

The objective of this focus piece is to provide a high-level summary of bioenergy as an alternative to other decarbonisation technologies. The [IEA](#) defines bioenergy as **energy derived from organic material (biomass) containing carbon absorbed by plants through photosynthesis**. Five key topics are explored, summarised to the right.

There is ongoing debate around bioenergy. Some of the associated issues are complex, and as a result there is a lack of clarity regarding the accounting for GHG emissions from bioenergy.

While consumers of bioenergy can claim lower operational (Scope 1) emissions, the production of bioenergy is not net carbon neutral – particularly where fertiliser is required to sustain large scale farming of agricultural feedstocks, or if the land use change for bioenergy production results in deforestation or net negative change in soil carbon stocks.

Furthermore, there are other socio-environmental concerns: water security, competition with food and animal feed production, loss of biodiversity and impingement on the traditional use of bioenergy by local communities.

The current consensus is that a ‘sweet spot’ might exist, where feedstock is local and from residual or waste products. It is also accepted that scaling up application for industrial purposes creates risk of unintended negative impacts - and net carbon neutrality becomes harder to substantiate.

Supported by government policies to address energy security and meet decarbonisation targets, bioenergy will become widely adopted across different sectors and jurisdictions. Although this can make bioenergy commercially-viable, companies considering its adoption need to question whether it aligns with sustainability objectives and conduct due diligence on the overall carbon impact across the fuel supply chain.

1

Setting the Scene

Bioenergy is not new. Policies drive supply and consumption, particularly in the US, Brazil, EU and Indonesia. Considered a ‘renewable’ fuel with potential to reduce GHG emissions, bioenergy is incorporated into national decarbonisation targets and roadmaps and demand is expected to increase. However, bioenergy *can* have a net negative impact on GHG emissions. Sustainability concerns extend beyond climate change, with potential impacts on a range of UN Sustainability Development Goals (SDGs).

2

Science of Bioenergy

Capture of solar energy through photosynthesis is not particularly efficient, and therefore not always the optimum use of land compared with other alternatives, including photovoltaics and wind. The GHG footprint of bioenergy is highly situational and dependent on feedstock type. GHG emissions from land use change, particularly [indirect](#), can have a significant impact but are difficult to measure and align on methodology.

3

Economy of Bioenergy

Bioenergy trades at a premium to fossil fuels. Three main components of production costs are capital, operating and feedstock. The latter varies widely and quoted as a negative cost for pathways that consume waste products. Widescale adoption is typically in areas of consistent local feedstock supply; various miners have reported challenges of sourcing high volumes of sustainable bioenergy feedstock.

4

Accounting and certification of bioenergy (a GHG emissions perspective)

Policies trend toward requiring a threshold reduction target for bioenergy relative to fossil fuel equivalents, such as the EU Renewable Energy Directive. Jurisdictional requirements on calculating GHG emissions differ, with various voluntary schemes available for certification. However, land use change – indirect in particular – is not always included in the scope of reporting and certification requirements

5

Application in Metals & Mining

At mines, biofuel substitution or blending has been adopted in jurisdictions with supportive policies. Downstream processes use biomass as an alternative reductant to coal. Producers shipping bulk commodities such as coal and iron ore have trialled the use of biofuels in carrier vessels.

All about energy security: The use of bioenergy (including both biomass and biofuel) derived from organic material into forms compatible for substitution, is not new technology; the first commercial demonstration of vegetable-oil-based diesel fuel was at the 1900 World’s Fair in Paris, with a diesel engine built by Otto Company to run on peanut oil. Today, the consumption of biofuels is concentrated in the US, India, Brazil, EU and Indonesia, where government policies and subsidies to address energy security have driven development and demand (IEA), specifically to reduce domestic reliance of imported fossil fuels.

Traditionally bioenergy has primarily been generated from first- and second-generation feedstock (read more), often directly or indirectly reliant on mono-crop farming such as corn (US), sugar cane and soy (Brazil) and palm oil (Indonesia). The sustainability of bioenergy, and whether its production is truly carbon net neutral, is the subject of much debate. Assessment is complex and intertwined with numerous other SDGs. Potentially negative impacts include competition of land for food and feed, water use management, soil depletion from mono cropping, and competition with existing demand for bioenergy by local communities.

