Energy Transition and Industry Decarbonisation
Emerging Pathways and Technologies

AIESRE 2025

Dr. Hacib BEN AISSA
Product Development Manager - Lynas Rare Earths

Introduction

Hacib BEN AISSA

- *Chemical Engineer: 1996 – USTO (Algeria)*
- *Magister in Catalysis and Environment 1998 –Tlemcen (Algeria)*
- *PhD in Catalysis 2006 – Liverpool (UK)*

Various Positions

Shell

- *Catalyst Consultant (UK)*
- *Senior Process Engineer in a gas plant (UK)*
- *Senior Technologist Gas to Liquid (Qatar)*
- *Process Implementation Coordinator (Netherlands)*

ExxonMobil

- *Technology Advisor - Chemical Process (UK)*
- *Project Development Engineer (UK)*

Ceres Power

- *Principal System Engineer - Solid Oxid Electrolysers (UK)*

Lynas Rare Earths

- *Product Development Manager (Malaysia)*

Patent Applications

- WO2023/161610 ASU Enriched Air Electrolyser System
- WO2023/161609 FCC Enriched Air Electrolyser System
- WO2023/161611 Refinery & Wastewater Plant Enriched Air Electrolyser System
- WO2024/165852 SOEC H2 Compression
- WO2024/157023 SOEC Intermittency
- WO2024/189349 SOEC H2 Turbocharger
- 63/652,512 Boron Removal from Lithium Brine - U.S. Provisional Application
- FR2315319 Ammonia Cracking Catalyst - FR Provisional Application
- 63/715,020 Hydrothermal Gasification - US Provisional Application

Introduction to **Lynas**

- Headquartered in Perth, Australian company
- Operating in both Australia and Malaysia for > 10 years
- Ethical and Environmentally responsible producer of rare earth materials
- World's only significant producer of separated rare earth materials outside of China

Lynas Rare Earths

- The Lynas Mt Weld mine in Western Australia is one of the world's premier rare earths deposits
- Lynas also operates the world's largest single rare earths processing plant in Malaysia
- Produces high-quality separated rare earth materials in Malaysia for export to manufacturing global markets
- Lynas' materials essential to growth industries and are used in many high tech and future facing applications

Why Decarbonization?

"Critical to tackling the climate crisis"

"The current ***greenhouse gas induced warming*** *of Earth is essentially irreversible on human timescales. The amount and rate of further warming will depend on how much more CO_2 is added to the atmosphere. A sharp reduction in CO_2 emissions is needed to slow climate change and avoid the most severe impacts on weather extremes, ecosystems, human health, and infrastructure".*

"The ***2016 Paris Agreement*** *set an aspirational target of* ***limiting warming to 1.5°C****. Meeting that goal will require global emissions to be reduced by about 45 percent from 2010 levels by 2030, reaching net-zero emissions by 2050. Meeting those emissions targets will* ***require dramatic reductions in global CO_2 emissions*** *combined with the active removal of CO_2 from the atmosphere"*

Source: The National Academies Press

Transition to a **Decarbonized**, cleaner and more **Sustainable Energy** is subsequently **Required**

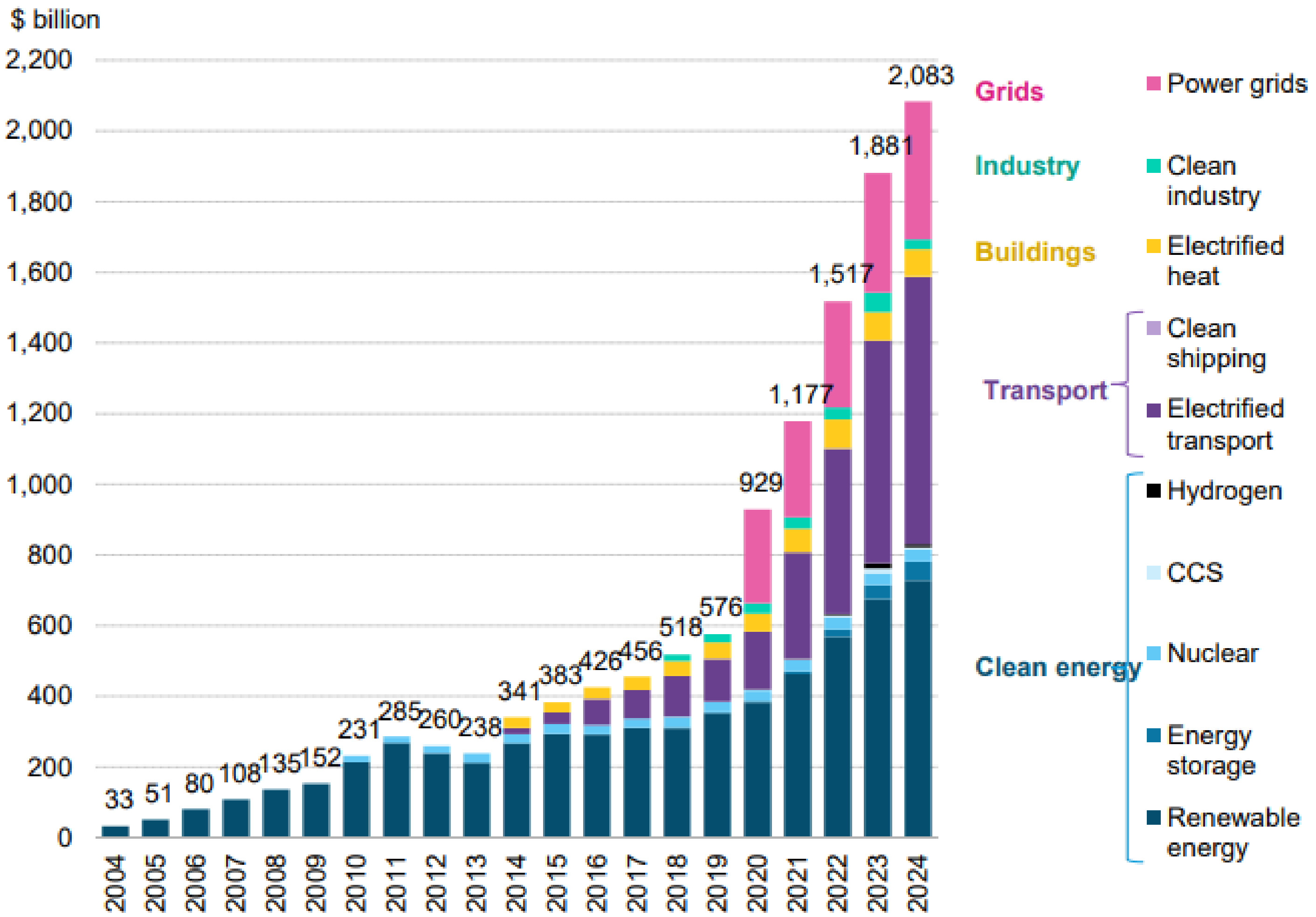
Energy Transition and Decarbonization

" Transformative shift in how energy is produced, distributed and consumed, aiming to move away from fossil fuels towards a system centred on renewable energy sources"

*"Involves adopting **Cleaner Energy** Sources but also **Enhancing Energy Efficiency**, Deploying **Advanced Technologies**, and **Decarbonizing** key sectors such as **Electricity**, **Transportation** and **Industry**"*

Is Energy Transition happening ?

- Global investment in the low-carbon energy transition surged in **2024** to reach **$2.2 trillion**
- **90%** of the total investment in **Electrified Transport**, **Renewable Energy**, **Power Grids**
- Companies and Businesses and States are investing **billions USD Developing** and/or **Driving**/ and/or **Adopting new sustainable technologies**
- Business is as **Unusual**, strongly driven by **Geopolitical Consideration**
- China (37%), USA and Europe are leading, followed by rest of the word (15%)



Source: BloombergNEF. Note: Start years differ by sector but all sectors are present from 2020 onwards; see Methodology for more detail. Most notably, nuclear figures start in 2015 and power grids in 2020. CCS refers to carbon capture and storage.

- [*Energy Transition Investment Trends 2025*]

The Trend

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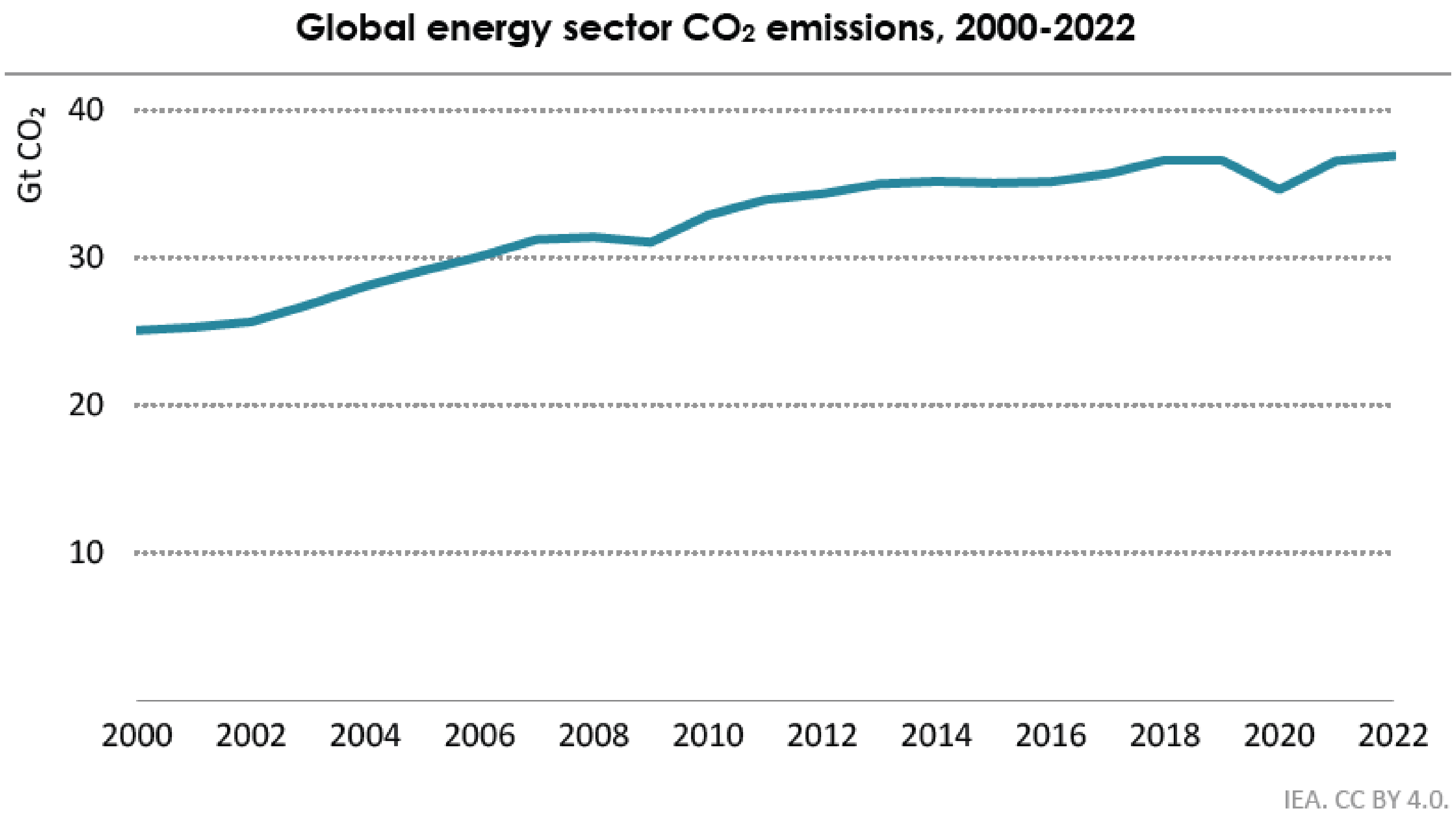
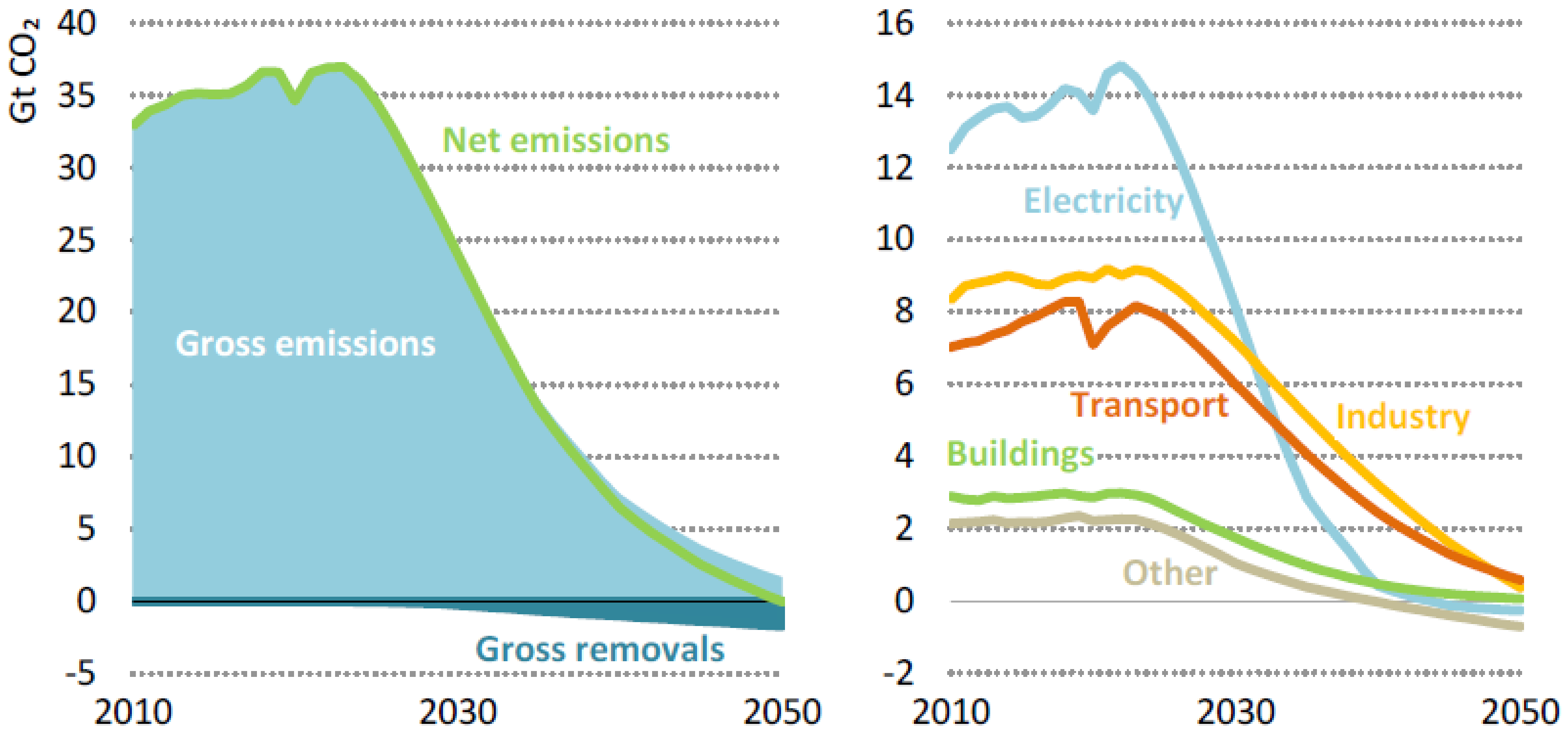


