# Global Availability of Biogenic $CO_2$ and Implications for Maritime Decarbonization

**Mærsk Mc-Kinney Møller Center**
for Zero Carbon Shipping

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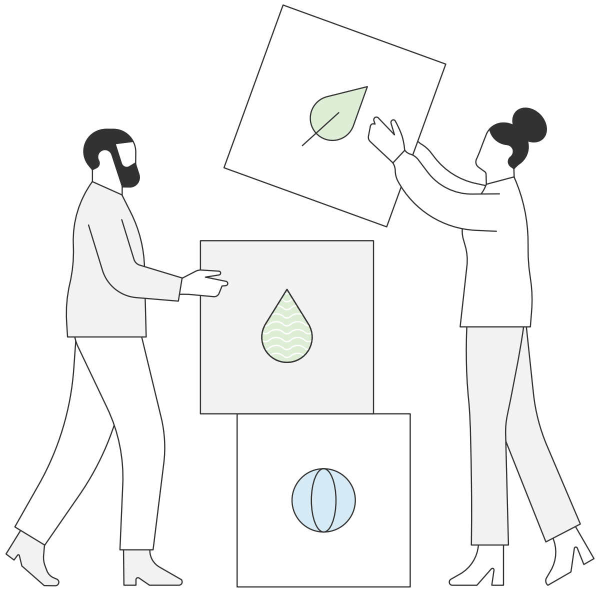
# Executive summary

Sustainable decarbonization of the shipping industry will rely on replacing fossil fuels with low- or zero-carbon alternative fuels. Among these alternative fuels, carbon-containing e-fuels (e-methanol, e-methane, and e-diesel) are some of the front-running options. Since combusting these e-fuels releases carbon dioxide ($CO_2$), utilizing such fuel pathways in a sustainable manner requires producing them from $CO_2$ feedstocks that can be accounted as carbon removals. Biogenic $CO_2$ provides one of the most straightforward and least costly such feedstocks. Therefore, the industry needs to understand how much biogenic $CO_2$ is available globally, as well as where and at what cost. In addition, we need to understand the opportunities and barriers for shipping to access this feedstock.

To address these knowledge gaps, the Mærsk Mc-Kinney Møller Center for Zero Carbon Shipping (MMMCZCS) has undertaken an analysis of the global availability of biogenic $CO_2$ and its implications for maritime decarbonization. This publication presents the results of geospatial and economic analysis using a global dataset of point-source emissions of biogenic $CO_2$, assembled by the MMMCZCS's knowledge partner Rystad Energy. Our quantitative results are supported by qualitative insights drawn from a series of interviews with industry experts engaged in project development.



We estimate that the global supply of biogenic $CO_2$ suitable for e-fuel production lies in the range of 320-370 million tonnes per year. This volume is located mostly in Europe and the Americas and is found across 360 geographically clustered sites – each of which could theoretically correspond to an e-fuel plant capable of producing the equivalent of 1,000 metric tonnes per day of e-methanol. Most of the supply of lower-cost biogenic $CO_2$ comes from the pulp and paper industry.

While many point sources in our dataset could potentially cease operation before they become economical to invest in for e-fuel production, even 20% of our estimated total biogenic $CO_2$ supply would enable the production of around 1 EJ equivalent of e-fuel per year. This is enough energy to decarbonize 8% of the current global fleet and is ample to meet near-term maritime decarbonization targets, such as those set by the International Maritime Organization (IMO) and the FuelEU Maritime regulation.

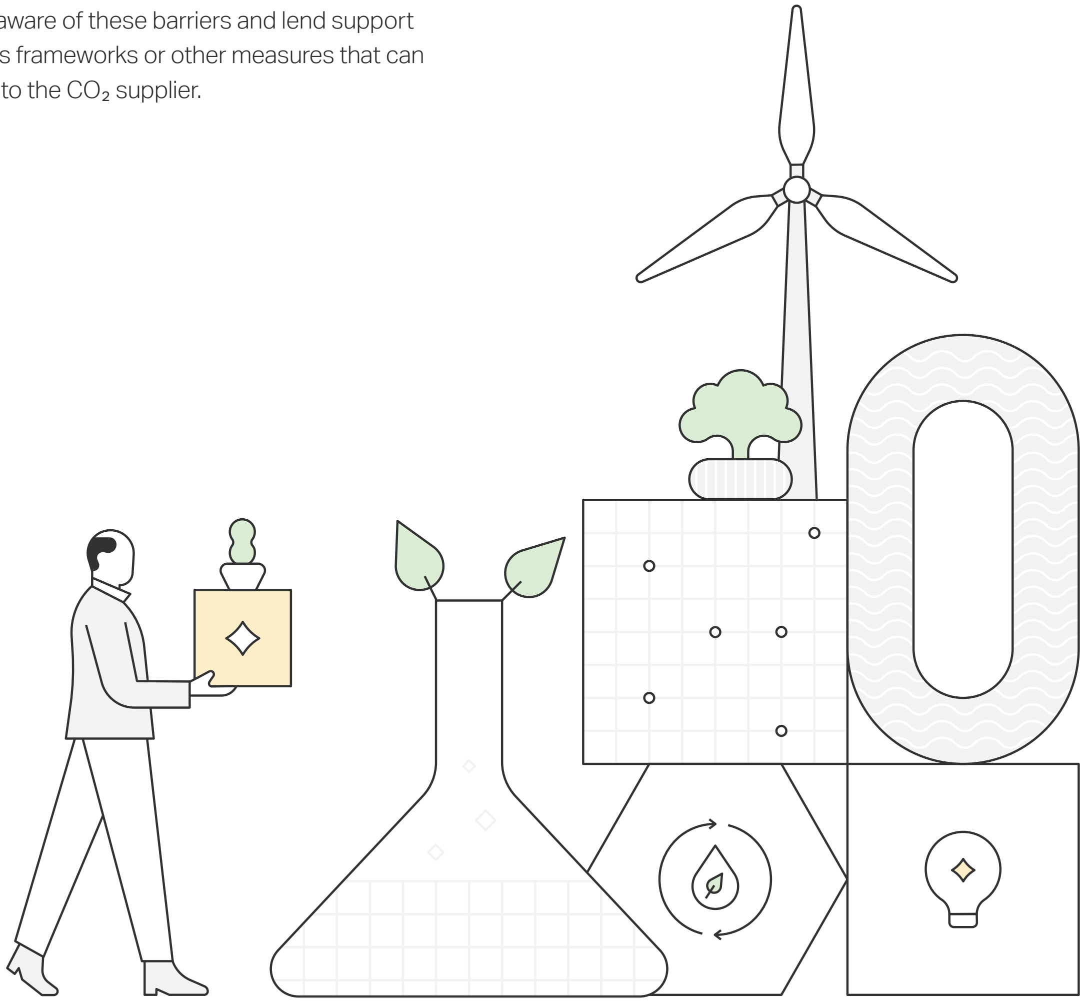
On the other hand, our estimated biogenic $CO_2$ supply will not be plentiful enough to enable full decarbonization of the maritime sector. Even if the entire supply is economically accessible, it could only generate around 5.4 EJ equivalent of methanol per year. As the shipping industry currently consumes about 12.6 EJ of energy per year, the entire global supply of biogenic $CO_2$ is only enough to decarbonize 43% of the global fleet. Therefore, our analysis confirms that activating other fuel pathways in parallel will be essential for shipping's full decarbonization.

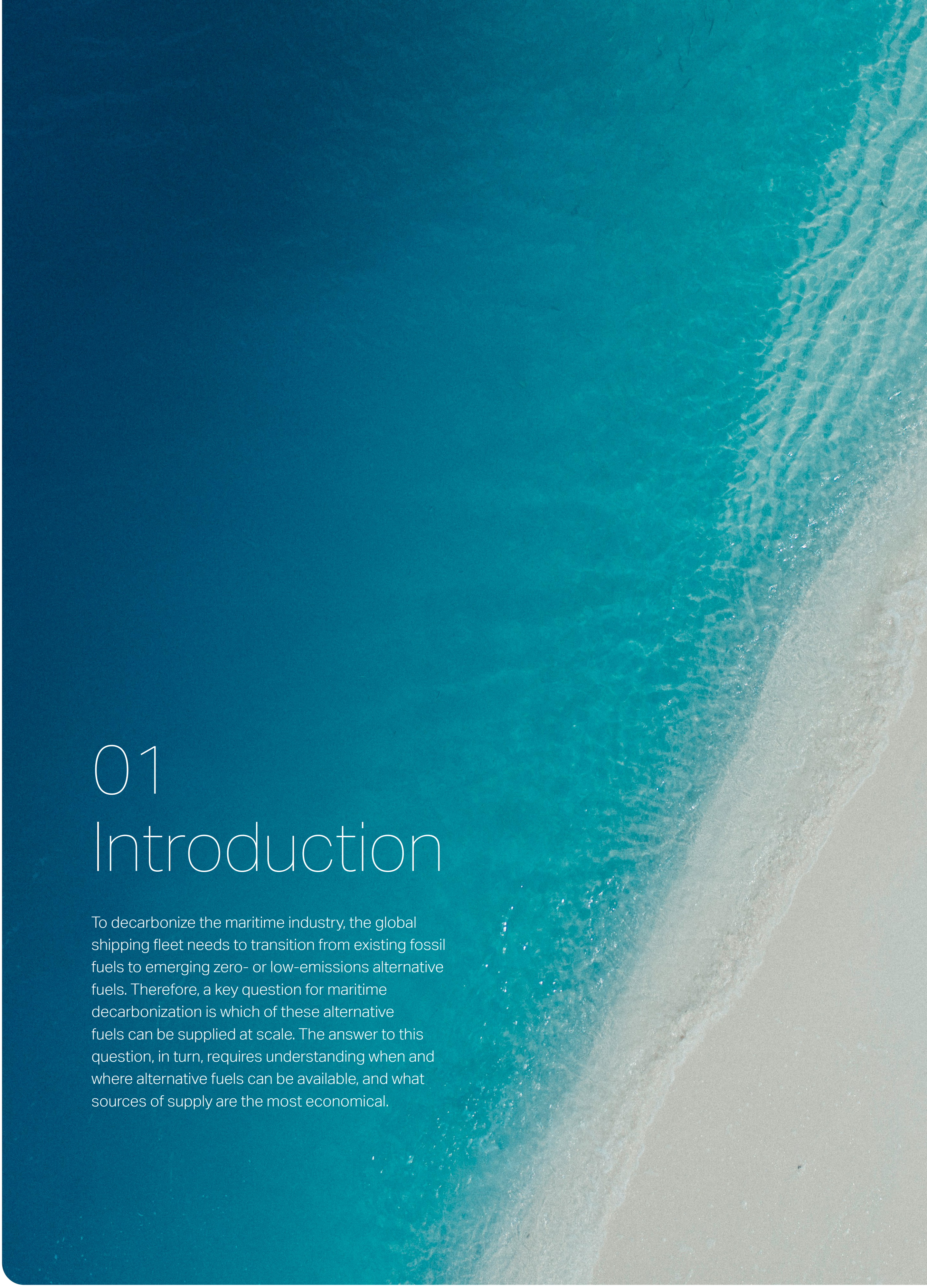
Our interviews with industry experts highlighted competition with CCS as a major barrier to accessing biogenic $CO_2$ for e-fuel production. Storage is perceived as a less-complicated option and is associated with better financial and regulatory incentives than $CO_2$ utilization. Therefore, e-fuel producers seeking to secure biogenic $CO_2$ supply may be well served by identifying contexts where carbon storage is less prevalent or attractive. Regulatory incentives to balance the incentives for storage, and/or market mechanisms such as book and claim systems for $CO_2$, could also support better e-fuel availability.

Another challenge identified in interviews is the comparative lack of appetite among a segment of pulp mill owners, who emit large volumes of biogenic $CO_2$, to engage with offtake for e-fuel production. This may be partly driven by the attractiveness of CCS, as previously mentioned. Other factors include lack of awareness of fuel markets by some emitters, a lack of regulatory incentives, and the risks associated with contractual obligations and investment in carbon capture technology. Regulators and potential offtakers will need to be aware of these barriers and lend support to new business frameworks or other measures that can offset the risks to the $CO_2$ supplier.