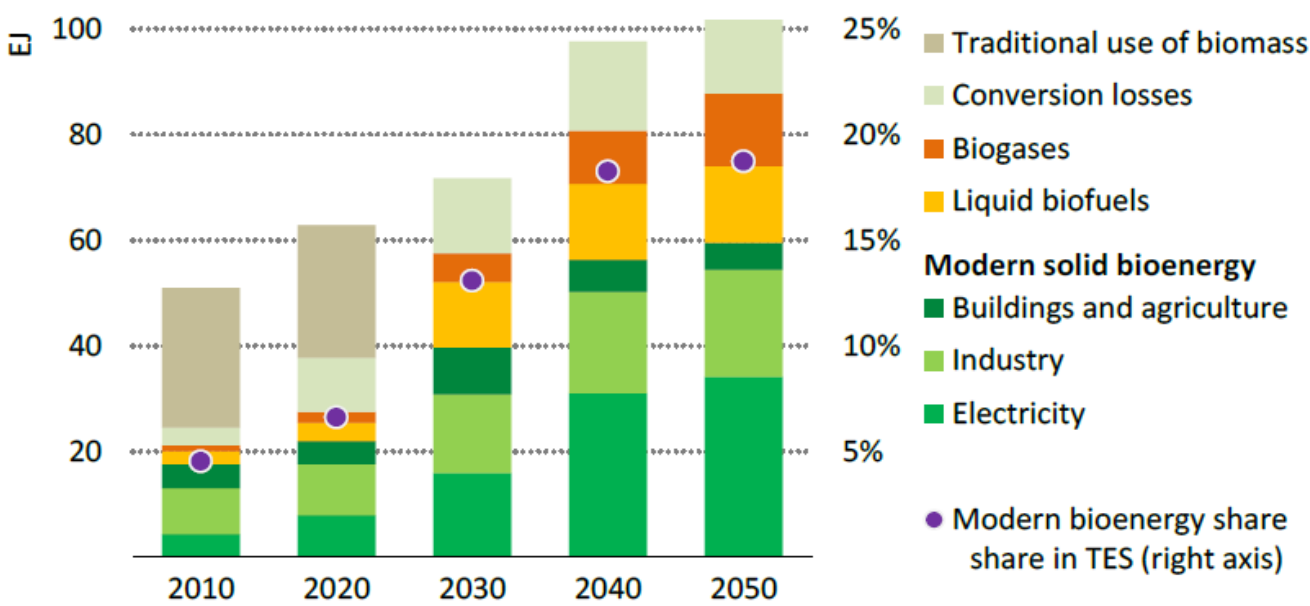
Now a part of many countries’ decarbonisation roadmap: With progress in global efforts to address climate change, many countries have set decarbonisation targets with roadmaps including growth in demand for bioenergy, with biofuel predominantly a substitute fuel for transport, and biomass utilised for heat and as a reductant. The IEA projects future bioenergy demand to come from five key regions – Brazil, China, Europe, India and United States underpinned by dedicated policies to support its uptake. Key blending mandates for biodiesel with conventional diesel in select countries is summarised in the table to the right; **however, ensuring sustainable sourcing of bioenergy are inconsistent and not always present.**

It is expected that future supply and consumption will rely mostly on second generation feedstocks (residues, waste, renewable diesel). Development of third generation feedstock (algae) continues, but is not yet commercialised. In the US, the renewable fuel standard, state-level low-carbon fuel standards and the IRA’s tax credits boost demand for renewable diesel and biojet fuel derived primarily from vegetable oils and residue oils. The EU plans to phase out the use of palm oil and has placed limits on other feedstocks, shifting to production from wastes, residues and rapeseed oil. Brazil and Indonesia both have biodiesel blending mandates that will become more stringent over the forecast period. Indonesian biofuel manufacturers primarily use palm oil to produce biodiesel, and Brazilian producers rely on soybean oil (IEA Bioenergy).

Beyond GHG emissions: The key issue seems to be whether it is possible to scale up bioenergy production in a sustainable way. To quote the IEA:

*“...large-scale deployment of biofuels, especially crop-based, raises sustainability concerns in some areas, mainly related to land use, net GHG emission balance, and unintended impacts on biodiversity or food prices. These concerns can undermine the credibility of biofuels as a sustainable option, and in some cases pose a barrier to investment and trade. **Using carbon accounting for policymaking purposes is further complicated by mixed reports on biofuel GHG emission results and the lack of consensus across methodologies.**”*

Modern bioenergy use rises to 100 EJ in 2050 in the NZE



Source: IEA (2021) Net Zero by 2050 - A Roadmap for the Global Energy Sector

Current biofuel shares in transport fuels and near-term targets

* Volumetric shares of biofuels in total diesel and gasoline demand as of 2023.

Country	2023*	Targets
Brazil	27%	Existing: Up to 27% ethanol blending; up to 35% under discussion 2025: Up to 15% biodiesel blending 2033: 74 million carbon credit reductions in the transport sector
Canada	8%	2030: 15% reduction in carbon intensity of liquid fuel sold in Canada from 2016 baseline
China	1%	2025: 50 000 t of sustainable aviation fuel to be used between 2022 and 2025
EU	7%	2030: 14.5% GHG intensity reduction or 29% renewable content on an energy basis (including double-counting provisions)
India	4%	2025/26: 20% ethanol blending target 2030: 5% biodiesel blending target 2028/29: 5% compressed biogas blending target
Indonesia	17%	2025: 35% biodiesel blending target
US	11%	2025: 22.3 billion gallons of ethanol equivalent
ICAO	< 1%	2030: Aspirational goal of 5% CO ₂ emission reduction in aviation from using sustainable and lower-carbon aviation fuel, other cleaner energy sources

Source: IEA (2024) Carbon Accounting for Sustainable Biofuels

Definition and application of bioenergy: The [IEA](#) defines bioenergy as energy derived from organic material (biomass) containing carbon absorbed by plants through photosynthesis. In the combustion of biomass, carbon is released and returned to the atmosphere. Direct or partial substitution of conventional fossil fuel is possible in many cases but subject to criteria on the quality of input fuel to comply with engine manufacturers' warranties. Biofuels have a lower energy density compared with fossil fuel equivalents; for example, biodiesel has an LHV of 37MJ/kg which is 14% less than diesel with the LHV of 43MJ/kg ([Transport and Environment](#)). Depending on the feedstock, other compounds may be released during combustion which can potentially affect the efficiency or applicability of biodiesel.

