



When will CCU go mainstream?

The utilisation of CO₂ as feedstock for fuels and chemicals is the future



Michael Carus, founder of nova-Institute
& executive manager of the Renewable Carbon Initiative

nova-Institut GmbH – private and independent research institute

multidisciplinary and international team of nearly 50 scientists

Renewable Feedstocks

Future feedstock supply
Supply chain resilience

Technology & Markets

Science-based evaluation of
new markets, technologies
and business cases



Policy & Strategy

Guiding through policy frameworks and
building your renewable carbon strategies

Sustainability

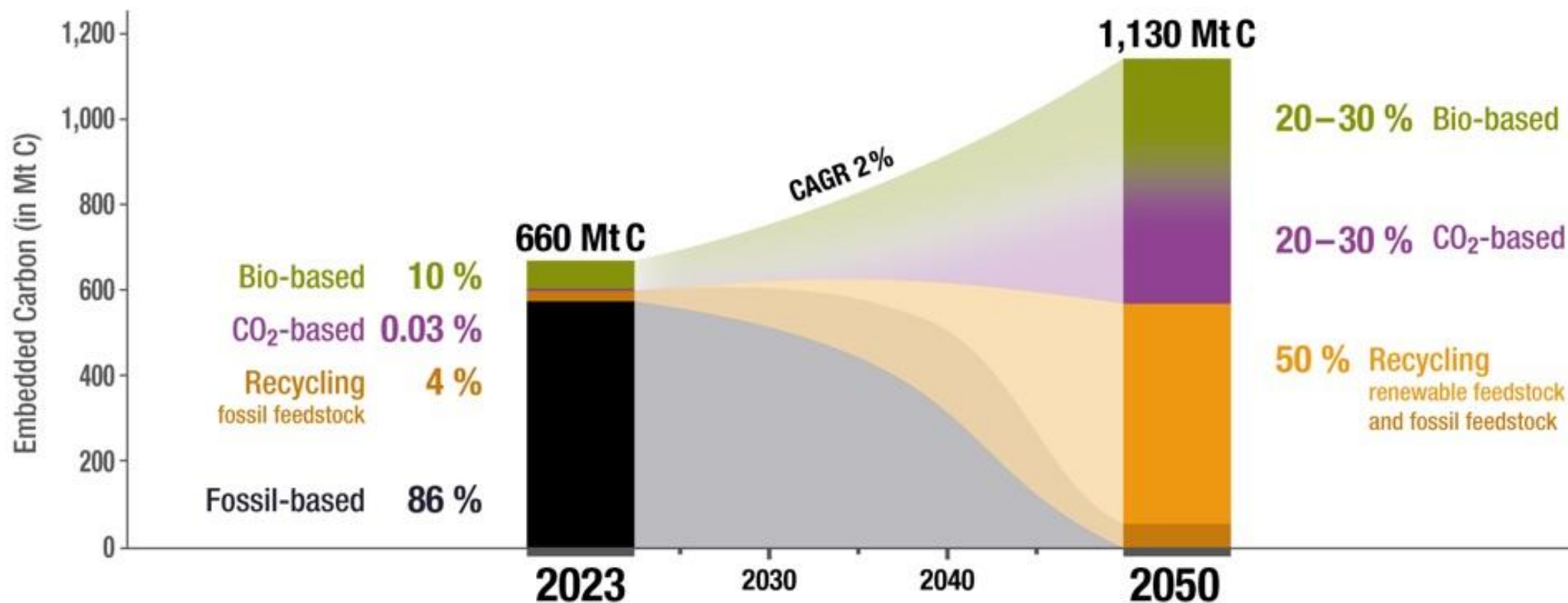
Quantifying Sustainability
LCAs and ESG Reporting

The tremendous potential of CO₂ utilisation in the chemical industry

For this topic, I would usually need ten slides at other conferences, but here, with a well-informed CCU audience, I need only three.

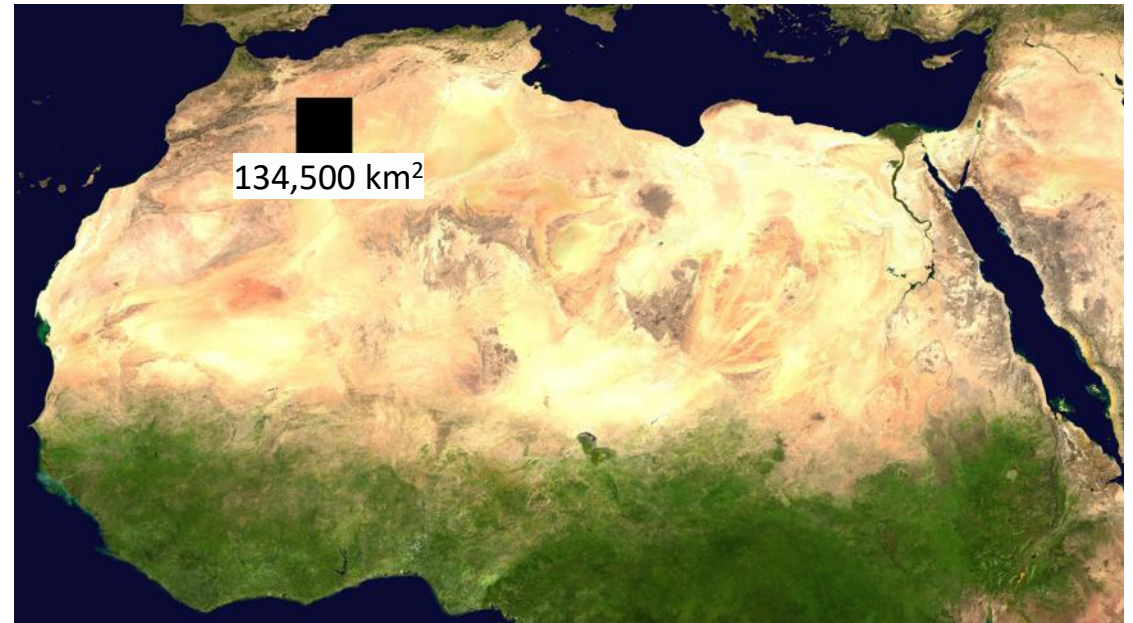
Fossil and Renewable Feedstock (in Mt C) for Embedded Carbon in Chemical and Derived Materials

