Biomass for Marine 2025

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OIL AND GAS CLIMATE INITIATIVE

argus

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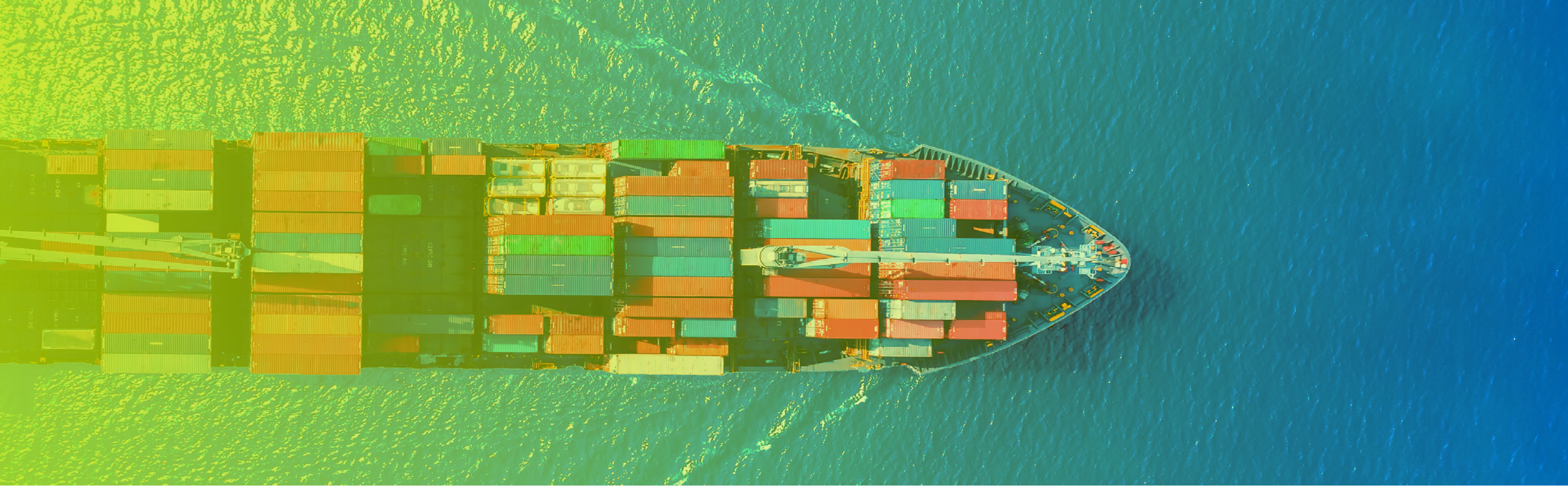
Definitions and abbreviations

Abbreviation	Definition
Bn	Billion
CO_2	Carbon dioxide
EJ	Exajoule
EU	European Union
FAO	Food and Agriculture Organization of the United Nations
FuelEU Maritime	EU regulation to promote the use of renewable, low-carbon fuels and clean energy technologies for ships, essential to support decarbonization in the maritime sector
EU ETS	EU Emissions Trading System
GHG	Greenhouse gas
IMO	International Maritime Organization: A specialized agency of the United Nations responsible for regulating maritime transport
ILUC	Indirect land use change
Liquid waste feedstocks	Waste- or residue-based liquid feedstocks such as used cooking oil (UCO), crude tall oil (CTO), and palm oil mill effluent (POME) for the production of biofuel and/or biogas; the classification of liquid waste feedstock varies between different countries
LUC	Land use change
MAGIC	Marginal Lands for Growing Industrial Crops: An EU-funded project that aims to help farmers to decide which industrial crops are suitable for the respective marginal location
MEPC 80	The 80th session of the IMO's Marine Environment Protection Committee
MSW	Municipal solid waste
Mn	Million
NO_x	Nitrogen oxides
RED	Renewable Energy Directive: Legal framework for the development of clean energy across all sectors of the EU economy
ReFuelEU Aviation	EU regulation to promote the increased use of sustainable aviation fuels (SAF) as the single most powerful tool to decrease aviation CO_2 emissions
SO_x	Sulphur oxides
t/ha	Tons per hectare
t/yr	Tons per year
1G	Biofuel derived from biomass that are generally edible
2G	Biofuel produced from a wide array of different wastes or residues, ranging from lignocellulosic feedstocks to municipal solid wastes



01 Executive summary

Following the Paris Agreement in 2015, the international shipping community has set out decarbonization targets to remain aligned with the global climate ambitions. The International Maritime Organization (IMO), for example, has declared aggressive goals, targeting 100% GHG reduction by, or around, 2050 compared to the base year (2008). To achieve this, the industry has been evaluating various technological and operational solutions.

One key solution is to substantially increase the use of biofuels derived from biomass. The potential for biofuels to play a role in the marine sector comes down to availability, a general term encompassing the annual global inventory of bio-feedstocks, the definition of sustainability for those feedstocks, their economic recoverability, compatibility with conversion processes, and competition for a limited resource by other industrial and transportation sectors.

To fully understand the potential of biofuels to decarbonize the transportation sector, OGCI recently worked with Argus Media to outline the global availability of biomass for marine fuel and estimate the overall annual volumes suitable for use in the sector through to 2050. This study was conducted to update the findings of the *first investigation in 2021* to reflect the changes to the drivers of biomass availability for marine, including legislation, assumptions on competition demand, and additional feedstocks. While the study was conducted to assess the global biomass availability, the methodologies employed to evaluate the availability of feedstocks and the demand for biofuels mainly reflect those included in European legislations as they were deemed to be the most progressive. This was to ensure that standards and requirements selected for the study would still be applicable across different regions in the medium to long term. For example, energy crops in this study only include non-food crops grown on severely degraded land, as defined by the European Commission while sustainable energy crops would be acceptable under IMO.

This study initially assessed the global biomass availability across all key categories including woody biomass, agricultural biomass (including intermediate and energy crops), and biowastes. Subsequently, the availability of sustainable biomass for biofuel production was determined by implementing several screens to the initial figures, including environmental, social, and geographical filters. Finally, the competing uses for solid biomass feedstocks such as non-energy (e.g., animal feed and building materials) and energy (e.g., domestic cooking and heat and power generation) were evaluated before finalising biomass availability for marine fuels.

The study found that the global availability of sustainable biomass eligible for biofuel use under legislative specifications presently stands at approximately 1.8bn tons (2025) and is set to increase to 3.3bn tons by 2050. With aviation and road sectors projected to only require 200mn tons of biomass by 2050, there is significant volume of biomass available for the marine sector. It is important to note, however, that this study mainly evaluates the availability of biomass without a detailed consideration of the associated economic viability along the value chain, from feedstock collection to the supply of end products into the market, all of which determined by various drivers including geographic factors, technology advancements (e.g., development biomass-to-liquid pathways), and the overall renewable fuel demand. As the market and technology continues to mature, it is likely that the economic viability will change and ultimately impact the biomass availability to the marine sector.

02

Maritime emissions reduction ambitions

02 Maritime emissions reduction ambitions

Three legislative drivers currently shape the decarbonization efforts in the marine sector through various means including biofuel consumption. Although these legislations, specifically IMO, FuelEU Maritime, and EU ETS, drive the marine sector in different ways, the overarching objective is the same: to encourage emissions reduction in the maritime sector.

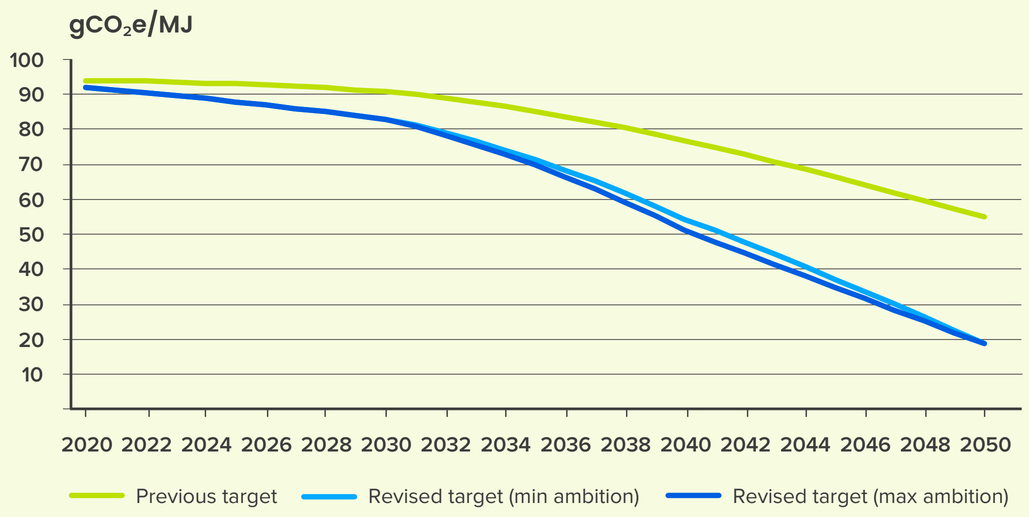
Given the MEPC 80 revision to the IMO targets, the reduction in GHG emissions from international shipping can be summarized as follows (IMO, 2023):

i. **Average carbon intensity (CO_2 per tonne-mile) reduction target of 40% by 2030 and a 5% total fuel share of fuel from zero/near-zero GHG technologies.**

ii. **Absolute reduction target of 20% to 30% by 2030; 70% to 80% by 2040; and 100% by, or around, 2050 compared to 2008.**

Previously, the IMO targets were mainly carbon intensity based, targeting a 40% reduction in carbon intensity by 2030 and 70% by 2050. Although the 40% target still remains, the focus is on the absolute reduction targets. Emissions have increased in current years, around 10% higher than the 2008 levels and therefore, extra effort is required to meet 2030 targets as these *extra* emissions must also be accounted for. Therefore, more emissions reduction is needed than the targets may initially imply.