Looking to the future, the aviation industry is likely to be a competitor for biogenic $CO_2$ and/or e-fuels in the medium term. However, technologies for some maritime-relevant e-fuels (e-methane, e-methanol) are more mature in comparison to jet fuels, for now and in the near future. In the longer term, industry stakeholders expect the petrochemicals sector to emerge as a major competitor for renewable carbon.

Overall, we expect carbon-containing e-fuels to play a meaningful role in the decarbonization of the shipping industry. However, while the global availability of biogenic $CO_2$ is sufficient to meet near-term regulatory targets, this feedstock can be challenging to access and has a time-limited availability. Therefore, we urge investors and developers to secure the supply of biogenic $CO_2$ to support maritime decarbonization while the opportunity to do so exists.





# 01 Introduction

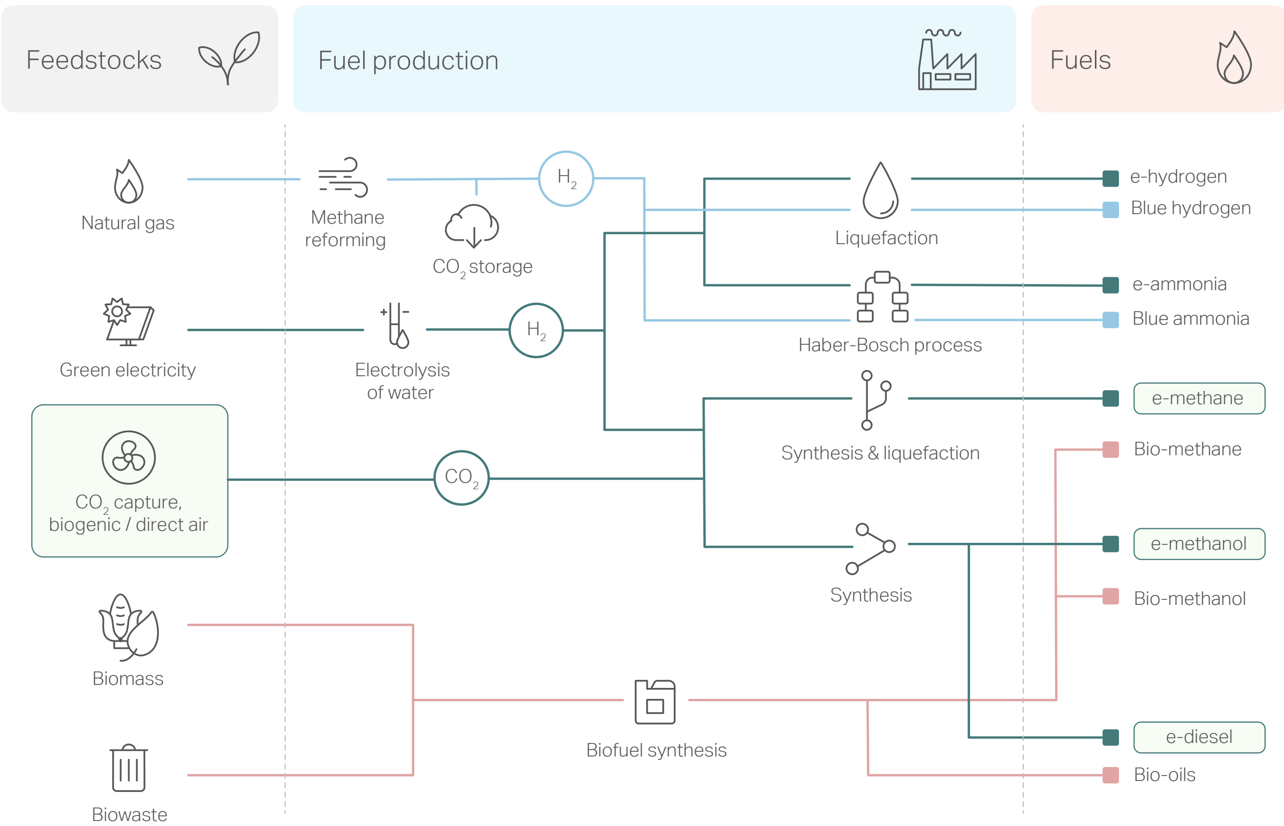
To decarbonize the maritime industry, the global shipping fleet needs to transition from existing fossil fuels to emerging zero- or low-emissions alternative fuels. Therefore, a key question for maritime decarbonization is which of these alternative fuels can be supplied at scale. The answer to this question, in turn, requires understanding when and where alternative fuels can be available, and what sources of supply are the most economical.

Previous work by the Mærsk Mc-Kinney Møller Center for Zero Carbon Shipping (MMMCZCS) has established that carbon-containing electro-fuels ('e-fuels') will be required as part of the mix of alternative fuels needed to decarbonize shipping, alongside ammonia and biofuels (Figure 1).[1] These carbon-containing e-fuels include e-methane, e-methanol, and e-diesel. Such fuels can function as a convenient, dense, and transportable form of energy from e-hydrogen, which may become plentiful in the future.[2]

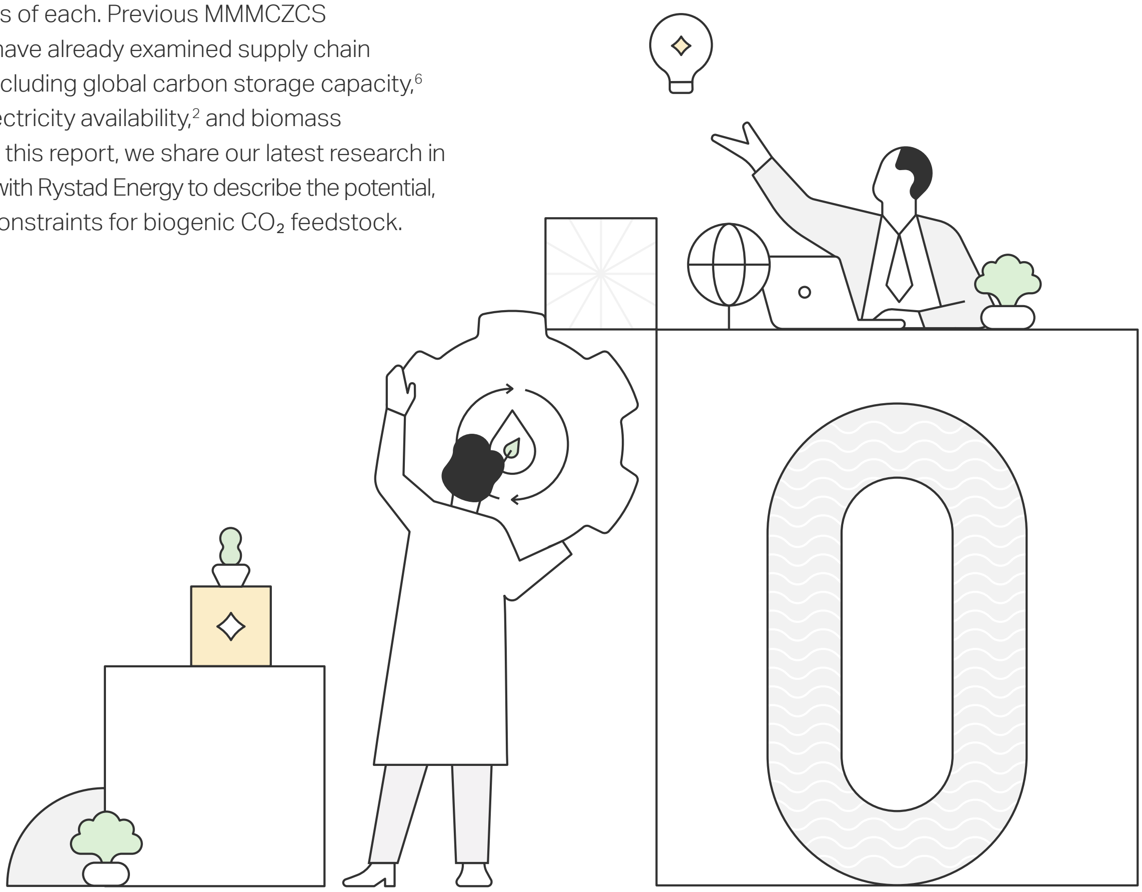
In a shipping context, the onboard technologies and standards for using these fuels already exist; therefore, it is technologically feasible to begin using these fuels in ships today. To illustrate, e-methane could be used in existing ships fueled by liquefied natural gas (LNG), e-methanol could fuel ships already ordered as methanol-ready, and e-diesel could act as a pilot fuel or a drop-in replacement for conventional fuel oil.[3] While biofuel counterparts (i.e., bio-methane and bio-methanol) will likely be the first supply source for zero-carbon fuels, their availability will be constrained by biomass availability and competition for fuels from other sectors.[4,5] Therefore, e-fuels will become an important supplement in the course of shipping's green transition.

Importantly, carbon-containing e-fuels require carbon as a feedstock for their production. Among the options for renewable carbon feedstocks, biogenic carbon dioxide ($CO_2$) is relatively lower-cost, accessible, and scalable in the near term. However, since biogenic $CO_2$ is too scarce to provide for full maritime decarbonization alone, we need to understand both the potential global supply of this feedstock and the challenges in accessing it. In this way, we can make an informed assessment of how far carbon-containing e-fuels can drive the transition, and how different stakeholders can optimize drivers and constraints in the supply chain.

Figure 1: Summary of key alternative fuel pathways for the shipping industry. The carbon-containing e-fuels, as defined by their critical feedstock of captured $CO_2$, are highlighted in green.



Carbon-containing e-fuels are not the only alternative shipping fuels that present supply chain constraints. Since many fuel types will need to be activated to decarbonize the industry, it is important to examine the challenges of each. Previous MMMCZCS publications have already examined supply chain constraints including global carbon storage capacity,[6] renewable electricity availability,[2] and biomass availability.[5] In this report, we share our latest research in collaboration with Rystad Energy to describe the potential, drivers, and constraints for biogenic $CO_2$ feedstock.



## 1.1 What is biogenic $CO_2$?

Biogenic $CO_2$ generally refers to any $CO_2$ originating from biomass or bio-based products. In the context of sustainable decarbonization using e-fuels, in this study we more specifically assume that biogenic $CO_2$ must be the waste product of an industry whose main product results from transforming biomass to $CO_2$. The scope of this study includes industries such as biomass power (including thermal power, electricity, or both), bio-ethanol, pulp mills, waste to energy (fractionally biogenic), and biogas (albeit small). We did not include future potential $CO_2$ sources, such as possible emissions from alternative biofuel production.

Beyond introducing a sustainability requirement, our definition of biogenic $CO_2$ also helps to distinguish between e-fuels' and biofuels' separate constraints on carbon feedstocks. Whereas biofuel pathways start with biomass as the feedstock, e-fuel pathways use $CO_2$ that exists because another industry uses biomass with the intention of making another product. The $CO_2$ produced from biomass during these processes is most often a waste product. Such $CO_2$ is predominantly released at a single location or 'point source', such as a chimney. Point-source $CO_2$, which is tied to a given industry, is a more convenient source of $CO_2$ than capture from the atmosphere.

While biogenic $CO_2$ is an important feedstock, its availability is limited to the few industries that use biomass in production. This dependency on the existence of such an industry limits the geographies for sourcing biogenic $CO_2$. For example, biogas is produced predominantly in Europe and North America, though growing quickly in certain other regions.[7]

## 1.2. Why biogenic $CO_2$ is important for maritime decarbonization

Despite carbon's convenience as a carrier of hydrogen energy, there are limited $CO_2$ feedstock options that can be accounted as net carbon removals (and without imposing a $CO_2$ emissions burden on an industry product).[8] This carbon removal is required in order to avoid net-positive emissions, because combusting a carbon-containing fuel, such as methane or methanol, releases $CO_2$ again. In this way, carbon-containing fuels may contrast with other carbon-containing products such as plastics in certain applications, which may hold the carbon captive for a longer time.