Application of biofuels in transport is mature and deployed across various sectors, with established forms to include ethanol from sugar and starch crops, biodiesel from triglycerides and lipids (FAME), hydrogenated triglycerides and lipids (HVO), and biomethane from upgrading of anaerobic digestion biogas ([IEA Bioenergy](#); [Appendix](#) for a summary of application). Biodiesel is typically blended with diesel fuel at various levels as the use of neat biodiesel (FAME) can cause problems in exhaust gas systems. Other forms derived from algal mass are in development and show potential as candidates for use as aviation fuel, with given their higher lipid content. Feedstock used to produce bioenergy falls into four categories, summarised as follows:

- **First generation:** grains, seeds, and feedstocks such as soy, sugarcane, corn – direct competition with food chain
- **Second generation:** lignocellulosic biomass from crop wastes (straws, leaves, stovers), forestry residues, solid cattle manure, energy grasses, and municipal solid waste (food waste, paper waste) – dependent on food chain
- **Third generation:** Algal biomass (both macro and microalgae) - high lipid content (70% on total dry weight), high carbohydrate content, can be grown easily and are relatively inexpensive
- **Fourth generation:** Genetically modified algae to boost yield - combination of biology and technology, enhanced in their characteristics and metabolic activities such as the improved rate at which chemicals, such as triacylglycerol, are produced.

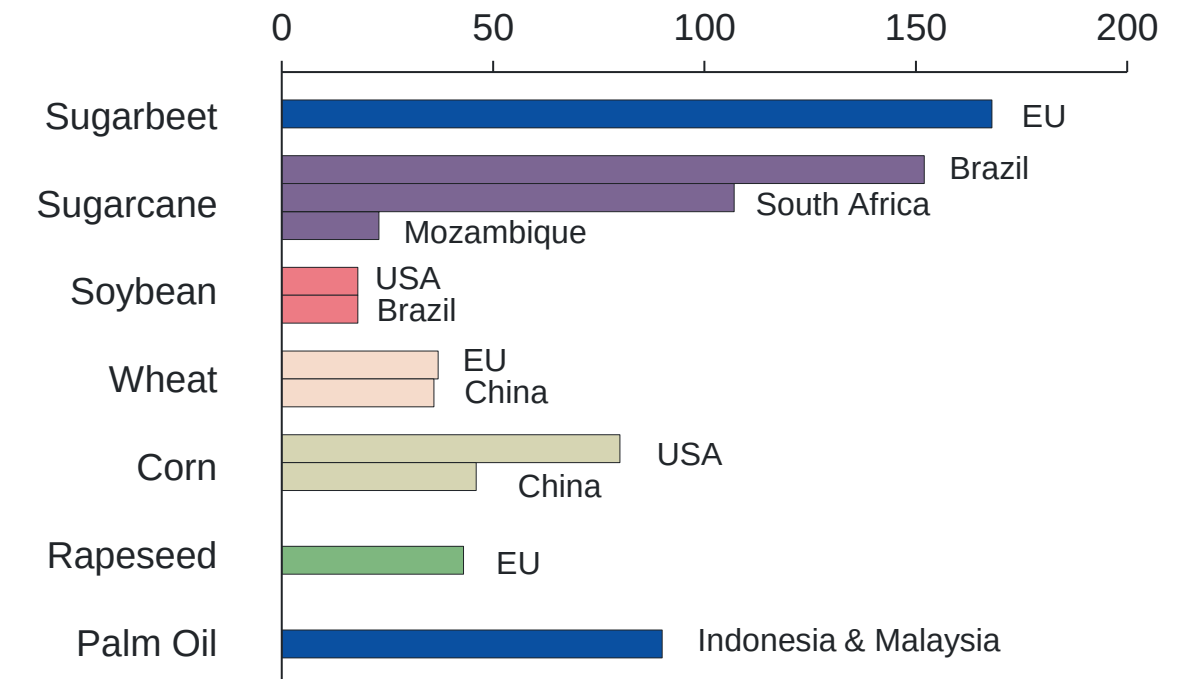
Energy efficiency: Photosynthesis, the natural chemical process to capture energy from sunlight and convert it to biomass, has a very low efficiency ranging between 2 and 6% ([Slattery and Ort, 2015](#); [Zhu et al., 2008](#)). In comparison, photovoltaic solar panels have a conversion rate of 21% on average ([University of Michigan](#)). Anecdotally, [Birdlife](#) estimates that the land area required to generate 1MW of biogas is 1,300 times greater than for the equivalent generation from wind power.

Energy yield per unit of land varies widely as a function of feedstock and location, which we illustrate with an example but note productivity also varies widely within these subgroups and is highly situational (chart, top right). Furthermore, incremental energy is required to convert biomass to a form of energy that can be consumed by existing machinery whether it is electricity or as fuel for transport vehicles. This process varies once again by feedstock and can yield a wide range of LCA GHG emissions intensity (chart, bottom right).

Where the energy balance makes most sense is when feedstock is sourced from material that would otherwise be waste such as forest residues (e.g. palm oil husks) and used cooking oils. Policies coming into effect (e.g. [EU RED](#)) emphasise the [cascading principle](#) whereby the use of biomass to generate energy should be considered last, after prioritising use in long-lived products (e.g. building materials, refurbishment, re-use and recycling).

