Chemistry and Energy
Symbiotic relationship for a fossil-free future

Koenraad Debackere, KU Leuven

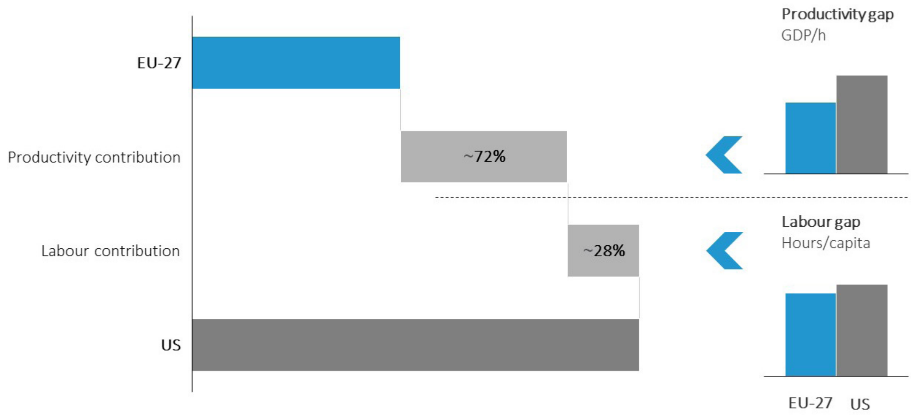
Catalisti & Moonshot Day

November 27th, 2025

Setting the broader scene, Draghi and Letta, 2024

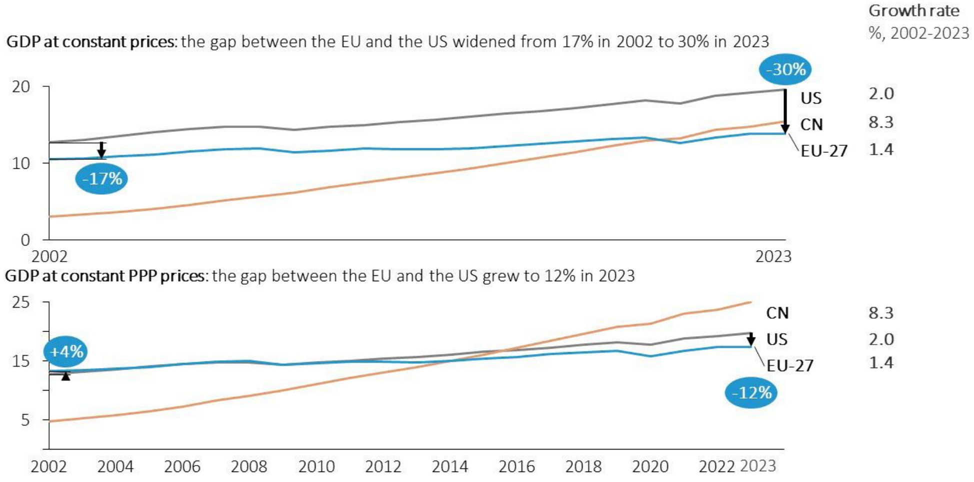
Setting the scene, Draghi concerns (1/4)

FIGURE 4
GDP per capita gap
GDP per capita, 2023, constant PPP prices (EUR)



Source: AMECO, 2024.

FIGURE 3
GDP evolution
2015 reference levels, in EUR trillion

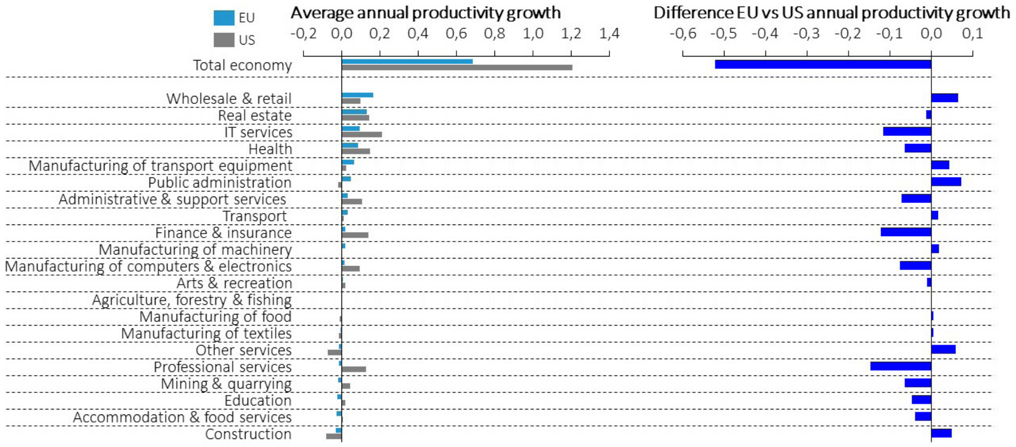


Source: OECD, 2024.

Setting the scene, Draghi concerns (2/4)

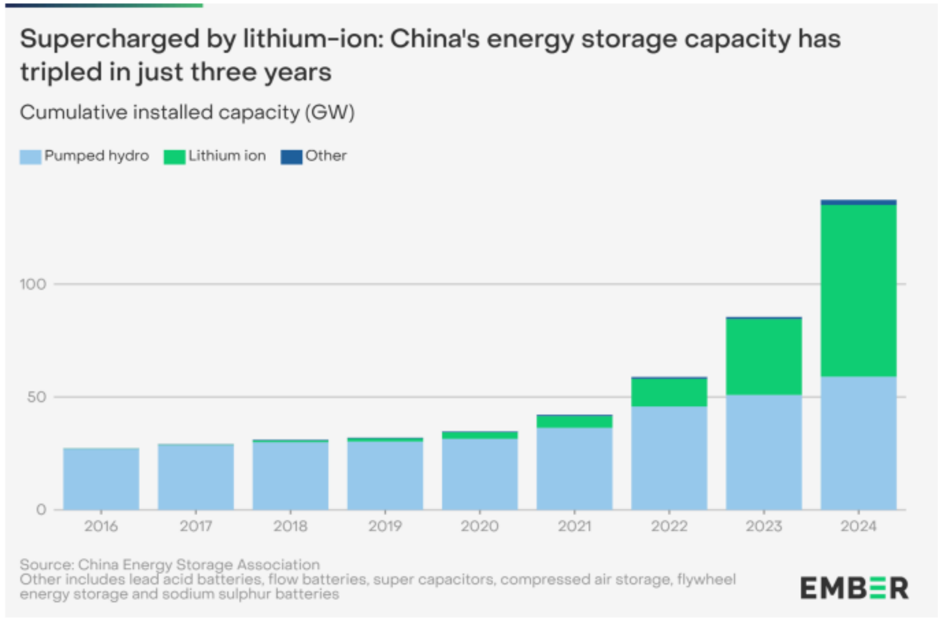
FIGURE 2

Decomposition of average annual labour productivity growth
Selected sectors, US and EU (pp, 2000-2019)



Note: EU is the GDP-weighted average of AT, BE, DE, DK, ES, FI, FR, IT, NL, SE. The values are the average annual labour productivity (GVA per hour worked) growth contributions over the period 2000-2019.

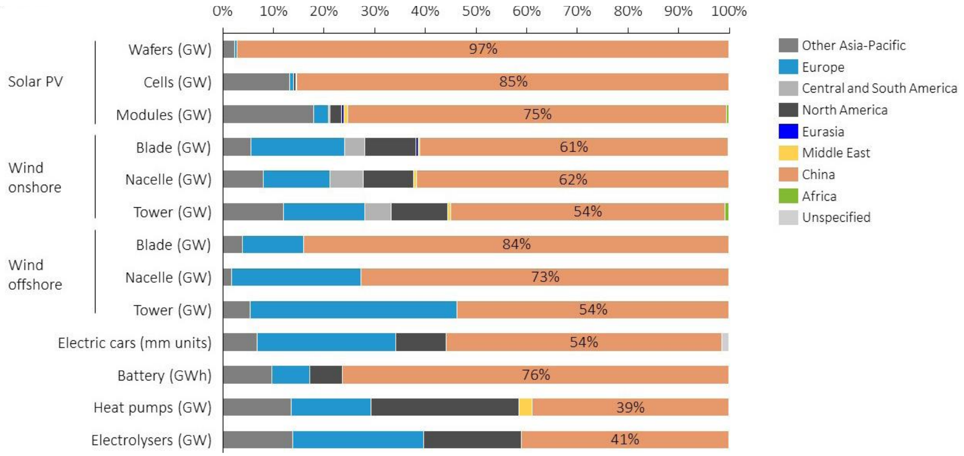
Source: Nikolov, P., Simons, W., Turrini, A. Voigt, P., forthcoming.



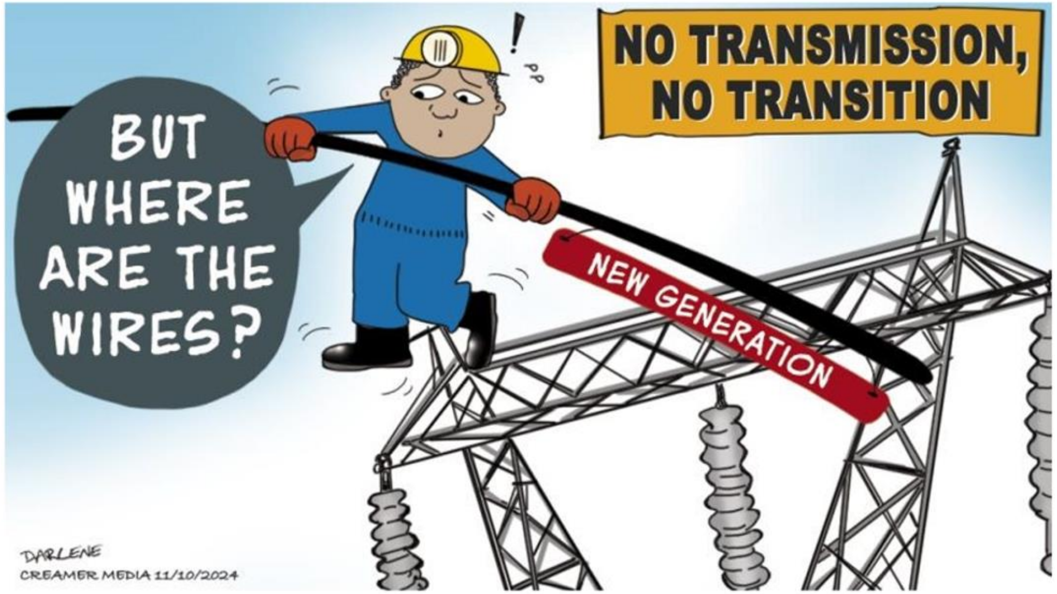
This surge brought China's new-type energy storage capacity to over 30 GW in 2023 – achieving its 2025 target two years early. By the end of 2024, total capacity exceeded 78 GW, with batteries overtaking pumped hydro as the largest source of storage. At the end of H1 2025, battery capacity had climbed to 95 GW – up 69% year-on-year.