Biogenic $CO_2$ represents a relatively low-cost option for sourcing $CO_2$ with zero greenhouse gas (GHG) intensity. Direct air capture (DAC) and direct ocean capture (DOC) are inherently more expensive than point-source capture, as the concentration of $CO_2$ is so much lower in the air or ocean than at a point source. Another option for sourcing $CO_2$ feedstock could be carbon removals that are required to offset the net emissions burden of products associated with fossil or industrial waste $CO_2$. However, this option is also expensive and sometimes paradoxical if carbon capture and storage (CCS) of the same $CO_2$ is possible.

Therefore, future suppliers and potential offtakers of biogenic $CO_2$ can benefit from better understanding the global availability of this resource. However, there have been few studies to date addressing this topic,[9,10] and even many biogenic $CO_2$ emitters are not yet aware of their role. Increasing understanding of biogenic $CO_2$ availability can both facilitate the provision of e-fuels for the maritime industry and shed light on how much decarbonization can be achieved via this fuel pathway.

## 1.3. About this project

This project was a collaboration between the MMMCZCS, our knowledge partner Rystad Energy, and our strategic partners Sumitomo Corporation, Mitsui, Maersk, and Topsoe. The MMMCZCS's mission ambassadors Ørsted, HIF Global, and Methanex, along with Flexens, Enertrag, OCI Global, and four additional anonymous e-fuel producers, also contributed to the project.

### Partners

RystadEnergy

MAERSK

MITSUI & CO.

TOPSOE

Sumitomo Corporation

### Mission Ambassadors

Ørsted

HIF

methanex the power of agility

### Participants

OCI Global

Flexens FLEXIBLE ENERGY SOLUTIONS

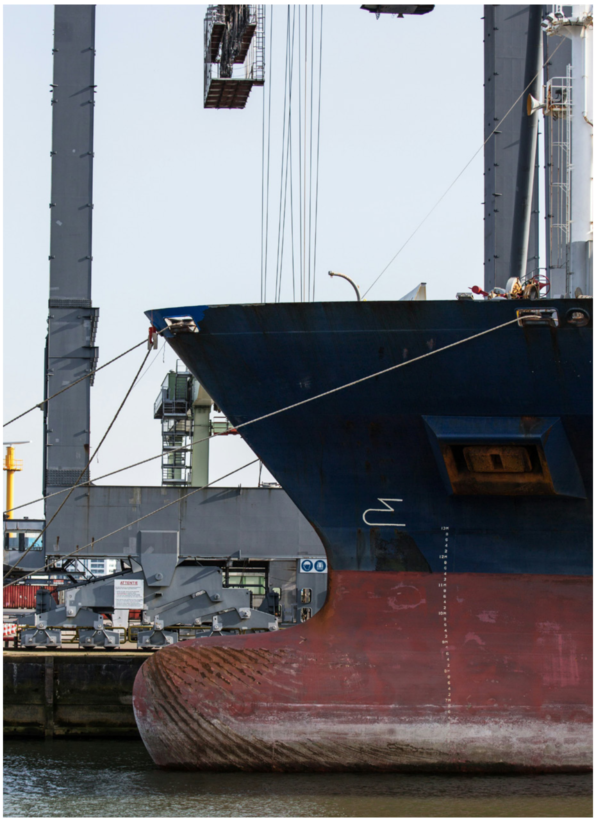
ENERTRAG One energy ahead

# 02 Methodology

## 2.1 Study objectives and approach

Our major objective for this study was a global assessment of the availability and cost of biogenic $CO_2$ as a feedstock for e-fuels. Knowledge of biogenic $CO_2$ availability helps with estimating global scale-up constraints and thereby the need for other alternative fuel pathways, while establishing a $CO_2$ cost baseline is useful for techno-economic assessment of e-fuels. As we chose to focus only on biogenic $CO_2$ availability, questions of access or proximity to sources of renewable electricity were outside the scope of this specific study. However, the supply of e-hydrogen based on renewable electricity is a critical consideration for the production of e-fuels and warrants further analysis.

Assessing the maximum potential volume available of biogenic $CO_2$ requires global point-source emissions data. To meet this need, Rystad Energy assembled both public and independently researched data to be used in this study. Rystad is a knowledge partner to the MMMCZCS and a leader in market intelligence.



To support the biogenic $CO_2$ cost baseline, we specifically considered costs for capture, transport, and aggregation. We aimed to assess baseline values that consider only these costs, and we did not attempt to model prices, which are generally higher and based on demand. These baseline costs, therefore, represent a lower threshold for full cost, to which other project-specific costs need to be added when evaluating more complete business cases for e-fuel production. Examples of such project-specific costs could include product logistics, overheads, labor, liquefaction and storage, and other expenses to guarantee continuous supply and offtake. Our approach of assessing capture and transport costs requires knowledge about the $CO_2$ concentrations for each emitter type, as well as their individual emissions volumes and relative transport distances.

To simultaneously evaluate both cost and volume, we constructed a supply cost curve. This curve can provide added insight into volume potential and cost forecasting, compared to simpler calculations of cost or volume alone. The supply cost curve construction entails approximating the cost for each global portion of biogenic $CO_2$, which helps us to avoid excluding $CO_2$ volumes solely for being too expensive or too small. Instead, each volume is included and categorized by how economical it is, enabling us to estimate economically constrained supply. The curve also represents a cost distribution, improving analysis of near- versus long-term costs.

The secondary objectives of our study were:

- To understand geographic locations with high availability of biogenic $CO_2$
- To understand which industries provide the most potential for economical $CO_2$ supply
- To understand market barriers to accessing this biogenic $CO_2$ commercially

Finally, we aimed to collect qualitative industry perspectives on trends and perceived tradeoffs in the biogenic $CO_2$ space, including whether other sectors and applications may outcompete the demand from the maritime industry.

## 2.2 Assumptions

Our supply cost curve depends on several assumptions. Importantly, we only consider present-day biogenic $CO_2$ in our analysis – that is, we do not forecast availability in future decades according to the growth or decline of industries.

Furthermore, we chose to use equipment-only cost estimates for $CO_2$ capture and transport, as if an e-fuel producer owned everything within battery limits. We have not accounted for the cost of $CO_2$ storage or liquefaction (which may be preferable for storage purposes). Such buffering will likely be implemented in many cases to sustain e-fuel production when $CO_2$ sources encounter downtime. This choice results in lower limit costs compared to full project-specific costs and real-world prices, which will also include profits, labor, permits, and contractual costs such as guarantee of supply.

However, to make the global estimate relevant to e-fuels, we do apply some constraints to volume and transport distance. Firstly, we set a minimum volume of aggregated $CO_2$ by assuming an adequate plant size of 1,000 metric tonnes per day (MTPD) of methanol production. This capacity is notably higher than that of most projects announced to date. However, we assumed that this limit was reasonable for the purpose of calculating more optimistic future e-fuels costs, as smaller plants produce significantly more expensive methanol due to losing economies of scale.[1] We also verified that decreasing this limit to 500 MTPD did not exclude a significant amount of further global volume (about 6%), in part because our methodology enables the interconnection of smaller sources.

Secondly, we assumed transport distances of no more than 200 km when combining emitters smaller than the threshold volume, based on the assumption that small emitters would not achieve (1) economic payback on costs of $CO_2$ transport over longer distances or (2) environmental payback on the emissions from establishing transport infrastructure.

For a fuller list of assumptions in our analysis, please refer to the Appendix.

* Based on a low average capture cost and low transport cost.

## 2.3 Methodology

As previously described, Rystad Energy assembled a global dataset of biogenic $CO_2$ emissions point sources. We carried out a geospatial analysis of these data using an algorithm that forms clusters of individual emitters that aggregate their $CO_2$ at a spatial center where a carbon-containing e-fuels plant could theoretically be located. The algorithm:

1. Searches for the lowest-cost site in the list,
2. As long as the site is still not big enough, finds the next cost-optimal* site to connect to,
3. Repositions the $CO_2$ collection hub at the center of the connected sources,
4. Records the total $CO_2$ volume and total cost for each collection hub, and
5. Repeats the above steps globally until all global point source emissions have been evaluated for assignment to a $CO_2$ collection hub.

An example of the output of this analysis is illustrated in Figure 2.

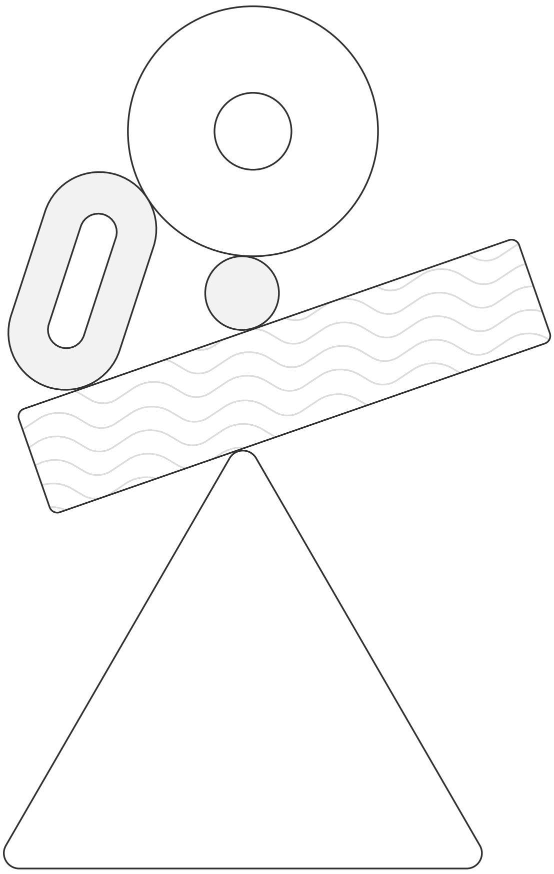
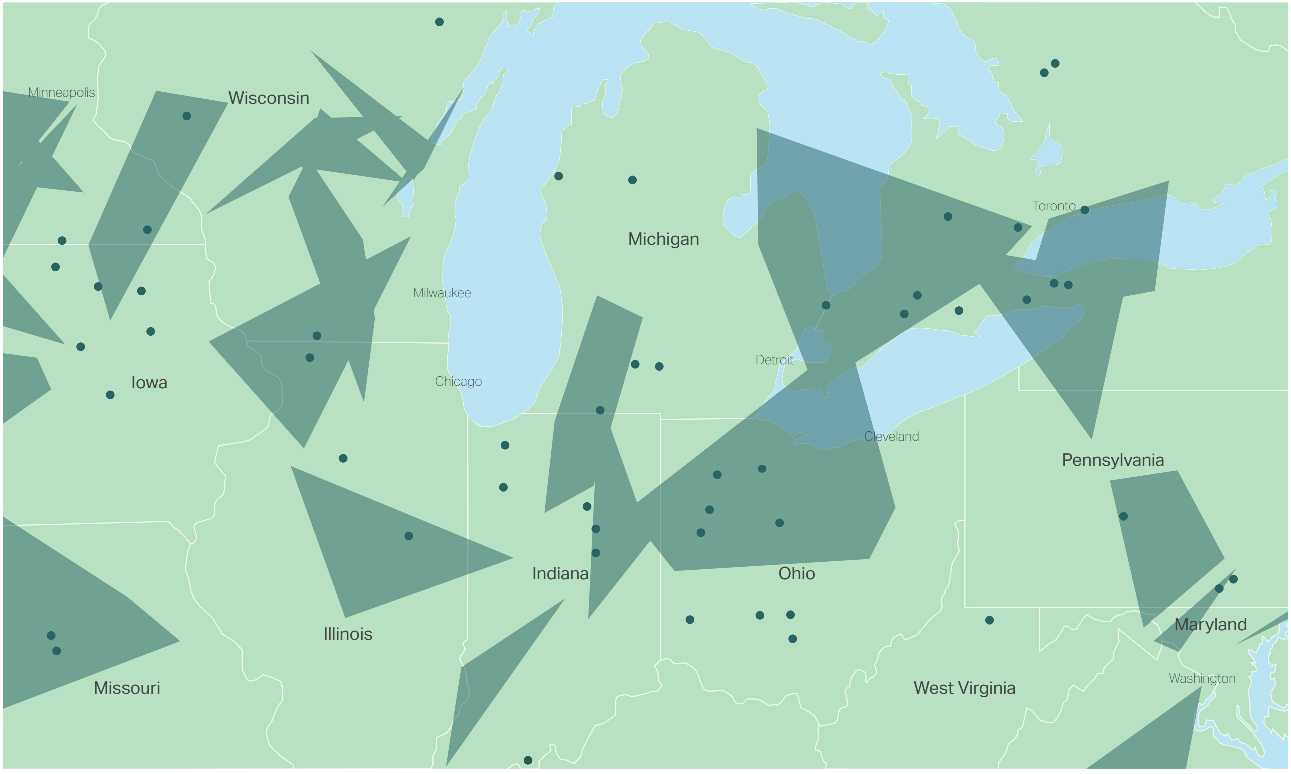


Figure 2: Example of applying our geospatial methodology to biogenic $CO_2$ point sources in a selected region. The $CO_2$ collection hubs comprise single point sources (small dots) with sufficient scale of emissions and aggregated sites (polygons) formed by interconnecting point sources smaller than the emissions threshold.