Figure 1: IMO fuel carbon intensity targets. *Argus Media, Consulting Services.*



The EU's FuelEU Maritime aims at decreasing GHG emissions that arise from both domestic (EU Member States) and international shipping. Some of its key measures are the voyage coverage (includes all domestic voyages and 50% of international voyages) and GHG intensity reduction targets (emissions per unit of energy consumed) of 2% in 2025 vs. 2020, increasing to 80% in 2050.

The final key legislative driver is the EU ETS, which recently came into force and includes the maritime sector 2024 onwards. Under EU ETS, shipping companies will have to gradually surrender emission allowances: in 2025, 40% of verified emissions reported in 2024; in 2026, 70% of verified emissions reported in 2025; and 2027 onwards, 100% of verified emissions.

03

Sustainable biomass feedstocks

03 Sustainable biomass feedstocks

The study began by identifying the global availability of sustainable biomass feedstocks. To achieve this, a screening methodology was applied on biomass, which is defined as *organic material of recent biological origin.*

The aim of the sustainability screen was to screen out unsustainable feedstocks which would not be compatible with the current and future marine biofuel legislation (in terms of possible future direction), as well as ensuring the sustainability credentials of the maritime industry. This is particularly important considering how various regions or countries can define ***sustainable*** differently. Thus, it is imperative to ensure the term sustainability is applicable across all, if not most, geographies and markets.

The screening methodology followed a four-step process: (i) identify the key categories of major biomass feedstocks; (ii) review definitions, schemes, and legislation; (iii) develop sustainability criteria; and (iv) screen out unsustainable feedstocks.

Table 1: Environmental, social, and economic sustainability criteria. *Argus Media, Consulting Services.*

	Indicator	Criteria	Impact on availability
Environmental	Lifecycle GHG emissions	Biofuels must achieve a 70% reduction in well-to-wake GHG emissions relative to fossil fuels	Any biomass feedstocks which do not achieve this level of GHG reduction will be excluded
	Soil quality	Soil quality (notably organic carbon content) must be maintained or improved, or adverse soil degradation must be reversed	Soil best practises mean certain agricultural or forestry residues should be left on-field and are unavailable for biofuel production
	Air quality	Air pollution must be minimized or eliminated (and ship operators are to comply with IMO standards on SOx and NOx)	Any feedstocks with scientific evidence of producing polluting gases throughout lifecycle must be excluded
	Biodiversity	Biomass should not be taken from areas of nationally recognized high biodiversity, critical ecosystems, protected areas, where conservation is taking place and/or there are endangered species	This will exclude many areas from availability modelling, such as primary forest, protected areas, grasslands, etc.
	Land use change	Biomass production must avoid negative land use change (greater release of emissions driven by croplands for biofuel production)	Feedstocks with associated high ILUC and biomass produced on land that was previously cultivated/primary forest will be excluded
	Carbon stock	Biomass cannot be taken from land with high-carbon stock	Biomass from areas such as peatlands and wetlands are deemed unavailable and forest biomass can only be sustainably removed if harvest levels do not exceed forest growth
Social	Food security	Operations ensure the human right to adequate food and improve food security in food insecure regions	Biomass production cannot replace arable crops and any feedstocks associated with increasing food prices will be removed
	Legality	All international, national and local laws must be observed	Any countries that do not comply with laws/legislation must be excluded
	Social rights	Human rights, labour rights, land use rights and social equity must be met	Any countries that do not meet these criteria means it would be unsustainable socially to produce biomass and will be discounted
Economic	Economic & financial viability	Biomass must be produced and traded in an economically and financially viable way	Any feedstocks that cannot be produced in an economically sustainable way must be excluded
	Infrastructure & accessibility	Biomass must be accessible through relevant infrastructure	This will remove any regions that biomass is economically and technologically inaccessible

To apply the sustainability screen, biomass was disaggregated into three key categories: woody biomass, agricultural biomass, and biowastes. Each category is then split into several subcategories, each corresponding to a specific description and level of sustainability. The second step involved the review of various sources of regional and national legislations, maritime industry standards, and biomass sustainability schemes. This is then followed by the third step, the development of a list of sustainability criteria (refer Table 1). The criteria can be disaggregated into three key categories: environmental, social, and economic. Applying these steps enabled the outlining of biomass segments that are deemed sustainable, as shown in Table 2.

Table 2: Screening results of the various biomass categories. *Argus Media, Consulting Services.*

Category	Subcategory	Sustainability assessment	Comments
Woody biomass	**High quality stemwood**	Unsustainable and fully unavailable	Carbon stock and land use change criteria disqualify using stemwood due to concerns over deforestation and expansion of commercial forestry into non-commercial forests in order to meet increased demand
	Forestry residues	Branches, bark and low-quality wood available (~60% of total residues), but roots, stumps and leaves unavailable	It was determined that roots, stumps, and leaves must be left in the forest to enhance soil quality, but other residues such as branches, bark, and non-merchantable stemwood may be sustainably removed without impacting soil health
	Wood processing residues	100% sustainably available	These residues are a by-product with no associated negative consequences of their use (given they do not impact the primary activity)
Agricultural biomass	**1G**	Unsustainable and fully unavailable	EU legislation disqualifies 1G biofuels from counting towards FuelEU Maritime targets, but currently 1G biofuels are eligible under IMO provided they meet LUC criteria (although robust methodology to assess ILUC has not yet been developed so it is uncertain which feedstocks will be eligible)
	Field residues	40% sustainable removal rate assumed (in base case)	A significant portion of field residues (such as straw) must be left or ploughed back into the field to enhance soil health and reduce the application of fertilizers. The amount depends on the crop species, location, climate, etc.
	Processing residues	100% sustainably available	Residues produced from the processing of the primary crop are highly sustainable feedstocks as they are a waste that would typically be burnt on site
	Energy crops	Degraded land only	Assuming definition of degraded land only met, then considered sustainable (although enforcement/verification potentially problematic)
	Intermediate crops	100% sustainably available	Assuming definition of not interfering with primary crop cultivation met, then considered sustainable (although enforcement/verification potentially problematic leading to some risk of land use change and interference with food supply)
Biowastes	**FOGs**	100% sustainably available	All biowastes are assumed to be sustainable as they would otherwise be burnt or sent to landfill in most cases
	Other biowastes		

04

Biomass availability

04 Biomass availability

With the screening methodology and category definitions in place, the global availability of feedstocks across the major biomass categories, namely woody biomass, agricultural biomass, and biowastes, were subsequently determined. Given the high potential of intermediate crops and degraded land energy crops, two feedstocks that were newly added to the feedstock lists of EU's Renewable Energy Directive (European Commission, 2024), they will be discussed separately.

4.1 Agricultural residues

4.1.1 Modelling approach

To determine biomass availability for biofuels in the agricultural residue segment, a modelling structure was developed. The structure considers two key verticals, field and processing residues, the definitions of which are as the following:

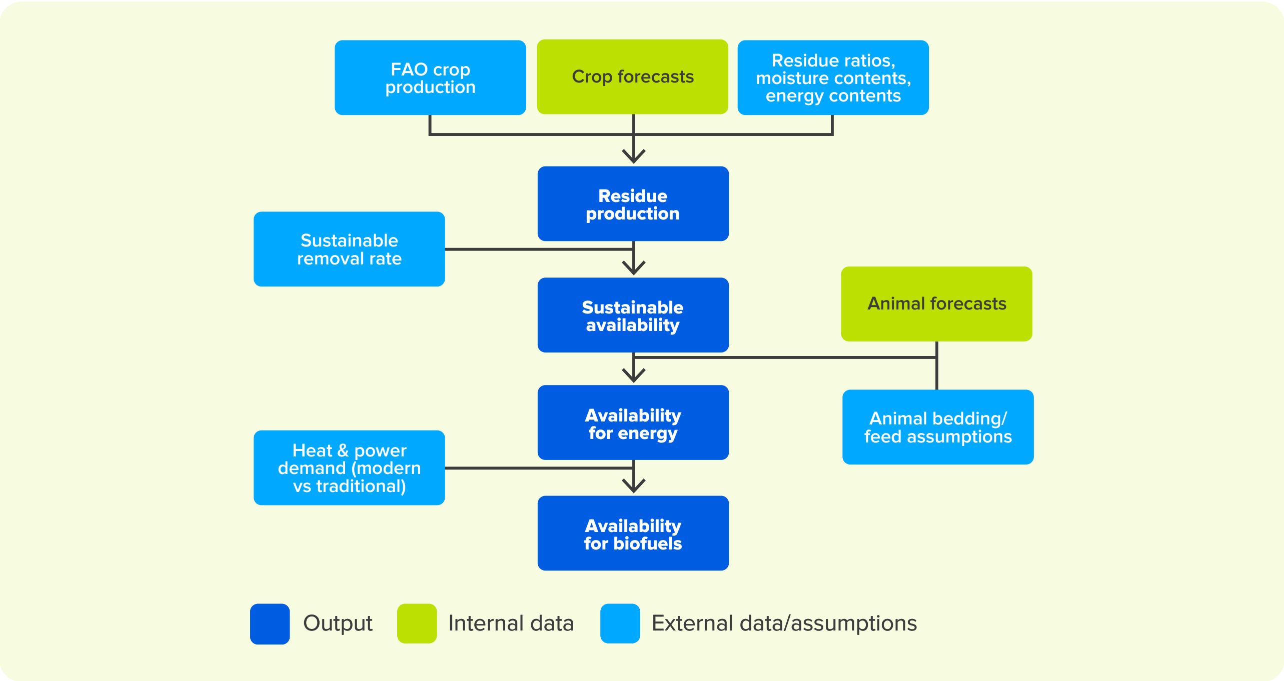
i. ***Field residues:*** **produced on the field during the cultivation of the primary crop, such as straws, stalks, stover, tops & leaves and tree prunings.**

ii. ***Processing residues:*** **produced during the processing of crops, such as bagasse, cobs, husks and bran, oilseed cake, and fruit pomace.**

The modelling approach began with comprehensive global forecasts of all major crops (crop production from Food and Agricultural Organization of the United Nations, FAO). Here, key factors such as residue ratios, moisture contents, and energy contents were taken into account to determine the overall biomass availability. The respective residue ratios were then applied across all crop subcategories, before a sustainable removal rate was applied to estimate sustained availability.