Energy yield of biofuel feedstock (GJ/ha)

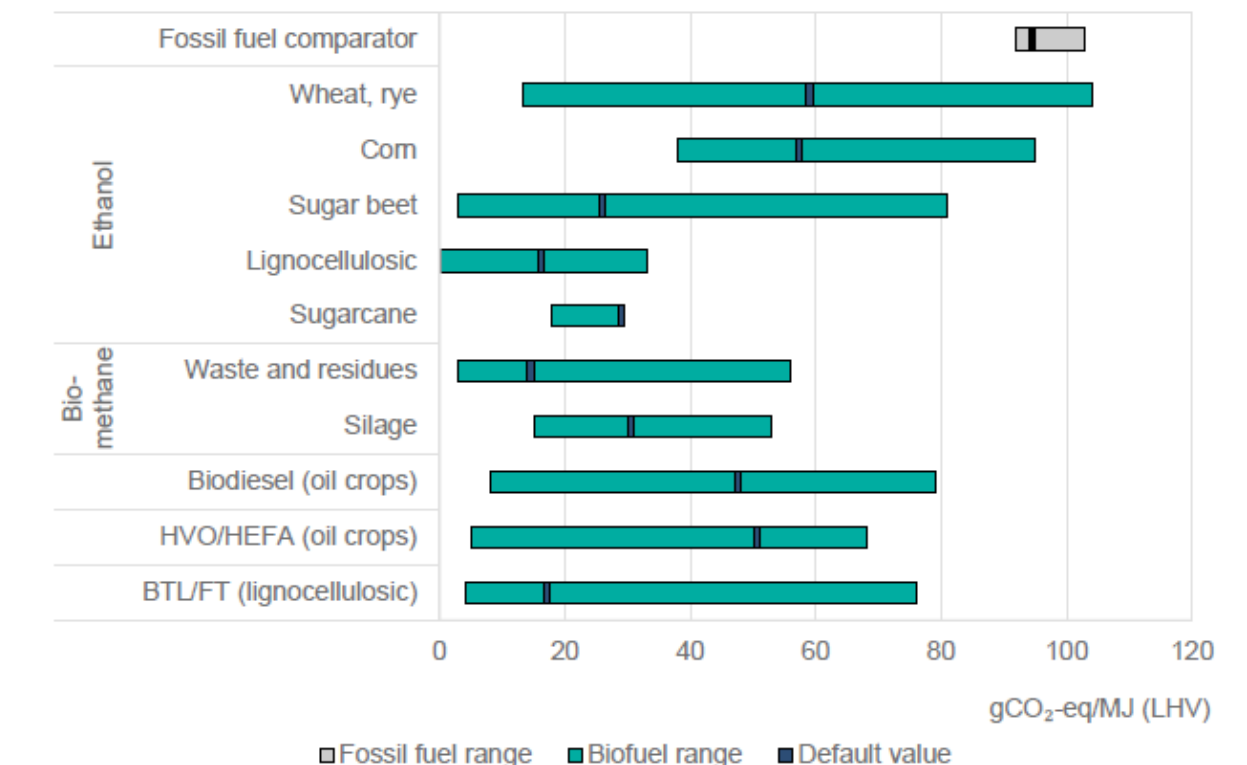
Referenced as an example only; productivity is highly situational and ranges vary greatly in the literature



Source: [University of Michigan – Centre for Sustainable Systems](#)

LCA GHG emission ranges in the literature for selected biofuels

Referenced as an example only; GHG emission footprint is highly situational and ranges vary greatly in the literature



Source: [IEA](#) (2024) Carbon Accounting for Sustainable Biofuels

[IRENA](#) explores the barriers to deploying bioenergy, summarised in the table below, noting that most bioenergy options are higher cost than fossil fuels. In its latest World Energy Transition Outlook, it reported that the levelised cost of electricity (LCOE) had increased for bioenergy in 2023 compared to the decreases in other renewable technologies (top right). The [IEA](#) illustrates comparatively higher costs of biofuels with conventional fuels (top bottom). Generally, bioenergy is most widely adopted in jurisdictions with supportive government policies including US, Brazil and Indonesia where production is subsidised directly or indirectly to absorb some of the premium relative to fossil fuels. Since biofuels have a lower heating value than the fossil fuel equivalents, it is important to compare cost in terms of unit energy rather than by volume.

[IEA Bioenergy](#) explores the cost structure of bioenergy production in Chapter 6 of “The Role of Renewable Transport Fuels in Decarbonizing Road Transport” with three main components being capital costs, operating costs and feedstock costs. The latter varies widely and quoted as negative for pathways that consume waste products. Additionally, transport costs must be factored in.

