Energy
Transitions
Commission

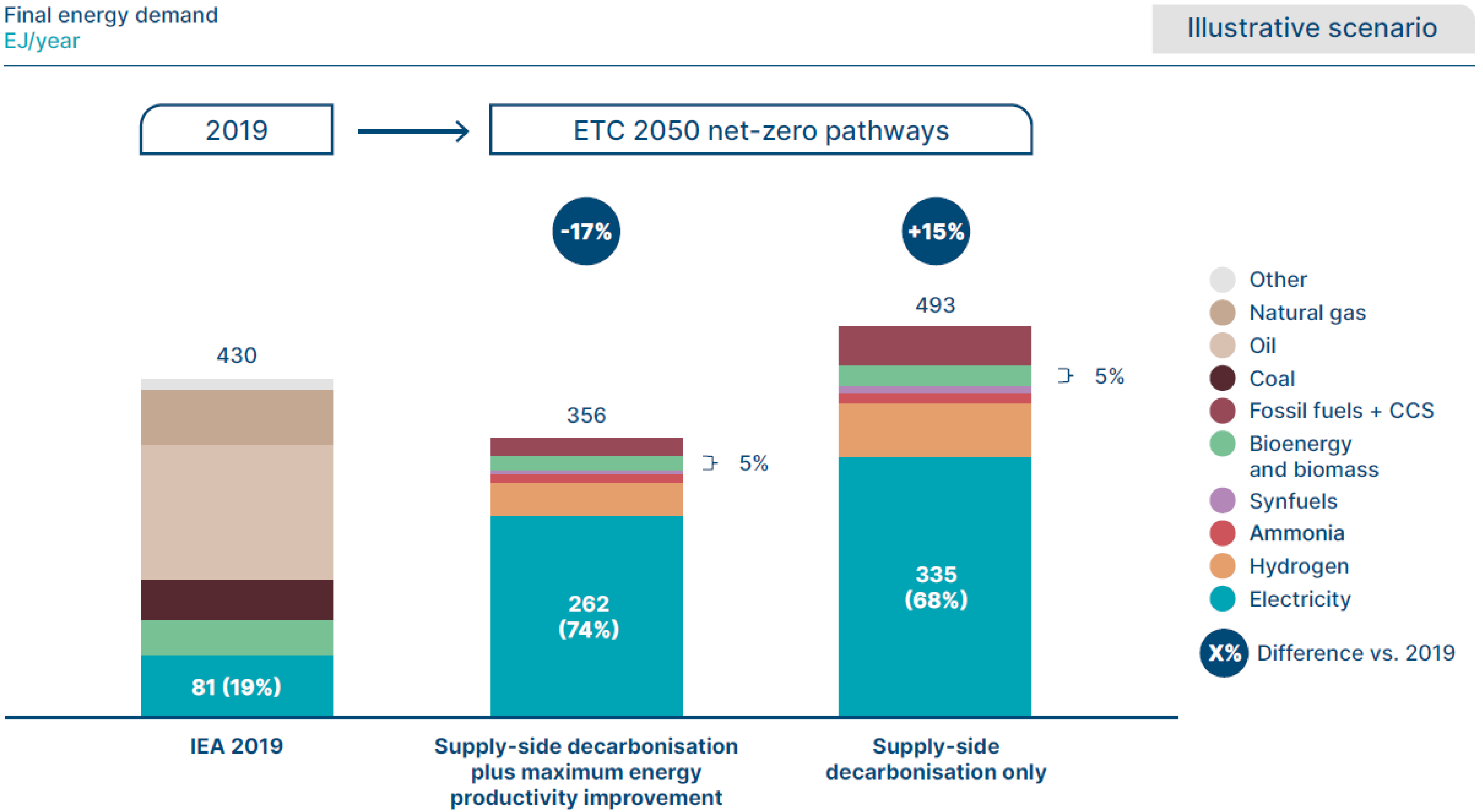
The **Making Mission Possible** Series

Bioresources within a net-zero emissions economy

May 24th 2023

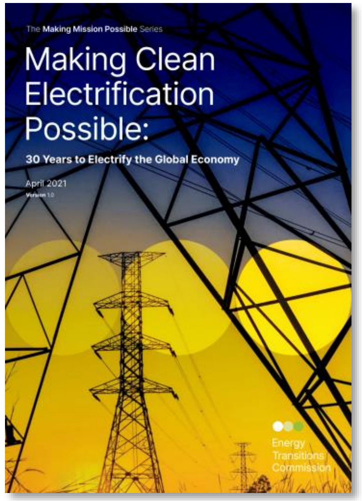
A net-zero global economy is technically and economically possible by mid-century, but we need to act in the 2020s to put mid-century targets within reach.

Final energy mix in a zero-carbon economy: clean electricity is the dominant form of energy, complemented by hydrogen and fossil fuels with CCS, with a constrained role for bioenergy

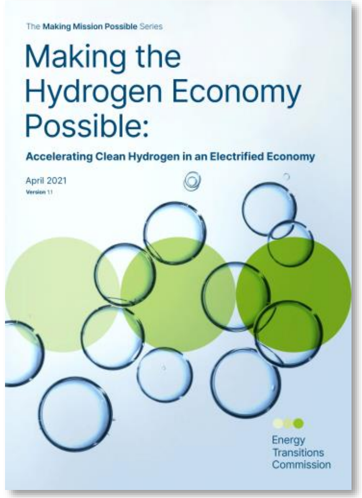


Source: SYSTEMIQ analysis for the Energy Transitions Commission (2021); IEA (2020), *World Energy Outlook*

Mission Possible Series – Bioresources deep-dive



April 2021



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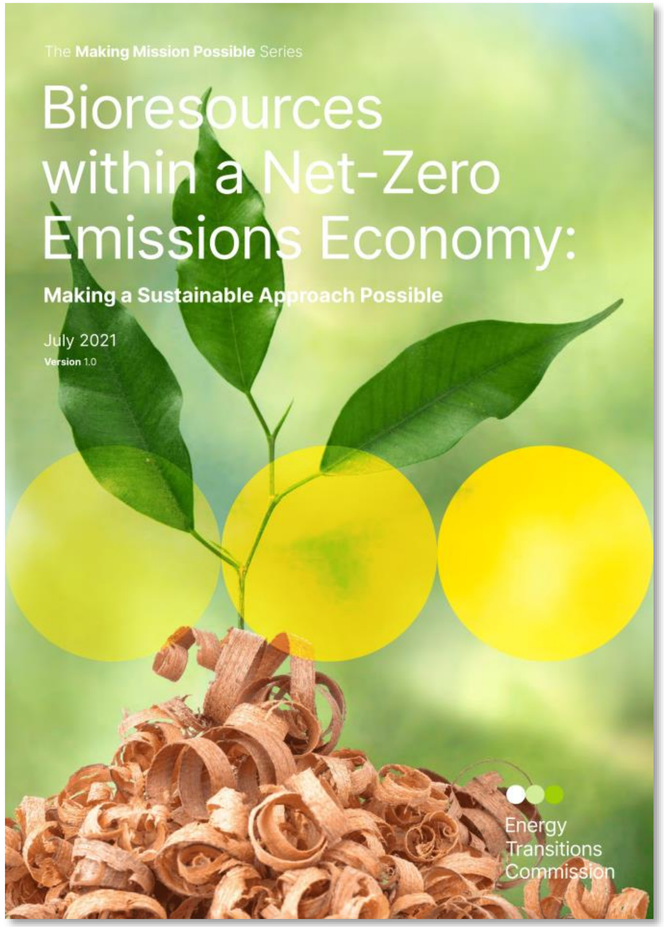

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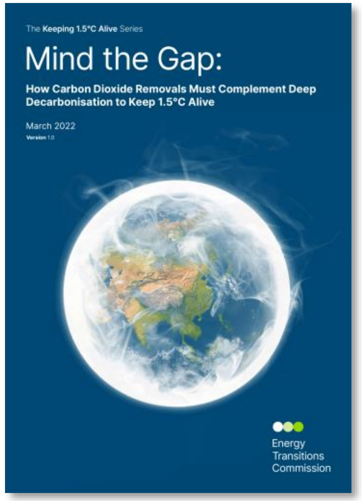
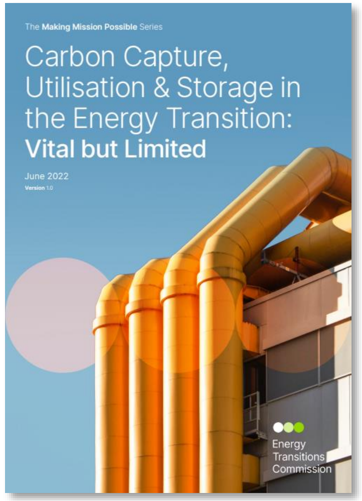
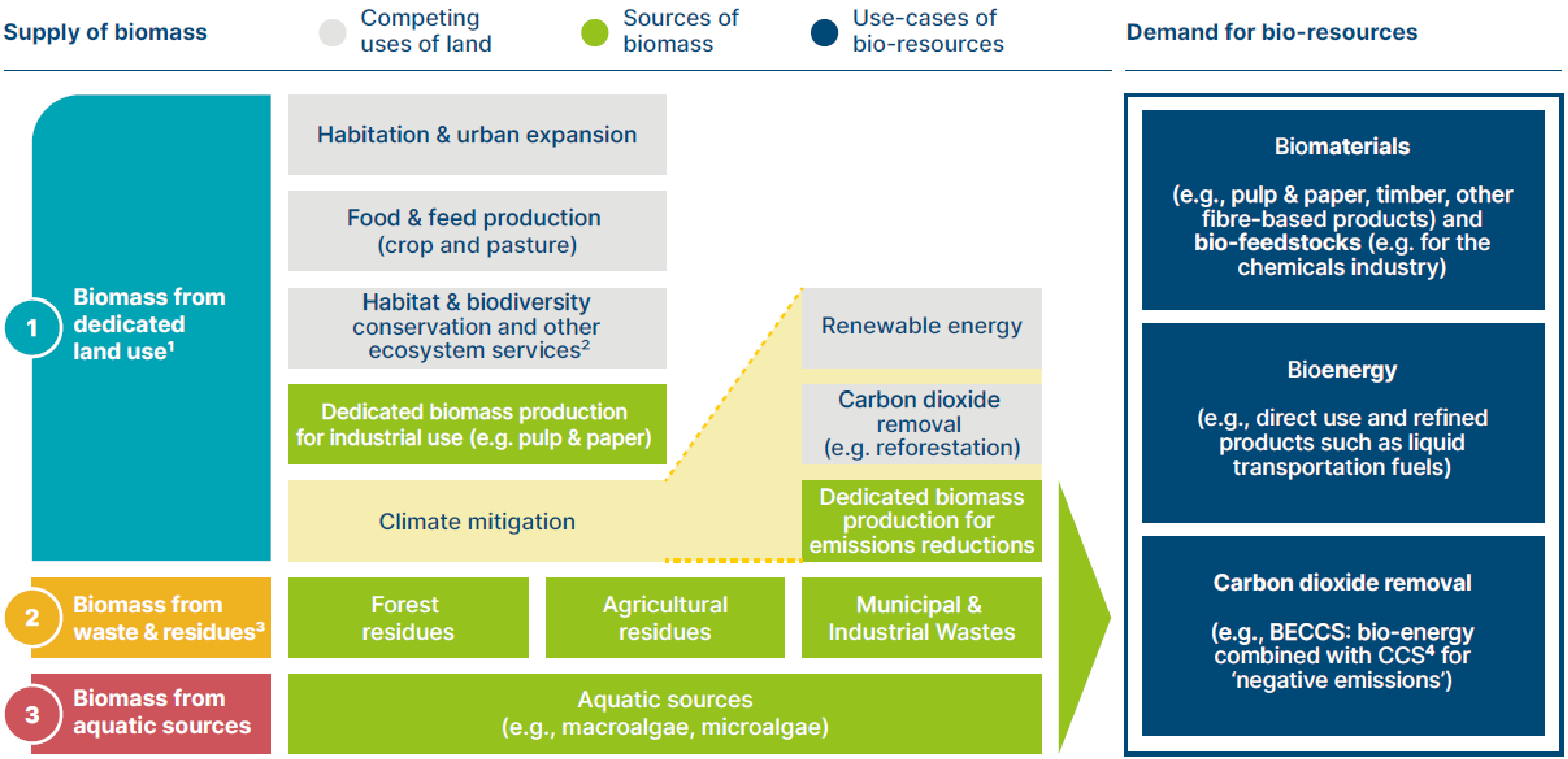


March 2022



June 2022

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).

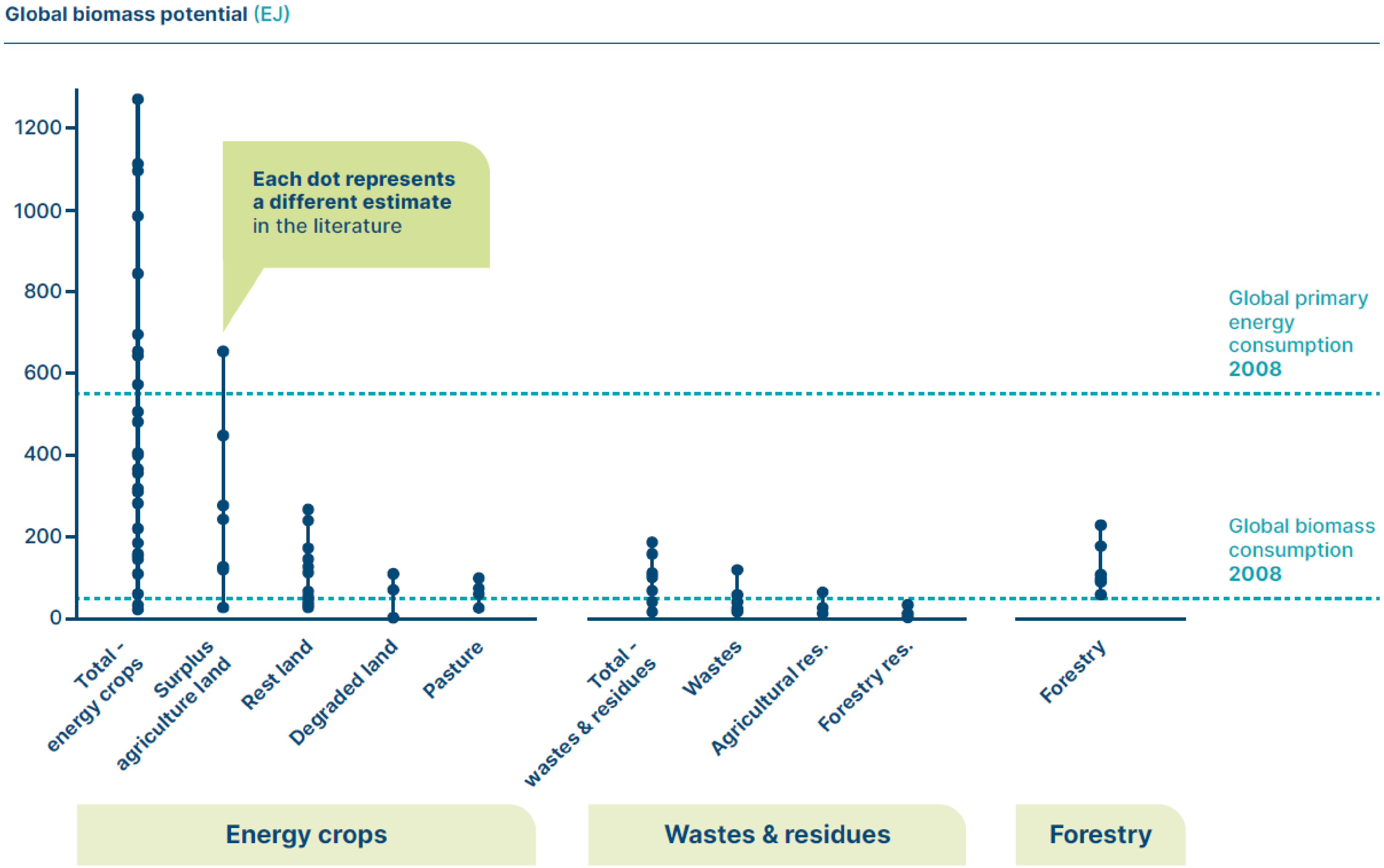
Bioresources within a net-zero emissions economy