Update 2026 nova Scenario for a Global Net-zero Chemical Industry in 2050



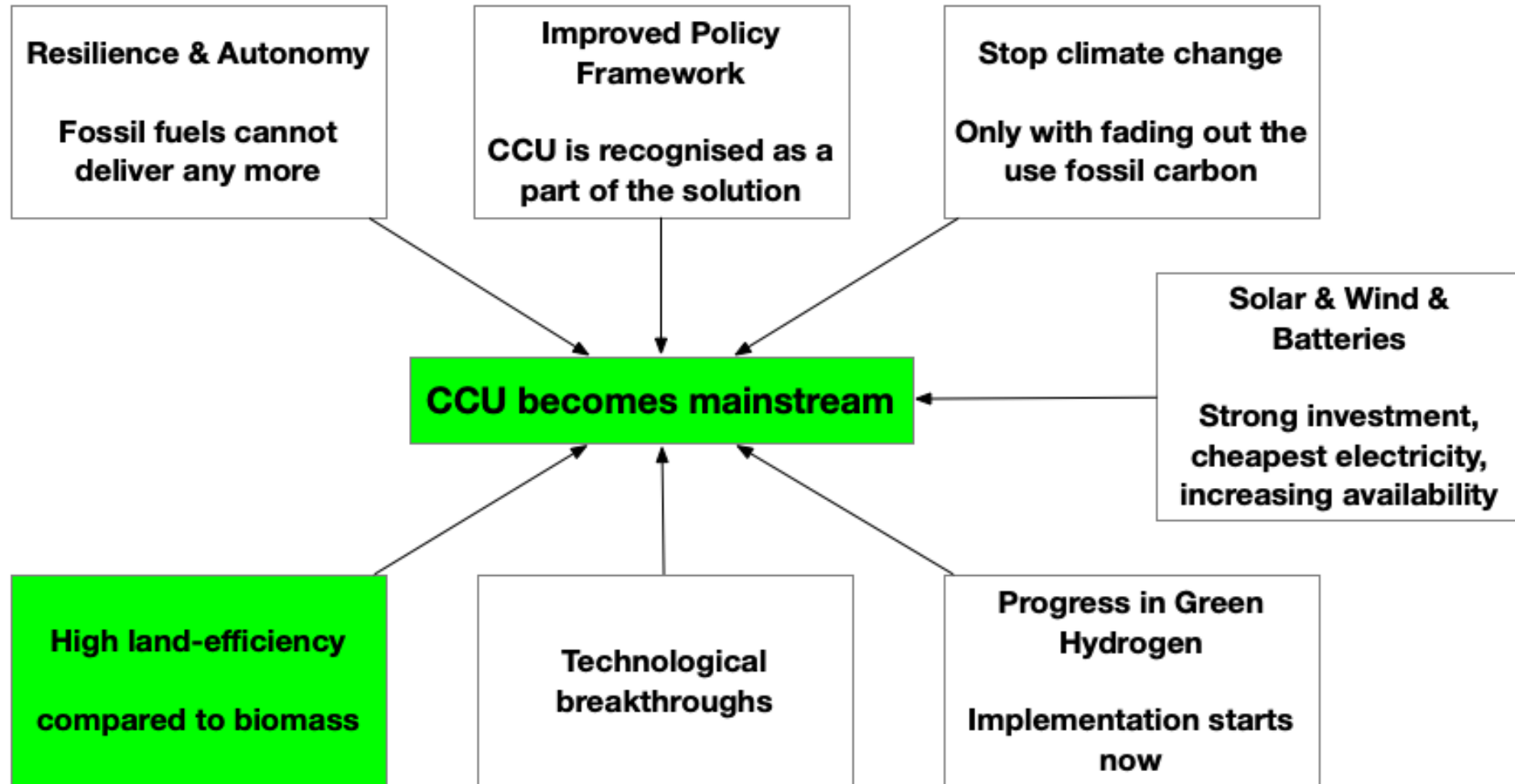
PV area and absolute electricity demand and emission reduction potential (Update 2026)

- Global carbon demand today: **660 Mt C** embedded carbon for chemicals
- **2050 scenario: 1,130 Mt C**
- To supply 1,130 Mt C via **Methanol**
 - 11,000 kWh / t_{methanol}
 - 33.5 PWh_{el} / year is required
 - 134,500 km² desert area is required (such as Greece)
 - **1.5% of the Sahara** desert (0.8% of the area of all subtropical deserts)
- Using completely decarbonised renewable energy, the reduction potential is **4.3 Gt CO₂ / year**
- Global CO₂ emissions today: **55 Gt CO₂ / y**



Source: RCI's scientific background report: "CO₂ reduction potential of the chemical industry through CCU" (May 2022, demand updated).

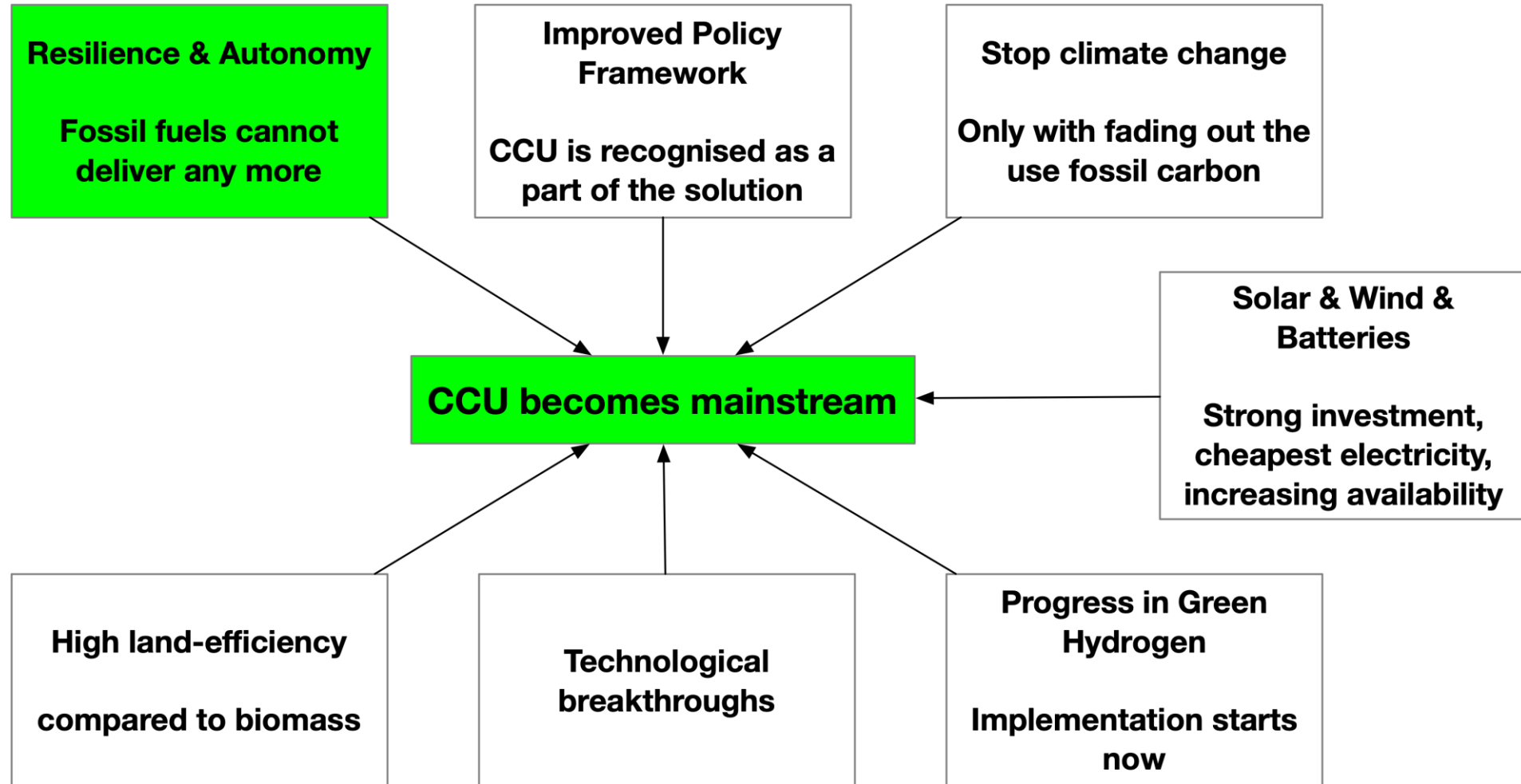
Seven drivers are the ones who will make CCU mainstream



Biomass-to-methanol routes based on gasification vs. DAC-to-methanol

- The result of a comprehensive report: **DAC is roughly 40–65 times more land-efficient than biomass-based methanol pathways.**
- Concerning **land use**, DAC-to-methanol is clearly superior.
- Concerning **electricity demand and CAPEX**, biomass-based or hybrid biomass-plus-power-to-methanol concepts can still be attractive, especially when residues are available.
- Using fossil or biogenic **point sources** instead of DAC would further increase land-efficiency, and lower electricity demand and CAPEX (compared to DAC).

The driver: Resilience and Autonomy



IEA chief says oil crisis has permanently broken fossil fuel industry

(The Guardian, 25 April 2026)

The oil crisis triggered by the war in Iran has **irreversibly changed the global fossil fuel industry, turning countries away from oil and gas toward cleaner alternatives**, International Energy Agency Executive Director Fatih Birol said this week.

This will have permanent consequences for the global energy markets for years to come”

Birol said the scale of disruption had **shaken governments’ confidence in fossil fuels as a reliable energy source**. **“Their perception of risk and reliability will change**. Governments will review their energy strategies,” he said, adding that the shock was “bigger than all the biggest crises combined.”

“There will be a significant boost to renewables and nuclear power and a further shift towards a more electrified future,” he said, noting that **solar energy is now cost-competitive with coal even in developing countries**.

“Coalition of Makers”: **54 countries want to move away from oil, gas and coal**. Colombia and the Netherlands are hosting the **first international energy transition conference on phasing out the fossil fuels coal, oil and gas**.

Notorious obstructionists must stay out this time.