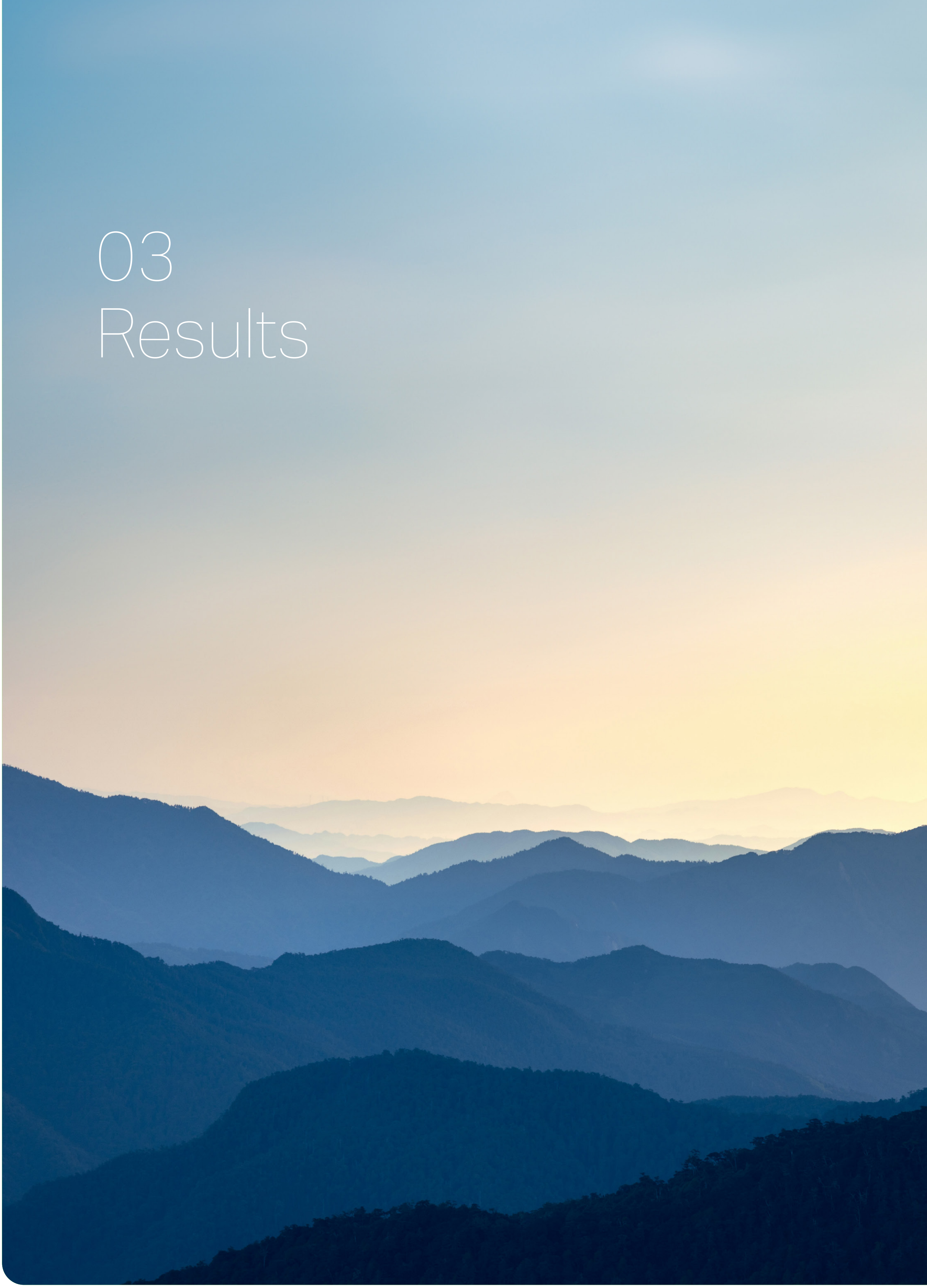

As some regions have incomplete or unreported emissions data, we attempted to approximate a more complete global $CO_2$ volume estimate by extrapolating $CO_2$ emissions from market data for geographies where data quality appeared to be weaker. In these cases, we focused only on the industry that contributes most dominantly to the reported global emissions of biogenic $CO_2$. As described later, this means that we selected the pulp mill market as the basis for extrapolation, as it was the dominant contributor in relevant regions.

Specifically, we identified that the South American and Asian regions were possibly missing data, since the ratio of emissions to pulp production was lower there in comparison to Europe and North America.[11,12] Therefore, we rescaled the emissions from those regions according to the size of each regional pulp industry, using a factor of 2.0 million tonnes $CO_2$ per million tonnes of pulp.* To this additional estimated $CO_2$ volume, we applied our $CO_2$ capture rate assumption, and we furthermore applied the fraction of volume exclusion that our algorithm found for each region, as a result of applying the volume and distance constraints.

To supplement our understanding of the relevant economics beyond our purely cost-based model, we interviewed significant stakeholders in the carbon-containing e-fuel value chain. Our intention was to gain a better informed and aggregated understanding of the trends, drivers, challenges, and prices that might be expected in real-world projects. The stakeholders we interviewed comprised ten e-fuel developers, two large industrial firms within the e-fuel value chain, and three independent agencies advising on the energy transition.

* A factor of 2.5 million tonnes would be a maximum; in many cases, a value closer to 2.0 is more accurate, based on different varieties of wood feedstock and different methods of pulp production, such as 'fluff pulp' used for hygiene products.

# 03 Results



## 3.1 Geospatial analysis and supply cost curve

The algorithm described in Section 2.3 produced a supply curve (Figure 3) showing the biogenic $CO_2$ cost for each of 360 potential cluster sites, each of which could supply $CO_2$ to theoretical e-fuel plants. These sites correspond to a global $CO_2$ volume of more than 320 million tonnes per year. Of note, our algorithm excludes almost 185 million tonnes per year (from a total of 510 million tonnes per year) via our decision to apply a maximum transport distance restriction of 200 km between sites with emission volumes lower than the set threshold (1,000 MTPD methanol). Lowering the plant size threshold to 500 MTPD has a small effect, since the estimate for larger plant sizes already includes most of the same point sources due to allowing aggregation by interconnections. We furthermore found that much of this volume difference (approximately an extra 20 million tonnes per year) could be reincorporated into our baseline estimate of availability, if we allow the collection hubs to include significant point sources located within 50 km of each formed collection site. Including this additional volume extends our estimate of availability above 340 million tonnes per year (see also Figure A2 in the Appendix).

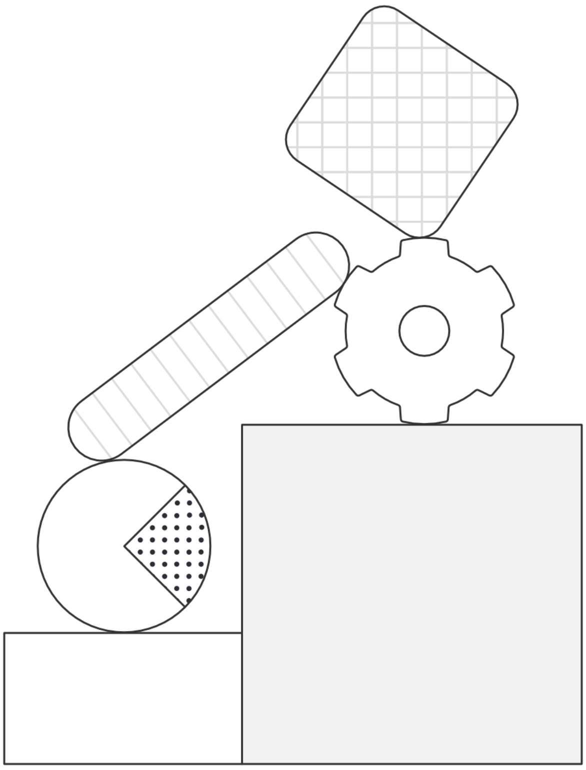
As mentioned in Section 2.3, we adjusted the estimates for South America and Asia based on the likelihood that data were missing from these regions. After this adjustment, we estimate that South America could have an additional 7 million tonnes per year of biogenic $CO_2$ and Asia an additional 18 million tonnes per year – bringing the total range of global potential volume up to nearly 370 million tonnes per year.

Figure 3 shows the supply cost curve for each cluster's volume of $CO_2$. Figure A3 in the Appendix shows a similar curve plotted by number of sites instead of by volume.

The average cost for capture and transport of $CO_2$ for each site ranges from 50 USD to 175 USD per tonne. The transport cost in most lower-cost sites is zero, because many single-source emitters are already large enough to supply an e-fuel plant at or above our selected size threshold. In principle, a chemical plant could choose to be at the same site as the point source, thereby avoiding the need for distribution networks.

In our interviews with ten global e-fuel producers, we received consistent feedback that the costs for capture and transport shown in our supply cost curve are considerably lower than the full costs of $CO_2$ supply observed by industry in planning real projects. Since our intention was to represent a baseline low cost, our analysis knowingly neglects significant influences on full costs that would need to be added according to the design selection of a specific e-fuels project, including:

- Costs beyond equipment capital expenditure (CapEx) or operational expenses (OpEx).
- Costs related to creating a $CO_2$ storage buffer, which may often be needed to mitigate the risk of interrupted $CO_2$ supply. Therefore, many e-fuel projects will require costly and space-consuming local storage, in addition to the expensive liquefaction equipment and process to feed into this storage.
- Mark-ups or other possible project costs such as labor, land, or permitting.