The Nature and Scale of the Task

* *IEA 2023*

Energy sector gross emissions and removals, total net CO_2 emissions, and net emissions by sector in the NZE Scenario, 2010-2050



Energy sector CO_2 emissions are reduced 65% by 2035 and reach net zero by 2050, with residual emissions of 1.7 Gt balanced by atmospheric removals of the same magnitude

The Measures

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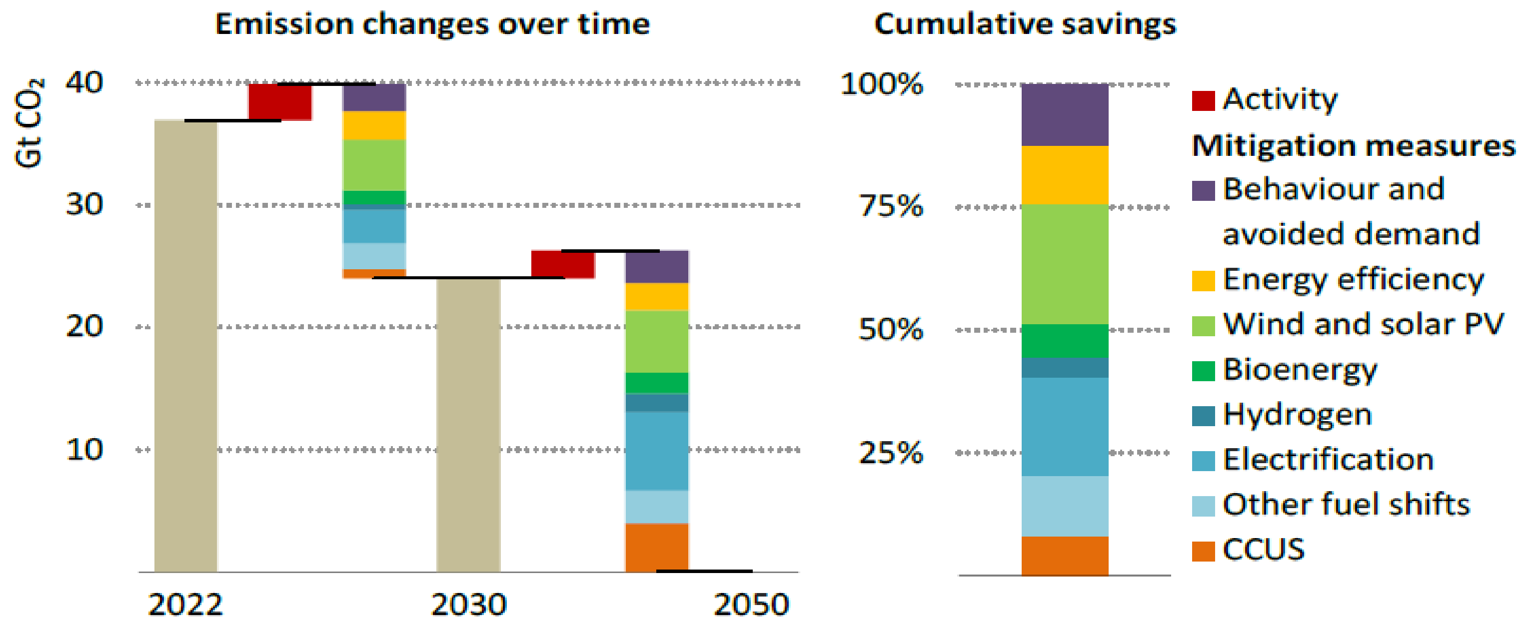
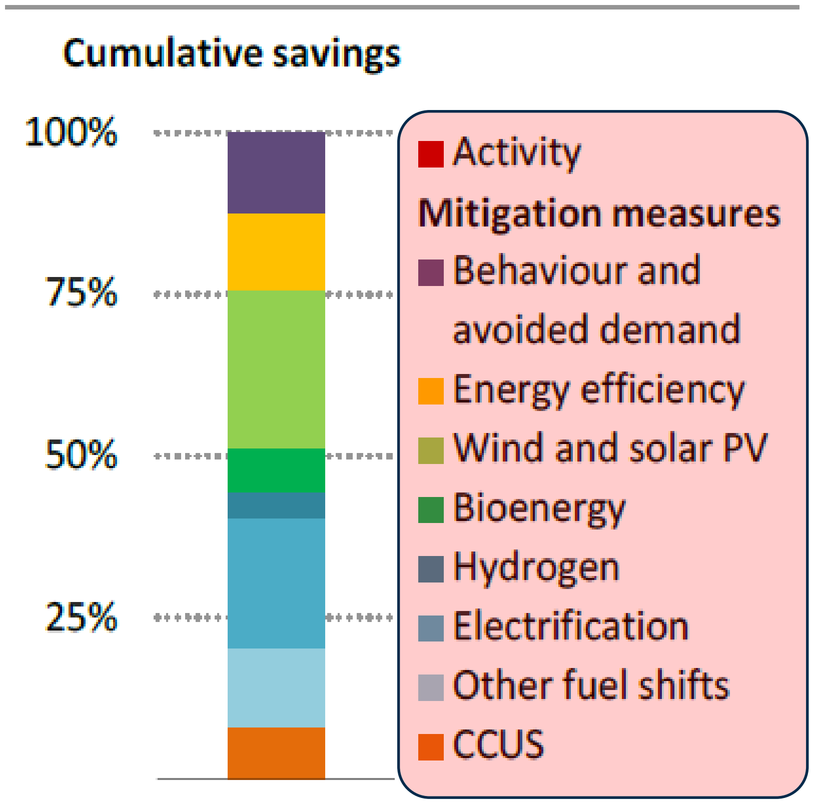
CO_2 emissions reductions by mitigation measure in the NZE Scenario, 2022-2050

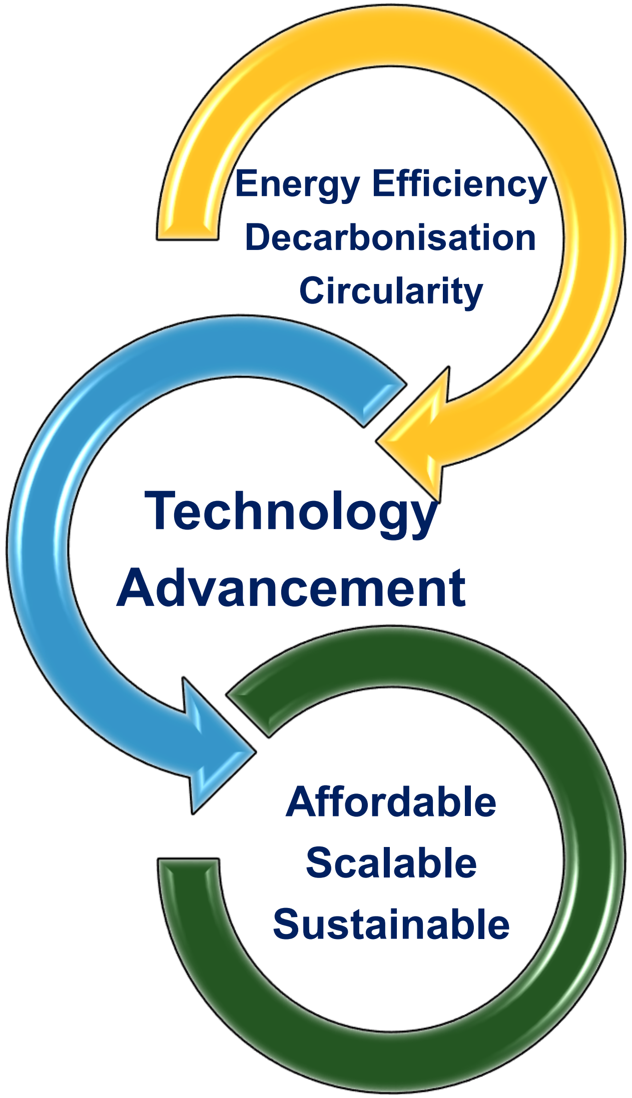


Expansion of solar PV, wind and other renewables, energy intensity improvements and direct electrification of end-uses combined contribute 80% of emission reductions by 2030

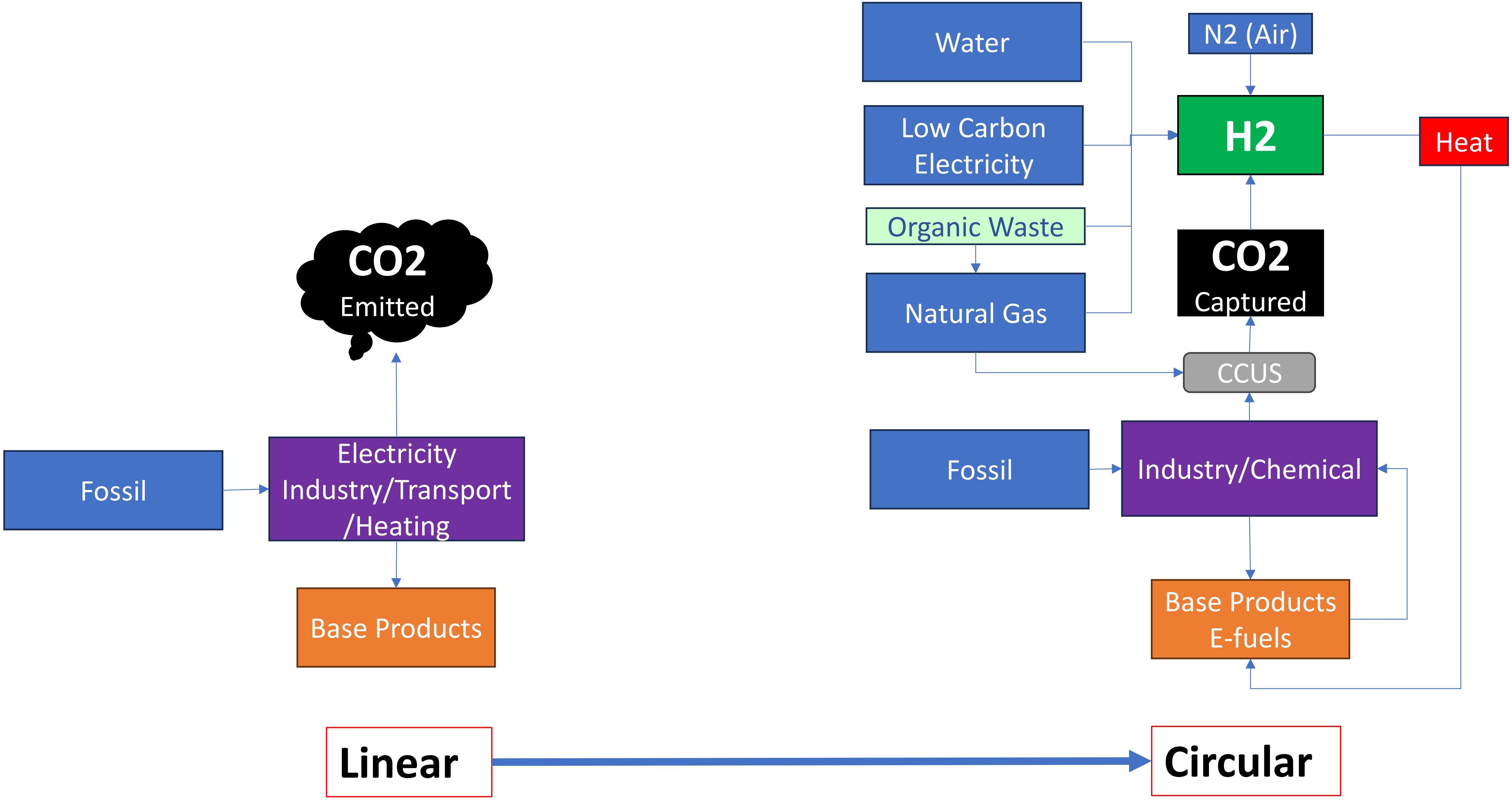
Notes: Activity = energy services demand changes from economic and population growth. CCUS includes BECCS and DACS.