Santa Maria (Columbia), 24-29 April 2026.

<https://transitionawayconference.com/>

Rheinmetall's GigaPtX

Giga PtX is Rheinmetall's project vision for a **Europe-wide network of modular e-fuel plants that use green hydrogen and captured CO₂ to produce synthetic diesel, marine diesel, and kerosene**, primarily for NATO and European armed forces. It is still at concept and partnership stage, but recent collaborations show they are actively moving toward first pilot and replication-ready plants.

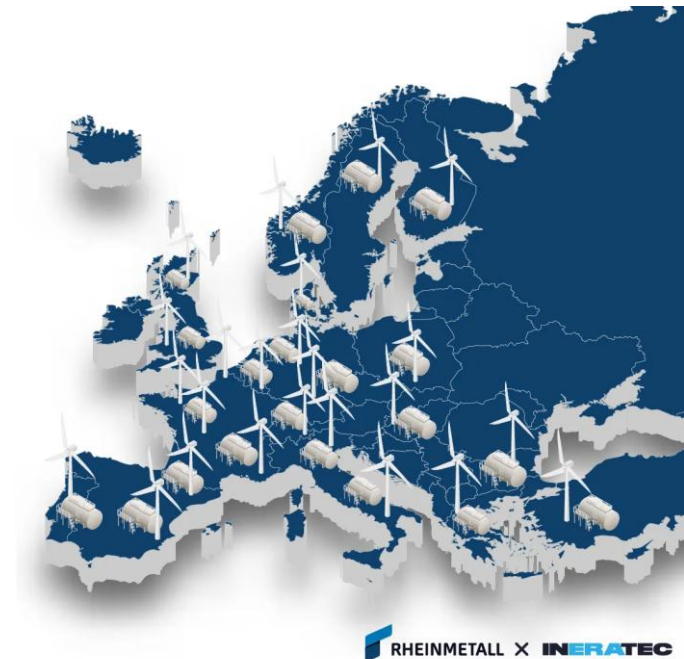
Giga PtX consists of **several hundred decentralised power-to-X plants, each with an electrolysis capacity of up to 50 MW**.

Each plant **integrates renewable power supply, water electrolysis for hydrogen, CO₂ capture/supply, and on-site fuel synthesis** producing around 5,000–7,000 tonnes of e-fuel per year.

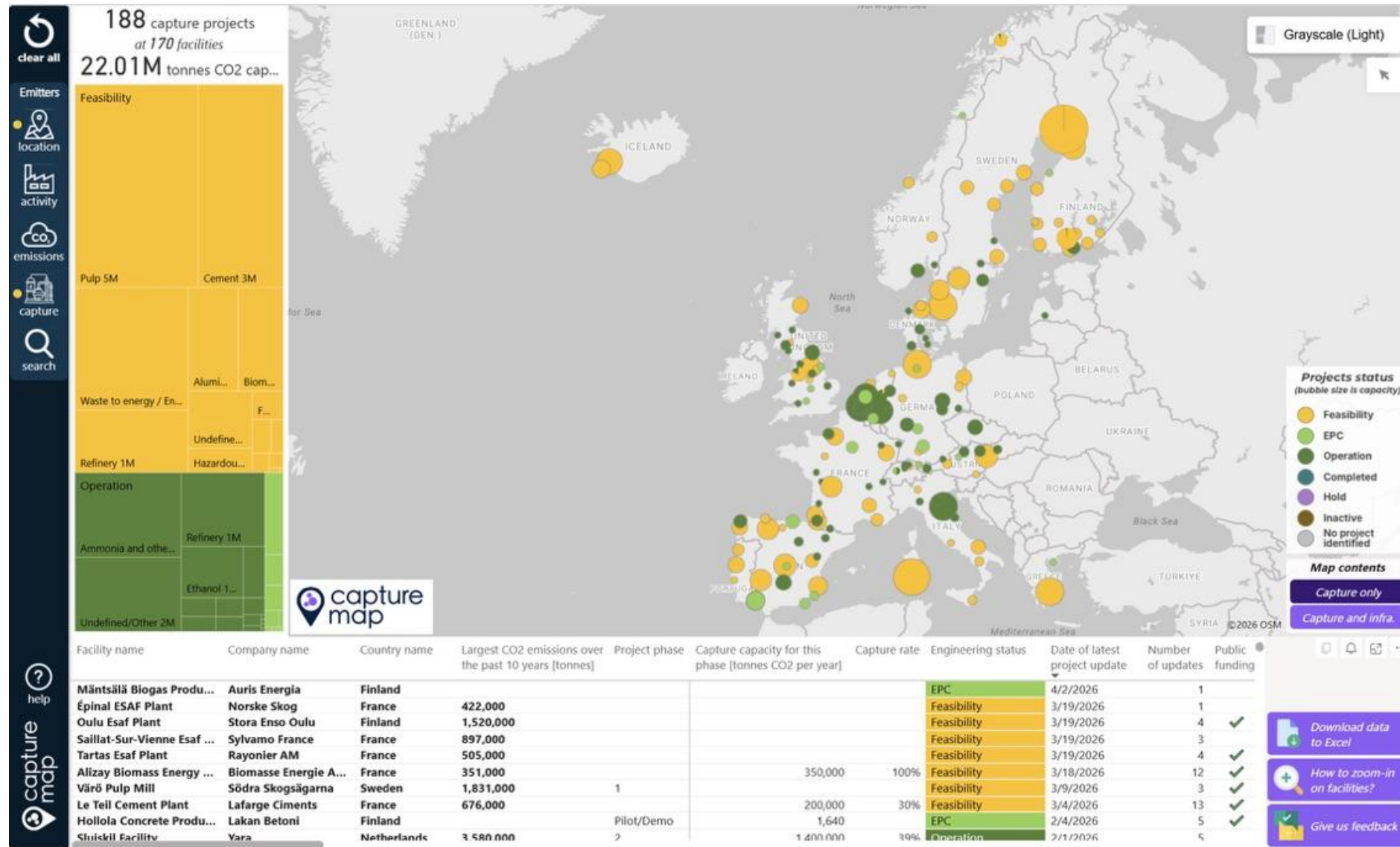
The vision targets **energy autonomy and fuel resilience** for European and NATO forces, making fuel supply less dependent on vulnerable long supply chains in crises or conflict.

