Global Insights | Sustainability

# Prioritizing Biomass for emission reductions

## A sectoral approach

11 Mar 2022 10:21:18 ET

# Executive Summary

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**Climate change is one of the most significant threats that our society is facing. To reduce this immense threat, we need to reduce greenhouse gas emissions and reach net zero by 2050. This will require investing in multiple solutions including the use of biomass. Biomass can be used to produce energy or as a feedstock for a number of different chemicals and materials. It can help reduce emissions in a number of sectors including power generation, transport, industry, chemicals etc. However to be effective it needs to be sustainable. Given the uncertainty of how much sustainable biomass resources are actually available, we believe that its use should be prioritized for two main sectors- the aviation industry and the use of biomass as a feedstock for traditional industries such as pulp and paper and for industries such as the plastic sector.**

# Contents

# Glossary of Terms

**Figure 1. Glossary of Terms**

| Term | Description |
|---|---|
| Biomass | Biomass in its broadest term includes all biological material — plants, soils, and animals. It is any organic matter that is available on a renewable basis and includes agriculture crops, agriculture waste and residues, wood and wood wastes, animal wastes, municipal waste and aquatic plants. |
| Bioenergy | Energy derived from the production, conversion and use of material directly or indirectly produced by photosynthesis (including organic waste) to manufacture fuels, and substitutes for petrochemicals and other energy-intensive |
| Biofuels | Biomass converted to liquid or gaseous fuels such as ethanol, methanol and methane. |
| Biodiesel | A biodegradable transportation fuel for use in diesel engines that is produced through the transesterification of organically derived oils or fats. It maybe used as a replacement for or as a component of diesel fuel – there are a number of different blends available for example B20 and B100, even though the B100 is much less common than the B20 blend as it requires special handling and may require equipment modification. New energy crops such as Jatropha are currently being cultivated on a large scale for the production of biodiesel. Advanced biodiesel can also be produced through the gasification of lignocellulosic feedstocks or biogenic waste or from residues from the pulp/paper or forest industry |
| Bioethanol | Bioethanol is an alcohol made by fermenting the sugar and starch components of crops including wheat, corn, sugar cane and sugar beet. It is the most common used biofuel in the world, especially in Brazil and the US. Nearly all the US gasoline contains bioethanol in a low –level blend to meet the renewable standards requirements under the Clean Air Act. There is a technical limit as to how much bioethanol can be used in today's engine and in fact it comes in a number of different blends -E10, E15 and E85, the latter is an alternative fuel that can be used in flexi-fuel vehicles |
| Biogas | A gaseous mixture of carbon dioxide and methane that is produced by the anaerobic digestion of organic matter. |
| Biomethane | Methane that is derived from biomass. Biomethane has the same comparable properties to natural gas, possible applications include fuel in vehicle engines, fuel in CHP plants, for cooking purposes and for all purposes for which natural gas is used from the gas grid. |
| Biorefinery | A facility that processes and converts biomass into value-added products. These products can range from biomaterials to fuels such as ethanol or important feedstocks for the production of chemicals and other materials. Biorefineries can have different processing platforms including mechanical, thermal, chemical and biochemical processes. |
| Bio-based materials | Refers to products that mainly consist of a substance (or substances) derived from biomass and either occur naturally or are synthesized. Many common materials such as paper, wood and leather could also be categorised by the term bio-based materials, however the term is usually used for modern materials that have undergone more extensive processing such as bio-based plastics. |
| Bio-based plastics | Bio-based plastics is plastics that are derived from biomass. Bio-based plastics do not necessarily mean that they are biodegradable. Biomass used for plastics stems from e.g. corn, sugarcane or cellulose. |
| Butanol | It is an energy dense pure alcohol formed by the fermentation from corn, grass, leaves and other biomass. Butanol can be burned without modifications in an existing gasoline engine and is said to be less corrosive than ethanol. |
| Cellulosic Ethanol | This is chemically identical to first generation bioethanol but it is produced from different raw materials such as agriculture residues, wood chips or energy crops such as miscanthus and switchgrass. These raw materials are considered to be more abundant and more sustainable however the process is more complex compared to conventional bioethanol |
| Methanol | Methanol is an alcohol and like ethanol can be used as a fuel. Currently it is produced from fossil fuels however it can also be produced from biomass (biomethanol). Technically, biomethanol can be used for a number of things- as a substitution for gasoline, as a substitution of diesel or biodiesel, in purpose-built biomethanol powered vehicles or in plug in and hybrid vehicles. Biomethanol is one of the solutions that the shipping industry is looking at using to help reduce their CO2 emissions. |
| Renewable/Green Diesel | Renewable diesel also known as green diesel is produced using the same feedstocks as biodiesel mainly animal fats or vegetable oils, however the production process is different. Green diesel is produced through hydrocracking or hydrogenation. It has the all the chemical properties of regular diesel and therefore there is no need to make modifications to the engines. |
| Sustainable aviation fuel (SAF) | SAF is a substitute for fossil fuel jet fuels. SAF is produced from renewable biomass and waste resources had has the potential to deliver the performance of petroleum-based jet fuel but with a fraction of its carbon foorprint. There are a number of different feedstocks that can be used to produce SAF- these include oils and greases, agriculture residues, municipal waste, dedicated energy crops etc. |



Source: Citi Global Insights, Office of Energy Efficiency & Renewable Energy, ETIP bioenergy, European Bioplastics, Advanced Biofuels Association, NREL, US Department of Energy, P. Morone and L Cottoni (2016)

# Introduction

Climate change is one of the most significant threats that our society is facing. The Intergovernmental Panel on Climate Change (IPCC) in their Assessment Report (ARG) have clearly stated that unless we reduce our emissions we are going to face an increasing threat of extreme climate events, including heat waves, heavy rainfall, and droughts. These events will become more frequent and more severe. Climate change is already affecting every region on Earth, and it is difficult to overstate the magnitude of this global challenge and the importance of taking action.

To have any chance of limiting the negative impacts that we face from climate change we need to reduce emissions by 45% in 2030 from 2010 levels, reach net zero by 2050, and move towards net negative emissions in the second half of this century. Basically we need to go from emitting 50GTCO2e per year to emitting zero or close to it, while still meeting people's energy needs[1]. This requires transforming almost everything we do and how we do it. We need to change the way we produce energy and the way we consume it. We need to find ways to heat our buildings, manufacture products, produce electricity, produce food and move goods without emitting greenhouse gas emissions. We need to improve energy efficiency and we need to deploy multiple solutions. We need to invest in renewables, energy storage, in hydrogen and hydrogen derivative products (Link to report), CCUS (Link to report) and in the use of sustainable biomass to produce both energy and products.

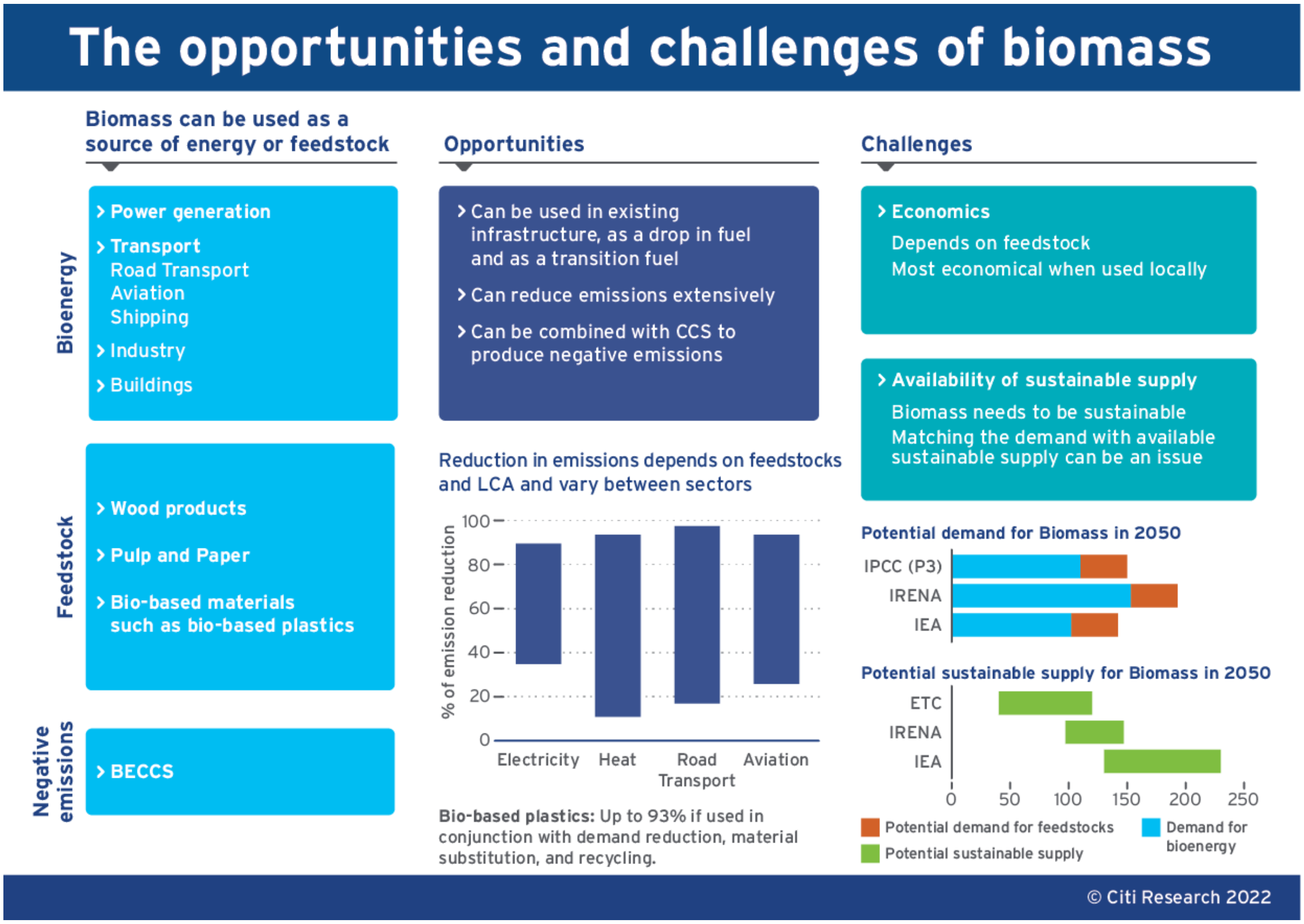
This report focuses on biomass. Biomass has not received the same media attention as other alternative energy sources and technologies such as hydrogen and carbon capture and storage, and yet it has been available for many years.

Biomass can be used as both a source of energy and as a feedstock for traditional industries such as wood products and pulp and paper and other industries such as the plastic sector. Biomass has a number of advantages when compared with other fuels and technologies – it can for example be used in existing infrastructure reducing the need for capital investment in new facilities, it can be used as a drop in fuel, and most importantly it can reduce significant emissions when used in many different sectors. It can also be coupled with CCS, and provide a net negative emissions technology. Therefore it has an extremely important role in helping us reach a net zero world, in fact many institutions such as the IEA and IRENA expect the use of biomass to significantly increase over the years.



[1] United Nations Environment Programme (2020). Emissions Gap Report 2020. Nairobi

**Figure 2. The opportunities and challenges of biomass**






Source: Citi Global Insights, Citi Global Insights

However, it also has a number of challenges. The cost of using biomass depends on a number of factors such as scaling up certain supplies, and whether biomass is locally sourced. Secondly there is also the immense challenge of assessing whether the biomass used comes from sustainable sources or not. Defining what is sustainable biomass and determining the availability of sustainable biomass supply is not straight forward, and is extremely uncertain. The range of estimates calculating the future availability of sustainable biomass feedstocks is wide- close to zero to above today's energy levels depending on what feedstocks are included in the analysis. For example the IEA state that approximately between 130 and 240 EJ of sustainable biomass is available, while the Energy Transition Commission takes a more cautionary approach putting the figures at 40-60EJ in their prudent scenario and 120EJ in their ambitious scenario. This matters, as not all biomass is good, the use of unsustainable biomass can actually cause higher emissions than their fossil fuel counterparts.

Having said this, there is not one net zero scenario that does not include the scaling up of biomass over time. For example the IEA in their net zero scenario include the use of 102EJ of biomass in 2050, whilst IRENA is more bullish estimating that a total of 150EJ of biomass is needed to reach net zero. Most scenarios also include the use of bioenergy with carbon capture and storage as an essential technology to reduce emissions over time.

We do agree that biomass is important, however we agree with the Energy Transition Commission that we should take a cautious approach to its use and prioritize where possible the use of biomass for sectors where the economics work and where there is a lack of alternative available solutions. These include:

1) The use of biomass for the aviation industry, as sustainable aviation fuel is essential in reducing emissions from this sector.

2) The use of biomass as a feedstock for the plastic industry. It is extremely difficult to decarbonize the plastic industry and because of this, we need to deploy all the available solutions together which include demand reduction, material substitution, the use of biomass as a feedstock and recycling.

**This does not mean that biomass should not be used in other sectors. In fact we think that in certain countries where sustainable biomass is plentiful and where the economics make sense, the use of biomass will continue to form an important part of decarbonizing multiple sectors**. For example biomass plays an extremely important part in reducing emissions from the transport and steel sector in Brazil. In Europe we are seeing the cement industry make use of biomass in the form of waste as a way to reduce emissions cheaply. We agree that BECCs is an important technology in limiting the negative impacts of climate change, but this should not encourage the unsustainable use of biomass or a reduction in available sustainable supply of biomass for priority sectors.

This report is divided into 3 main sections. Section 1 provides an introduction as to what is biomass, its feedstocks, greenhouse gas emission reductions etc. Section 2 discusses the potential use of biomass in various sectors including power generation, industry, transport and in the plastic industry. Whilst section 3 compares the potential demand for biomass with the availability of sustainable biomass resources.

## What is Biomass?

Biomass in its broadest term includes all biological material –plants, soils and animals. It is basically any organic matter that is available on a renewable basis. It includes agricultural crops, agricultural waste and residues, wood and wood waste, animal waste, municipal waste and aquatic plants. There are numerous terms that are used when discussing biomass and its applications, and it is important to understand them as they are quite different, yet unfortunately they are often used interchangeably in many studies. For this reason we have included a glossary of terms at the beginning of this document.

**Biomass feedstocks**

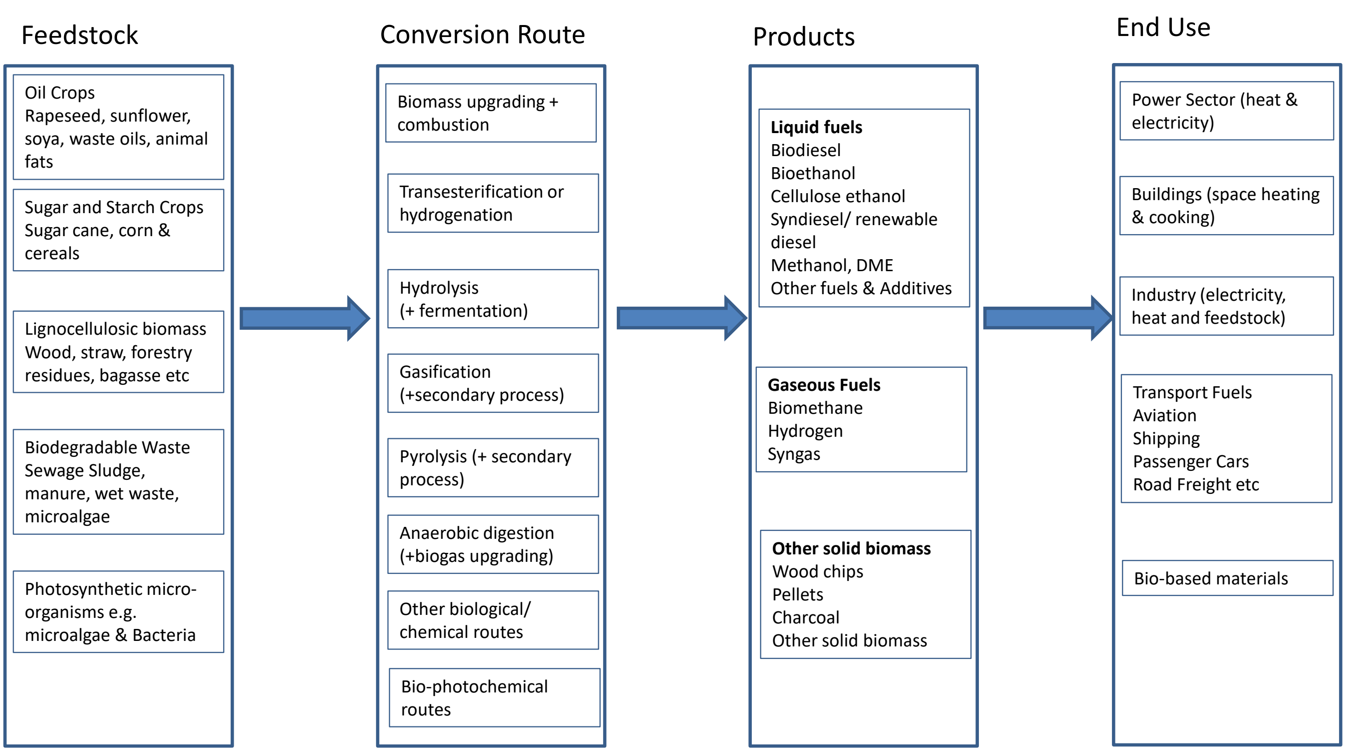
Biomass can be grown on agricultural land, and includes: Conventional energy crops such as cereals, corn or sugar cane. It can also be grown on marginal land, for example miscanthus or short rotation coppice and it can also be provided from forest areas such as woody biomass used to produce materials.