Energy Transition and Sustainability

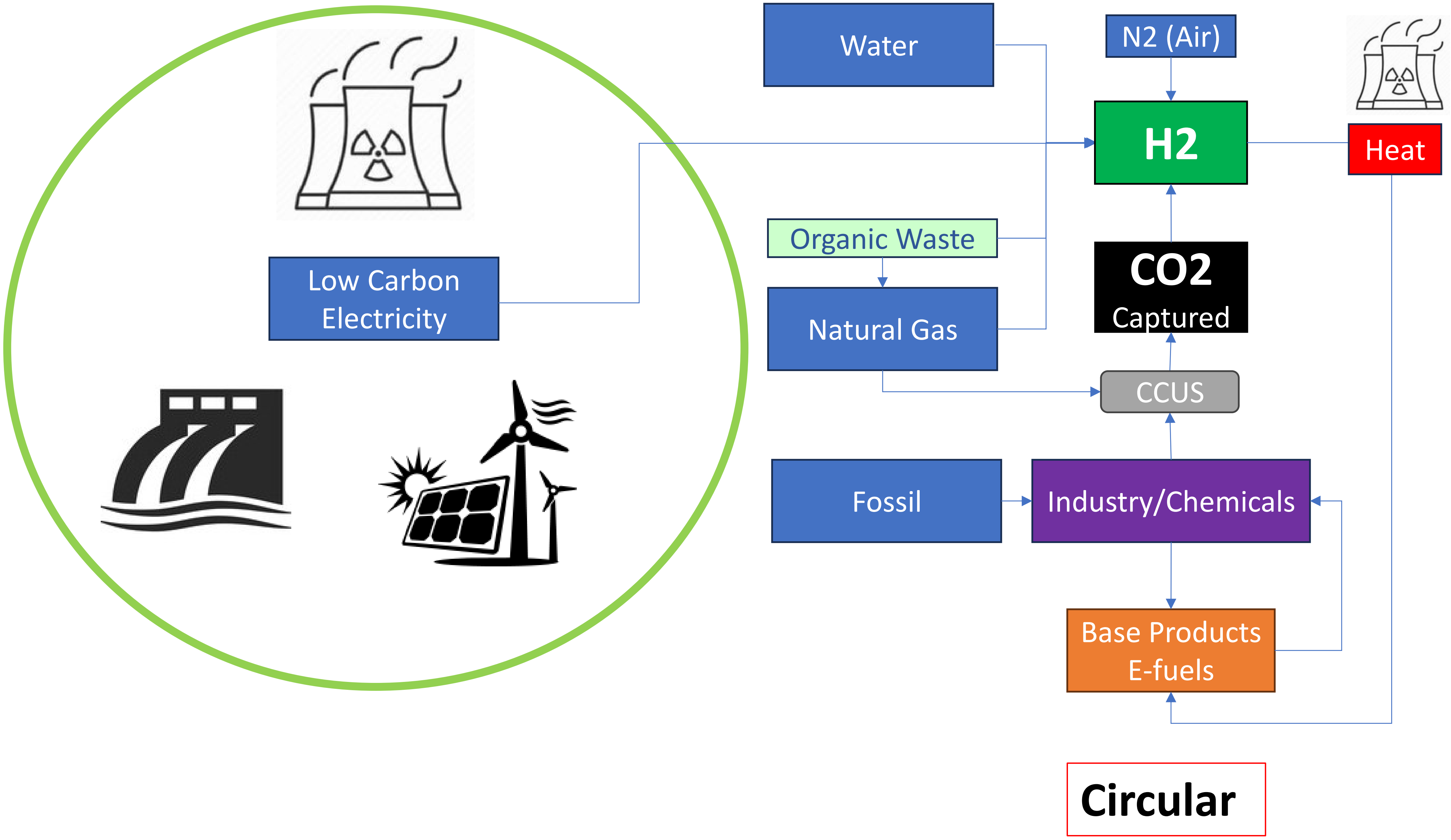




A Pathway to Decarbonisation



A Pathway to Decarbonisation



Demand in Fossil Fuel – NZE

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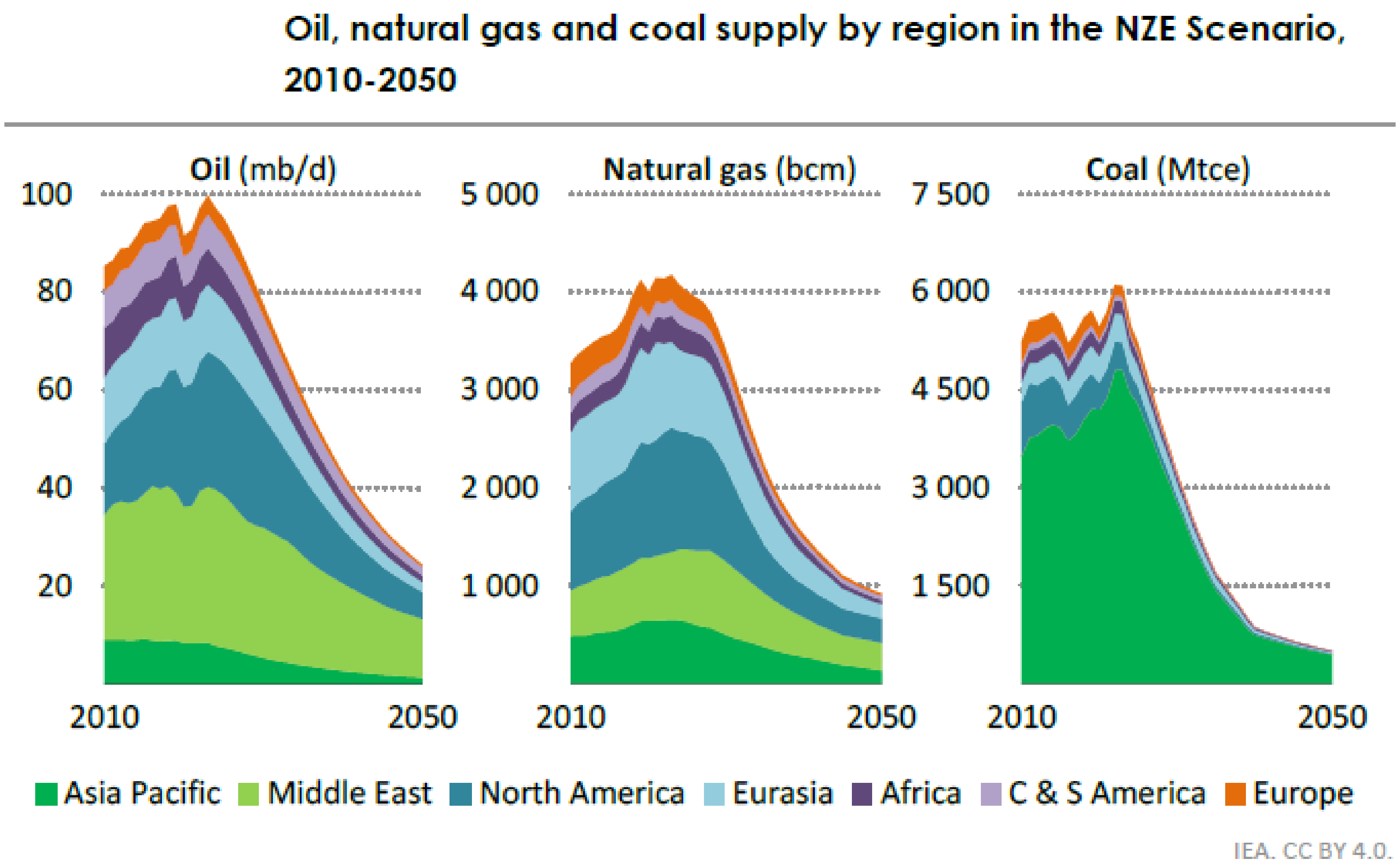

Declines in demand can be met without approving new, long lead time upstream conventional oil and gas projects, new coal mines or mine lifetime extensions

Demand in Carbon Capture – NZE

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Milestones	2022	2030	2035	2050
Total CO_2 captured (Mt CO_2)	**45**	**1 024**	**2 421**	**6 040**
CO_2 capture from fossil fuels and industrial processes	**44**	**759**	**1 712**	**3 736**
Power	1	188	568	811
Industry	4	247	769	2 152
Merchant hydrogen	0	161	285	756
Other fuel transformation	38	163	90	17
CO_2 capture from bioenergy	**1**	**185**	**506**	**1 263**
Power	0	44	204	438
Industry	0	23	77	232
Biofuels production	1	114	213	474
Other fuel transformation	0	5	13	121
Direct air capture	**0**	**80**	**203**	**1 041**
Total CO_2 removed (Mt CO_2)	**1**	**234**	**632**	**1 710**

Demand in Low emission Hydrogen – NZE

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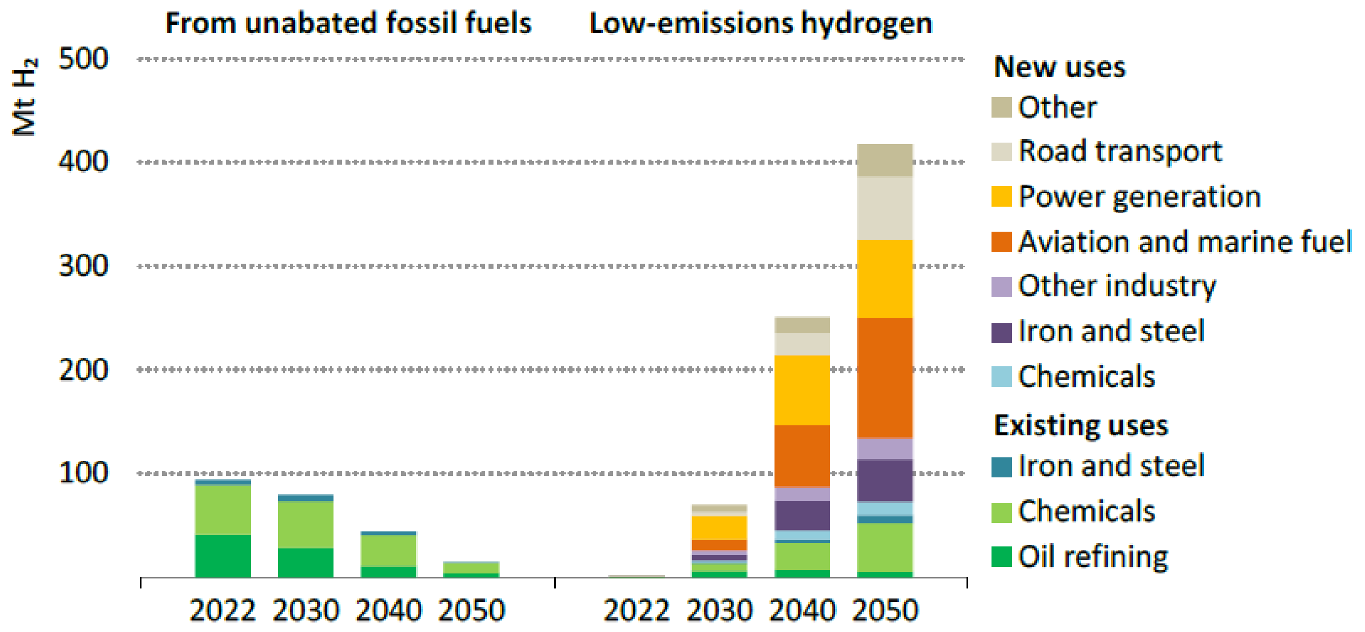
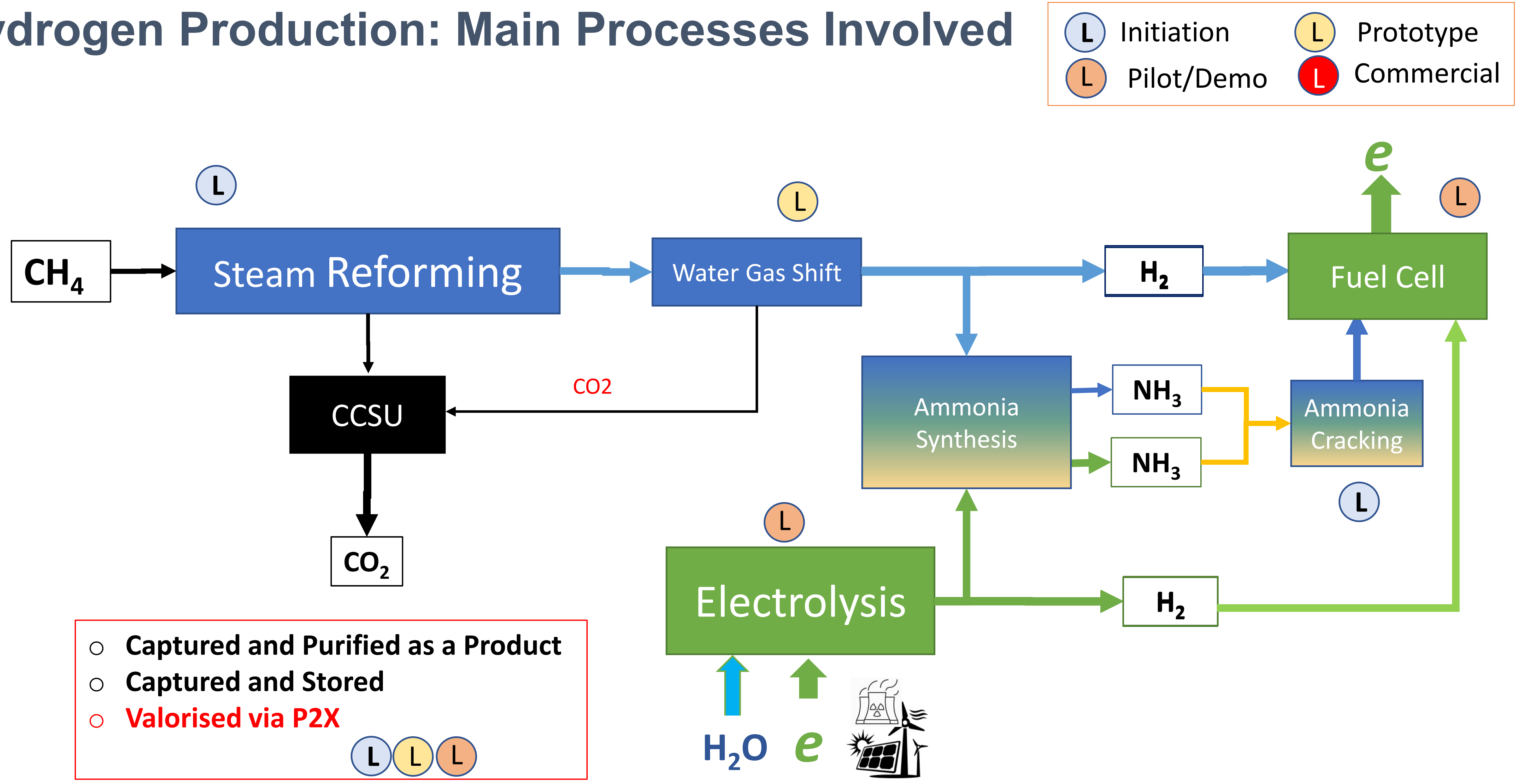


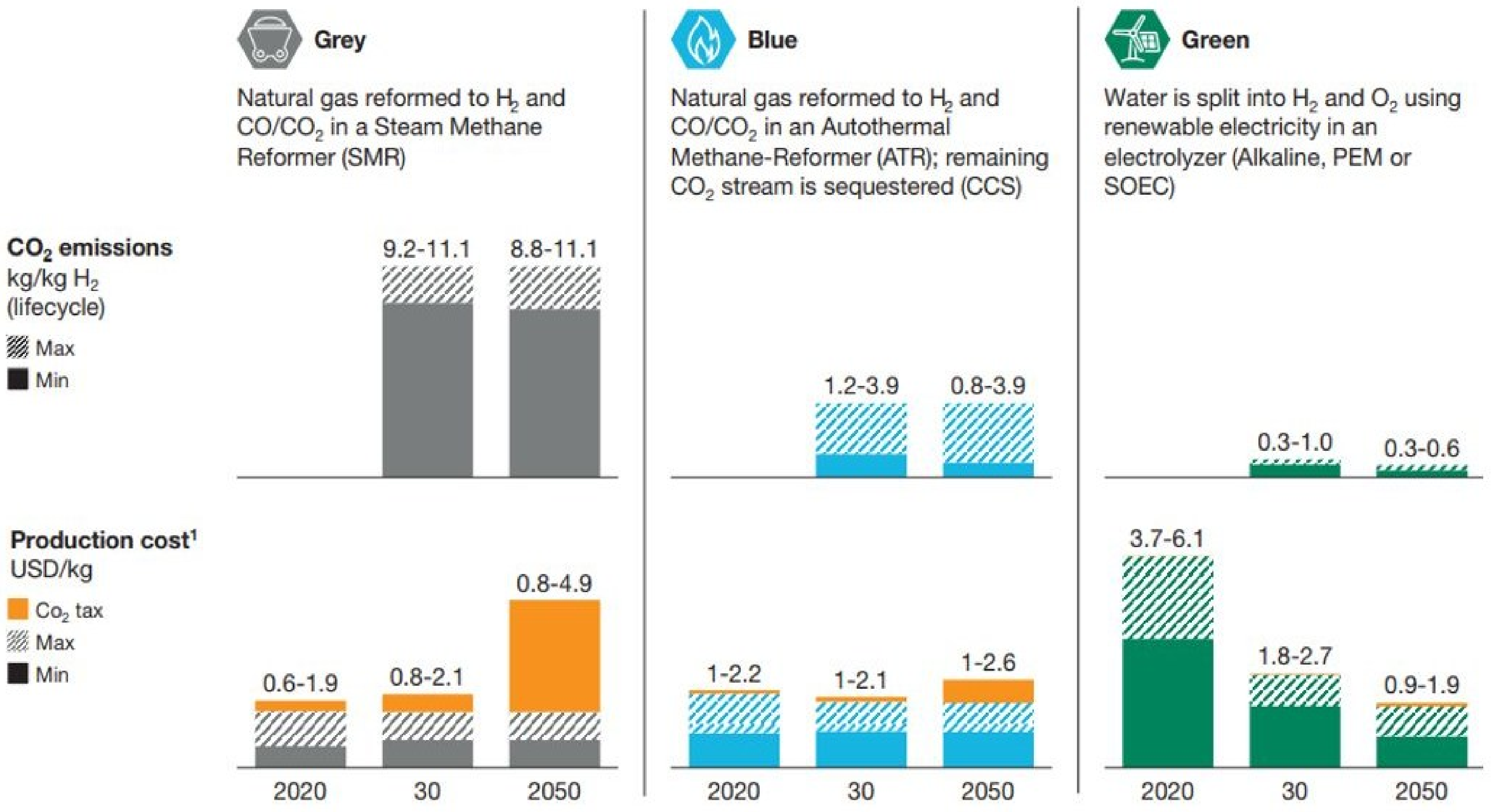
Milestones	2022	2030	2035	2050
Low-emissions hydrogen production (Mt H_2)	1	70	150	420
From low-emissions electricity	0	51	116	327
From fossil fuels with CCUS	1	18	34	89
Cumulative installed electrolysis capacity (GW electric input)	1	590	1 340	3 300
Cumulative CO_2 storage for hydrogen production (Mt CO_2)	**11**	**215**	**410**	**1 050**
Hydrogen pipelines (km)	**5 000**	**19 000**	**44 000**	**209 000**