Partners

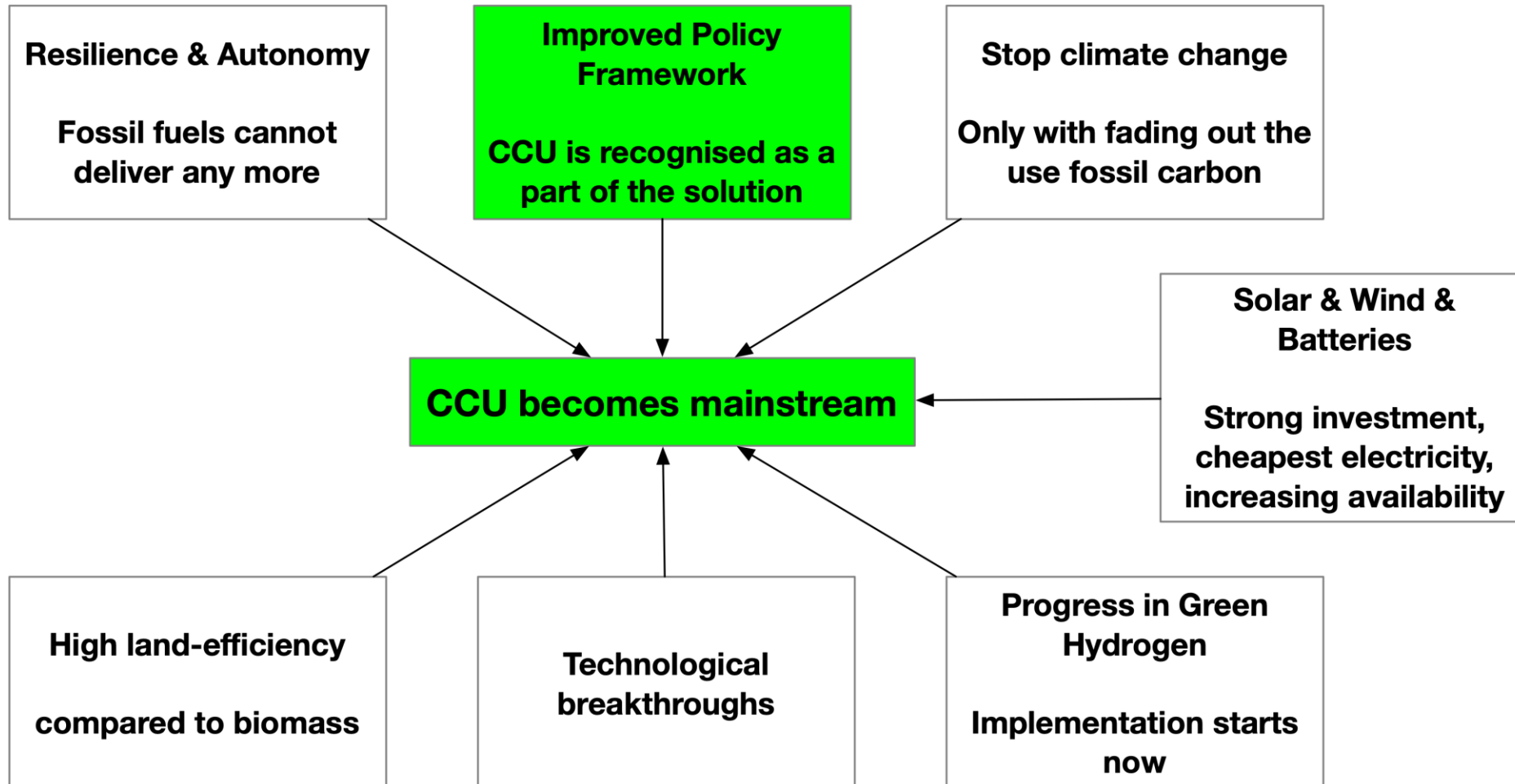
- Rheinmetall: system integration, overall concept
- INERATEC: RWGS and Fischer-Tropsch synthesis module
- Sunfire: high-temperature SOEC electrolyzers
- Greenlyte Carbon Technologies: CO₂ capture
- ITM Power: large-scale PEM electrolyzers



188 CO₂ Capture Projects in Europe



The driver: Improved Policy



Policy signals for CCU are getting stronger

MARKET PULL

Transport (aviation) first to create guaranteed demand

- ReFuelEU Aviation and FuelEU Maritime explicitly enable CCU-derived fuels.
- Synthetic aviation fuel share: 1.2% in 2030 → min. 35% in 2050.
- The transport framework gives CCU a concrete, reliable demand signal.

RECOGNITION

CCU enters key industrial policy of the EU

- 2040 Climate Target, Industrial Carbon Management and Net-Zero Industry Act recognise CCU as part of the solution.
- Clean Industrial Deal names CCU among three alternative carbon feedstocks.
- Industrial Carbon Management modelling reaches up to 200 Mt CO₂ used in 2050.

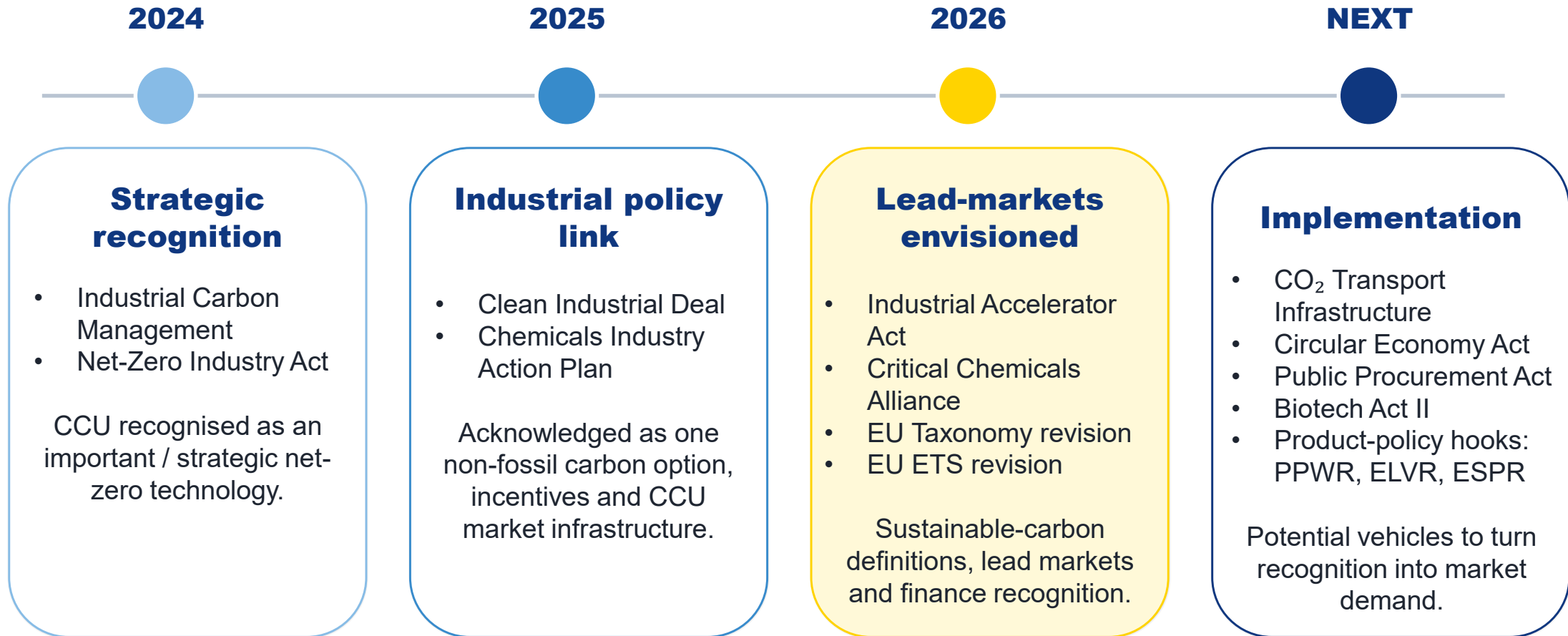
SCALE-UP VISION

Chemicals & materials move into focus

- Chemicals Industry Action Plan links CCU to ETS accounting, incentives and CO₂ markets/infrastructure
- Industrial Accelerator Act and Critical Chemicals Alliance connect CCU to sustainable-carbon lead markets.
- The policy question is shifting from “is CCU eligible?” to “how do we scale?”

Direction of travel: CCU is incorporated as a sectoral (fuels) instrument and now moving towards a wider sustainable carbon feedstock option.

The next step: creating markets for CCU-based chemicals & materials



Policy recognition is increasingly being translated into lead markets, finance and infrastructure. Will these files translate policy recognition into real demand for renewable-carbon products?

EU Emission Trading System (ETS) revision: a critical turning point for CCU?

The recently released 2026 revision proposal introduces dedicated CCU accounting also for material products, and pairs it with a supportive funding architecture