Biomass can also come from waste and residues of other sectors such as bark, woodchips and branches from forestry, agricultural residues such as cereal straw and husks, and municipal and industrial wastes (i.e. waste oils, manure, and other organic wastes). New biomass resources are currently being researched which include biomass from aquatic sources such as seaweed and microalgae. These types of biomass are very land efficient, requiring either no land at all, or using unproductive land. However, significant developments are needed in technologies and business models to increase capacity, if aquatic biomass resources are to be used at scale.

Available feedstocks of biomass are very unevenly distributed across regions, and vary according to local characteristics.

There are a number of different products that can be produced from biomass including liquid fuels, gaseous fuels and solid biomass, as shown in the diagram below. The feedstock first needs to be harvested and/or collected, transported to biorefineries (if needed) and converted in different forms. These products can then be used for a number of different applications including power generation, transportation, and as a source of heat for industry or in buildings. Biomass can also be used as a feedstock, to produce furniture and other wood products, to produce fibres in the textile or construction industry, and as a chemical building block to produce plastics and other chemical feedstocks, such as solvents, paints, and pharmaceuticals etc.

**Figure 3. Biomass Feedstock, conversion route, products and end use[2]**




Source: Citi Global Insights, adapted from Committee on Climate Change (2018) and updated

Biomass resources can be transported and traded globally, however they are most economical when used locally, as the collection and transportation of biomass is costly, especially when the biomass that is moved is bulky. Moreover, locally sourced biomass is often preferred as it is easier to ensure that it is sustainable

[2] Committee on Climate Change (2018), Biomass for a low carbon economy

(refer to section below on sustainability of feedstocks)[3]. Therefore, it is more likely that biomass will be used more extensively in regions where supply is plentiful. This does not mean that biomass is not traded globally; indeed there are a number of different trading routes, such as North America sending wood pellets to Europe[4].

With the demand for biomass expected to increase, it will undoubtedly lead to more products being traded across the globe. However, it is critical to understand that biomass can only contribute to emission reductions if it is sustainably sourced, with low levels of carbon emissions across its supply chain, from lifecycle growth, through collection, and to transformation. Herein lies the problem of biomass use - it is inherently complex to ascertain the sustainability of biomass resources, as discussed below. However, if done well, using biomass for energy and for materials can count as low or zero emission use, because the carbon released at the point of combustion was previously removed from the atmosphere during the biomass growth (we discuss GHG reductions later in the report).

### The Sustainability of Biomass

So, biomass can have an important role in reducing emissions, so long as we can ensure that it is sustainable. But how do we define sustainable biomass? There is as yet no consensus about what 'sustainable' biomass actually means, though a number of organisations have issued recommendations with regards to sustainability criteria. For example, the European Commission issued guidelines on sustainability criteria for biomass for energy installations of at least 1 MW of thermal heat or electrical power.[5] These:

- forbid the use of biomass from land converted from forest, and other high carbon stock areas, as well as highly biodiverse areas;
- ensure that biofuels emit at least 35% less greenhouse gases over their lifecycle (cultivation, processing, transport etc.) when compared to fossil fuels. This increases to 50% and 60% for new installations in 2017 and 2018, respectively;
- favour national biofuels support schemes for highly efficient installations; and
- encourage the monitoring of the origin of all biomass consumed in the EU to ensure their sustainability.

The Energy Transitions Commission (ETC) states that there are three key sustainability criteria that need to be adhered to, for biomass to be considered sustainable:

(1) Any biomass production should consider competing uses of land - for example for food production, human habitation, habitat conservation and for climate mitigation such as forests. These alternative land uses define the opportunity cost of using the land, and provide a baseline for carbon emissions against which using the land for biomass should be judged. This means that the land made available for biomass production should be

[3] Energy Transition Commission (2021), Bioresources within a net-zero emissions economy, Making a Sustainable Approach Possible

[4] Ibid

[5] European Union Sustainable https://ec.europa.eu/energy/topics/renewable-energy/biomass_en#proposal-for-updated-sustainability-criteria-for-biofuels-bioliquids-and-biomass-fuels.

restricted to marginal land and/or crop land, or pasture land that can be released from its current use. It is important that the last statement, 'as released from its current use', does not necessarily mean using existing productive agricultural land which is used for food production to grow energy crops, as this could impact food prices. The food vs. energy debate has been raging for many years, and has been a key source of caution regarding biomass use, especially first generation biomass.

(2) A lifecycle analysis also needs to be undertaken, to ensure that carbon dioxide absorption during the growth of the biomass balances with emissions across its full lifecycle (i.e. its use). For example, land with especially high soil carbon content should not be used for biomass production, as this defeats the purpose of biomass as a renewable resource, as the emissions associated from direct land use change would be large.

(3) The footprint associated with the production, collection, transportation and processes should be close to zero.

We also need to ensure that biodiversity is not adversely affected by biomass use. This is important as extensive use of, for example, solid biomass such as wood pellets and charcoal could drive deforestation.

Over the years a number of sustainability principles and criteria have been set up to help corporations and governments understand what constitutes sustainable biomass, and what does not. For example, the Global Bioenergy Partnership produced a set of 24 indicators to determine the sustainability of biomass feedstocks, which are aimed principally at government agencies. These fall under three main headings — environmental, social, and economic — and include indicators such as life-cycle GHG emissions, soil quality, harvest levels of wood resources, water use and efficiency, allocation and tenure of land for new bioenergy production, infrastructure and logistics for the distribution of bioenergy. The Round Table for Sustainable Biomaterials (RSB) provides a global certification standard for sustainable biomaterials, biofuels, and biomass production. They take eleven principles into consideration when assessing the sustainability of biomass (see figure below). Many industries, such as the aviation sector (which we discuss later in the report), have based their sustainability criteria for biomass use on these principles.

However, though many of these guidelines overlap and use similar criteria, a universal definition or common standard to assess the sustainability of biomass remains elusive. Many agree that for biomass to be sustainable, it should be generated in addition to what is naturally occurring, be salvaged from waste, or be a residue. This is important, as it is critical that we do not end up destroying forests or other high carbon land to provide biomass for energy systems.

Figure 4. RSB Principles

| THE 12 RSB PRINCIPLES | | | |
|---|---|---|---|
| **Principle 1: Legality** | **Principle 2: Planning, Monitoring & Continuous Improvement:** | **Principle 3: Greenhouse Gas Emissions** | **Principle 4: Human and Labour Rights** |
| Operations follow all applicable laws and regulations | Sustainable operations are planned, implemented, and continuously improved through an open, transparent and consultative impact assessment and management process and an economic viability analysis | Biofuels contribute to climate change mitigation by significantly reducing life-cycle GHG emissions as compared to fossil fuels | Operations do not violate human rights or labour rights and promote decent work and the well-being of workers. |
| **Principle 5: Rural and Social Development** | **Principle 6: Local Food Security** | **Principle 7: Conservation** | **Principle 8: Soil** |
| In regions of poverty, operations contribute to the social and economic development of local, rural and indigenous people and communities | Operations ensure the human right to adequate food and improve food security in food insecure regions | Operations avoid negative impacts on biodiversity, ecosystems, and conservation values | Operations implement practices that seek to reverse soil degradation and/or maintain soil health |
| **Principle 9: Water** | **Principle 10: Air Quality** | **Principle 11: Use of Technology, Inputs and Management of Waste** | **Principle 12: Land Rights** |
| Operations maintain or enhance the quality and quantity of surface and groundwater resources, and respect prior formal or customary water rights | Air pollution shall be minimised along the whole supply chain | The use of technologies shall seek to maximise production efficiency and social and environmental performance, and minimise the risk of damages to the environment and people. | Operations shall respect land rights and land use rights |

Source: Roundtable for Sustainable Biomaterials (RBS)



## Availability of Sustainable Supply

So if a key challenge with biomass is the sustainability of the feedstock, how much is actually available for use? The range of estimates for the future availability of sustainable biomass feedstock is wide, with some studies estimating it is close to zero, while others stating that it is above today's energy use levels – the difference essentially depending on which feedstocks are included in the analysis.

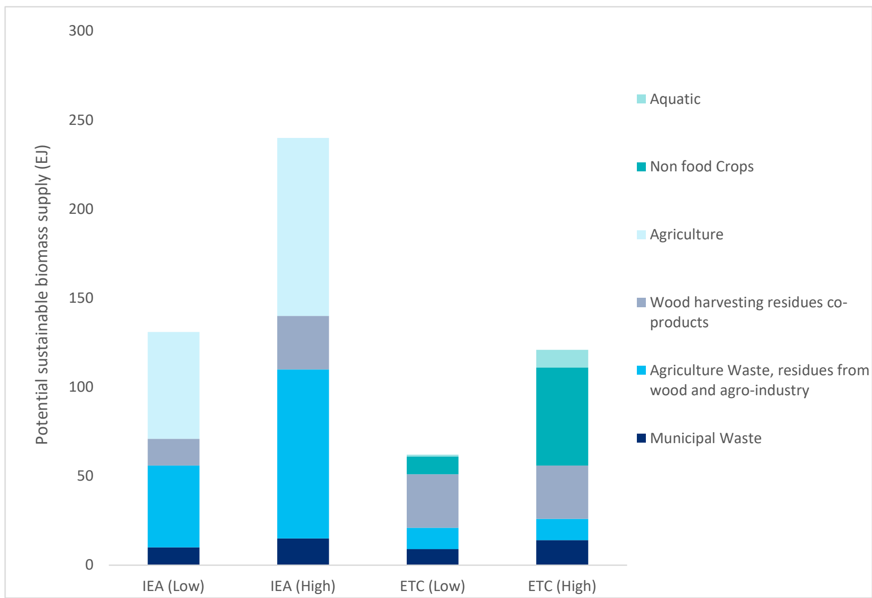
An analysis by the IEA shows how much sustainable biomass might potentially be available in 2060, taking into consideration a number of factors, including:

- the waste management hierarchy for municipal waste;
- the need to reserve some agricultural waste for animal feed and to leave sufficient residues in the field for soil protection;

- sustainable forestry plans with regard to wood harvesting residues and co-products; and
- producing energy crops on agricultural land that avoid threatening food availability and increasing emissions associated with land-use change.

In total, the IEA states that between 130 and 240 EJ of sustainable bioenergy could be available by 2060 (refer to figure below). To put this number into some sort of context, globally we consume about 580 EJ of energy. So, the IEA's high scenario suggests that there could be enough energy to meet more than 40% of (current) energy consumption. However, other groups put the figures much lower – for example the Energy Transitions Commission (ETC) estimate sustainable biomass availability at 40 to 60EJ per year under their prudent scenario, increasing to about 120EJ under their ambitious scenario. The IEA is more bullish on non-food crops (called agricultural land in their scenario) and agricultural residues compared to the ETC's scenarios.

**Figure 5. Potential Available Biomass Supply per year**






Source: Citi Global Insights, IEA Technology Roadmap- Delivering Sustainable Bioenergy, Energy Transition Commission (2021)- Bioresources within a Net-Zero Economy

We should recognize however that these figures, indeed any estimates of the potential availability of sustainable biomass feedstocks in the future, are highly uncertain. They take into account a number of factors, most notably yields for energy crops, policies promoting sustainable biomass, and investment. The risk of failing to deliver sustainable feedstocks also increases as the estimates rises. While our biomass future could focus on certain feedstocks, such as agricultural waste and sustainable forestry residues, the most likely outcome is that there will be a mix of different feedstocks used for biomass production.

The choices also vary significantly by region. Countries in the Scandinavian region and Canada, for example, offer more opportunities for forestry residues, while countries such as Brazil and the U.S. may continue growing energy crops as they have the right policies and investments in place.

## Greenhouse gas reduction of biomass use

If done well, the use of biomass has the potential to reduce greenhouse gas emissions materially. However calculating emission reductions from its use is not a straight forward process. Burning biomass releases greenhouse gas emissions, but the net greenhouse gas outcome of using biomass cannot be determined just by examining emissions at the point of combustion. Biomass forms part of the natural cycle of growth and decomposition, operating within the natural carbon cycle. In basic terms, plants absorb $CO_2$ when they grow, and then release most of their carbon into the atmosphere when they die, which completes the natural carbon cycle. The reality is more complex, as some carbon is retained in soil systems, some is consumed by animals, and some is used for plant growth. Overall, the carbon dioxide released when biomass is burned is offset by the amount of carbon dioxide absorbed during the natural life of the feedstock. However, additional greenhouse gas emissions are inevitably generated through the production of those feedstocks (e.g. agriculture), conversion of the biomass to end-products (e.g. bioethanol), and transportation of products for end use (e.g. fueling road vehicles).

The use of biomass can also induce emissions if it leads to a change in carbon stocks, for example due to land-use change, or via soils that also store carbon. This is why it is important to prevent the conversion of high-carbon land for biomass production. There is also a debate on whether we should increase the amount of food crops for biofuels and other products, given that overall demand for food is expected to increase, creating competition for land between food crops and energy crops. This so-called the ‘food vs fuel’ debate which has been raging for years, with many suggesting that energy crops have had a direct impact on food production. The risk undoubtedly exists that other land would be diverted for food production in order to meet food demand, leading to an increase in land-use emissions (indirect land use emissions).

Again, if done well, there is evidence that crops grown for bioenergy and for other uses such as bio-based plastics can deliver significant reductions in GHG emissions. For example, the Climate Change Committee (CCC) in the U.K. estimates that current bioethanol production in Brazil, which is produced from sugarcane, reduces GHG emissions by 86% when compared to gasoline, even after taking into account land-use change. Selective programs have been used to increase yield and sugar content, leading to a doubling of yields and a 67% reduction in costs over the last 50 years. The CCC acknowledges that since sugar cane is grown on agricultural land, the risk of emissions from indirect land-use change exists. If the future production of ethanol is to remain sustainable, then any increase in demand for feedstocks should not occur on high-carbon land.

If we look at waste as a source of bioenergy, then emission reductions occur because one avoids sending the waste to a landfill, which would ultimately cause methane emissions as decomposition occurs.

There is no one-size-fits-all answer to determine with any certainty whether the use of biomass for different products and services is low-carbon, as there are a number of factors to consider. On the one hand, low greenhouse gas biomass and its products depends on preventing the loss of land carbon stocks both through direct and indirect effects, and reducing the GHG emissions associated with cultivating and processing biomass. On the other hand, some biomass production for energy and other products can also be associated with much higher GHG emissions when compared to fossil fuels, particularly when it drives large losses in land carbon stocks, for example, through the conversion of peatland and primary forest. This is particularly relevant to some conventional or first generation biofuels, but less relevant for many advanced biofuels given that many advanced biofuels would not have an impact on land use change.

To understand the greenhouse gas net benefits of using biomass for energy and other products it is important that a life cycle assessment (LCA) is undertaken encompassing all of the processes. This is complex and includes numerous factors, though many LCA studies show bioenergy pathways can have much lower supply chain emissions than fossil fuels. According to the IEA, in the best cases biofuel emissions can be over 90% lower than those emitted by the fossil fuel equivalent.[6] The European Commission has produced a number of default GHG reduction values (not accounting for emissions due to land-use change) for different biomass feedstocks and production methods, which are summarizes in the table below.