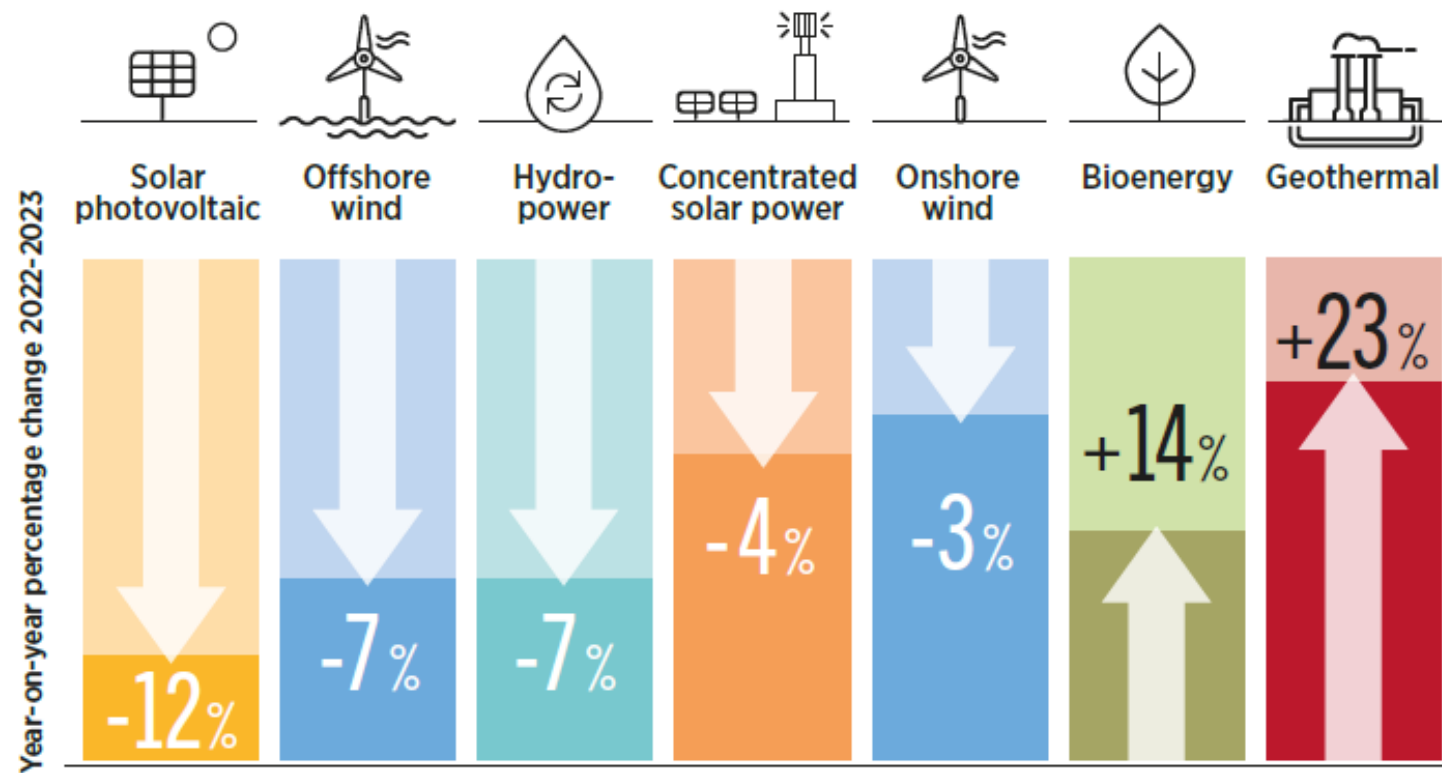
The other main barrier is questions around sustainability, given the absence of clear methodologies to quantify GHG emissions, particularly from land use change, and of other social and environmental parameters. Various producers have commented on this challenge including [Vale](#) and [Nickel Industries](#). In Australia, [Rio Tinto](#) noted insufficient domestic biofuel feedstock to meet demand and announced a biofuel crop farming trial to explore the potential for Pongamia seed oil as feedstock.

Barrier type	Summary of issues	Key Impact
Political and institutional	• Policy uncertainty • Weak institutional structures	Misalignment of policy priorities and targets in related sectors raise concerns about sustainability
Financial and economic	• Fossil fuel subsidies • High cost • Lack of access to affordable finance	In the absence of measures (e.g. emission trading systems or carbon taxes) that account for the costs of negative environmental and social impacts from fossil fuel burning, most bioenergy options have a higher cost than fossil fuels
Technical and infrastructure	• Low-level technology readiness • Reliability of technologies • Lack of infrastructure	Low technology readiness levels for advanced biofuel including aviation and second generation have not matured for large-scale deployment
Supply chain	• Lack of stable feedstock • Lack of qualified workers and skills • Sustainability risks	Weak, inconsistent supply chains including feedstock cultivation, harvesting and collection, pre-treatment or upgrading is a major barrier to large-scale deployment
Information and public awareness	• Lack of reliable information • Low public awareness	Lack of awareness especially around modern and clean bioenergy solutions discourage the market from participation in the face of concerns around sustainability

Source: [IRENA](#) (2022) Bioenergy for the energy transition – Ensuring sustainability and overcoming barriers