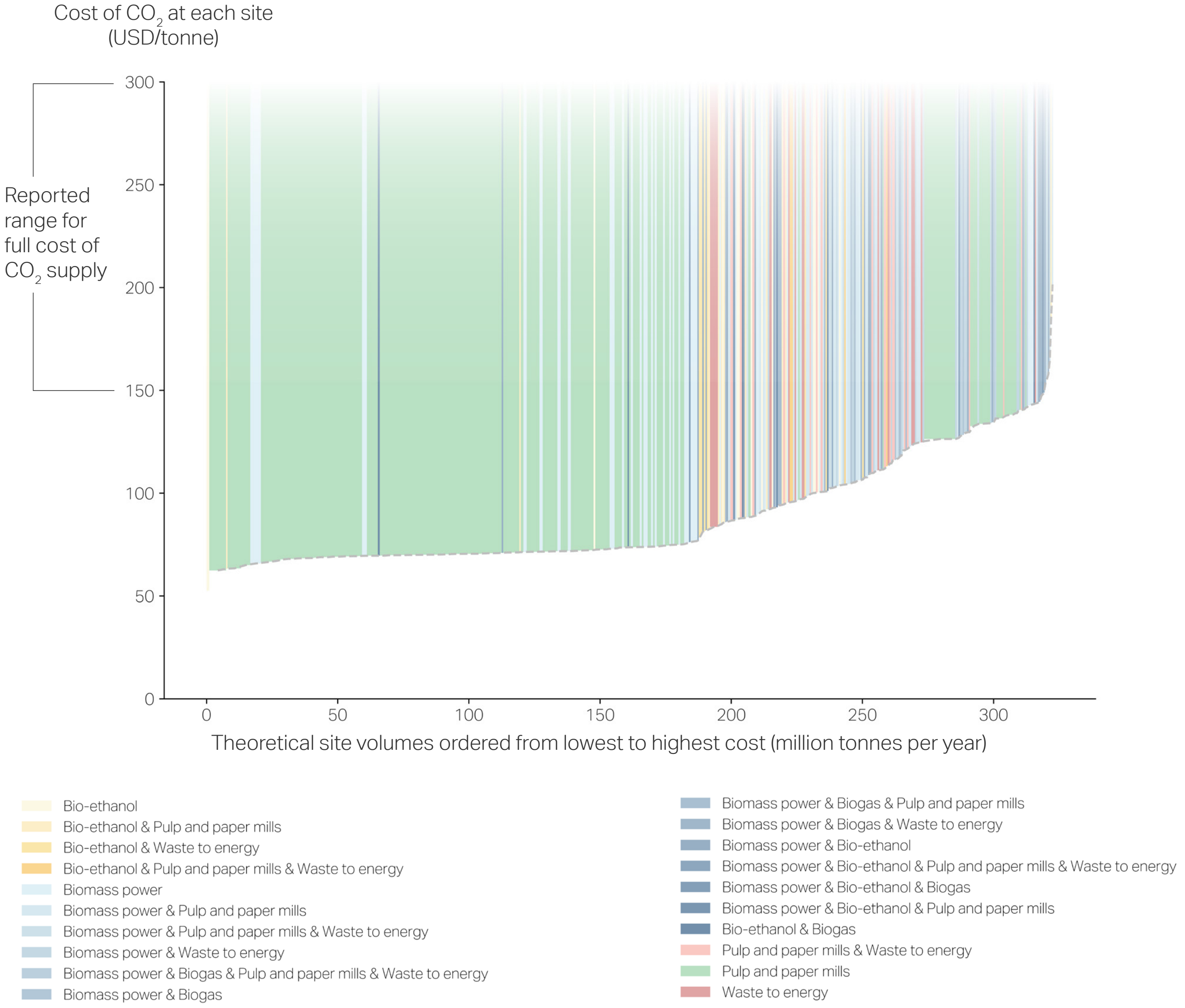


- Additional costs for $CO_2$ offtake, which will need to be negotiated since e-fuel producers generally do not own the full scope of supply (including the $CO_2$ source).
- Costs for transport of the e-fuel product (e.g., to a port). It is a project-specific decision whether to:
  a. Produce e-fuel close to the $CO_2$ source and transport the final product (e.g., by ship, train, truck, or pipeline), or
  b. To transport the $CO_2$ feedstock to a production facility near a port for subsequent e-fuel production.

Furthermore, we have assumed commonplace, optimized industrial systems, but current-day projects usually require tailor-made solutions because the market is new.

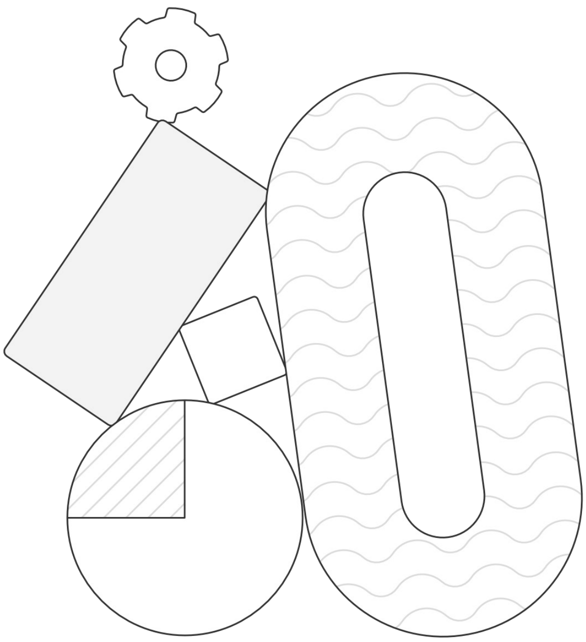
Interviewees reported that current unsubsidized cost estimates for $CO_2$ are closer to the 150-300 USD per tonne range (see 'reported range for full cost of $CO_2$ supply' indicated in Figure 3). Further, typical near-term costs, including transport costs, would not fall below 100 USD per tonne. However, these costs could be lowered by the effects of regulatory policy, or by opportunities where the costs of e-fuel production are covered by the public, such as through subsidies or offtake from state-owned emitters.

Figure 3: Cost of capture and transport, for each portion of global biogenic $CO_2$ volume, labeled by industry sector. For comparison, the range of reported full costing of $CO_2$ supply is indicated to the left of the Y-axis.



## 3.2 Biogenic $CO_2$ availability by industry

Our industry-level findings lead to several observations relevant to the questions of where to find biogenic $CO_2$ and how supply can be scaled up. Pulp and paper mills (green in Figure 3) appear to dominate among the low-cost $CO_2$ supply contributions, i.e., as the sector that could provide biogenic $CO_2$ that is simultaneously low in cost and high in volume (see also Figure A4 in the Appendix). These mills offer access to large amounts of waste biomass, as approximately half of the biomass present at the site ends up in the pulp, while the other half can be used for power production. Our dataset contains many examples of point sources where a single pulp mill provides a sufficient volume of $CO_2$ to supply a large-scale e-fuels plant without the need to transport additional $CO_2$ from other sources.



Biomass power plants (blue in Figure 3) could also be a significant contributor of biogenic $CO_2$, albeit usually at a higher cost than for pulp mills. This industry is characterized in our dataset by a very high count of individual point sources. However, most of these are small, which results in either an increased $CO_2$ cost or exclusion from the total $CO_2$ volume in our analysis. Therefore, only the higher-volume biomass power sites present effective opportunity for economical supply of biogenic $CO_2$.

The bio-ethanol industry (yellow in Figure 3) may provide the lowest-cost opportunities to source biogenic $CO_2$, but this source is relatively scarce. The greatest volumes are in South America and the US. The high $CO_2$ concentration available at bio-ethanol sites results in lower costs and sometimes a complete absence of $CO_2$ capture costs – that being said, we have assumed a stream concentration of less than 100% $CO_2$, in part because there are other, more dilute, streams on site. On the other hand, many of the individual plants are small, creating a need for $CO_2$ aggregation. Furthermore, industry stakeholders noted in interviews that first-generation biofuels can be challenged by sustainability criteria, especially if land use change is involved, and so might not be available as a long-term source of $CO_2$.

The waste-to-energy sector (red in Figure 3) generally offers higher costs and somewhat less global volume than the other industries in our dataset; however, some individual sites from this sector can provide opportunities at the lower end of the cost spectrum.

Finally, biogas plants (no specific color in Figure 3)* represent a tiny fraction of the global total. These sites are associated with low volumes of $CO_2$ and, therefore, high transport costs.

* The lack of specific color for the 'biogas' category is due to the small volumes of these point sources, which results in them always being combined with $CO_2$ from at least one other sector in order to meet our defined volume threshold.

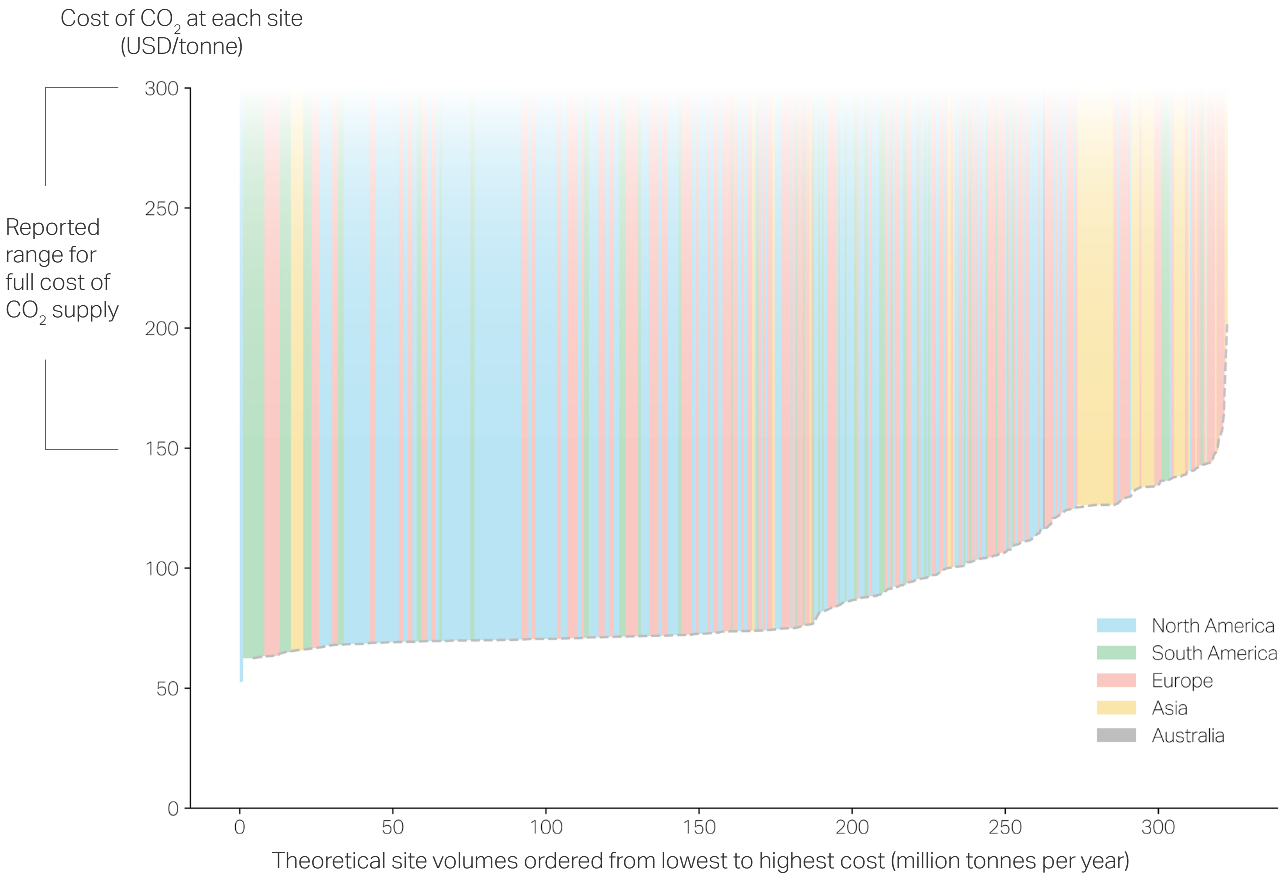
## 3.3 Biogenic $CO_2$ availability by region

One of our secondary objectives was to understand which geographic regions have high availability of biogenic $CO_2$. Figure 4 shows our supply cost curve labeled by geographic region rather than by industry sector.

Figure 4 shows that the majority of biogenic $CO_2$ volume is located in Europe (red in Figure 4) and the Americas (blue and green in Figure 4). These regions exhibit potential for similarly low-cost $CO_2$ supply. All have significant volumes of pulp and paper, but South America has a higher proportion of potential from bio-ethanol.

The Asian region (yellow in Figure 4), including China, also contributes significant volumes of biogenic $CO_2$ in our dataset. However, some project participants expressed surprise to find that the overall contribution from this region is less than 10% of the global total volume of biogenic $CO_2$. China does host some large $CO_2$ emitters and was the second-largest producer of pulp for paper production in 2022.[12] However, while the potential for the region is significant, we found that many biogenic $CO_2$ point sources in Asia are smaller and separated by longer distances in comparison to other regions.

Figure 4: Cost of capture and transport, for each portion of global biogenic $CO_2$ volume, labeled by region. For comparison, the range of reported full costing of $CO_2$ supply is indicated to the left of the Y-axis.