Animal bedding and feed estimations were then factored into the model, screening out further biomass and leaving only those available for energy use. Heat and power demand, including both modern and traditional, were then considered in the screening model.

Figure 2: Agricultural residue availability modelling structure. *Argus Media, Consulting Services.*

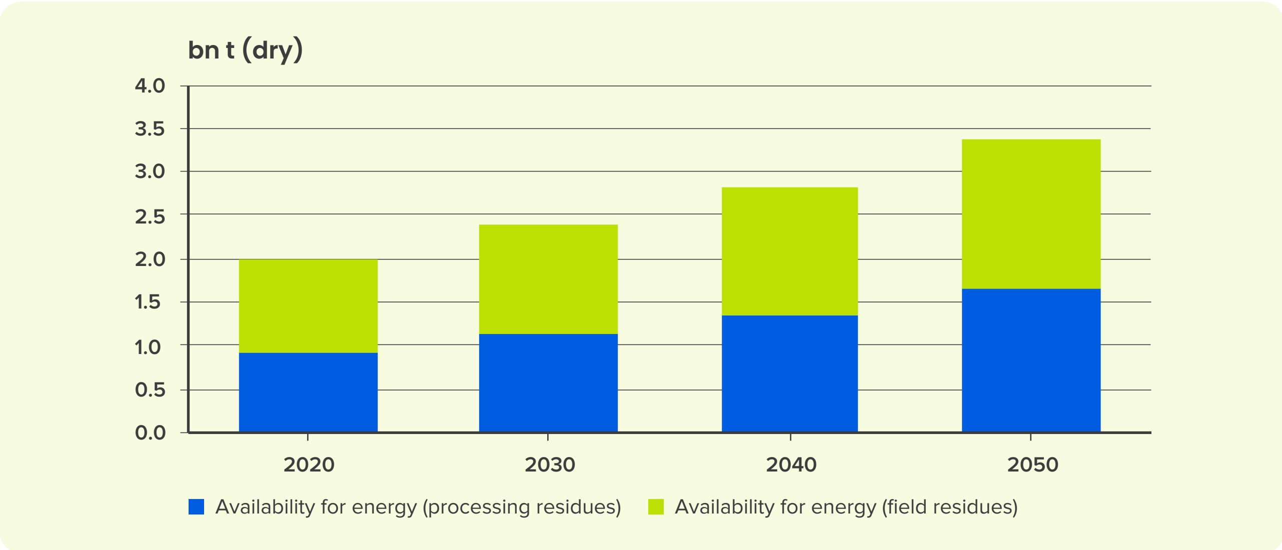


4.1.2 Results

Although ***field residue*** production is projected to increase significantly by 2050, driven by expansion of crop production to meet increasing food demand from increasing populations and changing food habits, most of the residues were deemed unsuitable for extraction and should be left in the field (e.g. ploughed back into the field) to maintain soil nutrients and quality. This proportion, of course, varies according to various factors such as climate, crop type, crop rotations, field slope, and harvesting techniques. To account for this, it has been assumed that 40% of field residues are available (i.e. 60% are left in the field for environmental use), which is within a range of 15% to 75% that was found reviewing a range of academic and industry sources. (Note that prunings from vineyards and fruit trees have a 100% removal rate applied because these residues are not left on fields as they have limited environmental value.)

For ***processing residues***, the production is estimated to increase by approximately 60% between 2020 and 2050, driven by increasing crop production. As there is limited environmental uses of these residues, 100% of the production is assumed to be available for biomass removal.

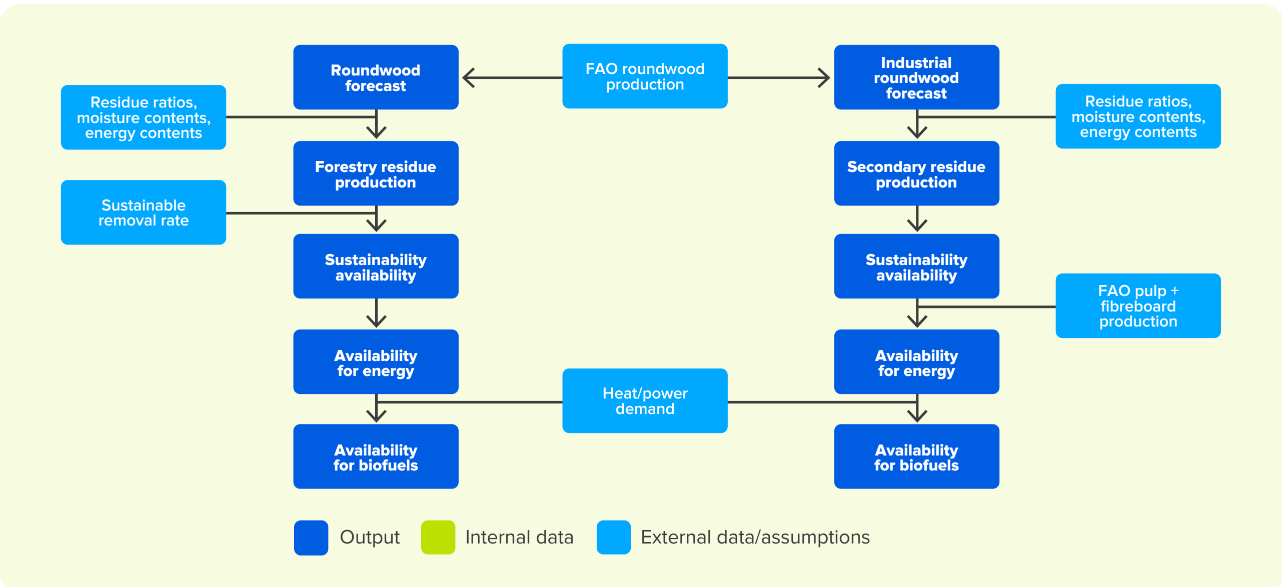
Figure 3: Processing and field residue availability for energy. *Argus Media, Consulting Services.*



4.2 Woody biomass

4.2.1 Modelling approach

Figure 4: Woody biomass availability modelling structure. *Argus Media, Consulting Services.*



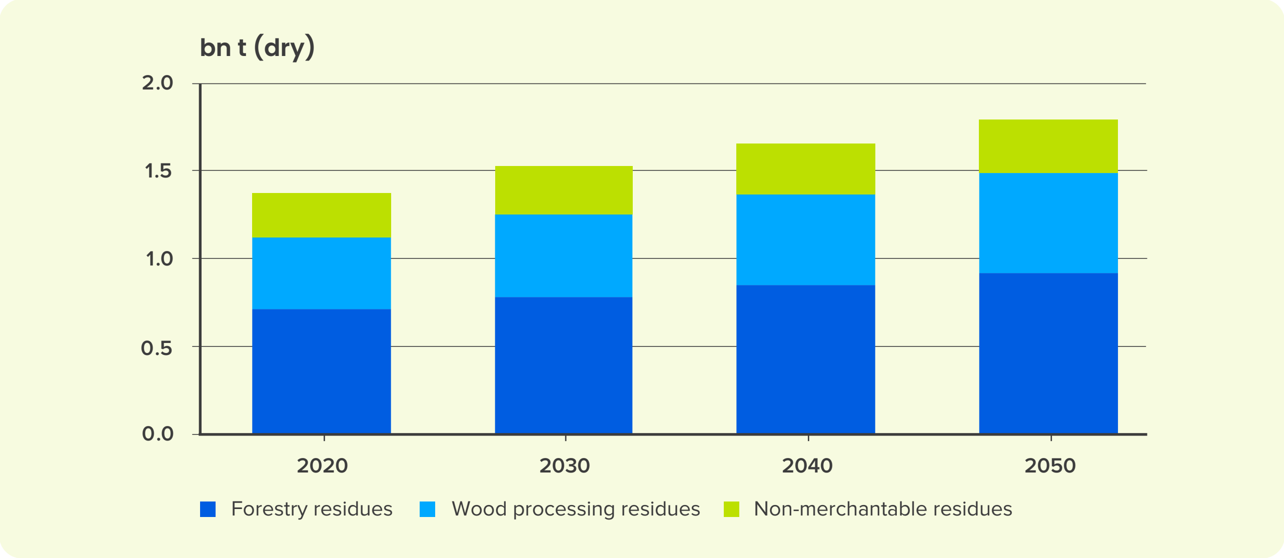
The woody biomass category was disaggregated into two key segments, primary and secondary wood residues. ***Primary wood residues*** refer to forestry residues produced in forests during forestry activities (thinning and felling) including branches, stumps, roots and small diameter/non-merchantable stemwood while ***secondary wood residues*** are wood processing residues including wood chips, sawdust and bark produced in sawmills, and other wood processors.