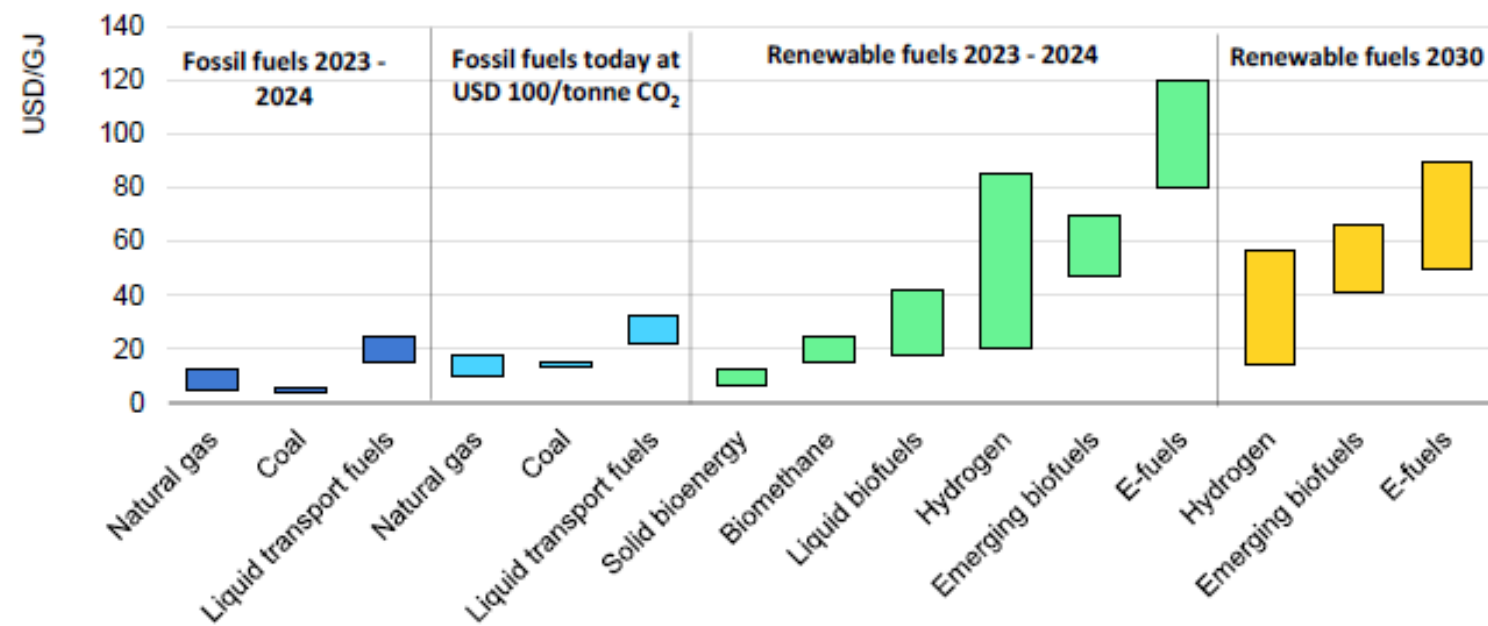
Global weighted average LCOE reduction per technology (2022 vs 2023)

LCOE = levelised cost of electricity



Source: [IRENA](#) (2024) World Energy Transitions Outlook

Renewable fuel and fossil fuel costs, 2023 and 2030



Source: [IEA](#) (2024) Renewables

A clear alignment on methodology to assess the full impact of GHG emissions across the bioenergy supply chain does not yet exist. However, this space is continuously evolving and with jurisdictional policies and GHG reduction requirements coming into effect, we expect that there will be increasing scrutiny on how carbon emissions are accounted. The importance of a clear framework and regulation has been reiterated by various bodies such as [IEA](#) and [IRENA](#).

GHG Protocol (GHGP) on bioenergy: Under the [GHGP](#) guidance (2016), consumers of bioenergy are required to report the emissions of CH₄ and N₂O from combustion of biofuels as Scope 1, **but CO₂** emissions are excluded. Emissions arising throughout the value chain, including land use change, would fall under Scope 3. It is therefore possible for consumers to **reduce stated operational emissions regardless of the upstream emissions** arising from production and transportation.

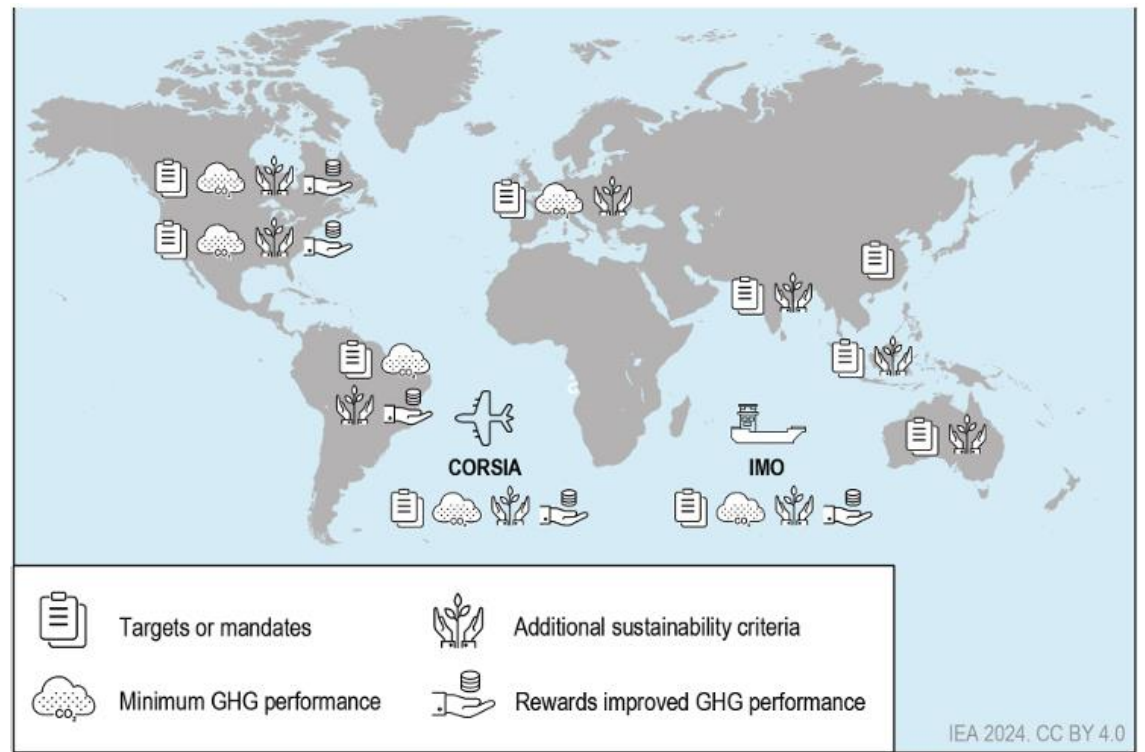
On land use change, the GHGP [Corporate Standard](#) (2004) notes that “*consensus methods have yet to be developed under the GHG Protocol Corporate Standard for accounting of sequestered atmospheric carbon as it moves through the value chain of biomass-based industries*” though some general considerations for accounting for sequestered atmospheric carbon are discussed in Chapter 9 and Appendix B of the GHG Protocol Corporate Standard. GHGP is expected to publish a [Land Sector and Removals Standard and Guidance](#) in Q1 2025, which will delve into further detail on accounting for both Scope 1 and 2 emissions as well as Scope 3 emissions arising from upstream (producers) and downstream (consumers) life cycle emissions.