Bioresources

Prioritised, and tightly regulated use of constrained supply of sustainable, low lifecycle emissions bioresources

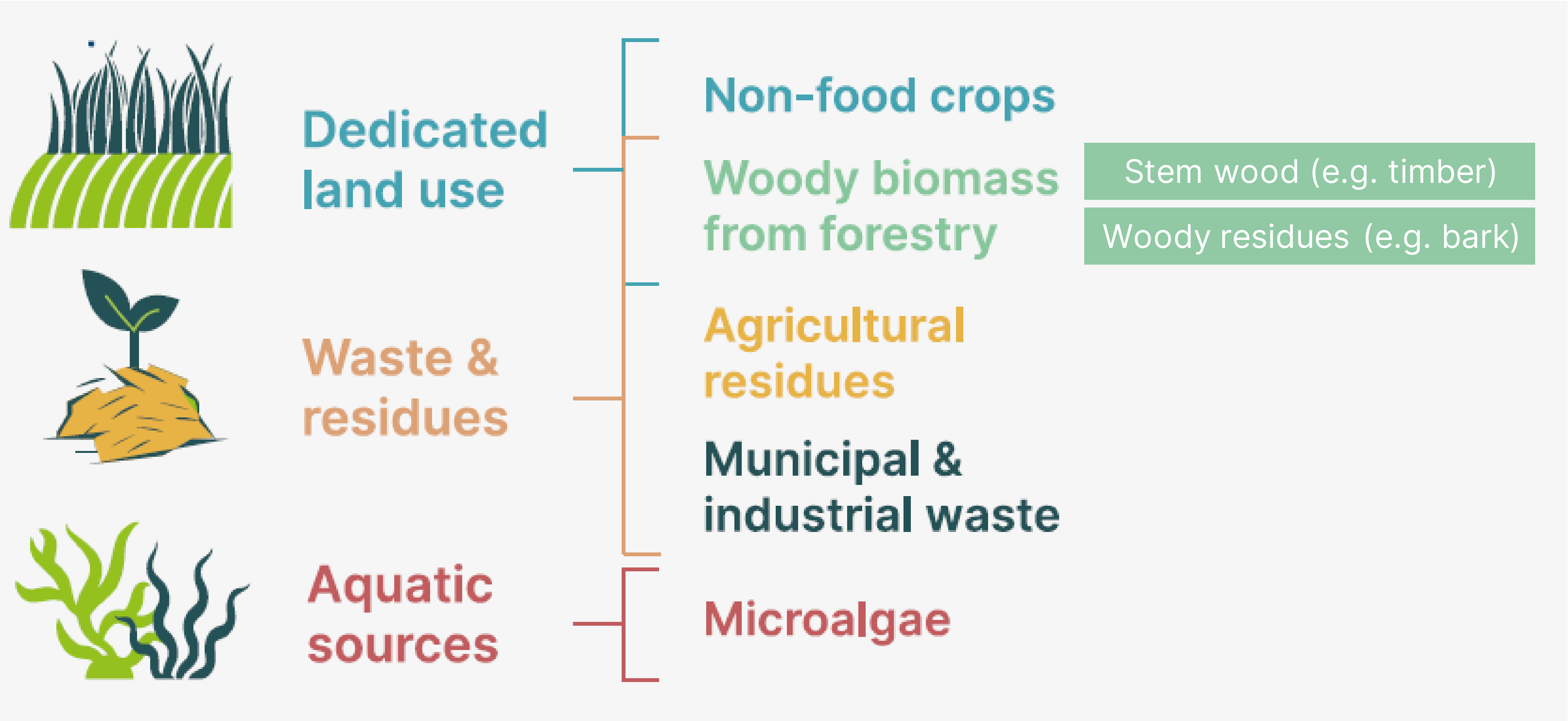
1. **Estimating sustainable biomass supply**
2. **The optimum role for biomass in a net-zero economy – prioritising the use of bioresources across sectors**
3. **The role of bio-based carbon dioxide removal**
4. **Industry and policy actions required to ensure optimal use of bioresources**
5. **Examples from current events**

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*.

Biomass for energy and industry can be produced in three ways



Not all biomass is beneficial for climate change mitigation. What is sustainable biomass?

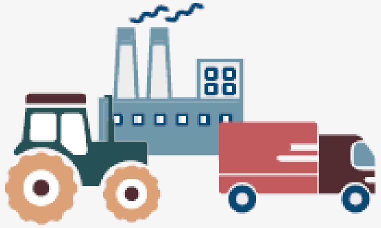
Avoid competition with other critical uses of land

No deforestation or peatland conversion

Target degraded land, with little plant growth

Respect growth periods which will delay supply

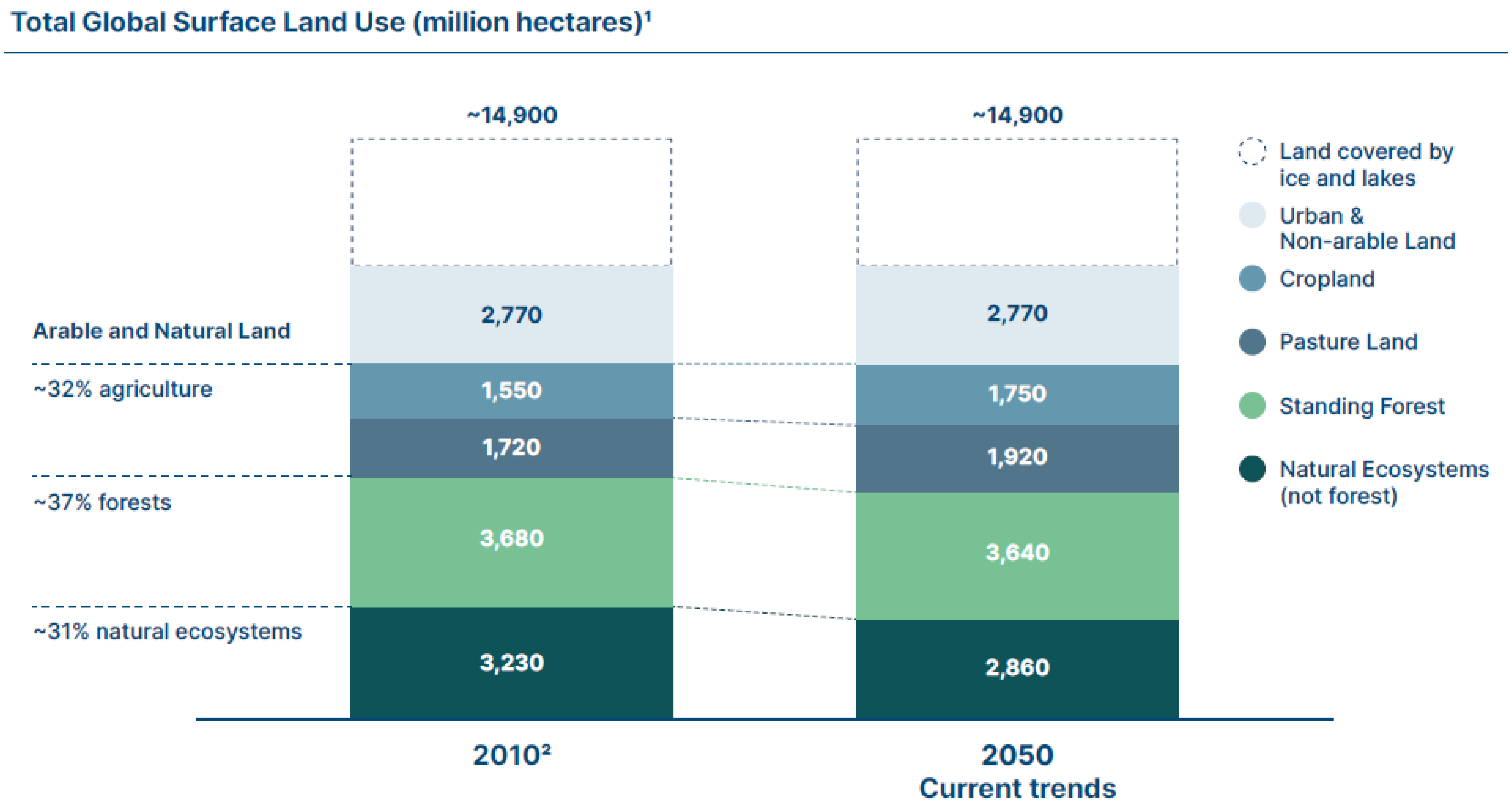
Close-to-zero emissions collection, transportation and processing



Account for other critical environmental and social considerations

No environmental or social harm

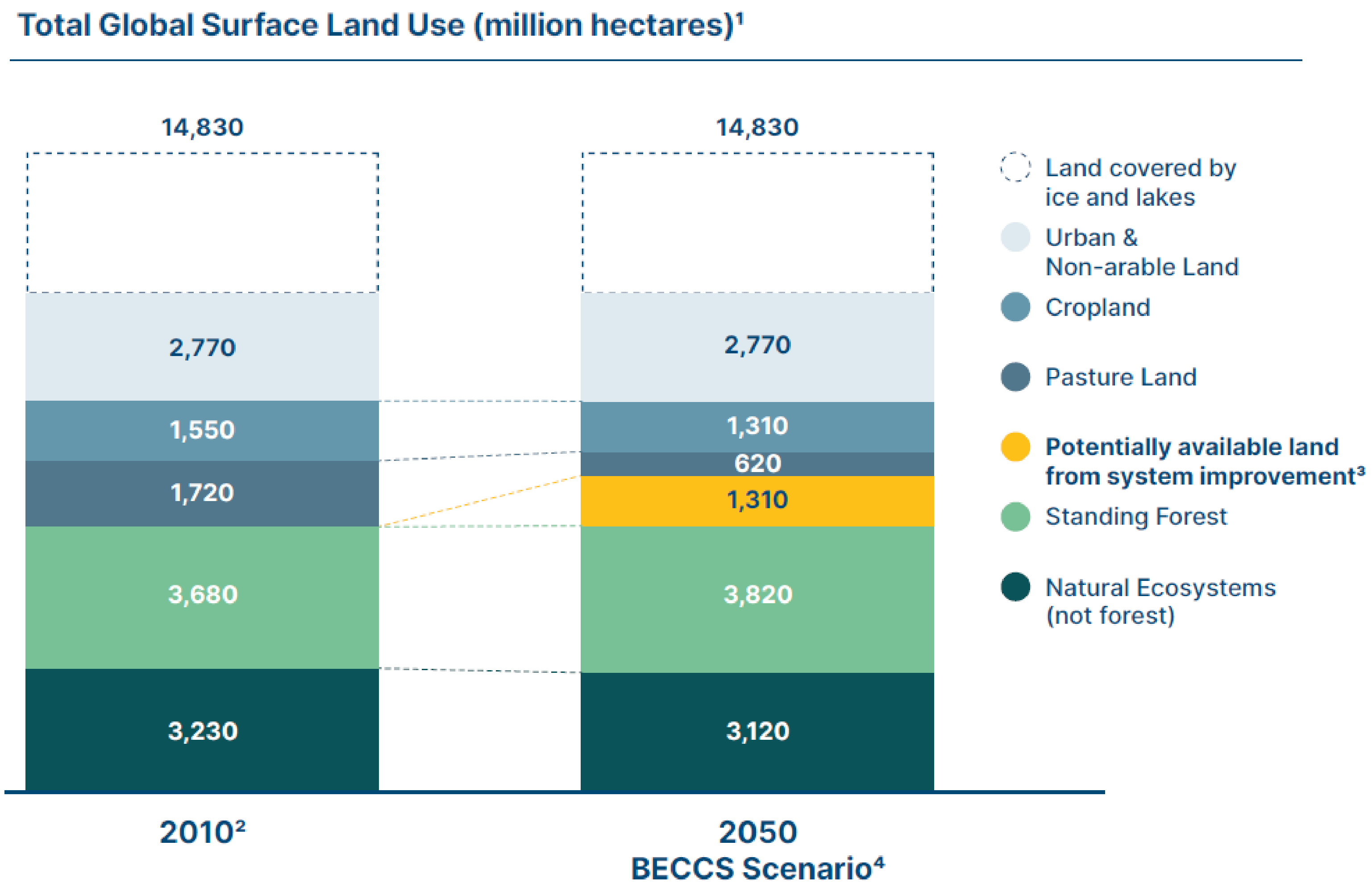
Under current trends, need for crop & pasture land will continue to grow at the expense of nature



(1) Global surface area excludes oceans. Land covered by lakes and ice (e.g., Antarctica) not available. Minor difference in totals and percentages due to rounding. (2) Baseline data forecast from 2000.

Sources: ETC analysis interpreted from IIASA GLOBIOM / FOLU Growing Better 2019 Report; Ritchie et al. (2013), *Land Use - OurWorldInData.org*.