**Figure 6. GHG savings from using Bioenergy**

| | Bioenergy Option | No. of Routes | Max Saving (%) | Min Saving (%) |
|---|---|---|---|---|
| Transport | Conventional biofuels | 35 | 98 | 24 |
| | Advanced biofuels | 14 | 89 | 78 |
| | Biomethane for Transport | 12 | 179* | 17 |
| | | | | |
| Electricity | Agriculture Residues | 15 | 90 | 33 |
| | Wood Chips | 21 | 90 | 35 |
| | Biogas | 18 | 219* | 14 |
| | | | | |
| Heat | Agriculture Residues | 15 | 93 | 11 |
| | Wood Chips | 21 | 93 | 57 |
| | Wood Pellets | 57 | 94 | 32 |
| | | | | |

*In cases where direct methane emissions to the atmosphere are reduced, emissions savings can exceed 100% of those associated with fossil fuel alone, as methane is a significantly more potent GHG than CO2

Note: These savings do not take into account emissions due to land-use Change

Source: European Commission (2016), Proposal for Directive on Renewable Energy, 2016 Annex 5

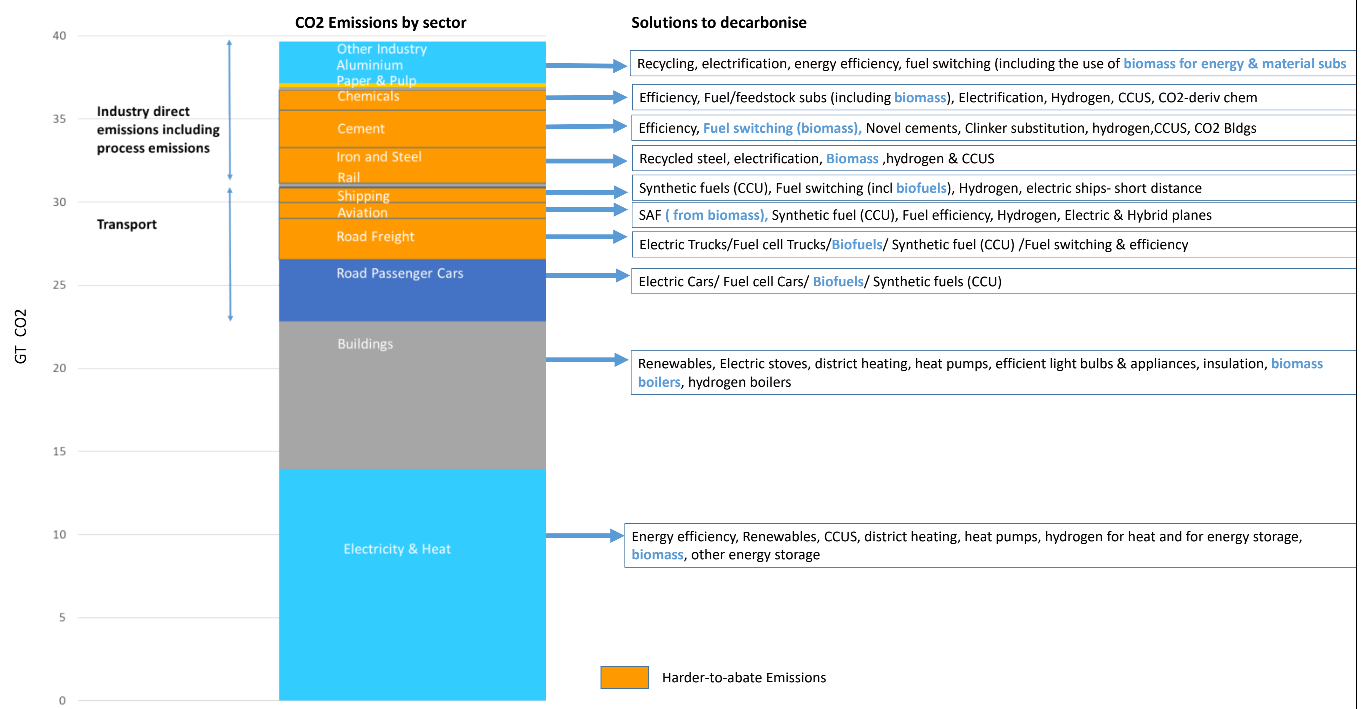
# What is the unsustainable thing it will alleviate?

As we described in the previous chapter, biomass can be used to reduce emissions in most sectors, as shown in the diagram below. While the use of biomass is not the only solution available, for certain sectors, and in certain regions, it could really make a difference in the battle to reduce emissions.



[6] IEA, Technology Roadmap, Delivering Sustainable Bioenergy.

**Figure 7. Some solutions to CO2 emissions by sector**

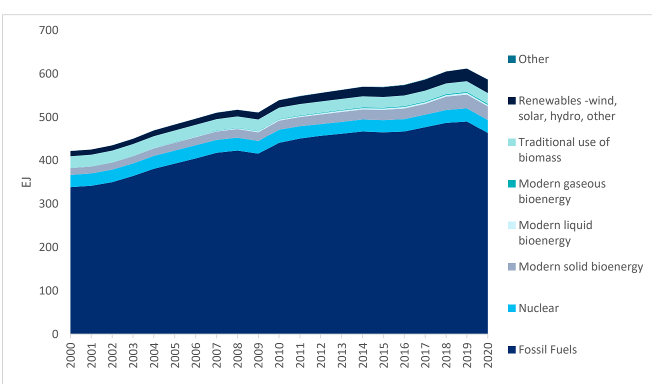





Source: Citi Global Insights

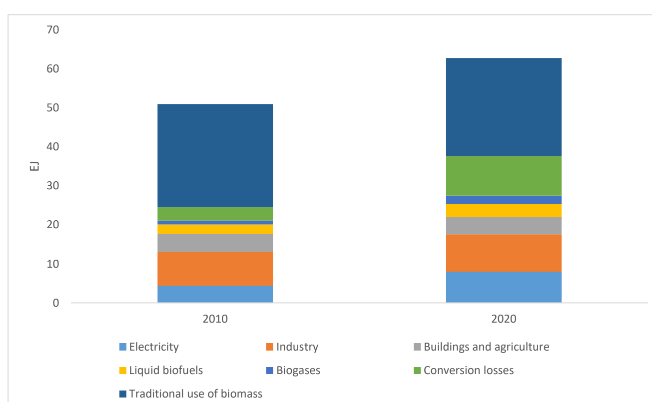
Currently, bioenergy provides just over 10% of total energy supply; however, most of this comes from 'traditional biomass' feedstocks including wood, charcoal, manure, or other organic waste and residues. Although it is very difficult to quantify the exact use of traditional biomass given its unregulated nature, the IEA (International Energy Agency) reports approximately 2.5 billion people worldwide still use traditional biomass for their energy needs, in particular for heating and cooking.  Approximately 60% of total bioenergy used today is considered to be unsustainable (BNEF).

**Figure 8. Bioenergy is currently 10% of energy supply**




Source: IEA (2021) Net Zero by 2050

**Figure 9. Current use of Bioenergy by sector**




Source: IEA

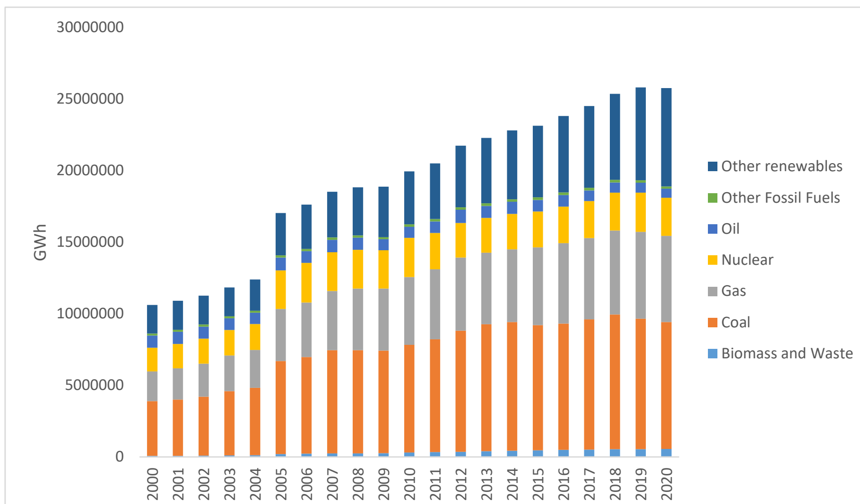
Biomass is also used as a feedstock and is particularly important for a number of sectors including the construction industry, as well as in producing pulp and paper. It is estimated that approximately 16 EJ/year of biomass is used for these industries alone.

The demand for biomass is expected to increase over the years. In this chapter we analyse the potential use of biomass across different sectors including power generation, industry, transport and the plastic industry. We discuss the costs associated with the use of biomass across these sectors and compare them to other alternative technologies. We conclude that given the use of biomass is constrained by the amount of sustainable biomass available, we should prioritize its use for sectors that have limited other options available, and where the economics work.

## Power generation

Biomass for the production of power accounts for over 12% of bioenergy used today (not including traditional biomass). However it is only a small part of total resources used for electricity generation (refer to figure below).

**Figure 10. Power Generation by source**



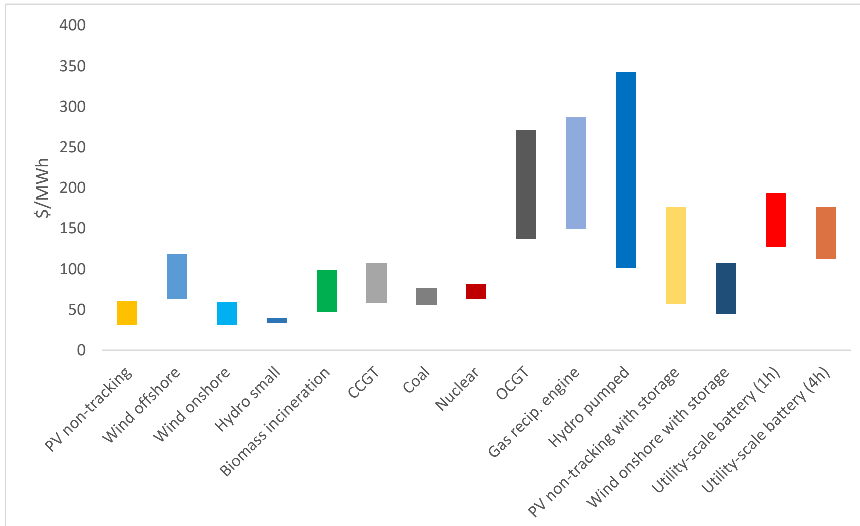



Source: Citi Global Insights, BNEF

The generation of electricity from bioenergy uses a variety of biomass and waste fuels in solid, liquid or gaseous forms, with the consumption depending on the available national resources. Feedstocks include waste, or residues from logging such as wood pellets or agriculture residues, etc. These feedstocks can be converted to electrical power through a number of different processes - the most common method being via the direct combustion of biomass material such as agricultural waste or woody biomass. In some cases, the steam from the power plant is also used for manufacturing processes or to heat buildings, with these CHP plants obviously being more energy efficient vs. standard biomass electricity only systems. Other methods to convert biomass into electric power include gasification, pyrolysis or anaerobic digestion, the method chosen depending on the type of biomass used. For example woody chips, pellets and sawdust are either combusted or gasified to produce electricity, whilst corn stover and wheat straw residues are bailed for combustion, or converted to gas using an anaerobic digestor.

The use of biomass for power does have some advantages compared to other renewable options such as solar and wind. It doesn't have the problem of intermittency, and can be used for both baseload electricity production and/or for seasonal power generation - to balance the demand when needed. However, the disadvantage is that especially for baseload generation, long term supplies of sustainable sources of feedstocks need to be secured in order for the economics to work. There is also an issue of cost; in many regions the cost of renewables such as solar and wind have decreased immensely, and are now cheaper than fossil fuels (see figure below for an example of China).

**Figure 11. LCOE for power generation in China**






Source: Citi Global Insights, BNEF

For baseload generation and daily balancing there are a number of other options that can also be used. However, if there is a need to provide power system balance over longer durations then this is a greater challenge. One option is to use flexible thermal plants using biomass, which could be an excellent solution, though it would need to compete with other alternatives such as green hydrogen, pumped hydro-storage, long-distance connection with other regions which have additional renewable resources, natural gas generation with CCS, and others[7]. The solutions used in many regions will depend on a number of factors including the availability of local sustainable biomass resources that can be used in power generation, the availability of CCS geological storage facilities that are near-by, the cost of green hydrogen etc. Therefore, given the availability of multiple options available to reduce emissions from the power sector, we believe that power generation via biomass is likely to be most effective in geographies that have plentiful sustainable biomass supplies, and where it can compete with the economics of alternative solutions.

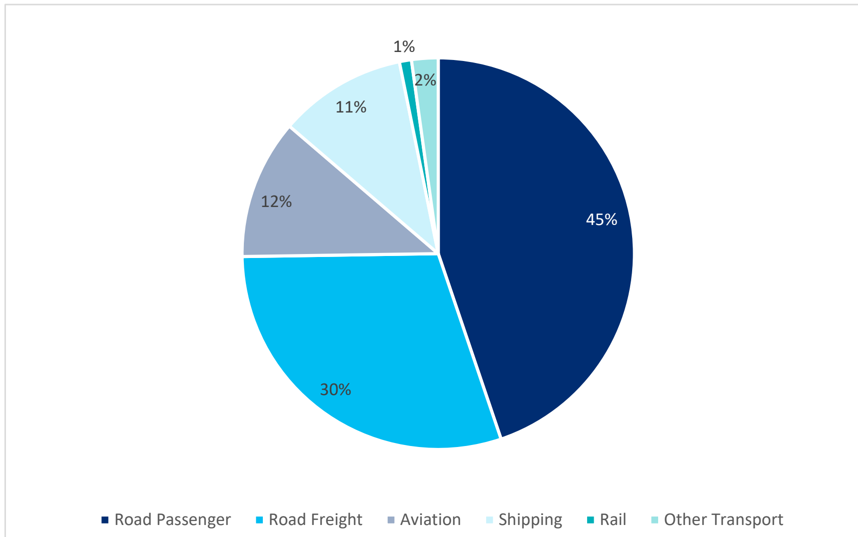
## Transport

Transport $CO_2$ emissions account for approximately 20% of total energy-related $CO_2$ emissions. Road travel accounts for approximately 75% of these emissions,

[7] Energy Transition Commission (2021), Bioresources within a net-zero emissions economy, Making a Sustainable Approach Possible

with 45% coming from passenger cars and 30% from carrying freight. Aviation and shipping account for approximately 12% and 11%, respectively. According to the IEA, transport demand is expected to grow across the world as the global population increases and income rises, making it more affordable to buy cars and travel. By 2070 global transport, measured in passenger-km is expected to double, and demand for aviation to potentially triple. There are a number of solutions to decarbonise these sectors; for example electric cars seem to be the ideal solution to help decarbonise passenger cars and potentially even road freight, whilst the use of green ammonia could be instrumental in reducing emissions from the shipping sector. However we believe that biofuels can also play an important part in reducing emissions in all transportation modes (especially in the near-term), and will be instrumental for the aviation sector.

