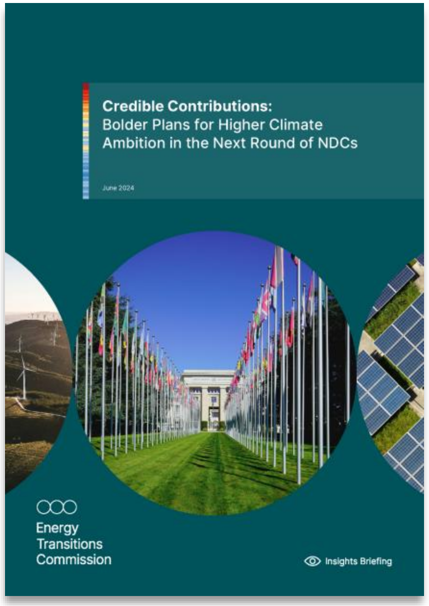
Energy
Transitions
Commission

The Role of Hydrogen & Bioenergy

ETC Webinar

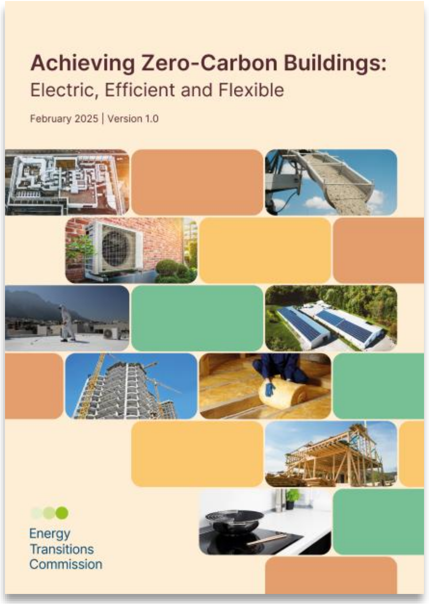
October 1st 2025

The ETC’s 2025 webinar series



February 13th

Credible Contributions: Bolder Plans for Higher Climate Ambition in the Next Round of NDCs



April 10th

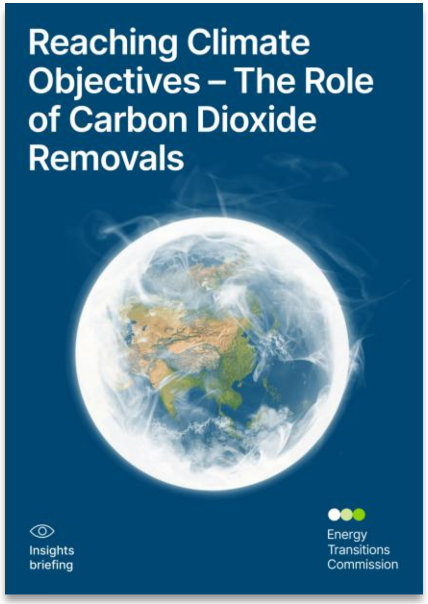
Achieving Zero-Carbon Buildings: Electric, Efficient and Flexible

July 15th

Insights across our “Barriers to clean electrification" series

October 1st

The Role of Hydrogen & Bio energy

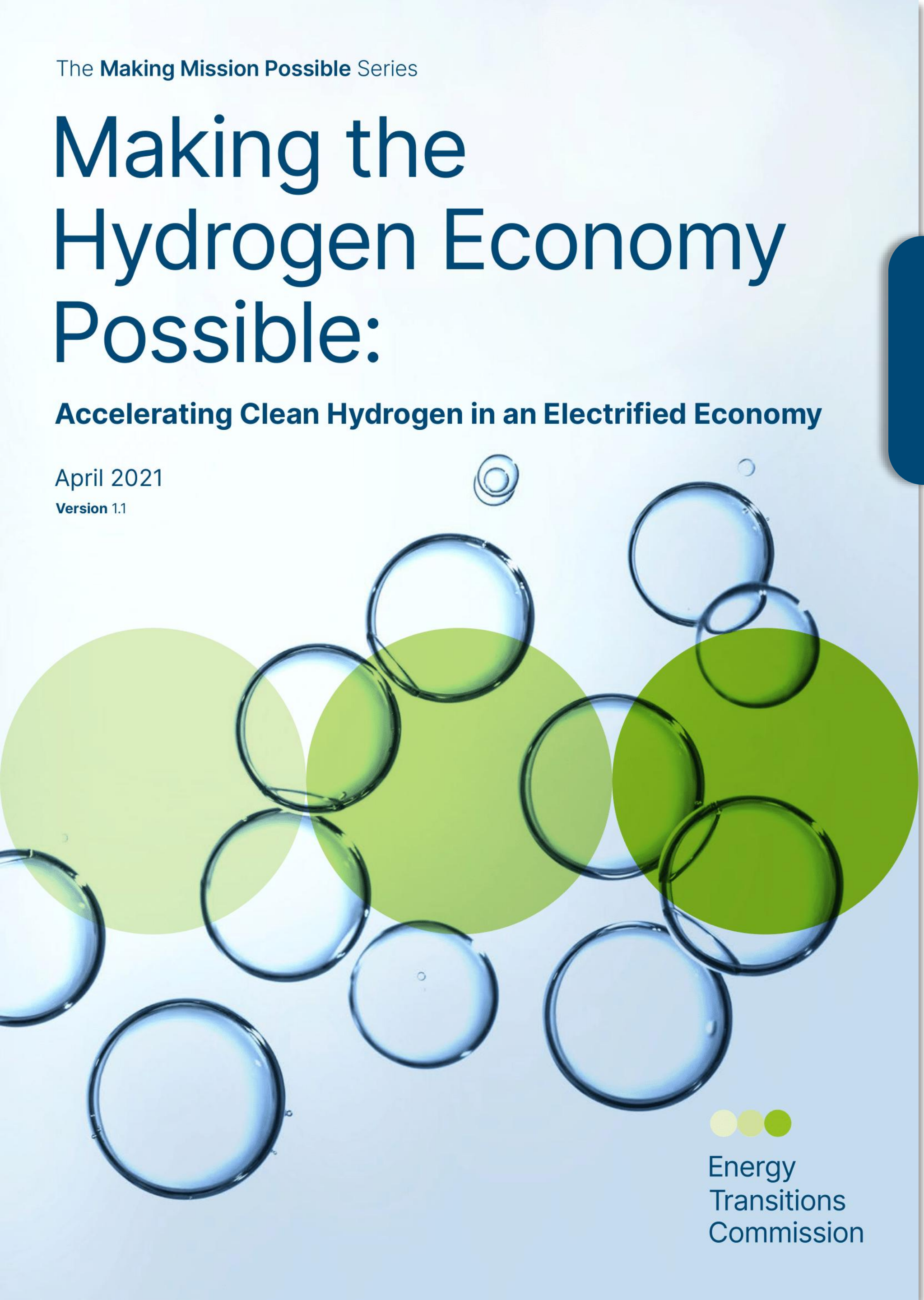


November 25th

Reaching Climate Objectives: the role of carbon dioxide removals

Agenda

- **Making the Hydrogen Economy Possible – key messages**
- Update on hydrogen outlook: costs, demand, and new innovations
- Bioresources within a Net-Zero Emissions Economy – key messages
- Update on bioenergy: considerations around maximum potential supply
- New view of final energy demand to meet net zero targets
- Q&A



Making the Hydrogen Economy Possible: Accelerating Clean Hydrogen in an Electrified Economy (2021)

Clean hydrogen will play a major role in decarbonising sectors that are difficult or impossible to electrify – with c. 500-800Mt of hydrogen used by 2050 vs. c.125Mt today

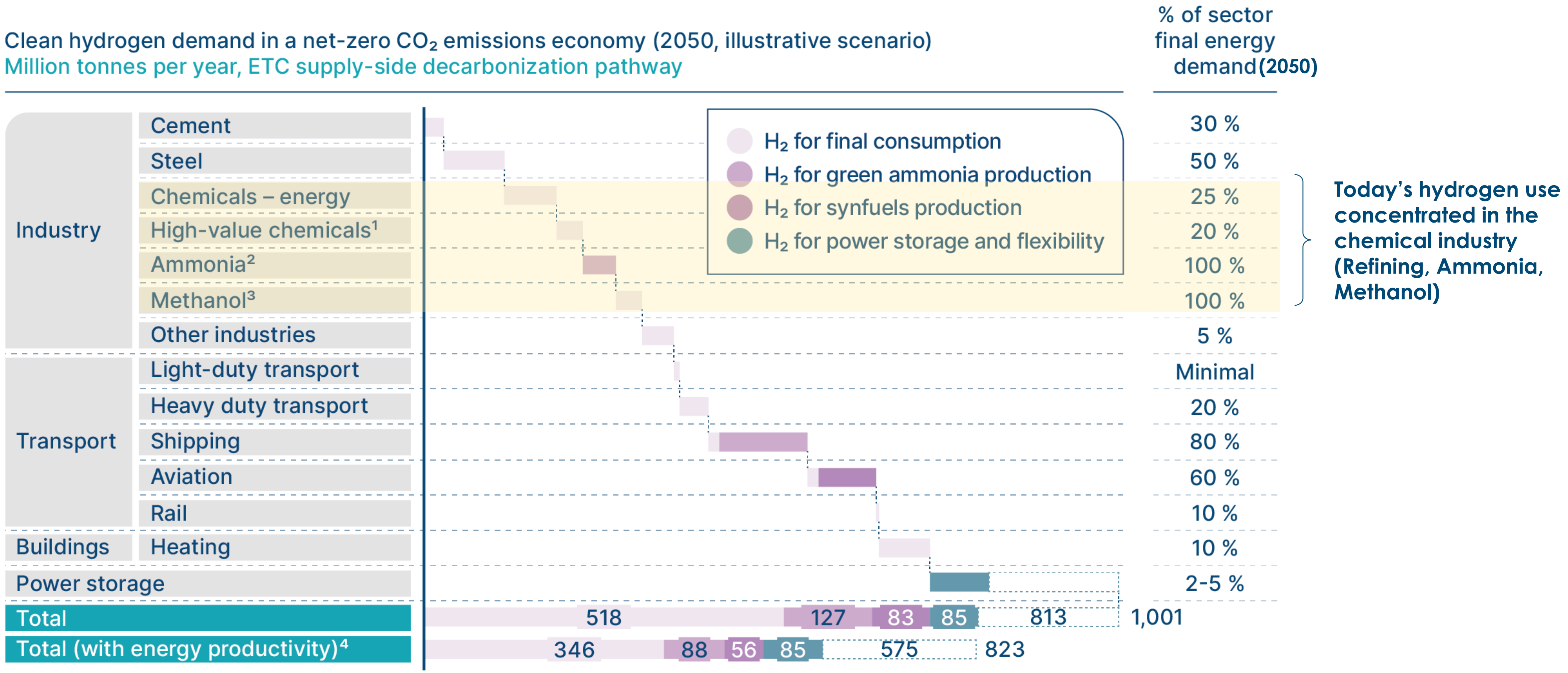
Key points:

- Hydrogen, the **second fuel after electricity.**
- **Critical role** in shipping, industry and last mile power decarbonization; limited role in buildings.
- **Most hydrogen can be green,** transitional role for blue.
- **Public policy** needs to focus on pulling forward clean hydrogen demand in the 2020s.
- The development of **hydrogen clusters** is critical during this first decade.

Impact:

- Helped define **global hydrogen objectives** for 2030 and 2050, and the **critical role of green H_2**
- Clarified the key **hydrogen using sectors in a net-zero economy**

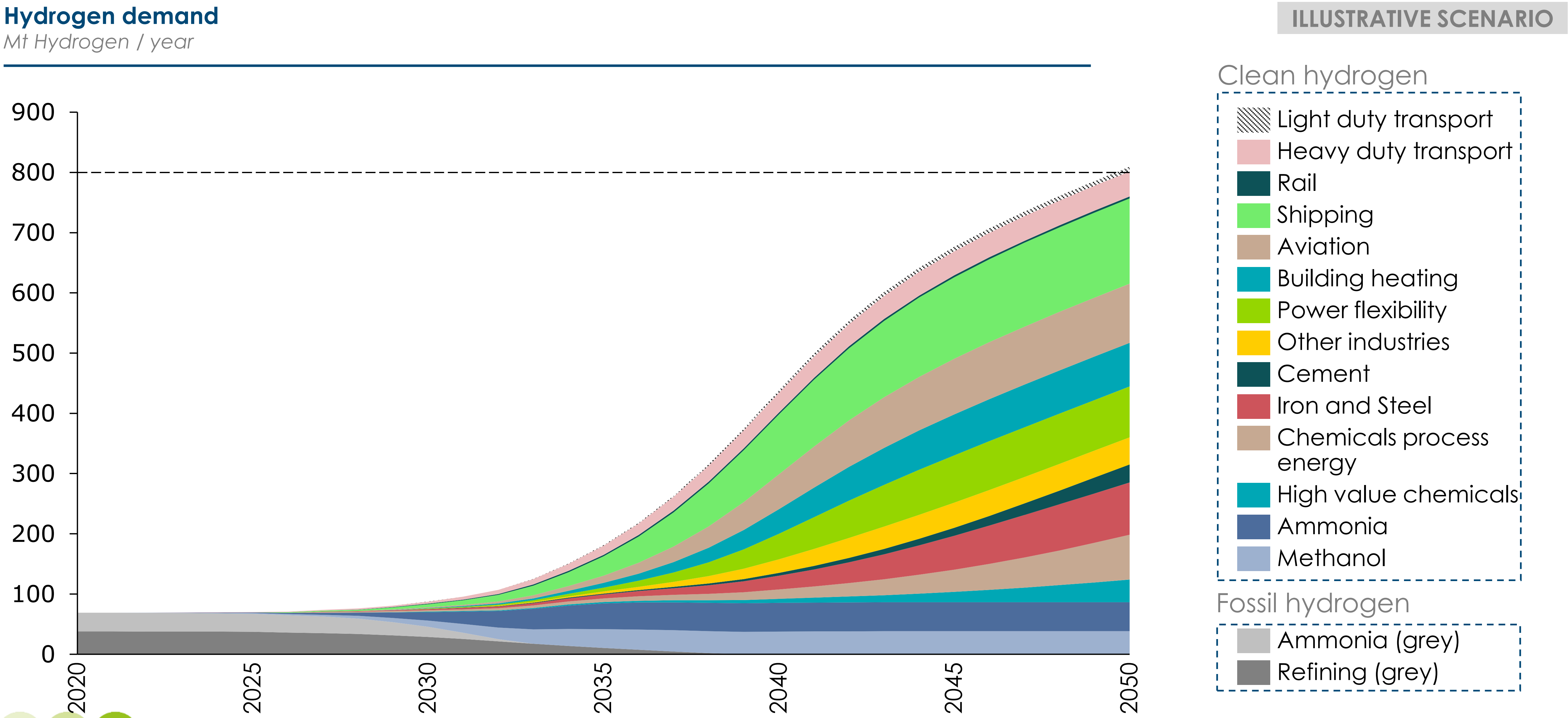
Clean hydrogen will play a growing role across the economy as the world transitions towards net-zero



NOTES: [1] High value chemicals predominantly used to produce plastics, which could potentially be produced via Hydrogen and CO_2 in the future (via methanol and MTO process); [2] Around 80% of ammonia (excl. shipping) is used to produce fertilisers; [3] Methanol is used as intermediate in numerous chemical processes, including plastics production. [4] ETC scenario including maximum energy productivity improvements.

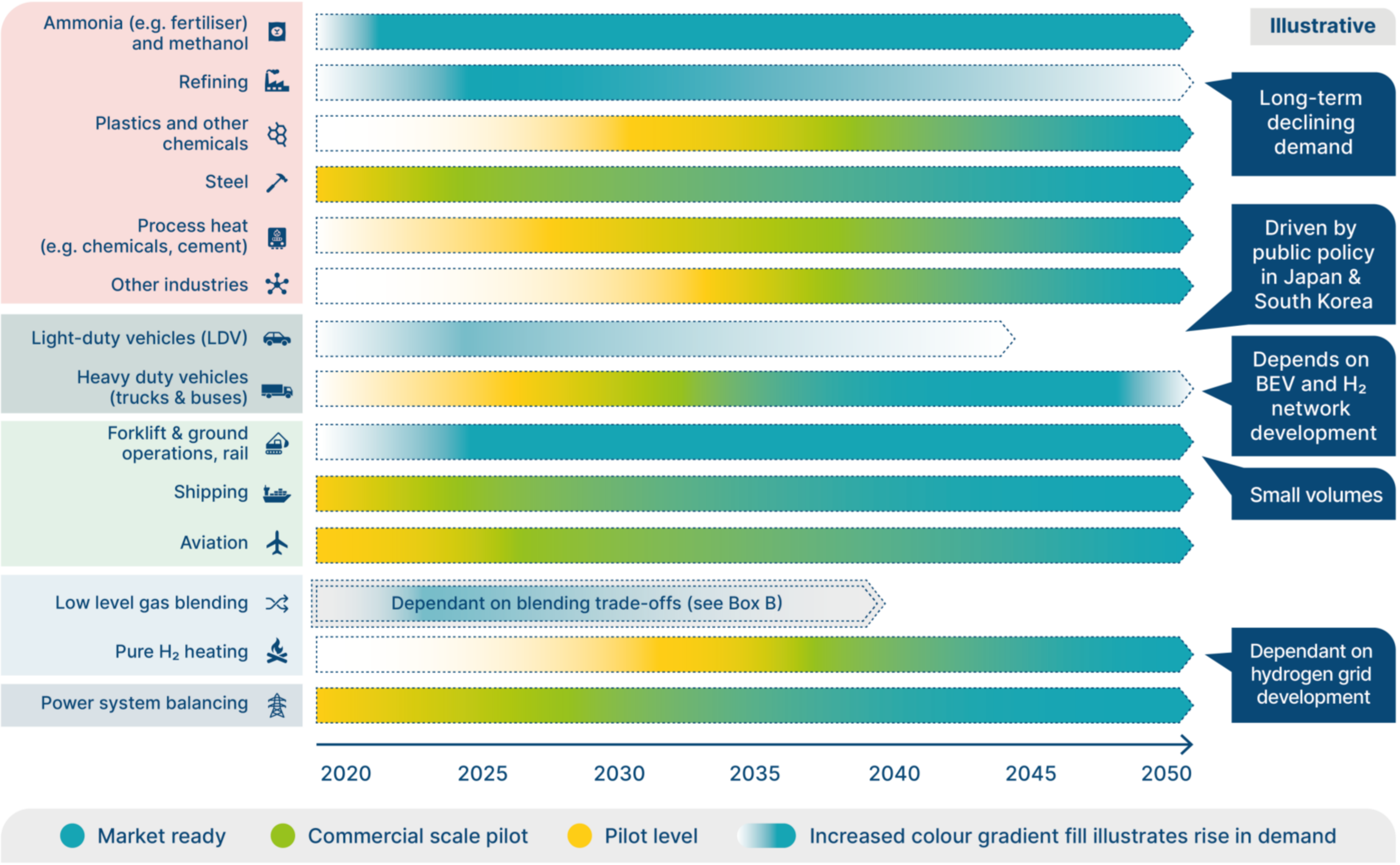
SOURCE: SYSTEMIQ analysis for the Energy Transitions Commission (2021)