Dietary shifts, agricultural improvements, and food waste reduction might free up >1B hectares globally



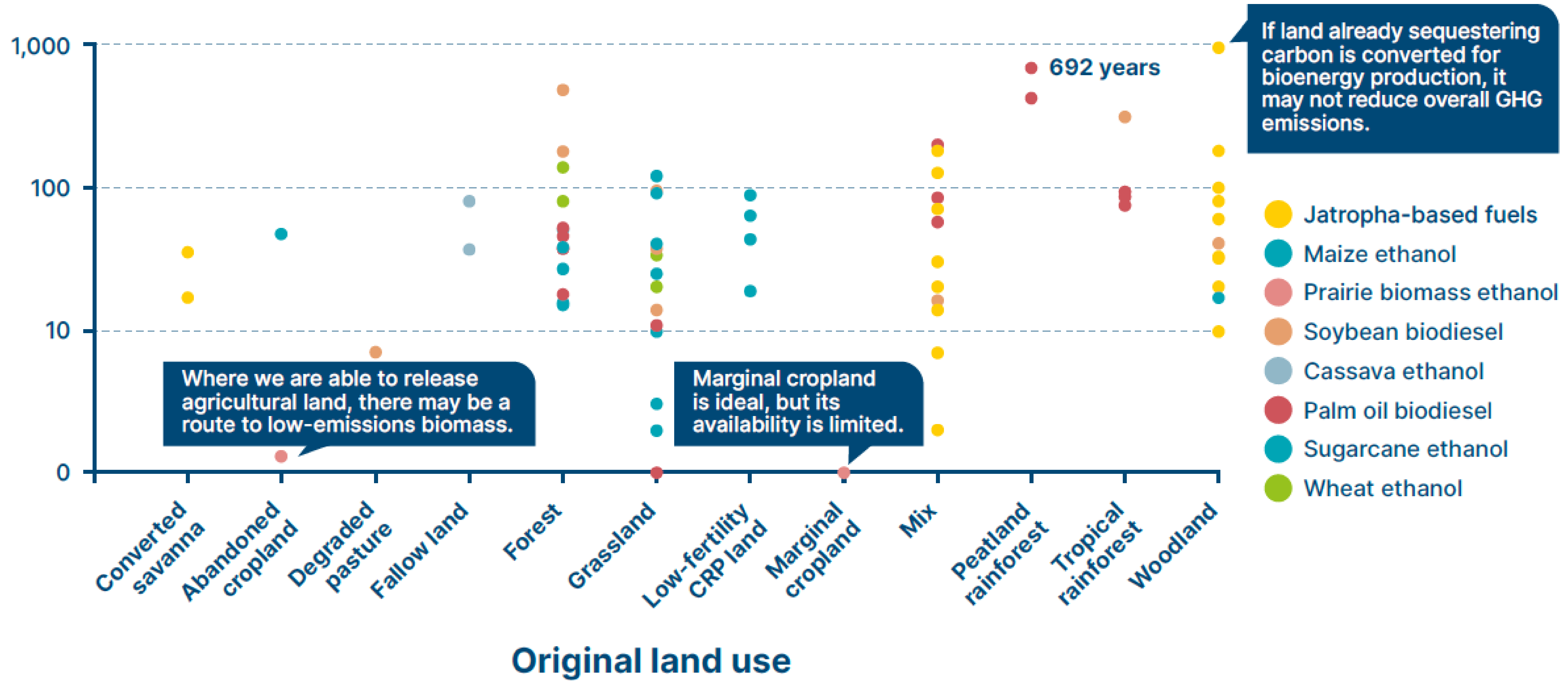
Freeing up this land would require:

- Significant dietary shifts (for example a 60% reduction in meat consumption in Europe).
- Productivity improvements.
- Reduction in food losses and waste.
- Breakthrough biotechnologies.

(1) Global surface area excludes oceans. Land covered by lakes and ice (e.g., Antarctica) also unavailable. (2) Baseline data forecast from 2000.
(3) Of which a maximum of 1,050 Mha is likely to be suitable for managed forests and/or energy crops, though only a fraction of this potential might be used as such.
(4) Unpublished scenario from FOLU/IIASA (2019), *Growing Better*.
Source: Adapted from IIASA GLOBIOM / FOLU (2019), *Growing Better: 10 critical transitions to transform food and land use.*

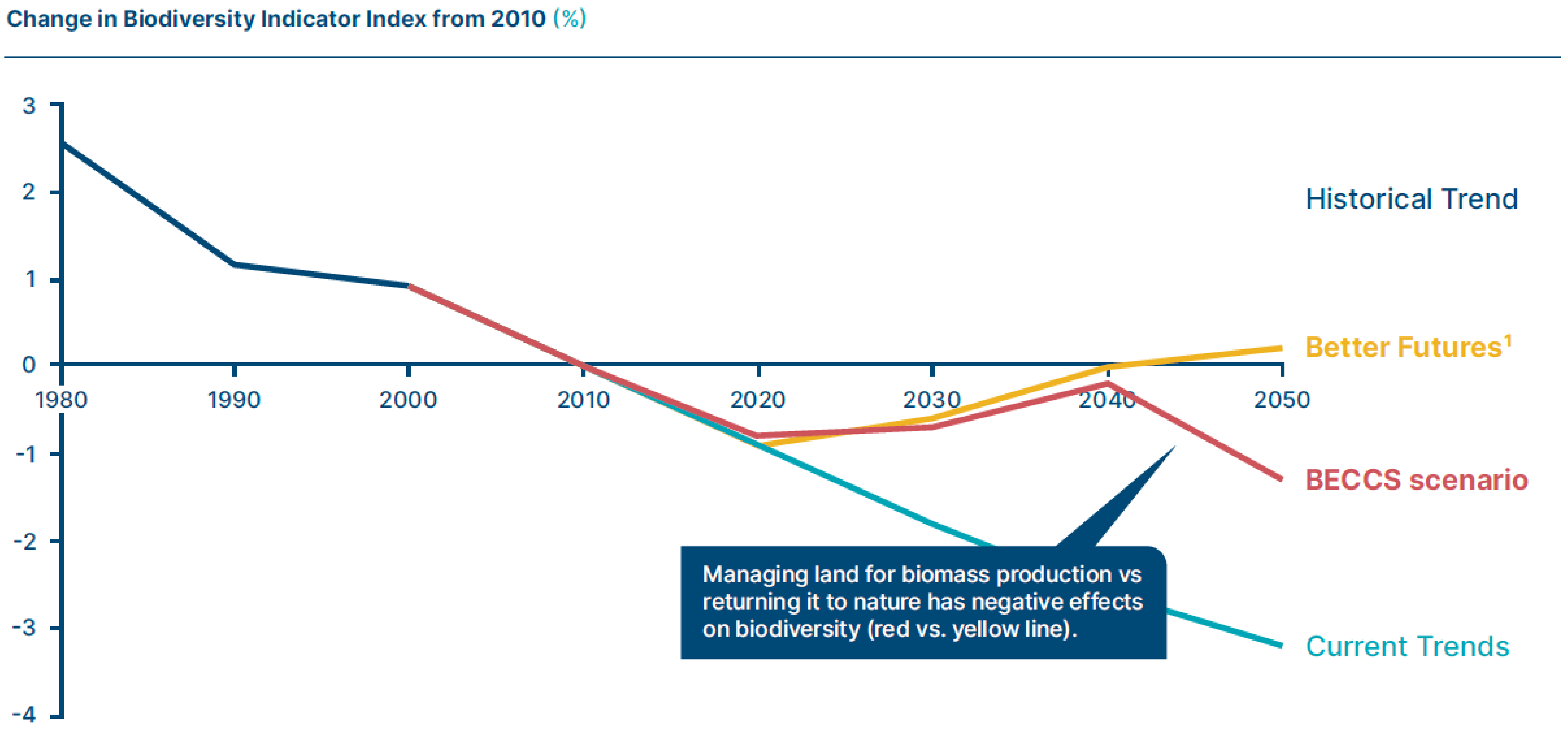
Where bioresource production involves conversion of land with high carbon stocks, it may be centuries before a climate benefit is achieved

Carbon debt payback period[1] (years), *biofuels example*



Note: GHG: greenhouse gas. (1) Carbon debt payback periods reported were compiled by Gasparatos et al. (2017) from a range of sources in the literature.
Source: Adapted from Table 1 of Gasparatos et al. (2017), *Renewable energy and biodiversity: implications for transition to a green economy*.

Intensive land management for biomass production has a negative impact on biodiversity



(1) Refers to the Better Futures scenario in the FOLU *Growing Better* 2019 report.
Sources: Food and Land Use Coalition (FOLU) *Growing Better* 2019 Report. IIASA GLOBIOM 2019; Leclère et al. (2018) for historical reconstruction; Bernes et al. (2015), *What is the impact of active management on biodiversity in boreal and temperate forests set aside for conservation or restoration?*

Each waste and residue source has its own sustainability considerations

	Potential sources	Key considerations
Waste & residues	Woody biomass from forestry	• Less than half of managed forest harvests are used for materials (e.g. timber), **main output is low quality 'fuel wood'** (currently used for heat) which could be reprioritised, alongside residues from forest management and industrial processing. • Sustainable forest management **reduces biodiversity levels** compared to natural land, but good practice can improve biodiversity levels on former agricultural land. • An industrially managed commercial forest can **hold a stable carbon stock while generating an on-going supply of biomass.** • **Supply of biomass** from new managed forests is **delayed** while trees grow.
	Agricultural residues	• Supply of residues depends on **amount of agricultural land and types of crops.** • Significant fraction (~70%) of residues **must be left on the land** for soil health. • Today ~10% of residues are used for **animal feed and bedding.**
	Municipal & industrial waste	• Mix of sources: - Municipal waste composed of **biogenic (e.g., food, paper)** and **non-biogenic (e.g., plastic, rubber)** waste, generally intermixed. - **Waste oils/fats and livestock manure** are also separately collected from industry. - **Biogas** from anaerobic digestion of manure, organic municipal waste, crop residues, & wastewater sludge. • Priority to **develop a circular economy and minimise waste.** • **Comprehensive waste collection often lacking and difficult to separate organics** from high-carbon products (e.g. plastics) in mixed waste streams. • **Waste oils and manure are valuable,** sustainable biomass sources but scale limited.

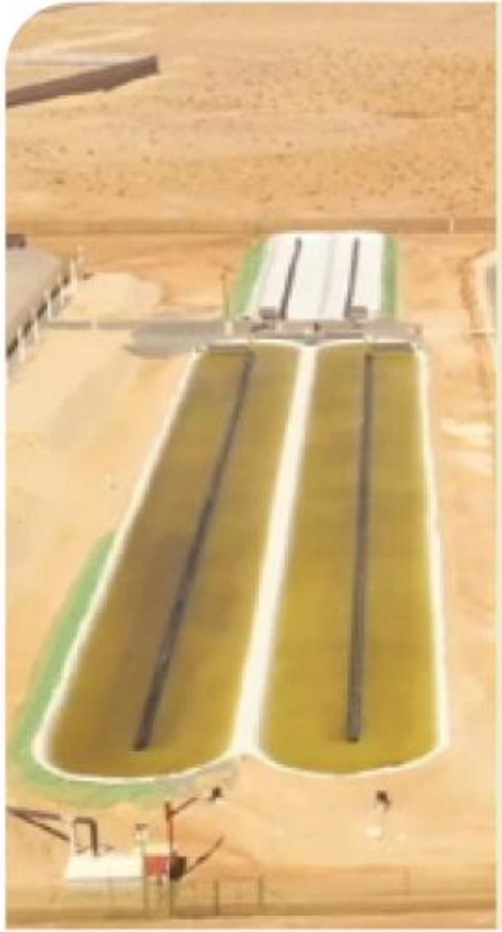
Sources: ETC (2021); UK Committee on Climate Change (2018), *Biomass in a low-carbon economy*; International Renewable Energy Agency (IRENA) (2019), *Bioenergy from boreal forests: Swedish approach to sustainable wood use*; IIASA analysis of forestry data from FAOSTAT (2010, 2018); IIASA GLOBIOM; Searle et al. (2014), *A reassessment of global bioenergy potential in 2050*.

Two main sources of aquatic biomass: macro- and microalgae. There is significant untapped potential for macroalgae production.

A Macroalgae (seaweed)

- **No need for land**
- Requires no inputs to grow
- No need for fresh water
- Grown in uncontrolled ocean environment
- No need for energy-intensive, synthetic nitrogen fertiliser
- Creates habitats for marine life
- Sequesters carbon and absorbs excess nitrogen

B Microalgae



- Grown in open ponds or photobioreactors **on land**
- Requires energy and nutrient inputs to grow
- Grown in controlled environment
- High lipid content under certain growth conditions
- Globally produced in small volumes today

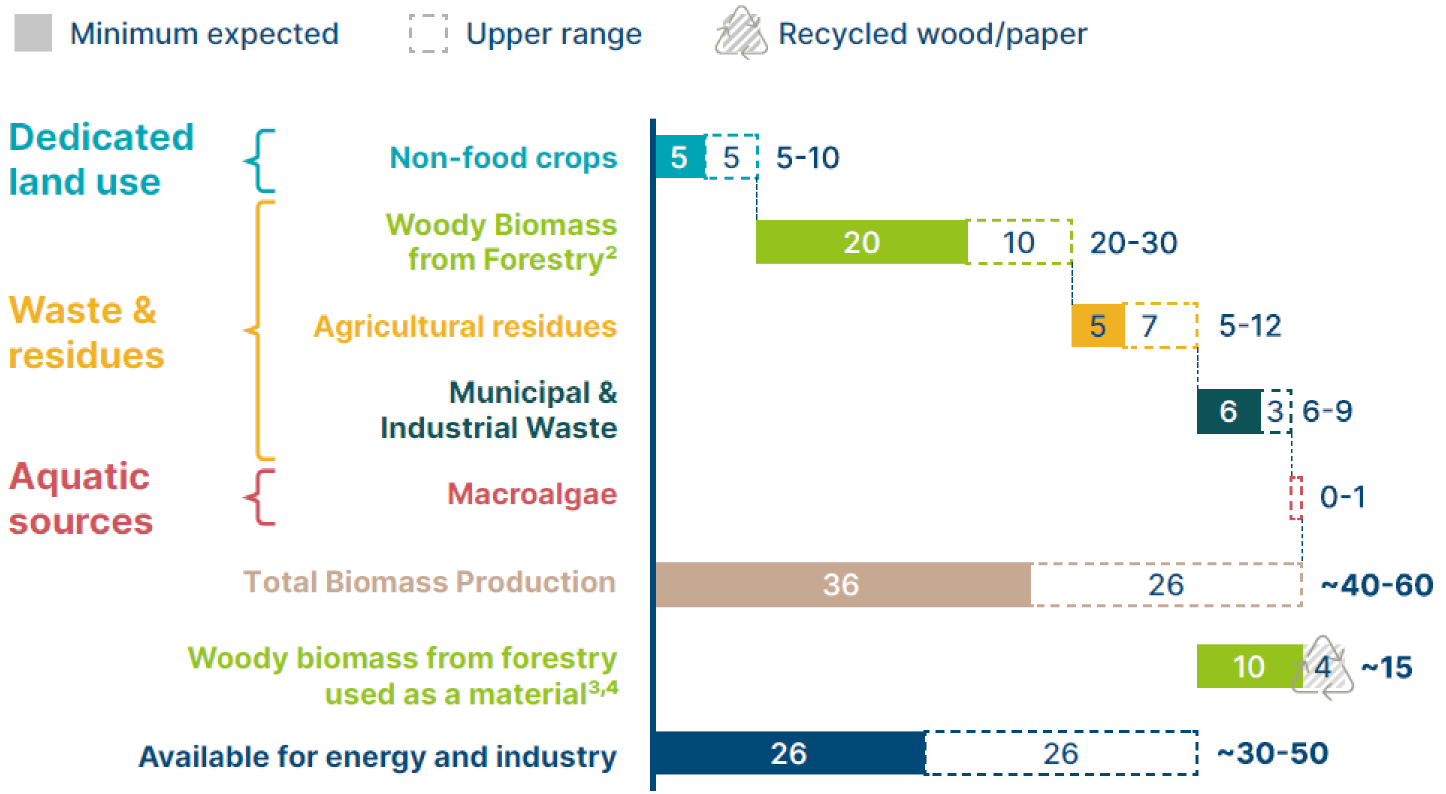
Sources: I.S. Tan et al. (2020) *Macroalgae – the Seaweed site*; Microalgae image curtesy of SuSeWi (2021).