A dedicated downstream mechanism for CCU

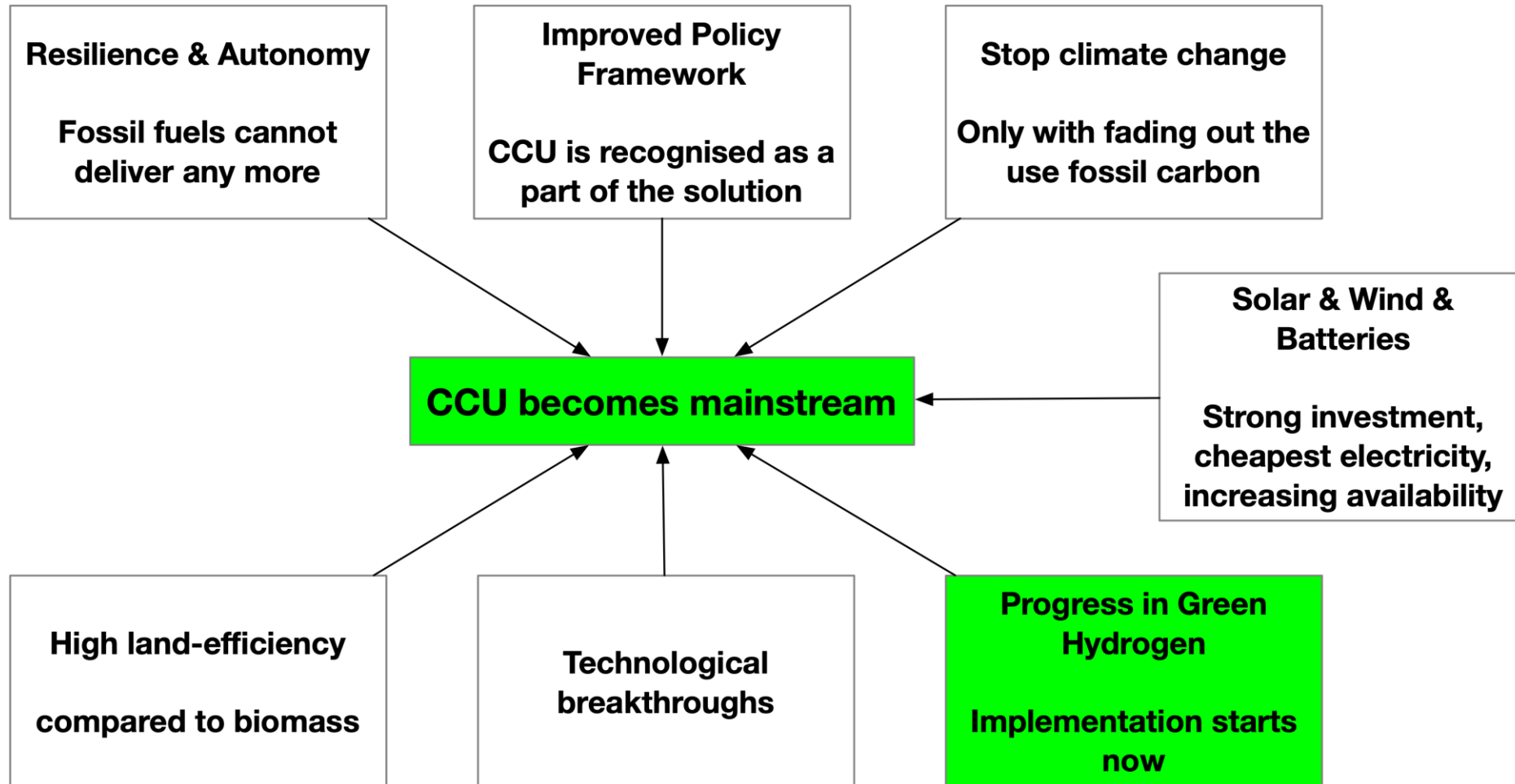
- Inclusion of waste incineration in ETS, biogenic emissions are excluded from ETS.
- **CCU = “not emitted”**: Non-permanent CCU products will not require surrender of an obligation at point of capture, but when CO₂ is finally released.
- Aviation & marine are part of ETS: Synthetic / e-fuels, CO₂ accounted for at the point of fuel distribution.
- CCU value chain added to Annex I; municipal waste incineration enters the ETS from 2031.

More explicit scale-up support

- 2028: As a first phase, an Investment Booster is envisioned to provide around €30 billion in support – also for CCU – through auctioning of 400 million allowances.
- 2031: As a second phase, 400 million additional allowances are used to support financing market-based mechanisms like Carbon Contracts for Difference
- Industrial Decarbonisation Bank is also formally in the package of the ETS revision, targeting €100 billion until 2040.

- **Timeline**: 17 Jul 2026 proposal → autumn 2026 negotiations → targeted 2027 adoption → implementation from 2028
- **If agreed, the ETS revision closes a major current gap for non-permanent CCU and gives the value chain clearer investment signals.**

The driver: Progress in green hydrogen implementation



Promising developments in the field of green hydrogen

The first **European Hydrogen Bank auction** was launched in November 2023, awarding nearly **€720 million to 7 renewable hydrogen projects across Europe**. The projects must start producing renewable hydrogen within 5 years. Together, they have **1.44 GW electrolyzer capacities** to produce **1.52 million tonnes of renewable hydrogen in their first 10 years** of operation.

In the second **European Hydrogen Bank auction**, 15 renewable hydrogen production projects across 5 countries within the European Economic Area (EEA) were selected to receive **€992 million in EU funding**. These projects, expected to produce nearly **2.2 million tonnes of renewable hydrogen over 10 years**.

Moeve (Spain) has approved **€1 billion final investment decision for 300 MW green hydrogen plant, backed by over €300 million in EU subsidies**. Signals accelerated **capital reallocation from oil production to low carbon infrastructure under Moeve's €8 billion transition plan**.

Green Hydrogen from Sunlight and Water

Photreon, founded at the Karlsruhe Institute of Technology (KIT), is developing **specialized panels designed for decentralized, cost-effective hydrogen production directly from sunlight and water**. This innovative approach eliminates the need for separate electrolyzers, electricity consumption, and grid connection. Instead of conventional photovoltaics, the technology uses **photocatalysis, where light directly splits water to generate hydrogen**. These scalable reactors can be used for decentralized applications or large-scale plants in sunny regions.

Commission approves €1.3 billion German State aid to support renewable hydrogen production (20 May 2026)

The European Commission has approved, under EU State aid rules, a **€1.3 billion German State aid scheme** to support the production of renewable hydrogen through the European Hydrogen Bank's “**Auctions-as-a-Service**” tool for the auction that closed in 2026. The scheme will contribute to the objectives of the Clean Industrial Deal to accelerate the decarbonisation of EU industry, the REPowerEU Plan to reduce dependence on Russian fossil fuels, as well as the EU Hydrogen Strategy.

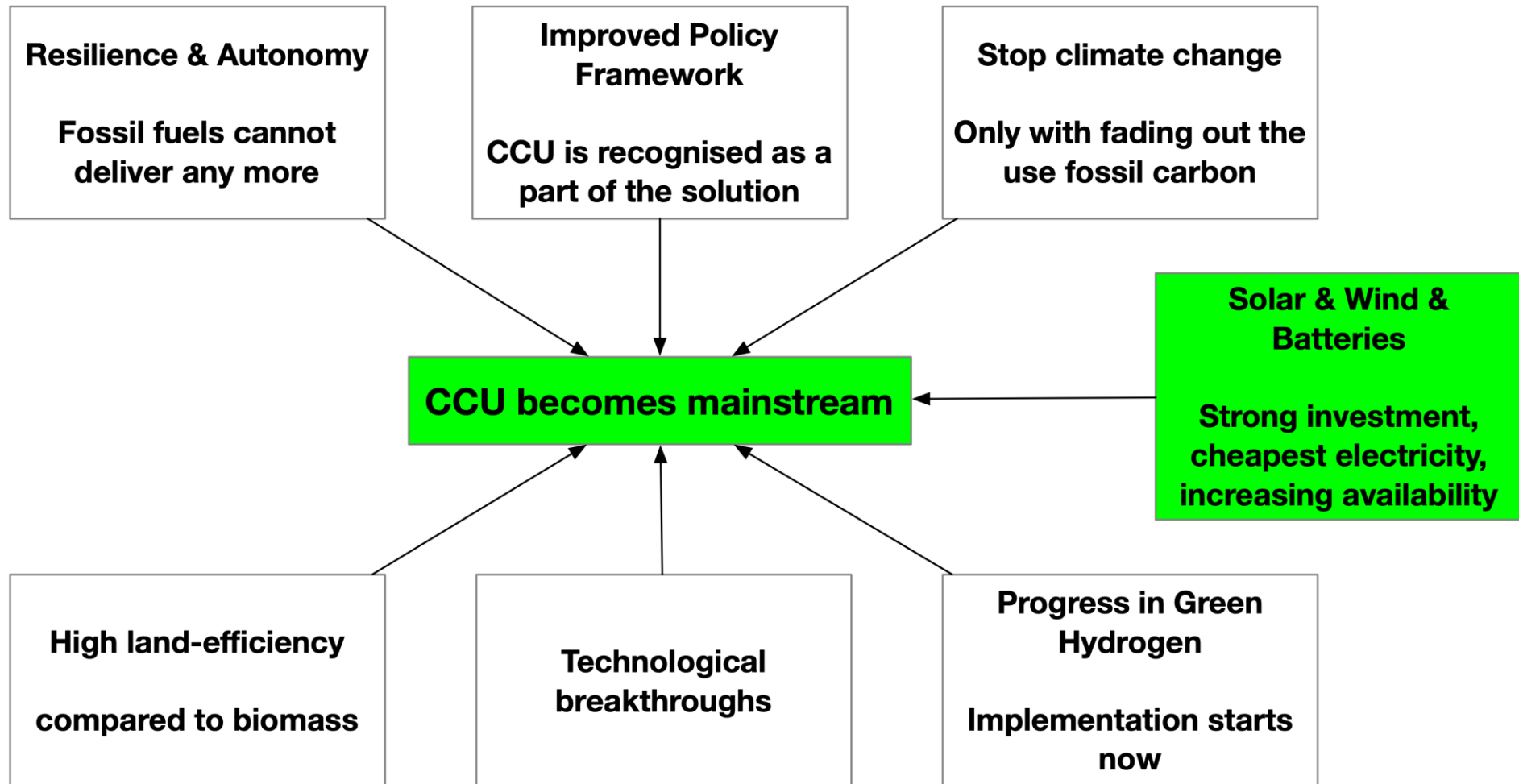
Germany notified the Commission of its intention to introduce a scheme to support the production of renewable hydrogen through the 'Auctions-as-a-Service' tool within the European Hydrogen Bank. **The approved scheme will support construction of up to 1,000 MW of installed electrolyser capacity, and the production of up to 10 million tonnes of renewable hydrogen.** This is estimated to avoid up to 55 million tonnes of CO₂.