Setting the scene, Draghi concerns (3/4)

FIGURE 7
Clean technology manufacturing capacity by region
%, 2021



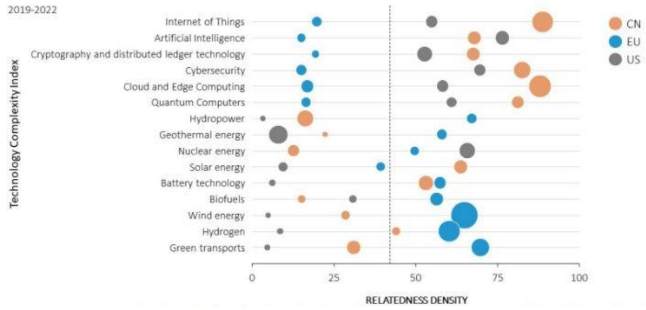
Source: European Commission, 2024. Based on IEA, Bruegel.



Setting the scene, Draghi concerns (4/4)

The technology gap: complexity matters

FIGURE 2
The EU's position in complex (digital and green) technologies

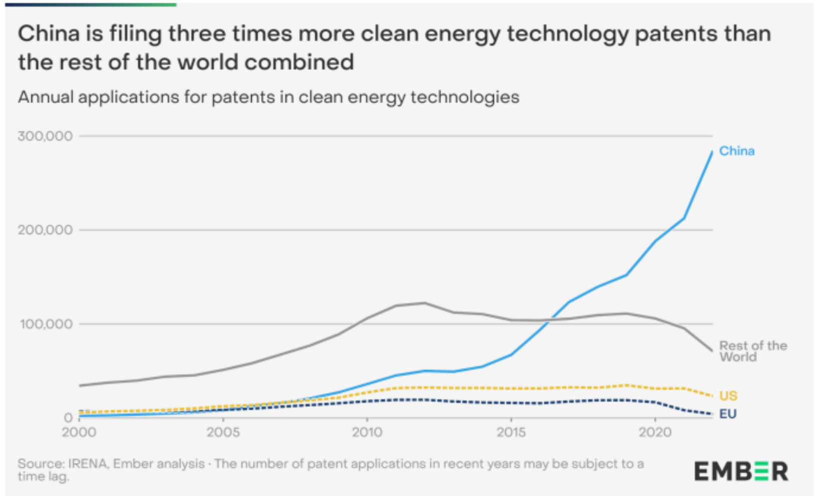


Notes: The results are based on an analysis of patent data to understand the complexity and potential for specialisation in different technology areas. On the y-axis, technologies are ranked according to how advanced or complex they are, with scores ranging between 0 (less complex) and 100 (more complex). The x-axis (showing the relatedness density) represents how easily a country can build comparative advantage in a particular technology, depending on how closely related it is to other technologies the country is already strong in. The size of the bubbles shows how much each country has already specialised in a technology, using a measure of "revealed comparative advantage"(RCA), which reflects their competitive strenght in that field.

Source: European Commission, DG RTD.

Draghi report and Science, Research and Innovation Performance of the EU 2024

European Commission



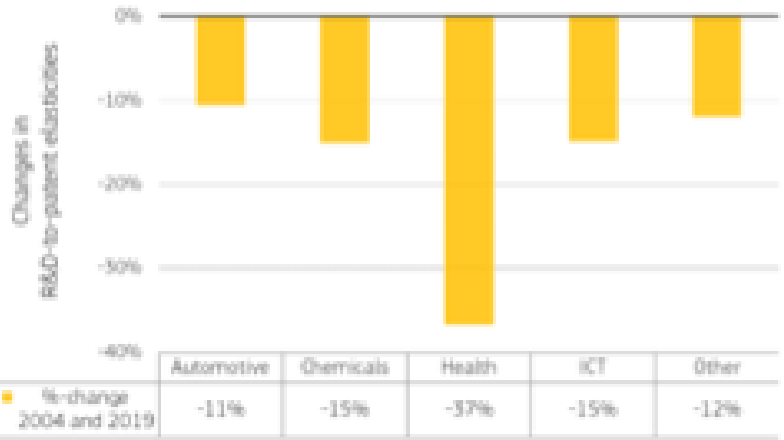
Equally striking is China's corporate Research and Development (R&D) spending in the energy sector, which has sailed past the US and Europe. In 2023, Chinese corporations invested ten times more in R&D in the electricity sector than their US counterparts. In concrete terms, this innovation acceleration has led to family-sized electric vehicles that charge in ten minutes for 400 km of range; batteries light enough to power heavy trucks and short-haul aircraft; offshore wind turbines as tall as the Eiffel Tower rated at 22 MW each; ultra-high voltage lines carrying 12 GW of desert solar power 3,300 km to coastal cities; and solar panels achieving 24% efficiency. In each case, it is a Chinese firm that is raising the ceiling of the possible; and the impact of raising the ceiling is global.

European R&D productivity declines

Source:

R&D productivity: Are ideas harder to find or does Europe suffer from a commercialisation gap?

Figure 2 – Estimated total decline in R&D–patent elasticity across sectors, 2004–2019 (*) (%)



(*) The first observation from China is from 2008 instead of 2004 because of data availability.
Source: EU Industrial R&D Investment Scoreboard.

Figure 3 – Estimated total decline in R&D–labour-productivity elasticity across sectors, 2004–2022 (*) (%)

(*) The first observation from China is from 2008 instead of 2004 because of data availability.
Source: EU Industrial R&D Investment Scoreboard.

R&D productivity in terms of patents has been falling globally, but most strongly in the United States and the EU. Coupled with the EU's persistent weakness in transforming its R&D into commercially successful product innovations, as the estimated R&D–labour-productivity elasticities show, that seems to warrant urgent policy action to bring the EU back on a growth path that secures its long-term global competitiveness.

The only way to do it: Just do it!

Jamie Dimon, July 2025

15 years ago, GDP-EU was 90% of GDP-US

Today, GDP-EU is 65% of GDP-US

You are losing …

Mario Draghi, September 2025

Europe’s citizens and companies value the diagnosis, the clear priorities and the action plans.

But they also express growing frustration. They are disappointed by how slowly the EU moves. They see us failing to match the speed of change elsewhere. They are ready to act—but fear governments have not grasped the gravity of the moment.

Too often, excuses are made for this slowness. We say it is simply how the EU is built. That a complex process with many actors must be respected. Sometimes inertia is even presented as respect for the rule of law.

That is complacency. Competitors in the US and China are far less constrained, even when acting within the law. To carry on as usual is to resign ourselves to falling behind.

A different path demands new speed, scale and intensity.

It means acting together, not fragmenting our efforts. It means focusing resources where impact is greatest. And it means delivering results within months, not years.

Economic challenge and transition challenge

Non-fossil grows fast and overtakes fossil in the 2050s

Primary energy demand (EJ/yr)

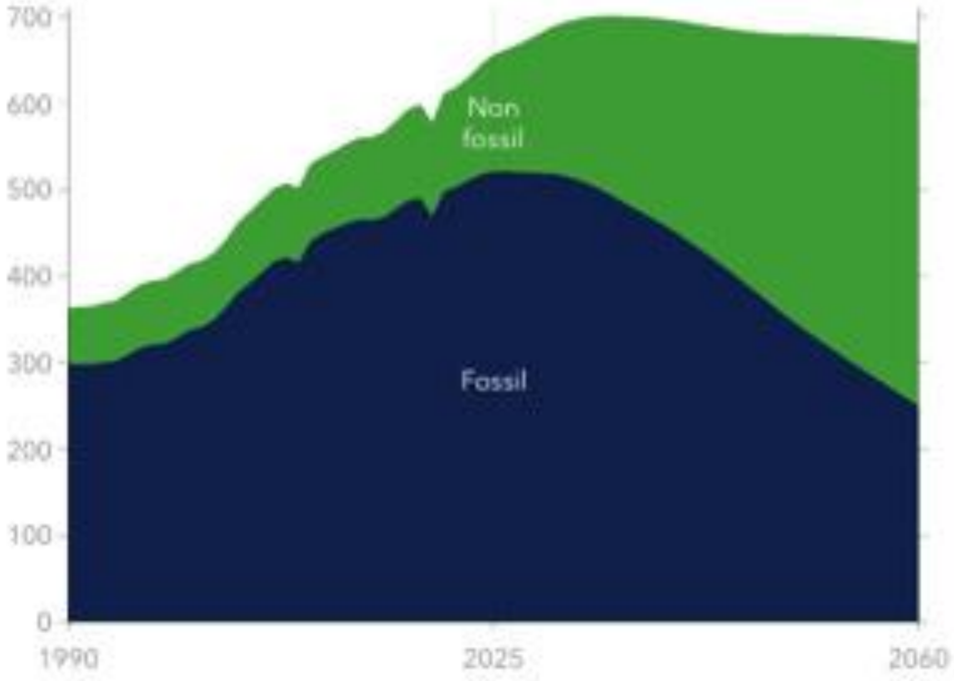


FIGURE 2.1 | Historical data source: IEA WEB (2025)

From energy addition to energy transition

Primary energy demand (indexed to 1990)

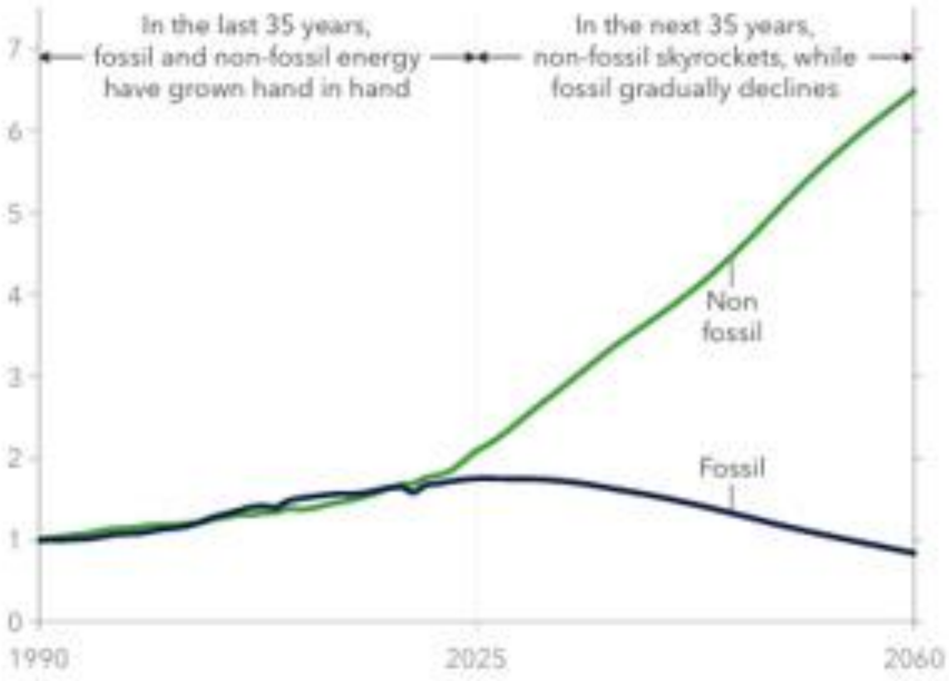


FIGURE 2.2 | Historical data source: IEA WEB (2025)