Regional and international policy frameworks and GHG reduction requirements: Various jurisdictions are setting targets to reduce the GHG emission footprint from bioenergy, summarised in the table to the right and referenced from [IEA](#). Globally, the UN International Civil Aviation Organization (ICAO) and the International Maritime Organisation (IMO) have set reduction targets the respective industries. EU’s Renewable Energy Directive (RED) requires bioenergy to be 50% less carbon intensive than fossil fuel equivalents if facility of production was operational before 2015, with higher thresholds for those commissioned thereafter.

Additionally, the Science Based Targets initiative ([SBTi](#)) published its target setting guidance for forest, land and agriculture sector (FLAG) which provides sector pathways for both companies with diversified FLAG emissions and for 11 specific commodities including maize, palm oil, soy, timber and wood fibre – all potential feedstocks in the production of bioenergy. Key requirements under this guidance include near-term and long-term science-based targets with minimum reduction of 72% emissions by 2050 and a “no-deforestation” commitment no later than 2025.

The use of “core LCA values” under the CORSIA framework and the California LCFS include emissions from production and use of biofuel but exclude emissions from land use change. Certain frameworks (US, Brazil) allow the use of default values while in the EU producers can opt to use default upper-bound emissions (not average) or calculate their own values. The frameworks also vary in how direct (dLUC) vs indirect (iLUC) land use change is considered. Emissions from indirect land use change are not quantified at the producer’s level, but the EU RED III includes detailed instruments subjecting biofuels with high iLUC to quota limitations or completely excluded for some sectors. **Indirect land use change represents both the highest degree of impact and uncertainty in quantifying net carbon emissions.** Quantification and certification of iLUC emissions fall outside the direct control of biofuel producers and the scope of [voluntary certification schemes](#), making it **essential for additional policies** to regulate for effective land use and protection of food security, natural forests and areas with high biodiversity or carbon stock. **While certification may allow for trade under certain policies and for recording offsets, not all standards are equally robust, and companies must carefully consider the sourcing of bioenergy for themselves.**

Main regional and international biofuel policy frameworks



Source: [IEA](#) (2024) Carbon Accounting for Sustainable Biofuels

Biofuel GHG reduction requirements: selected policy frameworks

*The Renewable Fuel Standard programme.

Jurisdiction	GHG Reduction Targets
Brazil	Specific annual GHG reduction 2024 target: 16-17% reduction 2033 target: 25% reduction
EU (RED III)	50% reduction compared with fossil fuels when operational before 2015, 60% when start of operations is 2015-2020, 65% in or after 2021
India	No specific GHG requirements
US (RFS*)	20% reduction in conventional biofuels compared with fossil fuels, 50% for advanced fuels and 60% for cellulosic biofuels
CORSIA	10% reduction compared with fossil fuels

Source: [IEA](#) (2024) Carbon Accounting for Sustainable Biofuels

Examples of biofuel and biomass application by leading mining companies are summarised to the right but is not intended to be a comprehensive review of use cases in the industry.

Mine: Rio Tinto's full transition to renewable diesel for US operations is the most wide-scale application noted by Skarn. Vale has various partnerships including the development of dual-fuel trucks to blend up to 70% of ethanol with diesel, and use of biodiesel in locomotives for transport of iron ore.

Shipping: BHP, Rio Tinto, Vale and Anglo American have held various trials using biodiesel blends for shipping of iron ore.

Downstream: Efforts focus on replacing coal as reductant and heat source in processing routes for iron ore to steel and for laterite ore to ferronickel. Depending on the feedstock, some sources of biomass with lower sulphur content vs. coal can produce superior products ([Sari et al](#)).

Jurisdictional: Widescale adoption of biodiesel in countries with incentivising policies such as Indonesia, Brazil and US. Grasberg uses biodiesel in its dual-fuel power generator.