The modelling structure of woody biomass follows a similar approach as that of the agricultural residues, where the overall availability forecasts were employed as the base of the analysis. The model then screened out unsustainable biomass by applying various screens including residue ratios, moisture contents, energy contents, and a sustainable removal rate. For sustainable removal estimation, a proportion of primary woody biomass was deemed to be non-extractable and to be left in the forest (e.g. stumps, roots and smaller branches & leaves) to improve or, at least, maintain soil quality. This, however, is not applicable to secondary woody residues, as the biomass in this category is not considered to have any positive sustainability impact.

4.2.2 Results

This study projects that both types of woody residues will be primarily driven by the production of roundwood (for high-quality stemwood) and will result in the increasing production of woody biomass residues from 1.9bn tons dry (34 EJ) to 2.5 bn tons dry (44 EJ) between 2020 and 2050. Upon applying the modelling screens, however, these annual figures saw a reduction of approximately 20% (refer to Figure 4 for the projection of woody biomass availability for energy).

Figure 5: Woody biomass availability for energy. *Argus Media, Consulting Services.*



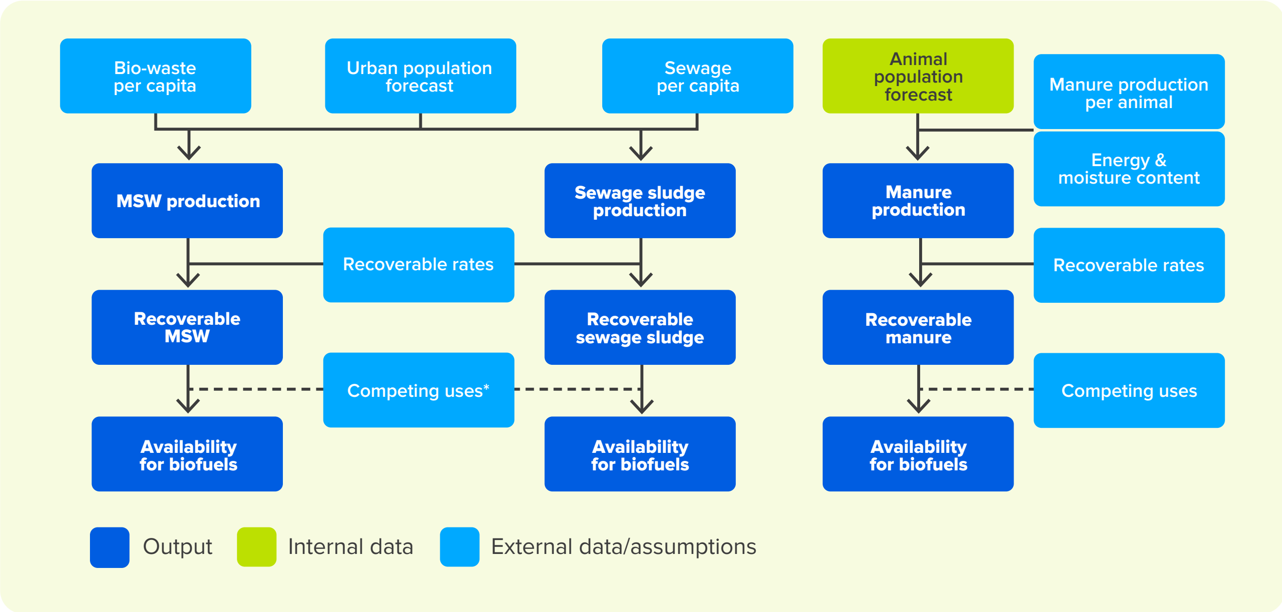
4.3 Biowastes availability

4.3.1 Modelling approach

Biowastes covered in the study include manure, municipal solid wastes (MSW), and sewage sludge. Two key forecasts were used as the basis for the availability evaluation: urban population (for MSW and sewage sludge) and animal population.

The availability of ***MSW*** and ***sewage sludge*** were determined by applying waste per capita of the urban population and screening it with a recoverable rate (which changes from one geographical location to another). Similarly, a recoverable rate screen was applied to the animal waste production to determine its availability for biofuels. In the ***manure*** category, five types of animals were assessed (cows, sheep, pigs, goats, and chickens), with cows being responsible for about 75% of total production (on dry tonne basis). The key limitation to utilisation of manure as a feedstock is the quantity which can be collected (i.e. recoverable) which is determined by the proportion of animals kept in stalls vs open pastures (where manure cannot be collected feasibly).

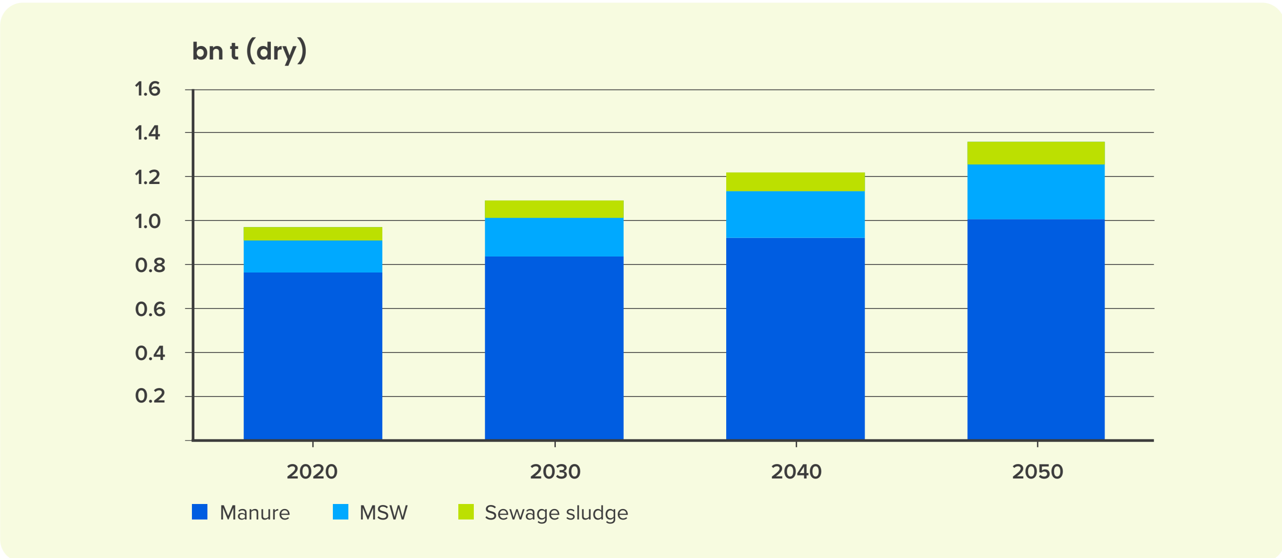
Figure 6: Biowaste availability modelling structure. *Argus Media, Consulting Services.*



4.3.2. Results

Presently, global biowaste production is estimated to be roughly 4.2bn tons (dry), with manure making up approximately 90% of total share. Over the next 25 years, the total biowaste availability is projected to grow by approximately 30% to 5.4bn tons (dry) by 2050. In 2024, due to the low recoverable rates, only about 1.05bn tons (dry) of the total 4.2bn tons (dry) biowastes is deemed available for biofuels. Although this figure is projected to grow, the availability remains limited over the forecast period, with only 1.4bn tons (dry) estimated to be available for biofuels in 2050.

Figure 7: Biowaste availability for energy. *Argus Media, Consulting Services.*



4.4 Intermediate crop availability

4.4.1 Overview

In this study, intermediate crops are defined as any crop grown on agricultural land that is not the primary crop cultivated in a given year and that is grown at a different time than the primary crop. The primary crop in a given year is assumed to be the crop harvested in that year that has the highest expected revenue, occupies land over the longest period in a year, and requires the largest share of agricultural inputs (work, fertilizer, pesticides). Here, intermediate crops include catch crops, cover crops, and rotation crops.

There is a large variety of crops that can be grown as intermediate crops, which varies according to factors such as climate, the primary crop and its corresponding intermediate crop cycle, and local environmental factors (e.g. soil quality enhancement, disease protection). Some examples of intermediate crops include brassicas (oil crops such as rapeseed and carinata) and grains (such as oats and rye).

Many examples of possible intermediate crops are themselves major commodity crops, such as rapeseed, oats, wheat, maize, and soybeans (i.e. it is not the crop type, but rather the production system or growth cycle that defines cover and intermediate crops). It is imperative to note that primary crop cycles can vary between different regions according to climate and other factors, which can complicate the potential implementation of intermediate crops across different geographies. Additionally, in some regions, multiple cropping of a primary crop within a single year is possible which means there is no potential for intermediate crops (as this would interfere with food supply).