Economic challenge and transition challenge

Emission paths diverge across regions, but almost all decline towards 2060

Energy-related CO_2 emissions by region ($GtCO_2$/yr)

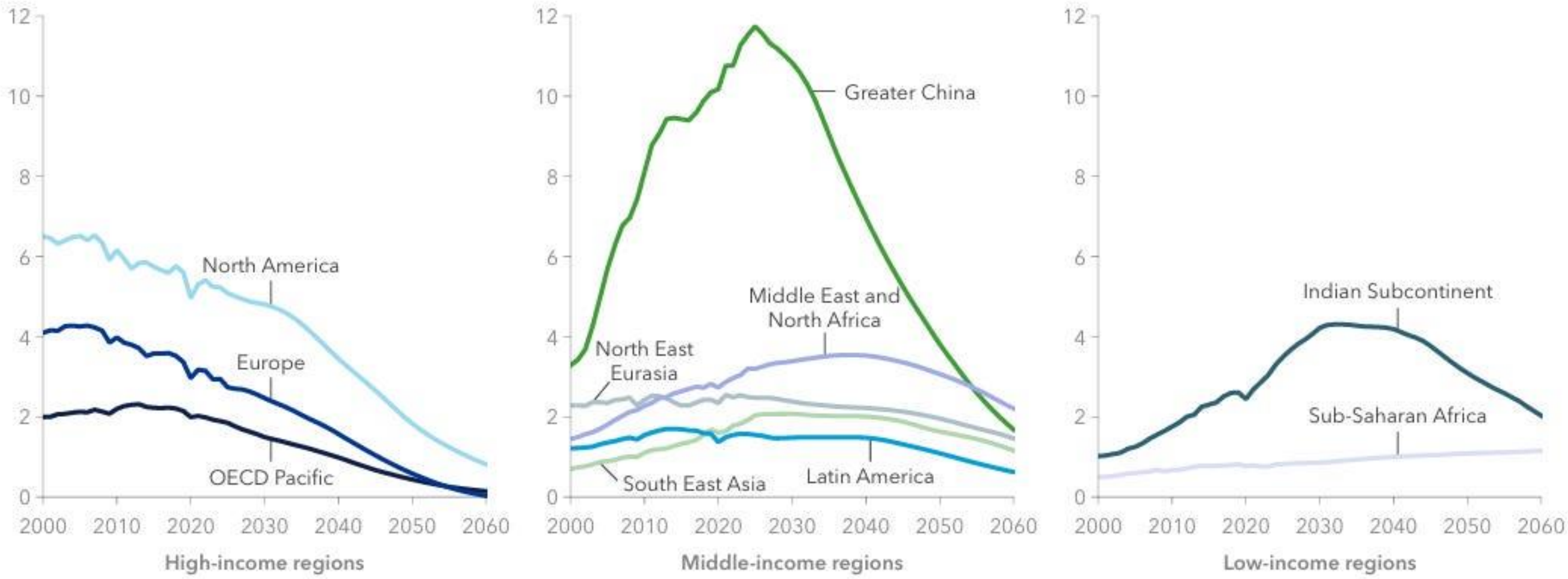
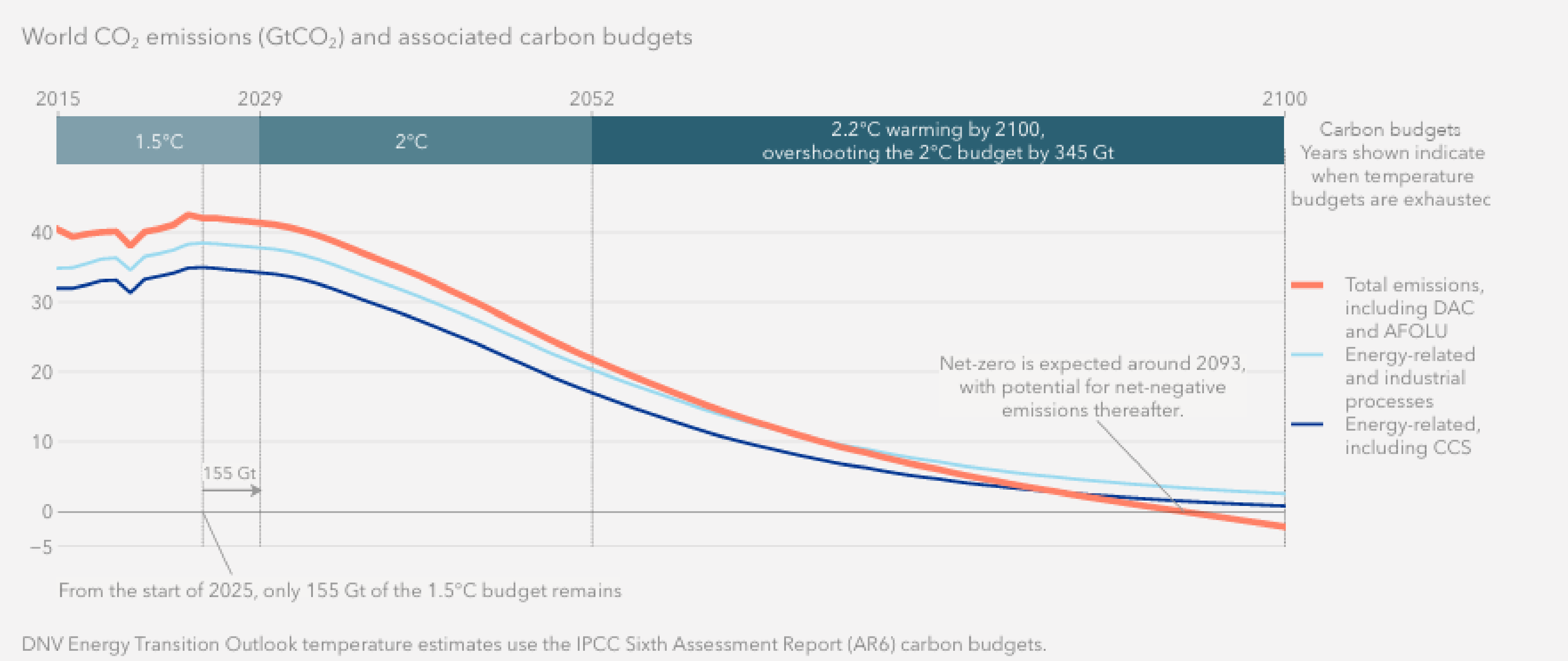


FIGURE 8.3 |

Economic challenge and transition challenge



Understanding transition limitations and rightsizing policies

Hydrogen has a very low energy density and is thus extremely hard and expensive to store and move around

→ **Need for synthetic hydrocarbons!**

C Journal of Carbon Research

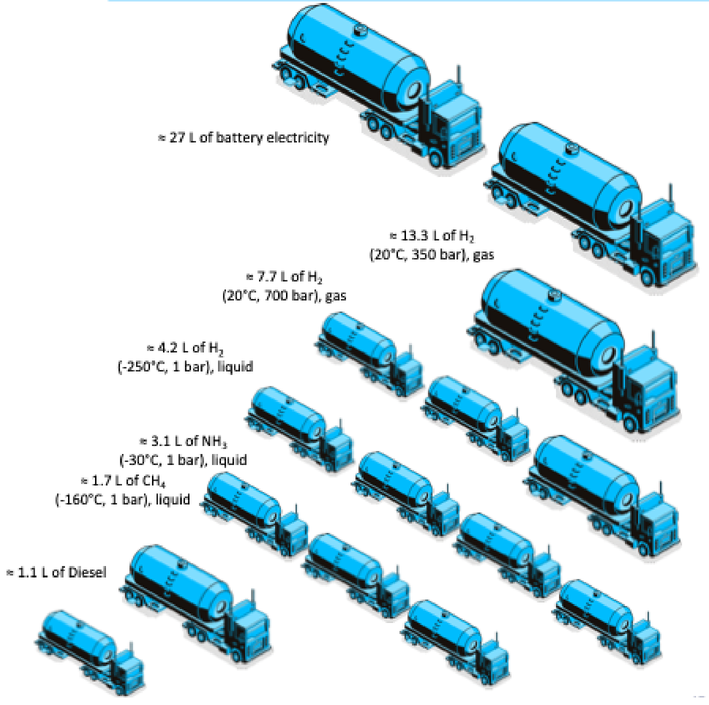
Article

Why the Carbon-Neutral Energy Transition Will Imply the Use of Lots of Carbon

Jan Mertens [1,2,*], Ronnie Belmans [3,4] and Michael Webber [1,5]

ENGIE GHENT UNIVERSITY

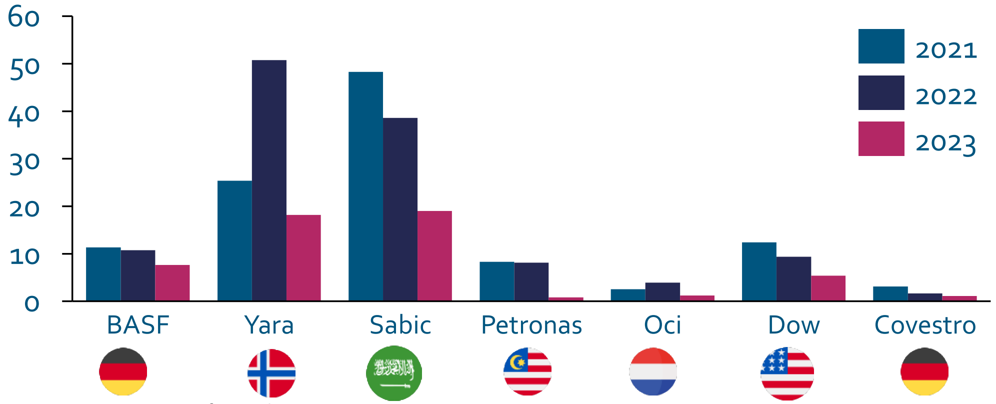
How to transport or store 10kWh of energy?



Focus on the chemical industry

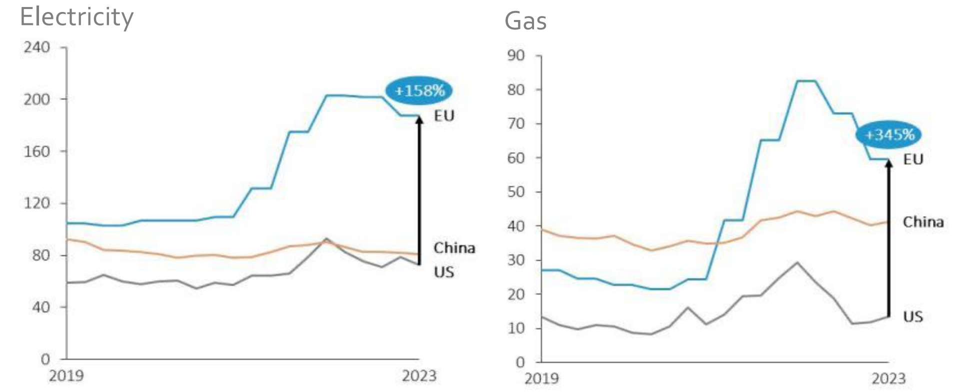
The chemical industry is suffering today due to an overcapacity and low demand growth, even more so in regions where energy costs are high since energy prices dominate the cash cost structure of basic chemicals.