Hydrogen Production: Main Processes Involved



Projection on cost of Hydrogen based on CO2 intensity*

** The Hydrogen Council*



[1] Costs for hydrogen produced in new installations; Assuming CO2 tax of USD 28/ton in 2020, USD 48/ton in 2030, USD 300/ton in 2050, excluding vectorization/transport

Source: LBST; Hydrogen Council – Path to Cost Competitiveness; McKinsey

Green Hydrogen Production Will Require Efficient, Reliable, Scalable and Low-Cost Technology

Energy consumption by Sources and Selected Industries

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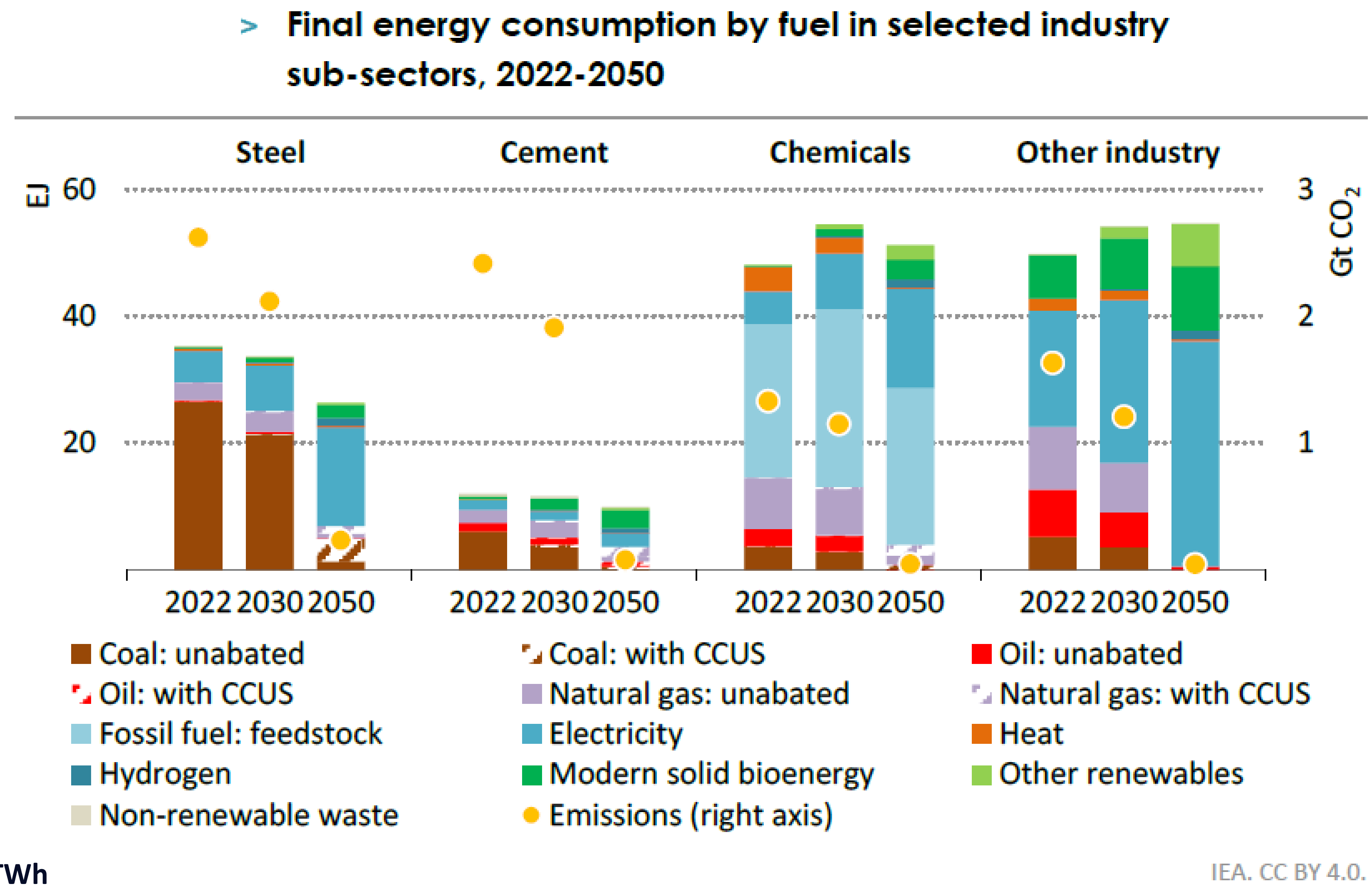

1 EJ = 278 TWh

Net zero emissions in industry relies heavily on electricity, hydrogen and CCUS. Unabated fossil fuel use plummets while petrochemical feedstock demand decreases more slowly.

The Technologies – Emerging and Capex/Opex Intensive

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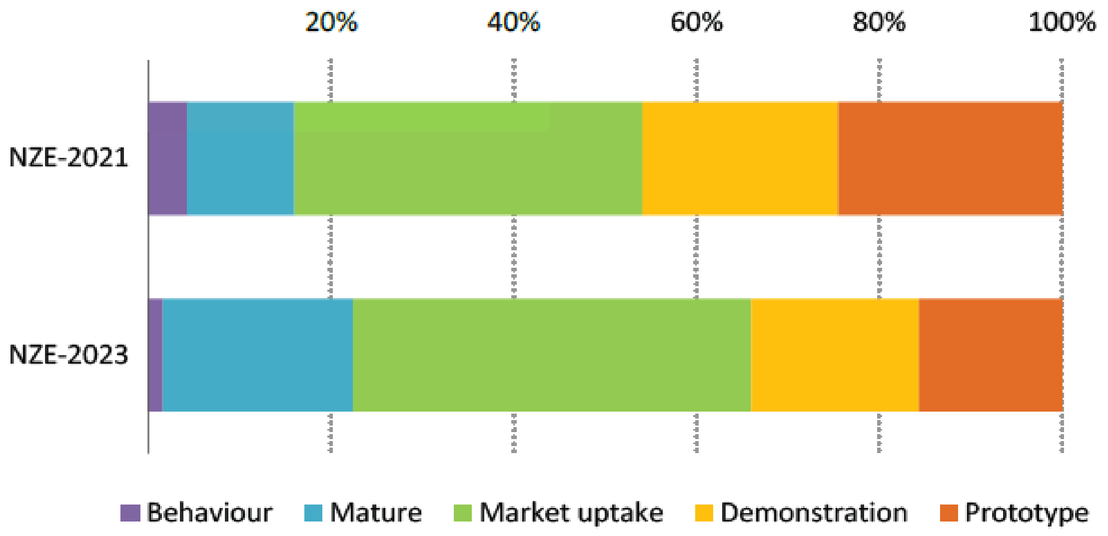
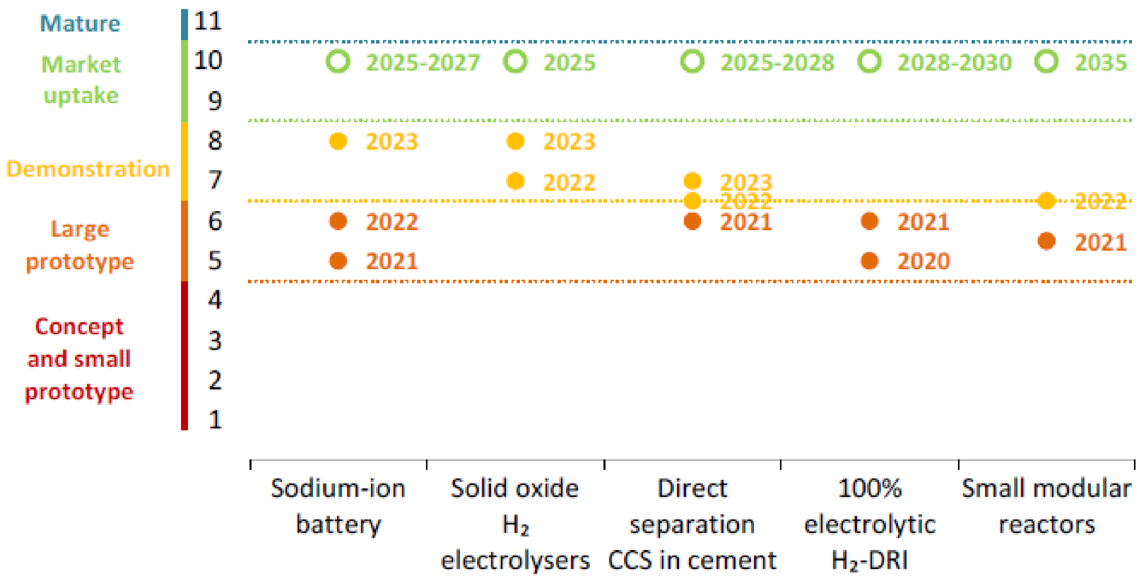
Comparison of CO_2 emissions reductions in 2050 relative to base year by technology maturity in the 2021 and 2023 NZE Scenarios



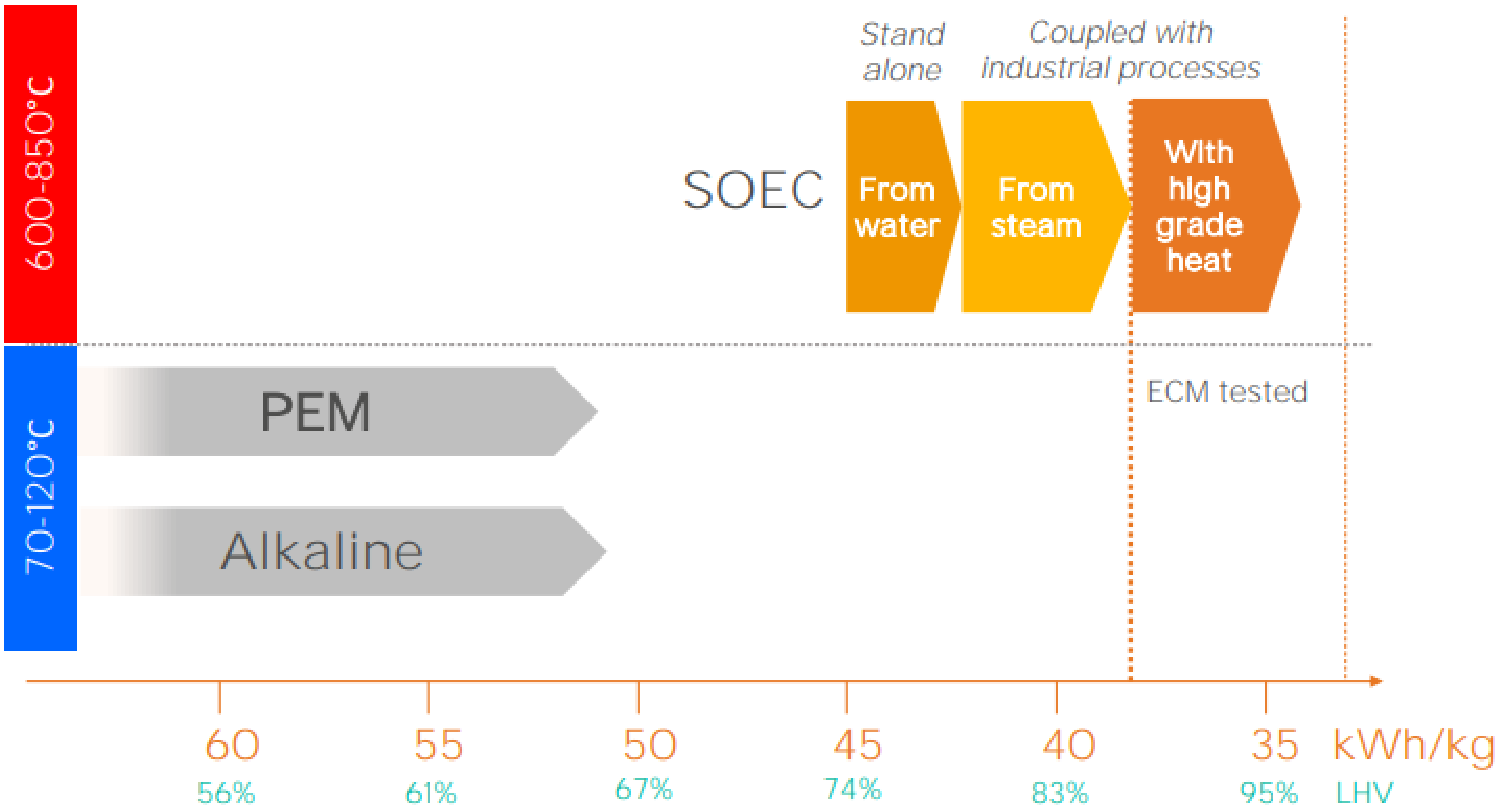
Emissions reductions by 2050 from technologies in demonstration or prototype stage have been reduced from almost half in the 2021 NZE to around 35% in the 2023 NZE Scenario

Technology readiness level for selected technologies relative to technology maturity targets in the NZE Scenario