# 04
# Discussion

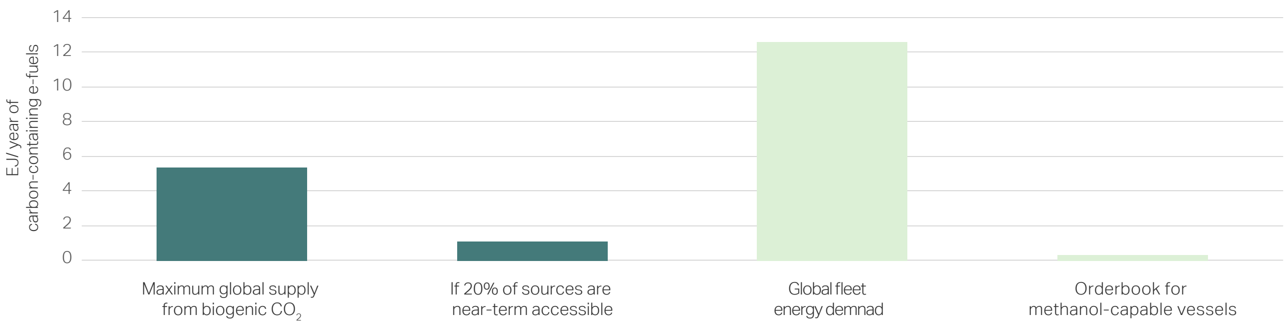
## 4.1 Near- and long-term supply of biogenic $CO_2$

All in all, we found that the point sources in our dataset can supply enough biogenic $CO_2$ to provide for a total of 360 hubs. This implies scope for an equivalent 360 e-methanol, e-diesel, or e-methane plants that could produce volumes of e-fuel above our selected capacity threshold of 1,000 MTPD methanol equivalent. Most of this $CO_2$ is not economically accessible in the near term, because investments in e-fuel production are justifiable only if the $CO_2$ emissions sources have a significant operational lifetime remaining. Typical feedback from our interviews was that, in the absence of subsidies, a remaining operational lifetime of under 20 years would make it difficult to justify investment in $CO_2$ capture and transport, as well as in renewable electricity and electrolyzers.

Despite the possibility of such limitations on bankable cases, even 20% of the sources in our dataset would enable the production of more than 1 EJ equivalent of e-methanol, e-diesel, or e-methane (Figure 5). This 1 EJ of e-fuel could decarbonize 8% of the global fleet[3] and is sufficient to meet near-term targets considering the ambitions of the International Maritime Organization (IMO) and the FuelEU Maritime regulation.[13,14] Furthermore, this energy is more than enough for the needs of the methanol-capable vessels currently on order (Figure 5). Therefore, even if we assume that only 20% of the $CO_2$ sources analyzed in this study have enough operational lifetime remaining to provide adequate payback over time, this biogenic $CO_2$ can make a significant contribution to near-term maritime decarbonization.

Taking a longer-term view, we do not foresee that full decarbonization of the maritime industry can be achieved with carbon-containing e-fuels alone. In our analysis, we estimate a current global potential biogenic $CO_2$ capacity of nearly 370 million tonnes per year with relevance to large-scale e-fuel production. As described in Section 3.1, this figure is calculated based on a raw algorithmic result of 320 million tonnes per year, plus 25 million tonnes per year from extrapolations for the regions with probable gaps in data, plus an additional 20 million tonnes per year from point sources that lie within 50 km of the simulated site but had been excluded due to minimizing net $CO_2$ cost (see also Figure A2 in the Appendix). Assuming that this entire 370 million tonnes per year could be economically accessible, this volume of $CO_2$ could be used to produce 5.4 EJ equivalent of methanol (see Figure 5). This figure is significantly less than the 12.6 EJ of energy that shipping requires today[1] – and energy demand from shipping is expected to grow further between now and 2050. Put another way, even if all available biogenic $CO_2$ were to go to shipping, producers could only supply enough carbon-containing e-fuel to decarbonize about 43% of the world fleet. Therefore, other fuel pathways – such as biofuels and ammonia for deep-sea shipping, and batteries or possibly hydrogen for short-sea – will be essential for shipping's decarbonization.

Figure 5: Comparison of the potential maximum supply of carbon-containing e-fuels from biogenic $CO_2$ versus reference scales of demand from the maritime industry.



In addition, this gap between biogenic $CO_2$ volume and shipping's energy needs does not take into account several important limitations on $CO_2$ availability. Such limitations include the demand for biogenic $CO_2$ from other industries (e.g., aviation, road transport, CCS, and chemicals), the time lag for scaling infrastructure to capture and transport large volumes of $CO_2$, and the need to access $CO_2$ with accepted contractual terms for continuously reliable supply over a long period. In particular, the demand from other industries implies that other sources of carbon (e.g., DAC or biomass) will be needed to provide sufficient carbon-containing e-fuel for even one of these industries.

## 4.2 Understanding drivers and barriers regarding pulp and paper

In our analysis, the pulp and paper industry emerges as the leading source for potential biogenic $CO_2$ supply. Therefore, it is important to understand more about this sector and what characteristics make it such an important contributor.

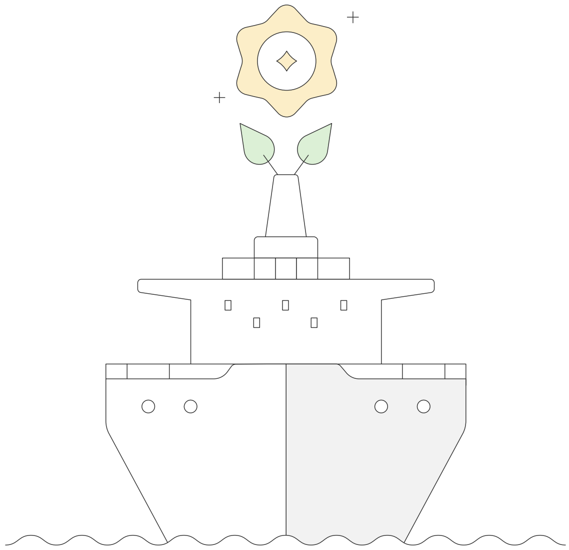
### 4.2.1 Insights into the pulp and paper industry

Industry interviewees generally agreed that pulp mills contribute extensively to the global volume potential for biogenic $CO_2$, especially among the lower-cost sources. When producing chemical pulp for paper, more than half of the biomass input is not part of the pulp yield. This unused portion becomes the eventual source of biogenic $CO_2$. In the Kraft pulp process used for around 80% of the world's pulp production,[15] a complicated series of treatments recovers the dissolved biomass that cannot be used in pulp, transforming it into 'black liquor'. The black liquor is incinerated for power generation, releasing large volumes of biogenic $CO_2$. According to Jyrki Ovaska, a retired executive and former Chief Technology Officer of a leading global forest products company, state-of-the-art pulp mills are self-sufficient in energy and have surplus biopower capacity of up to 100 MW. This power is used by the forest products company itself or sold to the national power grid.

In considering this sector, paper production should be differentiated from pulp production. Standalone paper production is itself a net consumer of power – and this power normally does not yield biogenic $CO_2$. The production of paper and board consumes significant power and heat, which may or may not come from biomass, according to Ovaska. In addition, the presence of paper production in one geography does not necessarily imply local biogenic $CO_2$ supply, as pulp can be exported for production into the final paper product. Nevertheless, integrated mills producing both pulp and paper can have an excellent energy balance, because the heat and power produced by the pulp mill can be used on site.

Increasingly large new pulp mills have raised the number of single sites that could provide adequate volumes of biogenic $CO_2$ for e-fuel production. According to interviews, the industry has seen a trend of building newer and larger plants, as older and smaller plants are gradually retired. The newest pulp mills are normally standalone and not integrated with paper production, according to Ovaska. This means that much of the $CO_2$ volume from pulp and paper production does not require any transport at all, as single sites can provide sufficient volume for an economically sized e-fuel plant.

Interviews also pointed to changing market drivers of paper production. For instance, while use of publication paper has declined, the industry has seen growing demand for hygiene products and for packaging applications such as e-commerce deliveries. Taking a geographical perspective, the main Kraft pulp geographies have traditionally been Europe (especially Sweden and Finland), the US, and Canada. However, production in Indonesia and in South American countries (Brazil, Uruguay, and Chile) have grown in recent decades.



## 4.2.2 Challenges for e-fuel production

Most interview respondents noted difficulties in accessing $CO_2$ from the pulp mill sector, due to industry characteristics or supply challenges that make it difficult to reach acceptable prices and contractual terms. Pulp mill owners are perceived to be comfortable with their current business models and unaccustomed to joint ventures, alliances, or other arrangements deviating from normal business. As previously touched on, pulp mills are often optimized for their heat balance and energy consumption, so adding $CO_2$ capture equipment to the setup is viewed as adding risk to operations – even if capturing $CO_2$ from flue gas chimneys will not materially affect the pulp mill's key processes.

Pulp mills generally prefer to operate steadily and without stoppages, implying a steady supply of $CO_2$. However, planned and unplanned stoppages can occur. According to feedback from interviewed e-fuels producers, this can be another reason why the pulp industry is reluctant to engage in offtake contracts. Pulp mill owners may need risk mitigation or co-investment to balance the costs and risks associated with investing in high-CapEx $CO_2$ capture equipment that depends on decades-long returns to justify the business case. This challenge could be addressed through new business models to accommodate risk aversion, such as co-investment arrangements or $CO_2$ brokering.

Unlike the ethanol industry, which produces fuel itself, pulp producers can be unfamiliar with fuel markets and with the drivers for e-fuels in particular. Therefore, some producers may be skeptical about the value of their biogenic $CO_2$. Interviewees pointed to regional variations in pulp producers' readiness to engage with fuel production. Therefore, efforts to raise awareness of fuel production opportunities may be needed to accelerate investments for e-fuels development.

Finally, the state of the broader $CO_2$ 'market' may also challenge access to $CO_2$ from pulp and paper. For example, pulp mills are not immediately incentivized to capture or sell their biogenic $CO_2$, because they are not penalized for emitting it. Hence, appropriate policy incentives could help promote biogenic $CO_2$ capture. Even with such incentives in place, however, pulp mill owners may be cautious in committing to offtake for e-fuels production. Among owners who are interested in gaining extra profits by contracting $CO_2$ offtake, subsidies for CCS may be perceived as a safer and less disruptive option than contracting with e-fuel producers.

Despite these challenges, the pulp and paper industry could offer opportunities for biogenic $CO_2$ supply to the maritime industry. Advisory agencies interviewed believed that the pulp industry's reluctance to engage with $CO_2$ capture will need to be adjusted in the future as $CO_2$ accessibility gains importance across multiple sectors. In addition, certain locations may move faster if pulp mills are close to an existing $CO_2$ pipeline that can be used for supply by mass-balance. Importantly, interviewees also highlighted the importance of matching biogenic $CO_2$ feedstock with a cost-effective supply of green hydrogen. That is, biogenic $CO_2$ can only be used to produce e-fuels if there is also sufficient incentive to install renewable electricity and electrolyzers.

## 4.3 Insights into market trends and drivers

All interviewees expressed that understanding biogenic $CO_2$ availability was crucial to better describe the potential for decarbonization through e-fuels and relevant decarbonization strategies for different sectors. Overall, the feedback from interviews was that the challenges to accessing biogenic $CO_2$ are different in the near and long term.

### 4.3.1 Utilization versus storage of biogenic $CO_2$

One of the emergent themes from our industry interviews was the consistent concern regarding competition between utilization of $CO_2$ for e-fuel production versus $CO_2$ storage for credits. CCS, or the practice of permanently sequestering captured $CO_2$, is supported by many current infrastructure projects that aim to support decarbonization of various industries.[6] Storage of captured $CO_2$ is an attractive choice because it is associated with a financial incentive – i.e., the possibility of either gaining a subsidy or avoiding a tax, depending on whether the stored $CO_2$ is of biogenic or fossil origin. Advisory agencies also pointed out that CCS appears to be a more efficient option with a lower margin abatement cost; that is, CCS can reduce more atmospheric $CO_2$ per dollar invested than $CO_2$ utilization.

Both commercial consultants and independent advisory agencies lamented the possible environmental harm caused by not directing biogenic $CO_2$ towards end uses with high payback for the climate. According to these stakeholders, CCS of biogenic $CO_2$ could potentially have a greater positive impact on decarbonization than using this $CO_2$ to make e-fuels that are subsequently burned into $CO_2$ again. From a global perspective, they pose the view that broader decarbonization could be achieved more efficiently via short-term continued use of maritime fossil fuels paired with offsetting of global emissions via CCS of biogenic $CO_2$.