EBITDA of chemical companies, Bn€/y



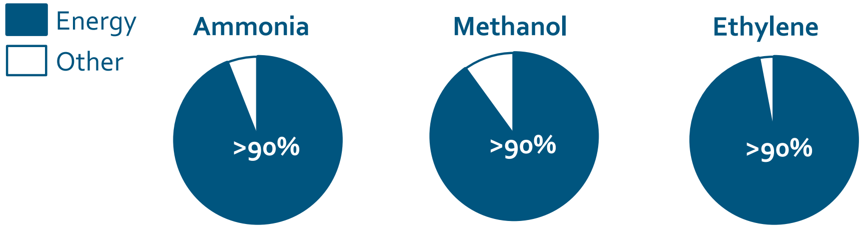
Source: Companies financial reports

Gas and electricity retail price gap for industry, €/MWh



Source: Draghi report (2024)

Cash cost of basic chemicals[1], €/t



Total production cost (fossil)	□500 €/tNH3	□300 €/tMeOH	□900 €/tEthylene

Source: Yara (2024), LuxResearch (2024), IEA (2019)

1. *Other includes among the other cost of labors, maintenance, and catalyst*

Macroeconomic environment - Europe oriented

"BASF closes ammonia production plant in Germany" (2024)
"Yara Curtails 2023 European Ammonia production by 19% (2024)
"ExxonMobil, Sabic to shutter European Ethylene (2024)
"Evonik cuts nearly 7,000 jobs" (2024)

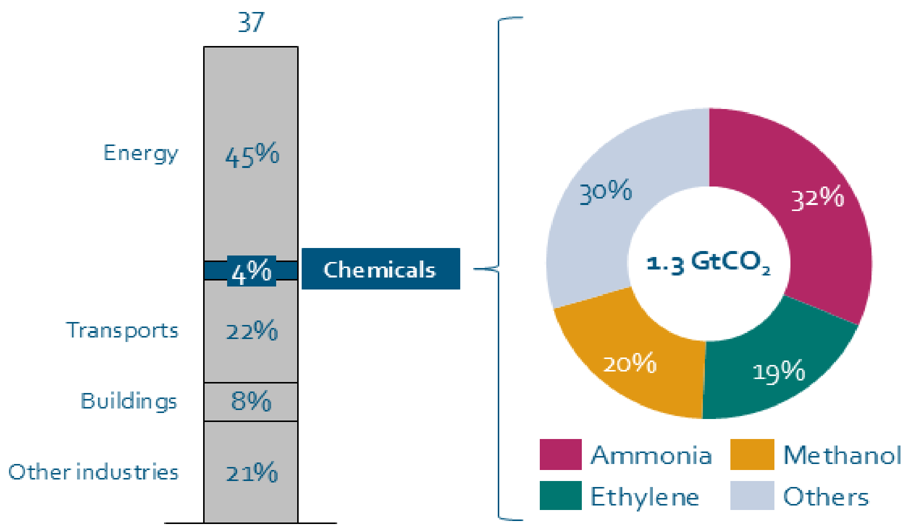
Regulatory environment

	EU	US	China
Energy	Greendeal, RED 2,3	Clean Power Plan, IRA	Incentives exist
Fuels	Greendeal, ReFuel, RED 2,3	IRA	Incentives exist
Chemicals	**No support**	IRA	Incentives exist

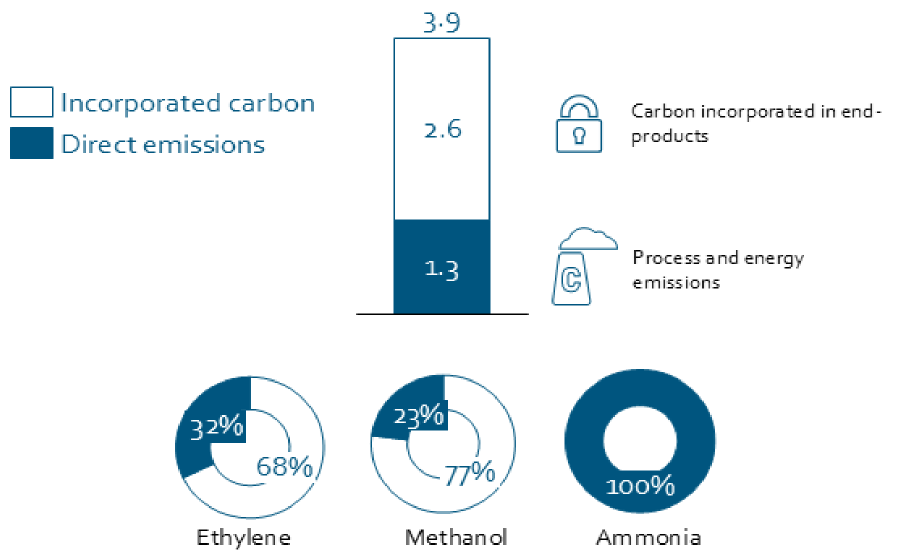
Draghi report (2024): The future of European competitiveness

Chemical industry, Scope 1 – 2 - 3

Global CO_2 emissions breakdown in 2022, $GtCO_2$



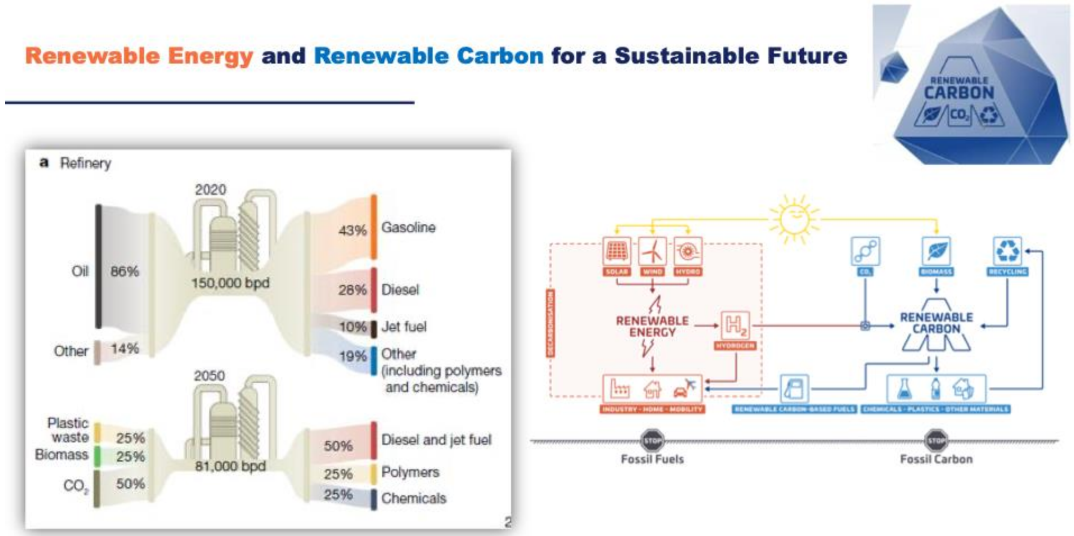
Total CO_2 emissions from global chemistry in 2022, $GtCO_2$



Chemical feedstocks

- Sustainable carbon feedstocks:
  - Each sustainable carbon feedstock (biomass, recycled plastics, or CO_2) presents distinct technological and economic advantages and limitations, and their relative deployment will significantly influence the feasibility, cost, and pace of defossilisation. Growing demand from diverse sectors for each potential carbon feedstock source will put the chemical industry in competition with multiple other sectors that will vie for them.
- Focus on biomass, recycled plastics, CO_2 as sustainable/renewable feedstocks.
  - Given this limited and uneven availability, biomass should be strategically prioritized for applications where alternative decarbonization pathways are either technologically immature or economically unviable. These include sectors such as pulp and paper, chemicals and plastics, woody construction materials, and sustainable aviation fuels.
  - Recycled plastics are expected to become a major pillar of sustainable carbon sourcing in the chemical and polymer industries. However, today only about 10% of plastics are recycled globally, reflecting limitations in collection systems, material sorting, and end-market demand. However, projections indicate that this share could increase to approximately 45% by 2050, provided that enabling conditions are met, e.g., technological, regulatory and infrastructural. And the sustainability of biogenic or recycled carbon also depends strongly on process choice.
  - Carbon dioxide (CO_2) is emerging as an important feedstock in the defossilization of the chemical industry, particularly in the context of long-term net-zero strategies. Unlike biomass or recycled plastics, CO2 offers the potential for near-unlimited availability, especially when captured directly from the atmosphere. However, its use as a feedstock is still in its infancy and its scaling presents both technical and even more so economic challenges.

Vogt & Weckhuysen, Refinery of the Future, Nature 2024



Vogt, E.T.C., Weckhuysen, B.M. The refinery of the future. *Nature* **629**, 295–306 (2024). https://doi.org/10.1038/s41586-024-07322-2

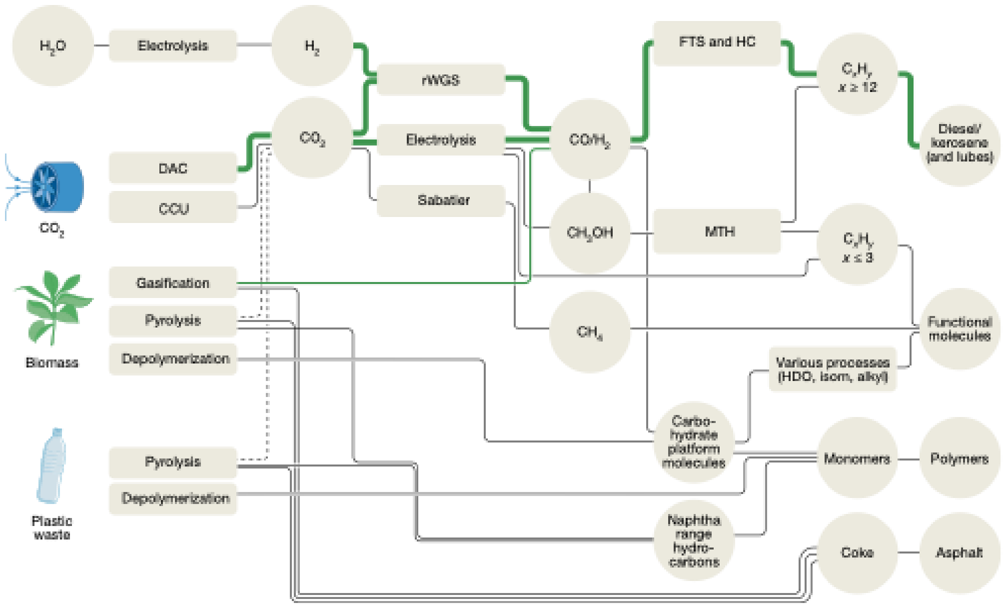


Fig. 2 | Overview of the various conversion processes in the refinery of the future. The starting materials are CO_2, biomass and plastic waste. The last two are taken as showcase examples of agricultural and municipal waste. The green process line shows the main process route for converting CO_2 to hydrocarbon fuels advocated in this Perspective. The dashed lines indicate that biomass and plastic waste conversion may produce CO_2 that can be used in the fuels train. Functional molecules are aromatics, oxygenates, amines, for example. Polymers are not necessarily produced in the refinery but are added in the process flow to clarify the plastic waste-to-polymers concept. alkyl, alkylation; CCU, carbon capture and utilization; isom, isomerization; MTH, methanol-to-hydrocarbons; FTS, Fischer–Tropsch synthesis; HC, hydrocracking; HDO, hydrodeoxygenation.