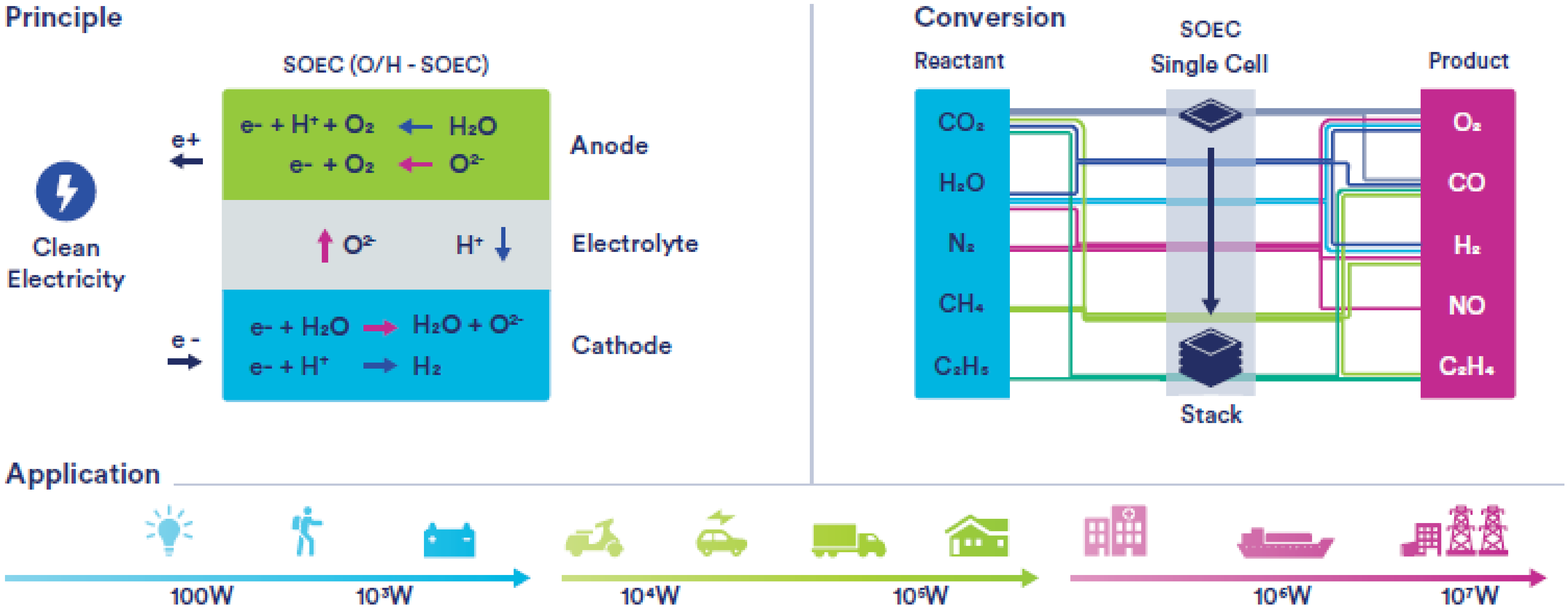


Accelerating clean energy innovation has delivered important technology upgrades in the last few years, although much remains to be done to achieve net zero pathways

Electrolyser Technologies



SOEC – Most Energy Efficient, Versatile and Scalable and



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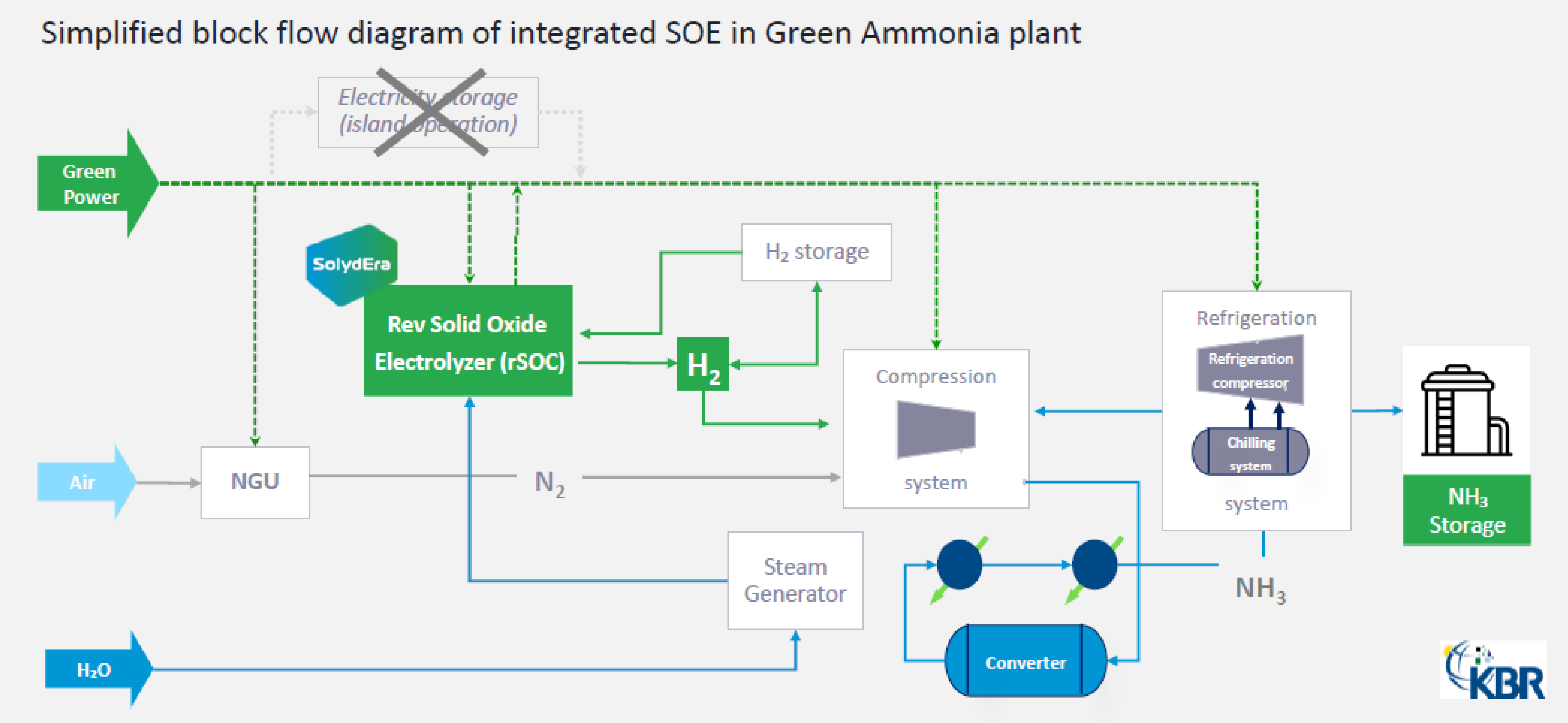
Examples of Industries
Developing Specific Pathways to Decarbonisation
Using Electrolysis Technology

Green Ammonia likely Product Process



Green Ammonia As Energy Carrier

Saudi Arabia:

- Joint venture Air Products, ACWA and NEOM,
- $5 billion investment, green hydrogen-based ammonia production for export to global markets
  - 4 GW of renewable power (solar, wind and storage);
  - 650 tons per day of H2 by electrolysis (thyssenkrupp technology);
  - Production of N2 by air separation (Air Products technology)
  - 1.2 million tons per year of green ammonia using Haldor Topsoe technology.
  - Project is scheduled onstream for 2025.

Oman:

- EDF Group, J-Power and Yamna Consortium
  - 4.5 GW of renewable (wind, solar and storage)
  - 2.5 GW Electrolyser.
  - 1 million tons per year of green ammonia

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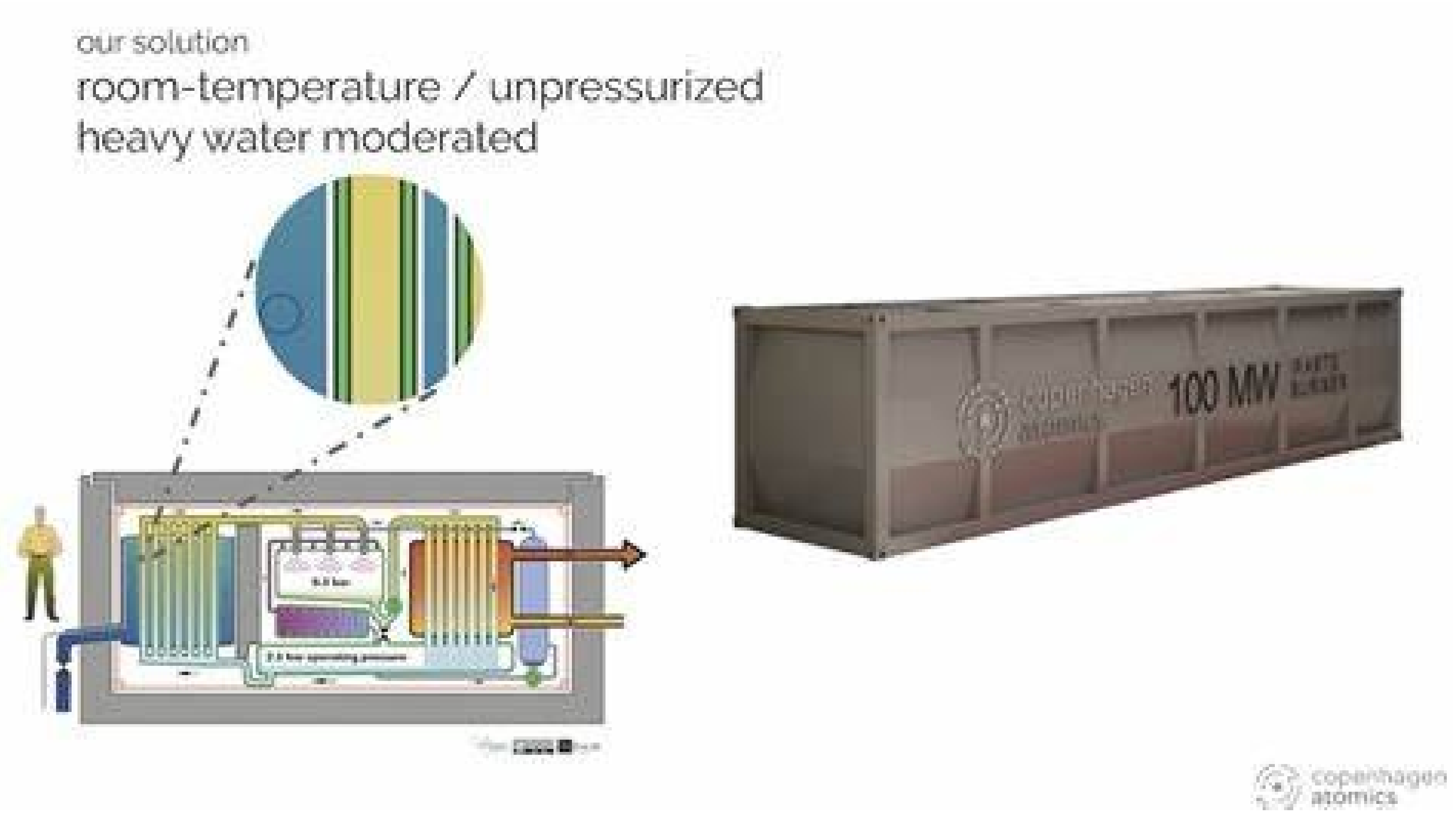
Green Ammonia powered by SMR Thorium Molten Salt Reactors

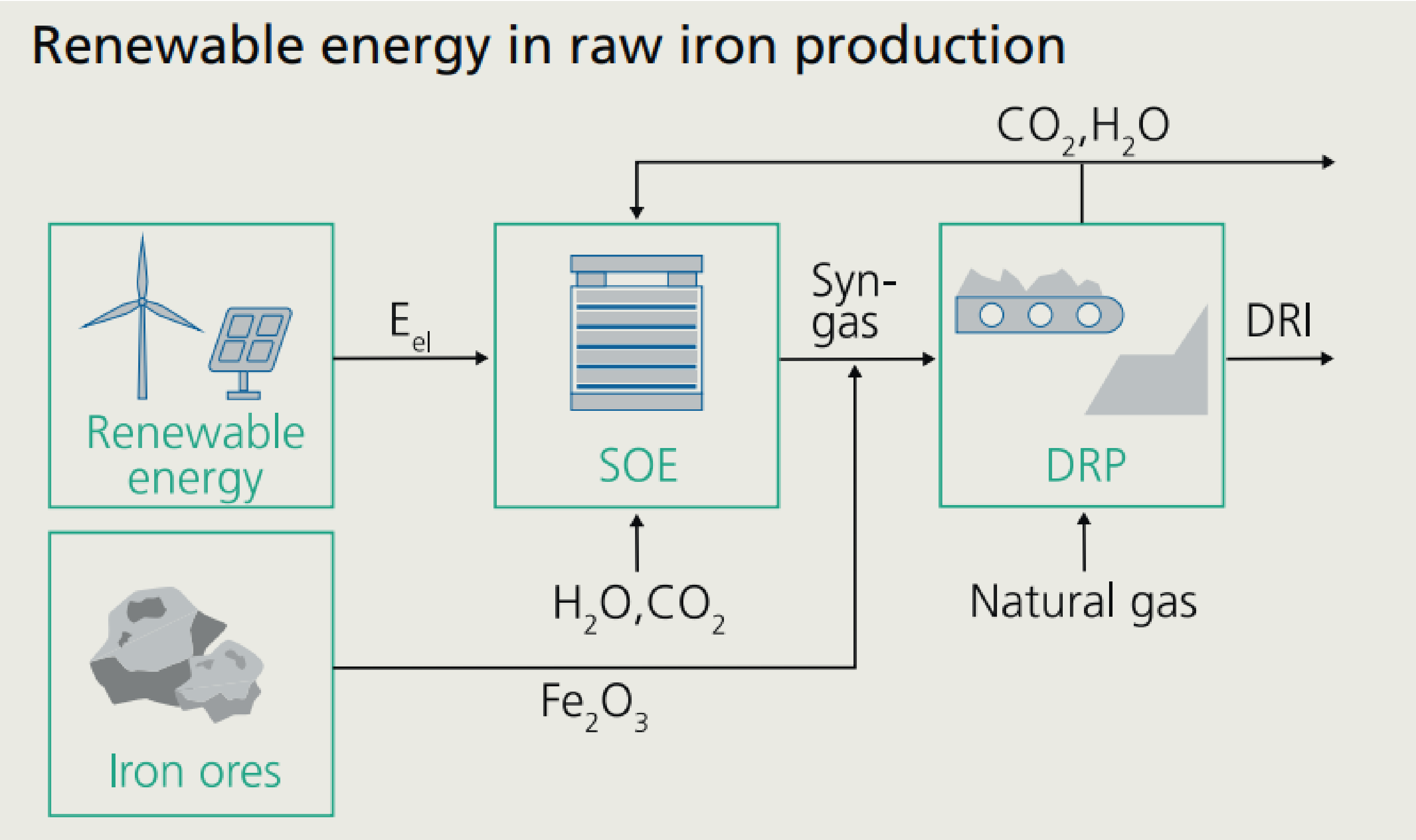
Project (MOU):