The aid will be awarded through a competitive bidding process that will be supervised by the European Climate, Infrastructure, and Environment Executive Agency (CINEA).

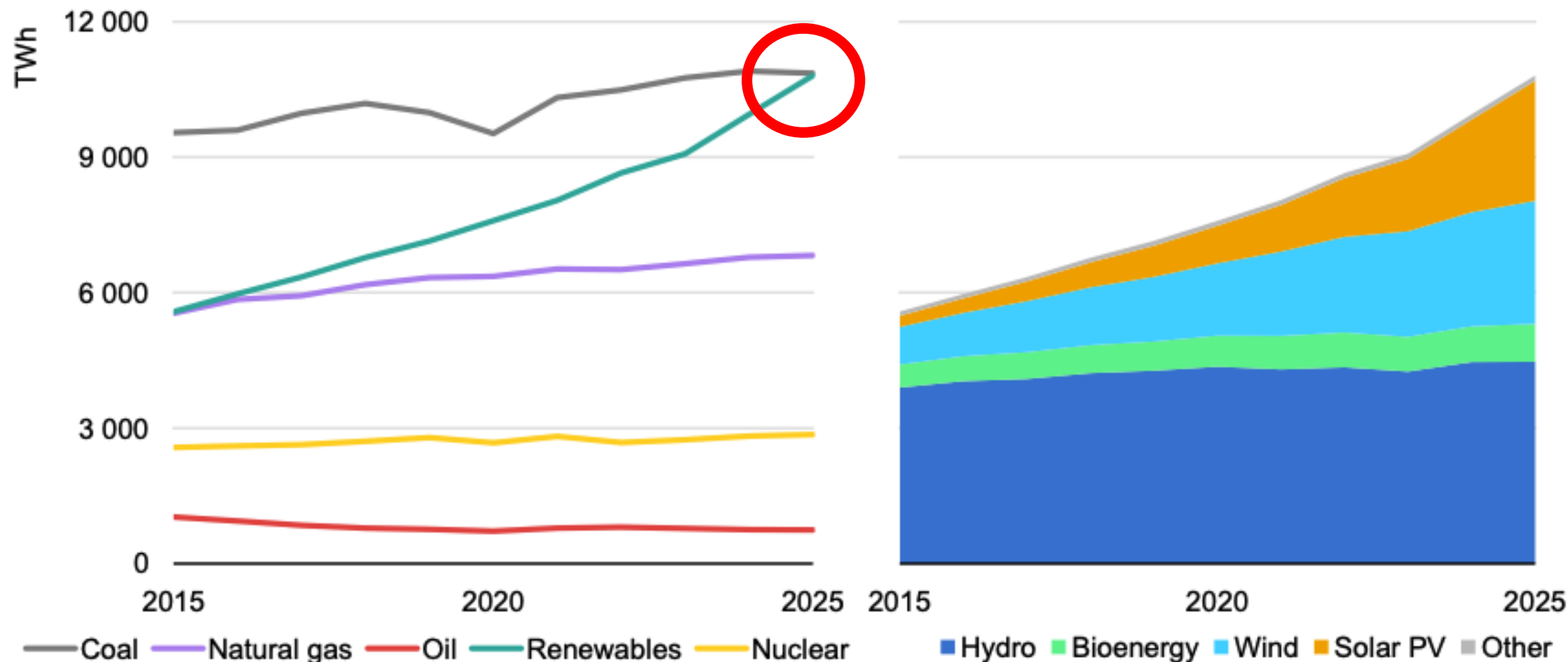
The scheme will provide support to companies planning to construct new electrolyzers feeding renewable hydrogen into the Danish Hydrogen Backbone 1 pipeline, which is a Project of Common Interest, and deliver it to buyers connected to the German Hydrogen Core Network. The aid will not only support the production of renewable hydrogen, but also cross-border infrastructure that connects renewable hydrogen sources in the North Sea to large-scale buyers.

Under the scheme, the aid will take the form of a direct grant per kilogram of renewable hydrogen produced. The aid will be granted for a maximum duration of ten years. Beneficiaries will have to prove compliance with EU criteria for the production of renewable fuels of non-biological origin (RFNBOs).

The top driver: Solar and wind power are taking over electricity production



Global electricity generation and renewable generation by source, 2015-2025



IEA. CC BY 4.0.

Note: 'Bioenergy' includes bioenergy and waste, 'Other' includes geothermal, concentrating solar power (CSP) and marine.

IEA Director Fatih Birol: Electricity consumption is growing much faster than overall energy demand – solar is growing much faster than any other energy source

Global electricity demand jumped around 3% in 2025 – more than twice as fast as overall energy demand.

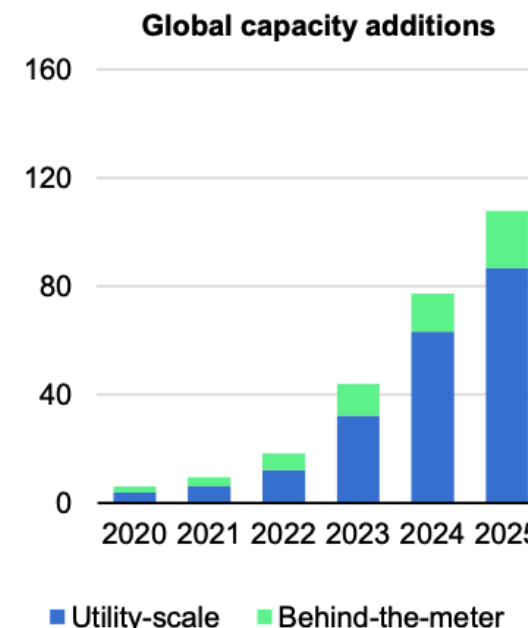
Solar was the single biggest contributor to global energy supply growth in 2025. It accounted for more than 25% of the increase – the first time a modern renewable has led global primary energy growth.

Solar added about 600 terawatt-hours of generation globally – the largest increase ever recorded in a single year for any power technology. That helped push overall coal-fired electricity generation down.

2025: Global solar capacity 2,400 GW and global solar electricity production: 2,700 TWh (doubled since 2022).

Source: IEA: Global Energy Review 2026

Battery storage was the fastest-growing power technology, with around 110 gigawatts (GW) of new capacity added – more than any year of natural gas capacity additions on record.