Wood as a renewable carbon feedstock, Sels lab, Biofpr 2024

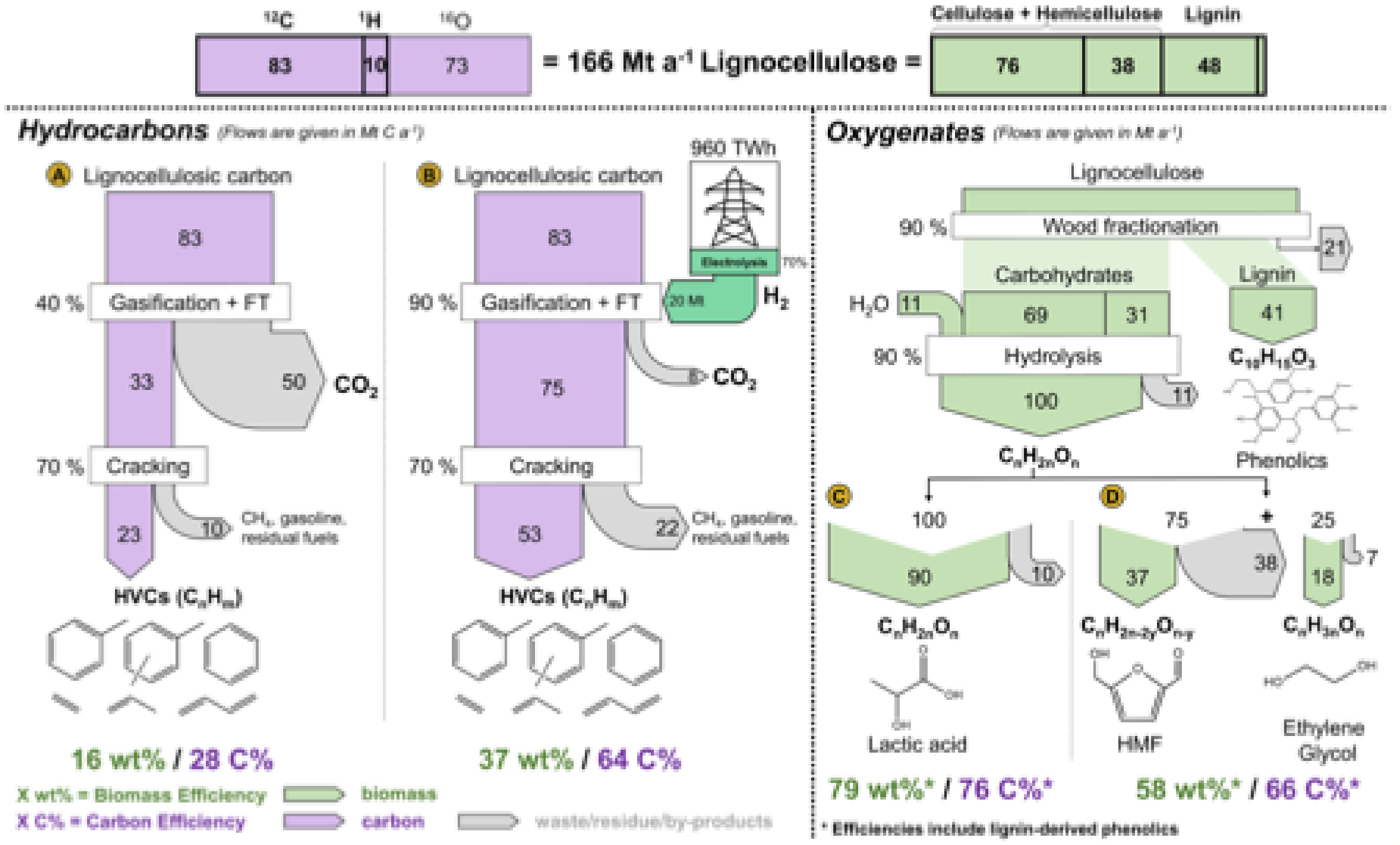


Figure 3. Example technological pathways from woody biomass to chemicals: 166 Mt of lignocellulose can be provided for biorefining per year in Europe (Fig. 2). Wood can be processed into hydrocarbon platform chemicals (*Hydrocarbons*), identical to fossil based HVCs, or into oxygenate chemicals (*Oxygenates*). The creation of this figure is discussed in Supporting Information, Note 5. FT, Fischer–Tropsch; HMF, 5-hydroxymethylfurfural; SC, steam cracking.

Biomass competitiveness, 2024

Table 1: Biomass competitiveness and potential scale

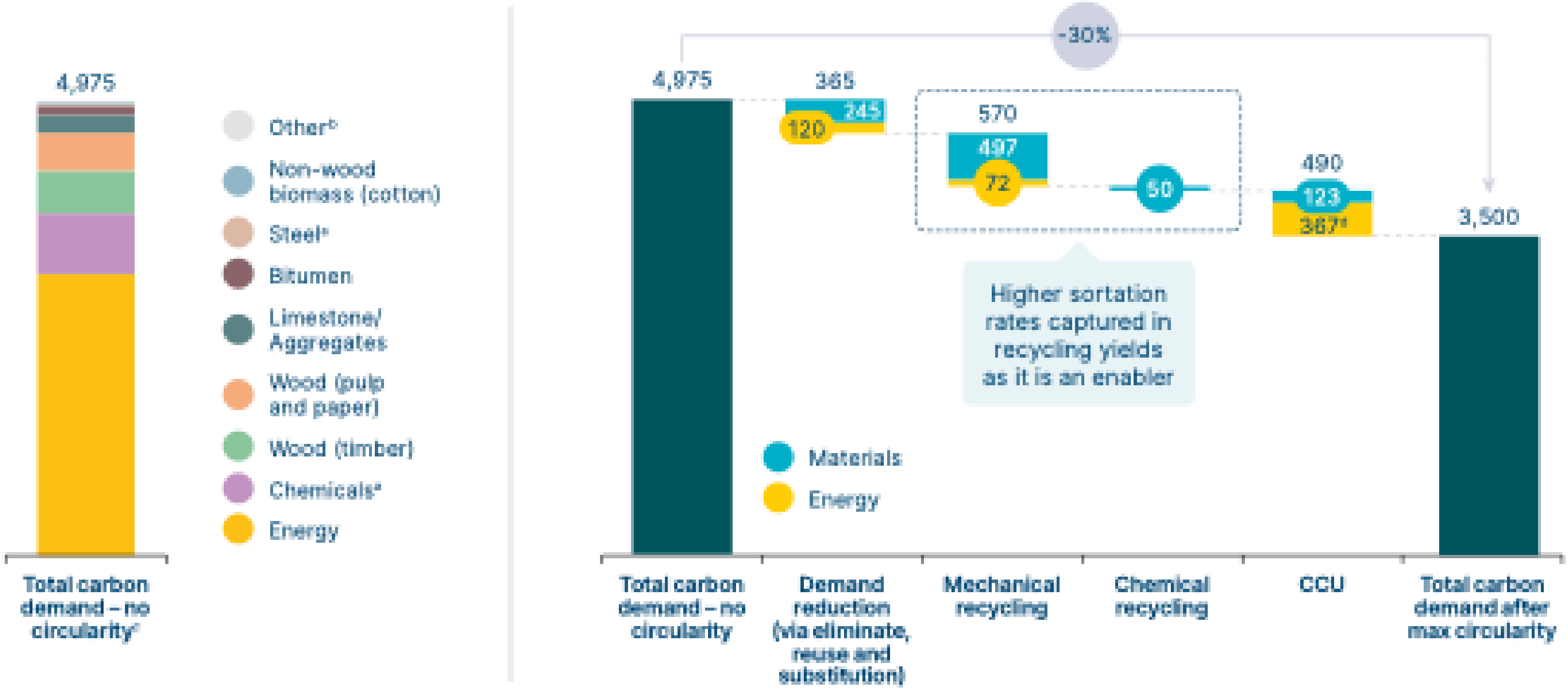
Application	Biomass types used	Competitive with unabated?	Competitive with other net zero?	Potential scale
Steel	Biocoal or pyrolized wood waste	No	Yes (retrofit)	Large
Cement	Forestry residues (biocoal, wood pellets)	No	Yes	Moderate
Biomass-to-power	Forestry residues (biocoal, wood pellets, waste)	No	No	Small
BECCS	Forestry residues (wood pellets, waste)	No	Yes (small-scale)	Small
Renewable diesel	UCO, oil seed crops	No	Yes	Moderate
SAF	UCO, oil seed crops	No	Yes	Small
Biomethane	MSW, agricultural residues, food waste	No	Yes	Large
Bionaphtha	UCO, oil seed crops	No	Yes	Small
Ethanol to ethylene	Sugarcane, corn, agricultural residues	No	Yes	Small
Biomethanol to aromatics	MSW, forestry residues, agricultural residues	No	Yes	Moderate

Exhibit 4

Circularity levers could reduce 30% primary carbon demand by mid-century

Carbon demand across the energy and materials sectors by mid-century

Million tonnes of carbon (C)



NOTE: [a]Chemicals and steel include the feedstock from the energy system that has remained in material, i.e. plastic, in order to show the circularity levers. [b]Other includes carbon ash, biochar, carbon fibre, charcoal. [c]Total carbon demand is shown without applying the circularity levers included in ACF. Enhance Oil Recovery (EOR) does not reduce the carbon demand.

SOURCE: Energy: Systemiq analysis for the ETC; ETC (2023), based on *Fossil Fuels in Transition*; Chemicals: Systemiq (2022), *Planet Positive Chemicals* (BAU Net-Zero scenario); Biomass: ETC (2021), *Bioresources within a Net-Zero Emissions Economy*; Steel: MPP (2022), Making net-zero steel possible.; MPP (2022), Making net-zero aviation possible; Cement: MPP (2023), Making net-zero concrete and cement possible. Cotton, Bitumen and Soda Ash: Systemiq analysis (2025).