E-fuel project developers and investors also saw $CO_2$ storage as the single largest competitor for utilization in e-fuel production. Some called for a $CO_2$ book and claim system to allow the physical decoupling of $CO_2$ production and consumption. In brief, a book and claim system is a method of accounting for two products that can be virtually swapped, thereby supporting both economic trade and environmental incentives.[16] Such a system for $CO_2$ could enable e-fuel projects to use fossil $CO_2$ sources where large volumes are available, in exchange for potentially paying for $CO_2$ storage elsewhere. Some developers mentioned the need for future $CO_2$ pipelines to improve access to feedstock for e-fuels. In particular, making such pipelines open-access (as is currently the case for natural gas grids) would relieve the expenses and risks of contracting for private pipelines.

Almost all industry players described the ability to secure $CO_2$ for e-fuels being challenged by competing demand for CCS subsidies. While one interviewee expressed skepticism that the demand for biogenic $CO_2$ storage credits could be as large as many millions of tonnes, all others believe that credits and subsidies will be the major source of competition for access to biogenic $CO_2$. In general, the costs and barriers for

CCS today are lower than those for $CO_2$ utilization. Interviewees noted, for example, that the cost of $CO_2$ storage is low relative to the investments needed for e-hydrogen infrastructure required for e-fuel production, and that contracts for $CO_2$ removal typically last only a few years. Especially due to the novelty of the e-fuels market, lending institutions reportedly require long offtake durations to secure the payback on their investments in the e-fuels value chain (e.g., chemical plants, wind and solar farms, electricity distribution, electrolyzers).

Furthermore, CCS is being driven by more attractive policies (e.g., in the European Union and US) and by corporate sustainability targets. For example, the US Inflation Reduction Act 45Q subsidizes both $CO_2$ storage and utilization, but the subsidy for utilization is lower. However, one interviewee expressed that this subsidy gap of 15-25 USD/tonne could be overcome by willingness to pay. According to industry sources, regulators who want $CO_2$ to be utilized for e-fuel production may need to implement more attractive subsidies that can balance against the demand for storage. At the same time, large companies are reportedly paying extraordinarily high prices for $CO_2$ removal offsets – sometimes bidding against themselves for the biogenic $CO_2$, as they attempt to source carbon-containing e-fuels at the same time.

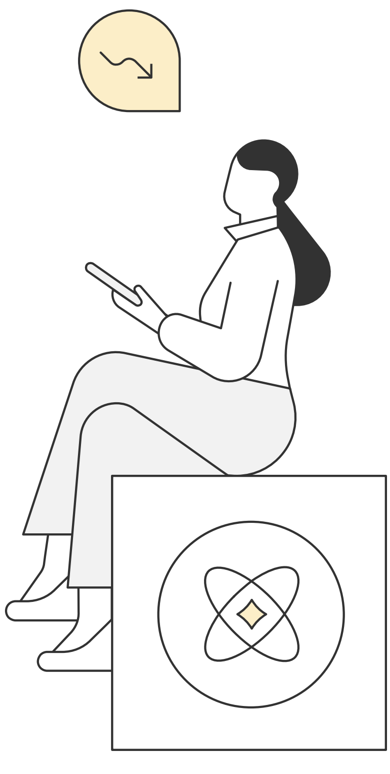
According to interviews, certain geographic regions may be more supportive of $CO_2$ utilization. Finland was mentioned as an example, where local sentiment has been promoting e-fuels rather than storage – although another interviewee noted that this trend is changing. This support for utilization might be due to the relative lack of $CO_2$ storage options in Finland compared to, for example, Sweden. South America is also a region with relatively few storage options, where $CO_2$ utilization could make more economic sense. Therefore, a useful approach for e-fuels projects could be to identify geographically 'stranded' biogenic $CO_2$ that might be more favorably transported as e-methane or e-methanol than as $CO_2$.

Finally, the decision to utilize $CO_2$ for e-fuels production depends critically on the local capability to supply e-hydrogen, i.e., the availability of renewable electricity to drive electrolysis. While the present study focused only on the supply potential of biogenic $CO_2$ feedstock, it would be highly pertinent to continue research on the economics of geographically co-locating the supply of biogenic $CO_2$ and e-hydrogen.

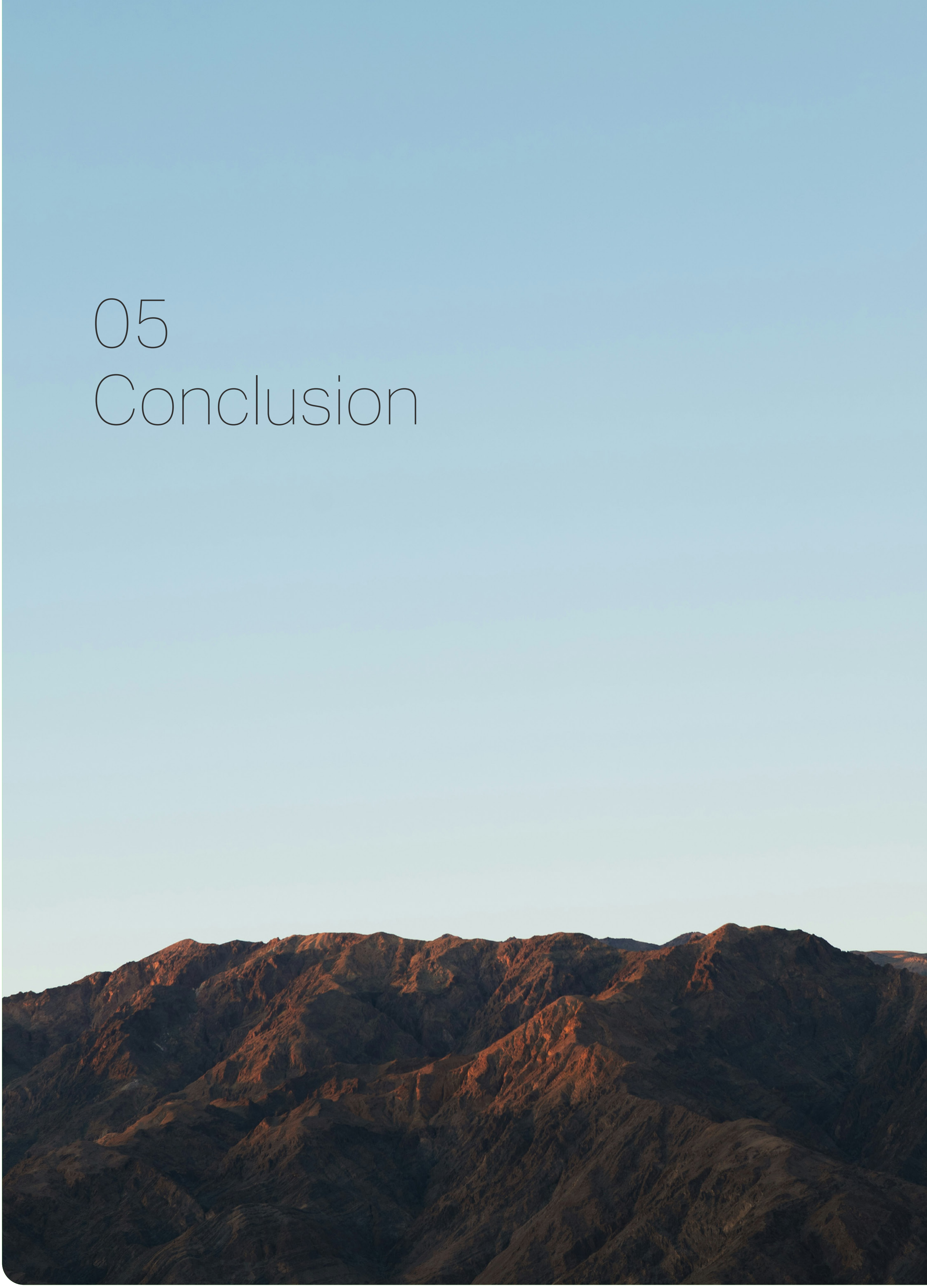
## 4.3.2 Competition from other sectors

A few interviewees indicated that the aviation sector has a stronger regulatory incentive and increased willingness to pay for e-fuels than the maritime sector. However, the timeline for aviation is longer than for maritime, as e-kerosene is not yet commercially ready. Conversely, methane and methanol are more convenient near-term choices due to higher readiness of the associated technologies. Methane has existing supply and demand capabilities, including infrastructure for delivery and storage, as well as energy customers beyond the maritime sector. Meanwhile, methanol has multiple offtakers (e.g., maritime, road, petrochemicals) and offers the potential for methanol-to-jet fuel production in the future. These fuels can, therefore, provide optionality to fuel producers depending on which industry proves more willing to pay.

Meanwhile, the petrochemicals sector was viewed as less relevant in the near term, but likely a significant future competitor for biogenic $CO_2$. As carbon is essential to many chemical products, manufacturers will need access to renewable carbon when this industry is regulated to decarbonize. However, there is currently no urgency for these companies to source renewable carbon. Therefore, it may be advantageous for the maritime sector to act to secure access to biogenic $CO_2$ before such regulation comes into play.

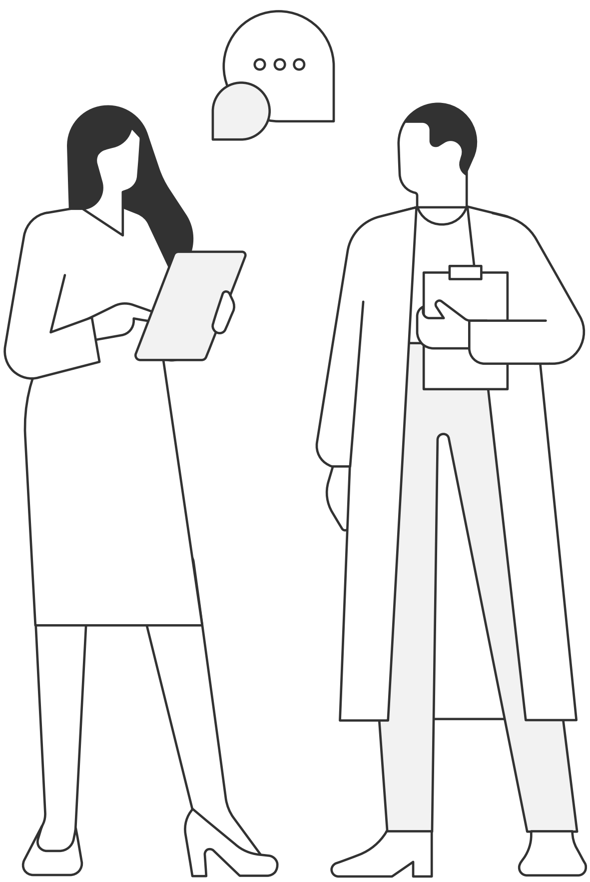


# 05 Conclusion



To summarize, our analysis indicates that current global potential of biogenic $CO_2$ with relevance for e-fuels is about 370 million tonnes per year – enough to supply about 5.4 EJ worth of e-fuels, assuming that the maritime industry is the only consumer of e-chemicals. This amount is enough to reach near-term maritime decarbonization targets defined in current policy, even considering limits on the remaining operational lifetime of $CO_2$ point sources.

However, despite this near-term sufficiency, this current supply is not adequate to supply even half of the maritime sector's long-term needs – even assuming that the industry can obtain 100% of this $CO_2$. This challenge is even greater if we consider that some volumes of $CO_2$ are considerably less economical to capture. Furthermore, other decarbonizing sectors will compete for access to the same $CO_2$ supply as shipping. To illustrate, today's market for methanol alone is equivalent to 2.2 EJ [17] – which already accounts for 40% of the $CO_2$ supply identified in this study.



We identified pulp and paper as the sector with the greatest potential volume of lower-cost biogenic $CO_2$. However, making $CO_2$ from this sector commercially available for e-fuel production will likely require new business models as well as policy incentives. Ethanol, biogas, and biomass power plants also figure among the lowest-cost options for biogenic $CO_2$ supply, but they make up a smaller percentage of the total global volume. Therefore, these industries are low-hanging fruits, but will not decarbonize a significant amount of shipping or other industries.