Operator	Asset(s)	Country	Bioenergy	Supplier	Effective from	Scope of application
Rio Tinto	US Borax and Kennecott Copper	United States	Renewable diesel	HS Sinclair	2023/2024	US Borax operations transitioned fully from conventional diesel to renewable diesel in 2023, followed by Kennecott Copper in 2024
	Pilot steel plant	Germany	Biolron™	Rio Tinto	2022	Successful trial of the Biolron™ process using raw lignocellulosic biomass from agricultural by-products instead of metallurgical coal as reductant at a small pilot-scale plant in Germany
	Pilot steel plant	Australia	Biolron™	Rio Tinto	2026	R&D facility including a pilot plant to test Biolron™ on a semi-industrial scale
BHP	Yandi	Australia	HVO	BP	2023	3-month trial of HVO for mining equipment at Yandi iron ore operations, Western Australia
	Tata Steel operations	India	Biomass	---	2022	MOU signed with Tata Steel to collaborate on reducing emissions at the blast furnace including use of biomass as source of energy and carbon capture and utilisation.
	Shipping	Global	B100	Norden	2024	Arrangement to use 1,000 tonnes of lower carbon emission biofuel on the Capesize vessel NORD Steel from Haypoint, Australia to Rotterdam, Netherlands
Vale	Shipping	Global	B24	Oldendorff carriers	2023	First biofuel shipment of iron ore from Brazil to Asia using B24 blended with biodiesel from used vegetable cooking oil and fuel oil
	Vitoria-Minas rail and Fabrica Nova mine	Brazil	R5	Petrobras	2024	Industrial scale testing of R5 diesel, an S10 diesel with 5% HVO (hydrotreated vegetable oil) produced by co-processing oil derivatives with raw materials of plant origin
	Various	Brazil	Bioethanol	Komatsu and Cummins	Tbc	Agreement to develop dual fuel haul trucks powered by a mixture of diesel and up to 70% of bioethanol
	Sao Luis pellet plant	Brazil	Biochar	---	2021	First pellet production using biochar, a carbonised form of biomass of which 25% was of vegetable origin
Anglo American	Niquelandia	Brazil	Biomass (Eucalyptus)	Anglo American	Pre 2004	Anglo American manages 12,200 hectares plantation for eucalyptus trees which in the form of wood chips provide carbon source for the production of ferronickel
	Shipping	Global	Biodiesel, unspecified	Toyota Tsusho Petroleum	2021	First trial of biodiesel blend (7%) with 93% marine fuel derived from used cooking oil
Freeport McMoRan	Grasberg	Indonesia	Biodiesel, unspecified	---	2023	PTFI commissioned its DFPP to use high efficiency dual-fuel reciprocating engines that can operate on biodiesel or natural gas
Teck	Shipping	Global	Biodiesel, unspecified	Norden	2023	Agreement to reduce shipping emissions for metallurgical coal through a combination of efforts including alternative fuels such as biofuel

Source: Company reports and news releases

Skarn highlights that bioenergy is a complex topic, and the scope of this focus piece is not a comprehensive literary review but a high-level summary with primary references to IEA and IRENA who themselves provide more detailed reports on the topic. Sources referenced are cited below.

[IPCC](#) (2019) Climate Change and Land

[Birdlife](#) (2021) Burn or Restore

[European Commission](#) (website) Voluntary schemes

[EIA](#) (2024) Biomass-based diesel and ethanol compliance credit prices decline 45% from start of year

[European Commission](#) (2015) The land use change impact of biofuels consumed in the EU

[European Commission](#) (2018) Guidance on cascading use of biomass with selected good practice examples on woody biomass

[European Commission](#) (website) Biomass

[IEA Bioenergy](#) (2017) Mobilisation of Agricultural Residues for Bioenergy and Higher Value Bio-products: Resources, Barriers and Sustainability

[IEA Bioenergy](#) (2020) The Role of Renewable Transport Fuels in Decarbonizing Road Transport, Chapter 6 - Production Technologies and Costs

[IEA Bioenergy](#) (2020) Advanced Biofuels – Potential for Cost Reduction

[IEA Bioenergy](#) (2023) How bioenergy contributes to a sustainable future

[IEA Bioenergy](#) (2011) Using a LCA approach to estimate the net GHG emissions of bioenergy

[IEA](#) (2021) Net Zero by 2050 - A Roadmap for the Global Energy Sector

[IEA](#) (2024) Carbon Accounting for Sustainable Biofuels

[IEA](#) (2024) Renewables

[IEA](#) (2023) Renewable Energy Market Update, June 2023

[IRENA](#) (2022) Bioenergy for the energy transition – Ensuring sustainability and overcoming barriers

[IRENA](#) (2024) World Energy Transitions Outlook

[Jeswani et al](#) (2020) Environmental sustainability of biofuels: a review

[RAC Foundation](#) (website) Price of biofuel v fossil fuel

[Sari et al.](#) (2024) Nickel recovery in ferronickel concentrate by green selective reduction of nickel laterite

[Singh et al.](#) (2022) A Comprehensive Review of Feedstocks as Sustainable Substrates for Next-Generation Biofuels

[Transport and Environment](#) (2022) Billions wasted on biofuels

[U.S. Department of Energy](#) (website) Alternative Fuels Data Center

[University of Michigan – Centre for Sustainable Systems](#) (2024) Biofuels Factsheet

[Zhu et al.](#) (2008) What is the maximum efficiency with which photosynthesis can convert solar energy into biomass?