**Figure 12. Transport related emissions divided by mode**





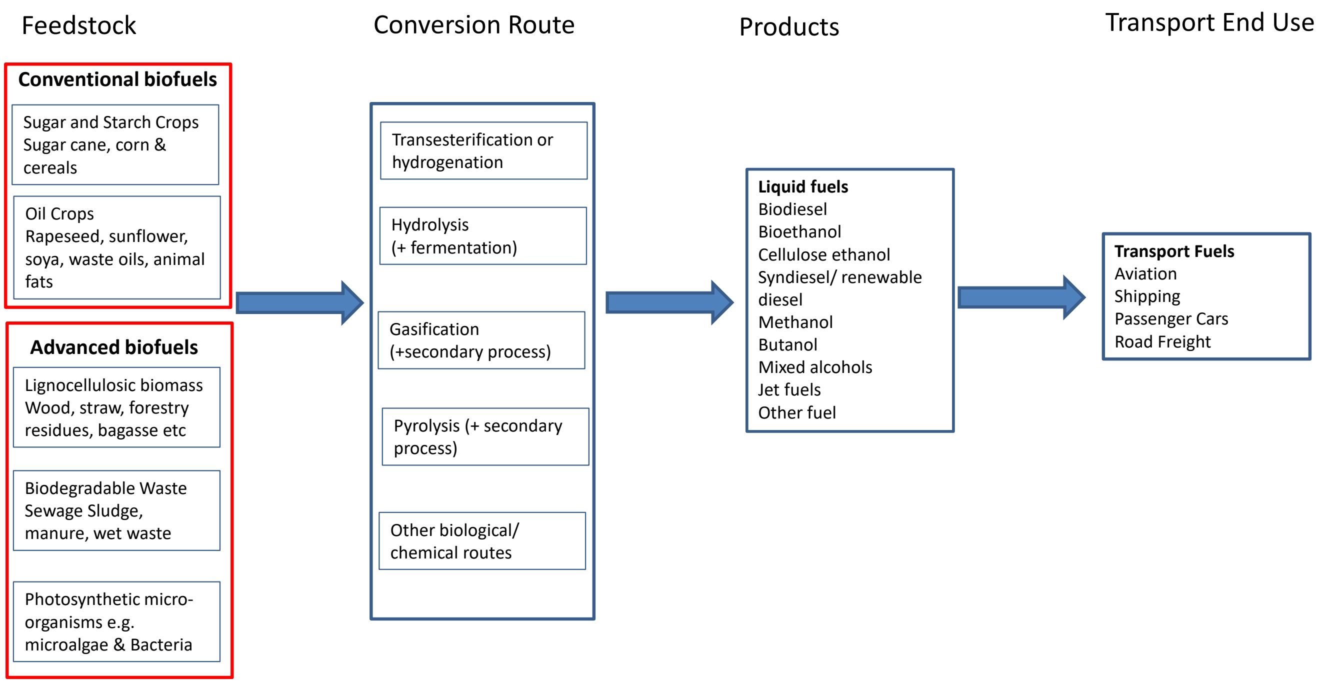

Source: Citi Global Insights, Hannah Ritchie (2020)

## Biofuels in transportation

Biofuels can be defined as liquid fuels derived from biomass. There are two main types of biofuels produced today - ethanol and biodiesel. Biofuels could be classified into two categories (1) conventional biofuels, which are also known as first generation biofuels, and (2) advanced biofuels also referred to second and third generation biofuels. Conventional biofuels are obtained through well-established processes and include sugar-and starch-based ethanol, oil crop based bio-diesel and straight vegetable oil. There are a number of feedstocks used to produce these biofuels including sugar cane and sugar beet, corn and wheat and oil crops such as oil palm, soya, sunflower etc. In some cases, used cooking and animal fats are used. Some experts classify the use of used cooking oils and animal fats as second generation biofuels. The food vs biofuel debate is the most contentious issue with regards to first generation biofuels given that an increase in biofuel production could divert food crops from being used to meet global food demand.

The IEA defines advanced biofuels (second or third generation) as 'sustainable fuels produced from non-food crop feedstocks, which are capable of delivering significant life-cycle GHG emissions savings compared with fossil fuel alternatives, and which do not directly compete with food and feed crops for agricultural land or cause adverse sustainability impacts[8]'. Feedstocks for advanced biofuels include agricultural residues, forestry residues, municipal solid waste (2nd generation), algae (3rd generation) and others. Some experts also classify energy crops such as miscanthus, switch grass and others as secondary or advanced biofuels, though in some instances these crops may compete with food or feed crops, or cause land-use change.

**Figure 13. Feedstocks for Biofuels**





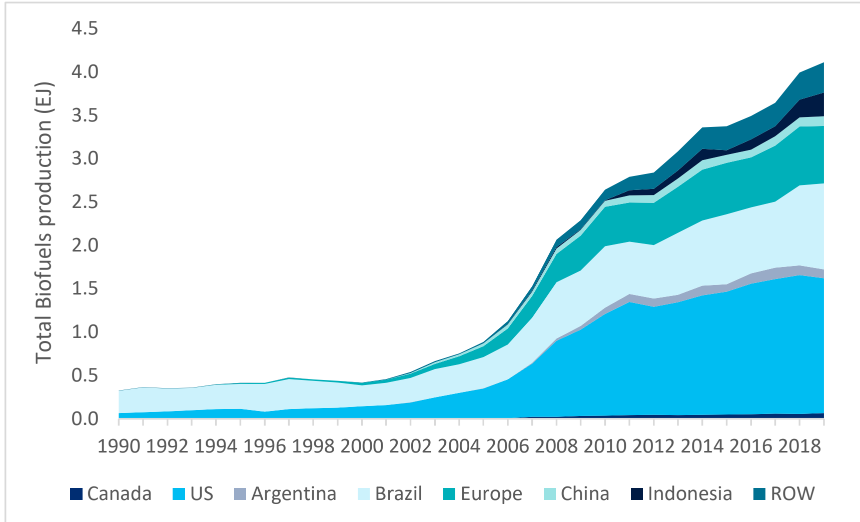

Source: Citi Global Insights

The majority of biofuels currently produced are considered to be conventional biofuels. Biofuel production has increased more than ten-fold since the year 2000, with a total of 4.1 EJ of biofuels being produced in 2019. The US and Brazil produce approximately 37% and 24% of the current supply, with both countries mostly focusing on the production of ethanol. The US relies exclusively upon corn to produce ethanol, whilst Brazil mostly uses sugar cane. The EU is the third largest producer of biofuels, but the focus in this region is mostly on the production of biodiesel. Biodiesel is a smaller market than ethanol, largely due to geography, as gasoline is the dominant fuel in the two largest biofuel markets in the world - the US and Brazil. Key Asian markets include China, Indonesia, India and Thailand, which collectively account for more than 80% and 90% of Asia's biodiesel and ethanol supply respectively.



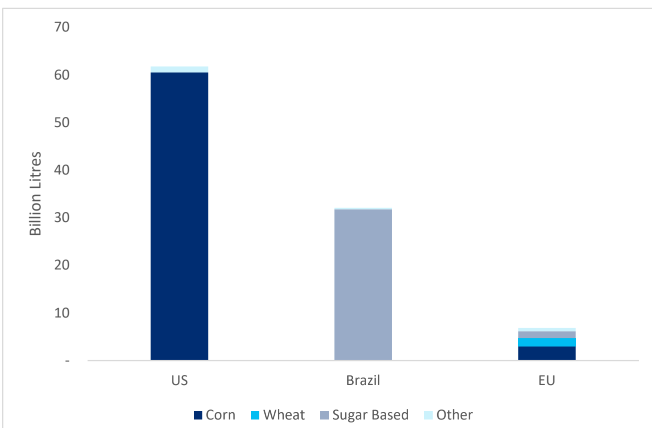
[8] IEA (2017), Technology Roadmap, Delivering Sustainable Bioenergy

**Figure 14. Global Biofuel Production**



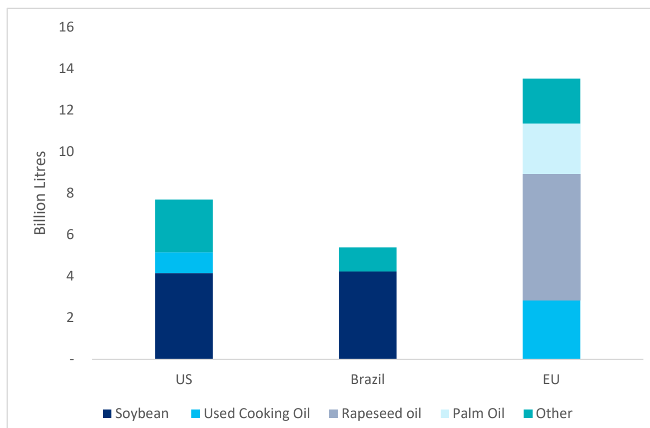

Source: BP

**Figure 15. Ethanol feedstock (billion litres)**




Source: BNEF

**Figure 16. Biodiesel Feedstock (billion litres)**




Source: BNEF



The majority of the biofuels used today are for road transport, though the use of biofuels is expected to increase in other transport sectors, including aviation and shipping. However, the processes to produce these biofuels would, in some instances, be different to those for road transport. Biofuels currently tend to be blended with gasoline or diesel; for example in the US, E10 (a blend of 10% ethanol, 90% gasoline) is widely-sold, whilst E15 (15% ethanol/85% gasoline) is compatible with vehicles that have been produced after 2001. E10-15 is generally considered the highest ethanol blend compatible with conventional internal combustion engines, although some models are able to run on E25. Flexi-fuel vehicles are designed to run on any blend of ethanol and gasoline, and these types of cars can actually run on unblended hydrous ethanol. For example, Brazil has a mandated blend level of 27%, and extensive use of unblended hydrous ethanol in its flexi-fuel vehicles.

Similarly with biodiesel, a number of different blends are available, the most common being B5 (up to 5%) and B20 (6-20% biodiesel). B100 is also available but is typically used as a blendstock to produce lower blends, and it is rarely used as a transportation fuel, due to the fact that it could clog up filters, impact engine warrantees, gel in cold temperatures etc. This technical limitation acts as a constraint on how far governments can push blending mandates without the need to change infrastructure/fleets. However, renewable or green diesel, produced using similar feedstocks to biodiesel but with a different process, does not need to be blended, as it has the same chemical properties as fossil-fuel diesel. Renewable diesel capacities are going through a rapid expansion in the US, with most of this increase happening in California as the state tightens its Low Carbon Fuel Standard, which aims to reduce the carbon footprint of fuel blends sold. Renewable diesel is also expected to grow in Europe, and is in fact expected to grow faster than biodiesel due to the the EU's Renewable Directive 2021-2030 (RED II), as well as via a potential increase in the use of Sustainable Aviation Fuel. The fact that renewable diesel can also be configured to be used as SAF[9] is a key advantage.

### Road Freight

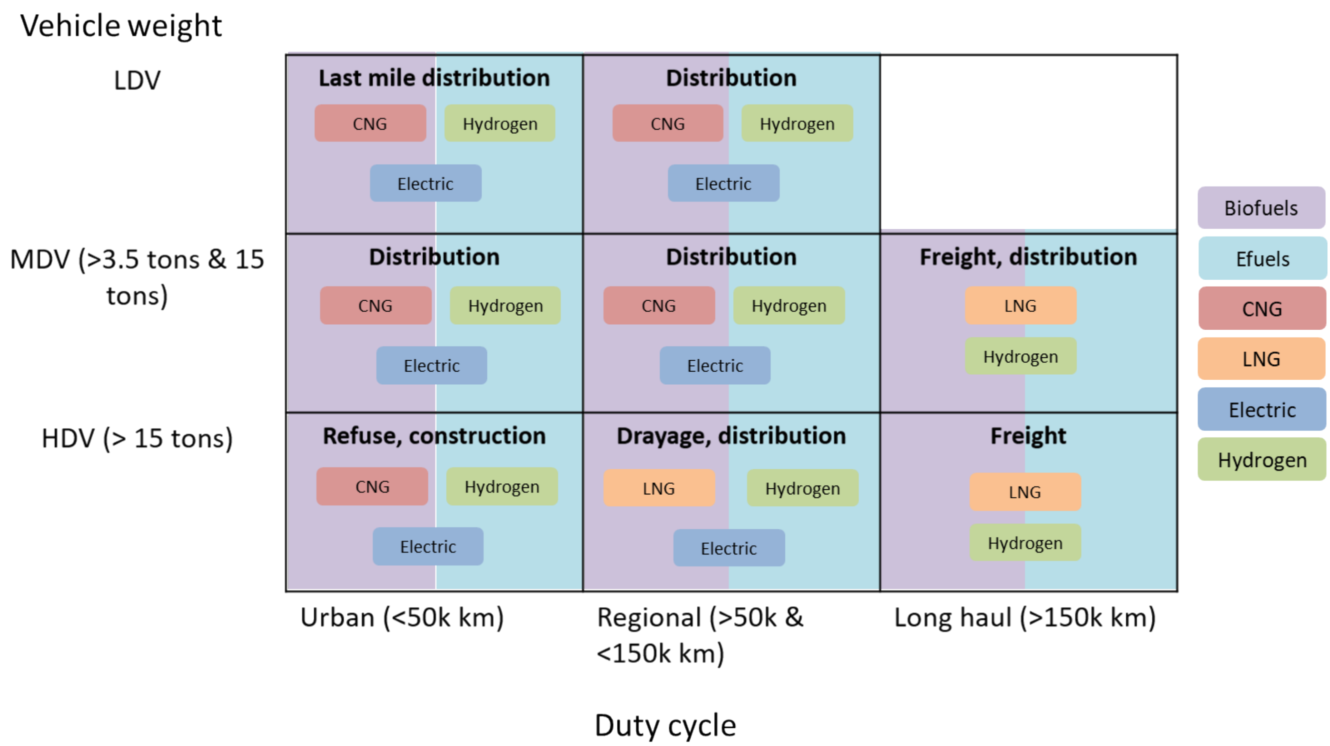
Road transport will become more electrified over the coming years, but not everywhere, not in all sectors, and not at the same pace.  While electric cars are likely to dominate light passenger cars, it will take a longer time for road freight, especially long-haul road freight, to become electrified, given that the technology is only just starting to hit the market. Hence biofuels may well be the best option for this sector to reduce its CO2 emissions in the near term.

The diagram below shows the different solutions available to reduce CO2 emissions from road freight, with biofuels offering potential in all categories, including urban, regional and long haul. Biofuels present an attractive option in part because they can be used in existing internal combustion engines.



[9] https://ihsmarkit.com/research-analysis/structural-shift-to-renewable-diesel-brings-accelerated-growth.html

**Figure 17. Alternative Technologies and Fuels for Trucking**

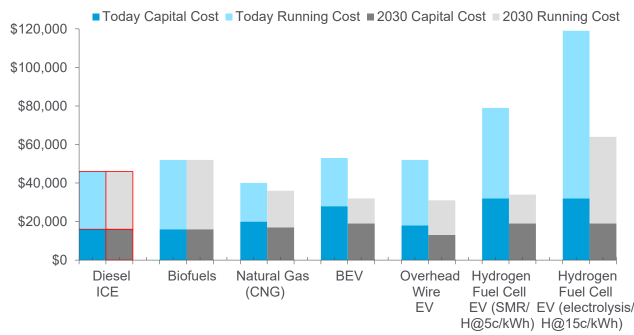



Source: Citi Global Insights, adapted from BNEF (2020), Long-Term EV Outlook 2020

However, biofuels are currently more costly than diesel (ignoring for the moment carbon). The left-hand diagram below compares the total cost of ownership (TCO) of a truck (capital and running costs) based on different alternative fuels and technologies today, and in 2030. The TCO of biofuels are currently cheaper than electric or hydrogen trucks, though according to the Energy Transition Commission, the TCO of electric trucks could potentially be cheaper than both diesel and biofuels in 2030. This clearly depends on the price of electricity in a particular region, and if electric trucks (including overhead wires) are to be scaled up, then adequate infrastructure would be needed, together with improvements to battery technology. By 2050, it is estimated that heavy duty trucks running on hydrogen (FCEV) will also be cheaper than biodiesel, as shown in the right-hand diagram. Again this would obviously depend on the price of electricity, as well as the price of hydrogen.

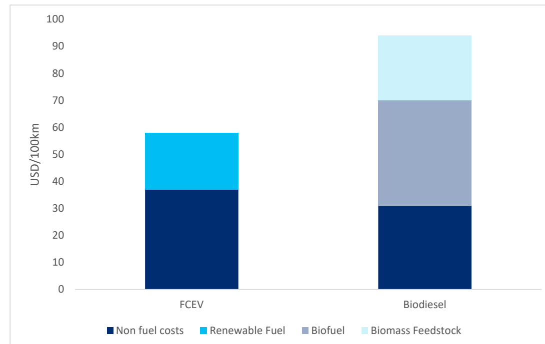
Biofuels do however have the added advantage of being used in existing internal combustion engines, though GHG reductions would depend on lifecycle analysis and blending requirements. So, in conclusion, we believe that biofuels will play an important part in the interim for road freight, especially in areas where this sector is well established such as the US and Brazil. However, in the longer term, alternative technologies such as electric trucks and/or FCEV trucks could replace combustion engines.