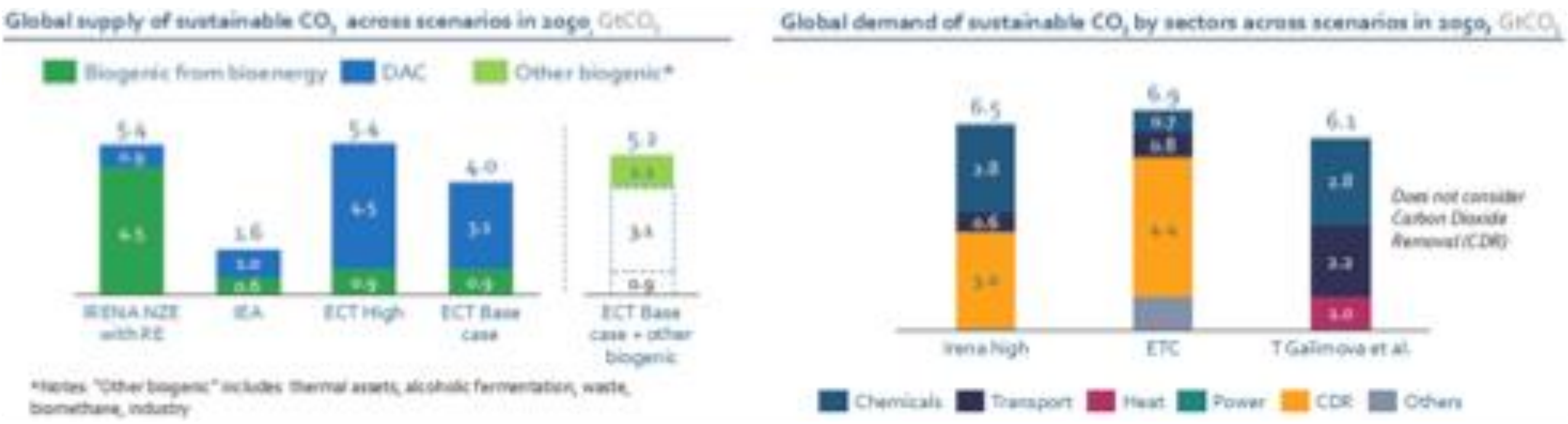
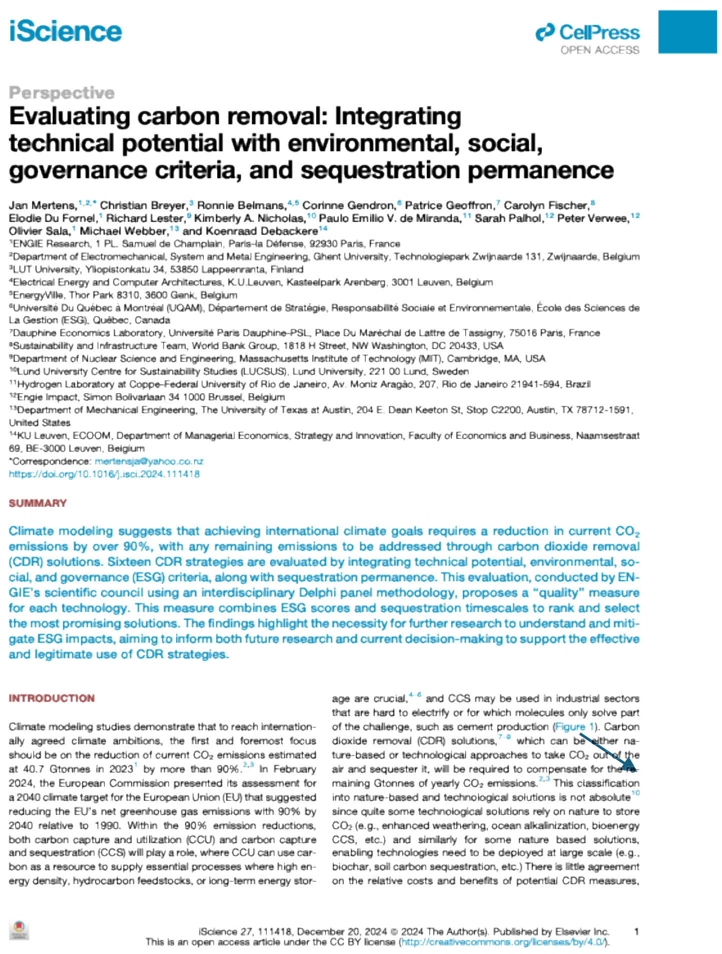


Figure 2. Estimated global supply and demand of sustainable CO_2 in 2050 across multiple scenarios

Supply estimates exceed predicted demand; the mismatch highlights the need for DAC to supplement biogenic sources.



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Perspective

Evaluating carbon removal: Integrating technical potential with environmental, social, governance criteria, and sequestration permanence

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https://doi.org/10.1016/j.isci.2024.111418

SUMMARY

Climate modeling suggests that achieving international climate goals requires a reduction in current CO_2 emissions by over 90%, with any remaining emissions to be addressed through carbon dioxide removal (CDR) solutions. Sixteen CDR strategies are evaluated by integrating technical potential, environmental, social, and governance (ESG) criteria, along with sequestration permanence. This evaluation, conducted by ENGIE's scientific council using an interdisciplinary Delphi panel methodology, proposes a "quality" measure for each technology. This measure combines ESG scores and sequestration timescales to rank and select the most promising solutions. The findings highlight the necessity for further research to understand and mitigate ESG impacts, aiming to inform both future research and current decision-making to support the effective and legitimate use of CDR strategies.

INTRODUCTION

Climate modeling studies demonstrate that to reach internationally agreed climate ambitions, the first and foremost focus should be on the reduction of current CO_2 emissions estimated at 40.7 Gtonnes in 2023[1] by more than 90%.[2,3] In February 2024, the European Commission presented its assessment for a 2040 climate target for the European Union (EU) that suggested reducing the EU's net greenhouse gas emissions with 90% by 2040 relative to 1990. Within the 90% emission reductions, both carbon capture and utilization (CCU) and carbon capture and sequestration (CCS) will play a role, where CCU can use carbon as a resource to supply essential processes where high energy density, hydrocarbon feedstocks, or long-term energy storage are crucial,[4–6] and CCS may be used in industrial sectors that are hard to electrify or for which molecules only solve part of the challenge, such as cement production (Figure 1). Carbon dioxide removal (CDR) solutions,[7–9] which can be either nature-based or technological approaches to take CO_2 out of the air and sequester it, will be required to compensate for the remaining Gtonnes of yearly CO_2 emissions.[2,3] This classification into nature-based and technological solutions is not absolute[10] since quite some technological solutions rely on nature to store CO_2 (e.g., enhanced weathering, ocean alkalinization, bioenergy CCS, etc.) and similarly for some nature based solutions, enabling technologies need to be deployed at large scale (e.g., biochar, soil carbon sequestration, etc.) There is little agreement on the relative costs and benefits of potential CDR measures,

	Direct Air Carbon Capture and Sequestration (DACCS)	Bio Energy Carbon Capture and Sequestration (BECCS)	Mineral Carbonation	Enhanced Weathering
Definition	CO_2 is captured from the atmosphere and then sequestered underground	CO_2, produced from biomass transformation into energy, is captured and then sequestered underground	conversion of alkaline minerals to solid carbonates, used as construction or filling materials	alkaline minerals spread on the ground to increase the speed of naturally occurring weathering of silicates minerals
Maturity *(TRL)*	7	7-9	7-9	4
Potential 2050 *($GtCO_2/y$)*	10	2.5	1	4
Cost 2030 *(€/tCO_2)*	100-600	100-200	50-600	50-200
Cost trend 2050	↘	↘	↘	
Environmental, social, governance aspects	Low biodiversity impact Social acceptance risk Lack of regulations	Negative effect on biodiversity Social acceptance risk	Mining needed (energy intensive) Possible restrictions on uses, Excluded from Emission Trading Systems	Increase soil quality, fight ocean acidification, Mining needed (energy intensive) No regulations

Novel processes and pathways to produce sustainable chemicals

The decarbonization of high-temperature industrial processes is increasingly supported by the emergence of electric heating technologies, which start offering a viable alternative to fossil fuel-based thermal energy when renewable or low-carbon electricity is used. High-temperature heat pumps are under development, but their temperature level is not likely to exceed 180◦C–200◦C, which is insufficient for many processes in the chemical industry. However, their deployment in other industries requiring lower heat levels such as the food, textile, and tobacco industries is kicking off today. For higher-temperature heat (up to 1,000◦C–2,000◦C or more) technologies such as electric boilers, resistance and induction heating, plasma torches, and electric arc furnaces are reaching high(er) TRLs (TRL 7–9), with some already deployed at commercial scale.

Novel processes and pathways to produce sustainable chemicals

The <u>integration of hydrogen into biomass conversion</u> processes represents a promising strategy to enhance carbon efficiency in the production of high-value chemicals. Biomass is inherently hydrogen lean and oxygen rich, whereas most chemical products are hydrogen rich. This elemental mismatch leads to significant carbon losses during conventional thermochemical conversion. By introducing hydrogen from low-carbon sources into the conversion pathway, the carbon yield of biomass-to-chemical processes can be substantially increased.

Novel processes and pathways to produce sustainable chemicals

Biogas and biomethane represent promising renewable feedstocks for the production of chemicals and plastics, offering a viable pathway to defossilise the chemical sector. These molecules can be converted into syngas (CO + H_2), a versatile intermediate used in the synthesis of fuels, methanol, ammonia, and high-value chemicals. Steam methane reforming, the most mature technology (TRL 9), is widely used today but emits significant CO_2 and requires water.

Emerging alternatives such as dry methane reforming and super dry methane reforming use CO_2 instead of H_2O, improving carbon efficiency and eliminating the need for water input. For example, super dry methane reforming follows the reaction $CH_4 + 3CO_2 \rightarrow 4CO + 2H_2O$, producing a CO-rich syngas ideal for Fischer-Tropsch synthesis. These routes are particularly attractive when using biogenic CO_2 from anaerobic digestion, enabling a more circular carbon economy and reducing net emissions.

Table 1. Comparative analysis of NOCM and OCM as emerging pathways for direct methane-to-olefin conversion

Parameters	Non-Oxidative Coupling of Methane (NOCM)	Oxidative Coupling of Methane (OCM)
Oxidant	None	O_2
Primary reaction	$2CH_4 \rightarrow C_2H_4 + 2H_2$	$2CH_4 + O_2 \rightarrow C_2H_4 + 2H_2O$
Coproducts	H_2 and aromatics	C_2H_6, CO, CO_2, H_2O, H_2 and aromatics
Catalyst	Zeolites, metals	Oxides (e.g. La_2O_3)
Selectivity	Challenging due to coking	Higher thanks to control oxidation
Temperature	>1000°C	700-900°C
Emissions	None, solid carbon as by-product	Potential CO_2 and CO emissions
TRL	4-6	5-7