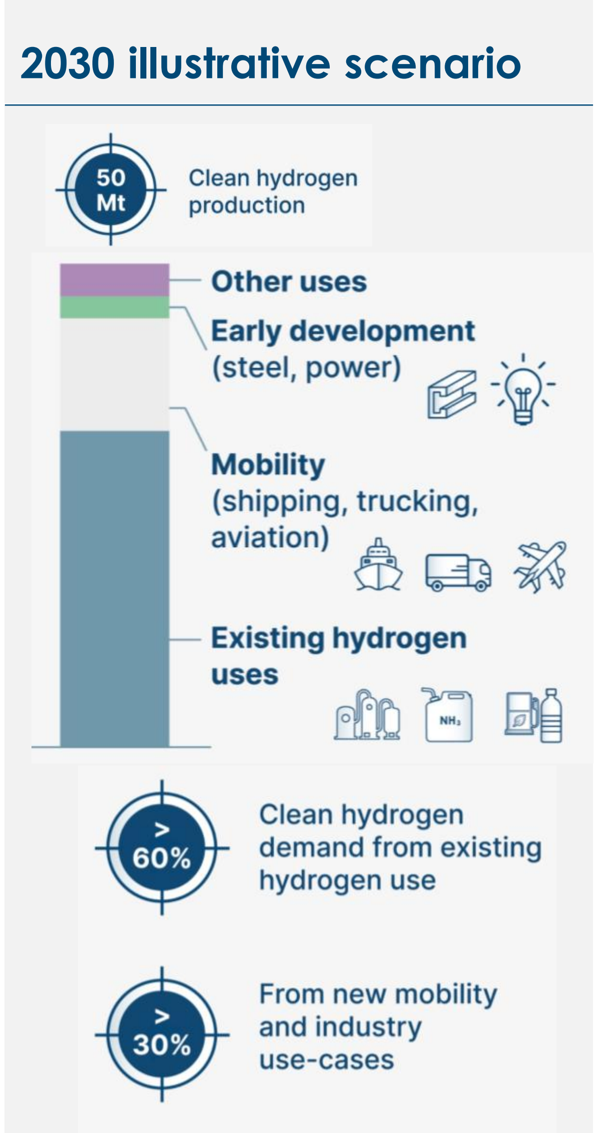
Potential scale-up of the hydrogen economy



Source: SYSTEMIQ analysis for Energy Transitions Commission (2021)

Pulling forward early demand to enable clean hydrogen scaling will follow sequencing of demand sector “take off” over next 3 decades

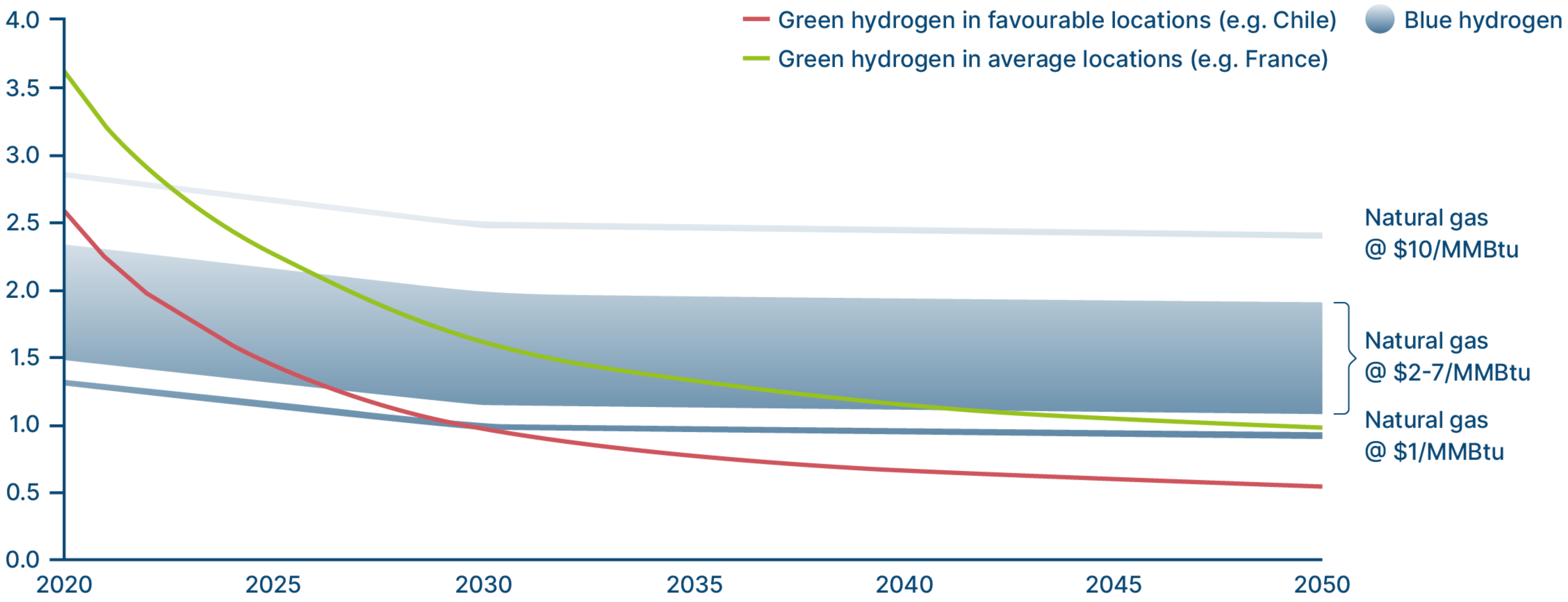




SOURCE: SYSTEMIQ analysis for the Energy Transitions Commission (2021)

Green hydrogen from electrolysis likely to become cheapest clean production route in the long-term; in favourable locations it could be competitive with blue in the 2020s

Cost of hydrogen production from different production routes (excluding transport & storage costs)
$/kg H_2

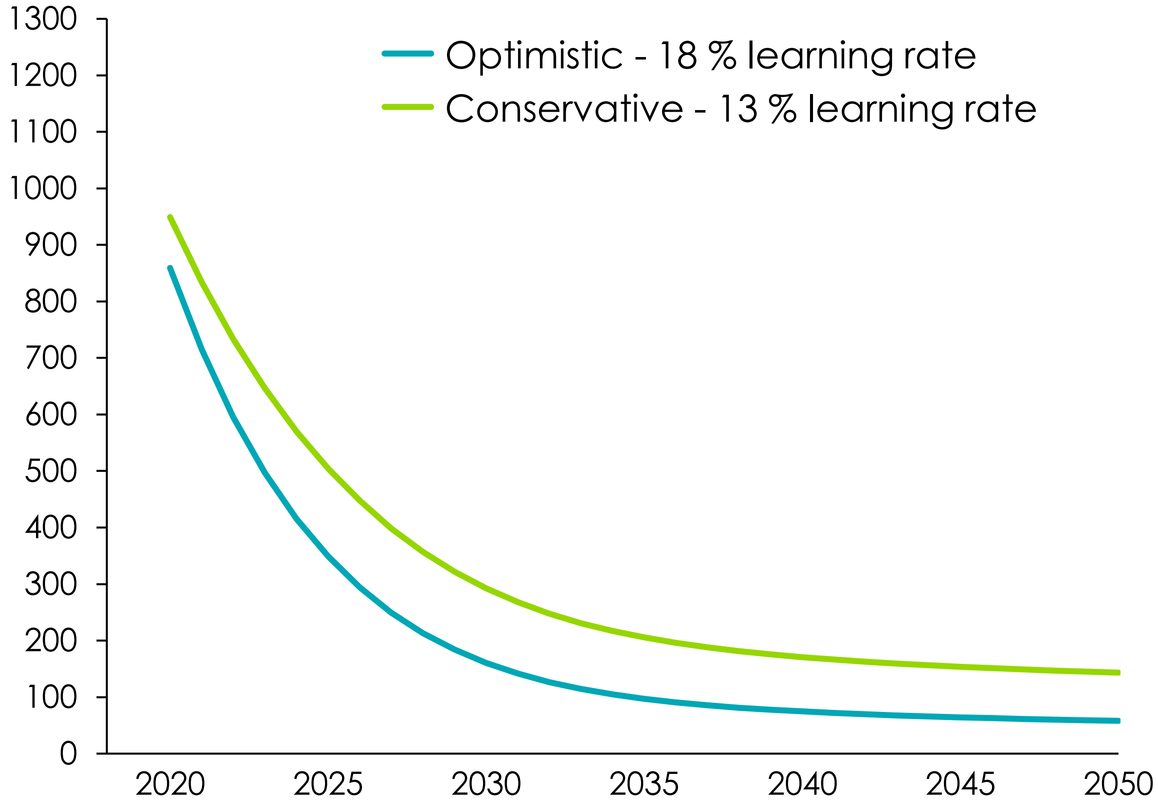


Notes: Blue hydrogen production: i) forecast based on SMR+CCS costs (90% capture rate) in 2020 transitioning to cheaper ATR+CCS technology in the 2020s; Green hydrogen production: i) favorable scenario assumes average LCOE of PV and onshore wind of lowest 33% locations (falling from $22/MWh in 2020 to $10/MWh in 2050) and average scenarios assumes median LCOE from lowest 75% locations (falling from $39/MWh in 2020 to $17/MWh in 2050) from BloombergNEF forecasts, ii) additional 20% (favorable) and 10% (average) LCOE savings included due to directly connecting dedicated renewables to electrolyser, iii) 18% learning rate for favorable & 13% for average scenario. Electrolyser capacity utilization factor: 45%. Comparison to BloombergNEF most favorable ($0.55/kg) and average ($0.86/kg) and Hydrogen Council favorable (ca. $0.85/kg) and average (ca. $1.45/kg) in 2050.
Source: BloombergNEF (2021), *Natural gas price database* (online, retrieved 01/2021), BloombergNEF (2020), *2H 2020 LCOE Data Viewer*; BloombergNEF (2021), *1H2021 Hydrogen Levelised Cost Update*; Hydrogen Council (2021), *Hydrogen Insights*

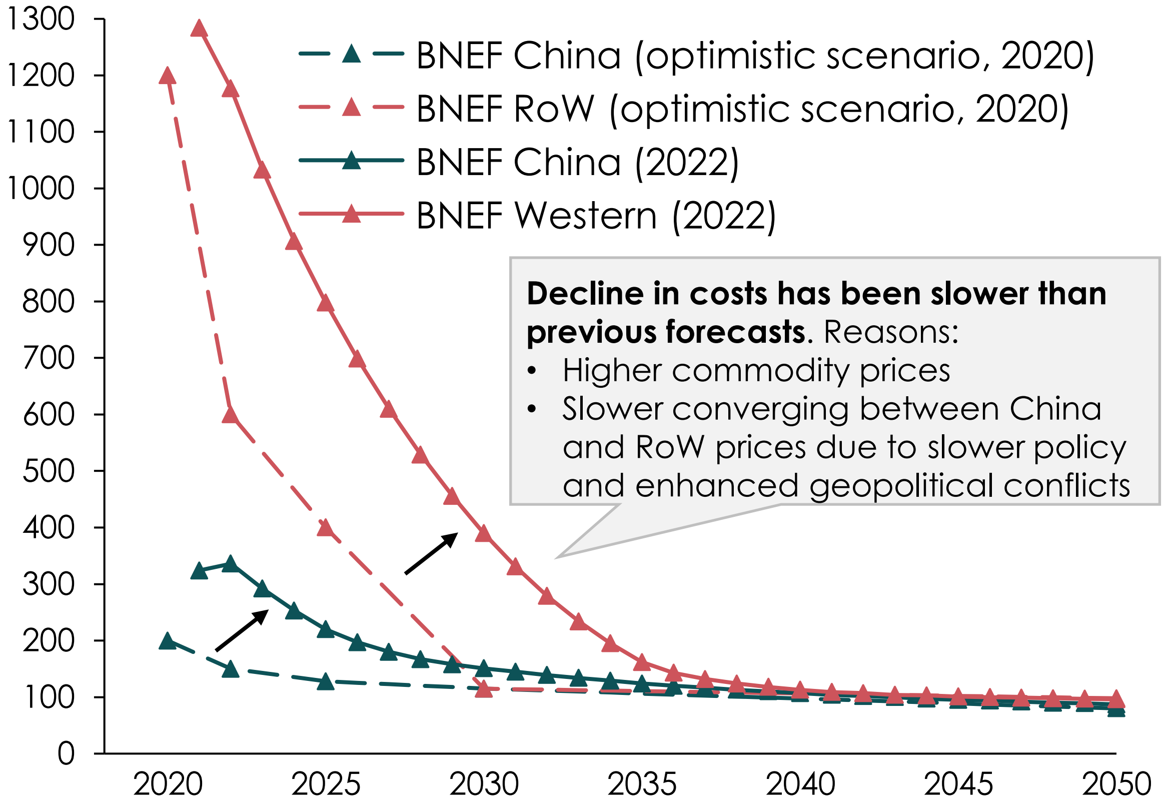
Cost declines in the near-term largely driven by falling costs of electrolysers

Fully installed system capex forecast of large alkaline electrolysis projects

US$ (2020)/kW



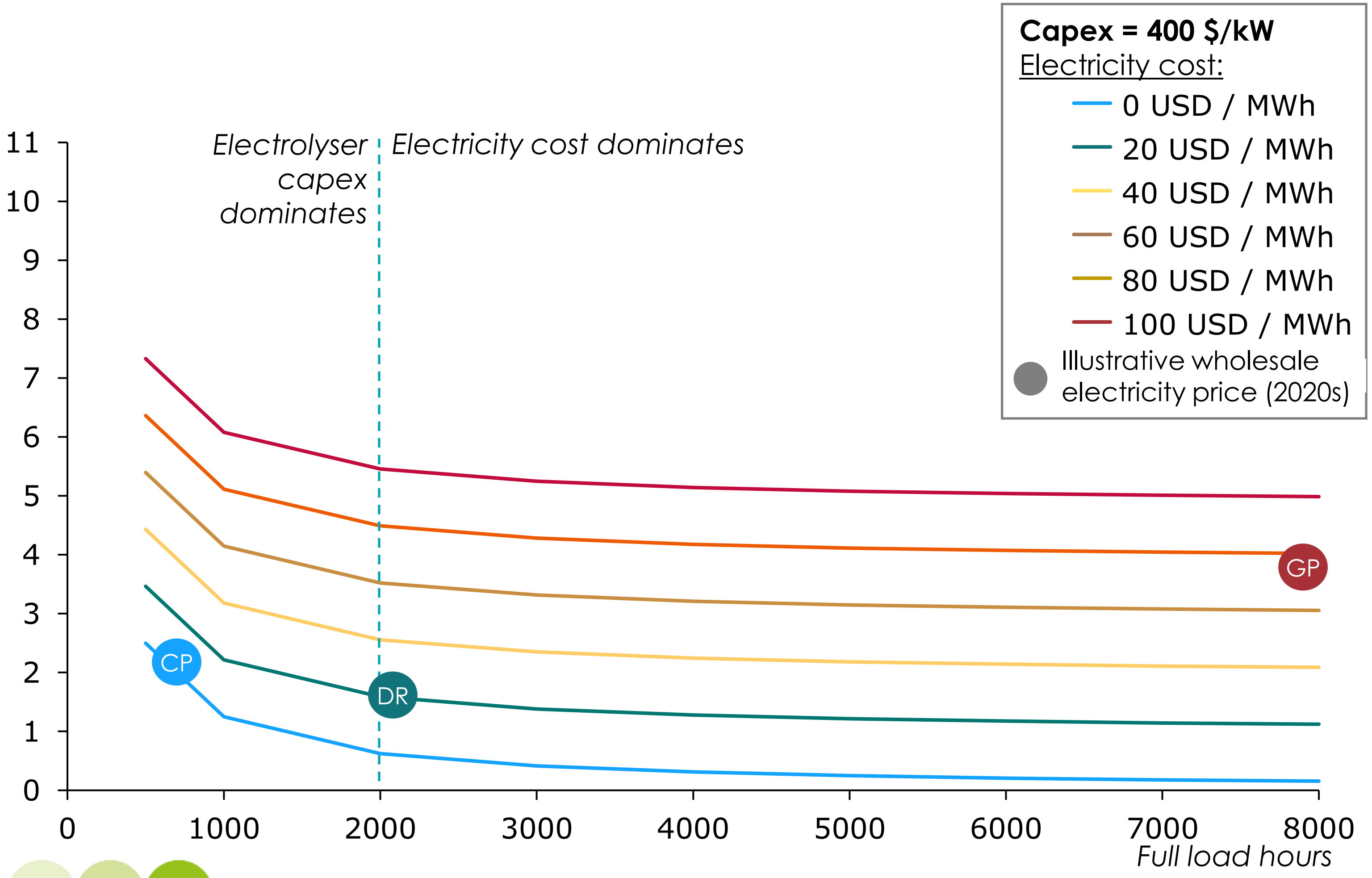
Electrolyser capacity (GW)	15	225	1300	3300	5500	7800



Above ca. 2000 hours annual electrolyser utilisation, electricity cost is key determinant of green hydrogen cost; dedicated renewables likely to be best source of zero-carbon power

Green hydrogen production costs

$/kg



Notes: Electricity consumption 48 kWh/kg, Electrolyser lifetime = 25 years, Discount rate = 8%

Source: SYSTEMIQ analysis for the Energy Transitions Commission (2020) based on IEA (2019), *The Future of Hydrogen*

Electricity sources for green hydrogen production – commentary

DR **Dedicated renewables**: **reasonable load hours (> 2k)** and **competitive electricity cost** (below $20/MWh in future), likely H_2 market price for will be set by H_2 price when produced with dedicate renewables

CP **Curtailed power volumes will develop if electrolyser CapEx declines considerably** (e.g., to $200/kW)

Increased variable renewables results in higher number of hours with cheap power (curtailment)

GP Given **higher average electricity price**, **grid power** would likely not be used

Load hour advantage (100%), but minimal costs benefits above ~2k hours

Note, in a renewables dominated power system (as discussed in the ETC's clean electrification report) **curtailed power** and **grid power** will start to overlap and merge, with electrolysers able to support grid balancing by **offering flexible demand** at times of over-supply

Transport, storage and international trade of hydrogen

Transport of hydrogen

- Many carrier forms (e.g., **gas, liquid, ammonia**) and technology options (**truck, pipeline, ship**)
- Most economic format depends on **volumes & distances**; **gas pipelines preferred** in most cases