Solar energy is now the world's cheapest source of power

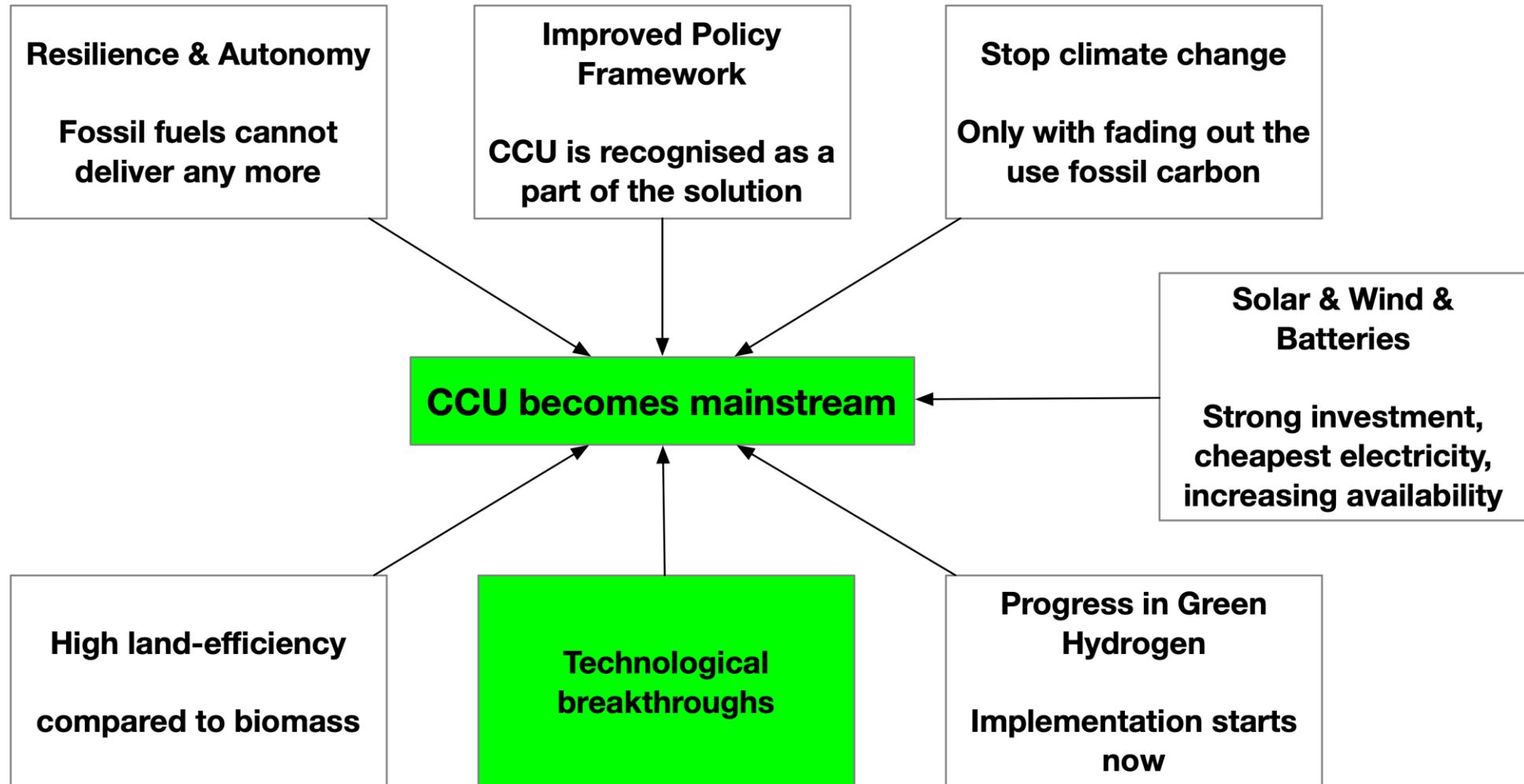
2025: **Solar energy** is now so cost-effective that, in the sunniest countries, it costs as little as **2 to 2.5 € cent produce** one unit of power, making it **cheaper than electricity generated from coal, gas or wind**, according to a new study from the University of Surrey. Solar photovoltaic (PV) technology is now the key driver of the world's transition to clean, renewable power.

The research team also found that the price of lithium-ion batteries has fallen by 89% since 2010, making **solar-plus-storage systems as cost-effective as gas power plants**. These hybrid setups, which combine **solar panels with batteries**, are now standard in many regions and allow solar energy to be stored and released when needed, turning it into a **more reliable, dispatchable source of power that helps balance grid demand**.

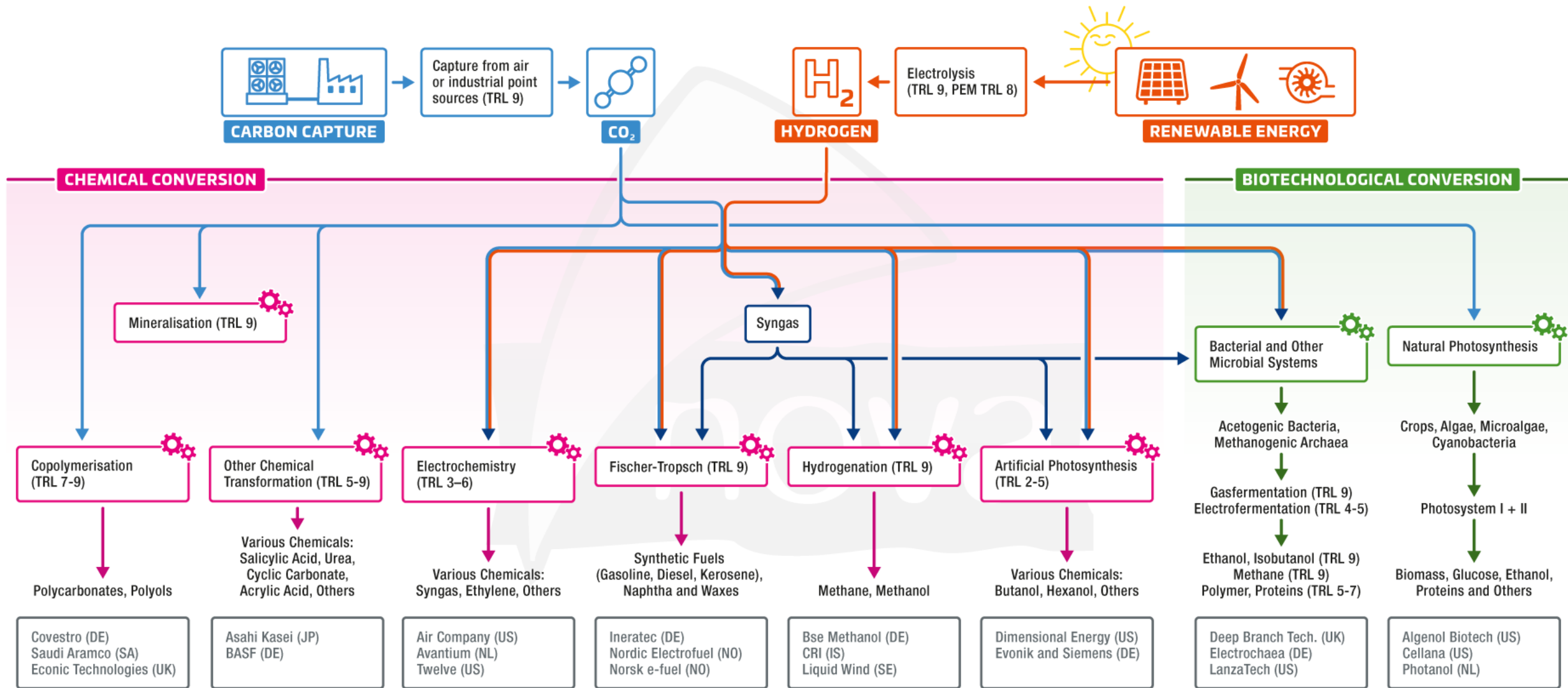
Despite many reasons to be optimistic, the ATI research team points to several challenges – particularly **connecting large amounts of solar power to existing electricity networks**.