Sustainable C- and H-logistics

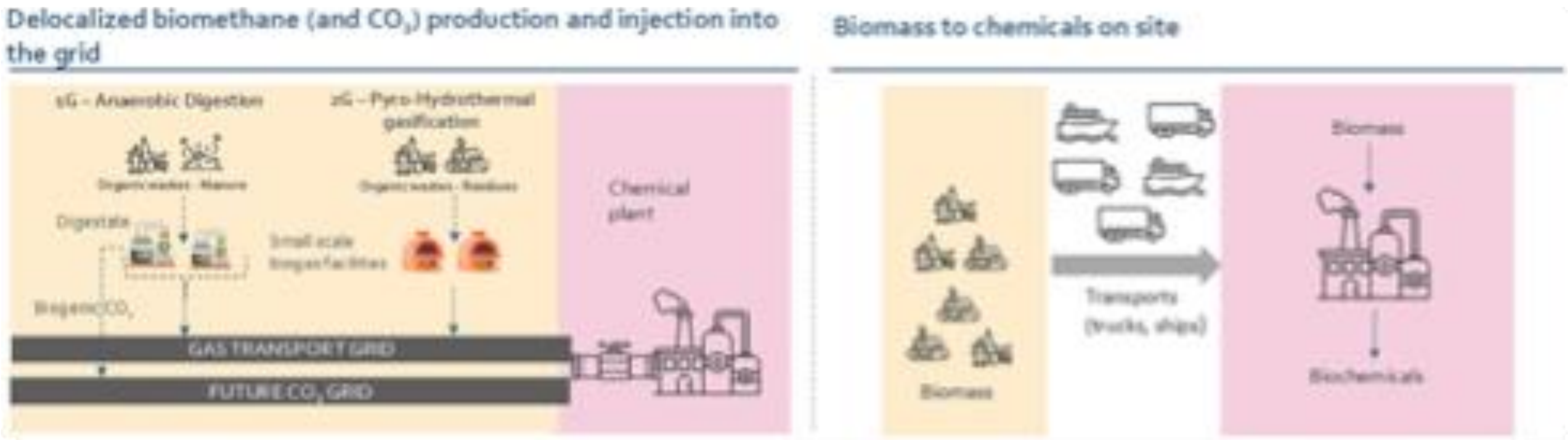

Figure 3. Comparison of two pathways for integrating biomass-derived carbon into the chemical industry: the left pathway illustrates de-centralized biomethane production via anaerobic digestion (1G) and/or pyro-hydrothermal gasification (2G), with subsequent injection into the gas grid and transport of biogenic CO_2 via a future CO_2 grid to chemical plants

The right pathway shows centralized biomass-to-chemicals conversion, where biomass is transported to chemical plants for on-site processing.

How Energy and Chemistry Converge for a Fossil-Free Future

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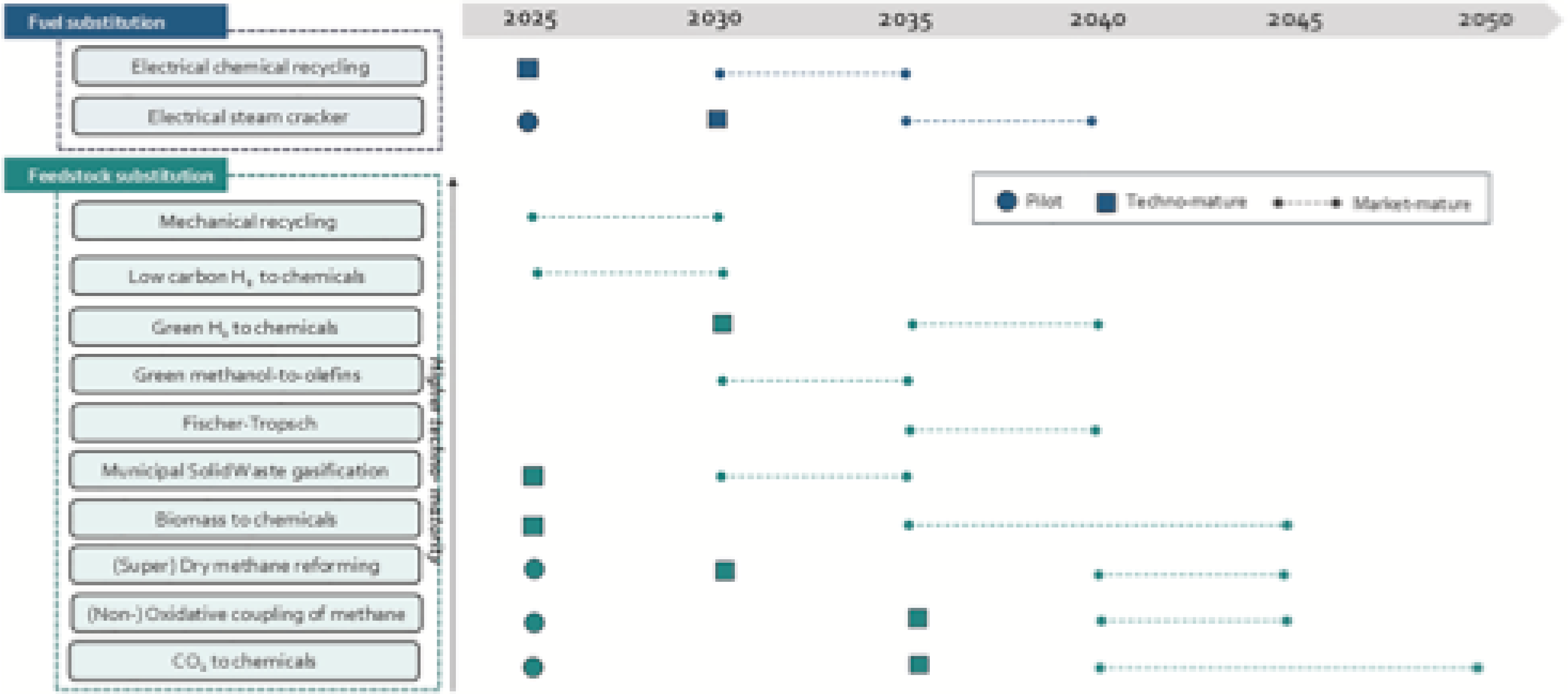

Figure 4. Projected development timeline and maturity levels of key technologies for fuel and feedstock substitution in the chemical industry, based on author's synthesis

Each technology is mapped across a timeline from 2025 to 2050, indicating stages of development from pilot (●), to technology mature (■), to market mature (dotted line).

iScience, 2025

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In this study, we explore how sustainable carbon feedstocks, i.e., sustainable biomass, recycled plastics, and CO_2, can be integrated into the chemical industry to replace oil and gas and how the energy industry can play a pivotal role in enabling this transformation.

iScience, 2025

We can summarize our findings into the following key recommendations for policymakers and industry.

- To what extent can electrification be a key lever to defossilise the chemical sector?
    - **Recommendations:** Electrify high-temperature processes for major chemicals (methanol, ammonia, and ethylene) where renewable electricity is abundantly available and grid capacity allows. Invest in grid upgrade and pilot projects to accelerate deployment. Where renewables are limited, look into the import of intermediates from energy-rich regions.
- What could be the role of hydrogen in the defossilisation of the chemical industry?
    - **Recommendations:** Deploy low-carbon hydrogen, prioritizing ammonia and methanol synthesis, and integrate with CO_2 utilization for platform chemicals. Build hydrogen infrastructure and foster cross-sector partnerships, starting with low-carbon hydrogen and transitioning to green hydrogen as renewables expand.
- What are the impacts of competition and opportunities for collaboration on sustainable carbon?
    - **Recommendations:** Invest in DAC for long-term carbon supply and integrate with renewable energy and hydrogen. Leverage existing infrastructure for biomethane and CO_2 transport and adapt supply chains to regional realities. Align energy and chemical sector policies and support commercialization of new technologies. Encourage adaptive, regionally tailored strategies to manage uncertainty and foster collaboration.

1. Carbon demand will persist even in a highly electrified world, so it must be actively planned for and managed.

2. Electrification and re-use are the most efficient tools for reducing carbon usage in the energy and materials sectors.

3. Circularity can play a significant role in reducing primary carbon demand but requires substantial policy interventions to achieve scale.

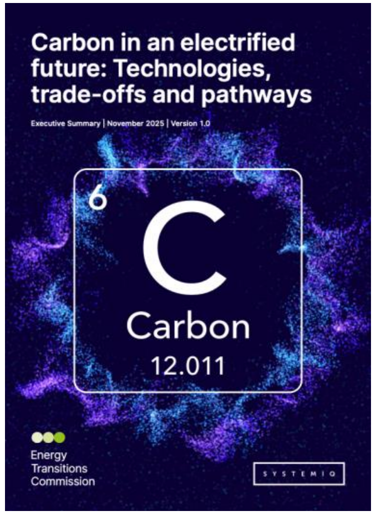
4. Linear end-of-life solutions are being advanced and will play a role in a pragmatic and timely transition, especially where circularity solutions are challenged, but should be carefully scaled to avoid giving license to inefficient sourcing and use of carbon.

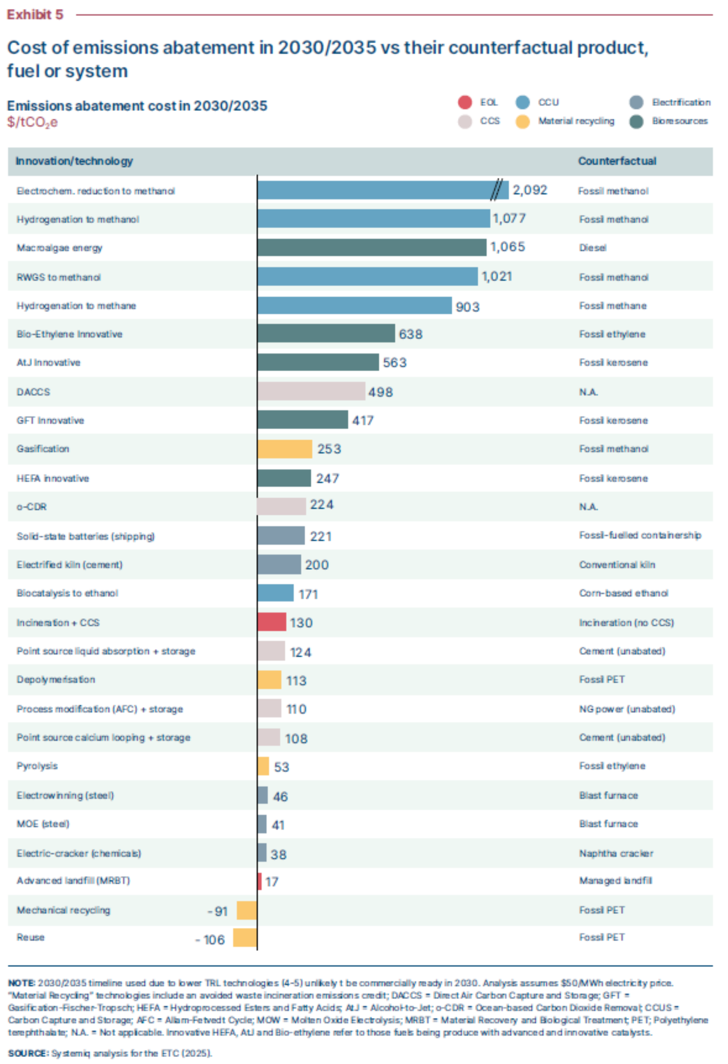
5. Sustainable primary biogenic carbon supply is constrained, and direct sourcing technology (DAC, CDR) is still emerging, while fossil is abundant. Although there is significant potential to scale sustainable sources of primary carbon, strategic usage of abated fossil and carbon removals will be necessary to deliver a timely transition.

6. While areas of the carbon system have commercially viable abatement solutions, several key gaps still exist in the carbon technology landscape. Further strengthening of the technology acceleration ecosystem is needed where promising technologies are still immature.

7. Flexibility in the solution mix is essential, given the trade-offs across the different technologies, meaning the "optimal" mix will vary significantly by geography, sector and time horizon.