Storage of hydrogen

- **Large scale geological storage** (e.g. salt caverns) cheapest but **uneven geographical distribution** and further development needed (esp. rock caverns and depleted oil & gas fields)
- **Rapid build out required** to support growing hydrogen economy

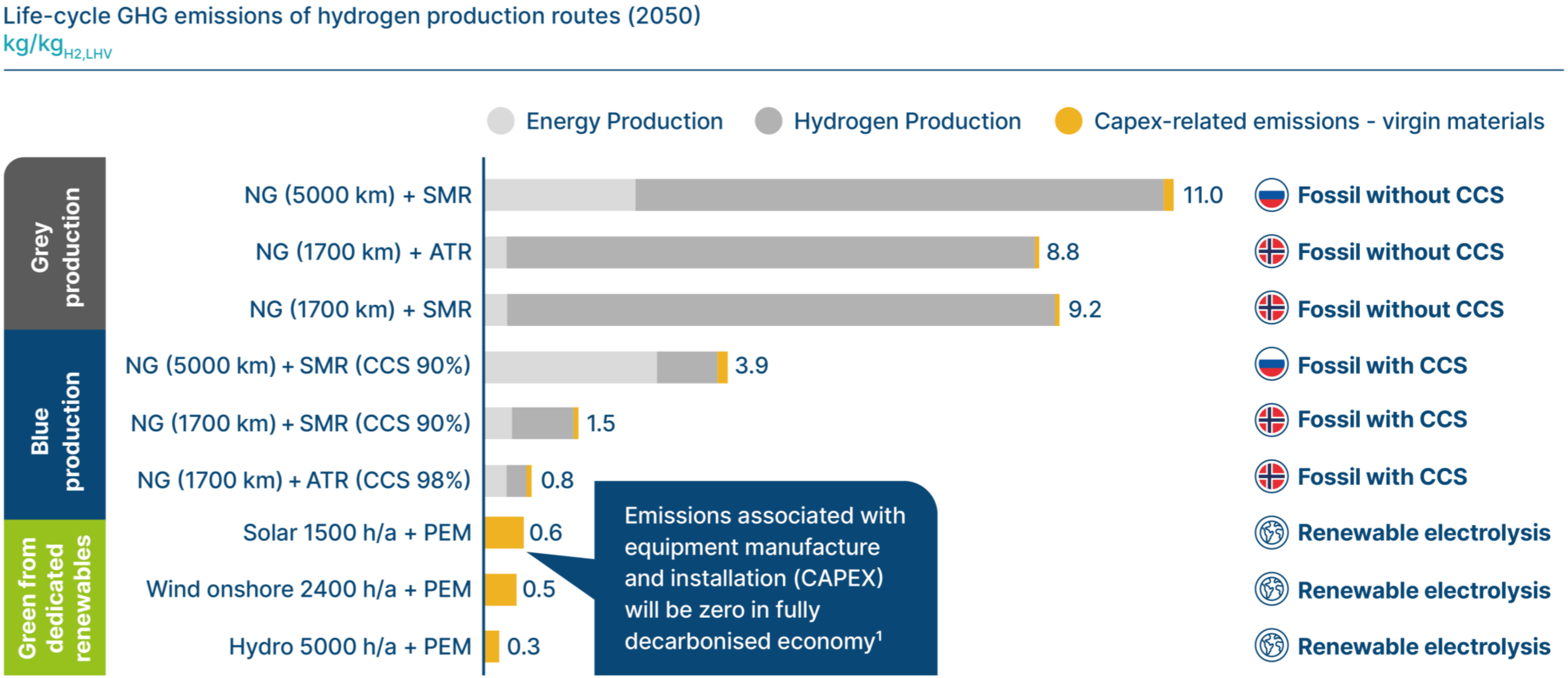
Alternatives to hydrogen transport

- **Moving electrons**: Over long distances (>1000km) transporting electrons via HVDC transmission lines may be competitive – partly dependant on location of geological hydrogen storage
- **Moving natural gas**: Where very cheap natural gas is available, transport via existing pipelines to areas with CCS infrastructure cheaper than transport of blue hydrogen

International trade of hydrogen / energy

- **Cost differential between production locations may drive trade of hydrogen**, but cost differential between low/high cost production regions decreases over time
- Domestic production in the long term likely to be approximately same cost as imported hydrogen
- International trade opportunities in long-term likely limited to:
  - **Cheap high-capacity pipeline** (4000t/day), especially retrofitted
  - **Ammonia transport via ship** with ammonia end-use
  - **Renewable resource constrained** countries
- In the long-term, **shift of production sites for energy intensive processes** also likely

<u>Beyond costs</u>, it is essential that 'clean' hydrogen is truly clean: For blue, upstream natural gas production, methane 'leakage', and capture rates drive bulk of emissions; green from dedicated renewables is near zero-carbon



NOTE: Energy production category includes upstream methane emissions; equals leakage rates of ca. 0.15-1.2 % based on natural gas source and transport distance; H_2 production refers to process emissions from SMR/ATR; [1] GHG emissions for CAPEX due to carbon emissions associated with grid electricity used to manufacture equipment.

SOURCE: Adapted with permission from Hydrogen Council and LBST(2021), *Hydrogen decarbonization pathways – A life-cycle assessment*

Policy and industry measures to cover the green premium are necessary to meet the national commitments

	Long-term, cross-sectoral policy	Key instruments in the 2020s			
	Carbon Pricing	**Mandates or product standards**	**Voluntary green premium**	**Public procurement**	**Contracts for difference**
Actor	Policy makers		Industry / Consumer	Policy makers	
Mechanism	Decrease fossil competitiveness	Create demand for green products			Cover cost differential
Main cost bearer	Diluted through all end-users	Green product end-user		Government budget	

Country targets & public support

- **Over 30 countries** released **hydrogen roadmaps**, with 13 full national hydrogen strategies
- **Concrete GW installation targets** (c. 2030) dominated by European players
- **International momentum growing** with many more national hydrogen strategies in development

European country green hydrogen commitments:

EU: 40 GW target by 2030 (6 GW in 2024), with national targets including:

- **Germany:** 5 GW by 2030
- **Poland:** 2 GW by 2030
- **France:** 6.5 GW by 2030
- **Italy:** 5 GW by 2030
- **Spain:** 4 GW by 2030
- **Portugal:** 2.1 GW by 2030

Chile: 25 GW target by 2030

Set in 2020

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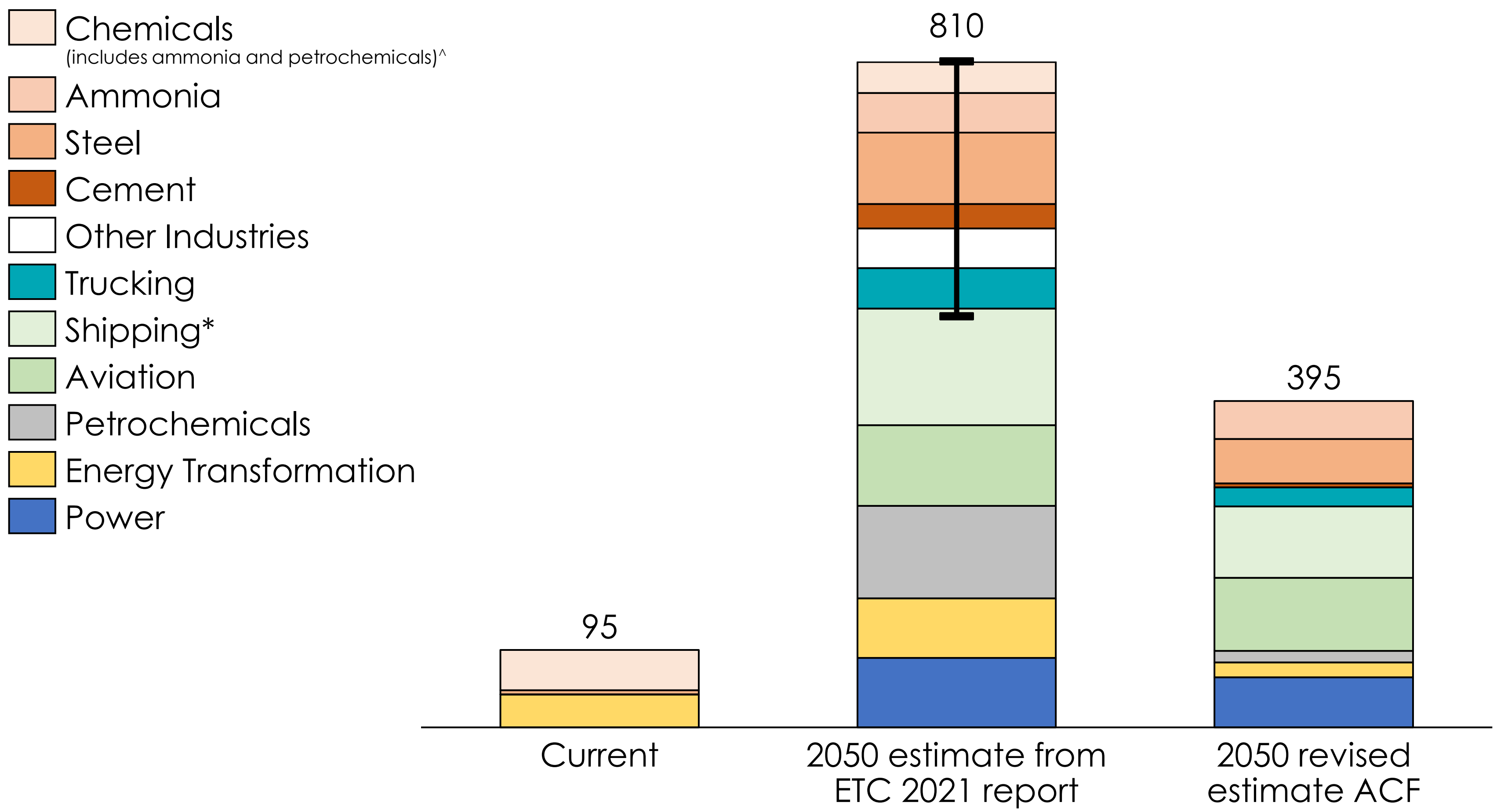
Downwards revision of hydrogen demand in 2050 by sector

Hydrogen (direct + indirect) demand by sector

Million tons of hydrogen (MtH_2) per annum



Fertilizer, ammonia for shipping, trucking and steel make up most of the direct use of **~150 Mt of H2** in final energy demand

Shipping in-part e-methanol within carbon-based molecules

For **aviation and petrochemicals**, a majority of H_2 use is within carbon-based molecules

Energy transformation and power H_2 use not in final energy demand

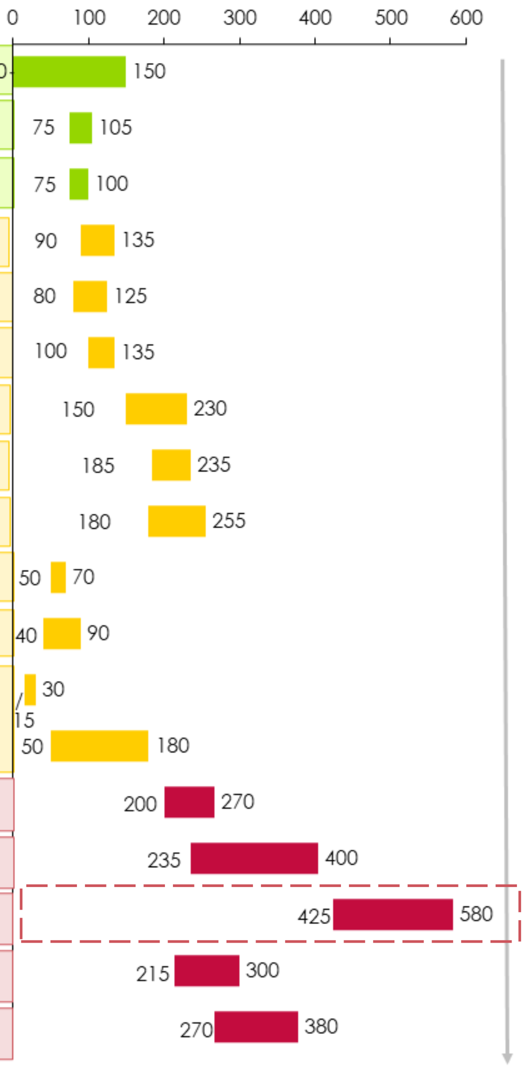
Note: ^Based on historical data that does not include split between chemical types. *ammonia does not include ammonia/hydrogen used in shipping, which is accounted for separately under 'Shipping', Energy transformation = energy consumed in processing raw fossil fuels into useable energy products, mostly to convert crude oil to refined oil products.
Source: Systemiq analysis for the ETC .

Recent ETC Power report highlights a limited role for hydrogen in power balancing, due to high conversion losses and storage costs

Electricity cost of $40/MWh (applies only to selected technologies)
$/MWh

Key zero-carbon balancing technologies across durations — **Cost of delivered electricity in 2035**

Duration	Technology		Low	High
Short / hourly duration (up to 8 hours)	Demand side flexibility		<0	150
	Lithium-ion batteries		75	105
	Sodium-ion batteries		75	100
Medium-long duration (8-50 hours)	Lithium-ion batteries		90	135
	Sodium-ion batteries		80	125
	CAES		100	135
	Pumped hydro		150	230
	Thermal storage (e.g. molten salt)		185	235
	Flow batteries		180	255
	Long-distance transmission (for balancing)		50	70
	Running nuclear flexibly	Existing:	40	90
	Running hydro flexibly	Existing:	15	30
		New build:	50	180
Ultra-long (50 hours+)	CCS on CCGT (10% utilisation)		200	270
	CCS on OCGT (5% utilisation)		235	400
	H_2 OCGT (5% utilisation)		425	580
	Unabated gas (5% utilisation) with $50/t CO_2 removal		215	300
	Unabated gas (5% utilisation) with $200/t CO_2 removal		270	380



Role of hydrogen in balancing limited by **high-cost** compared to other technologies

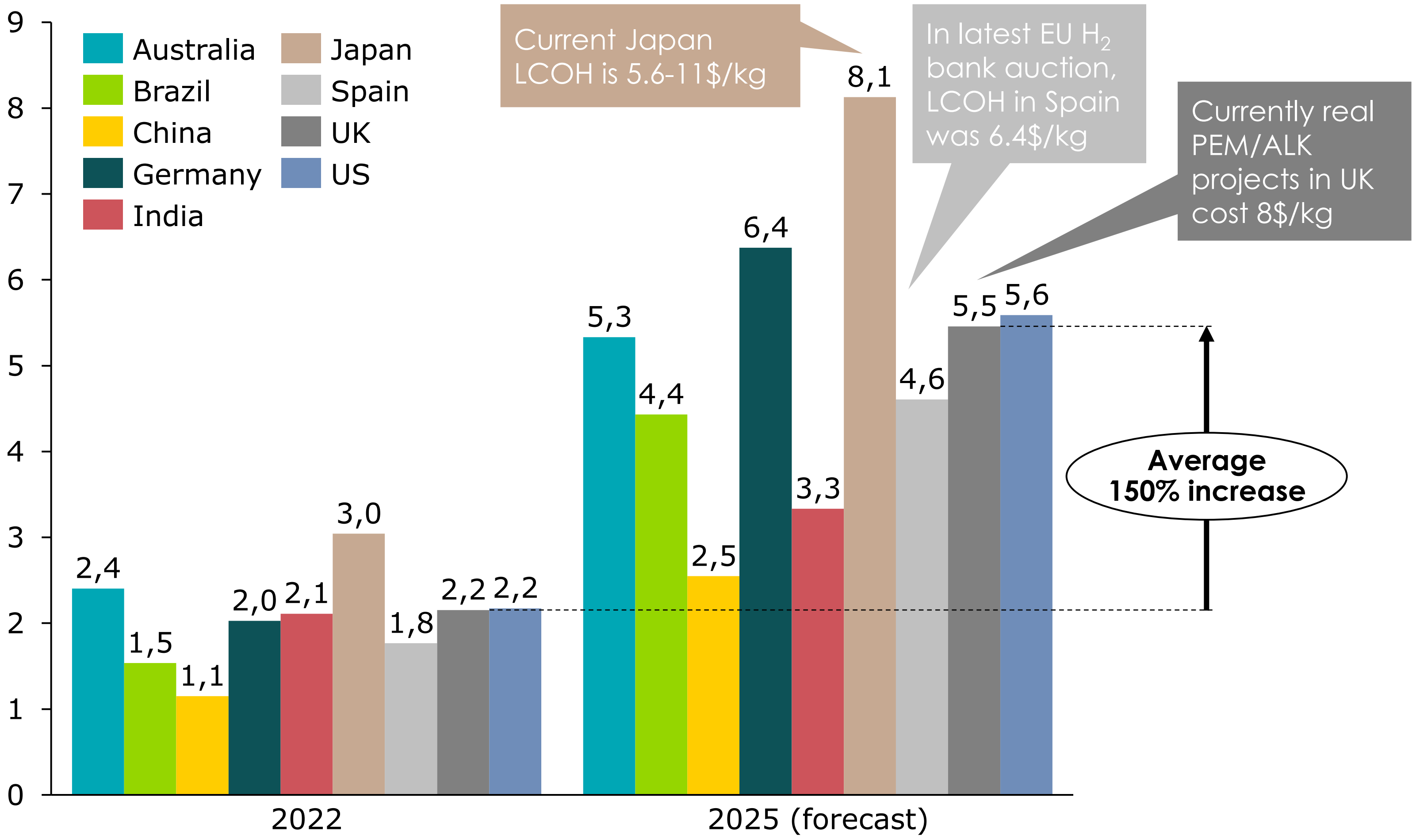
High costs stem from low utilisation rates of the assets at this duration, in addition to high capital costs

However, locating electrolysers within industrial clusters, where co-located offtakers and shared hydrogen infrastructure, can enable higher load factors and reduce costs

Hydrogen enters a reality check: slower momentum but tangible progress, led by China's $2.5/kg 2030 projections

Levelised cost of Hydrogen from renewable electricity BNEF revised projections for 2030