4.4.2 Modelling approach

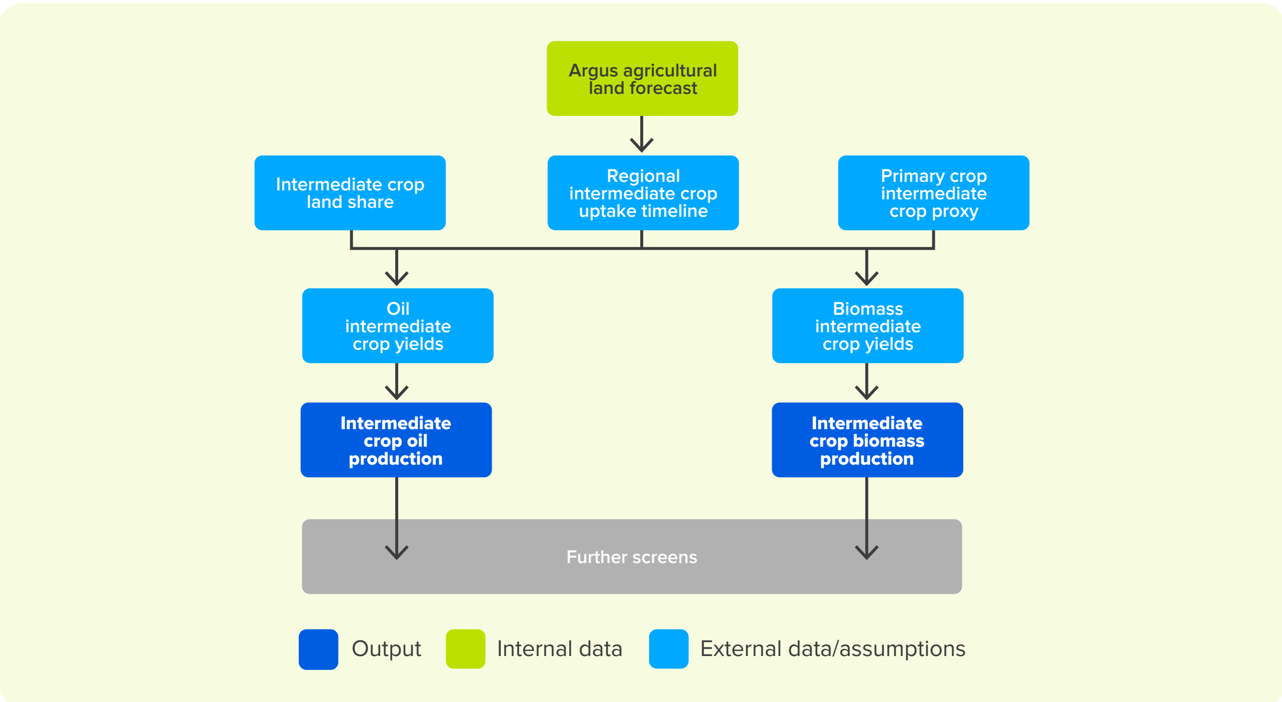
In this analysis, the definition of intermediate crops excludes perennial intermediate crops like miscanthus and switchgrass as their growth cycle exceeds a year (they will, however, be included in the assessment of energy crops grown on severely degraded land).

Although permitted under EU, this study has opted to exclude food oil crops to avoid any food versus fuel debate and mitigate any downstream risks. Therefore, the forecast uses established non-food oil intermediate crops such as carinata, camelina, safflower, mustard, oil seed radish, and flax.

These non-food intermediate crops are grouped under three broad categories (general, arid suitable, and fast growth cycle) to reduce the impact of farmers' choice of individual crops on the output.

At the core of the modelling structure was the Argus internal agricultural land forecast, which provided the global agricultural land area use by food crop, allowing the study to determine the land use for intermediate crops. Using the food crop's typical climatic, soil, and crop cycle requirements, the suitable intermediate crop groups were then selected.

Figure 8: Intermediate crop availability modelling structure. *Argus Media, Consulting Services.*



The study also made estimates of regional intermediate crop land shares and uptake timelines. Here, a cautious approach was taken, where key factors such as agroecological conditions, existing agricultural practises, and policy support to generate a generalized figure on the region's ability and appetite for intermediate crop use were incorporated. (Note that the land share designation had the greatest impact on intermediate crop availability, as national-level assumptions were made on the start and end points, as well as uptake rates, of land shares.)

For both intermediate biomass and oil production, a base yield assumption was applied. However, the study also provided two alternative sensitivities, higher yields and intermediate crop land use shares, to demonstrate their respective impacts on the outlook.

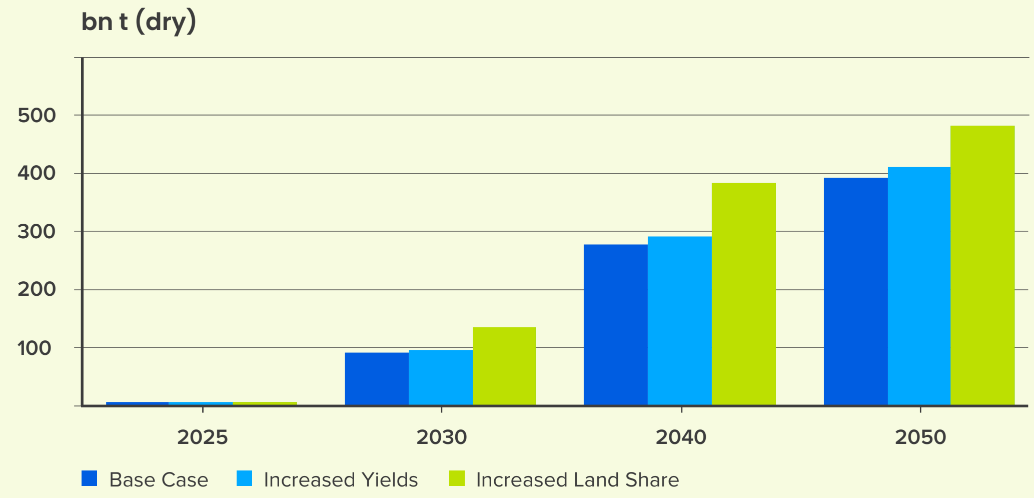
4.4.3 Results

intermediate crop biomass production is projected to total 394mn tons by 2050, which, using typical yields from agricultural biomass, could total 99mn tons of renewable diesel. General intermediate crops (e.g., carinata, camelina, and mustard) make up approximately 70% of the total share, with arid suitable (safflower) 20% and fast growth cycle (oil seed radish) 10% across the forecast period.

Significantly increasing the yields of the intermediate crops by 5% has the same direct impact on the intermediate crop outlook. In absolute terms, this 5% yield increase is equivalent to around 11mn tons of additional 2050 renewable diesel production.

However, making alterations to the land share assumptions across the forecast period has the greatest impact on the intermediate crop production outlook. For example, increasing Latin America's land share assumption by additional 2.5% across the forecast period would increase 22% of intermediate crop production by 2050—this is equivalent to an additional 50mn tons of renewable diesel production when compared to the base case.

Figure 9: Intermediate crop production outlook and sensitivity. *Argus Media, Consulting Services.*



4.5 Energy crop availability

4.5.1 Overview

To determine the availability of global energy crops grown on degraded land, a sustainability approach was taken rather than an economic one. In this analysis, energy crops are defined as non-food crops grown on severely degraded land not suitable for food and feed crops – this excludes both 1G food crops and the coppicing of trees such as willows. To maintain the conservative position of the study, strict definition of energy crops was assumed and applied across all regions. As a result, there may be upsides to the forecast, especially in markets with supportive policies around energy crops such as the US.

The EU's Renewable Energy Directive considers lands as severely degraded if for a significant period of time, they have either been significantly salinated or presented significantly low organic matter content. Determining this land area is difficult as there are few studies, particularly on a global level, which assess land degradation and even fewer that classify land based upon salination or low organic matter. This analysis has therefore used regional studies, specifically MAGIC (2021) in Europe, which use a more granular approach by allocating marginal land into categories such as chemical pollution and low productivity, to inform the make-up of marginal land in other regions. Considering the lack of data and uncertainty in assessing marginal land, this study has generally taken a cautious approach, attempting to ensure land is truly degraded if used.

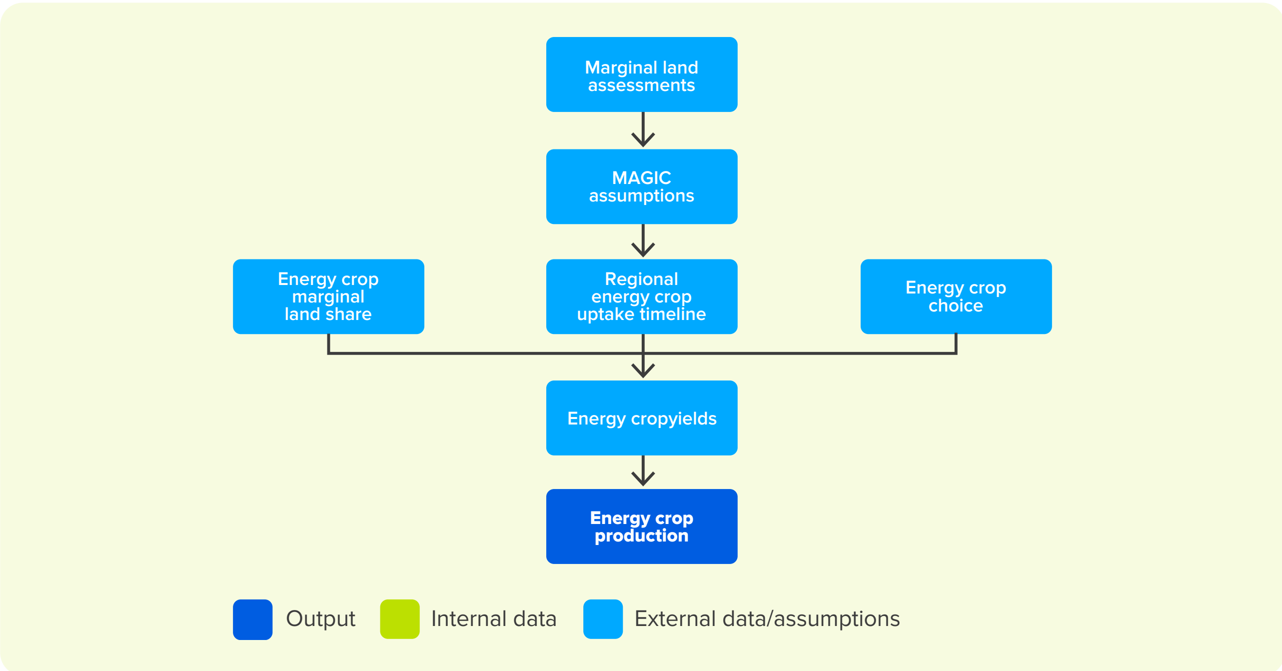
4.5.2. Modelling approach

To determine the share of marginal land caused by salination and low organic content, global marginal land studies with assumptions from MAGIC (2021) were used. This reduces the global marginal land from just under 1bn hectares to about 110mn hectares, which is equivalent to 1% of global land or 2.3% of global agricultural land. Despite the fact that the use of energy crops on marginal land is expected to rehabilitate land so that it is no longer marginal, this study has kept the forecast flat to account for the creation of marginal land over time.