- 1 Million t/y of Ultra-Low emission NH3
- Investment USD 4 billion
- Topsoe will supply SOEC
- Copehagen Atomic will provide x25 SMR Reactors (1GW)
- Start Up 2028-2029

SMR - Thorium fuelled Molten Salt Reactor

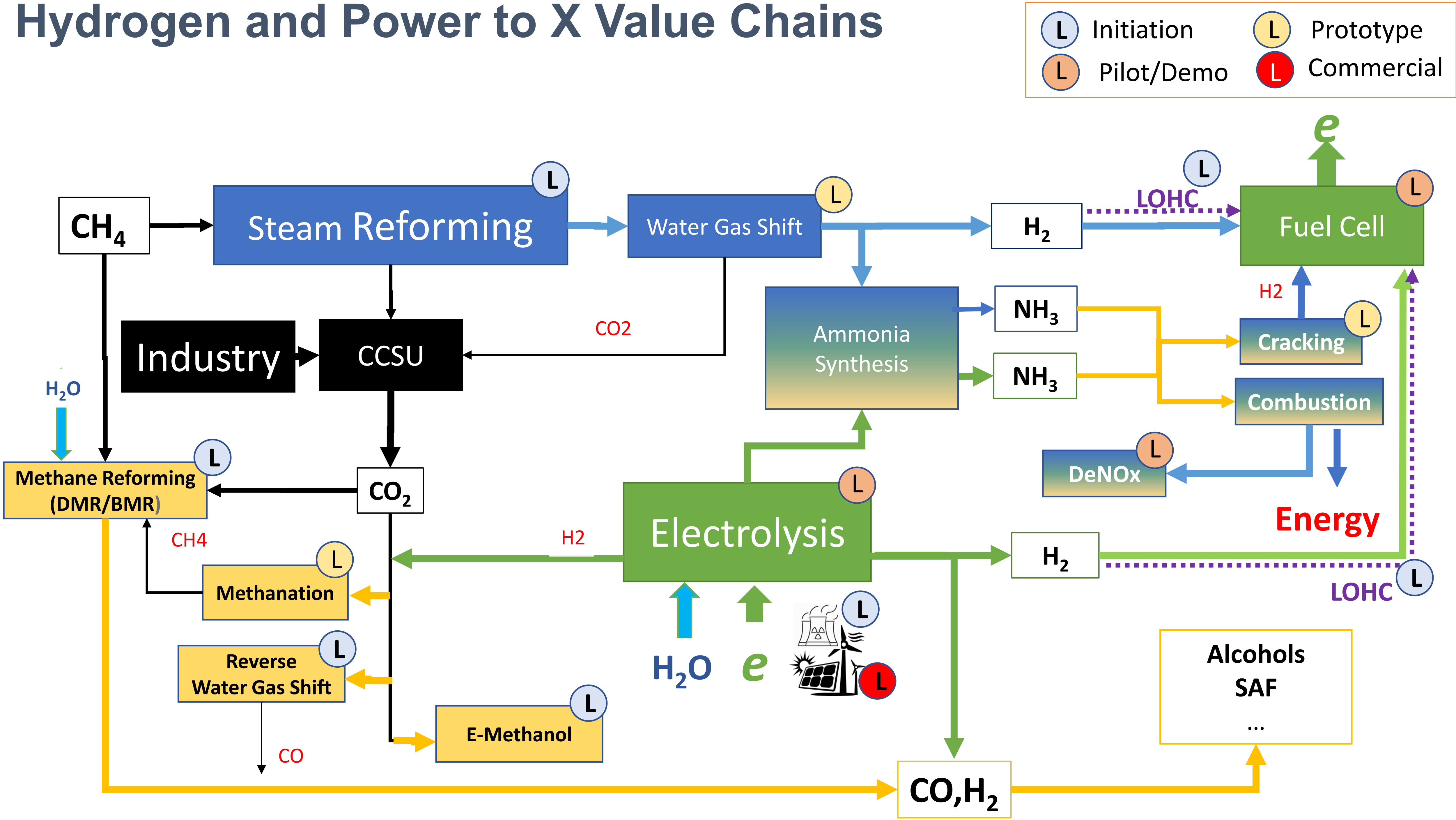


Renewable Energy in Raw Iron Production

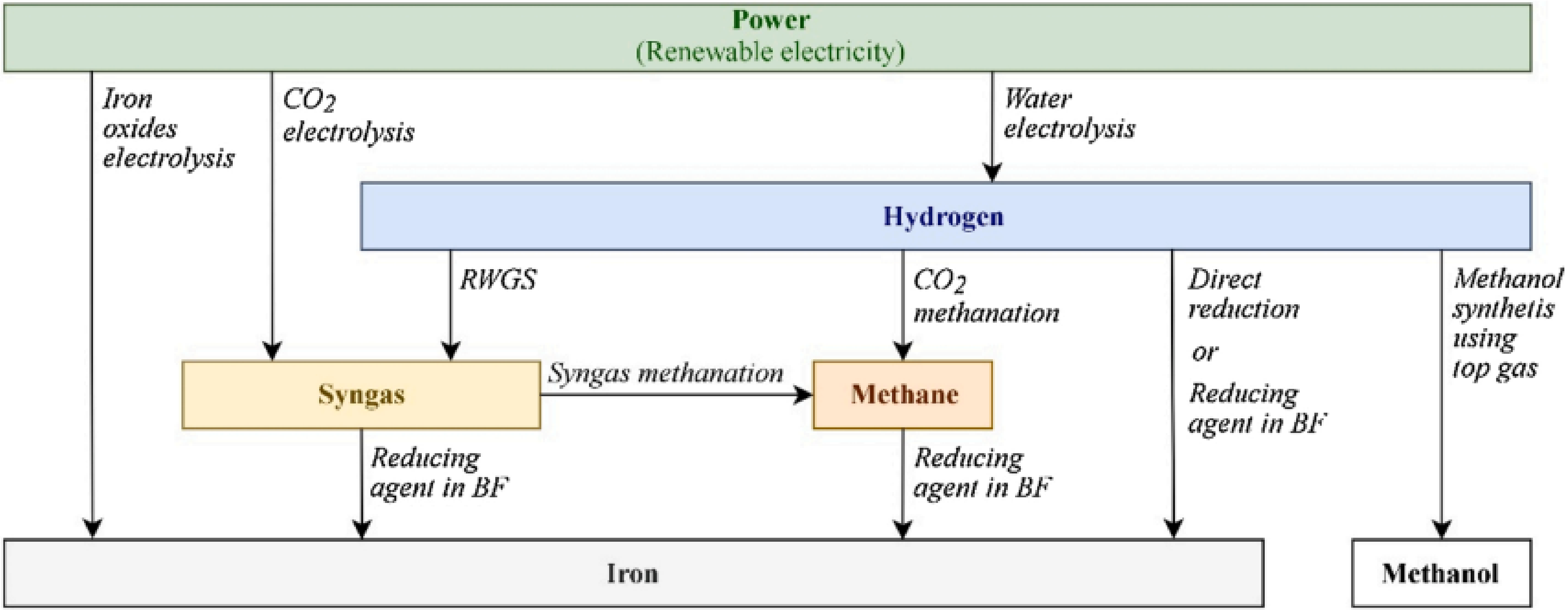


CO2 turned into syngas via **Co-Electrolysis**, then recycled as a reducing agent

Hydrogen and Power to X Value Chains



Power to X routes in the Iron and Steel industry



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Energy Transition
Sustainability and Circularity

Waste to Energy

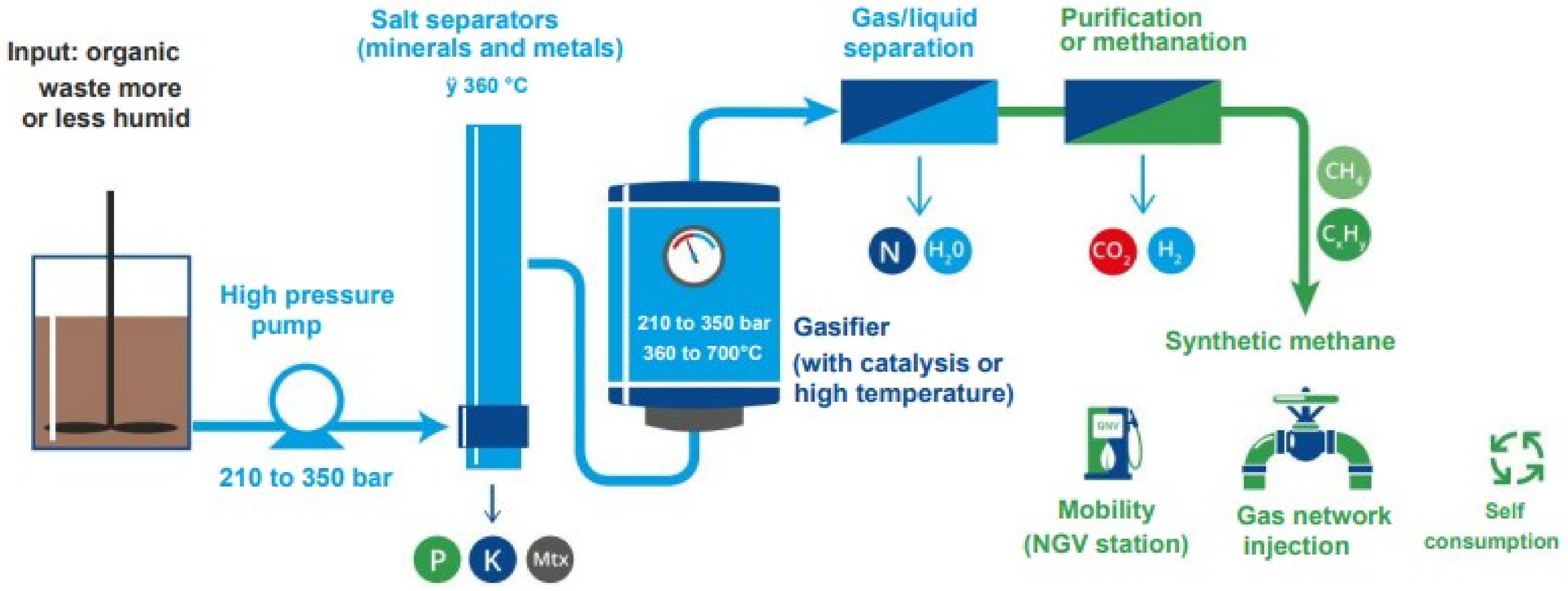
(Source: Cerema / GRTgaz)

Hydrothermal Gasification – The Technology

Hydrothermal Gasification Process

A thermochemical conversion working:

- **In the obligatory presence of water**
- **At the limit of the** liquid and gas phases around the **critical point** of water **(221 bar/ 374°C)**
  - **H_2O** becomes a **solvent (solid separation)** **+ very reactive** (H_2 separates more easily)
- **Either with catalysis :** 210 to 300 bars, **360 to 400°C**
- **Or at high temperature :** 250 to 350 bars, **550 to 700°C**
- With **high overall energy efficiency** : 75 to 90%

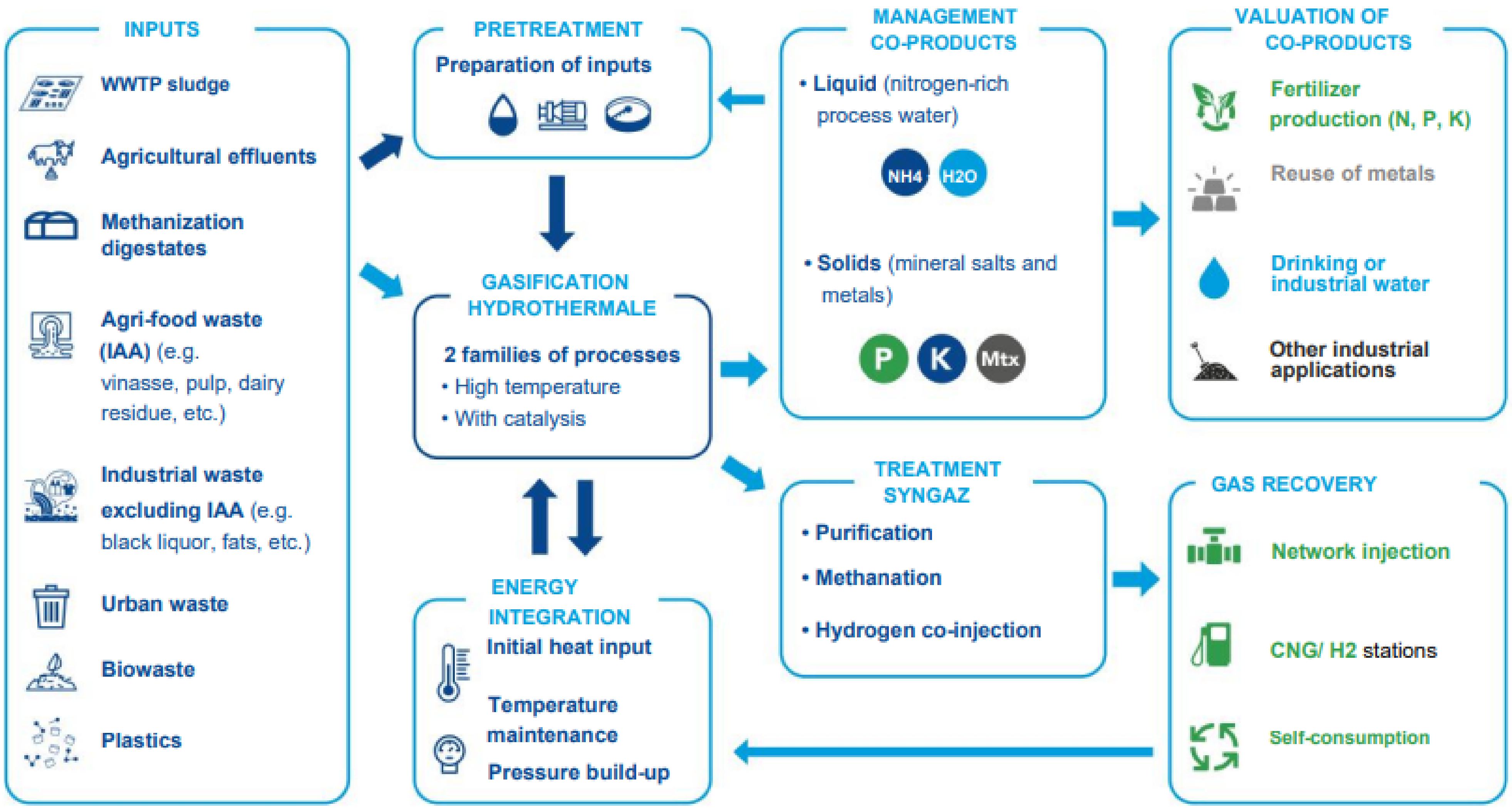


- Generates a <u>clean gas, sulfur free and rich in methane</u> (up to 70 vol.%)
- Produces a process <u>water free of contaminants</u> and rich in ammonium
- Enables <u>nutrients recovery</u> (e.g. phosphorus, ammonium)