**Figure 18. Cost comparison of Alternative Technologies vs Diesel**




Source: Energy Transition Commission, Note: Based on a heavy duty truck over one year of usage assuming a distance of 150,000 km/yr and a first depreciation of 12%

**Figure 19. Estimated total cost of ownership (US$ /100 km) in 2050**




Source: Energy Transition Commission (2021), Assumes a 2050 global levelised cost of electricity of $20/MWh and hydrogen at $1.4/kg. Boifuels assumes a cost reduction by 2050 of 28% on non feedstock OPEX/CAPEX costs from current figures

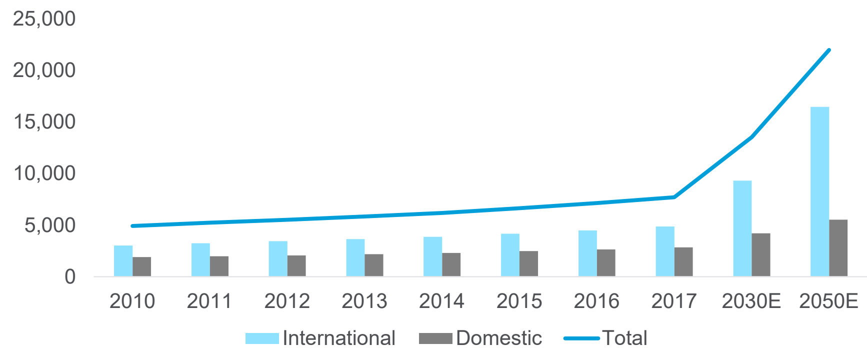
## Aviation

The aviation sector currently is responsible for ~12% of transport sector $CO_2$ emissions and ~3% of global $CO_2$ emissions. Expectations are that aviation demand will increase from an estimated 7.6 trillion passengers-km in 2017 to approximately 22 trillion passenger-km in 2050, as illustrated in figure below. This increase is the result of population growth, economic growth, an increase in wealth, and an improvement in air connectivity[10]. This analysis by the International Transport Forum (ITF) was carried out pre-COVID-19, and hence does not take into consideration drops in passenger numbers in 2020 and 2021, and potentially 2022 and 2023. This means that demand for aircraft fuel could increase by more than 50% by 2050, compared to pre-COVID-19 levels. Under a business-as-usual scenario, and assuming fuel efficiency improvements of 1% annually through to 2050, this would translate into an increase of $CO_2$ emissions from 0.7 Gt of $CO_2$ (pre-COVID-19) to 1.7 Gt of $CO_2$ in 2050. Every metric tonne of jet fuel burned produces approximately 3.15 tonnes of $CO_2$[11].

[10] ITF (2019), ITF Transport Outlook 2019, OECD Publishing, Paris, https://doi.org/10.1787/transp_outlook-en-2019.en.

[11] World Economic Forum in collaboration with McKinsey and Company (2020), Clean Skies for Tomorrow, Sustainable Aviation Fuels as a Pathway to Net-Zero Aviation, Insight Report, November 2020.

Figure 20. Projected Aviation Demand (Billion Passenger-km)





Source: Citi Global Insights

## Decarbonising the aviation industry

The aviation industry is under pressure to reduce its $CO_2$ emissions, however like the shipping industry (discussed in the next section), technology to completely decarbonize this sector is still far away. Domestic aviation emissions (including airport emissions and emissions from ground service equipment) are already covered in the Paris Agreement in national pledges, but international flights, which represent 65% of the aviation's $CO_2$ emissions, are instead covered by the UN's International Civil Aviation Organisation (ICAO). The ICAO Assembly at its 40th Session in 2019 reiterated two global aspiration goals for the international aviation sector: 2% annual efficiency improvement through 2050 and carbon neutral growth from 2020 onwards.

The aviation industry has a number of options to reduce its CO2 emissions such as aircraft technological improvements, operational improvements, the use of sustainable aviation fuels, hydrogen (medium and short-haul flights), electric planes (short haul) and market based measures such as offsets. The use of SAF is hence an integral part of the aviation sector's journey to reduce its CO2 emissions over time.

### Sustainable Aviation Fuel

Sustainable aviation fuel (SAF) is the term that the aviation industry uses to describe non-fossil derived fuels (also referred to as aviation biofuels if biomass feedstocks are used). SAF can be produced from biomass feedstocks such as plant or animal material, or non-biological sources such vegetable or waste oils, municipal waste, and through waste $CO_2$ (e-fuels). Due to the interest in sustainable aviation fuels, ASTM International (formerly known as the American Society for Testing and Materials) created a new specification — the ASTM D7566 — which outlines the standard required for synthetic hydrocarbons. There are currently five approved pathways for alternative jet with a 50% maximum blend on most of the authorized sustainable aviation fuels (due to the lack of aromatic compounds in these fuels).

1. **Hydroprocessed esters and fatty acids (HEFA) from vegetable oils and animal fat — up to 50% blend approved.** Feedstocks for this are safe, proven, and scalable, including waste and residual lipids such as cooking oil, as well as oil trees such as jatropha grown on degraded land, and oilseed bearing herbs such as camelina. Compared to jet fuel, HEFA

provides GHG emissions savings of approximately 73-84%, with additional reduction potential if produced using green hydrogen in the hydroprocessing step.

2. **Alcohol to Jet — up to 50% blend approved.** Feedstocks to produce this include ethanol, isobutanol, or methanol. Fuels produced via the methanol route are not yet approved. Sustainable feedstocks for the ethanol production route include forestry residues, wood-processing, agriculture residues, and purposefully grown energy cover crops such as miscanthus. Industrial waste gases can also be used. GHG savings are estimated at 85-94% compared with jet fuel.

3. **Fischer-Tropsch synthesis through the catalytic conversion of syngas — up to 50% blend approved.** To produce this, similar feedstocks are used for the alcohol to jet SAF plus municipal waste. The feedstock is gasified to produce syngas (which is a mixture of carbon monoxide and hydrogen) then fed into a Fischer-Tropsch reactor, where it is combined into a mix of hydrocarbons in the presence of a catalyst. $CO_2$ emission reductions are estimated at 85-94%. The approval of Fischer-Tropsch synthesis is not restricted to certain feedstocks, therefore Fischer-Tropsch fuels produced via power-to-liquids (also known as synthetic fuels) are also approved. It is important to note that carbon reduction savings from using $CO_2$ to produce these fuels depends on whether the $CO_2$ is captured from an industrial site or from direct air capture (DAC).

4. **Synthetic isoparaffins from hydroprocessed fermented carbohydrates — only 10% blend approved.**

Others fuels are waiting to be ASTM-approved, such as power-to-liquid jet fuels produced by methanol-to-gasoline. There are also current trials of alternate fuels blended up to 100% but substantial testing is needed to prove their safety and reliability[12]. In 2019, less than 200,000 tons of SAF were produced, which is a small fraction compared to the 300 million tons of jet fuel used in commercial airlines[13]. However, we expect this to increase significantly due to an increase in regulation on SAF use, and also due to the fact that the industry is increasingly seeking ways to reduce their emissions.

When burned, SAF produces largely the same $CO_2$ as jet fuel, however the reductions in $CO_2$ come from the production process absorbing $CO_2$, leading to a reduction of 70% to 100% on a life-cycle basis[14]. This obviously depends on the type of SAF used, and how it is produced. The advantage of using SAFs is that they do not require any changes to airport infrastructure, or indeed to the aircraft. However, one of the major challenges in scaling up SAFs is obtaining reliable quantities of sustainable feedstock to meet future demand.

There are many feedstocks that can be used to produce SAF but there is still disagreement as to which feedstocks are considered sustainable. The figure below shows feedstocks for the different SAF pathways, with their associated potential



[12] Gray et al. (2021), Decarbonising ships, planes and trucks: An analysis of suitable low-carbon fuels for the maritime, aviation and haulage sectors, *Advances in Applied Energy*, Vol 1, 23 February 2021.

[13] World Economic Forum in collaboration with McKinsey and Company (2020), Clean Skies for Tomorrow, Sustainable Aviation Fuels as a Pathway to Net-Zero Aviation, Insight Report, November 2020.

[14] Ibid.

emissions reduction. The feedstocks used to produce road biofuels and aviation biofuels are mostly the same, but processing may differ, and of course the end product is different. However, similar to road fuels, there are blending requirements for SAF.

**Figure 21. Sustainable Feedstocks and their emission savings**

| Conversion Process | Feedstock | LCA gCO2e/MJ | % emissions savings |
|---|---|---|---|
| Fisher-Tropsch | Agriculture Residues | 7.7 | 91% |
| | Forestry residues | 8.3 | 91% |
| | MSW (0% NBC) | 5.2 | 94% |
| | Short -rotation woody crops | 12.2 | 86% |
| | Herbaceous energy crops | 10.4 | 88% |
| | | | |
| HEFA | Tallow | 22.5 | 75% |
| | Used Cooking Oil | 13.9 | 84% |
| | Palm fatty acid distillate | 20.7 | 77% |
| | Corn Oil | 17.2 | 81% |
| | Soybean oil | 40.4 | 55% |
| | Rapeseed Oil | 47.4 | 47% |
| | Camelina | 42 | 53% |
| | Palm oil- closed pond | 37.4 | 58% |
| | Palm oil- open pond | 60 | 33% |
| | Brassica carinata | 34.4 | 61% |
| | | | |
| Synthesized IsoParaffins (SIP) | Sugarcane | 32.8 | 63% |
| | Sugarbeet | 32.4 | 64% |
| | | | |
| Iso -butanol Alchohol-to jet | Sugarcane | 24 | 73% |
| | Agriculture residues | 29.3 | 67% |
| | Forestry Residues | 23.8 | 73% |
| | Corn grain | 55.8 | 37% |
| | Herbaceous energy crops | 43.4 | 51% |
| | Molasses | 27 | 70% |
| | | | |
| Ethanol Alcohol -to-jet | Sugarcane | 24.1 | 73% |
| | Corn Grain | 65.7 | 26% |

Source: van de Sman et al. (2021)

### Cost of sustainable aviation fuel

Sustainable aviation fuel is currently estimated to cost between 1 and 8 times that of fossil kerosene. The cost is influenced by a number of factors such as feedstock, installation of equipment, and production. Currently HEFA produced from used cooking oil seems to be the cheapest option (see figure below), but even that is still approximately 2.3-2.8 times the cost of jet fuel. According to van der Sman et al. (2021), the price for HEFA is not expected to decrease over time, as the cost primarily depends on available feedstocks, which are not expected to decrease due to increased competition with other sectors. Fischer-Tropsch pathways from biomass are estimated to cost on average between $1.60 and $3 per liter depending on the process used.

Fischer-Tropsch power-to-liquids, also known as Synfuel, could be a potential competitor to biofuels used in aviation. Fischer-Tropsch power-to-liquids are produced from renewable electricity and CO2. It is estimated that the cost for power-to-liquids from $CO_2$ point sources could be as low as $1.10 per litre ($1,380/tonne) but again this will depend on the cost of renewable electricity which has a huge impact on the price. To be considered carbon neutral, the $CO_2$ used in the production of power-to-liquids needs to come from $CO_2$-neutral sources such as DAC. Using DAC technology to capture the $CO_2$ would increase the cost compared to $CO_2$ captured from industrial applications.

$CO_2$ abatement costs differ according to the type of SAF. The figures below are presented in U.S. dollars and reflect the lower bound cost trajectories, and are based on European prices, though it might prove cheaper in other regions. Costs for some SAFs are forecast to reduce over time — for example SAF from power-to-liquid could decrease by 67% in 2050 compared to today's prices[15].

**Figure 22. Pathways, Feedstocks, and CO2 Abatement Costs**

| Pathways | Feedstocks | Cost number of times compared to $1.20 for fossil fuels | CO2 Abatement cost US$/Tonne) |
|---|---|---|---|
| HEFA | Soy Oil, palm oil, Palm fatty acid distillate and used cooking oil | 2.3-2.8 | 258-430 |
| HEFA | Used cooking oil | 1.9-2.2 | |
| Fischer -Tropsch- Gasification | MSW | 3.4-4.8 | 480-600 |
| Fischer-Tropsch-Power to liquid | Renewable electricity & CO2 point sources | 6.4 | 950 |
| Alcohol-to-Jet | Corn,sugarcane, agriculture residues, energy crops | 4.1-6.4 | 950-5350 |
| Synthesized IsoParaffins (SIP) | Sugar Cane Molasses | 10.3 | 2980 |



Source: Citi Global Insights, Pavlenco et al. (2019), EASA EEA & Eurocontrol (2019), van der Sman et al. (2021)

So, in conclusion, biomass is likely to have a critical part to play in decarbonizing the aviation industry. Synfuels is another alternative which the industry could use, though these are only expected to be cost effective by mid-century. Investment needs to be scaled up in SAF to meet the growing needs of the aviation sector. We believe that biomass use for this sector should be prioritized as the alternatives available such as synfuels will not be cost effective for a while. The ETC estimates that if half of global energy demand for medium and long distance aviation is met by biofuels, then this could require approximately 15EJ/year of biomass feedstock[16].

## Shipping

The maritime shipping sector carries approximately 80% of global trade by volume, and 70% by value. It is responsible for transporting more than 11 billion tonnes of goods per year and as of 2019, the total value of the annual shipping trade reached

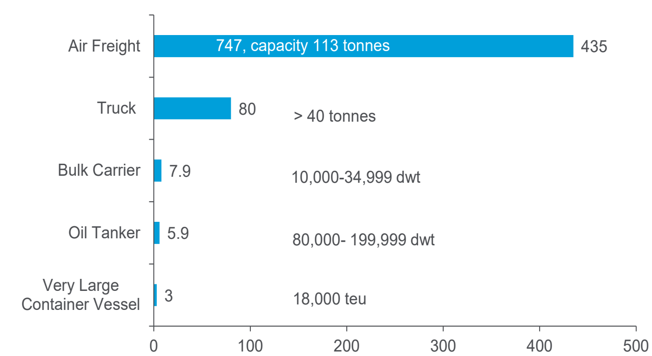
[15] World Economic Forum in collaboration with McKinsey and Company (2020), Clean Skies for Tomorrow, Sustainable Aviation Fuels as a Pathway to Net-Zero Aviation, Insight Report, November 2020.

[16] Energy Transition Commission (2021), Bioresources within a net-zero emissions economy, Making a Sustainable Approach Possible

more than $14 trillion. Shipping's capacity to transfer goods and materials from where they are produced, to where they are consumed, underpins modern life. It is an important part of the supply chain for many companies, and therefore decarbonizing this sector is important for many organizations if they want to truly become net zero on a scope 3 basis.

The shipping industry currently uses approximately 300 million tonnes of fuel per annum, of which 72% is from heavy fuel oil (HFO), 26% from marine diesel oil (MDO), and 2% from liquefied natural gas (LNG). HFO is characterized by very high viscosity and high sulphur levels and is $CO_2$ intensive. While the enormous scale of the industry means it is responsible for approximately 0.9 Gt of $CO_2$ emissions (more than Germany's total energy-related $CO_2$ emissions), ~11% of total transport $CO_2$ emissions, and ~2% of global $CO_2$ emissions, it actually remains one of the most efficient forms of commercial transport (per unit of volume/value). The vast majority of these emissions are attributed to international freight, as shown in the figure below. According to the International Maritime Organization's (IMOs) fourth greenhouse gas study, domestic shipping and fishing contribute 26% and nearly 4% of total shipping sector $CO_2$ emissions, respectively. Containerships, bulk carriers, and oil, gas & chemical tankers account for approximately 70% of these total $CO_2$ emissions.

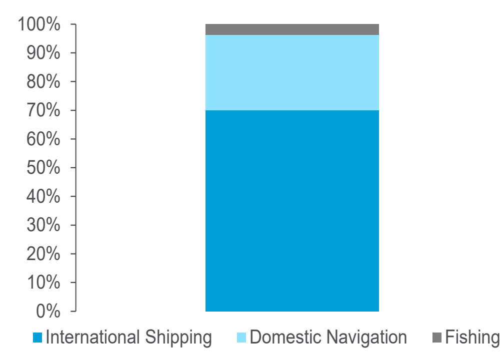
**Figure 23. Comparison of CO2 Emissions in Different Transport modes**





Source: Citi Global Insights, International Chamber of Shipping

**Figure 24. CO2 Emissions from Shipping (%)[17]**





Source: IMO (2020)

Shipping traffic is expected to increase over the coming years. In fact, the International Transport Forum estimates maritime freight transport could grow at a compound annual growth rate of 3.6% through 2050, which could lead to a tripling of maritime trade volumes over the period. A number of factors could change this upward trend, including the instability of global trade, the potential return of some industrial activities to developed economies, and a reduction in the transportation of fossil fuels due to a lower carbon economy. Conversely, there could be an increase in the movement of new low-carbon options such as hydrogen and ammonia. The IEA estimates under a business-as-usual scenario, $CO_2$ emissions from shipping could grow to almost 1.7 $GtCO^2$ by 2050, which is an increase of approximately 90% compared to current emissions[18].