This analysis has taken a cautious approach to allow room for error in the assessment of marginal land and for the fact that some marginal land may be practically inaccessible or unusable. Additionally, studies have shown that in general, the ability to grow energy crops on marginal land with lower inputs and rents does not compensate for the loss of production volumes (MAGIC, 2021). Thus, energy crops do not provide an economic incentive for farmers over traditional food crops without subsidisation.

Growing crops on severely degraded land is not expected to significantly reduce overall breakeven prices, as the reduced land costs are mitigated by the reduced yield of the crop. This study has selected perennial energy crops such as miscanthus and switchgrass as they provide more favourable economics than oilseed intermediate crops and these perennial energy crops have been grouped for the analysis to reduce the impact of farmers' choice of individual crops on the output.

Figure 10: Energy crop availability modelling structure. *Argus Media, Consulting Services.*



There is some consensus on the typical yields of perennial energy crops like miscanthus with most sources identifying a yield of 10 t/ha. However, there are few studies that cover the production of perennial energy crops on marginal land which is severely salinated or has low organic content. Some studies have indicated that a 30% to 35% reduction in yield can be expected but this fluctuates depending on the extent of the land's marginality. This, compounded with the global nature of the study, creates some uncertainty in the yield assumptions. This analysis maintained a cautious approach, using the marginal land yield of 6.5 t/ha, which creates the potential for upside in the production outlook.

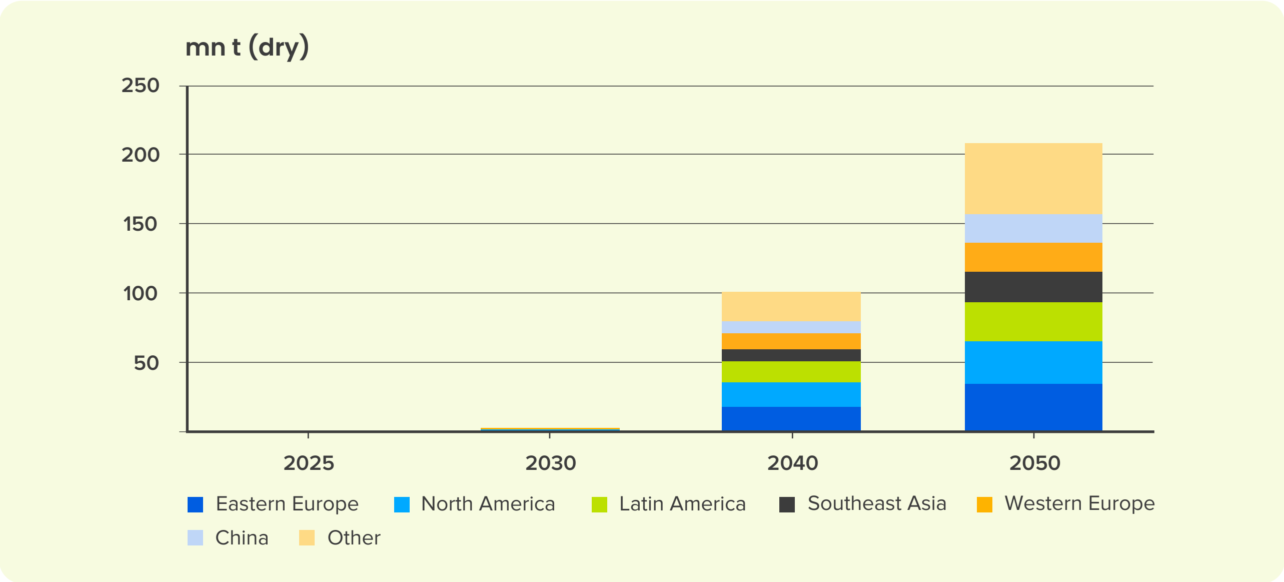
4.5.3. Results

The uptake of perennial energy crop production is projected to start slowly, with only 3mn tons by 2030 before quickly increasing over the next two decades. This is because there is an expectation that further research will be conducted to concretely identify severely degraded land and that farmers will have to be significantly incentivized and subsidized to make the production of energy crops more suitable than the growth of food crops on degraded land.

Perennial energy crops grown on severely degraded land such as miscanthus and switchgrass are projected to total over 101mn tons of biomass production by 2040, rising to 208mn tons by 2050. Using typical yields from agricultural biomass, this could total 25mn tons and 52mn tons of renewable diesel by 2040 and 2050, respectively.

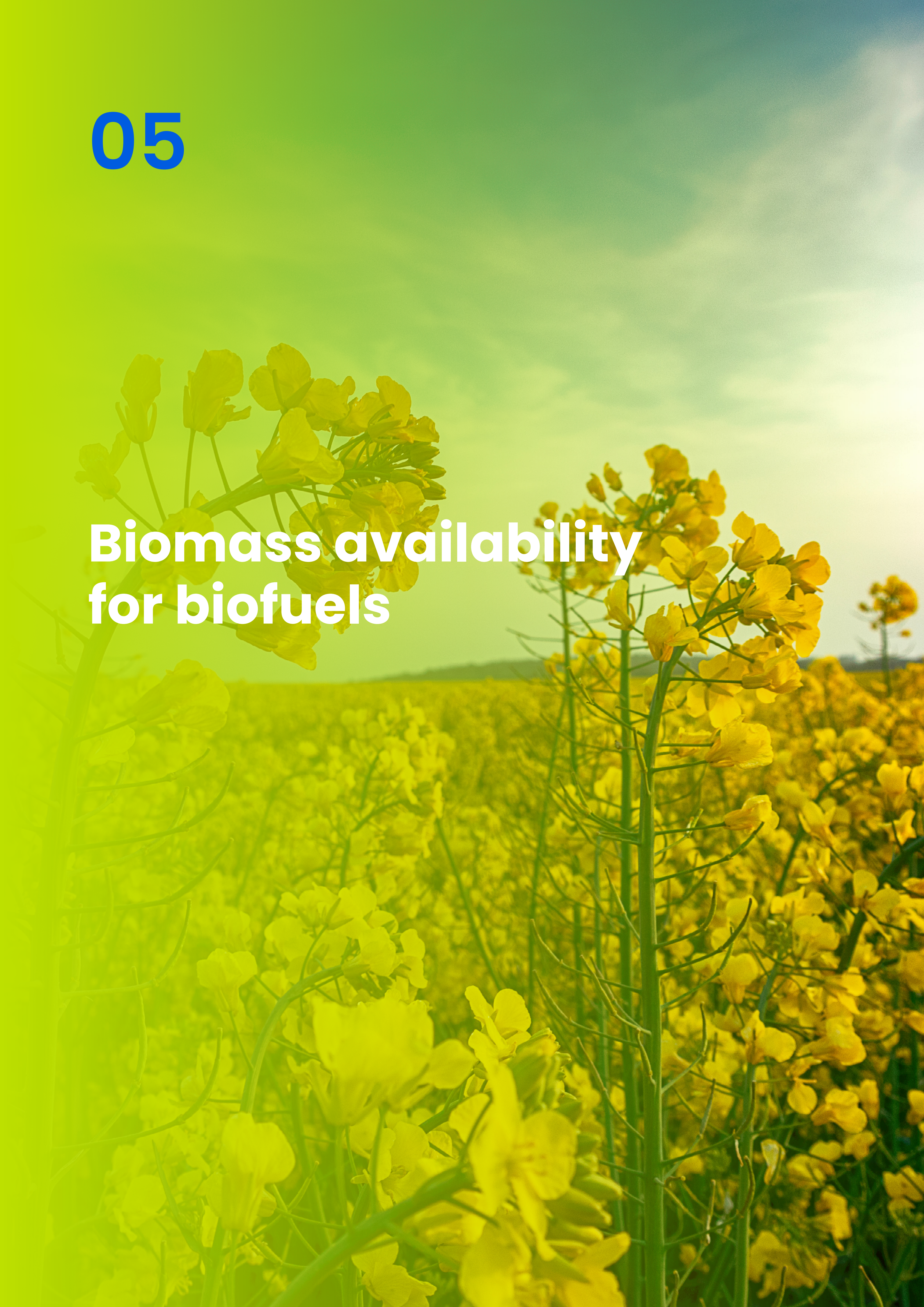
On a regional level, the largest markets for energy crops grown on severely degraded land are expected to be Eastern Europe, North America, and Latin America, which are expected to total >28mn tons of production by 2050.