Waste to Energy

(Source: Cerema / GRTgaz)

Hydrothermal Gasification – The Value Chain



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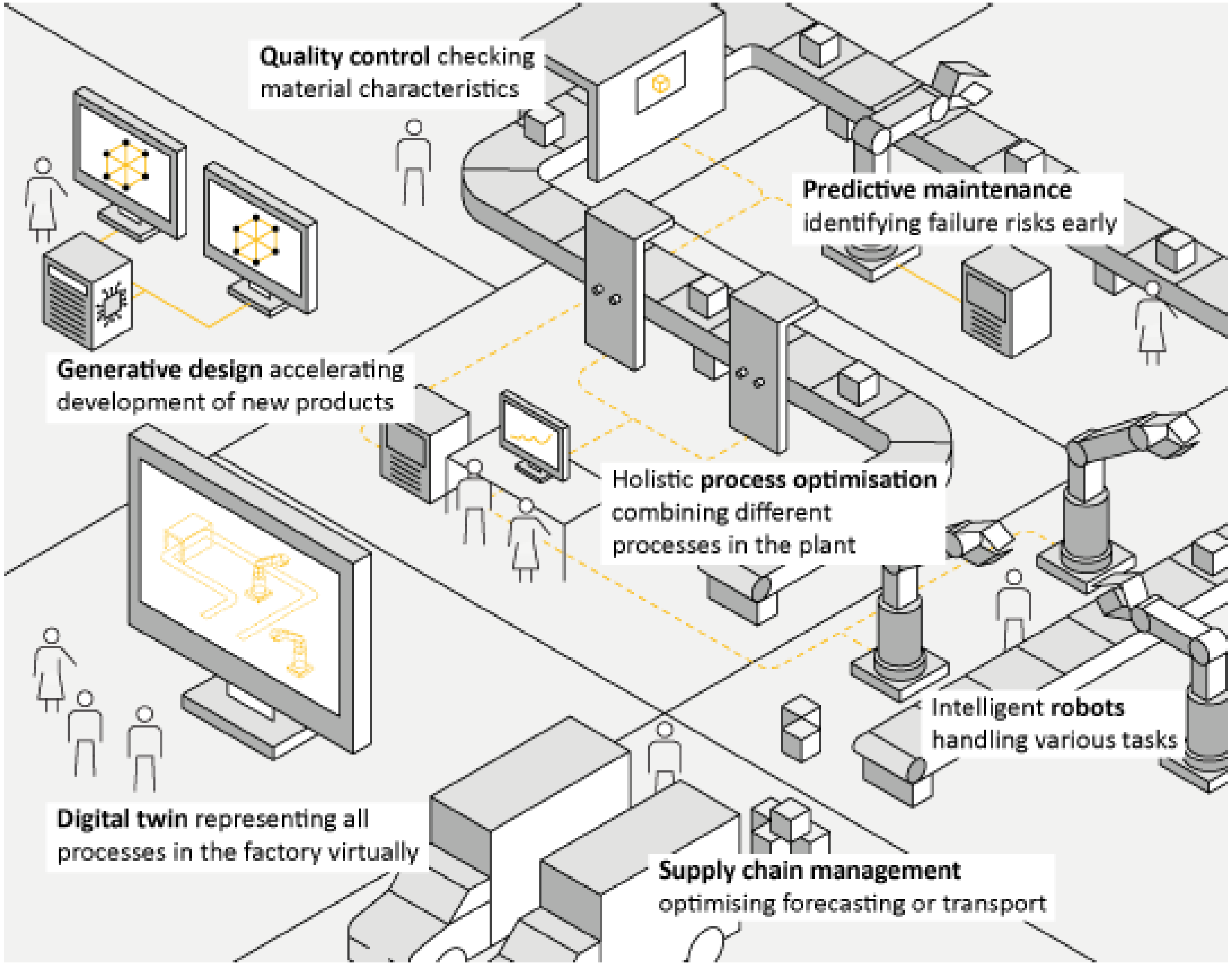
Energy Transition and Decarbonization
Could AI Help ?

AI Applications in Industry



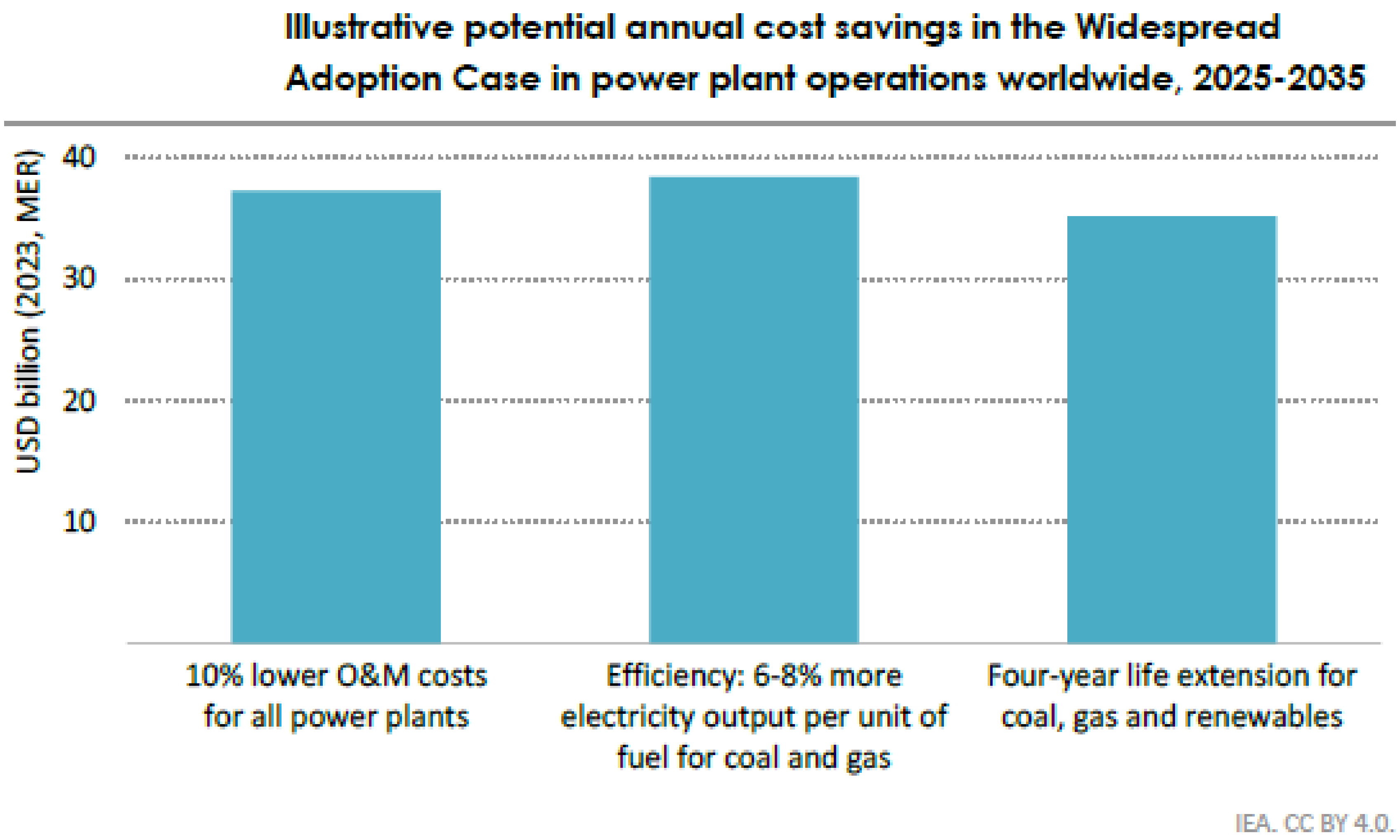
AI impact on various Industry and applicability in specific areas

Category	Oil and gas	Critical minerals	Power	Grids	Industry	Transport	Buildings
Resource management	🟢	🟡	🟡	n.a.	🟡	n.a.	n.a.
	Applications related to the assessment, characterisation and extraction of resources, including fossil fuels, critical minerals, renewables (e.g. wind, solar, hydro and geothermal) and CCUS.						
Design and development	🟡	🟠	🟢	🟡	🟡	🟠	🟡
	Applications related to the design, planning, development and construction of assets to extract, harness, transform and transport resources, and assets that are end-users of energy.						
Operational optimisation	🟡	🟠	🟢	🟢	🟢	🟢	🟢
	Applications that enhance the efficiency and output of a process (or set of processes) related to the extraction, generation, transformation and transport of energy, or in end-use sectors.						
Automation and autonomy	🟡	🟡	🟡	🟠	🟡	🟡	n.a.
	Applications that remove significant elements of human interaction within a system or process.						

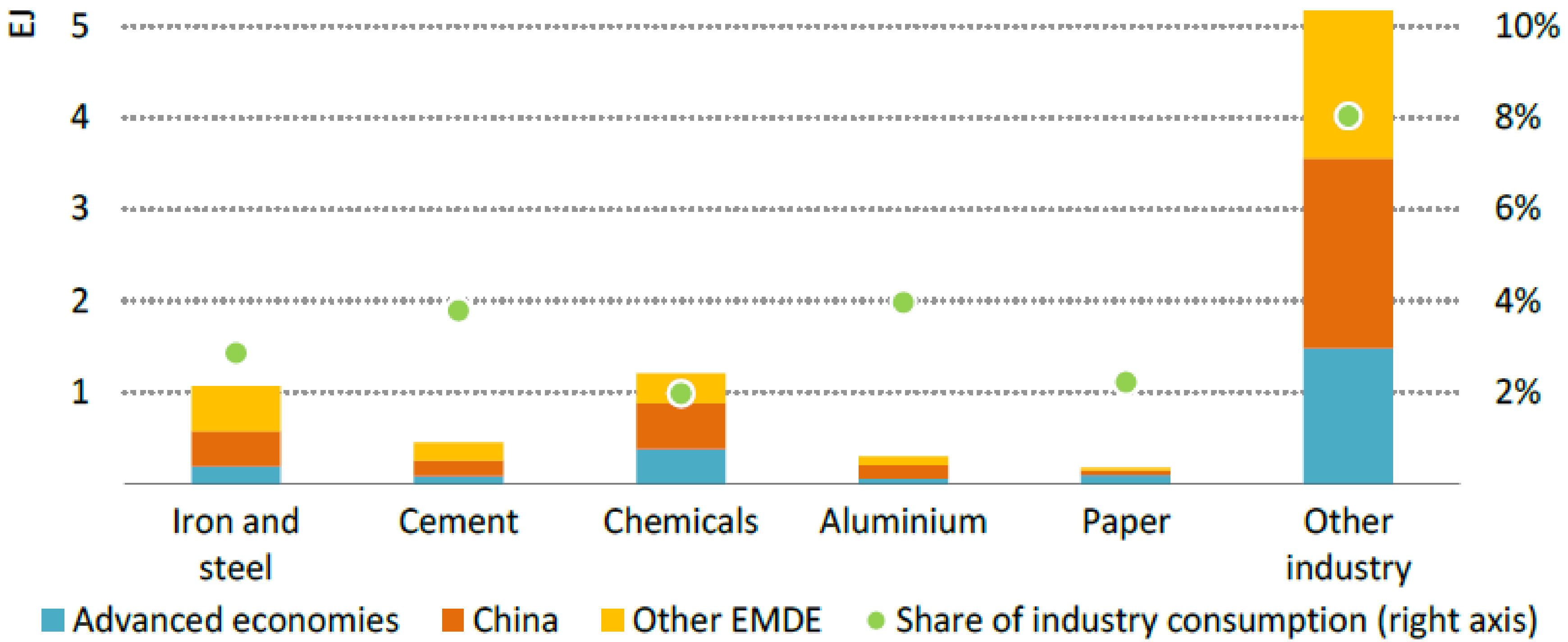
Legend: n.a. = not applicable; 🟠 = limited relevance; 🟡 = moderate relevance; 🟢 = highly applicable

Note: CCUS = carbon capture, utilisation and storage.

AI and Decarbonization by Improved Power Plants Operations



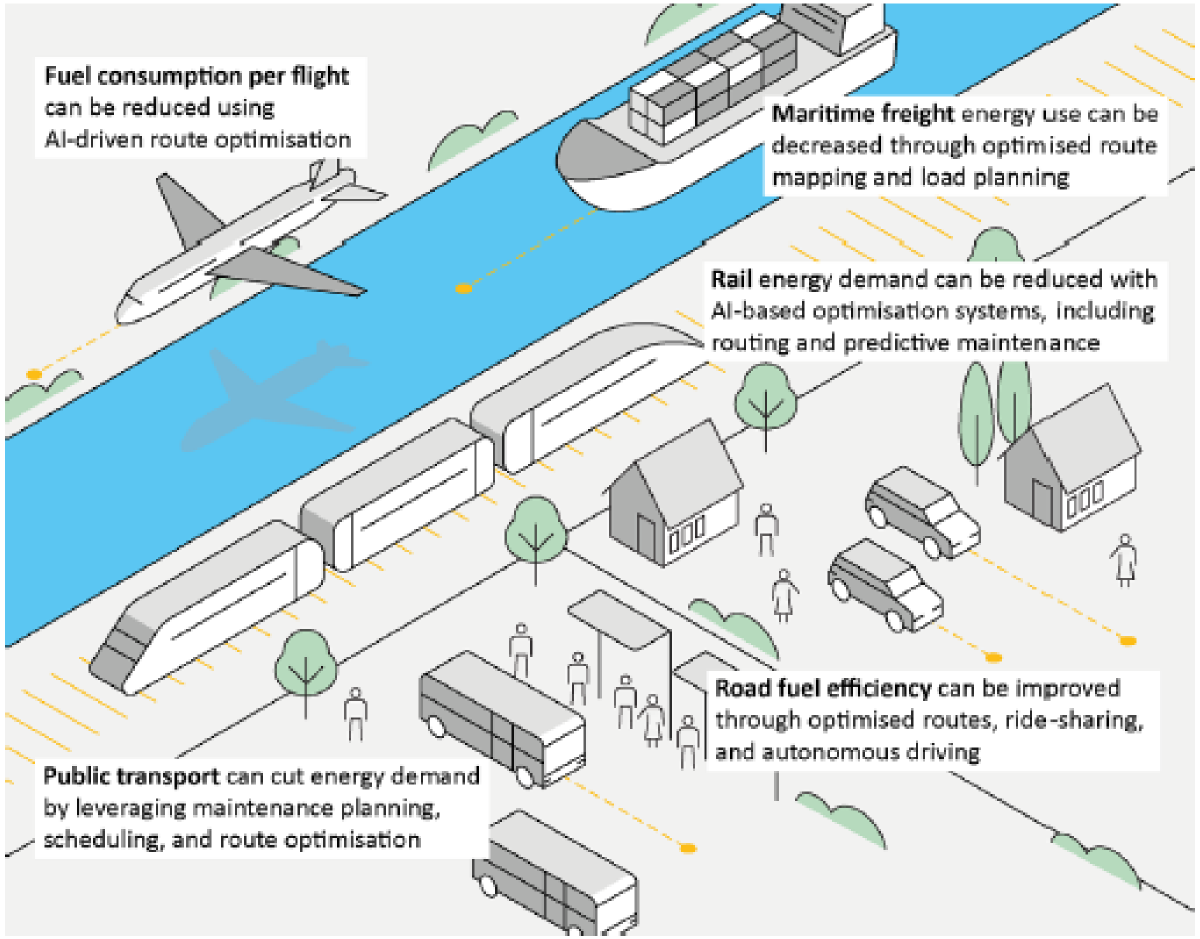
Decarbonization by Energy Efficiency – Some Examples



Light industries show a higher relative savings potential as energy use is less optimised; in heavy industries, AI can still improve energy efficiency and thereby also competitiveness

Note: EMDE = emerging market and developing economies.