[17] IMO (2020), Fourth IMO Greenhouse Gas Study

[18] IEA (2017), Energy Technology Perspectives.

The shipping industry is experiencing increasing pressure to decarbonize. The IMO has adopted a greenhouse gas reduction strategy that aims to reduce GHG emissions from shipping by at least 50% by 2050, based on a 2008 baseline. At the same time it intends to reduce the average carbon intensity measured as $CO_2$ per tonne mile by at least 40% by 2030, and 70% by 2050. The IMO also introduced legislation for ships to limit sulphur content of ship fuel to 0.5% worldwide. The EU requires ships calling to European ports to monitor and report their $CO_2$ emissions, fuel consumption, and average energy efficiency. The European Commission has also proposed to introduce shipping to the ETS system gradually from 2023, phasing it in over a three-year period. We are also seeing the industry come together through initiatives such as the Poseidon Principles and the Getting to Zero Initiative.  During the COP26 meeting, several countries also signed the Clydebank Declaration, declaring their aim to support the establishment of green shipping corridors - zero emission maritime routes between 2 or more ports.

### Decarbonising the shipping industry

So, as we have seen, there are a number of initiatives and new regulations which should help reduce emissions from this sector. However, the shipping industry remains particularly difficult to decarbonize compared to other sectors, due to the high cost of available low-carbon options, and the challenges created by long asset replacement cycles (the average lifetime of vessels is 25+ years).

So what options does the sector have? From a demand perspective, the industry can reduce its emissions by improving fleet management and optimizing voyage plans, but this can only reduce current $CO_2$ emissions by 5%. It can also improve energy efficiency by improving ship design and hull and propulsion efficiency, which can reduce $CO_2$ emissions between 30% and 55%[19]. Technologies such as wind propulsion systems can also reduce fuel consumption. However, the only way to fully decarbonize shipping is to invest in new technologies and alternative zero carbon fuels. These can include:

- electric engines, which are either battery operated or run on hydrogen/ammonia fuel cells;
- the continued use of combustion engines with biofuels or LNG (LNG does not fully decarbonize, while greenhouse gas (GHG) emissions reductions from biofuels depend on factors like feedstocks and indirect land-use change), and
- the development of new engines that can run on new alternative fuels such as ammonia or hydrogen.

Biofuels are not extensively used in the shipping industry, but they could play a part in reducing shipping's $CO_2$ emissions. They can be blended with conventional fuels and some types of biofuels can also be used as 'drop-in' fuels. A drop-in fuel can be used in existing installations without any major technical modifications. For this reason, biofuels are well suited to replace conventional petroleum-based fuels used currently in different vessels. Biomethanol in particular has been touted as a biofuel that can be used in this sector. There is a huge debate as to whether biomethanol is a net zero carbon fuel. The argument focuses on the type of feedstock used, whether it comes from sustainable sources, and the lifecycle GHG emissions from the source, production, and end use. Shipping company Maersk has taken the decision to invest in a methanol ship, and also announced its intention to produce a dual-fuel ship which is run on methanol and standard VLSFO (Very Low Sulfur Fuel

[19] Energy Transitions Commission, Mission Possible, Shipping.

Oil) containing low sulfur, being therefore compliant with IMO regulations on pollutants. Maersk's methanol feeder vessel will have a 2,000 twenty-foot equivalent unit (TEU) capacity and will be deployed in one of its intra-regional networks. The vessel will be able to run on standard VLSFO, but according to the company, the plan is to operate on carbon neutral e-methanol or sustainable bio-methanol from the first day of operation. The company acknowledges that operating on low carbon methanol will be a challenge in this time-scale given that the production of sustainable bio-methanol and e-methanol is still in its infancy.

In addition to bio-methanol there are a number of biofuels that can be used for the shipping industry, illustrated in the figure below.

**Figure 25. Biofuels and their applications**

| Biofuel | Applicability |
|---|---|
| Biodiesels (HVO, FAME) | Tugboats, small carriers/cargo ships, replacing MDO/MG |
| Bio dimethly ether (bio-DME) | Carriers and cargo ships (all sizes) replacing MDO/MG) |
| SVO | Carriers and cargo ships (all sizes) replacing IFO/HFO) |
| Bio-LNG | Tugboats, LNG carriers, ferries, cruise ships, support vessels, replacing conventional LNG in gas or dual fuel engines |
| Bio-alcohols | Tankers, cruise ships, passenger ships, blended with distilled fuels or in dual fuel engines |
| Pyrolysis oil | Carriers and cargo ships (all sizes) replacing IFO/HFO) |

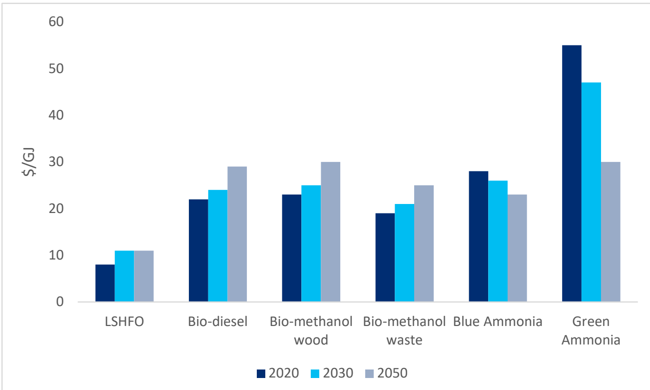
Source: Citi Global Insights, adapted from IRENA (2018). Note: FAME refers to Faty Acid Methyls Esters. This process uses renewable feedstocks like vegetable oil, animal fats, or tallow to produce diesel. HVO stands for hydrotreated vegetable oil; SVO stands for straight vegetable oil

### Costs of biofuels for the shipping industry

The figure below on the left compares the cost of a number of alternative fuels that can be used in the shipping industry with LHSFO. These projections are based on a study undertaken by Lloyd's Register and the University Maritime Advisory Services (UMAS) and conducted for an 82,000 deadweight tonnage (DWT) bulk carrier, so the cost may be different for other types of ships. Several assumptions have been taken to calculate these fuel projections, including electricity prices and natural gas prices from 2020 to 2050. The authors have also assumed that ammonia is produced in new plants rather than existing plants, which could be retrofitted with new technology to decarbonize production. Bio-methanol produced from waste and wood seem to be cheapest option in 2020; however, the costs increase in 2050 as it is assumed the cost of bio-methanol increases over time due to the lack of supply of sustainable feedstocks.

The Energy Transition Commission is more bullish on the cost of ammonia in 2050. They believe that if green hydrogen is produced at less than $1.6 per kg, then ammonia prices $13 and $11 in places like China and Australia respectively as shown in the diagram below, and would be cheaper than biodiesel. It is important to note that future biofuel prices are extremely uncertain, and data is extremely limited. However we believe that biofuels will play a small part in the shipping industry, and given that the shipping industry is looking for a zero carbon option (biofuels emit emissions at point of use), it is more likely that ammonia would be the alternative fuel of choice for this industry especially for long haul shipping.

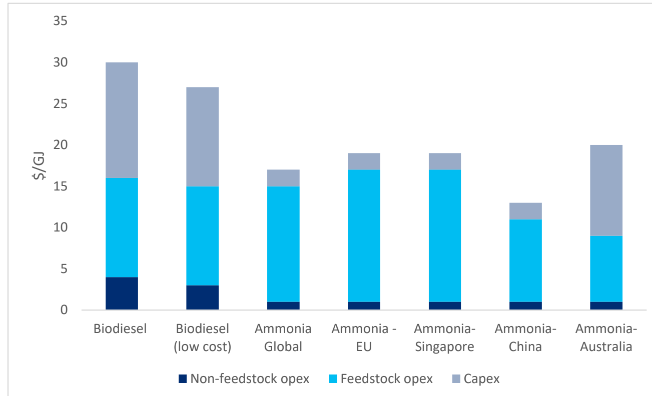
**Figure 26. Cost of alternative fuels vs LSHFO**






Source: Citi Global Insights, Lloyds Register and UMAS; Note: Blue Ammonia is assumed to be made with natural gas and CCUS

**Figure 27. Cost of green ammonia vs bio-diesel in 2050**



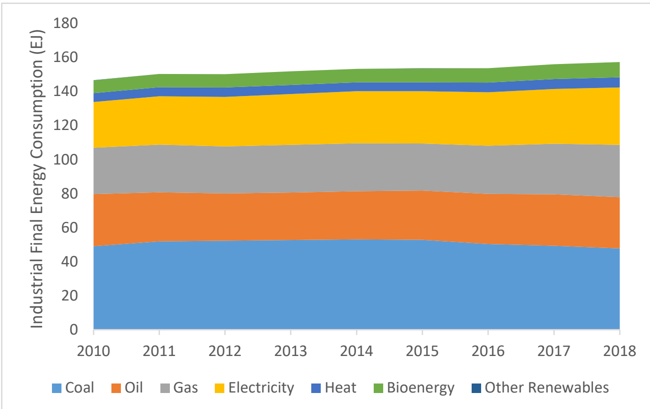

Source: Energy Transition (2021); Note It is assumed that bio-diesel is made from lignocellulosic biomass, several assumptions have bene made on the electricity procies and hydrogen capex in different regions . It is assumed that green hydrogen would cost ~1.4/kg

## Industry

The industrial sector is currently responsible for approximately 20% of global energy-related CO2 emissions, and whilst the majority of direct emissions (produced on-site) comes from energy production from fossil-fuels, CO2 emissions can also result from leaks and chemical transformations. The industrial sector encompasses a wide range of processes and product manufacturing, but some of the most energy and emission-intensive sub-sectors include iron, steel, and cement, as shown in the diagram below.

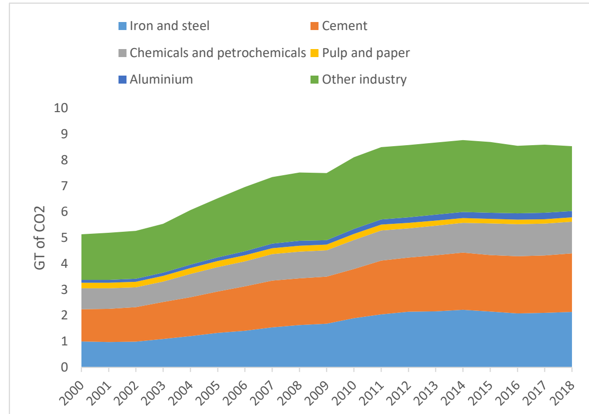
The industrial sector accounted for 37% of total global final energy use in 2018 (including energy use for blast furnaces and coke ovens, and feedstocks). The industry's energy mix has remained relatively unchanged overall from 2010 to 2018, with coal still playing an important part as shown in the diagram below. Industrial energy consumption increased at an average rate of 0.9% during this time period, mainly due to the ongoing long term trend of rising production in energy intensive industries such as iron and steel, cement and others. In fact, the demand for materials, which is closely linked to population growth and economic development, is a major determinant of total industry's energy consumption and related CO2 emissions.

**Figure 28. Industrial Sector Energy Mix**




Source: IEA (2020), Tracking Industry

**Figure 29. Industry's Direct Emissions (including Process Emissions)**




Source: IEA (2020), Tracking Industry

Many industrial processes require a certain amount of process heat supply which needs to be used at the correct moment, must be reliable, and must be at the lowest possible costs, especially in industries that have tight margins. Currently many industrial processes use fossil fuels such as coal, heavy oil or natural gas to provide the heat needed[20]. Bioenergy is already used in the industrial sector (16% of total bioenergy used today), but mainly for industries such as pulp and paper where biomass process residues are used to cover some of their own heat demand. However, given that there is increasing motivation (and regulation) for the industrial sector to reduce its CO2 emissions, several other industrial players are looking or shifting towards using biomass for their heat requirements especially in places where there is the availability of suitable biomass resources[21].

Biomass-based process heat can come in many forms, and in principle it can provide the heat requirements for most industrial use cases, but the specific nature of the process and the type of application would determine what kind of biomass-based process is used. Biomass can be used for both low temperature and high temperature use. Different industrial applications will need different forms of biomass to produce heat. For example the glass and ceramics industry requires temperatures above >500$^{o}$C, and it also needs a gaseous fuel to achieve clean combustion, therefore for this particular use, raw wood chips would not be feasible, but biomethane produced from the same wood chip could be a promising option[22].

Biomass use in the industrial sector is expected to increase going forwards. For example, the IEA in their net zero scenario estimate that bioenergy could more than double from 2020 to 2050- ultimately providing 15% of total energy consumed by the industrial sector. There are other solutions available that could help the industrial sector decarbonise including electrification, hydrogen and CCUS. The solutions chosen depend on a number of factors including sustainable biomass availability, and whether low or high temperature heat is needed.

For low temperature heat, biomass faces strong competition from industrial heat pumps. According to the Energy Transition Commission[23], bio-based options for

[20] Volker et al. (2020), Status and Perspectives of biomass use for industrial process heat for industrialized countries, Chemical Engineering and Technology, May 2020

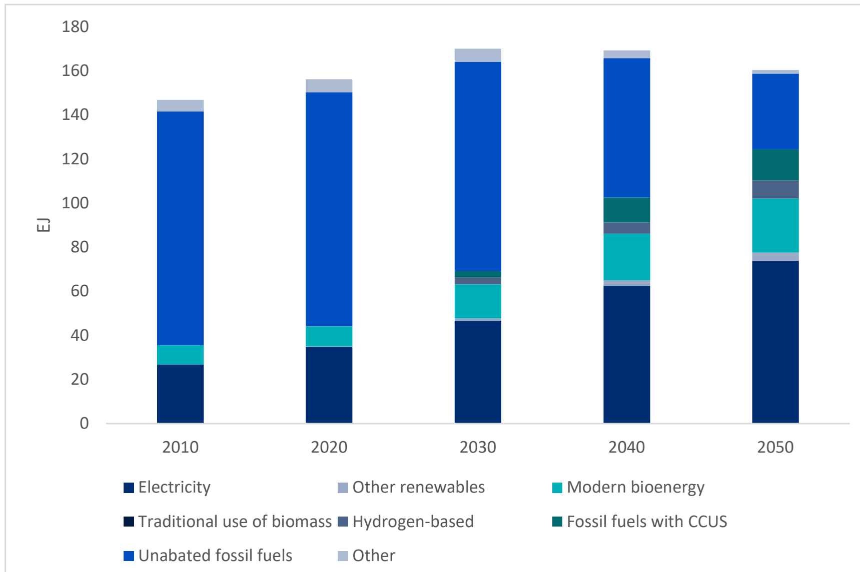
[21] IEA Bioenergy (2020), Industrial process heat : case study 4

[22] IEA Bioenergy (2021), Decarbonizing industrial process heat: the role of biomass

[23] Energy Transition Commission (2021), Bioresources within a Net-Zero Emissions Economy, Making a Sustainable Approach Possible

low temperature heat would only be competitive when cheap residues or wastes are used, and in periods where electricity prices are high. For high heat temperatures, the viability of biomass use for heating would depend on the technological process of electricity–based options, and the local costs of bio-based feedstocks. It would also depend on the age of the industrial asset, as switching to electricity or hydrogen-based options would require investing into a new asset, whilst biomass could potentially be used in the existing infrastructure.

**Figure 30. Industrial use of energy under IEA Net zero scenario**




Source: International Energy Agency (2021), Net Zero by 2050, IEA, Paris

So, even though biomass could really help reduce emissions from the industrial sector, we believe that it will only be cost effective in places where there is ample biomass supply. For example, biomass is already being used in small blast furnaces in Brazil, where there is plenty of available supply. Steel plants there have completely substituted the use of coke and coal with charcoal. However, the use of charcoal needs to be sustainable as some studies have claimed that charcoal use is causing deforestation. Biomass in the steel industry can be used as both a reagent and for heating purposes. Biomass alone does not achieve full decarbonisation, however in combination with CCUS it can enable the industry to produce carbon-neutral steel - though this will undoubtedly be costly and not applicable in many regions where biomass resources are scarce.