Figure 11: Energy crops grown on severely degraded land production outlook, assuming sufficient support through subsidies and incentives.
Argus Media, Consulting Services.



05

Biomass availability for biofuels

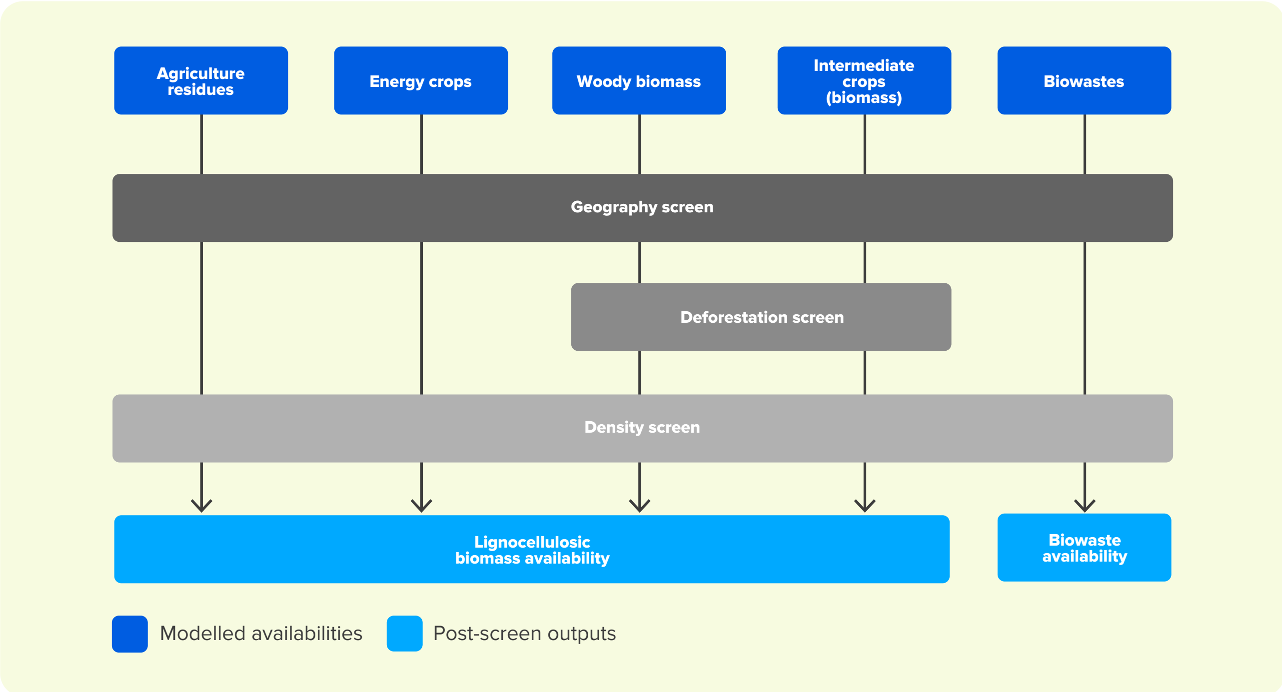


05 Biomass availability for biofuels

5.1 Additional screens

With biomass availability for energy (transport) and production (in the case of intermediate and energy crops) established, additional screens were then implemented to ensure that all potentially unsustainable sources are filtered out. Three major screens were employed at this stage of the study: geography, deforestation, and density.

Figure 12: Biomass availability for biofuel modelling structure. *Argus Media, Consulting Services.*



The ***geography screen***, which was applied across all categories of biomass, aims to remove countries where biomass would be unsuitable and/or unsustainable to produce marine biofuels. The first step uses the Political Stability Index by World Bank (2024) to remove countries where it would be unfeasible to operate biofuel production facilities. This removes countries such as Afghanistan, Somalia, Syria and Yemen as they have scored, on average, below -1.85 over the past three years. The second step excludes countries which are inaccessible to produce biomass and marine biofuels. This most notably includes landlocked countries with restricted access to the sea such as those in Central Asia and inland Africa.

The second screen, ***deforestation***, was implemented on woody and intermediate crop biomass. This screen was introduced to align the sustainability criteria under Renewable Energy Directive and the EU's recent deforestation regulation that applies to both wood products and some crops such as soy, which are expected to be used in conjunction with intermediate crops.

To assess this, the rate of change in forest area and the corresponding growth of agricultural area has been calculated using the Argus internal land use model. This flags countries as high risk if they have both a 3% growth in agricultural land and reduction in land forest area or just a -5% change in land forest area from 2010 to 2020. A minimum change in absolute terms was also implemented to prevent nations with small forested areas having small changes in land use being flagged by the screen. Using this approach, woody biomass and intermediate crop biomass from countries such as Brazil, Indonesia, and Angola are entirely excluded.

The final additional screen implemented in this stage of the analysis was ***density screen***. The critical economic hurdle for the utilisation of these feedstocks are the high costs associated with the transportation of biomass. Theoretically, a biofuel production facility can be built anywhere provided there is sufficient feedstock found within roughly a 42 km radius (MAGIC, 2021) of the facility. Thus, some form of feedstock concentration measure is required to determine economic availability.

This can be achieved through a density screen, which removes any biomass in low concentrations. The maximum number of plants in a country is calculated by dividing total area by the suitable catchment area of the plant (42km radius)

This "total area" uses the relevant land use for the biomass, i.e. forest land for woody biomass, to remove unsuitable land from impacting the density screen. This study assumed a typical biofuel capacity of 100,000 t/yr, which requires roughly 400,000 t/yr of dry biomass. Countries are rated as "high density" if the average density for lignocellulosic biomass and manure biofuel facilities exceeds 400,000 dry tons.

5.2 Availability for biofuels

The geography and deforestation screens removed 720mn tons of biomass in the year 2030 from markets that are not suitable for biomass production. Using a high, medium, and low density methodology, the vast majority of biomass is found in high density countries (96%).

Due to the limitations in using country level data during this screening, this 96% biomass should not be regarded as economically available (i.e., cost of retrieval not amounting to more than 70% of total biomass delivered cost), but merely an indication that biomass in most countries is expected to be economically accessible. Therefore, the results of this density screen are used as an indicator of density where it is assumed:

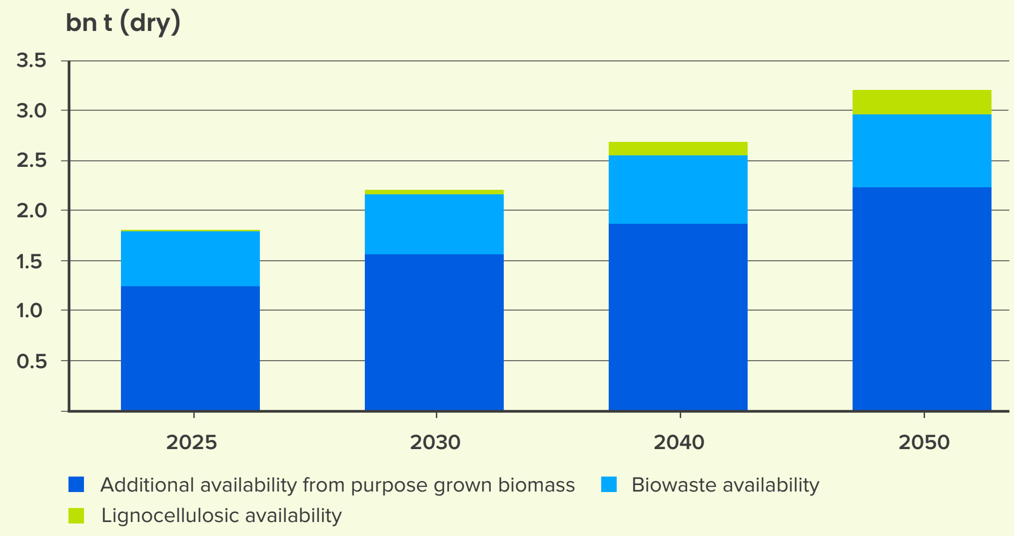
i. **80% of biomass in high density countries is economically available,**

ii. **65% of biomass in medium density countries is economically available, and**

iii. **50% of biomass in low density countries is economically available.**

In 2030, the density screen removes a further 640mn tons, leaving a remainder 2.2bn tons of biomass available for biofuel production. The removal of purposeful biomass like intermediate crop biomass and energy crops does not have a significant impact on a country's ability to pass the screen or the overall availability, but it does remove 240mn tons of biomass in 2050.

