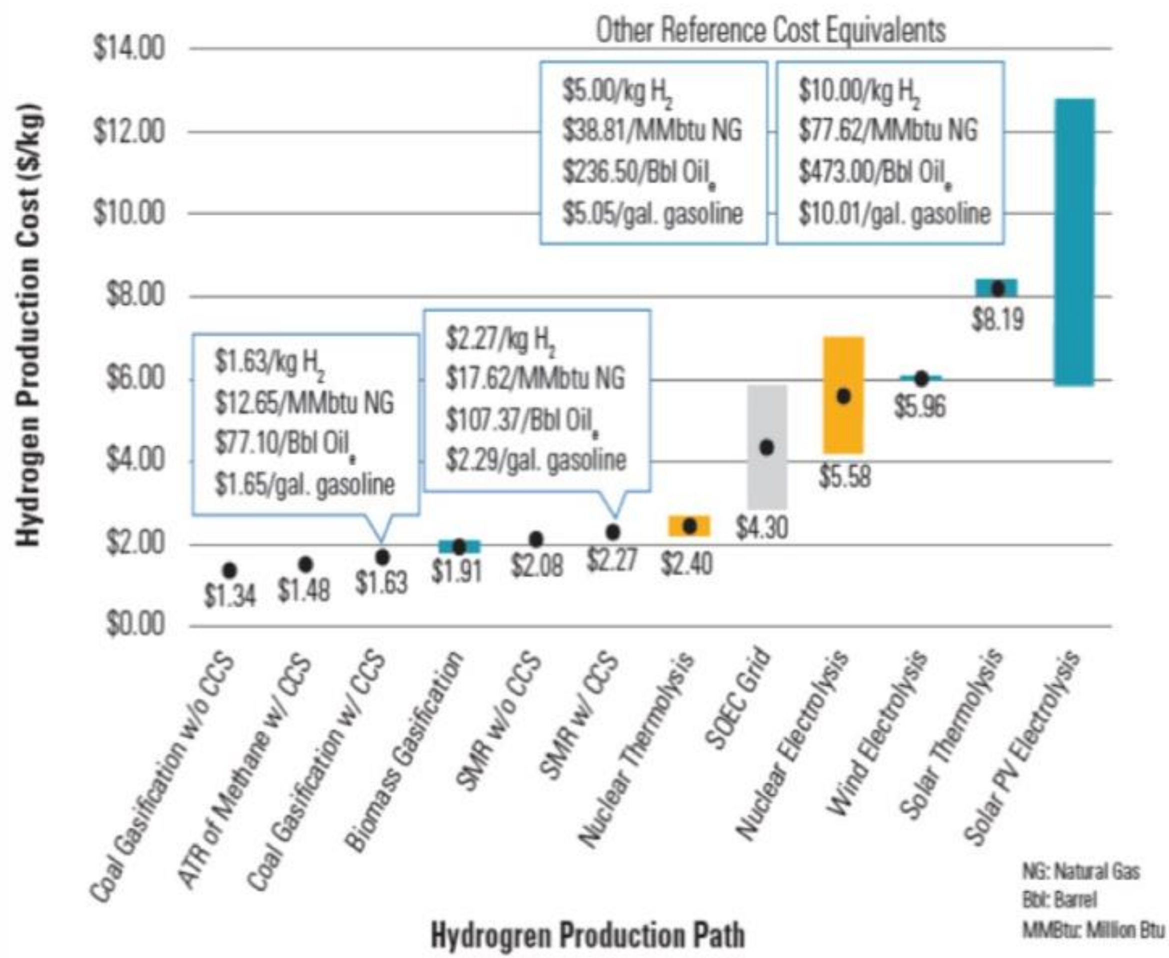
Coal Gasification to Hydrogen HESC Project

- 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

Hydrogen Cost

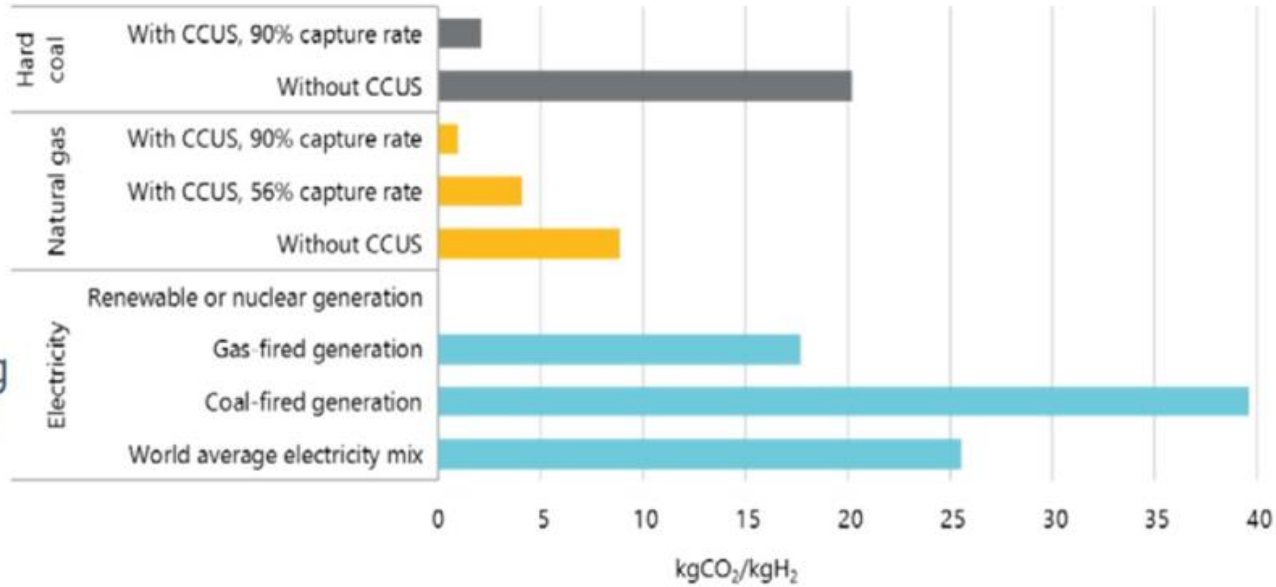
- Costs vary due to local factors, fuel price, renewable electricity, load factor, learning rates and carbon taxes
- H2 from coal gasification with CCUS as low as US$1.6/kg to US$2.4/kg