$/kg H_2



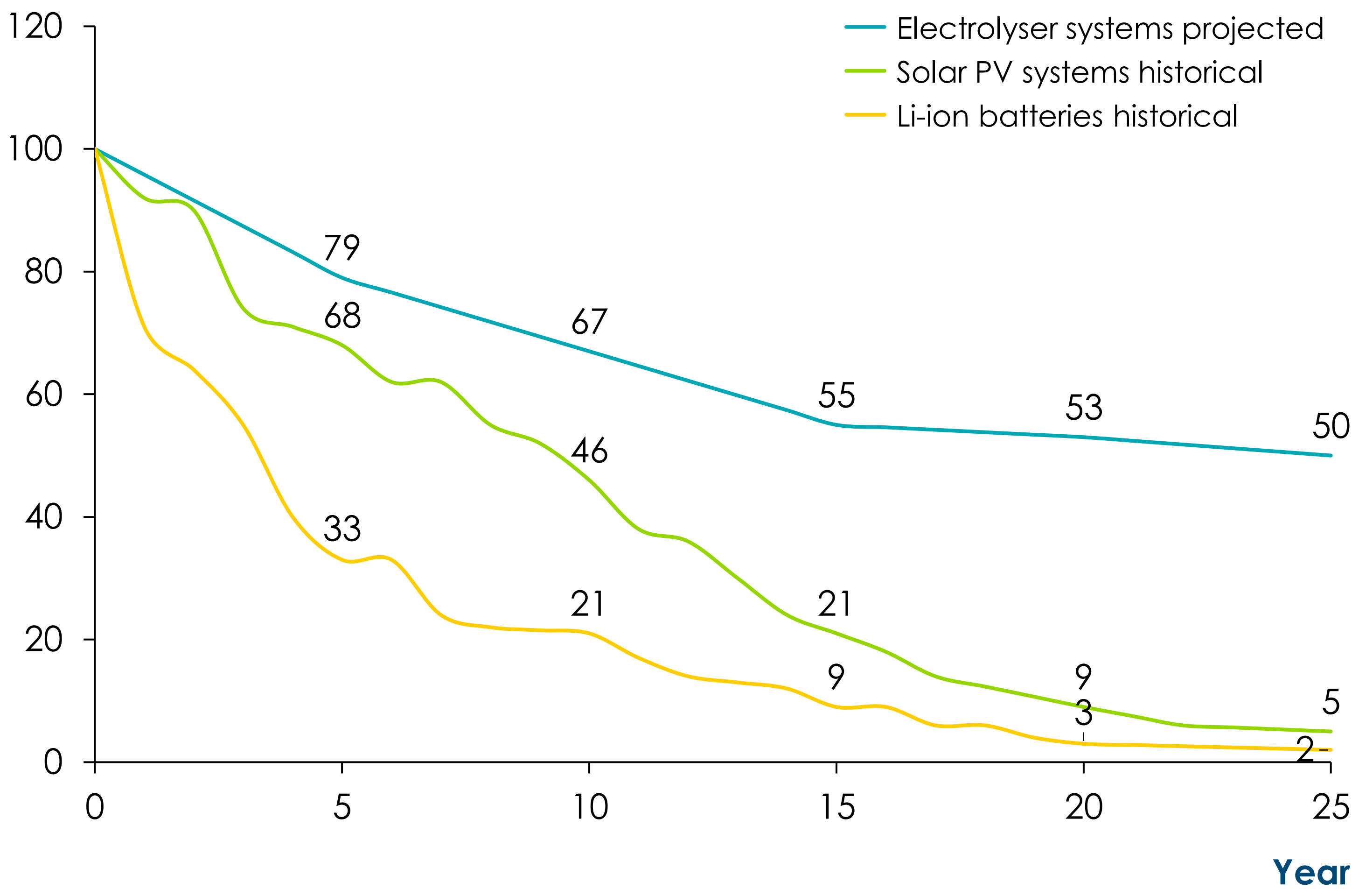
- **China and India are setting the pace** with large-scale projects and production costs falling to $2.5/kg and $3.3/kg respectively, without subsidies.
- **The EU continues to invest heavily** (with EIB support), aiming to build a hydrogen economy even as costs remain above global targets. Current EU renewable H_2 costs range is 5-12 €/kg in auctions.

Sources: BNEF (December 2024) Hydrogen Levelized Cost Outlook 2025; Clifford Chance (March 2025) Focus on Hydrogen State of the market 2025; International PtX Hub: Key takeaways from the first EU Hydrogen Bank auction; IF24 Auction; The Platts Hydrogen Wall

Electrolyser cost reductions are plateauing, threatening the scalability of green hydrogen

Learning rates

Index = 100



Electrolyser CAPEX down ~15% by 2040, which is too slow for cost competitive green hydrogen. Unlike solar PV or Li-ion, **no steep learning curve is expected**.

Structural cost barriers limit future reductions

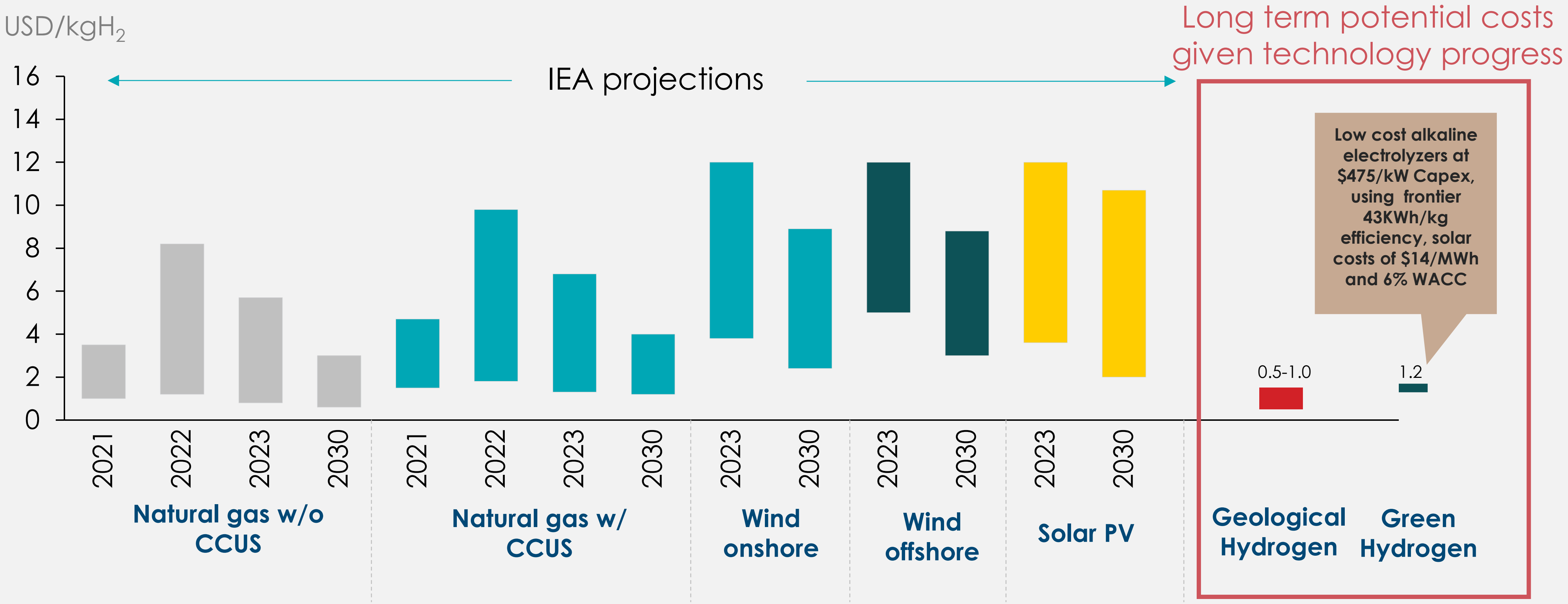
- Only 1/3 of the cost can Improve Fast
- Remaining 2/3 (Balance of Plant) includes mature components (e.g., compressors, tanks, purifiers) which are widely used, and show flat learning curves.
- Even 1 GW electrolyser projects show only modest CAPEX reduction, while most projects are still in the sub-200MW scale.

Sources: Visa Siekkinen (June 2025) Learning rates: The implications of slow decline in electrolyser system cost projections ; Hydrogen Council & McKinsey (2023) The state of the global hydrogen economy, with a deep dive into a renewable hydrogen cost evolution

Potential hydrogen costs in 2030 and over the long term

Hydrogen costs[1], $ per kg 2023

Hydrogen production cost by pathway, 2023, and in the Net Zero Emissions by 2050 Scenario, 2030

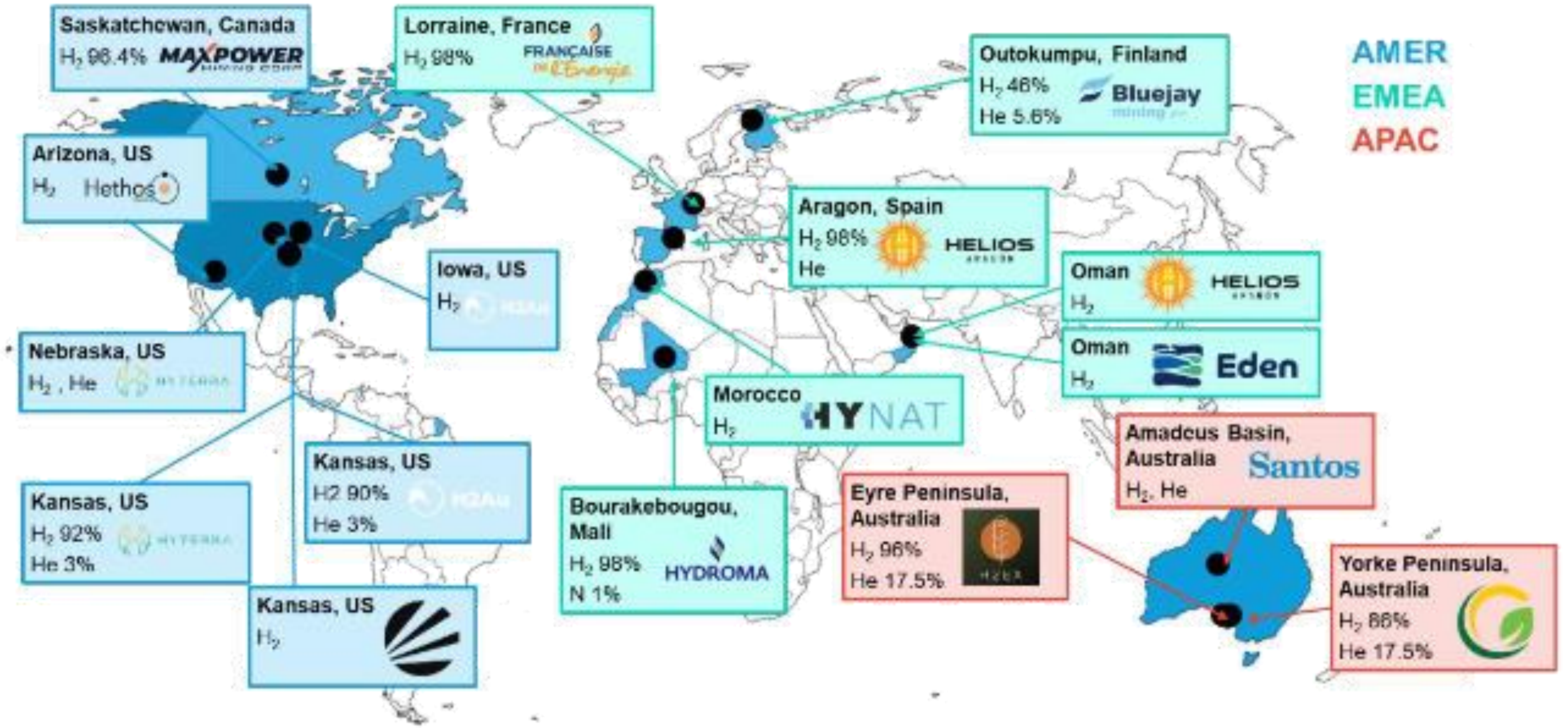


Note: 1. There is limited evidence of the breakdown of current levelized costs and how existing projects will achieve this cost reduction for geological hydrogen. Dashed area represents the CO_2 price impact, based on USD 15-140 t/CO_2 for the NZE Scenario. Source: Hydrogen insight (2024) A new gold rush | There are now 40 companies searching for natural hydrogen deposits — up from ten in 2020. IEA (2024) Global Hydrogen review 2024

Geological Hydrogen is still in early stages of exploration

Helium co-product can help project economics

Geological hydrogen and helium: Projects and exploration activity



Source: Bloomberg NEF (2023) *Tech Radar: Geologic Hydrogen*

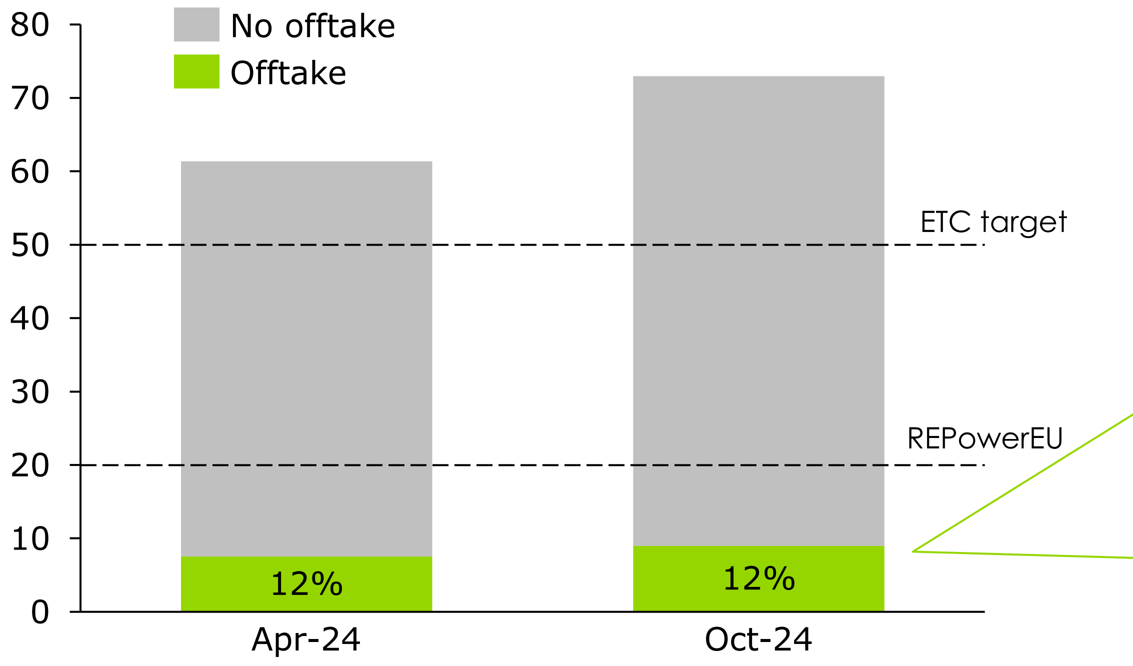
MARKET POTENTIAL

- **17** exploration projects ongoing for geological H_2
- **\$0.5-\$2.4** kg/H_2 targeted costs, with commercial production unlikely until 2030
- Exploration undertaken by **pure-play explorers** (e.g. Helios, Gold Hydrogen) and **existing oil, gas and mining companies** (e.g. Santos, Engie, EcoPetrol)
- Only **one geological H_2** resource has been developed to date – in Mali 2012
  - 50 t/H_2 per year
  - Combusted to power a nearby village

Only 12% of planned H_2 production capacity for 2030 has identified offtakers, with 15% binding contracts

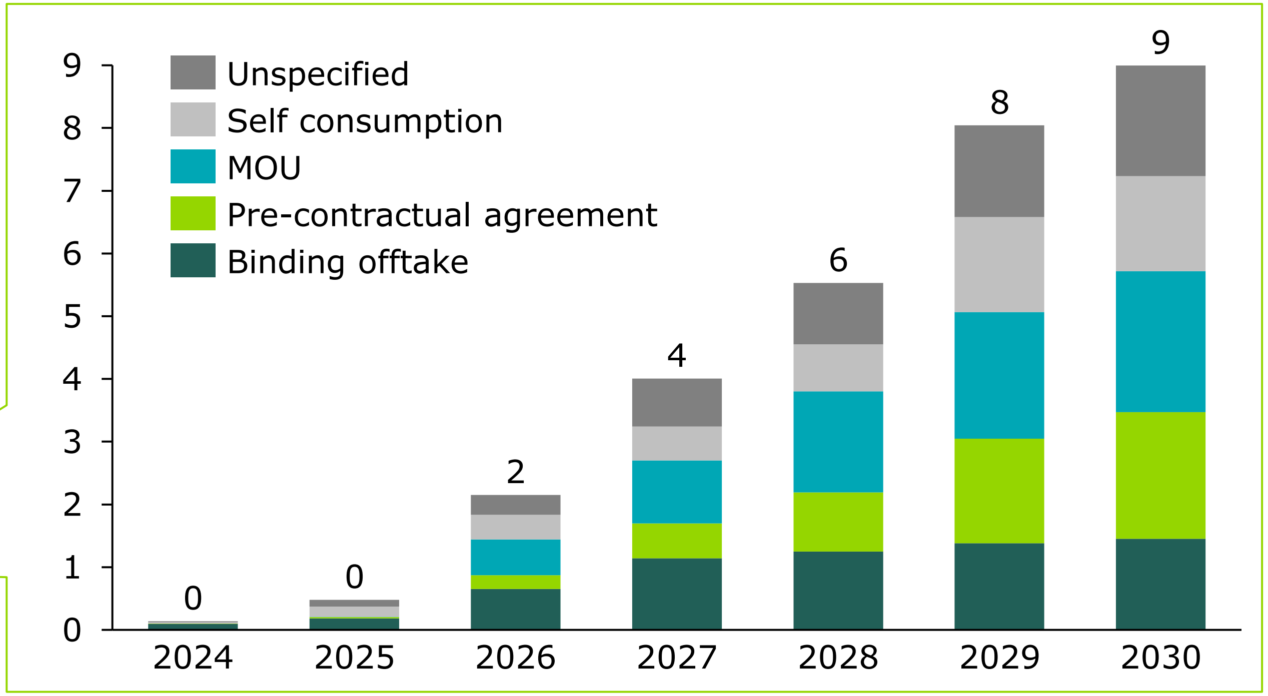
Announced clean hydrogen production and share of offtake by 2030

Million metric tons H_2 per year



Clean hydrogen offtake though 2030 by agreement type

Million metric tons H_2 per year



- China is outpacing the EU, accounting for **65% of newly added operational clean hydrogen capacity, in 2024**.
- **EU is likely to achieve only about 3 Mt/year** of clean hydrogen production by 2030, falling far short of the 10 Mt/year target.

Notes: 'MEA' refers to Middle East and Africa. 'APAC' refers to Asia-Pacific.
Sources: BloombergNEF's Clean Hydrogen Production Assets Database; BNEF Hydrogen Demand: 2H 2024 Update; Clean Hydrogen monitor 2024; BNEF (Jun 2025) China adds green hydrogen while west waits for subsidies

Summary of trends influencing globally traded sectors' 2030/35 transition pathways

	Carbon pricing	Maritime sector policy	Aviation sector policy
	EU CBAM	**IMO Carbon Levy (2027+)**	**ICAO CORSIA & SAF Mandates**
Key policies	• EU launching full implementation of CBAM in 2026 and phasing out free ETS allowances • Prices increasing in China's ETS	• Levy (~$100-380/t) to start in 2028	• Regions adopting regulation to drive SAF uptake, e.g. mandates in EU and UK
Current situation; implications	• Increased policy stringency should strengthen incentives for heavy industry decarbonisation • New cost pressures from domestic carbon pricing and border adjustments may lead to shifts in supply chains	• Levies send signal to accelerate ammonia/methanol adoption and bunker readiness • However, BNEF estimate that a carbon price of > €400/t would be required to incentivize a significant shift, so uncertainty remains	• SAF share of global jet fuel in 2024 was 0.3%, expected to double to 0.6% in 2025 • Currently, production overcapacity as stronger demand guarantees needed to scale to 2030 targets

Industry diversification: Over half of new projects now in EMDEs, driven by cheap renewables and national incentives.