Figure 13: Biomass availability for biofuel production. *Argus Media, Consulting Services.*



06

Biomass availability for marine

06 Biomass availability for marine

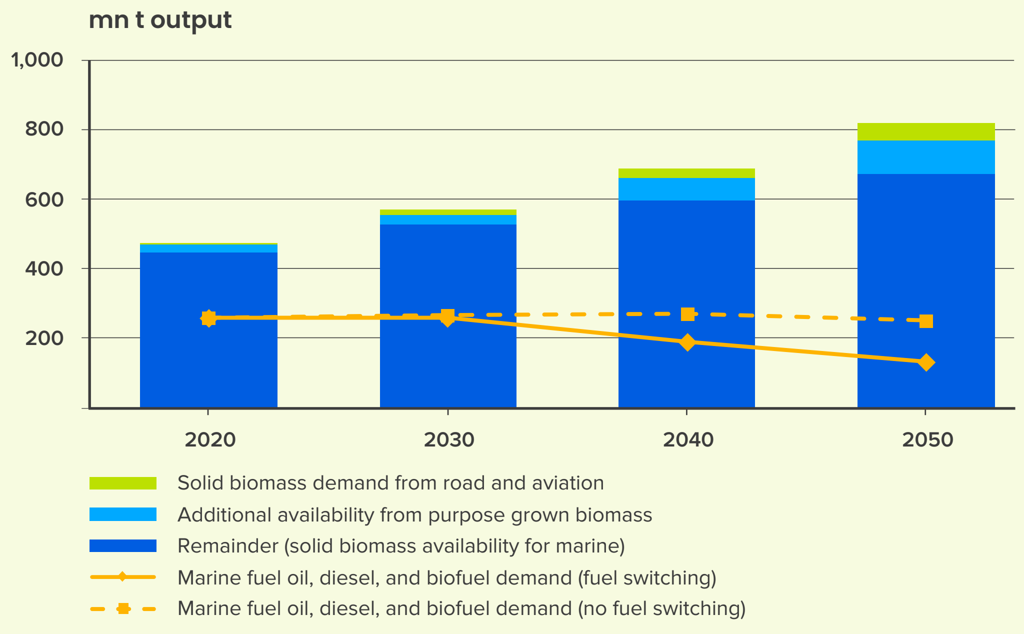
Global availability of liquid waste feedstock, which includes used cooking oil, animal fats, and advanced waste liquid such as tall oil and its distillates, is expected to be sufficient until the late 2020s, before increasing demand results in a liquid feedstock deficit. By 2030, this deficit is expected to total 23mn tons of renewable diesel, SAF, and other biofuels such as biomethanol and biomethane, and is forecast to grow to 84mn tons by 2050

This deficit could either be met by the addition of new hydroprocessing feedstocks such as intermediate oil crops or the use of alternative production pathways (e.g., biomass-to-liquid), which can harness solid biomass feedstocks. The former is likely to be preferred, considering the already mature hydroprocessing technology and the risks associated with novel pathways. Therefore, this study has assumed that intermediate oil crops are prioritized over solid biomass where possible.

Considering the EU Commission's most recent proposal where intermediate crops are only uncapped if used in the aviation sector, the majority of feedstock is expected to be used to produce a SAF. This is supported by the higher feedstock costs of intermediate oil crops over solid biomass options, which may make them more suitable for higher margin sectors. Despite the use of this feedstock, aviation and road demand are still expected to exceed intermediate oil crop demand and, therefore, stimulate demand for solid biomass feedstock into these two transport sectors. The solid biomass feedstock requirement for road and aviation, in output terms, is forecast to total 13mn tons in 2030, before rising to 51mn tons by 2050 (translating to 200mn tons of raw solid biomass by 2050, only a fraction of the total 3.3bn tons of availability for biofuel producers).

Thus, unlike in the *previous analysis*, this study sees less competition for biomass between the transport sectors due to the greater availability resulted from the additional types of biomass evaluated. Fuel oil, diesel, and biofuel demand from the marine sector currently totals around 260mn tons of fuel. Argus does expect this demand to decline to 132mn tons by 2050, as alternative fuels are expected to become commercially viable.

Figure 14: Biomass availability for marine. *Argus Media, Consulting Services.*



However, even if this decline was not to occur and only solid biomass was used to replace fuel oil and diesel, this study has identified that there should be plentiful solid biomass that is economically available for this marine fuel production on a global scale. This outcome remains even if there is no growth in the forecast availability of solid biomass for marine biofuel producers from 2020 levels, i.e., collection rates stagnate and there is a lack of biomass mobilisation.

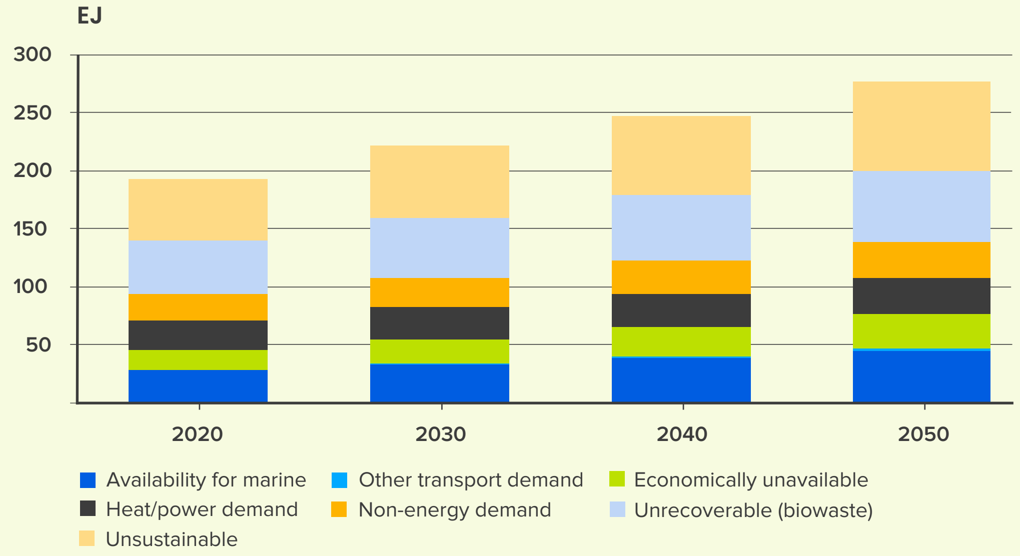
07

Conclusions

07 Conclusions

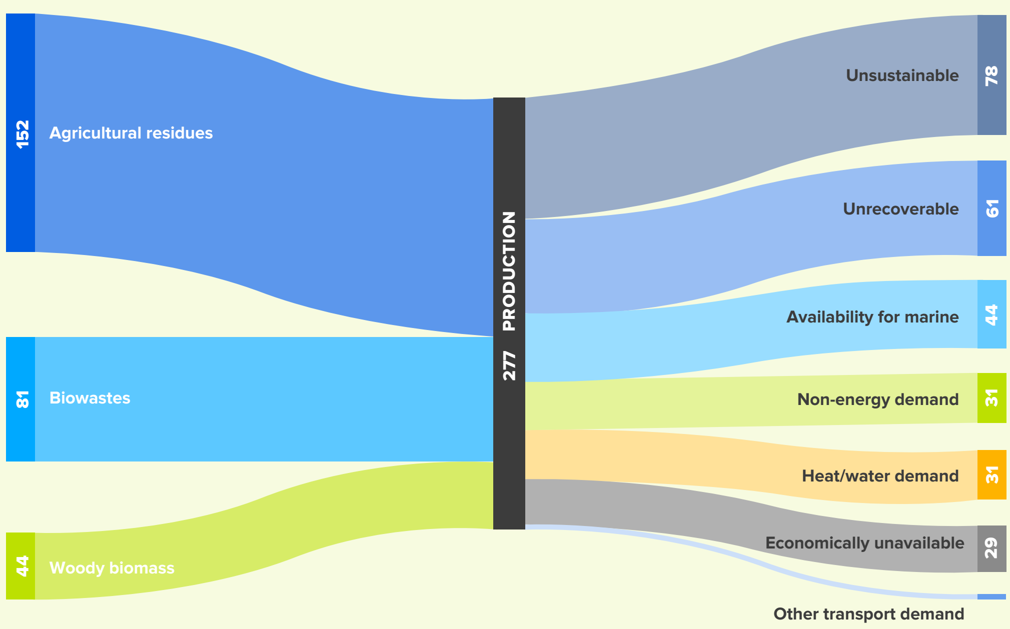
Waste and residue solid biomass feedstocks are produced in very large quantities, but availability is greatly limited by sustainability restrictions, collection issues, and competition from alternative uses. This study has provided a conservative view to determine the potential availability of biomass for marine fuels under a cautious approach.

Figure 15: Global biomass availability and utilisation in energy terms. *Argus Media, Consulting Services.*



The abundance of biomass availability for the marine sector means that the long-term targets outlined by IMO shown in Figure 1 is viable and practicable. There are, of course, other roadblocks that need to be addressed if this is to materialize, such as the economic viability of biomass-to-liquid pathway as a means to deliver biofuels for the sector and the overall uptake of low-carbon fuels (including biofuels) by the sector to decarbonize and comply with the targets.

Figure 16: 2050 global biomass availability and utilisation in energy terms (EJ). *Argus Media, Consulting Services.*



Nonetheless, this analysis indicates that there is a substantial volume of biomass available for marine biofuel production, but this must be caveated with the potential for downside risks due to the assumptions and approach outlined below:

i. **Firstly, the global nature of the study creates a large starting figure for total biomass which is gradually whittled down through multiple assumptions. Small changes in these assumptions have significant impacts on the final availability for marine biofuel production.**

ii. **This study has also assumed that woody biomass and agricultural residues can be used in the same facility. If they were to be screened separately there is the potential for a reduction in density and, consequently, availability.**

iii. **Further, the density screen is limited by country level data and does not distinguish between regional differences, e.g., assumed Siberia and Moscow in Russia are equally viable.**

iv. **The screen implemented in the study assumed that biorefineries are optimally placed so that each can be supported by feedstock within its radius. Imperfect coverage is likely with optimal biorefinery sites being competitive.**

v. **Heat and power demand from modern uses are expected to grow modestly and significant growth may reduce availability for biofuels.**

vi. **The economic viability of producing biofuels from biomass was not evaluated in detail and the study assumes that the biomass-to-liquid pathway will be commercially viable with very competitive production costs. If the cost of biomass-to-liquid remains comparatively high, it is likely that the definition of economic viability will change and impact the evaluation biomass availability.**

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