Another example is the use of biomass in the cement industry - for example in the EU, 50% of fuel needs in the European Cement Industry come from a variety of waste streams[24]. The industry can use a wide variety of biomass and waste inputs including old tyres, municipal waste, effluent sludge from wastewater treatment plants, forest residues and lignocellulosic sources. CO2 emissions reductions from the use of biomass and waste used for thermal heat generation would depend on the type of biomass used. Biomass would not fully decarbonize the cement industry, as 50% of the cement industry's emissions come from process emissions themselves, essentially a by-product of a chemical reaction, rather than from emissions producing heat for a process. Hence such emissions cannot be reduced

[24] Cembureau, The Sustainable Build Environment Agenda: Contribution from cement and concrete

simply by changing fuel sources. However using biomass, especially cheap waste products, can allow the industry to reduce its thermal emissions at a low cost.

So in conclusion, biomass will play an important part in helping the industrial sector reduce its emissions, though there are other options available, such as electrification, CCS and hydrogen. Given the tight margins that some of these sectors have, we believe that biomass use for this sector is likely to be localized, and will depend on a number of factors including the cost of feedstocks, the availability of supply, and the cost of other alternatives such as electrification.

## Biomass as a feedstock- the plastic sector

Plastic is everywhere – and has a vast number of different applications, from carrier bags to bottles, to cars, to name but a few. And plastic is not just 'one thing' – many different types of plastics are used for different purposes, depending on the end-use application. Individual types of plastics are usually distinguishable by their identification code, as shown in the box below.

**Figure 31. Types of Plastics**

**Types of Plastics**

There are 2 broad categories of plastics- thermoplastics and thermosets. Thermosets tend to be more specialised materials and resins whilst thermoplastics are those which are usually more familiar such as shampoo bottles, carrier bags, auto applications etc. Thermoplastics can be usually recycled whilst thermosets cannot. Thermoplastics are usually identified by their resin identification codes which are usually found at the bottom of the goods to help assist with their recycling. Below is a definition of key thermoplastics:

**01- PET**: key use is food and beverage packaging

**02-HDPE**: One of the most versatile plastics used in everything from shampoo bottles to hard hats. It is made entirely of ethylene

**03- PVC**: It is a tough resin mainly used in construction

**04- LDPE**: Another key plastic used for packaging such as carrier bags

**05- PP:** This type of plastic has a higher melting point and because of this is it used often in cars, where high temperature can be encountered.

**06- PS**: Made with polystyrene – examples include disposable coffee cups, plastic cutlery etc.

**07- Other thermoplastics** which have a wide use and include baby bottles, medical storage containers etc.



Source: Citi Global Insights, IEA

Global plastic production has grown from relatively small levels in the 1950's, to reach over 360 million tonnes in 2020. According to the Energy Transition Commission, the global demand for plastics could reach 1,350 million tonnes per annum by the end of the century. Thermoplastics alone could reach approximately 800 million tonnes by 2050.

The majority of plastics are derived from crude oil, natural gas or coal. Most of the plastics used today are derived from the following steps:

1. Extraction of raw materials mainly crude oil, and natural gas but in some regions also coal

2. Refining of these raw materials into different products, mainly ethane and propane

3. Ethane and Propane are then heated with high heat in a process called cracking. This is how they are converted into monomers such as ethylene and propylene

4. These materials are then combined together to create different polymers – a process called polymerization.

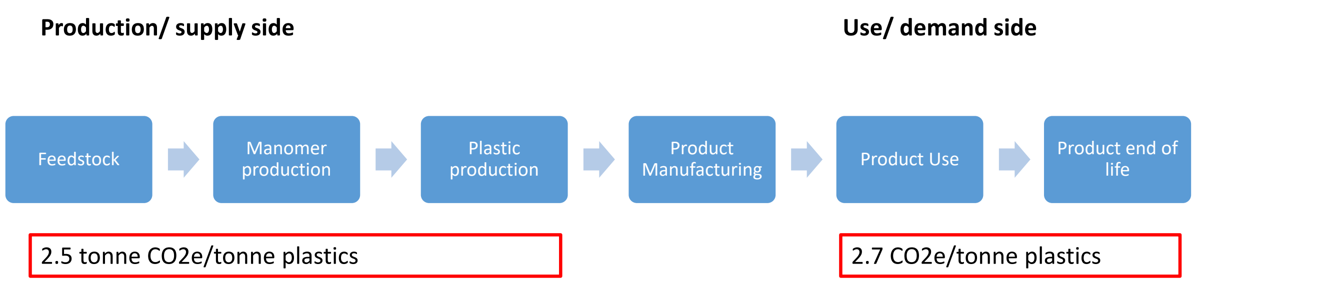
Decarbonising plastics is complex, as today's plastics emit CO2 both in their production, and in their end of life, as shown in the diagram below.

On the production side, emissions are generated from:

(1) The upstream production of feedstocks which include naptha, ethane or LPGs,
(2) The production of manomers and,
(3) From polymerization.

If plastics are incinerated at their end of life, then emissions from this process can result in 2.7 tonnes of CO2e per tonne of plastic. Even if plastics aren't incinerated, they still eventually produce emissions as the plastic slowly disintegrates.

**Figure 32. Emissions level for each step of the plastic production process**




Source: Energy Transition Commission, Material Economics

The sector is under a huge amount of pressure to reduce its emissions and also to reduce plastic waste which is having an impact on oceans etc. Just this month a historic resolution called 'End Plastic Pollution: Towards an internationally legally binding instrument' was adopted at the UN. This is due to be finalized by 2024. Details of how the industry will end pollution, whether it is through curtailment of production or other measures such as the use of biomass and recycling still needs to be determined. However such resolutions show just how under pressure the industry is to reduce its environmental impacts.

There are a number of ways to reduce emissions from plastics. Demand-side instruments include

(1) reducing demand through for example bans of single use plastics – this is already occurring in many countries;

(2) greater material efficiency,

(3) material substitution, and

(4) chemical or mechanical recycling where recycled plastics can be used instead of virgin material.

We can also deploy supply side levers such as

(1) CCUS in the production phase and incineration phase,

(2) switch to low carbon heat such as the use of biomass for heat production and

(3) switch to renewable feedstocks such as the use of biomass (bio-feedstock) or synthetic fuels.

Therefore biomass can be used as a

(1) feedstock to deliver not only zero-carbon production of plastics but also very low emissions across the entire product lifecycle,

(2) in the form of other bio-based materials and

(3) to produce heat which is covered in the previous sector.

We focus our analysis here on biomass being used as a feedstock in this industry, namely bio-based plastics.

## Bio-based Plastics

The term bio-based materials means that a material or product is derived, or partly derived, from biomass. The definition of bio-based materials could also include traditional wood and leather products, however it is usually used when discussing modern bio-based materials. There are a number of innovative biomaterials and/or bio-products that are being researched or entering the market. In the plastic industry these include either bio-based plastics which have similar characteristics to plastic materials, the only difference being they use biomass as feedstock rather than petrochemicals, or else alternative bio-based materials such as wood fibres that can be used instead of plastics. But before we discuss the existing market for such products, we really need to take a step back and understand some of the terminology that is being used, as it can be confusing.

### What are bio-based plastics?

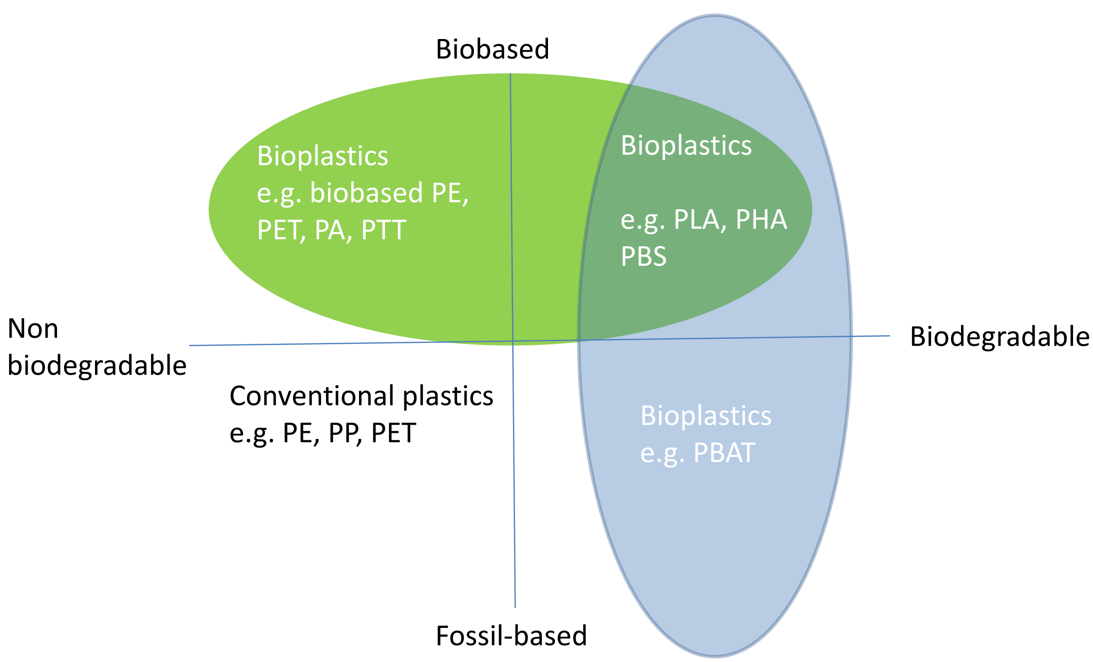
Most studies use the general term bioplastics for plastics that are either bio-based (use biomass as a feedstock), biodegradable or both. Bio-based plastic refers to plastic materials produced from biomass sources such as vegetable fats and oils, corn starch, straw, woodchips, recycled food waste and others. Biomass feedstock is used to create bio-ethanol, bio-methanol, biogas or bio-naphtha, which can in turn be used as feedstocks to produce conventional plastics[25]. Bio-based plastics does not necessarily mean biodegradable, as the property of biodegradation does not depend on the resource used in material production, but it depends on the chemical structure of the product. Some bio-based plastics are biodegradable, while others are not[26]. 'Biodegradable' refers to a chemical process during which microrganisms that are in the environment help convert materials into natural substances such as carbon dioxide, water and compost. Biodegradable plastics can either be bio-based or fossil-based plastics.

Bioplastics are broadly grouped in two categories:

1. Drop ins: these are bio-based versions of petrochemical plastics that are currently in use. They are derived from biomass but they are chemically the same as fossil-fuel plastics, and are not biodegradable. They deliver the same performance, and can be processed with existing supply chains and infrastructure, including recycling. Examples of drop-ins are bio-PET and bio-PE.

2. Substitutes: these are new biodegradable plastics that have different chemical and physical properties when compared to fossil-fuel based plastics. They can either be bio-based (e.g. PLA, PHA) or fossil-based (PBAT).

**Figure 33. Different types of bioplastics**




Source: European Bioplastics

[25] Energy Transition Commission (2021), EU Biomass Use in a Net-Zero Economy, A course of correction for EU biomass and Bioresources within a Net-Zero Emissions Economy

[26] European bioplastics, what are bioplastics?

Using biomass as a feedstock to produce plastics can help reduce emissions from the sector for a variety of reasons. Plastic produced from feedstocks such as corn, sugarcane or other plants have a smaller carbon footprint compared to fossil fuel feedstocks. According to IHS Markit[27], one bioplastic known as polymide 40 is completely carbon neutral. This bio-based plastic is made from a combination of renewable feedstocks made from caster bean oil and petrochemical feedstocks. The emissions from petrochemical feedstocks are offset by the amount of CO2 absorbed during the growth of the caster bean plant. If food waste is used as a feedstock, then this waste is diverted away from landfills thus reducing methane production from waste decomposition. However bio-based plastics do not reduce the impact that plastics have for example on other parts of the environment, such as oceans, as they still need to be composted or recycled at the end of their life. Also they do not fully decarbonize the sector as emissions are emitted throughout the lifecycle of the product. However if combined with demand reduction, material substitution and recycling, then we could see a reduction of 93% of emissions from this sector[28].

Currently about 2.4 million tonnes of bioplastics are produced, with the majority being used for packaging as shown in the figures below. It should be noted that 64% of bioplastics are fossil-fuel based biodegradable plastics, and 33% are bio-based plastics. Currently the figures are rather small when compared to global plastics production, which is estimated to be more 360 million tonnes in 2021.

According to Plastics Europe, it is expected that the production of bioplastics will more than double in the next 5 years, though it is not clear whether this increase will relate to fossil-fuel based biodegradable, or bio-based plastics. However, we are definitely seeing some movement in the market; for example Pepsi-Co Europe recently announced that it is moving away from the use of fossil-fuel based plastics, via a combination of using recycled plastics as virgin material, and using bio-based plastics. The company has also joined the Pulpex consortium of global consumer goods companies, to further develop and scale the world's first recyclable paper bottle[29]. Nestle has stated that it will be introducing bio-based lids and scoops for a range of its infant products[30].

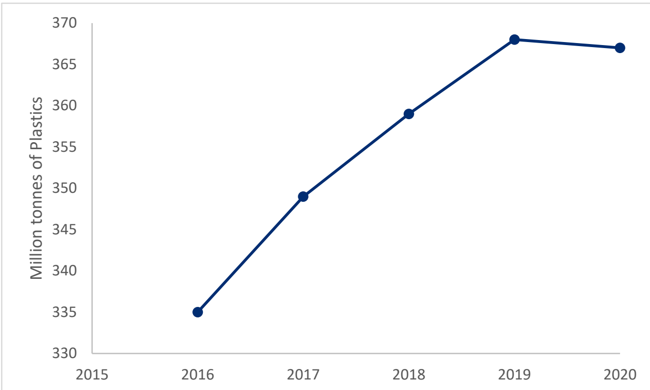
[27] IHS Markit, Bioplastics offer a smaller carbon footprint, 20th November 2018

[28] Zheng and Suh (2019), Strategies to reduce the global carbon footprint of plastics, Nature Climate Change, Vol 9, pp374-378

[29] Pepsico Joins The Pulpex Consortium, www.pepsico.co.uk

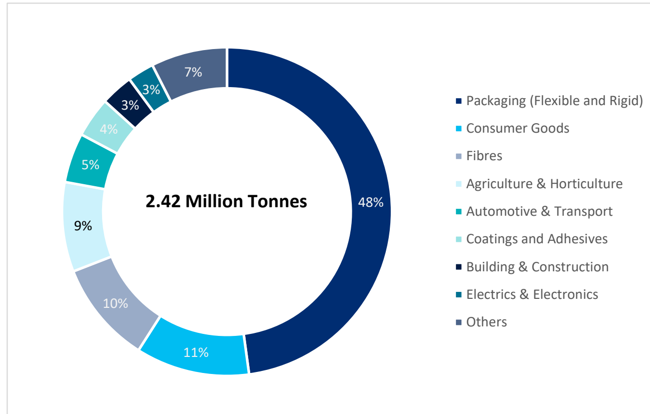
[30] https://www.nestle.com/media/news/launch-bio-based-lids-scoops-renewable-resource

**Figure 34. Global Plastics Production**




Source: Plastics Europe Market Research Group

**Figure 35. Bioplastics Production in 2021**




Source: European Bioplastics

### Other bio-based products that substitute plastic material

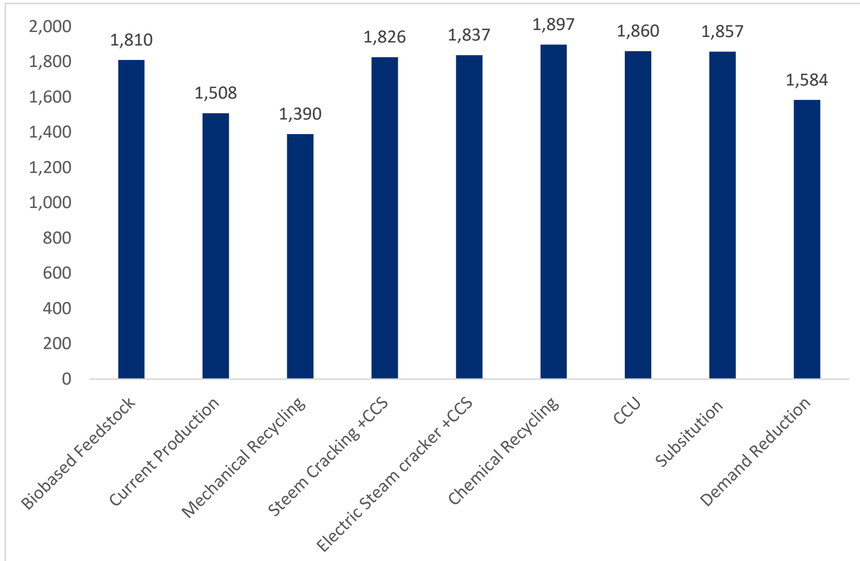
Besides bio-based plastics we are also seeing innovation in products that could substitute for plastic entirely. Legislation on the banning of single-use plastics in many countries has provided an incentive for companies to research and produce new innovative bio-based products that could replace plastics completely (refer to Citi GPS report -Rethinking Single Use Plastics.) Examples of such products include cartons made from renewable wood fibres, edible six-pack rings which are made of barley and wheat remnants, which themselves are a by-product of the brewing process, palm leaf packaging for food etc. Obviously not all plastics can be replaced by innovative biomass products, but interest is clearly growing in these new products. It is however important to undertake a life cycle analysis for some of these innovations to ensure their sustainability. It is estimated that 17-25% of current plastics used in packaging could, in principle, be replaced by fibre-based alternatives[31].