Industrial players likely to diversify, including pivoting to emerging markets (e.g. India, Brazil, Namibia) and adapt to a more distributed deployment landscape.

Source: MPP November 2024 Update; Carbon Border Adjustment Mechanism (March 2025); Carbon Offsetting and Reduction Scheme for International Aviation (CORSIA); Elisabetta Cornago et al. (2024) Learning from CBAM's transitional phase; BCG (September 2023) The Start of CBAM: A Major Landmark for Global Trade and Carbon Accounting, BNEF (2025), 2025 Sustainable Aviation Fuel Outlook: Reaching New Highs

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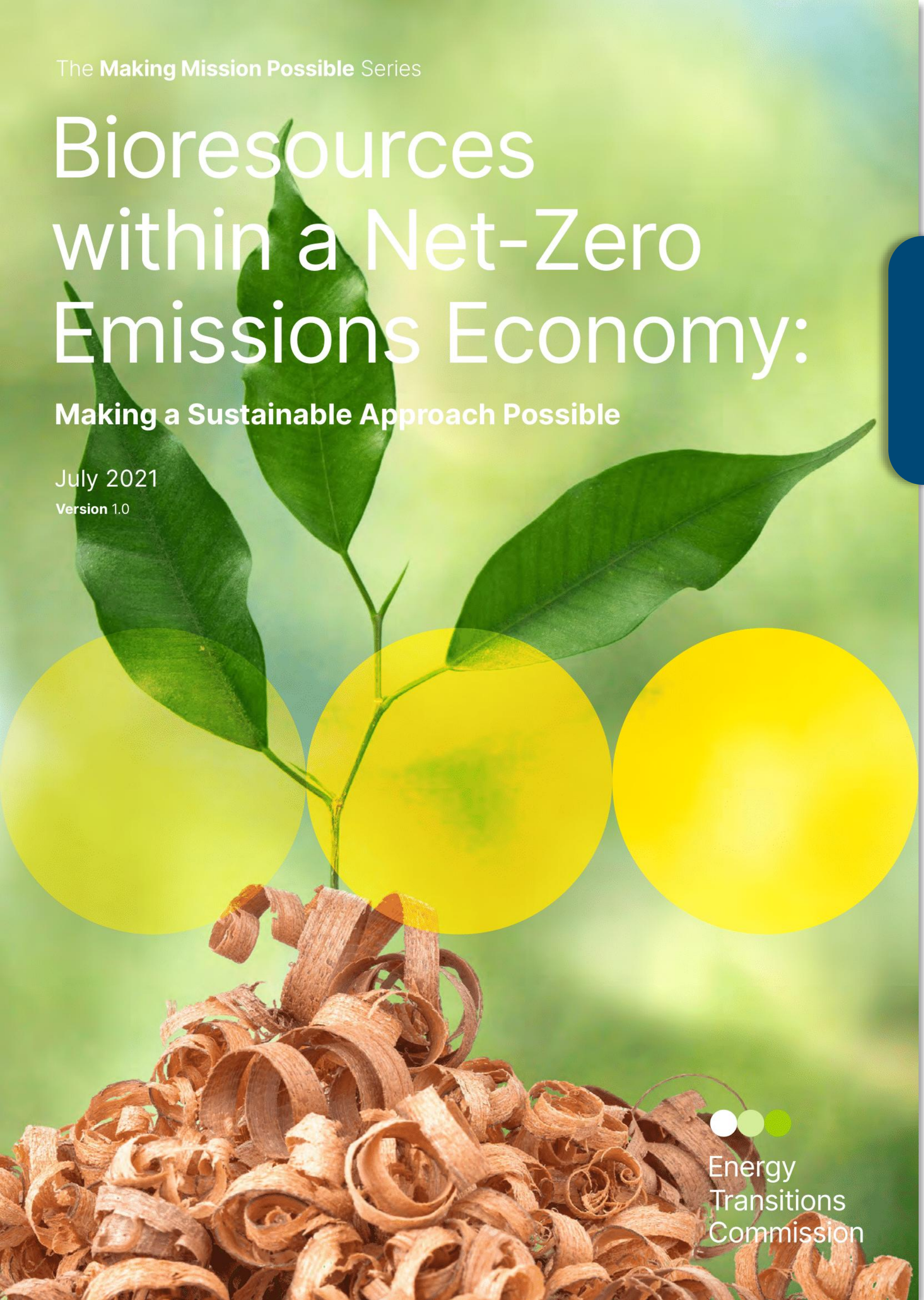


Bioresources within a Net-Zero Emissions Economy (2021)

Rapidly increasing demand for bioresources is likely to outstrip sustainable supply, unless alternative zero-carbon options are rapidly scaled-up and use of bioresources carefully prioritised

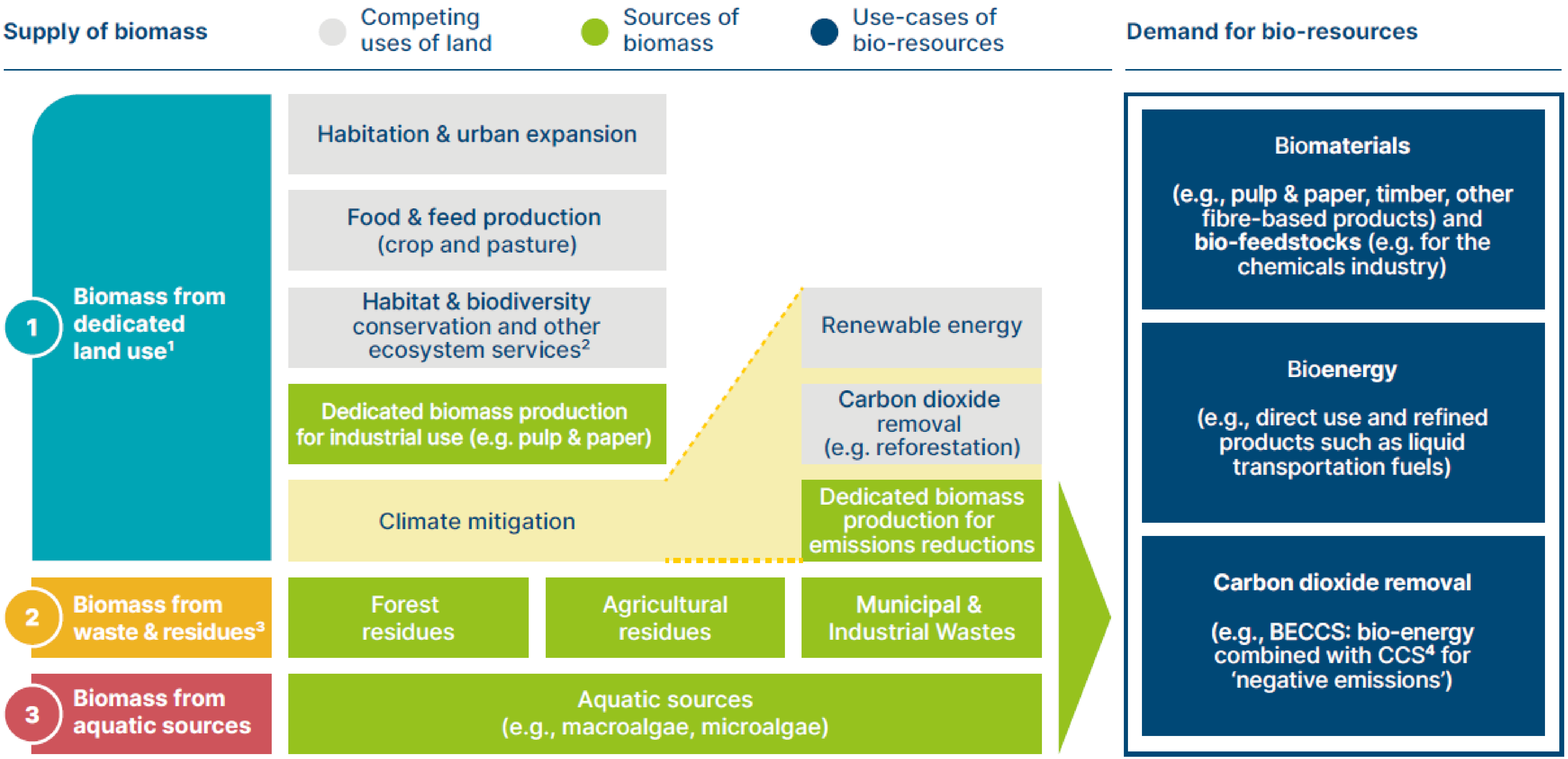
Key points:

- Not all forms of biomass are "good" biomass. Total sustainable potential is **limited.**
- Use should be **prioritised** towards wood products, aviation, plastics and Carbon Dioxide Removal, where alterative decarbonisation options are limited.
- Alternative zero-carbon solutions, like **clean electrification or hydrogen** use, should be developed rapidly to lessen the need for bio-based solutions.

Impact:

- Clarified the **limited but useful role of bioresources** in decarbonisation.
- Helped refine understanding of **sustainable bioresource supply**

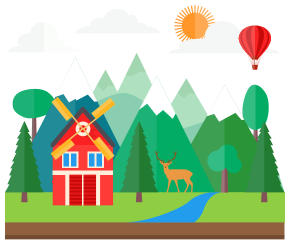
Bioresources are in high demand, but supply of sustainable, low lifecycle emissions biomass is constrained by competing uses of land



Notes: (1) Parallel uses of land (e.g., double-cropping and forest/landscape management) can reduce competition between uses of land by combining biomass production with agriculture or ecosystem services. (2) Includes ecosystem services such as nutrient cycling, soil quality maintenance, water regulation, erosion mitigation, water and air purification, recreation, etc. (3) Biomass from waste and residues are generated as a by-product of using land for other primary purposes listed in category 1 (e.g., agriculture, human habitation, managed forestry). (4) BECCS: bioenergy with carbon capture & storage (CCS).

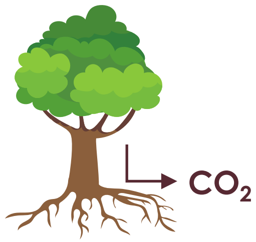
Biomass can only be considered sustainable if certain conditions are met

No competition with other critical uses of land



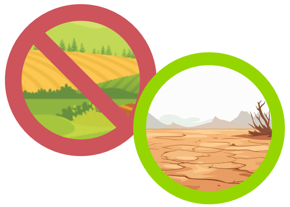
Biomass **sourcing must not displace essential functions of land**, including food production, housing and conservation

No deforestation or peatland conversion



Biomass **sourcing must avoid land-use changes that release stored carbon and destroy natural ecosystems**, especially in forests and carbon-rich peatlands

Target degraded land, with little plant growth



Biomass **sourcing should prioritize using marginal or degraded lands** with low ecological value to avoid disruption productive ecosystems and high-carbon landscapes

Respect growth periods which will delay supply

Harvesting must align with natural regeneration cycles to maintain long-term productivity and ecosystem health, even if it slows supply

Close-to-zero emission collection, transportation and processing

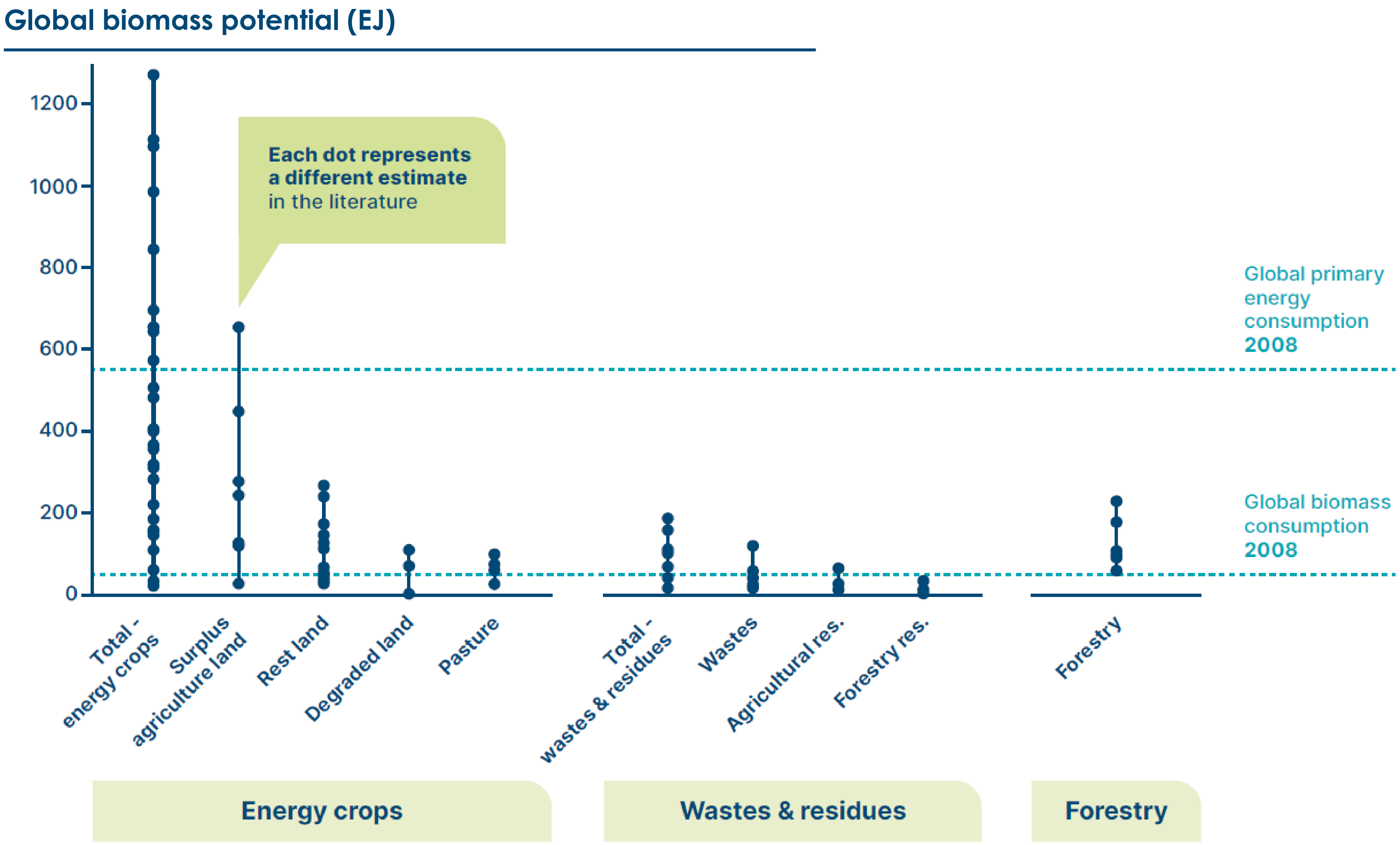
Biomass supply chains must minimize emissions across logistics and processing to **ensure real climate benefits**

No environmental or social harm

Projects must safeguard local environments and communities, delivering benefits without causing displacement or degradation

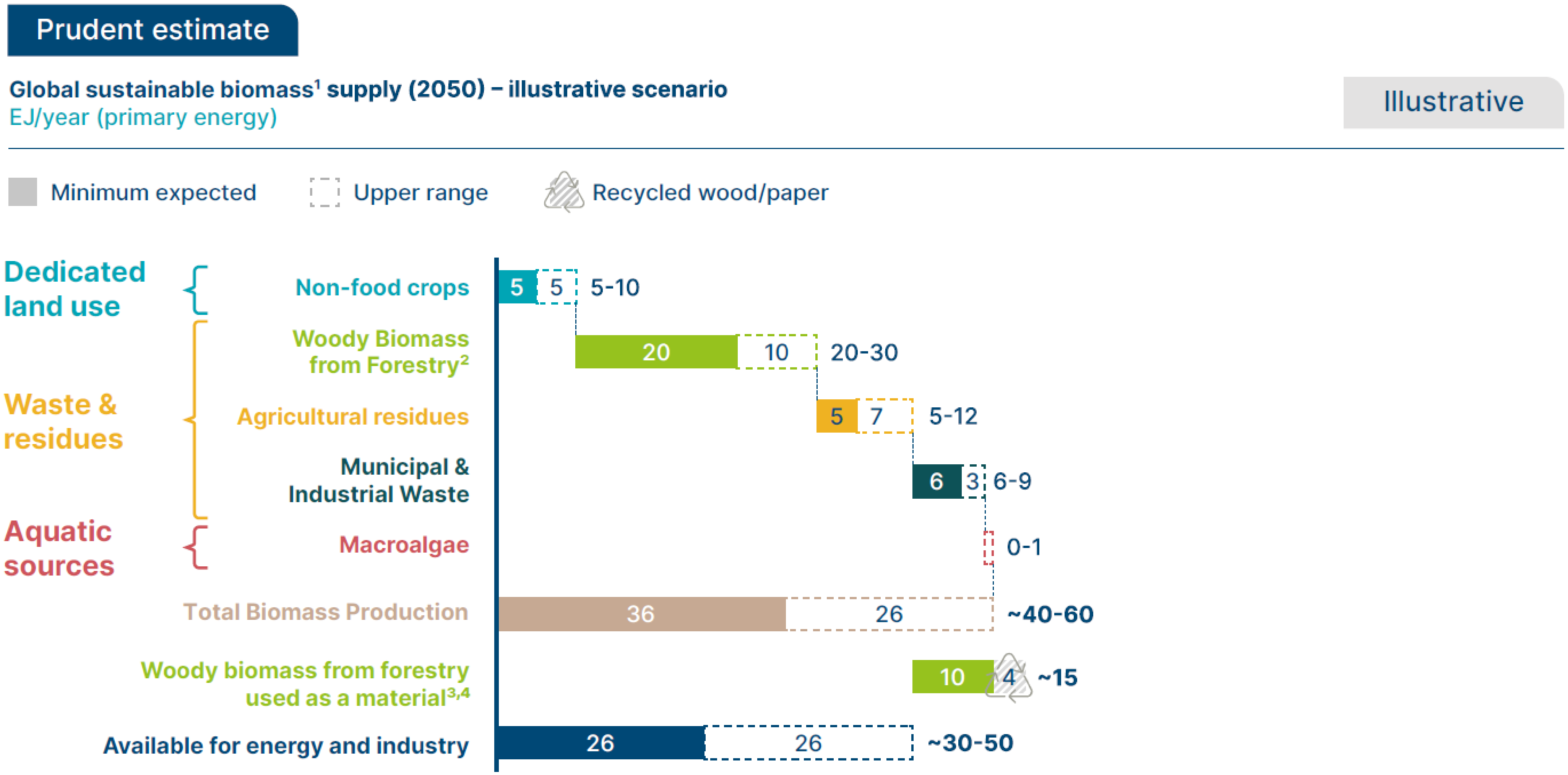
Source: ETC (2021), Bioresources within a Net-Zero Emissions Economy: Making a Sustainable Approach Possible

Estimates for total global biomass potential vary substantially



Sources: Figure reproduced with permission from UK Energy Research Centre (UKERC) (2011), *Energy from biomass: the size of the global resource* adapted from Slade et al. (2014), *Global bioenergy resources*.