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

Prudent estimate

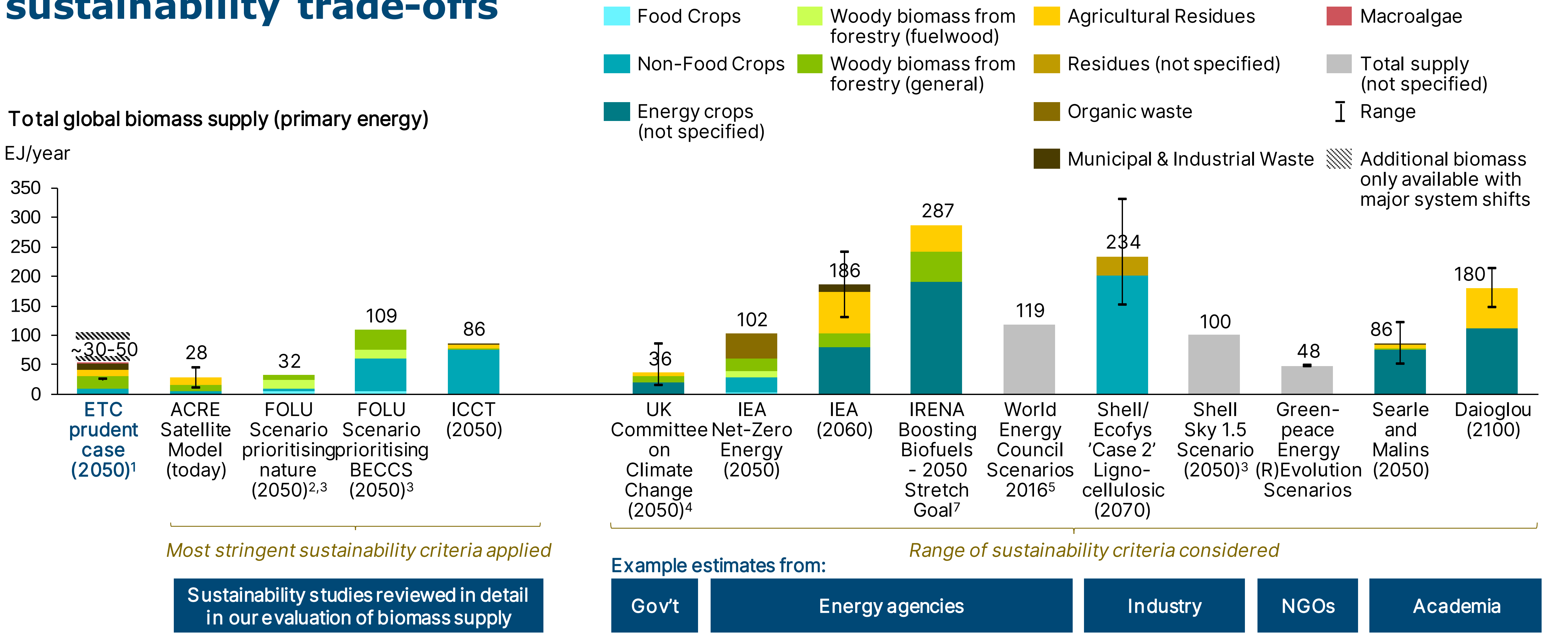
Global sustainable biomass[1] supply (2050) – illustrative scenario
EJ/year (primary energy)

Illustrative



(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).

ETC estimate is consistent with sustainability-focused estimates but lower than many others due to different assumptions around land use and sustainability trade-offs



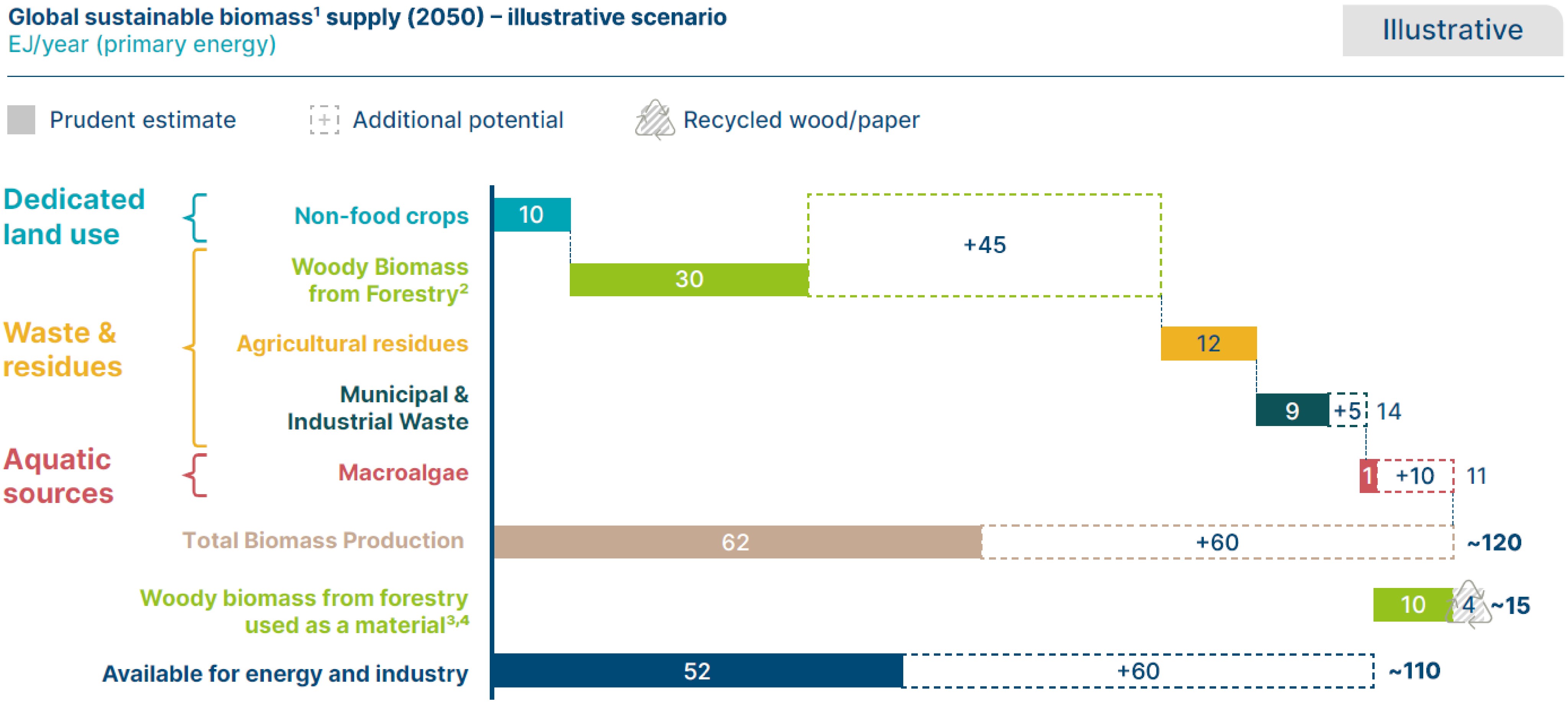
(1) ETC estimate shows high end of prudent range, excludes ~10 EJ of woody biomass from forestry used as materials (based on current harvests from commercial forestry; may increase if forestry practices expand); dashed areas shows maximum potential from seaweed, waste and freeing up agricultural land (~60 EJ); excludes traditional fuelwood (~5-15 EJ) and biomass used in recycled materials (~4 EJ today). (2) This scenario is effectively a 'no BECCS' scenario. (3) Excludes traditional uses of biomass (fuelwood, charcoal and dung used in the residential sector, predominantly in developing countries). (4) Mid scenario. Figures represent 'tradable' bioenergy feedstock suitable for international trade (e.g. forestry and energy crop feedstocks) while excluding 'non-tradable' feedstocks not suitable for long-distance trade due to low energy densities or other physical properties (e.g. biogenic waste). (5) Unfinished Symphony Scenario. (6) Organic waste streams include agricultural residues, food processing, and municipal and industrial organic waste streams. (7) Recent 1.5°C Scenario from IRENA estimates primary bioenergy demand to be 153 EJ in 2050.

Sources: ACRE satellite model; FOLU/IIASA (2019), *Growing Better: Better Futures*; ICCT – Searle et al. (2015) *A reassessment of global bioenergy potential in 2050*; Deng et al. (2015), *Country-level assessment of long-term global bioenergy potential*; IEA (2017), *Technology roadmap: Delivering Sustainable Bioenergy*; IEA (2017), *Energy Technology Perspectives* (and sources within); UK Committee on Climate Change (2018), *Biomass in a low-carbon economy*; Shell (2018), *Sky 1.5 Scenario*; IEA (2021) *Net-Zero by 2050 - A Roadmap for the Global Energy Sector*; IRENA (2021), *World Energy Transitions Outlook*.

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)



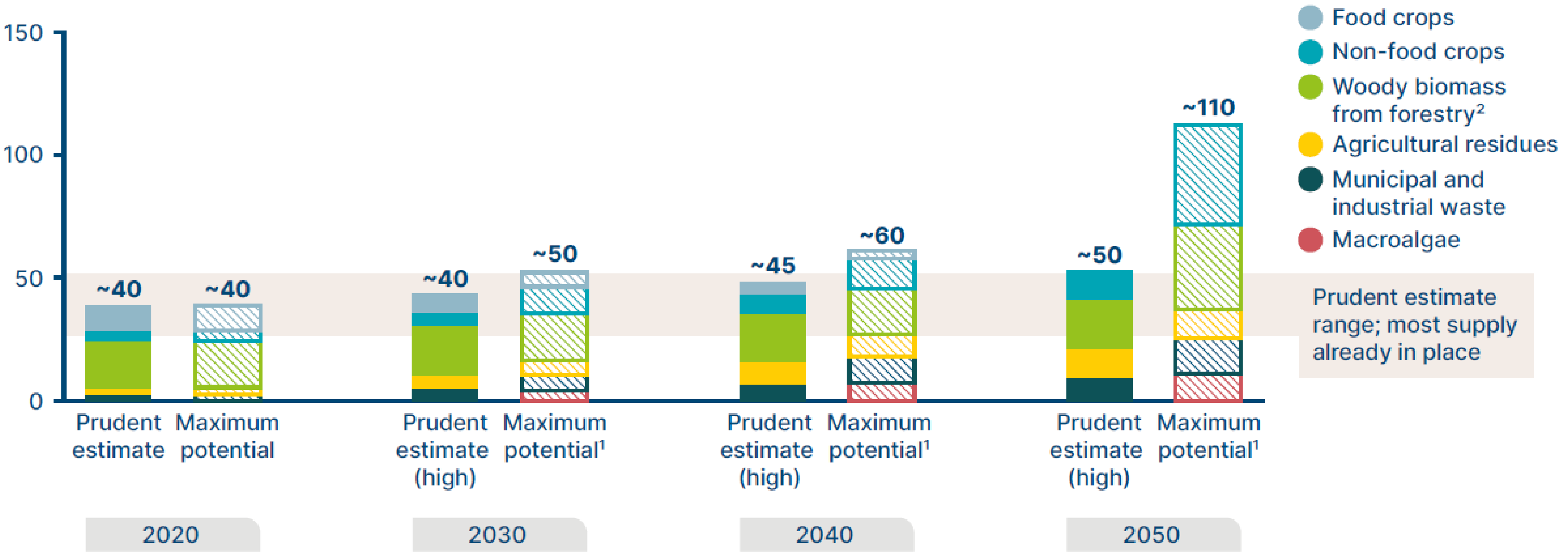
(1) The term 'sustainable biomass' is used to describe organic material that is renewable, has a lifecycle carbon footprint equal or close to zero (including considerations for the opportunity cost of land), and for which the cultivation and harvesting practices used are mindful of ecological considerations 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).

In prudent scenario, supply of biomass to remain broadly flat; if land can be released from agriculture, additional bioresources are likely to become available from late 2030s

Global sustainable biomass supply (2020-2050) – illustrative scenarios[1]

EJ/year (primary energy) excluding stemwood for materials[2] and traditional biomass use[3]

Illustrative



(1) Illustrative scenario for maximum potential supply over time of non-food crops and woody biomass from forestry is based on modelling by IIASA GLOBIOM / FOLU in an unpublished BECCS scenario. Other sources of biomass were assumed to scale linearly to 2050 maximum potential values. (2) Excludes stemwood for materials uses, estimated to be c.10 EJ/year based on IIASA analysis of FAO industrial roundwood figures after removing by-products used for energy. This could increase if managed forestry practices are expanded. (3) Excludes biomass for traditional uses (i.e., woody biomass and dung used as fuel for cooking and heating purposes, mostly in developing countries). This is estimated to be ~25 EJ of biomass today and is expected to be phased out over time in order to reduce air pollution and deforestation. (4) Maximum achievable only under extremely ambitious systems change scenarios.

Sources: IIASA GLOBIOM / FOLU (2019), *Growing Better: 10 critical transitions to transform food and land use*; IEA (2021) *Net-Zero by 2050 - A Roadmap for the Global Energy Sector*.