Source: <https://www.surrey.ac.uk/news/solar-energy-now-worlds-cheapest-source-power-surrey-study-finds>

The driver: Technological breakthroughs

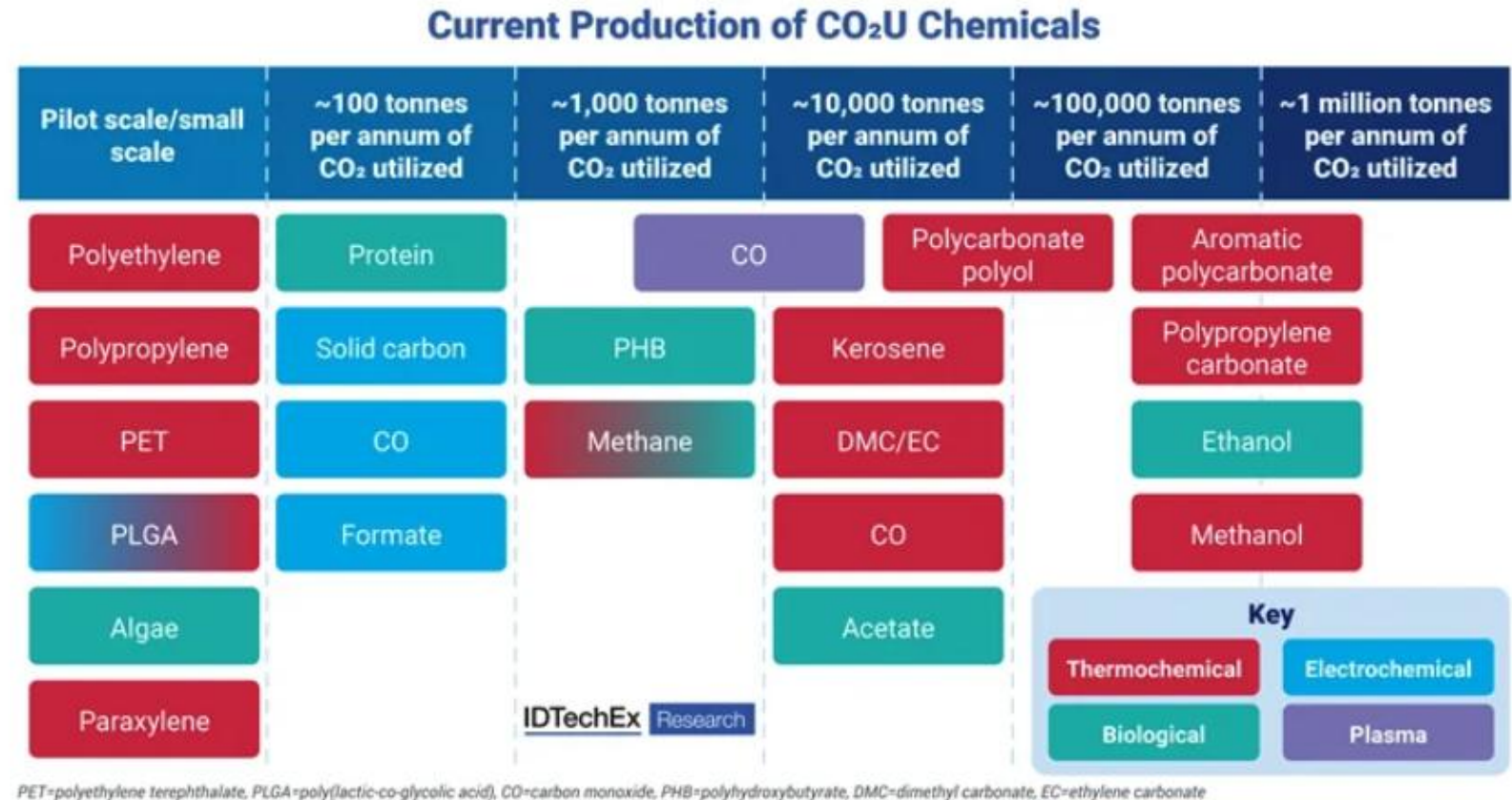


Carbon Dioxide Utilisation and Renewable Energy



Carbon Dioxide Utilisation: The Future of Green Chemicals?

- Petrochemicals underpin the global economy and are found in most manufactured goods. However, the chemicals sector is also a major emitter of carbon dioxide.
- Green alternatives to fossil fuel feedstocks are a promising solution. Utilizing captured CO₂ as the replacement source of carbon found in chemicals, creating a circular economy, is particularly attractive.
- According to IDTechEx's "Carbon Dioxide Utilization 2026-2036: Technologies, Market Forecasts, and Players" report, production of **CO₂-derived polymers is forecasted to reach 4 million tons per annum by 2036.**
- Source:
www.azocleantech.com/news.aspx?newsID=36485



Overview of chemical products that can be made via CO₂ utilization. Image Credit: IDTechEx's Carbon Dioxide Utilization 2026-2036: Technologies, Market Forecasts, and Players report

What shares will the various CCU technologies and pathways hold in 2050? nova: nova-Experts / PAB : RCI Project Advisory Board

C1: Fischer-Tropsch, Syngas -> Naphtha, waxes	21% (nova) / 20% (PAB)
C2: Hydrogenation -> Methane, Methanol	31% (nova) / 30% (PAB)
C3: Electrochemistry -> CO, formic acid, methane, methanol, ethylene and other C2/C3 chemicals	18% (nova) / 25% (PAB)
C4: Biotechnological Conversion / Fermentation -> Glucose, Ethanol, Isobutanol, Methane, Polymers	13% (nova) / 15% (PAB)
C5: Artificial Photosynthesis-> Butanol, Hexane and others	4% (nova) / 4% (PAB)
C6: Special chemical transformation incl. Polyols, Polycarbonates, PUR, Cyclic Carbonate, Acrylic and Salicylic Acid and more.	13% (nova) / 7% (PAB)

Examples (semi-)commercial CCU polymer producers (capacities, running & under construction)

Polycarbonates

- Lotte Chemicals (KR) (450,000 t/y)
- Saudi Kayan (SA) (260,000 t/y)
- Kazanorgsintez (RU) (100,000 t/y)
- Jilin Boda New Materials (CN) (50,000 t/y)
- Taizhou BangFeng Plastic (CN) (30,000 t/y)
- Tianguan Group/ Nanyang Zhongju Tianguan Low Carbon Technology (CN) (25,000 t/y)
- LXBIO Technology Co. (CN) (25,000 t/y)
- Jiangsu Zhongke Jinlong CAS Chemical (CN) (10,000 t/y)

Polyols / PUR

- Changhua Chemical (CN) & Econic (UK) (80,000 t/y)
- ViridiCO₂ (UK), also detergents
- **NIPU**: Eastern New Century Corporation (TW)

Ethylene -> PE / PET

- LanzaTech (US) (Ethanol) (200,000 t/y) & TotalEnergies (FR) (ethylene, PE / PET)
- Dioxycle (FR) (Ethylene)

MTO -> Ethylene / Propylene -> PE / PP

- Vioneo (CH/CN) (200,000 t/y)
- (Blue Circle Olefins (NL) (200,000 t/y)

EVA

- CO₂ based Naphtha from Infinium -> Borouge steam cracking -> ethylene -> EVA (On shoes)

Global share of CCU polymers ca. < 0.1%

CO₂ conversion to products



Beiersdorf
LanzaTech

men moisturizer



EVA-based shoe bottom unit

Recyceltes CO₂ wird Verpackung und Inhaltsstoff



dm setzt als erstes Unternehmen mit Partnern das recycelte Treibhausgas als Rohstoff für Verpackungsmaterial und Tensid (Schmutzlöser) ein.

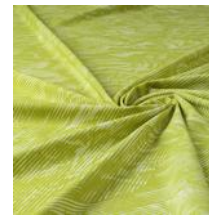
LanzaTech TOTAL L'ORÉAL



Polyethylene-based cosmetic bottle



Ethylene oxide-based surfactant for laundry capsule



LanzaTech lululemon INDIA GLYCOLS LIMITED 遠東新世紀 FAR EASTERN NEW CENTURY

Polyester-based athletic apparel



Ethanol for surface cleaning



LanzaTech COTY SINCE 1904

Ethanol for fragrances

Best CO₂ Utilisation 2025

Winners of the Innovation Award

UP Catalyst (EE)
**Battery-grade
Graphite from CO₂**



**Far Eastern New Century
Corporation (TW)**
**FENC® TopGreen®
CO₂-based NIPU**



Oxylus Energy (US)
**Methanol Producing
Electrolyzer**



Thank you for your attention!



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