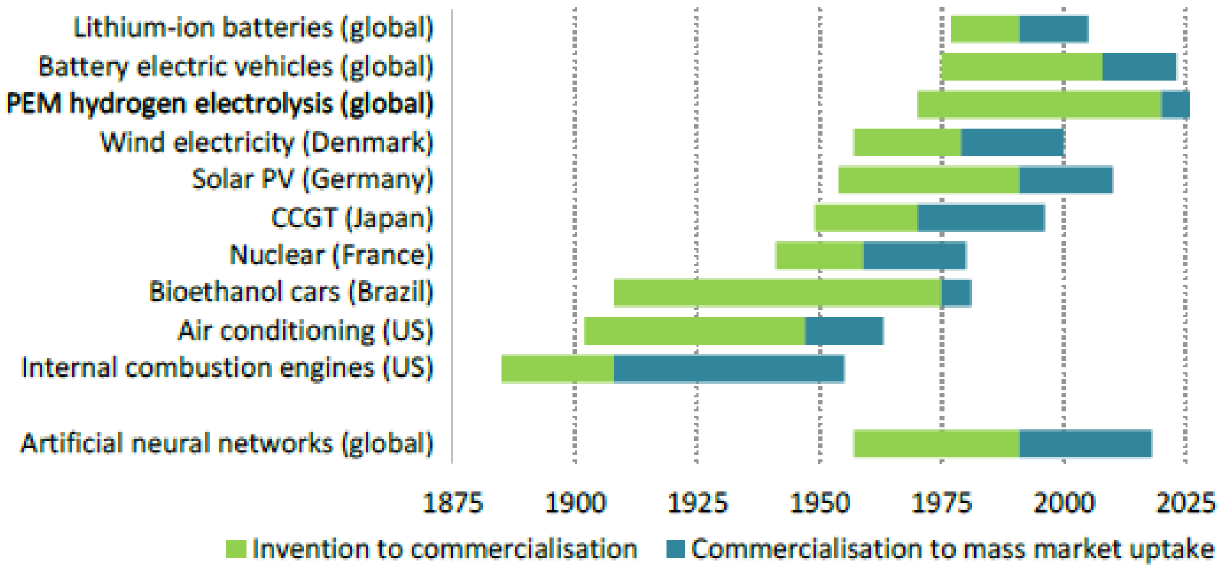
Decarbonization in Transport via Efficiency and Optimization



AI can deliver optimisation and improved operations across multiple end-uses, especially for passenger and freight urban mobility

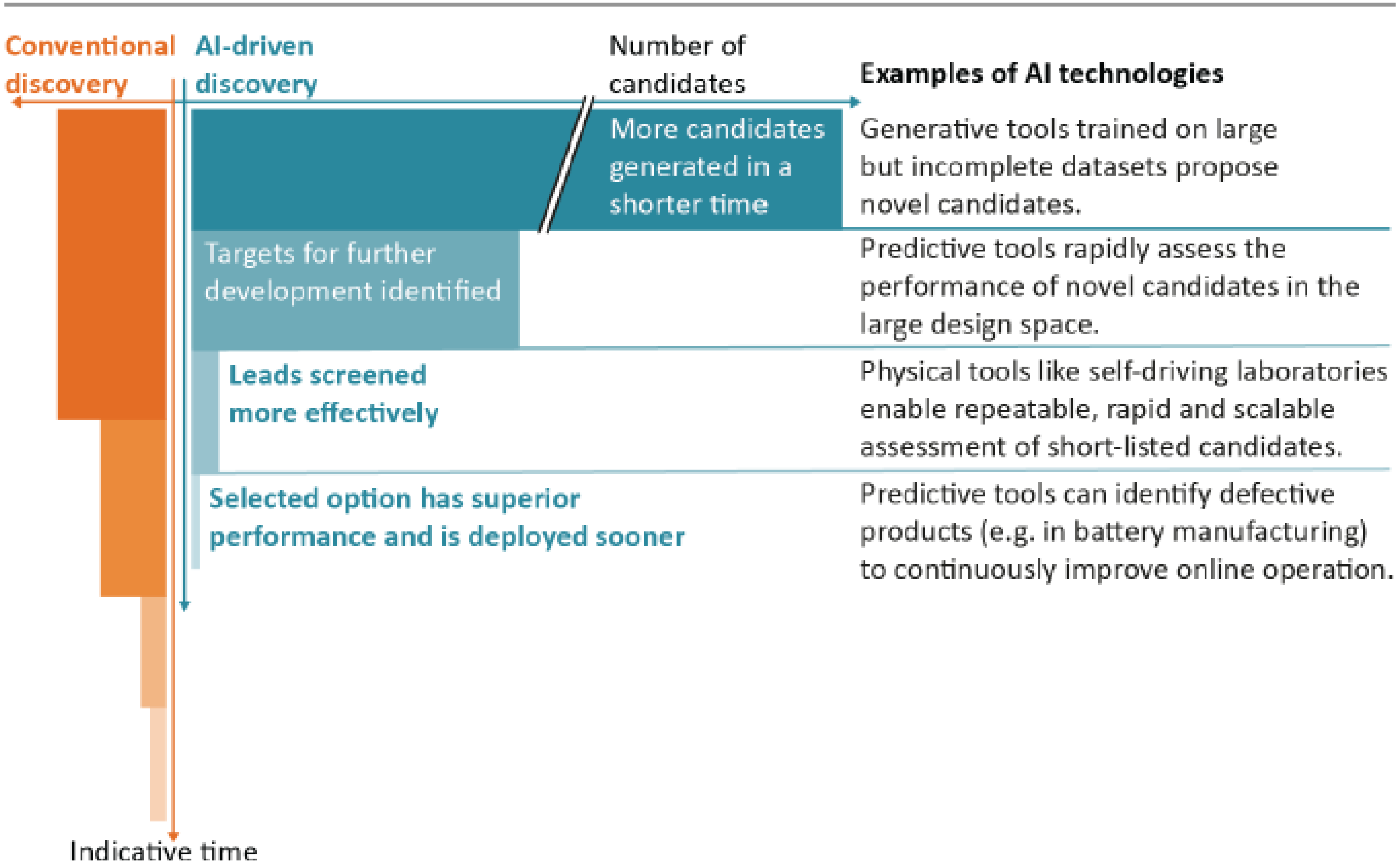
Decarbonization in Transport via Efficiency and Optimization

Figure 4.1 ▷ Innovation timelines for selected energy technologies and artificial neural networks



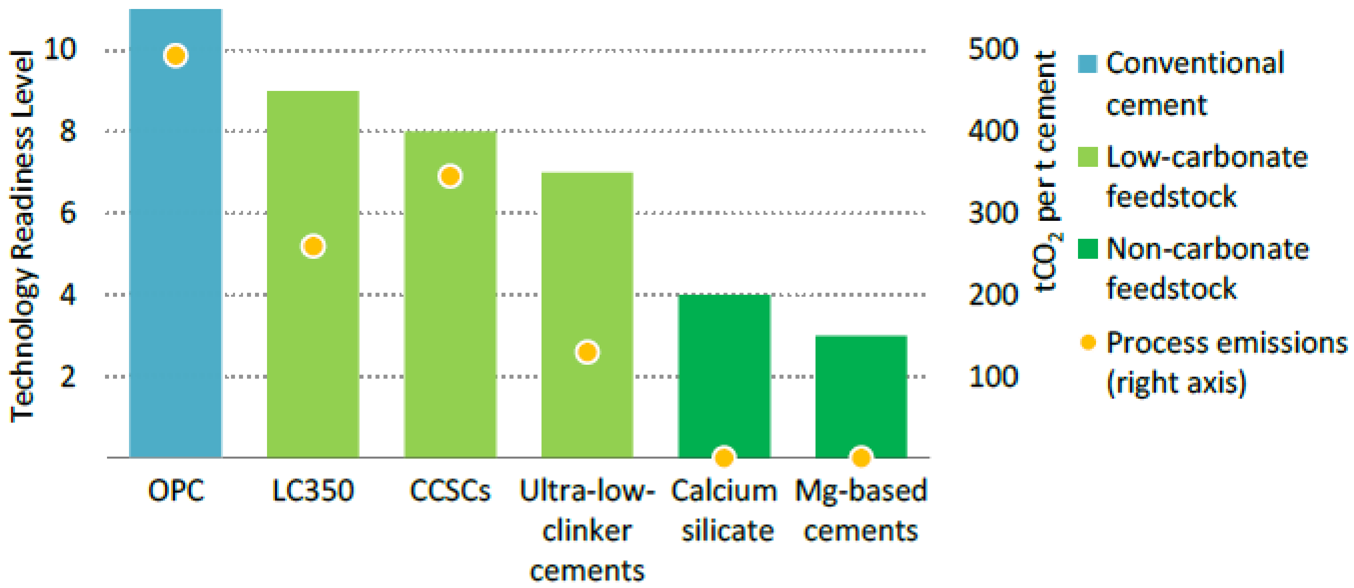
In the past, it has typically taken several decades for an energy technology to go from invention to commercialisation and a further 20 years to reach mass market uptake

AI and Accelerated pace from Invention to Commercialisaiton



AI-led design approaches can use existing information to systematically expand the search space to consider more options than could ever be experimentally feasible

AI and Accelerated pace from Invention to Commercialisation e.g. Cement Industry Decarbonization



Novel cement types can offer significantly lower process emissions but require ongoing innovation to reach the market

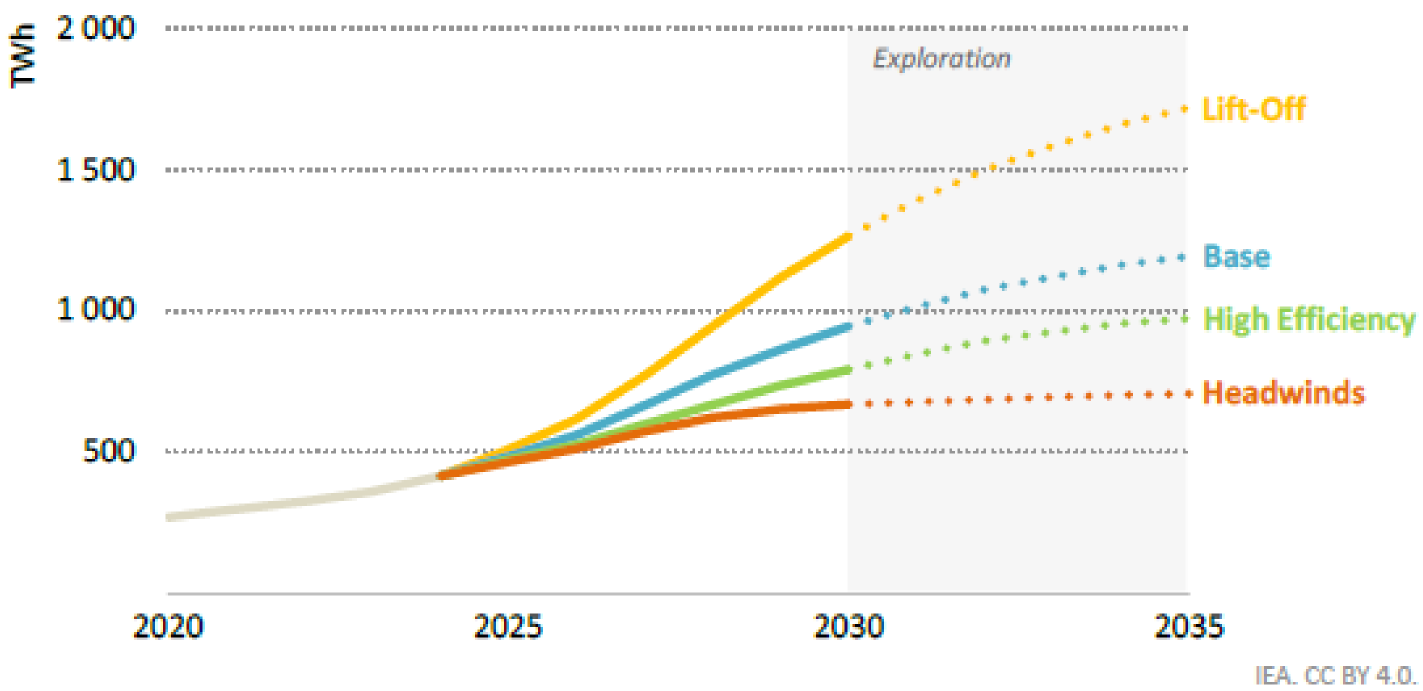
Notes: OPC = ordinary Portland cement; LC350 = limestone calcined clay cements with a clinker content of 50%; CCSCs = carbonating calcium silica cements; Mg = magnesium. OPC is a mature technology with a TRL greater than 9. Sequestration effects during the carbonation of CCSCs are not counted in the estimation of their process emissions.

Potential Barriers to adoption of AI applications in Energy

Barrier	Potential impact on success	Effort to overcome
Access to data	🔴	🟠
Access to digital infrastructure	🟠	🟠
Skills and training	🟡	🟢
Regulation	🟡	🟡
Security	🟠	🟡
Culture and social trust	🟡	🟠

🟢 Low 🟡 Moderate 🟠 High 🔴 Very high

Potential Barriers - Powering Data Centre



The outlook for data centre electricity demand is highly uncertain, driven by factors including efficiency improvements, AI uptake and potential energy sector bottlenecks

Base Case: 945 TWh by 2030

- ~3% of total global electricity consumption
- (x2 from 2024)

Challenge: Access to Affordable Low Carbon Power on site/on time

Summary

Energy Transition and Decarbonization are necessary to address climate change challenges

Despite large investments (Trillions of USD) Deployment of Cleaner Energy Sources, Energy Efficiency improvements, Deployment of Advanced Technologies, leading to Decarbonizing of key sectors such as Electricity, Transportation and Industry is Slower than earlier Anticipated

Challenges are associated to low pace of new technologies deployment (from invention), high CAPEX/OPEX

As a Result, Meeting Net Zero Scenario by 2050 is a Real Challenge

AI can help optimize existing assets and operations leading to substantial efficiencies and carbon reduction

AI can help accelerate new technology invention to deployment process accelerating their deployment and therefore, energy transition and decarbonization

Thanks

Questions ?