Comparison of H_2 costs (USDOE, 2020)



Emissions comparison

- Carbon intensity of H_2 from coal with CCUS (90% capture) can be limited to 3 $kgCO_2/kgH_2$
- Higher capture rate of co-firing with biomass/waste can reduce intensity further



CO2 intensity of H_2 production (IEA, 2019)

Hydrogen strategies

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

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

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

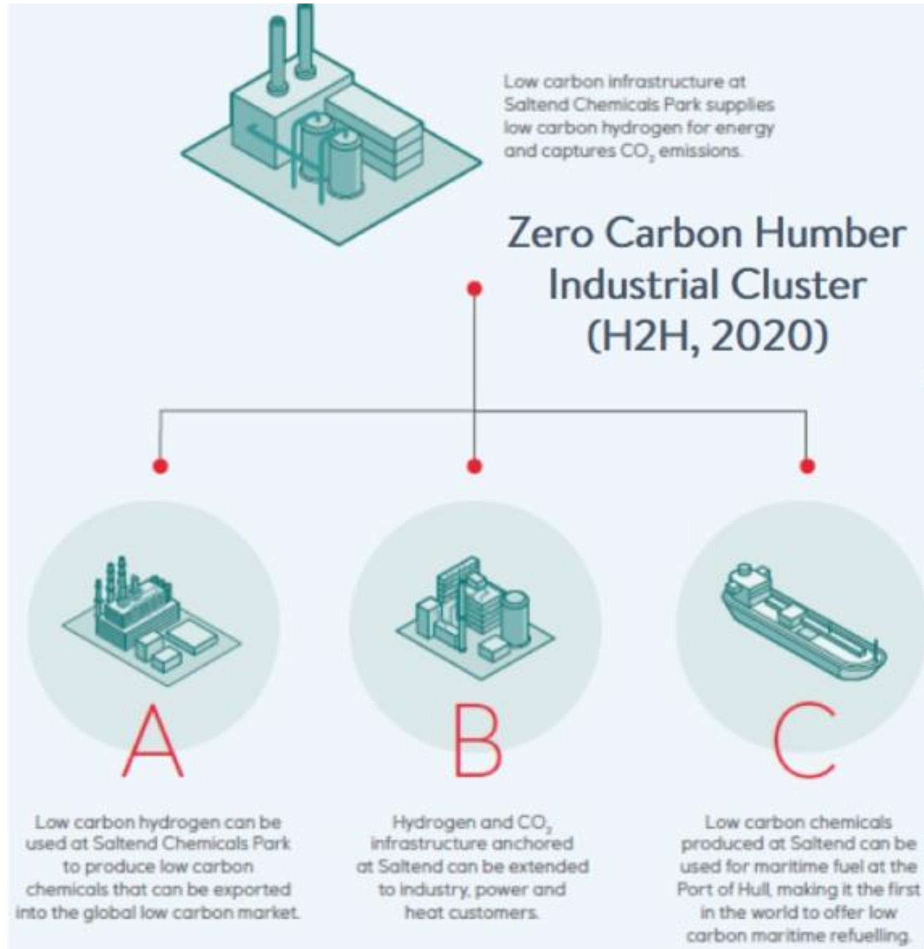
Supporting policy actions
IEA 2019

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

- 115 MtH_2/y global demand in 2018, was 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 to <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

Regional context

- Central Asia republics need to expand infrastructure as part of an energy transition
- In many cases, strong wind sources can support power projects, currently coal fired

- Coal and other fossil fuels are available and are traded between Central Asian Republics. Significant scope to produce tradable hydrogen from coal via gasification with CCUS route.
- Kazakhstan seen as a key regional driver for this approach with significant coal deposits
- Tajikistan may pursue this approach


INTERNATIONAL CENTRE FOR
SUSTAINABLE CARBON
THANK YOU FOR LISTENING
Technology Collaboration Programme
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Discussion on national potential, priorities, identified opportunities and challenges

ENERGY

Dialogue with project beneficiary countries:

- Kazakhstan
- Uzbekistan
- Kyrgyzstan
- Tajikistan
- Turkmenistan
- Armenia
- Moldova
- Azerbaijan
- Belarus

ENERGY

Sustainable Energy Division

UNECE

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