8. For most carbon technologies, policy interventions will determine what scales first and how fast; carbon pricing is a critical lever but should be part of a broader policy architecture.





Pan-European Value Chains, Belmans & Glachant, Flagship Report, 2025

Five Constraints

Five “EU Energy Constraints”, that you can ignore only if you are not strongly interested into getting a significant EU energy transition:

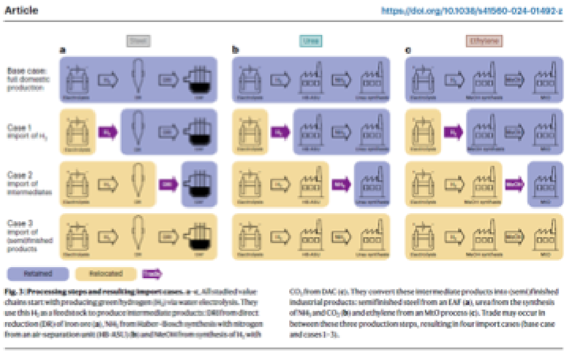
1. Electrification is equivalent to “energy efficiency first”: defossilising by reducing consumption. It is not a preference for electricity as such, only for its genuine efficiency performance.
2. But generating and delivering clean electricity requires a lot of investments, representing a gigantic economic effort, with pleasant surprises too.
3. Clean Electricity also implies to create a new integrated industry, with new supply chains upstream.
4. Clean electricity is absolutely unable to replace every other energy vector - it is why Clean Molecules are very welcome, wherever they fit.
5. Literally to end: Energy intensive industries too are very welcome. And, as they are mainly a transformation of large energy and material flows into other products, they are very welcome everywhere the EU and the EU countries can supply them.

Can we rethink the chemistry-energy nexus in a European industry landscape?

- Can EU rethink rationally, at different horizons [as: 2035 (+10) _ 2045 (+20) _ 2055 (+30]) the different industrial decisions regarding investment for upgrading, retrofitting, rebuilding, reshoring, re-locating, etc. etc. … A typical example: what could be gained from new CCS- CCU infrastructures, and from related public CfDs protecting their industrial users?
- Electrification is welcome mainly to decarbonize our energy demand for a given energy service by reducing the energy consumption. Therefore, everywhere electricity cannot enter and do the job, all clean molecules are very welcome as bio-molecules, E-molecule. The latter being based on so-called green hydrogen, i.e. hydrogen produced from water using green electricity.
- Clean Molecules have their own strong operational points. 1° Their operational readiness: the equipment to use them mostly is already in place, with existing supply chains, and proper users know how. 2° Their operational easiness: storability, dispatchability. 3° Their operational effectiveness: in specialized usages (as aviation, or long-distance shipping), or in chemical reactions to produce materials (plastics, fertilisers, medicines, steel, etc.).

Reconfiguring chemistry - energy value chains

Shipping of intermediates (e.g. ammonia, methanol and reduced iron ore) from ‘renewable rich’ areas to ‘renewable poor’ areas may be cheaper than shipping H_2



‘Conserving today’s production patterns by shipping hydrogen is substantially costlier, whereas trading intermediate products could save costs while keeping substantial value creation in renewable-scarce importing regions.’

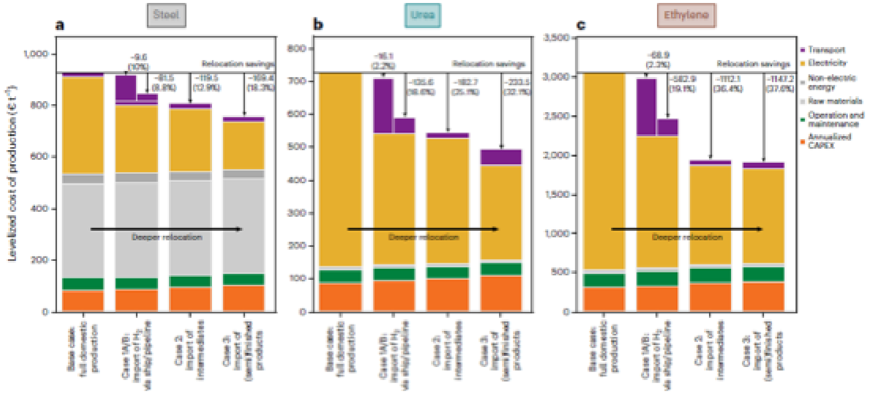


Fig. 5 | Levelized cost of production. **a–c**, Low-carbon production of steel (**a**), urea (**b**) and ethylene (**c**). Results are again shown for the four import cases illustrated in Fig. 3 and assume an electricity-price difference of €40 MWh^{-1} (medium-pull case from Table 1). The levelized costs visualize how the relocation savings in the steel value chain are smaller in comparison to the other value chains as a result of the high feedstock cost. Moreover, annualized CAPEX assumes a higher WACC of 8% in the RE-rich region compared to 5% in the RE-scarce region over a lifetime of 18 years, resulting in higher levelized capital cost, yet this effect appears to be small compared to the renewables pull. For a detailed composition, we encourage readers to view this figure in the online webapp or download the accompanying spreadsheet file (see ‘Data availability’).

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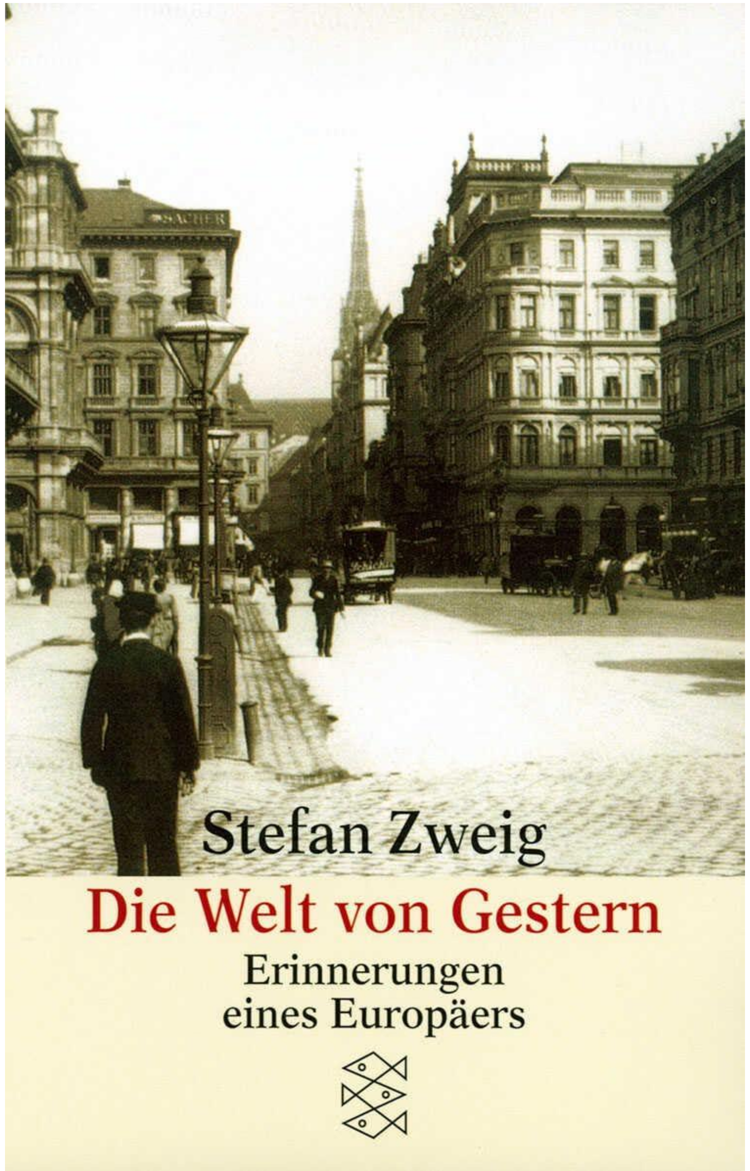
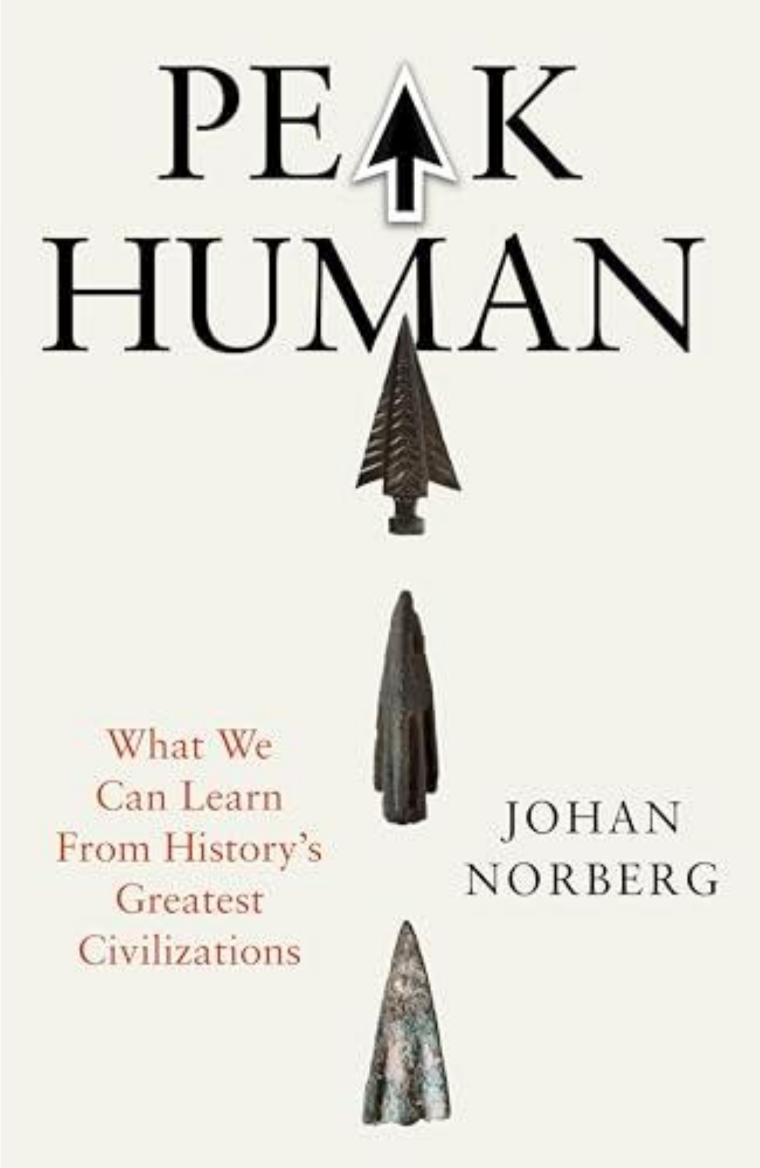
Verpoort , P.C., L. Gast , A. Hofmann and F. Ueckerdt, 2024. Impact of global heterogeneity of renewable energy supply on heavy industrial production and green value chains. *Nature Energy* , 9 ,491–503

Conclusion


Stefan Zweig
Die Welt von Gestern
Erinnerungen
eines Europäers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