In ETC Prudent Scenario, global supply of sustainable biomass could be ~40-60 EJ/year, of which ~10 from forestry favouring material uses, leaving ~30-50 for energy and industry



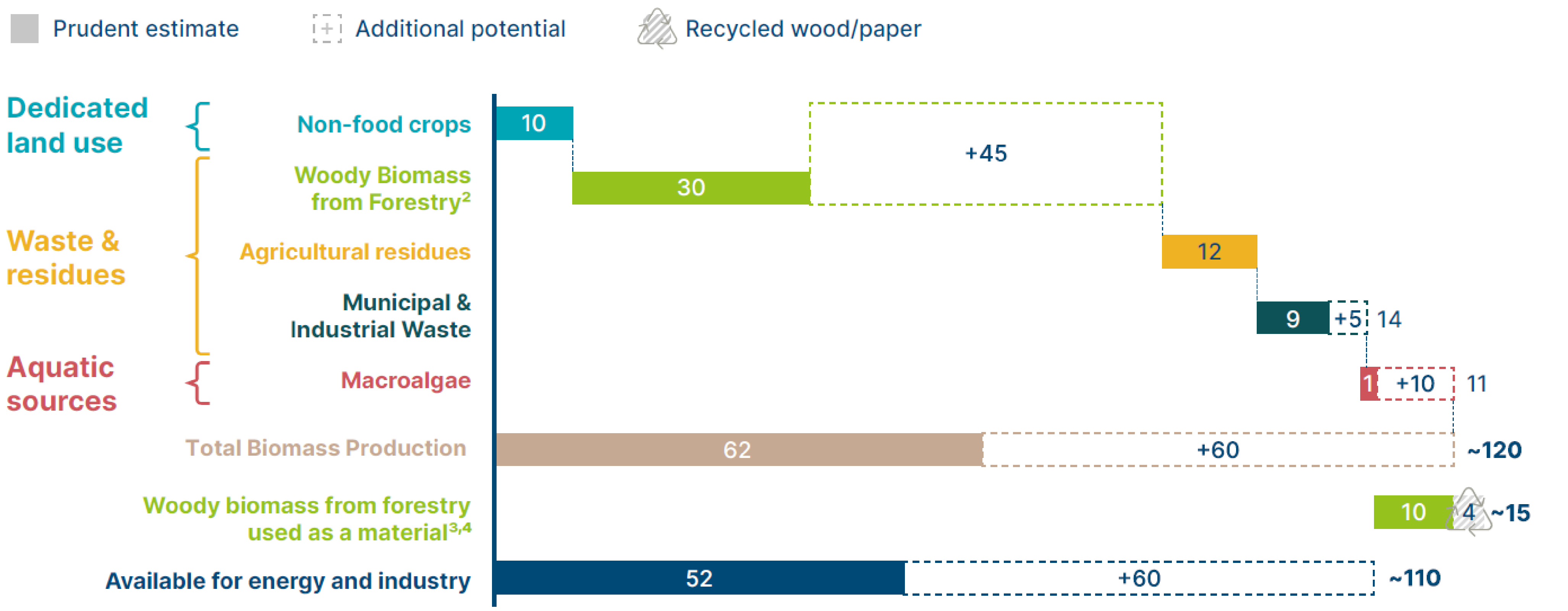
(1) The term 'sustainable biomass' is used to describe organic material that is renewable, has a lifecycle carbon footprint equal or close to zero (including considerations for the opportunity cost of land), and for which the cultivation and harvesting practices used are mindful of ecological considerations such as biodiversity and health of the land and soil. (2) Includes high-quality stemwood from forestry suitable for the timber and pulp & paper sectors (~10 EJ/year today, FAO Industrial Roundwood production less by-products used for energy). This category also includes residues from forestry but excludes traditional fuelwood (~25 EJ/year today, assumed to reduce with modernisation) due to collection and sustainability assurance challenges. (3) E.g., timber, pulp & paper. Based on current harvests from commercial forestry; additional high-quality stemwood could be made available if freed up land were dedicated to forestry. (4) Additional supply from recycled materials (~4 EJ/year today).
Source: SYSTEMIQ analysis for ETC (2021).

If ambitious systems changes are achieved, maximum biomass potential by 2050 could be ~110 EJ/year for energy & industrial uses

Maximum potential Maximum achievable only under extremely ambitious systems change scenarios; additional potential NOT to be relied upon.

Global sustainable biomass[1] supply (2050) – illustrative scenario
EJ/year (primary energy)

Illustrative



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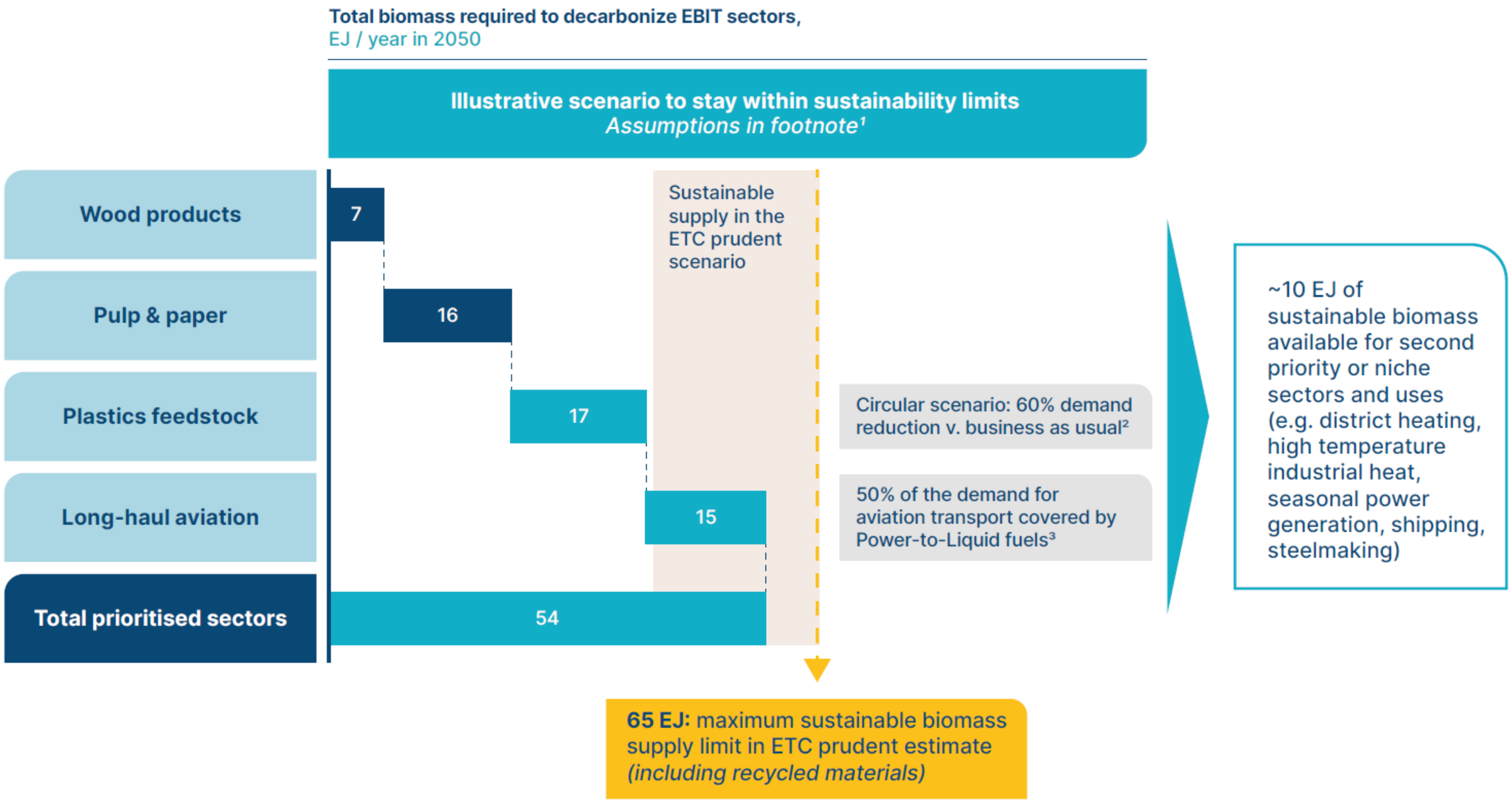
Source: SYSTEMIQ analysis for ETC (2021).

There are certain sectors where sustainable biomass should be prioritised



1) Food products: 824 Mm3 demand for wood product in 2050 (+21% vs 2006); 0.009 EJ/Mm³. Source: Material Economics (2021) *EU Biomass Use in a Net-Zero Economy - A Course Correction for EU Biomass.* Pulp and paper: 550 Mt demand for pulp in 2050; 80% pulp yield per t feedstock; 0.19 EJ/Mm3. Source: Material Economics (2021). Plastics feedstock: 818 Mt plastics demand in 2050; 51 GJ biomass per t plastics; 60% circularity and recycling in an average zero-carbon pathway v. business-as-usual (19% circularity, 15% mechanical recycling, 26% chemical recycling). Source: Material Economics (2021)
Aviation: 19 EJ final energy demand for aviation in 2050 (IEA RTS); 46% biomass to biojet fuels efficiency; 73% long-haul demand. Source: IEA (2017), *Energy Technology Perspectives.*
2) Through increased materials efficiency, reuse and recycling. Corresponds to 56% demand reduction vs Business-as-Usual 2050 scenario.
3) If in addition to the deployment of PtL, energy efficiency and modal shifts are optimised (based on the 2DS scenario of the IEA Energy Perspectives 2017), demand for biomass for aviation could go down to 10 EJ.

Biomass is limited, so the real solution is to prioritize its best uses while rapidly scaling non-bio decarbonisation.

SAFEGUARD SUSTAINABLE SUPPLY

1. Set clear standards for sourcing truly sustainable, low-emission biomass
2. Use supply chain transparency, data analysis & governance to enforce standards
3. Protect tropical forests, peatlands
4. Incentivise alternative uses of land (e.g. payments for ecosystem services and CO2 removals)
5. Use data analysis to improve land use choices; develop technologies to improve supply chain visibility and monitoring of Natural Climate Solutions

GROW SUSTAINABLE SUPPLY

1. Increase organic waste collection globally
2. Scale seaweed-for-energy production
3. Release land from food production:
   - Improve global agricultural productivity;
   - Produce micro- & macro-algae for food/feed;
   - Reduce food waste
   - Global shift to plant-based diets
   - Develop and scale synthetic meat and dairy alternatives
4. Make land-use more efficient through innovation in precision biotechnologies, regenerative agriculture, synthetic meat / dairy and micro/macro-algae

CREATE CONDITIONS FOR OPTIMAL BIORESOURCE USE

1. Establish meaningful carbon taxes / prices
2. All policy support for biofuel use based on lifecycle carbon content
3. Drive deliberate policies to discourage suboptimal use of bioresources (e.g. light duty road transport) and to encourage priority use (e.g. aviation and plastics feedstocks)
4. Develop national and regional bioresource strategies reflecting local supply and demand
5. De-risk pilot projects in biogasification for jet fuels and for plastics biofeedstocks

SUPPORT KEY TECHNOLOGIES TO ENABLE EFFICIENT, SUSTAINABLE SUPPLY & USE OF BIORESOURCES

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- Making the Hydrogen Economy Possible – key messages
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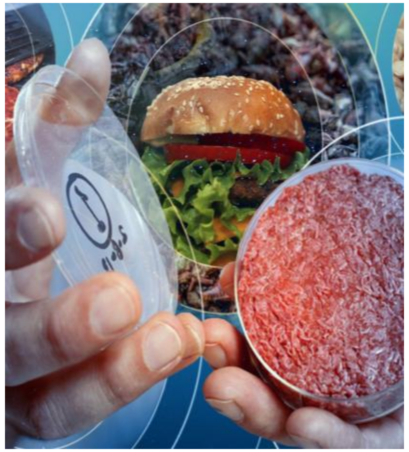
The potential of biomass supply could increase through radical changes

Use more productive land

Update estimate of degraded land, while ensuring that biomass crops expand only on land that does not displace food production or critical ecosystem restoration

Make additional land available

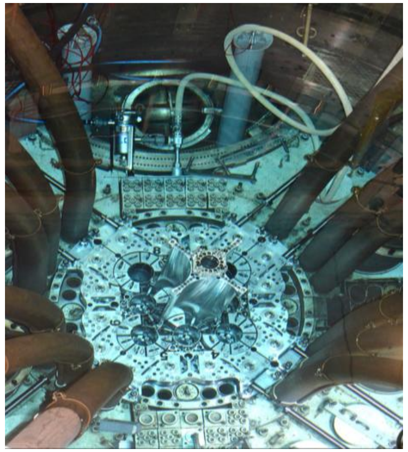


Land needed for energy crop cultivation can be freed by adopting alternative protein production methods

Use new sources of biomass

Both macro and micro algae offer pathways to increase overall biomass supply and efficiency by shifting to aquatic systems

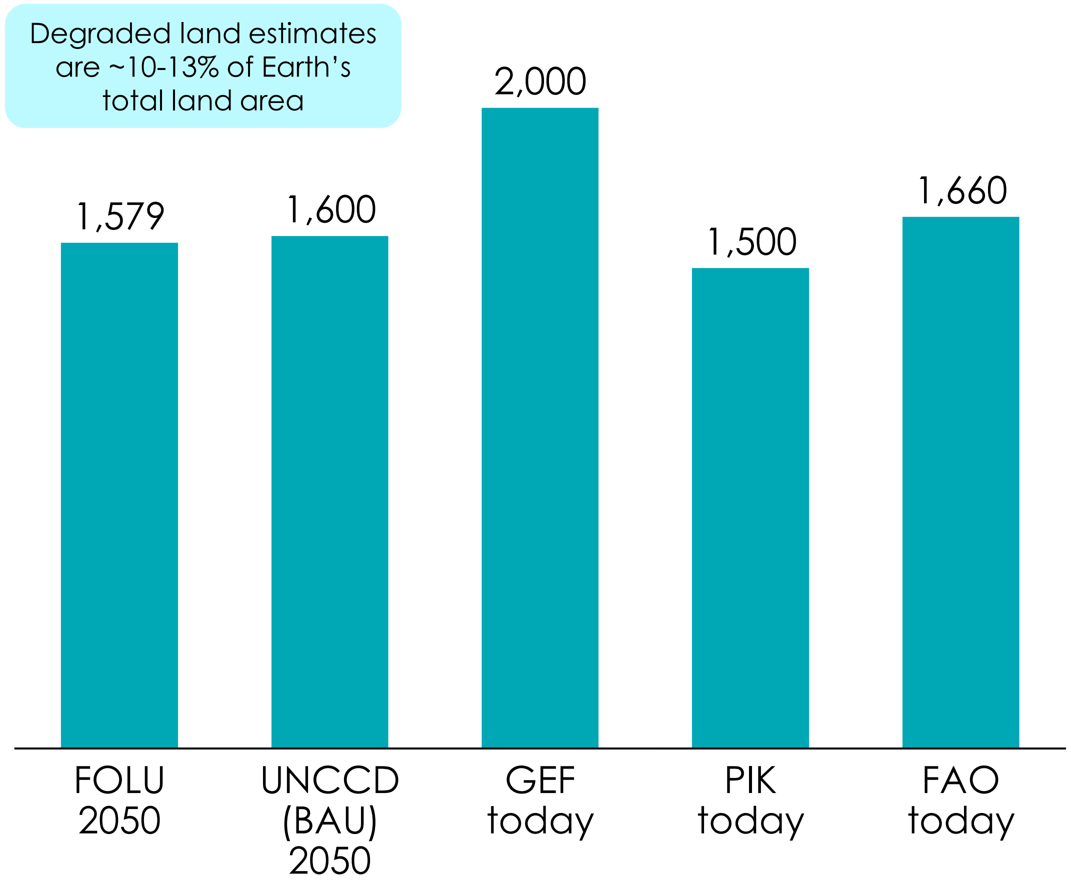
Improve biomass conversion



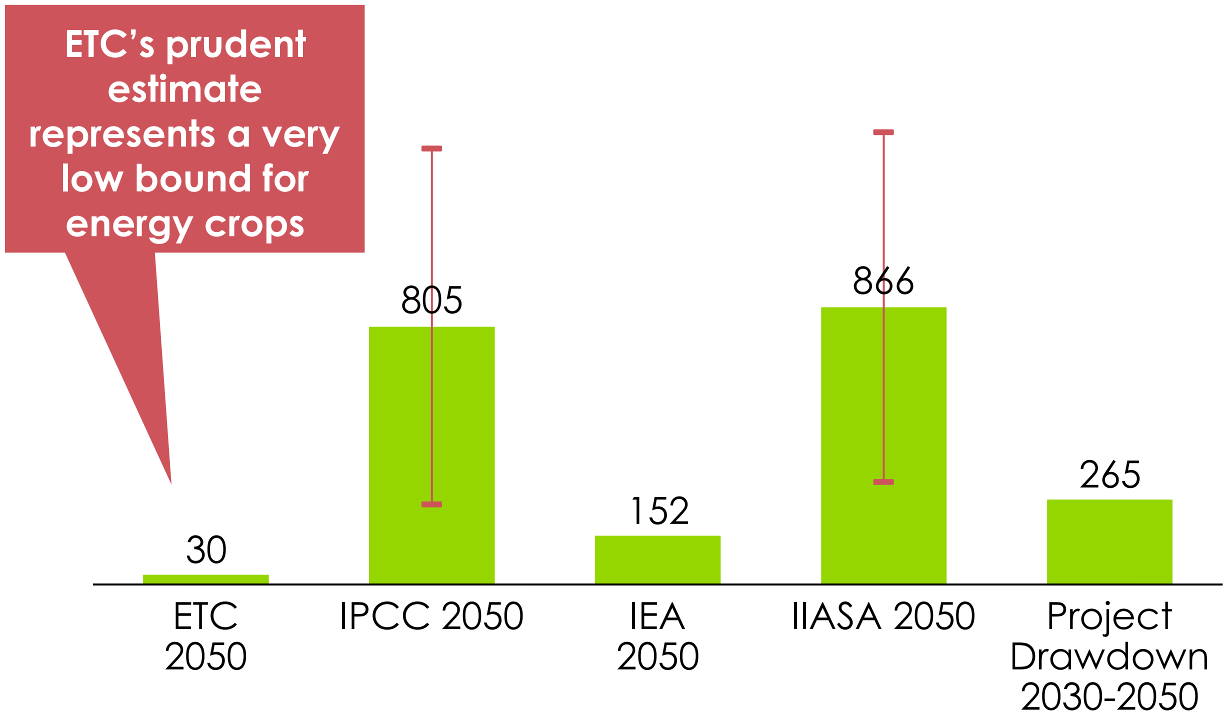
Reactors and catalysts improvements lead to cost reduction due to yield increase.