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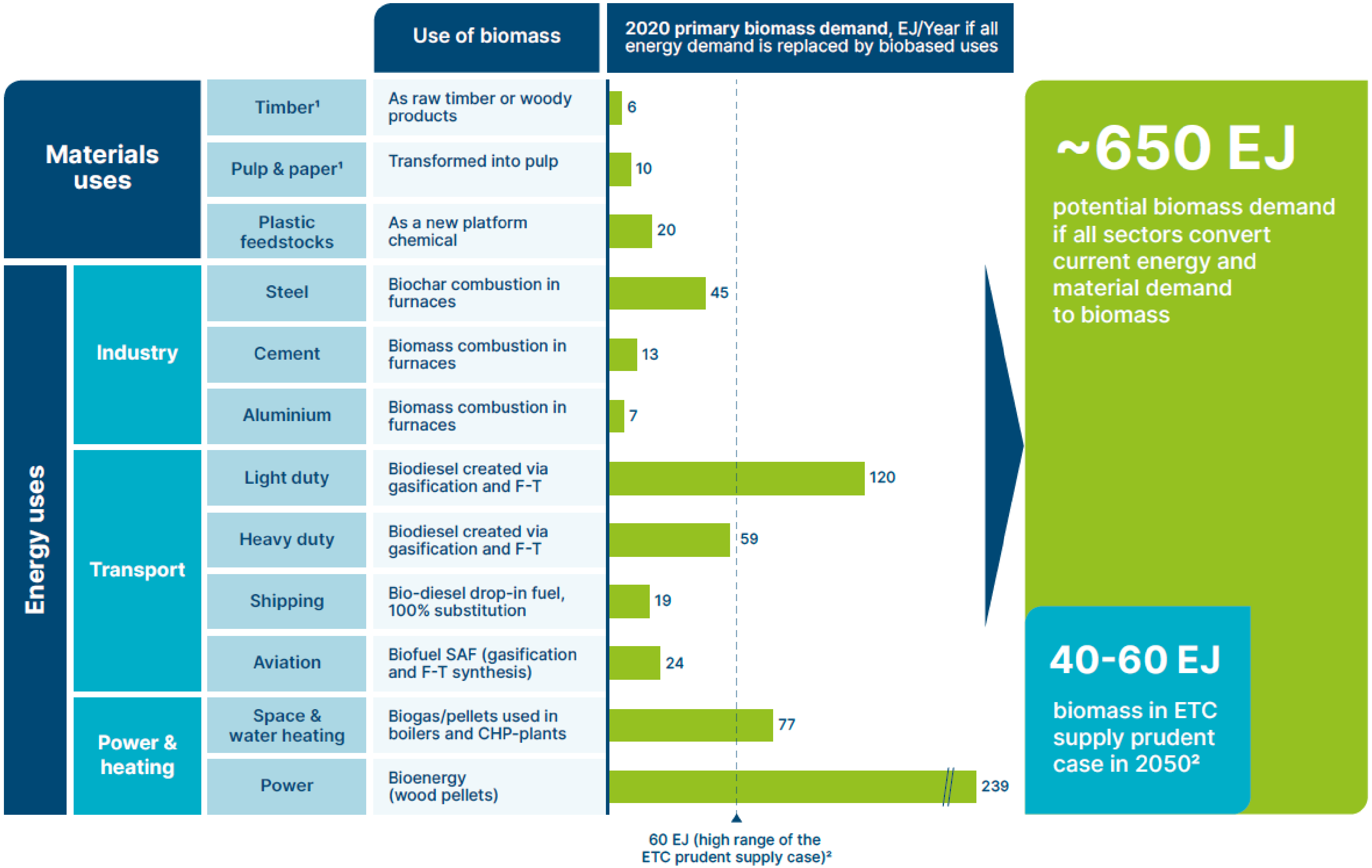
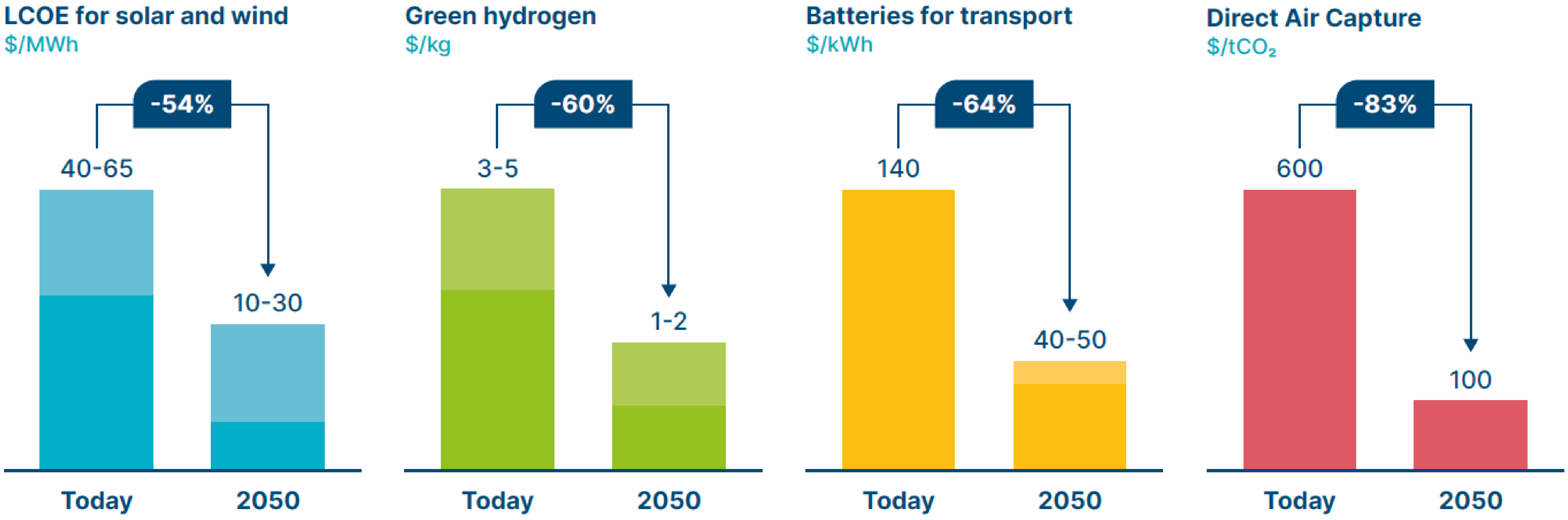
Bio-based decarbonisation can only be a small share of the decarbonisation technology mix



Notes: F-T: Fischer-Tropsch. (1) Wood resource balances show a ~13% gap between FAO sources (c.14EJ, primary and secondary resources) and uses of woody biomass. (2) Excludes c.4 EJ of recycled woody biomass. (3) Example bioresource for comparison; not exhaustive.
Sources: IEA ETP 2017 & 2020; Material Economics

Falling costs of renewables and batteries, and prospects for much lower-cost green hydrogen, means these options are likely to be more cost-effective in most applications



Notes: Ranges for cost numbers show that costs are likely to vary by location with lower bound being most favourable locations, and upper bounds representing a global average.
Sources: SYSTEMIQ analysis for the ETC, based on ETC (2020) *Making Mission Possible* and Material Economics (2021) *EU Biomass Use in a Net-Zero Economy - A Course Correction for EU biomass.*

Bio-based options are ~8-70x more land intensive than all alternative decarbonisation options

Shipping example

Type of resource	Resource	Feedstock/s	Energy efficiency of resource production and use			Efficiency of land use	
			Feedstock to resource[4] GJ resource / GJ feedstock	**Resource to use case output[3]** GJ output / GJ resource	**Feedstock to use case output** GJ output / GJ feedstock	**Feedstock from land** GJ feedstock / ha	**Land use requirement** ha / GJ output / year
Bio	Bio-diesel	Lignocellulosic biomass	60%	x 49%	= 29%	x 35[1] <350[1]	0.10 0.01
Non-bio, low-emissions	'Green' ammonia	'Green Hydrogen' (renewable electricity)	55%	x 49%	= 27%	x ~2,000[2]	0.002

5-50x less land intensive than bio routes

(1) Maximum land productivity of biomass feedstock growth presented (i.e., top of productivity range for lignocellulosic biomass crop miscanthus grown on fertile, dedicated land (~25 tonnes/ha/yr = ~350 GJ/ha/yr)). Biomass from waste and residues (e.g., primary and secondary forest residues from managed forest land) expected to be ~10-fold less. The figure of 35 represents area of land needed for other processes (e.g., forestry for wood-based materials) as only residual fractions would be sourced for energy. (2) Renewable electricity assumed to be generated from solar PV at 600 MWh/ha/yr. Assumes 80% energy efficiency of green H2 production from renewable electricity. (3) Assumes use of internal combustion engine (ICE) (4) Assumes global long-haul shipping fuel demand of ~19.5 EJ/yr and 49% conversion from fuel to engine output energy. Sources: ETC analysis; P. Lauri et al. / Energy Policy 66 (2014) 19–31; PlanEnergi (2018) Solar cell and solar heating systems on arable land; 2019 National Academies-Negative Emissions Technologies and Reliable Sequestration; Giddey S, Badwal SPS, Munnings C, Dolan M (2017) Ammonia as a Renewable Energy Transport Media; ETC (2018) Mission Possible Sectoral Focus: Shipping

Bio-based routes have higher technology readiness levels today but face carbon abatement and transition issues by mid-century

- Criteria favourable to bio (green)
- Bio & non-bio are equivalent (generally or in specific locations / timelines) (yellow)
- Criteria favourable to non-bio (red)

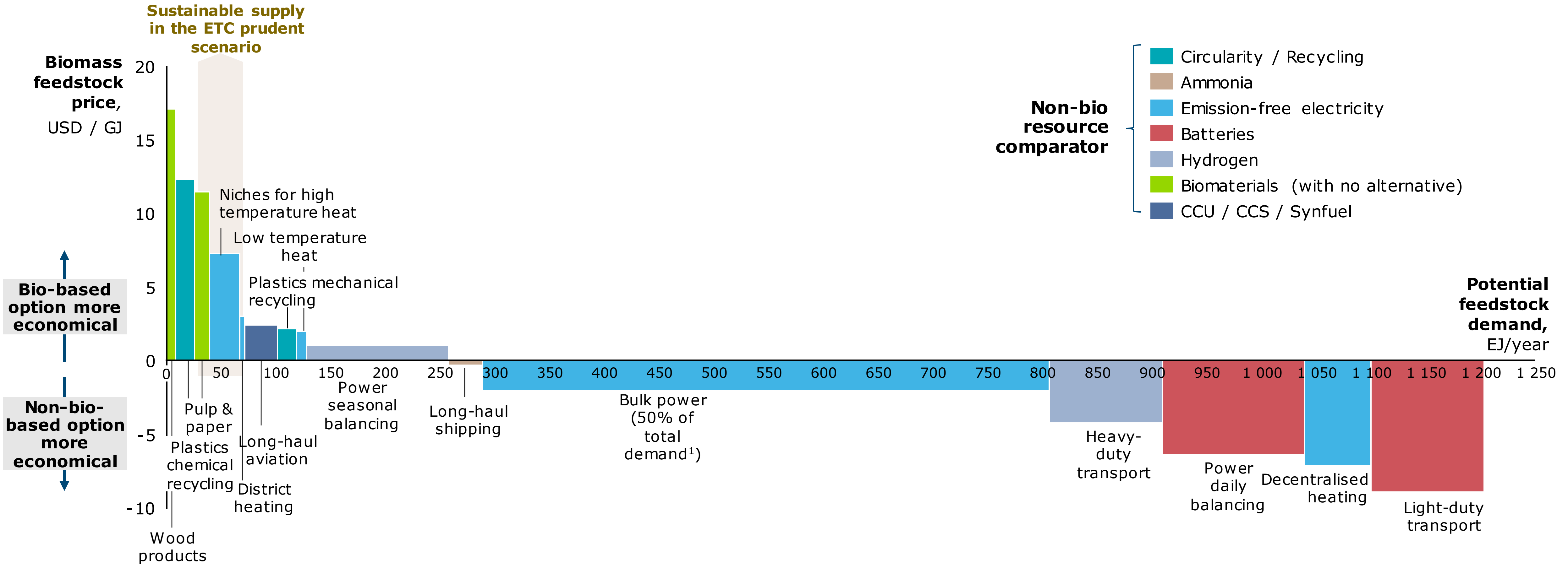
			Key decarbonization route		How does the bio-route compare with the non-bio options in terms of...	
			Bio	Non-bio	Feasibility today	Carbon abatement
Material uses	Timber		Timber	None	No non-bio alternative	
	Pulp & paper feedstock		Pulp	None		
	Plastics feedstocks		Chemical feedstock	Recycling	Mechanical recycling at commercial scale; primary routes have low TRLs	Non-bio route based on clean electrification technologies is zero carbon (even at point of use). The bio route CO_2 abatement potential: • Is highly dependent on source and supply chain of biomass • Emits carbon at point of use, except if combined with CCS (not feasible in transport sectors). This also adversely affects local air quality.
Energy uses	Industry	Steel	Biochar reduction / heat	Electrification / CCS / Hydrogen	Non-bio routes at pilot stage	
		Cement	Biomass combustion	CCS	CCS not applicable to process emissions	
		Industrial heating	Biomass boiler	Heat pump	Heat pumps not applicable to high temperatures	
	Transport	Light duty	Bioethanol	BEV	BEVs and biofuels at commercial scale	
		Heavy duty	Biodiesel	FCEV	FCEV trucks close to commercial stage	
		Shipping	Biofuels	Ammonia in ICE	Ammonia ships at pilot stage	
		Aviation	Bio jetfuels	Synfuels	Synfuels production at pilot stage	
	Power & heating	Power bulk generation	Biomass plant	RE	Renewables deployed at scale	
		Power intraday		RE + batteries	Battery storage starting its commercial deployment	
		Power interday		Hydrogen storage	Hydrogen storage at pilot stage	
		Residential heating	Biomass boiler	Electric heat pump	Heat pumps deployed at scale	

Source: ETC analyses (2021).

Use of biomass in all sectors could far outstrip supply

Cost-parity curve – Breakeven biomass cost vs. alternative leading non-biogenic solution; global (2050 outlook)

"At what biomass feedstock price is the bio option cost effective?"



Note: Currently excludes carbon removal applications. 1. We limit the potential demand for biomass for bulk power to 50% of the demand of the segment in order to make the graph readable.
Source: Material Economics and ETC analysis (2021)

Materials and feedstocks are highest priority uses of bio

Cost-parity curve – Breakeven biomass cost vs. alternative leading non-biogenic solution; global (2050 outlook)

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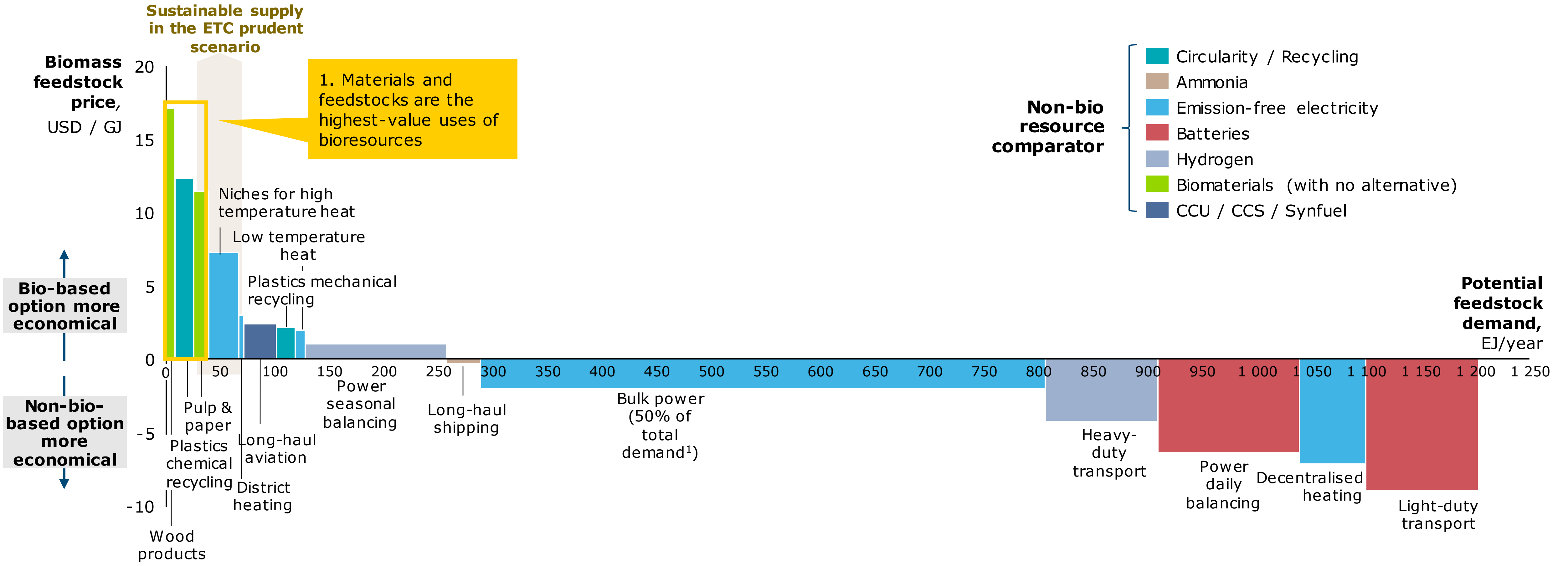