## Comparison of costs

The diagram below compares the different costs of solutions to reduce emissions from the plastic industry in 2050. The production of bio-based feedstocks is more expensive than mechanical recycling, but is on a par with other technologies. Some of these technologies such as steam cracking + CCS reduce emissions from the production stage, whilst mechanical and chemical recycling allow for a reduction in virgin feedstock from fossil fuels.

[31] Energy Transition Commission (2021), Bioresources within a net-zero emissions economy, Making a Sustainable Approach Possible

**Figure 36. Costs of solutions to reduce plastic emissions (US$ per tonne of plastic)**




Source: Energy Transition Commission (2021)

The plastic industry is extremely difficult to decarbonize and a number of measures need to be used together to decarbonize this sector including the use of bio-based plastics. It is for this reason that biomass use should also be prioritized for this sector. It is estimated that a total of 16.5EJ of biomass per year in 2050 could be needed as a feedstock for this industry. This assumes that there is a demand reduction of 19% for primary plastics and an increase in mechanical and chemical recycling[32]

## BECCS

Biomass, if combined with CCS, could actually be used to reach net negative emissions. The IPCC has stated that to limit temperature increase of the planet we not only need to reach net zero by 2050, but we need to move to net negative emissions by the second half of the century. There are four ways we can do this

(1) natural climate solutions such as re/afforestation,

(2) direct air capture (DACC) which uses energy inputs to sequester CO2 from the atmosphere,

(3) hybrid solutions such as bioenergy with carbon capture and storage (BECCS),

(4) biochar, ocean alkanisation and enhanced weathering.

The benefits of each of these technologies depends on a number of factors including cost, technology readiness, CO2 sequestration and permanence etc.[33].

BECCS is a carbon removal technology that depends on two technologies; first, the biomass is transformed into heat, electricity or liquid or gas fuels, and then the

[32] ibid

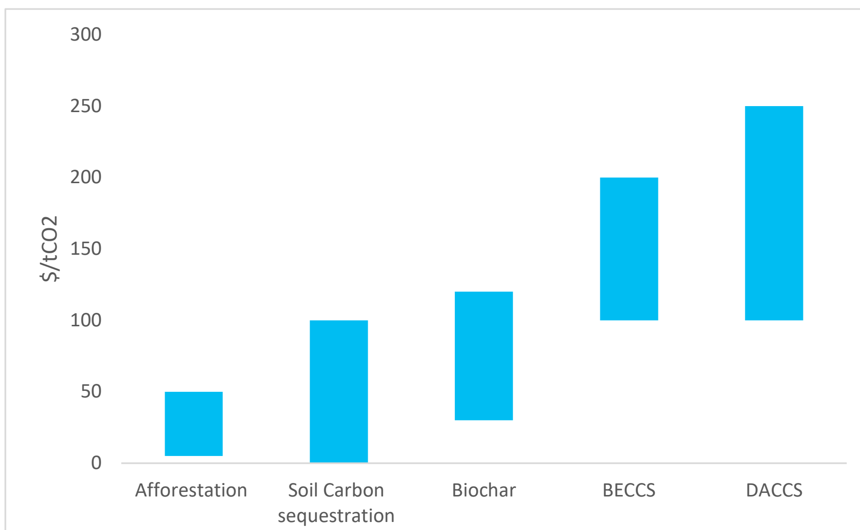
[33] Ibid

carbon emissions from this process are captured and stored in geological formations or used to produce other products. Because biomass when grown absorbs $CO_2$ from the atmosphere as it grows, many experts claim that BECCS can be considered a negative emissions technology, if implemented well. Most of the IPCC scenarios include BECCs in their analysis of how to limit temperature increase to a 1.5oc or 2oC[34]. The IEA in their net zero scenario state that 10% of total bioenergy is used in facilities equipped with CCUS, and around 1.3GTCO2 is captured using BECCS. 45% of this $CO_2$ is captured in biofuels production whilst 40% in electricity, whilst the rest is in heavy industry. The inclusion of $CO_2$ capture facilities that produce liquid biofuels could be a 'low hanging fruit'. This is because in several biofuel production pathways, $CO_2$ is already separated as part of the process, and therefore concentrated $CO_2$ streams are available, which reduces the cost of capture - this is particular true for bioethanol production[35].

However there remains some skepticism with regards to the extensive use of BECCS to reach net zero. BECCs systems are not simple, nor are they easy to monitor. They involve a number of steps from growing and harvesting the crops, to processing the harvest, transporting it to use, capturing the $CO_2$ and transporting it to either geological storage or re-utilizing the $CO_2$ for other products. Each of these steps can release $CO_2$ and other greenhouse gas emissions. There are also a number of players involved at each step, and a number of different supply chains. Once again, we also need to ensure that the biomass used is sustainable.

Costs also seem to be a sticking point. Biofuels are currently more expensive than their fossil-fuel counterparts, therefore including the cost of capture on top of this would increase the costs even further. In certain regions renewables are also cheaper than the use of biomass for power generation. However as shown in the diagram below, BECCS is likely to remain cheaper than DACCS, but it is far more expensive than natural climate solutions such as afforestation or reforestation.

**Figure 37. Cost range of Capture cost range in 2050**




Source: Energy Transitions (2021) Bioresources within a Net-Zero Emissions Economy

[34] American University Washington D.C, Fact Sheet: BECCS

[35] IEA Bioenergy (2020), Deployment of BECCS/U value chains, technological pathways, policy options and business models, IEA Bioenergy : Task 40, June 2020

As of 2019, there were five facilities that are currently using BECCS based in North America. Together they are capturing 1.5 million tonnes per year of CO2, which is a small fraction of total greenhouse gas emissions estimated at over 50GTCO2e. Another three additional plants are also being planned in Japan, the UK and in Norway.

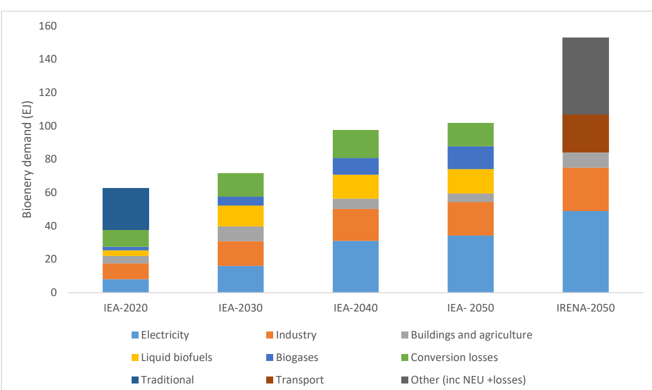
So in essence and if done well with controls and with adequate monitoring, the use of biomass in combination with CCS can help us reduce emissions, however they are costly compared to natural based solutions. We believe that given the uncertainty of available sustainable supply of biomass, increasing its use in certain sectors where it makes no sense, just so we can implement BECCS is not the right strategy.

## Balancing supply and demand for biomass

There are a number of institutions that provide estimates for future demand of biomass. The IEA in their net zero scenario estimate that biomass used for energy (bioenergy) could increase to approximately 102 EJ from 62EJ in 2050, whilst IRENA estimate that bioenergy could increase to 150 EJ in the same period. Both the IEA and IRENA have high estimates for biomass used in power generation, this is driven by the use of BECCS. Calculating the future demand for bioenergy is an uncertain process, as it depends on numerous variables, including cost to the end user as described above, government policy and regulation, investment, and the availability of sustainable biomass feedstocks.

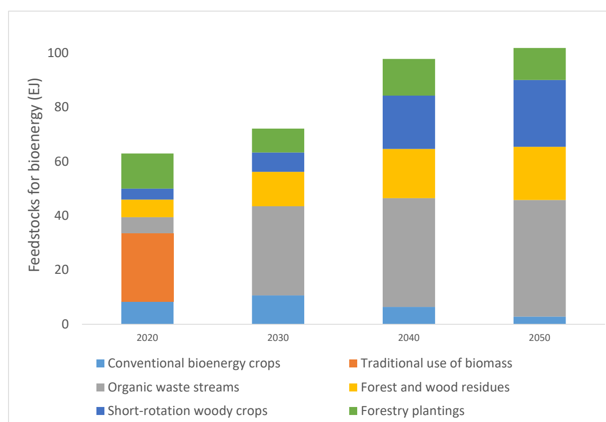
The biomass feedstock used would also change from current, with conventional energy crops decreasing over the years, being replaced by other feedstocks such as forest residues, short rotation crops etc. that would be used to produce advanced biofuels.

**Figure 38. Bioenergy demand in 2050, IEA and IRENA Scenarios**




Source: IEA, IRENA

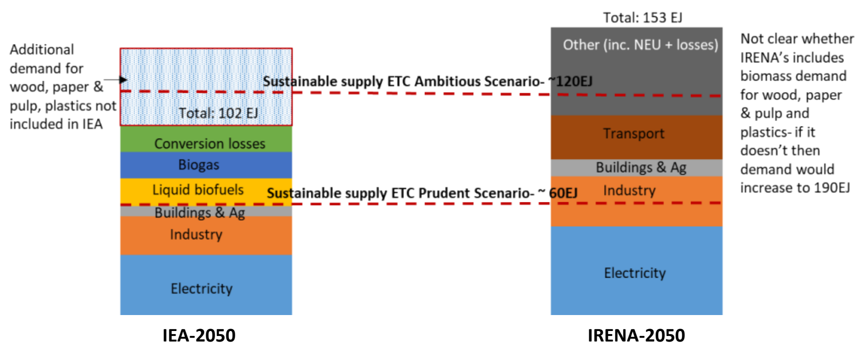
**Figure 39. Feedstocks used for IEA 2050 Scenario**




Source: IEA

Both the IEA and IRENA state that there is more than enough sustainable biomass available to meet this demand. However most of these studies do not include the amount of biomass needed as a feedstock and only include the demand of biomass for energy. It is estimated that the demand for biomass from the construction and pulp and paper industries could reach 23 EJ/year in 2050, while the demand for biomass as a feedstock for the plastic sector could reach 17 EJ/year[36]. Including these figures to the potential demand scenarios given by these institutions, and mapping these across cautious figures for sustainable available biomass supply given by the ETC, shows that potentially we do not have enough sustainable supply to meet all the potential demand. However we need to be cautious about these figures as there is a huge uncertainty in the availability of sustainable biomass supply- which some say is close to zero whilst other state is above today's energy levels.

**Figure 40. Sustainable biomass supply vs potential demand in 2050**






Source: Citi Global Insights, IEA, IRENA

Given this uncertainty, we believe that biomass use should be prioritised for sectors which have a lack of alternative scenarios and where the economics work- mainly as a feedstock for traditional industries such as wood and pulp and paper, plastics and as a fuel for the aviation industry. This does not mean that other sectors should not make use of biomass to reduce their emissions (and again this depends on the type of feedstocks used), however given that the competition for biomass is expected to increase over time, we should ensure that these sectors are prioritised.



[36] Energy Transition Commission (2021), Bioresources within a net-zero emissions economy, Making a Sustainable Approach Possible

**Figure 41. Biomass-options vs non-biomass-options for different sectors**

| | Bio-Option | Other alternatives | Comments |
|---|---|---|---|
| **Material Uses** | | | |
| Timber | Timber | No alternative to feedstock | It is estimated that demand for timber would increase slightly from 6 to7 EJ of biomass |
| Pulp & Paper | Pulp | No alternative to biomass feestock-recycling paper can reduce virgin feedstocks | It is estimated that demand for timber would increase slightly from 10 to16 EJ of biomass |
| Plastics | Bio-based plastics | Material substitution/ recycling/ reduction/CCUS | In 2050 the costs for bio-based plastics seem to reach parity with other solutions. The use of bio-based plastics would allow significant emission reductions across the entire lifecycle of the product. |
| **Bioenergy** | | | |
| Power generation – Bulk | Biomass plant | Renewables, fossil fuels with CCS, nuclear, batteries | The price of renewables is decreasing in many regions, so it would be difficult for biomass power generation to compete. However bio-power maybe important in certain geographies |
| Power generation-seasonal | Flexible thermal plants using biomass | Long distance interconnections, green hydrogen, natural gas with CCS etc. | There are plenty of solutions for seasonal power generation, we believe biomass will play a part in regions with ample sustainable feedstock supply |
| Buildings | Biomass boiler | Electric heat pumps, district heating | We do not cover this in our analysis |
| Heat in industry | Biomass boilers/ biochar/ charcoal/ waste | Hydrogen, electrification, CCUS | Biomass use is highly dependent on locally available supply and cost |
| Road freight | Biofuels | Hydrogen, Electric | Biofuels will be important in the interim |
| Aviation | Sustainable aviation fuel made from biomass feedstocks | Hydrogen and electric planes for short-haul, for long-haul an alternative is synthetic fuels | SAF from biomass is rather costly today, but increasing supply should decrease the costs. Synthetic fuels will reduce in cost, but this will take sometime, so SAF from biomass is extremely important for this sector |
| Shipping | Biofuels | Short voyages- Electric<br>Long voyages- ammonia, e-methanol and hydrogen | Given that the industry is looking for a zero emission solution we believe that ammonia will be the main choice for this sector. However biofuels could play a part in the interim |


Source: Citi Global Insights

## Conclusion

Biomass will undoubtedly play an important part in reducing CO2 emissions as we continue our journey to net zero. However, due to the uncertainty in the availability of sustainable biomass resources, we think that a cautious approach should be taken, and that biomass use should be prioritised in sectors that have limited other solutions available, and where the economics work. This includes the aviation sector, the continued use of biomass for woody products and for pulp and paper, and the use of biomass as a feedstock for bio-based materials such as bio-based plastics.

Having said this, we believe that biomass will play an important part in reducing emissions in many sectors in regions where the availability of sustainable biomass resources is plentiful, and in areas where the cost comparisons are favourable. Biomass will also play an important part in reducing emissions in the interim, given that many other solutions such as green hydrogen for industry, and green ammonia in shipping, will need time to scale up and become feasible. Biomass offers the potential to bridge this gap, with the added advantage of being usable in existing infrastructure.

In conclusion, we believe that to have any chance of limiting temperature increases to 1.5oC, or at most 2oC, we will need to use multiple solutions, and this will include the use of biomass in many sectors. However we need to ensure that the biomass we use is sustainable, it is measurable and it is accountable. We will also need legislation to ensure the sustainability of its use, and to ensure that investment is directed to the sectors that need it most, so we do not inadvertently drive emissions elsewhere. Biomass and biofuels may have been – unfairly - overshadowed in recent years by the attention being lavished on ‘new’ technologies such as hydrogen, CCUS, and the rapid growth/cost reductions of solar and wind. However, we should not forget that biomass was arguably our earliest scaled renewable alternative, with the earliest competitive economics, and that looking forwards, it will remain a critical, and growing, element of our journey towards net zero.

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