There is broader agreement around the area of degraded land, but more variance of opinion around the potential to regenerate it for energy crop

Ranges of degraded land estimates
Millions of ha



Range of estimates for energy crops on degraded land
Millions of ha



Sources: Food and Land-Use Coalition (FOLU) (2019) Growing Better, Global Environmental Facility (GEF) (2017) GEF-7 Replenishment Programming Directions, Potsdam Institute for Climate Impact Research (PIK) (2024) Transforming land management within planetary boundaries key to addressing global land use crisis. United Nations Convention to Combat Desertification (UNCCD) 2021 by Van der Esch et al The global potential for land restoration: Scenarios for the Global Land Outlook 2. PBL Netherlands Environmental Assessment Agency, The Hague. Food and Land Organization (FAO) 2024 Restoration of degraded agricultural lands.; IPCC (2022) Climate Change 2022: Mitigation of Climate Change; IEA (2024) Bioenergy

Within alternative proteins, three key innovations offer the highest potential to reduce land demand for animal feed and grazing

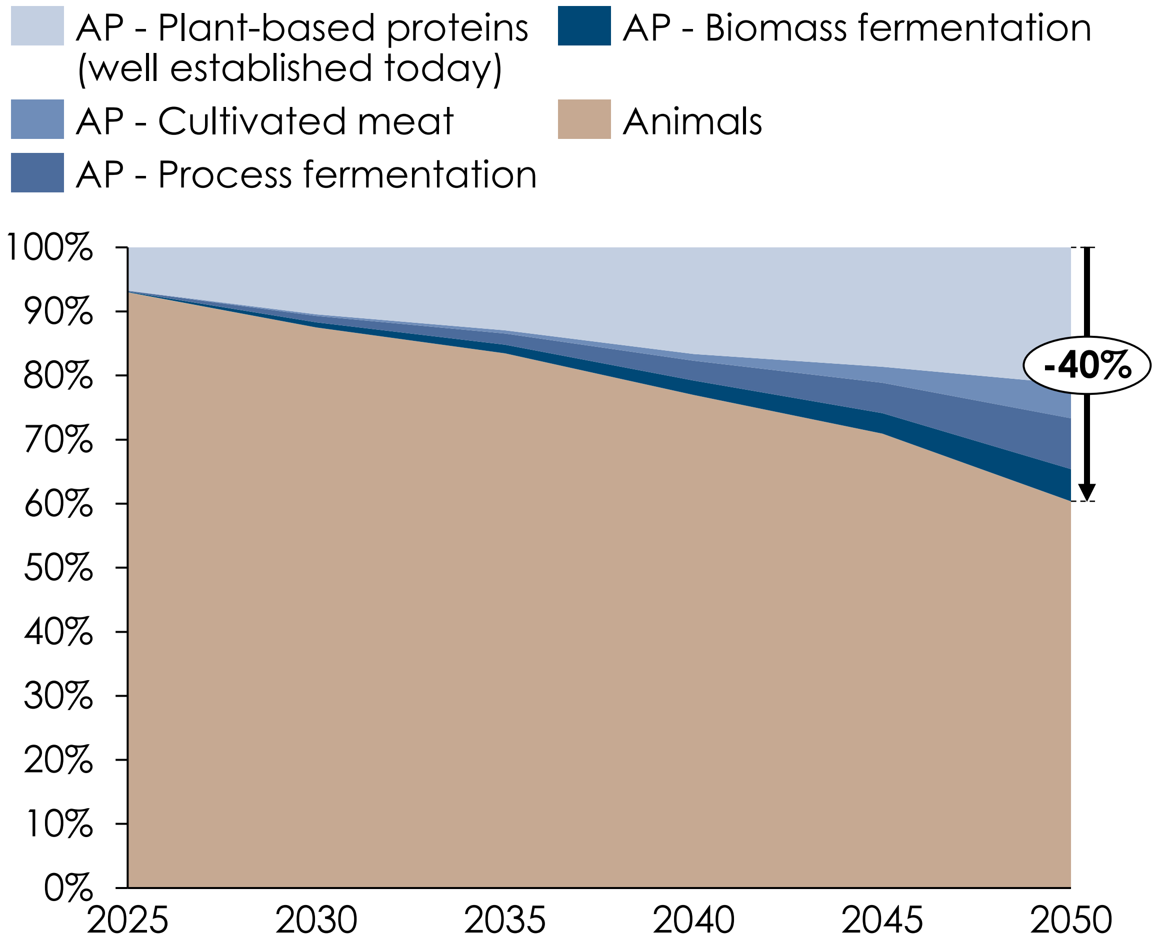
	Innovations	Overview					Benefits	
		Goal	Use case	Examples	TRL	Companies	Efficiency potential	Land saving potential
1	**Biomass fermentation (BF)**	Produce whole **protein-rich biomass**	• **Base ingredients in meat-like foods** • e.g., mycoprotein **(Quorn)**, fungal burgers		6-8	Quorn, Solar Foods, air protein	**~13%** more energy **~79%** less water **~92%** less GHGs **vs. beef**	**Very high (up to ~90%)** – but products do not fully replicate the look or taste of meat
2	**Precision fermentation (PF)**	Make **specific molecules** for use as **ingredients**	• **Functional ingredients** for food production • e.g., **egg white** for baking, casein, rennet		7	Perfect Day, Geltor, Every	**~15%** less energy **~85%** less water **~40%** less GHGs **vs. eggs**	**Very high (up to -60%) –** varies by ingredient
3	**Cultivated meat (CM)**	**Grow real meat** tissue from animal cells	• **Cuts of meat** including muscle, fat and tissue • e.g., **beef steaks,** chicken breasts		3-5	Mosa Meat, Believer, Upside Foods	**~50%** less energy **~88%** less water **~88%** less GHGs **vs. beef**	**Very high (up to -94%) –** properties uniquely identical to meat

Sources: Our World in Data (2022), Environmental impacts of food production; Sustainable Nutrition Initiative (2023), Do the environmental impacts of fermentation-produced protein outweigh those of conventional protein sources?; Hassan Halawy (2024), White Paper: Precision Fermentation – A Sustainable; Breakthrough in Food Production; University of Helsinki (2022), Biotechnology could provide an environmentally more sustainable alternative to egg white protein production; Tuomisto & Teixeira de Mattos (2011), Environmental Impacts of Cultured Meat Production; Mattick et al. (2015), Environmental Impacts of Cultured Meat: A cradle-to-gate life cycle assessment; GFI, 2023: "Environmental benefits of alternative proteins", Blue Horizon, 2020: "Environmental impacts of animal and plant-based food", Sinke et al, 2023: "Ex-ante life cycle assessment of commercial-scale cultivated meat production", Poore, J., & Nemecek, T., 2018: "Reducing food's environmental impacts through producers and consumers".

Alternative proteins adoption and comparative land-use with traditional proteins

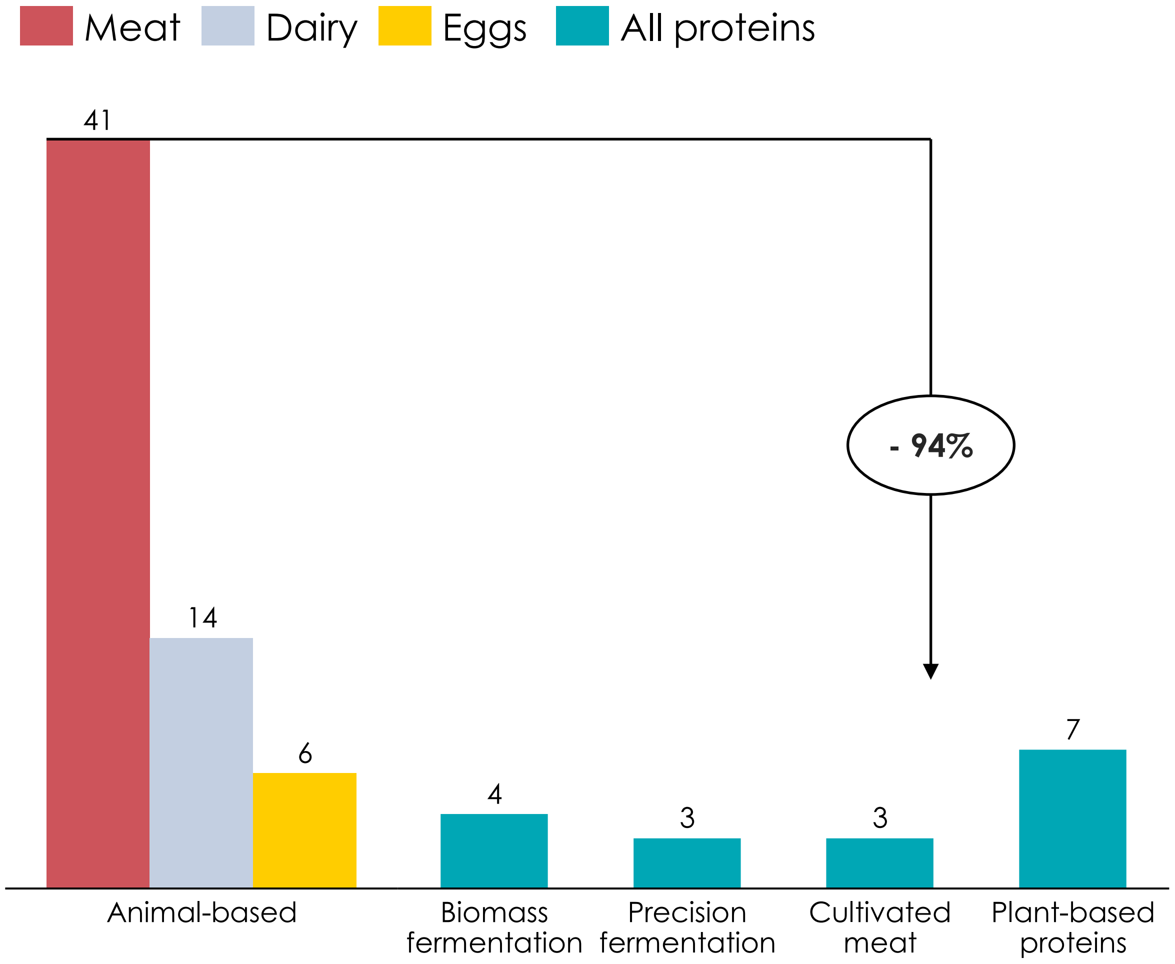
In a high ambition scenario, alternative proteins could capture up to ~40% of the global animal-based protein demand

Breakdown of global protein demand by protein source[1]



Cultivated meat could significantly reduce land usage compared to conventional meat in best case scenario

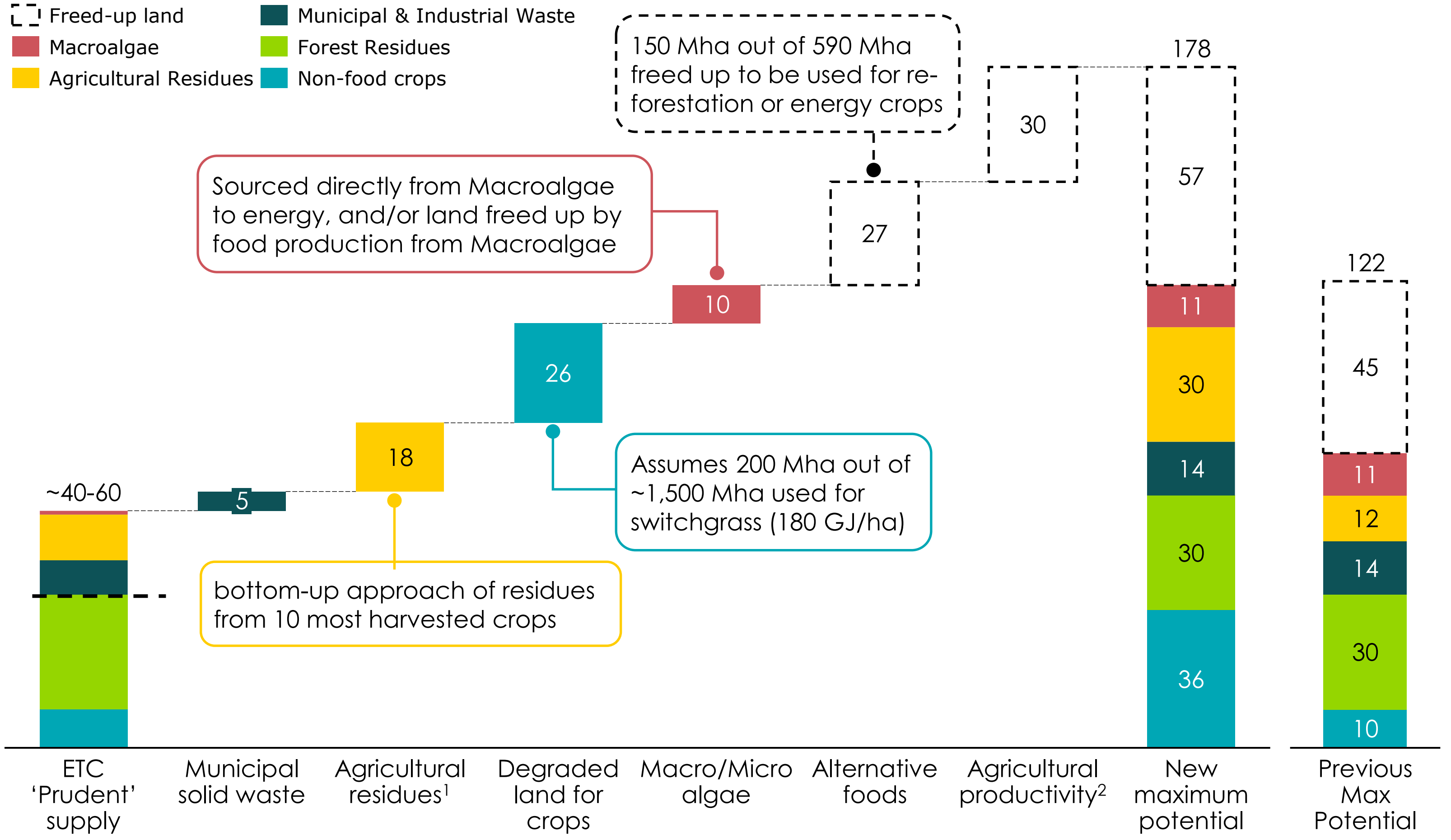
Land-use intensity by protein type and source, m^2/kg



Notes: [1] In alternative proteins made via biomass fermentation, precision fermentation, or cultivation, cell-grown ingredients make up only ~5–20% of total protein weight; the rest comes from plants—driving plant-based proteins' dominant role in meeting 2050 global protein demand [2] Volume of animal protein consumption net of animal carcass weight. Sources: ETC analysis; Systemiq (2025), A Taste of Tomorrow: How Protein Diversification Can Strengthen Germany's Economy; FAOSTAT. Sources: Systemiq (2025), A Taste of Tomorrow: How Protein Diversification Can Strengthen Germany's Economy; GFI (2023), Environmental benefits of alternative proteins; Blue Horizon (2020), Environmental impacts of animal and plant-based food; Sinke et al. (2023) Ex-ante life cycle assessment of commercial-scale cultivated meat production; Poore, J., & Nemecek, T., (2018), Reducing food's environmental impacts through producers and consumers; expert interviews.

A new possible maximum scenario estimates that sustainable biomass availability around ~180EJ

Biomass supply potential, EJ primary biomass



Indicative measures to manage degraded land-use for biomass

Measures

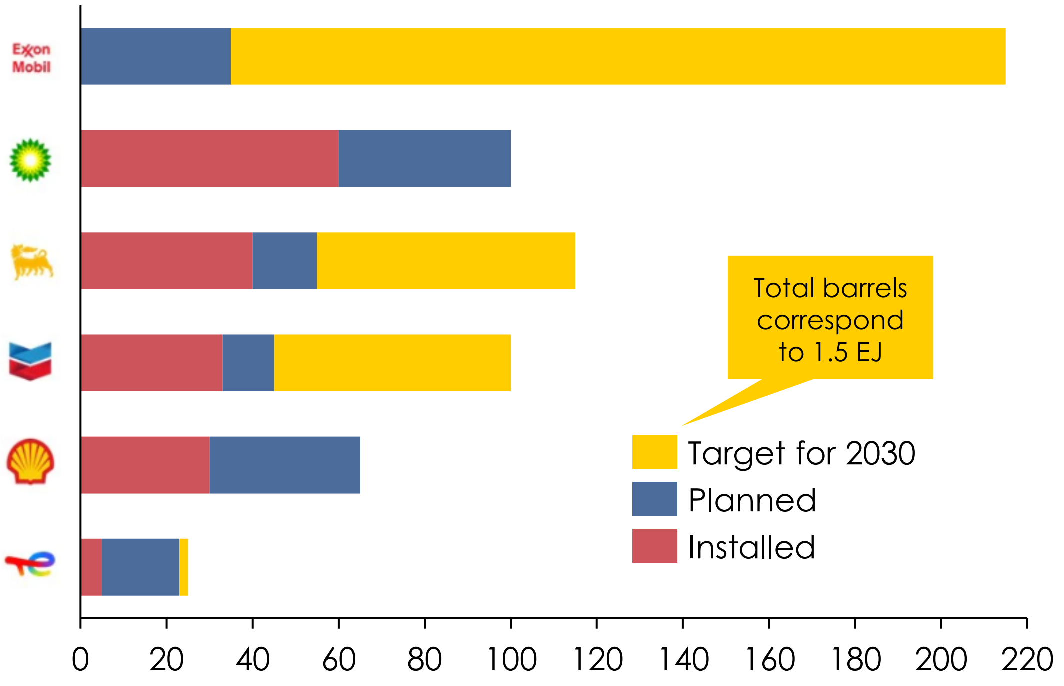
1. Eligibility baseline & definition
2. Geo-registration & continuous satellite MRV[3]
3. Digital chain of custody & traceability
4. Restoration review & performance linked incentives
5. Enforcement, exclusions & transparency

Notes/sources: 1) From total unprocessed residues, 70% are left on ground and a recoverability of ~50% is assumed. Production from 2023 is taken and extrapolated to 2050 using the same CAGR for the 2003 – 2023 period. 2) 0.9 CAGR taken from 2019 to 2050 plus an additional 12% increase by 2050 due to technological advancements yields a total of 40% increased productivity. This frees up 640 million ha, which is split in the same way as freed land from Alternative Proteins or Macroalgae, yielding additional 30 EJ
Sources: Systemiq Analysis (2025) using FAO data, ETC analysis; ETC (2021), Bioresources Within a Net-Zero Emissions Economy: Making a Sustainable Approach Possible.