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Source: Material Economics and ETC analysis (2021)

Current uses such as power and transportation can use non-bio-based alternatives

Cost-parity curve – Breakeven biomass cost vs. alternative leading non-biogenic solution; global (2050 outlook)

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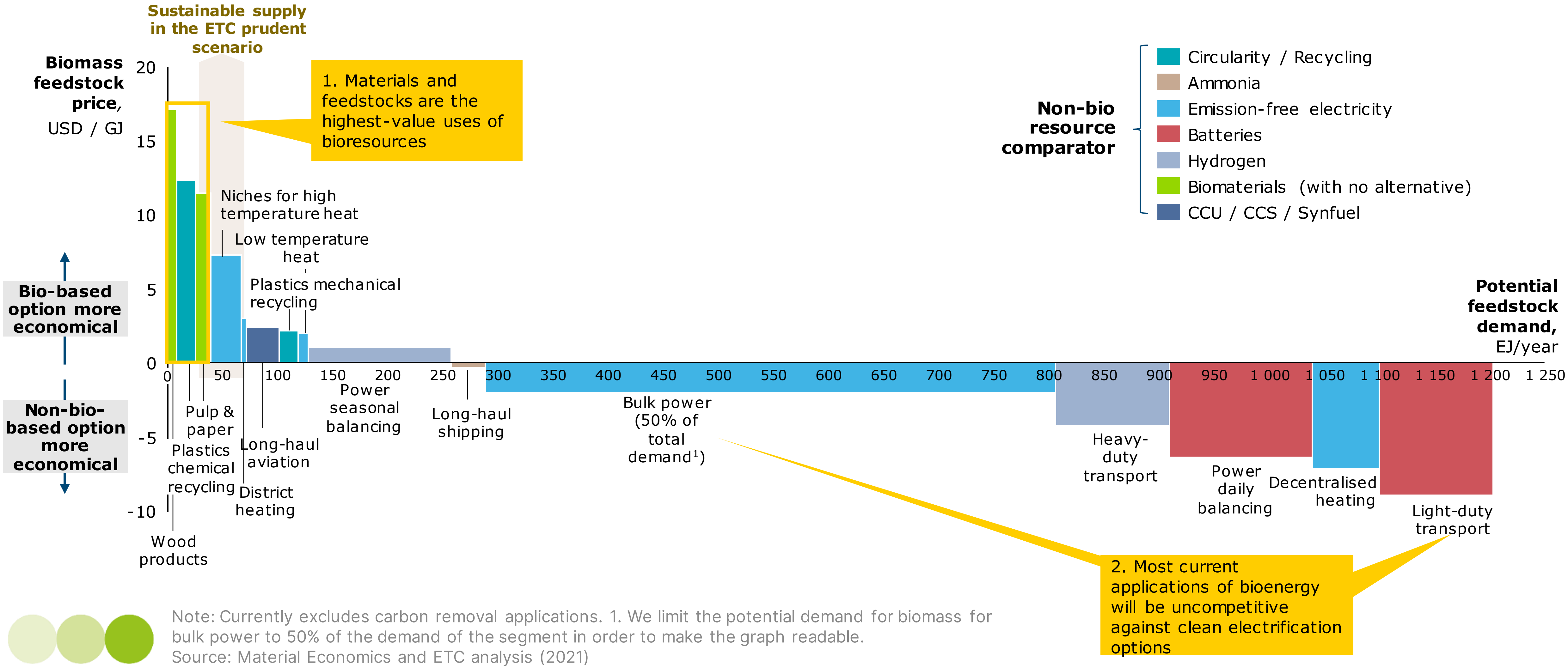
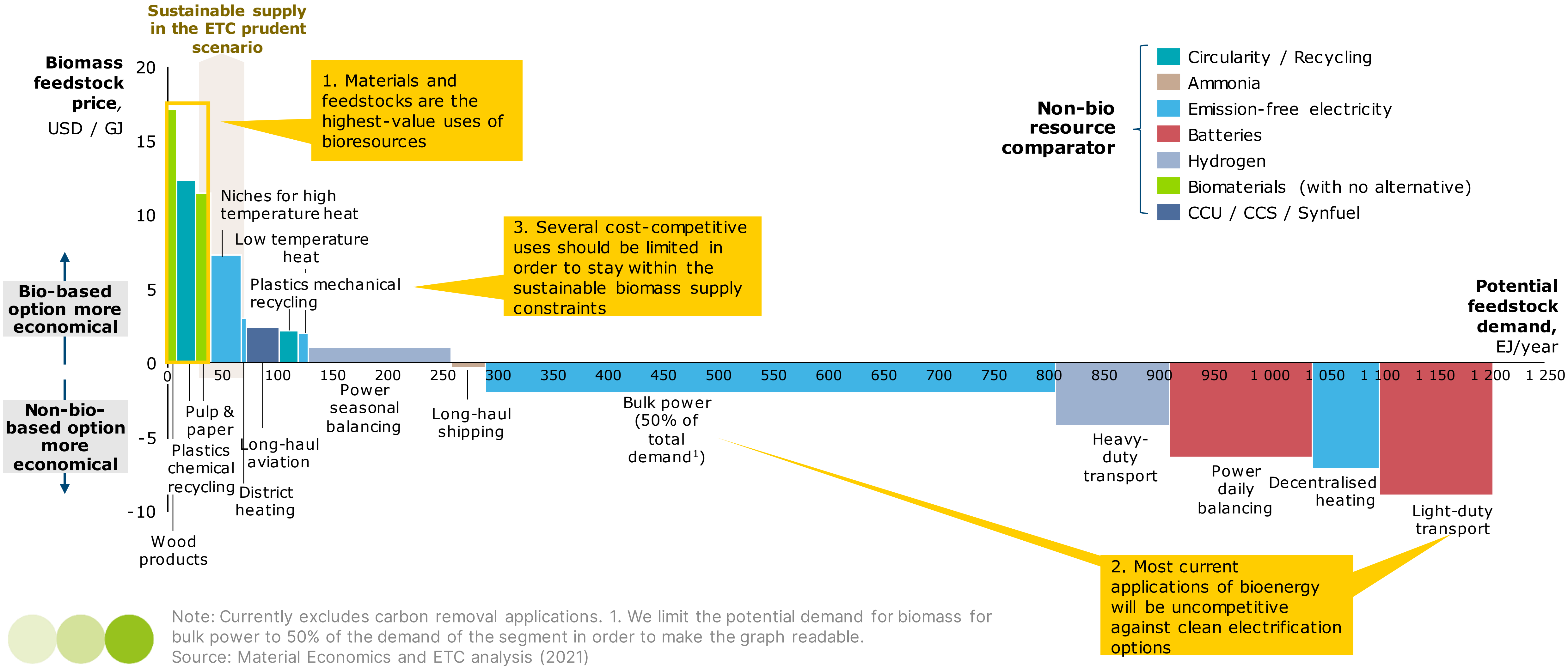


Note: Currently excludes carbon removal applications. 1. We limit the potential demand for biomass for bulk power to 50% of the demand of the segment in order to make the graph readable.
Source: Material Economics and ETC analysis (2021)

Not all cost-competitive uses will be able to use bioresources given limited supply

Cost-parity curve – Breakeven biomass cost vs. alternative leading non-biogenic solution; global (2050 outlook)

"At what biomass feedstock price is the bio option cost effective?"



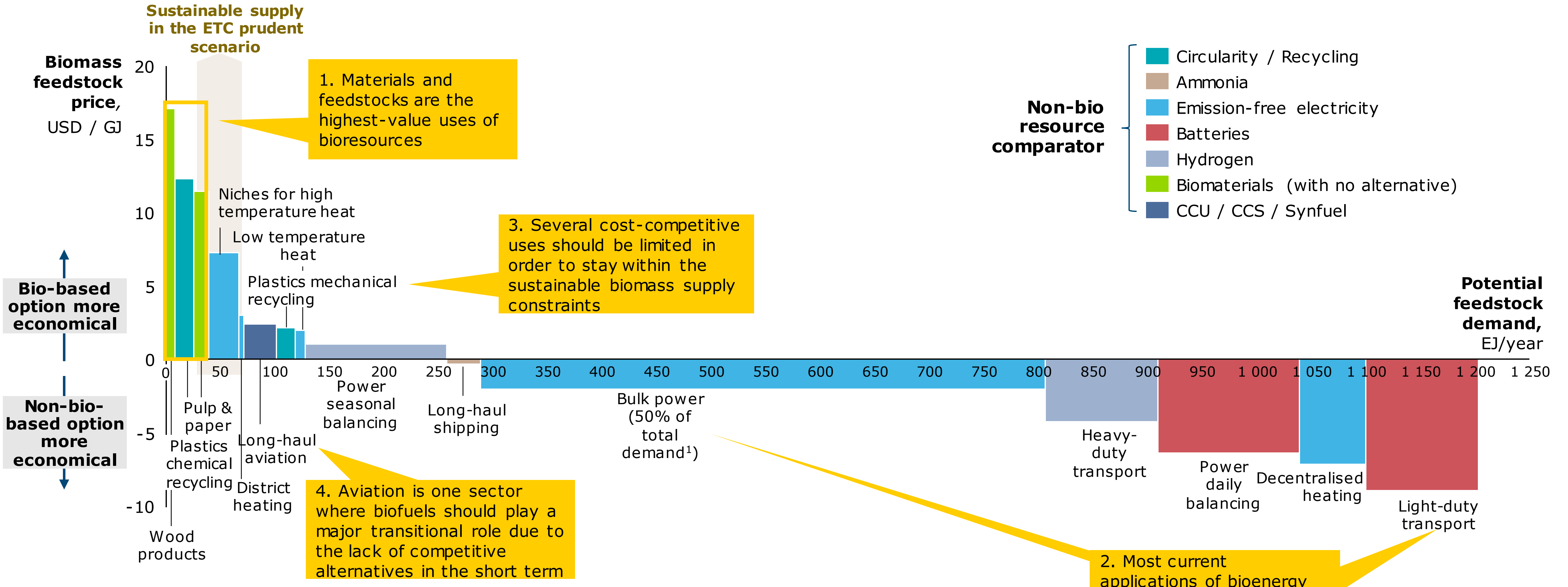
Note: Currently excludes carbon removal applications. 1. We limit the potential demand for biomass for bulk power to 50% of the demand of the segment in order to make the graph readable.

Source: Material Economics and ETC analysis (2021)

Aviation biofuels are a priority use given current lack of alternatives

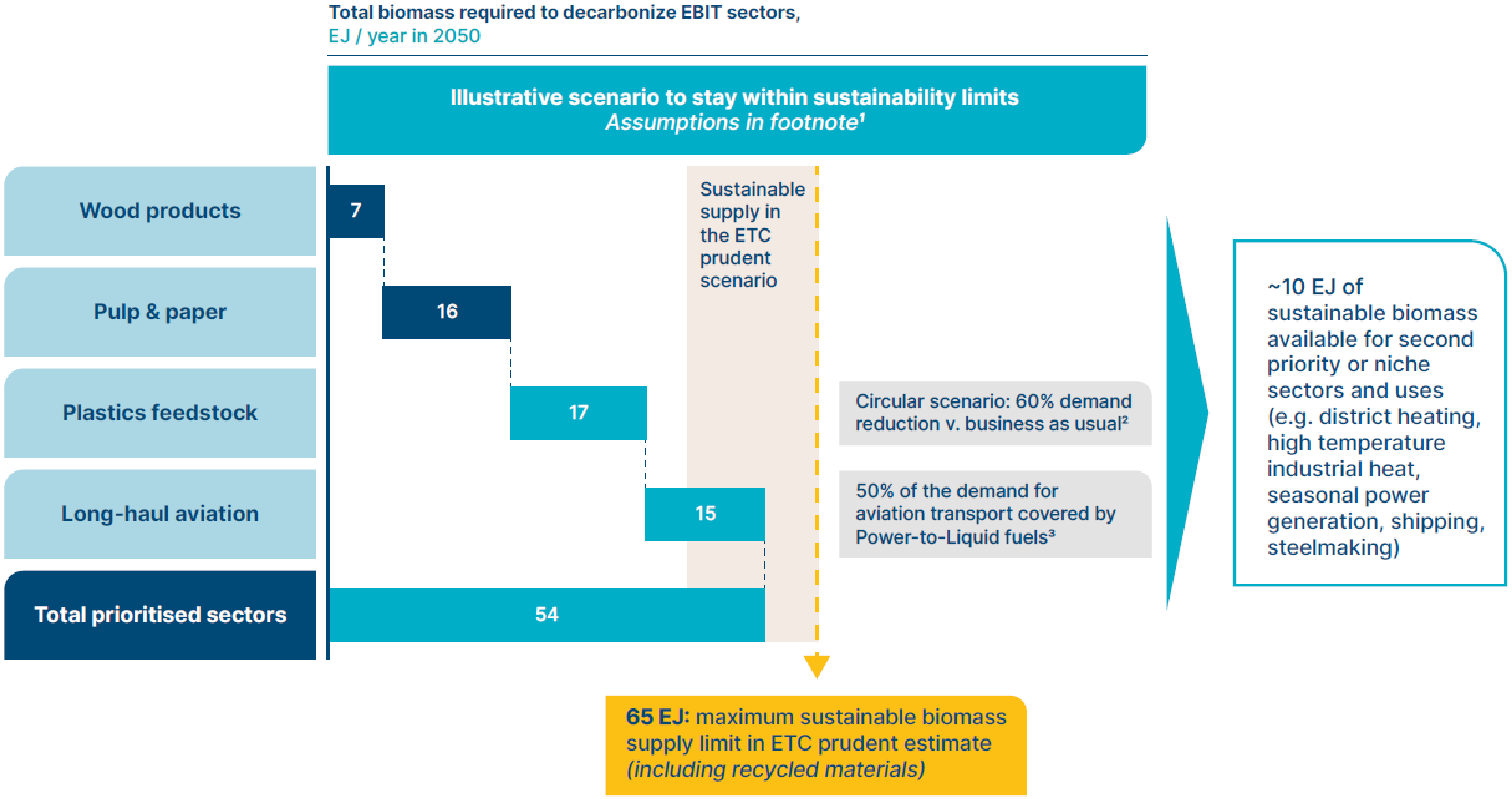
Cost-parity curve – Breakeven biomass cost vs. alternative leading non-biogenic solution; global (2050 outlook)

"At what biomass feedstock price is the bio option cost effective?"