Bio: Transition from 1st to 2nd generation biofuels is accelerating, but production portfolio must double to meet 2030 targets

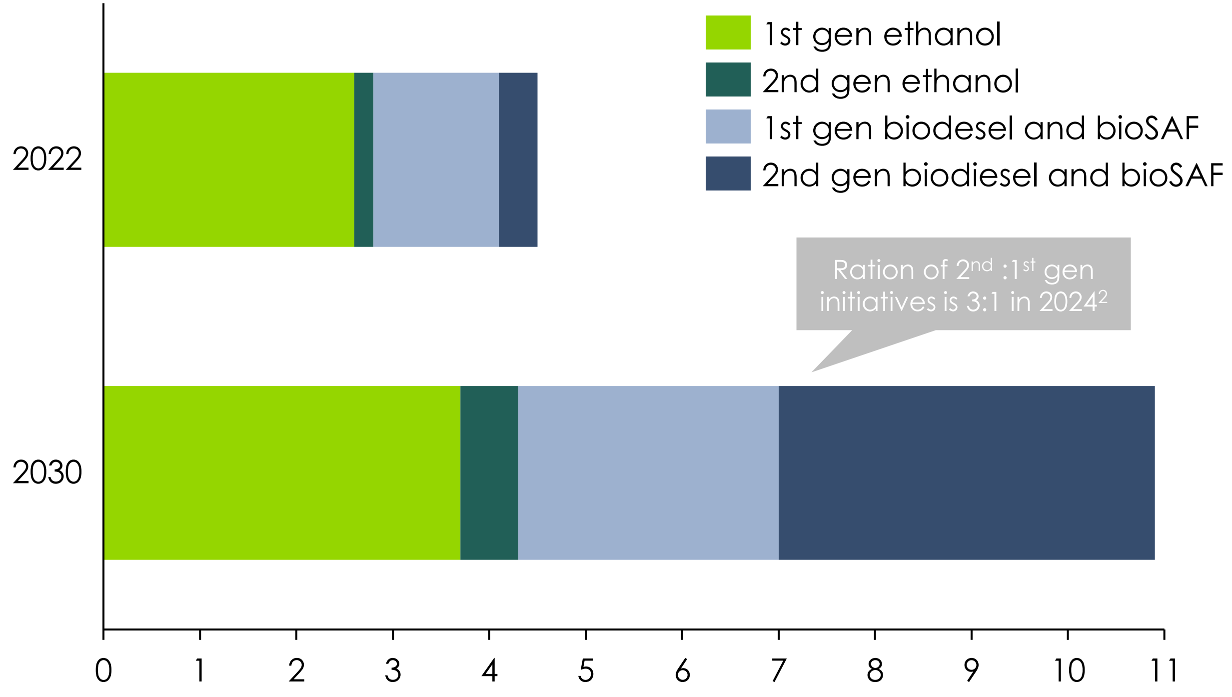
Oil majors' Biofuel production portfolio capacity

Thousand barrels per day



Liquid biofuel production by feedstock and technology in 2022 and IEA net-zero 2030 target

EJ



- Currently, IEA Database consists of **258 biofuel projects**, of which 39 are on-hold/cancelled. Major oil companies plan for **43 projects** until 2030, focusing on sustainable aviation fuel (SAF) and 2nd generation diesel.
- New biofuel projects are shifting from road use **toward aviation**.

Notes: Includes both operated and equite share projects.
Sources: Rystad Energy's BioEnergy Solution, November 2024; IEA Bioenergy (December 2024) Development and Deployment of advanced biofuel demonstration facilities; Energy News November 2024

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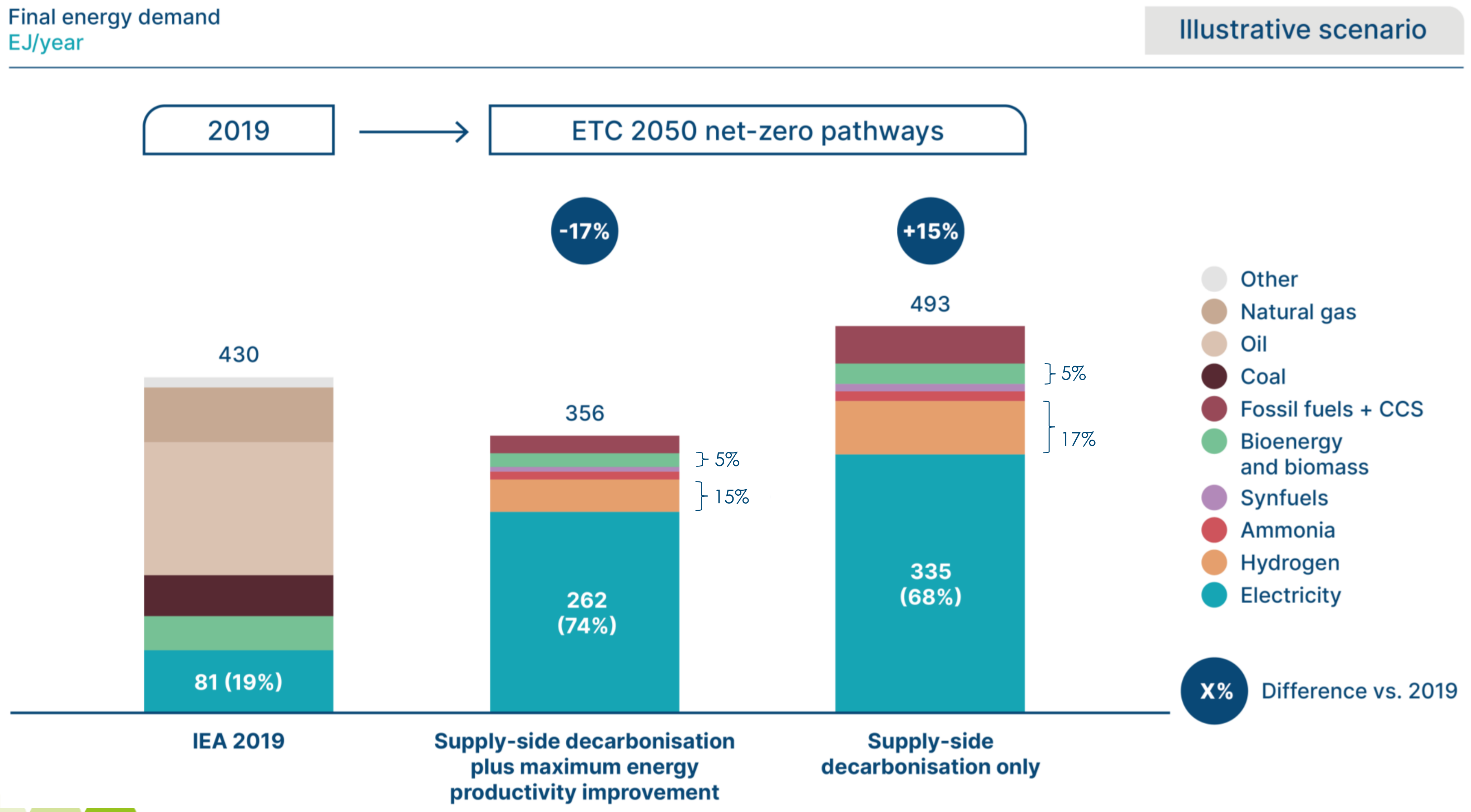
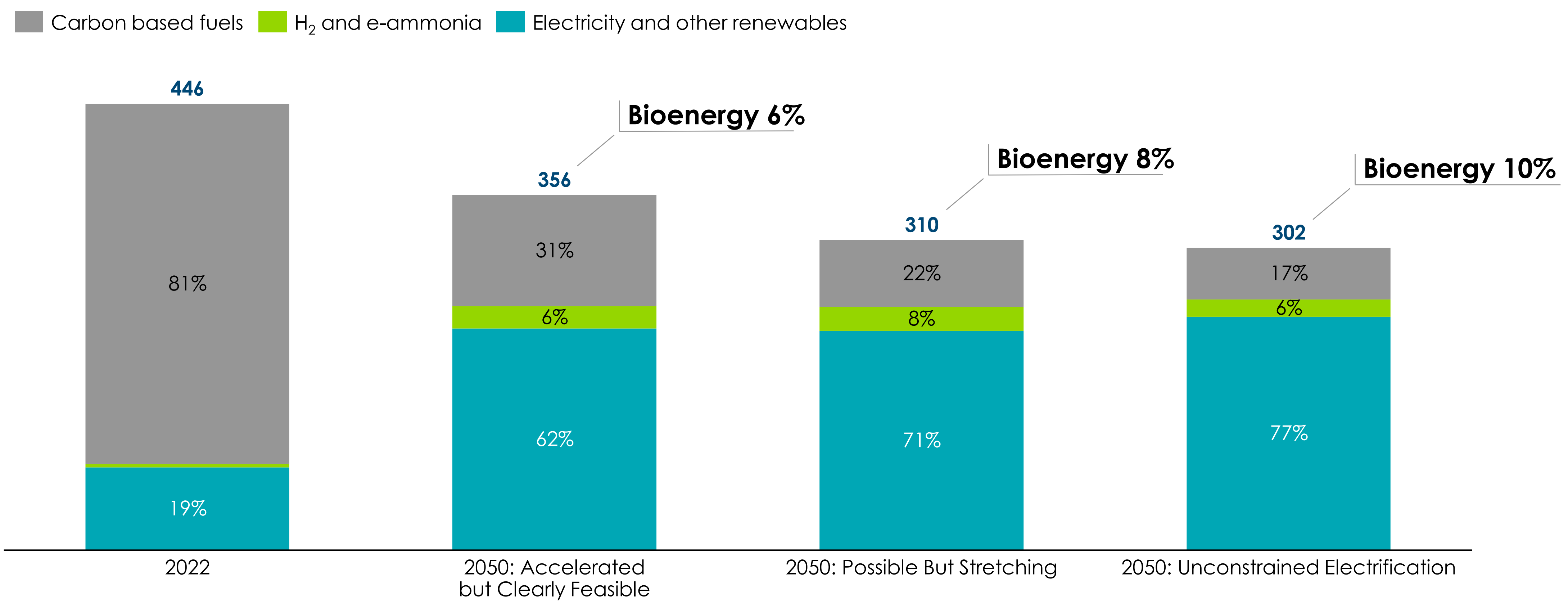
Final energy mix in a zero-carbon economy: Electricity will become the dominant energy vector, complemented by hydrogen and fuels derived from it



In revised scenarios the share of hydrogen is <8% but bioenergy can supply the majority of carbon requirements

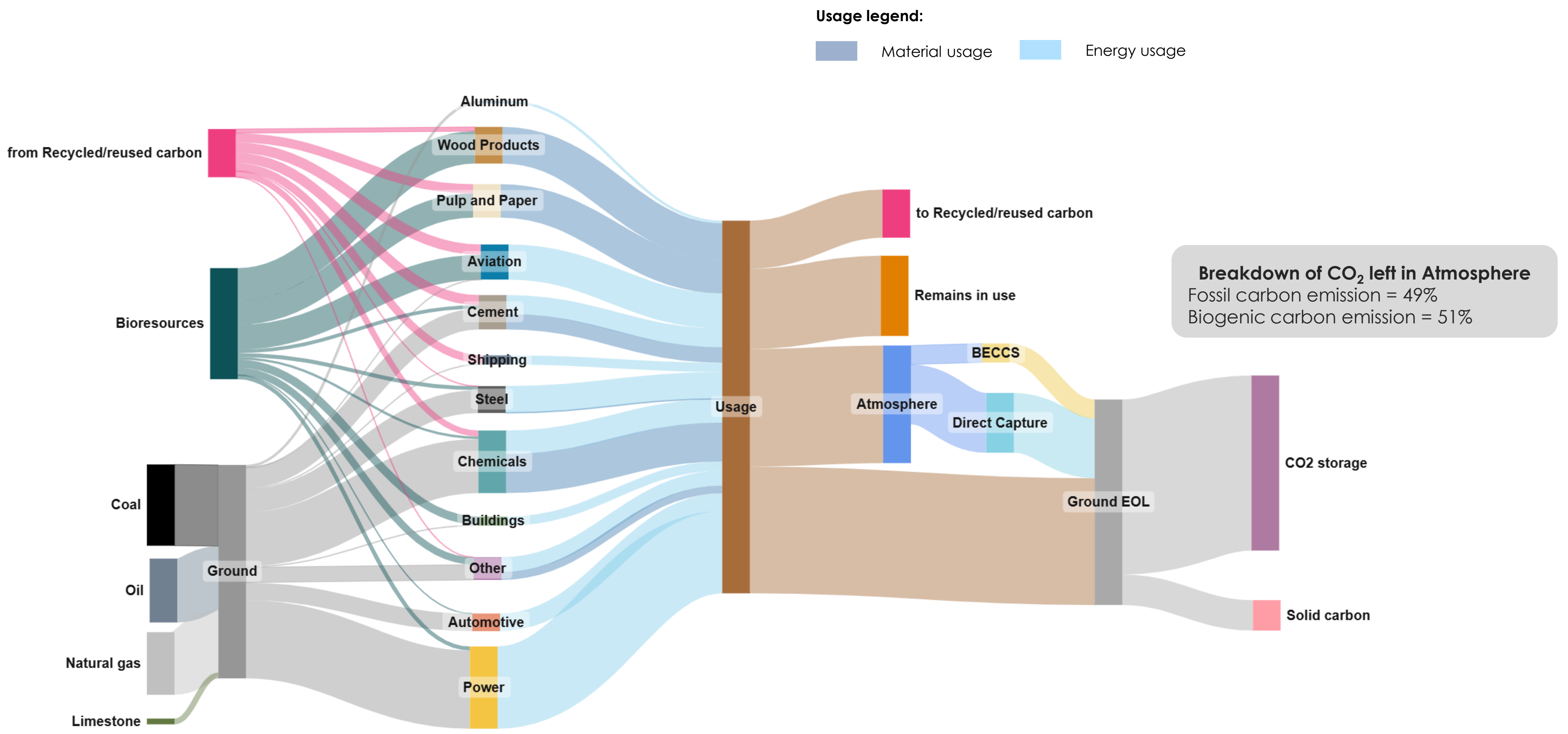
Global final energy demand by energy source and scenario
EJ/y (%), 2022 and 2050



Note: ACF = Accelerated but Clearly Feasible; PBS = Possible but Stretching
Sources: 2022 scenario, and PBS scenario based on ETC (2023) Fossil Fuels in Transition report

ACF: 57% of carbon supply still derives from fossil fuels

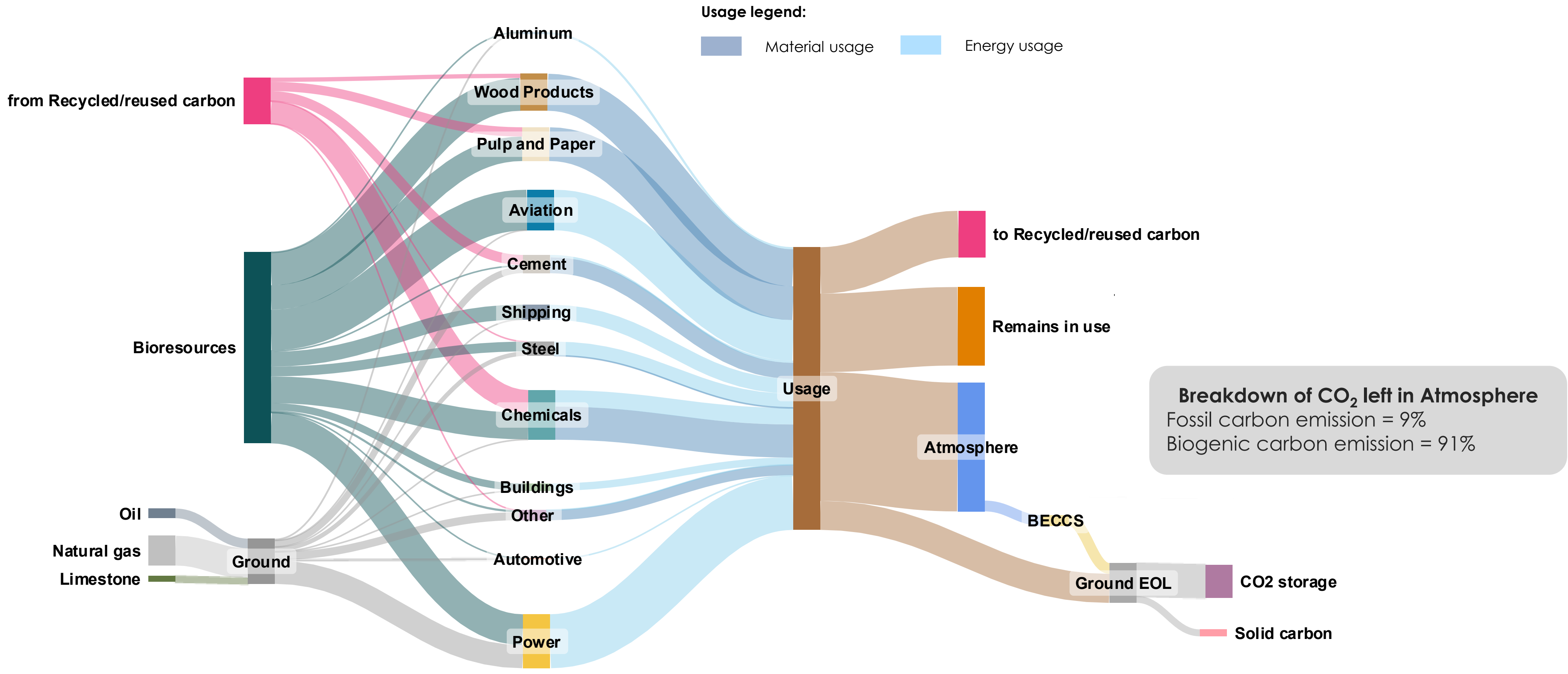
ACF mid-century Carbon source and destination for the Energy and Materials Sectors, *Mt C*



Source: Systemiq analysis for the ETC (2025) *based on* Fossil Fuels in Transition (2023)

Unconstrained Electrification: 90 EJ of biomass supply (half of new maximum) can reduce fossil carbon to only 16%

Minimise fossil carbon use, Carbon source and destination for the Energy and Materials Sectors, *Mt C*



Source: Systemiq analysis for the ETC (2025) *based on* Fossil Fuels in Transition (2023)

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