Note: Currently excludes carbon removal applications. 1. We limit the potential demand for biomass for bulk power to 50% of the demand of the segment in order to make the graph readable.
Source: Material Economics and ETC analysis (2021)

Balance between demand and supply of supply biomass to decarbonise the economy can be reached under conditions



1. Wood 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.

Bioresources within a net-zero emissions economy

Bioresources

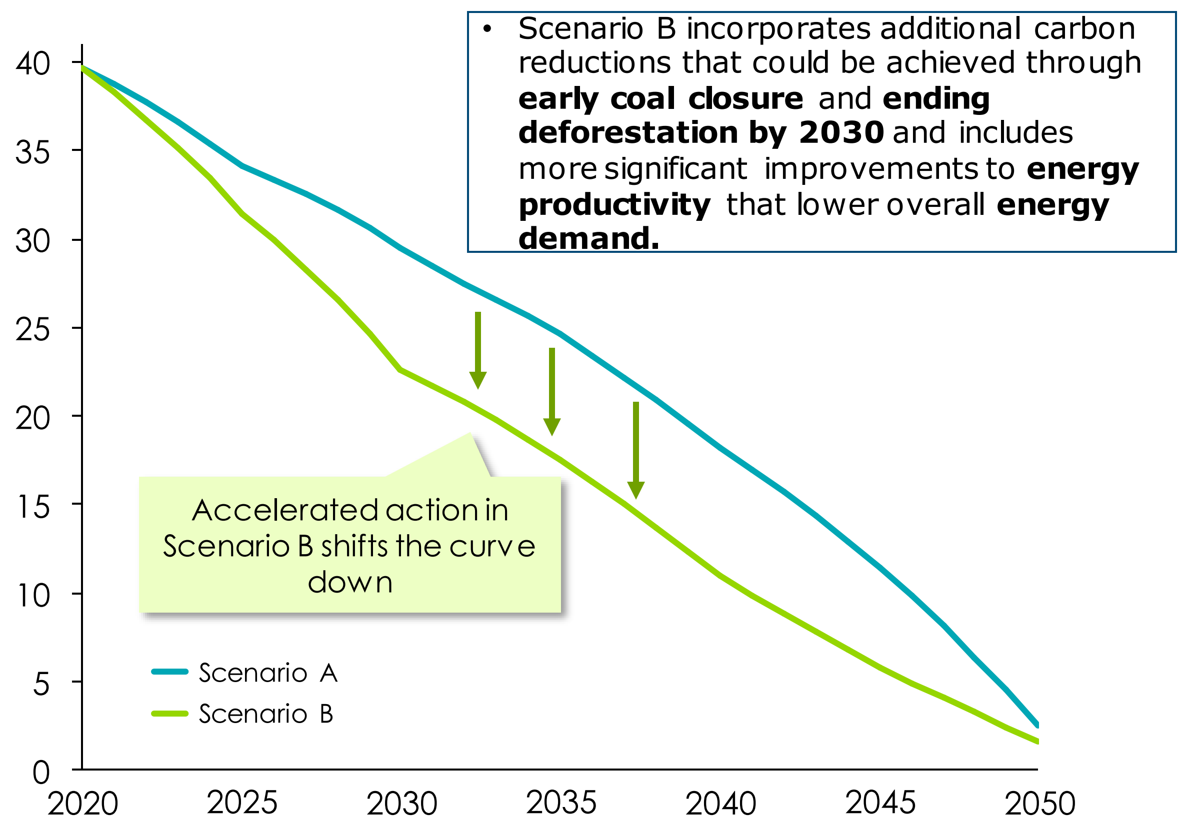
Prioritised, and tightly regulated use of constrained supply of sustainable, low lifecycle emissions bioresources

1. **Estimating sustainable biomass supply**
2. **The optimum role for biomass in a net-zero economy – prioritising the use of bioresources across sectors**
3. **The role of bio-based carbon dioxide removal**
4. **Industry and policy actions required to ensure optimal use of bioresources**
5. **Examples from current events**

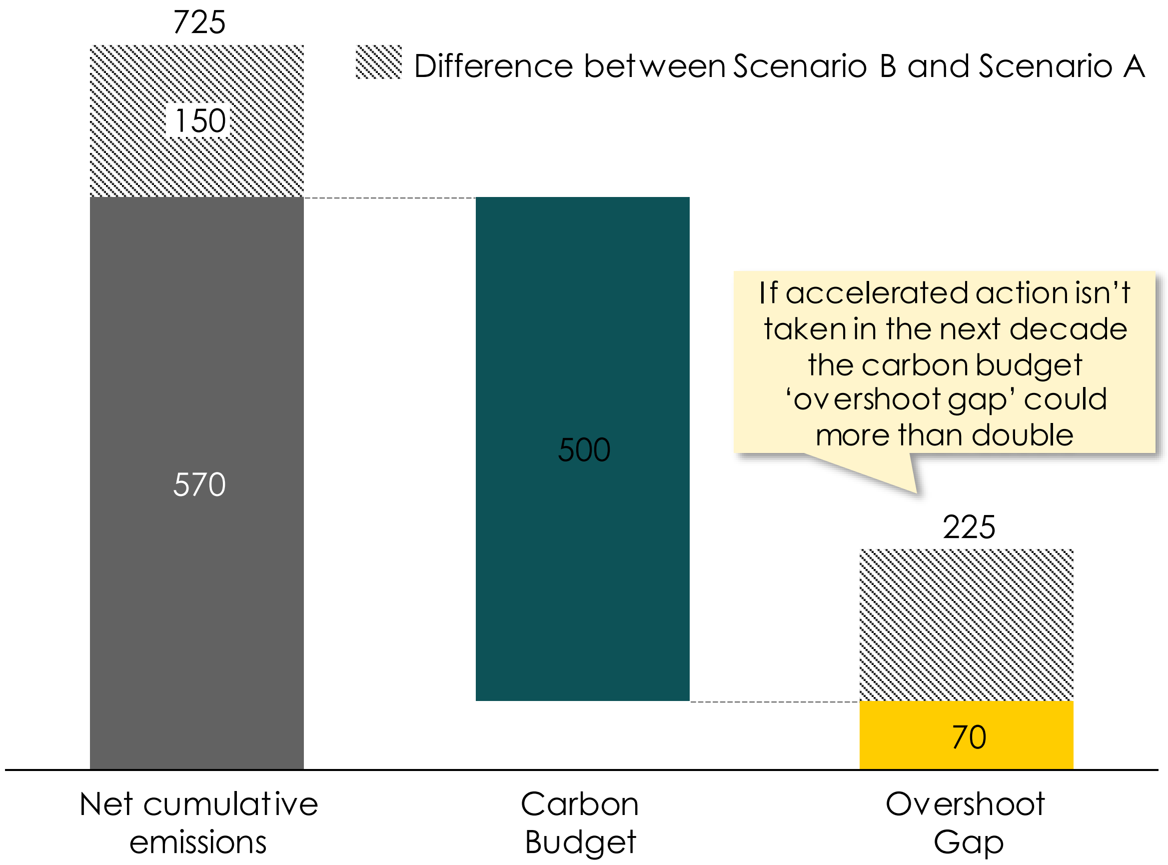
Cumulative emissions to 2050 are expected to overshoot the carbon budget by at least 70 $GtCO_2$

Gt CO_2/year, Global, Scenario A & B

Total annual gross emissions in two ETC scenarios



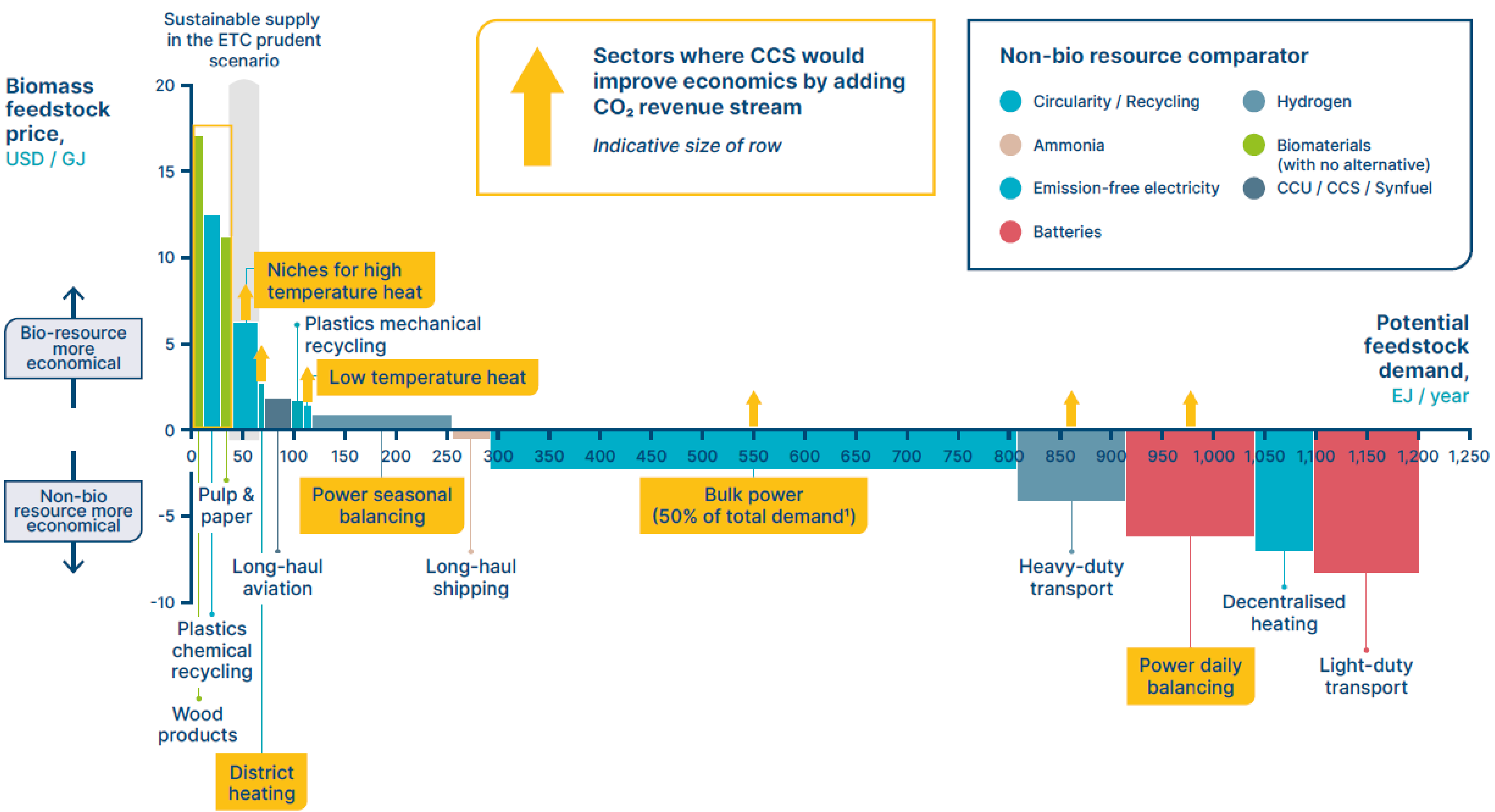
Cumulative emissions across sectors and compared with the carbon budget



Source: ETC (2021), *Keeping 1.5°C Alive*

Potential revenues from CO_2 capture and storage can change the cost-parity curve

Cost-parity curve – Breakeven biomass cost vs. alternative leading non-biogenic solution; global (2050 outlook)
"At what biomass feedstock price is the bio option cost effective?"



Note: 1. We limit the potential demand for biomass for bulk power to 50% of the demand of the segment in order to make the graph readable.
Source: Material Economics and ETC analysis (2021)

Bioresources within a net-zero emissions economy

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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)

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

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

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

Safeguard sustainable supply

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

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

5. De-risk pilot projects in biogasification for jet fuels and for plastics biofeedstocks

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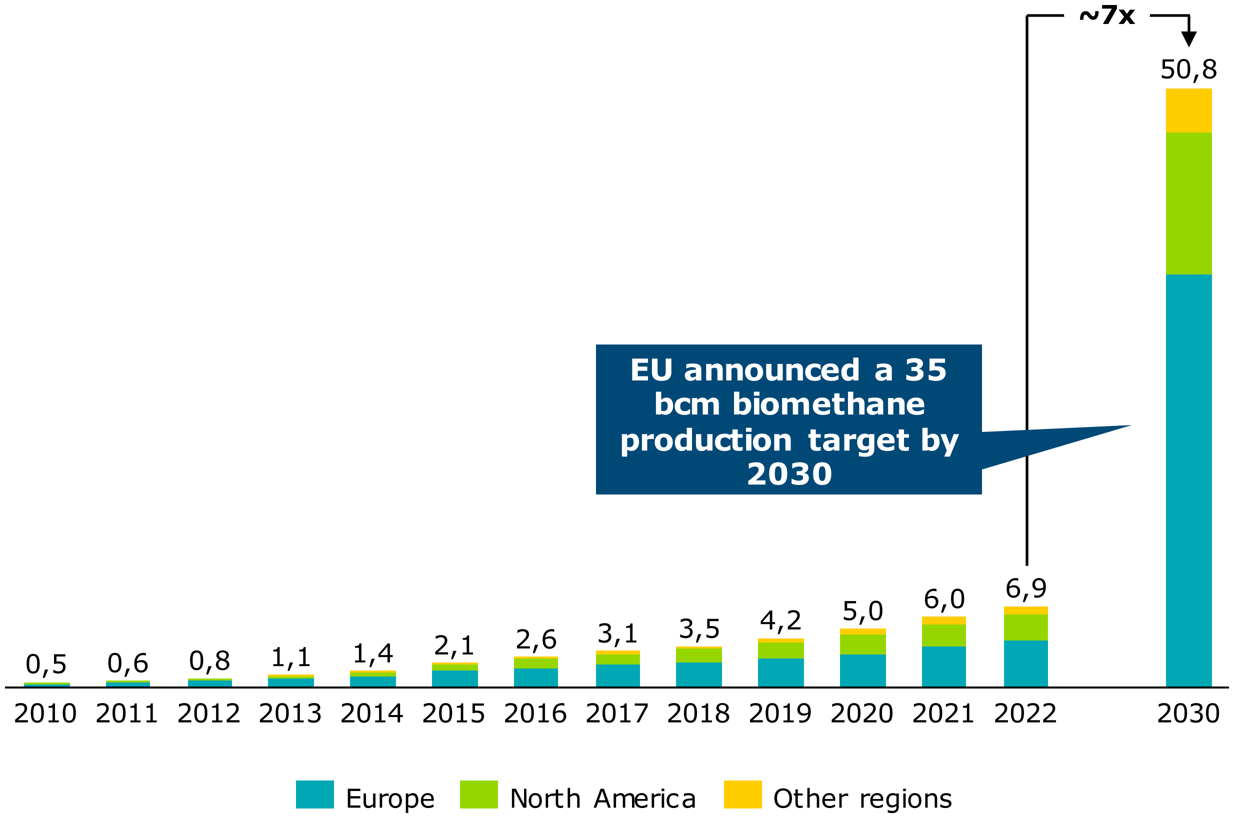
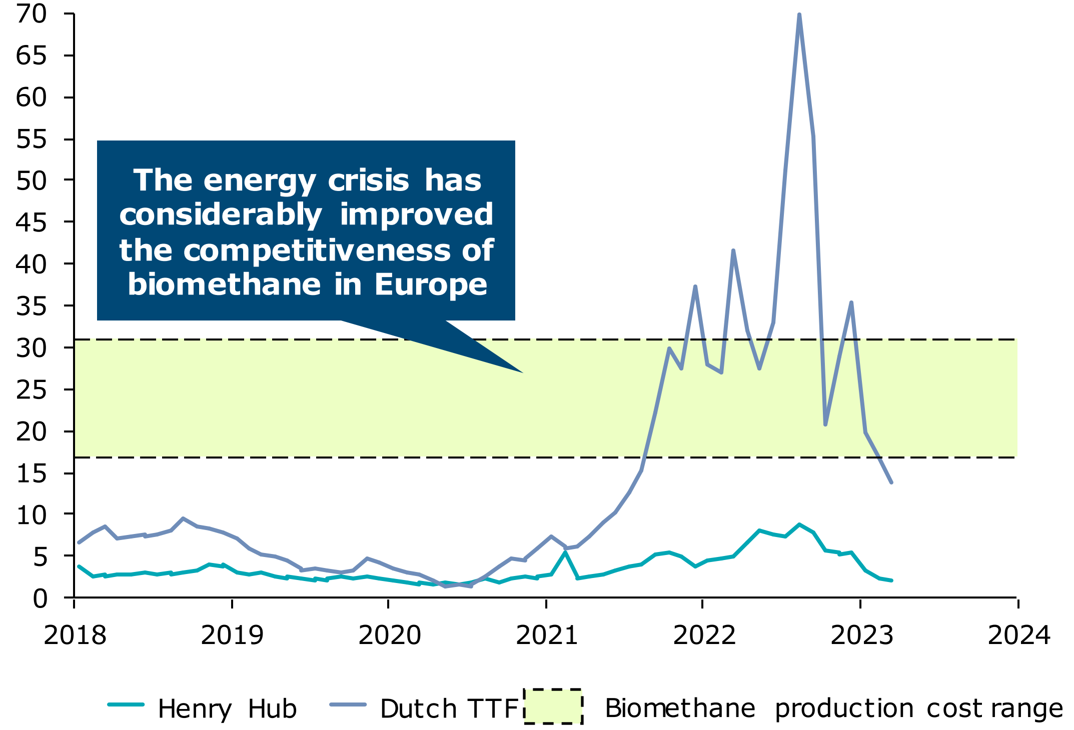
The current energy crisis has shined the light on low-emission gases as a competitive, secure and low-carbon alternative to natural gas

Projected global biomethane production, in bcm p.a.



Natural gas price markers, in $/Mmbtu



Note: 2030 figure is taken as EU target for 35 bcm of biomethane production for 2030, North America & other regions projections is computed taking CAGR for 2015-2022 period and applying it to get 2030 estimate.
Source – IEA (2023), *Q1 2023 Gas Market Report*

But current uses of biogas should be redirected to high-value applications, such as chemical feedstock or industrial heating

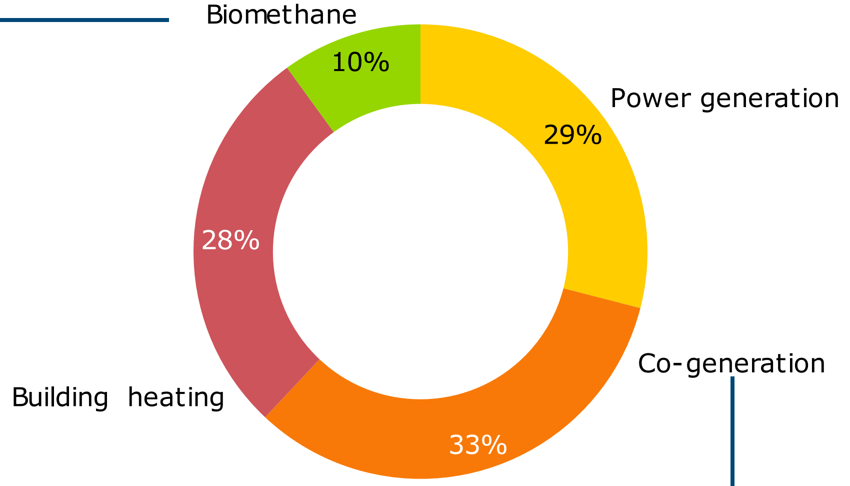
Biogas consumption by end-use for 2018, in %

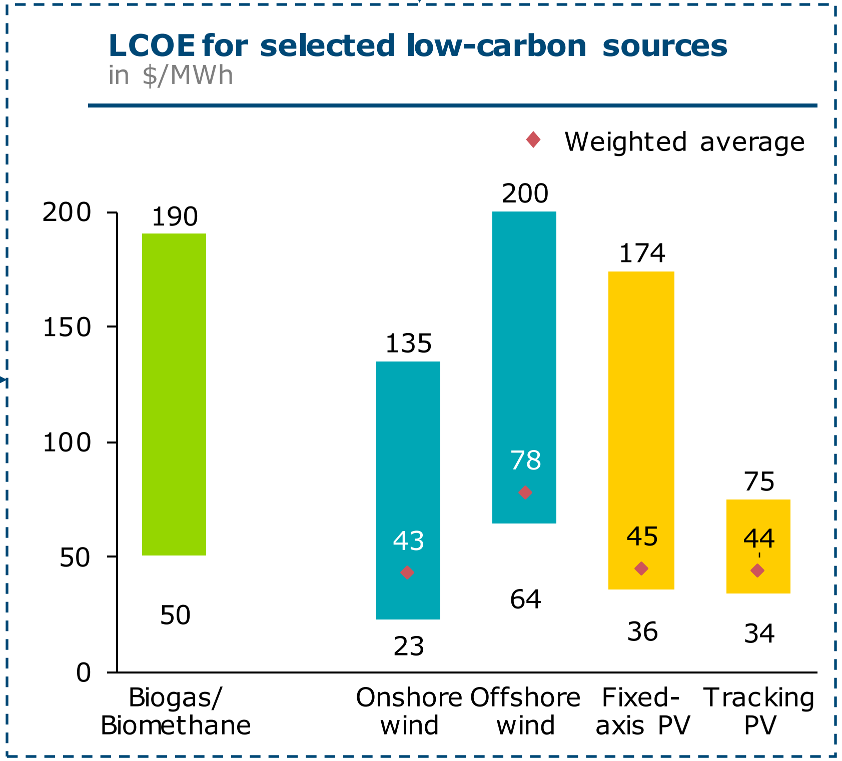
Current uses:

- **Heavy-duty transport**
- **Bended in natural gas grid**

Future high-value applications :

- Feedstock in **chemical and petrochemical** industries
- **High-temperature industrial heating**
- **Seasonal energy storage**
- Transitional role in **heavy transportation** *(e.g. shipping, trucking)*

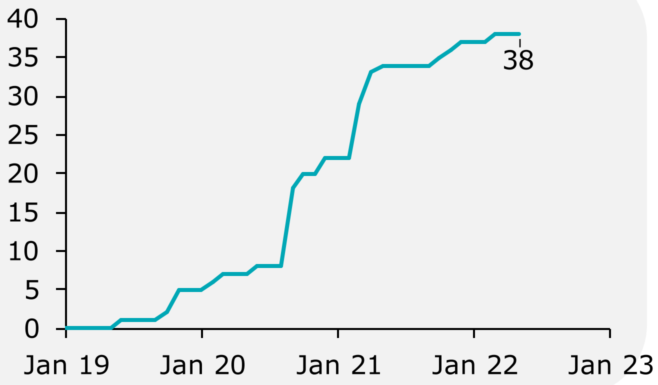




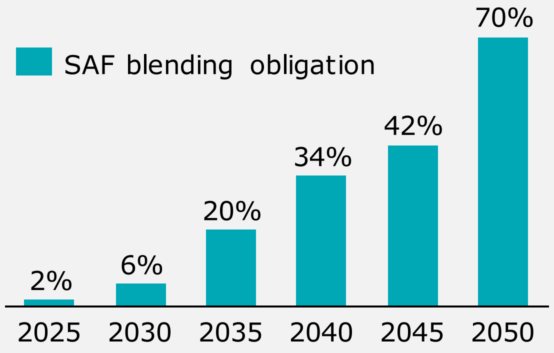
Source – IEA (2020), *Outlook for biogas and biomethane,* BNEF (2022), *2H 2022 LCOE update*

Bio-based sustainable aviation fuels are expanding thanks to ambitious EU policies and growing net-zero commitments from airlines…

38 of the world's top airlines have committed to net-zero since 2019

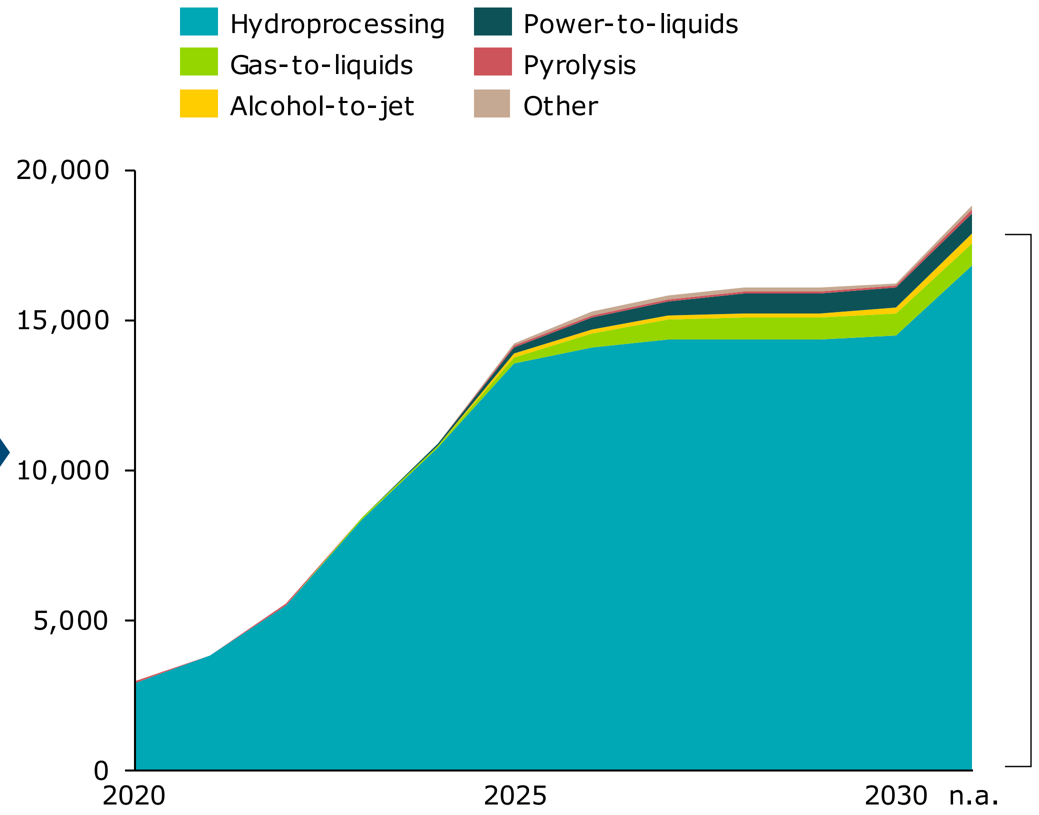


The EU has introduced ambitious targets for SAF blending



Cumulative SAF capacity by technology

In billion gallons p.a.



95%
of production is expected to be bio-based

Sources – European Council (2023), *Fit for 55: increasing the uptake of greener fuels in the aviation and maritime sectors*, BNEF (2022), *Sustainable Aviation Fuel: 2022 Outlook*, BNEF (2021), *Sustainable Aviation Fuels (Part 1): Pathways to Production*

… but feedstock availability and sustainability are already being questioned as part of accrued commitments

Europe Battles Flood of Green Fuel Suspected to Be Fraudulent

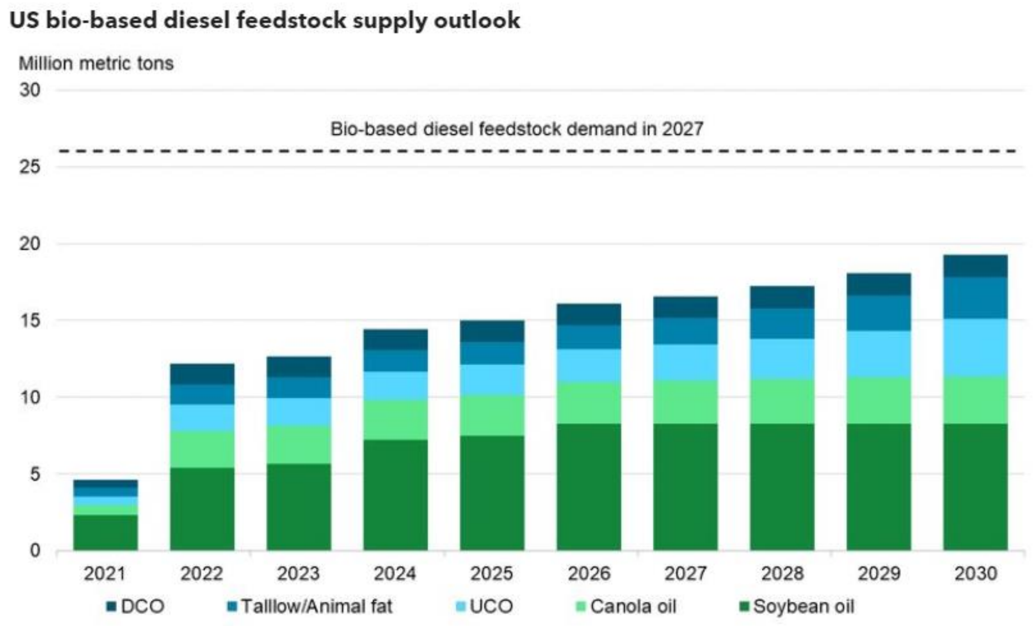
- Surge in Chinese biodiesel exports to EU sparks fraud concerns
- Group warns EU biodiesel industry faces ‘existential’ threat

UK suggests restricting green jet fuel from waste cooking oil

UK airlines’ new ‘sustainable’ fuels may be causing deforestation in Asia

Exclusive: Experts fear lack of industry regulation means virgin palm oil is being passed off as ‘used’ cooking oil

Discrepancy in British and Irish used cooking oil imports raises biofuel fraud concerns



Source: BloombergNEF

Note: Total feedstock demand is for both renewable diesel and biodiesel production in a business-as-usual scenario. DCO = distillers corn oil, UCO = used cooking oil.

Sources – Dedicated news search, BNEF (2023), *US, Canada Renewable Fuel Ambitions face feedstock crunch*

Energy
Transitions
Commission