The demand for $CO_2$ removal or storage credits is seen by industry stakeholders as e-fuels' single largest competitor for biogenic $CO_2$. CCS is currently cheaper and less complex than engaging with e-fuel production. Project developers may benefit from finding opportunities to access biogenic $CO_2$ where storage is a less attractive option. The aviation sector is also a competitor, perceived as better regulated and more willing to pay than the maritime industry.

Overall, carbon-containing e-fuels such as e-methane, e-methanol, and e-diesel will be a necessary part of shipping's decarbonization. The current orderbook for vessels capable of sailing on these fuels reflects shipowners' expectations of future supply of these low-GHG fuels. Here, we have identified factors that can guide both fuel producers and consumers to make wiser investment decisions:

- Timely investment: Biogenic $CO_2$ is limited in scale based on the specific industries that produce it. Since the feedstock is limited and must be shared among multiple decarbonizing sectors, it will likely be claimed before global decarbonization becomes a reality. Therefore, investors and developers should act urgently to secure the supply of biogenic $CO_2$ while the opportunity to do so still exists.

- Selection of feedstock industry and location: E-fuel developers looking to achieve economies of scale for their chemical plants will need to secure large volumes of $CO_2$ feedstock. Our results suggest that producers can achieve this by identifying sufficiently large single point sources, thereby removing some of the costs of transporting and aggregating $CO_2$. Many such sites are owned by the pulp and paper industry, with some additional opportunities in the bio-ethanol and biomass power sectors.

- Avoiding competition: CCS may be the biggest risk to a $CO_2$ emitters' willingness to supply, in contexts where subsidies for carbon storage and/or private demand for offsetting credits are present. Therefore, e-fuel producers may benefit from pursuing locations where local permanent sequestration of $CO_2$ is less available.

- Successful contractual offtake: Contractual supply of $CO_2$ brings risks for point-source emitters, including disturbance to their plants' power balance and the inability to guarantee no or few supply interruptions over long periods. Offtakers must be prepared to either pay prices that reflect these risks (for example, flexible supply sourcing or covering the costs of liquefaction and volume buffering), to accept flexible supply or shorter contracts, or to establish new business frameworks that lessen supplier risks.

In addition, regulators should develop policies that can accelerate decarbonization initiatives. Regulators who view the production of carbon-containing e-fuels as strategically important should understand the importance of subsidizing these pathways to effectively counterbalance the demand for CCS. Due to geographical constraints, the e-fuel industry could also benefit from supporting business frameworks, such as a recognized international book and claim system for $CO_2$. This mechanism could help to minimize supply risks, optimize $CO_2$ capture costs, and provide e-fuel supply physically closer to offtakers. More broadly, policies addressing e-fuel supply need to provide clarity on what qualifies as appropriate and sustainable $CO_2$ feedstocks, in order to mitigate perceived risks in contracting for biogenic $CO_2$ offtake.

Beyond these near-term actions and policies, the longer-term decarbonization of shipping will need to rely on other feedstocks, since the availability of carbon-containing e-fuels will be fundamentally limited by biogenic $CO_2$ supply. We foresee that various biomass-based fuel pathways and ammonia will be part of the solution, as well as potentially direct air or ocean capture of $CO_2$ in the long term.

# 06
# The project team

This report was prepared by the Mærsk Mc-Kinney Møller Center for Zero Carbon Shipping (MMMCZCS) with assistance from our partners.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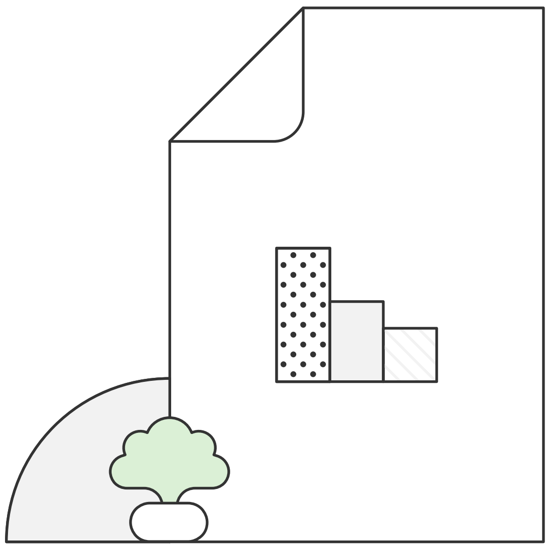
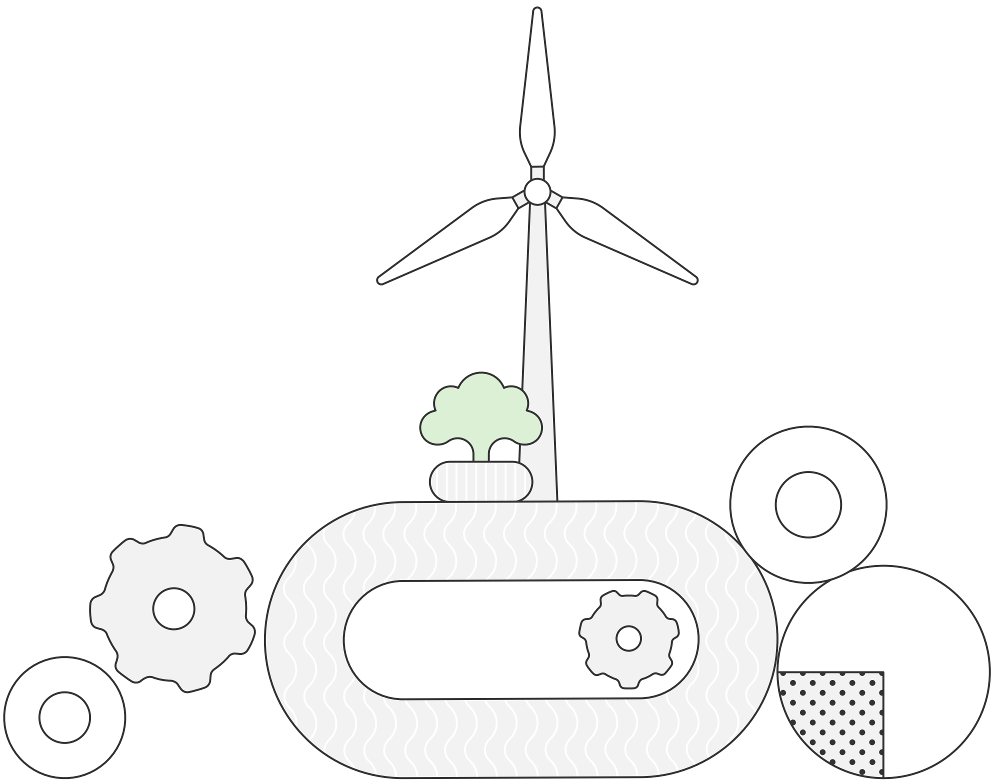


# Abbreviations

| | |
|---|---|
| CapEx | Capital expenditure |
| CCS | Carbon capture and storage |
| $CO_2$ | Carbon dioxide |
| DAC | Direct air capture |
| DOC | Direct ocean capture |
| GHG | Greenhouse gas |
| IMO | International Maritime Organization |
| LNG | Liquefied natural gas |
| MMMCZCS | Mærsk Mc-Kinney Møller Center for Zero Carbon Shipping |
| MTPD | Metric tonnes per day |
| OpEx | Operating expenses |



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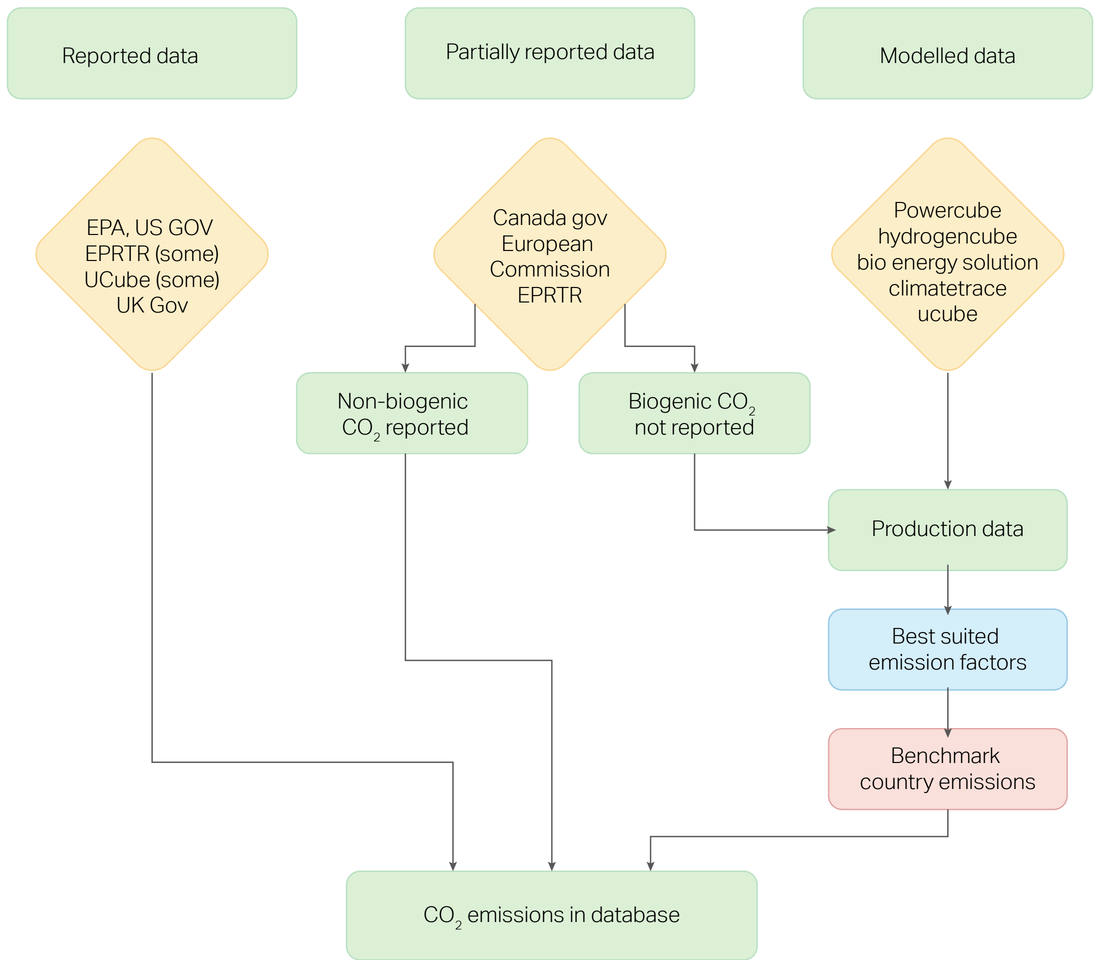
# Appendix

# A.1 Detailed assumptions

## Emissions modeling

- Our methodology for generating raw emissions data is summarized in Figure A1.
- Where available (98% of the data) we have used 2022 emissions.
- Emissions are constrained to >1,370 tonnes per day (stoichiometric conversion to 1,000 tonnes per day methanol).
- In regions where $CO_2$ emissions are not reported, we modeled emissions using known industry output and conversion by scaling with emissions factors. The modeling used a proprietary methodology from Rystad Energy.
- Emissions sources with capacities <0.0025 million tonnes $CO_2$ per year were excluded from the algorithm, on the basis that such a low capacity would likely not pay back in terms of net emissions reduction. To illustrate, meeting our assumed capacity target would require combining 200 such sources. This choice resulted in the exclusion of a total volume of about 25 million tonnes per year $CO_2$ from the algorithm. These exclusions primarily affect the many thousands of small biomass heating applications.

Figure A1: Flow chart explaining the methodology in generating raw emissions data, whether to select reported data or else model emissions based on industry data and emissions factors.



## $CO_2$ capture technology

The capture technology is assumed to be chemical absorption (30% MEA capture solution), with the following characteristics:

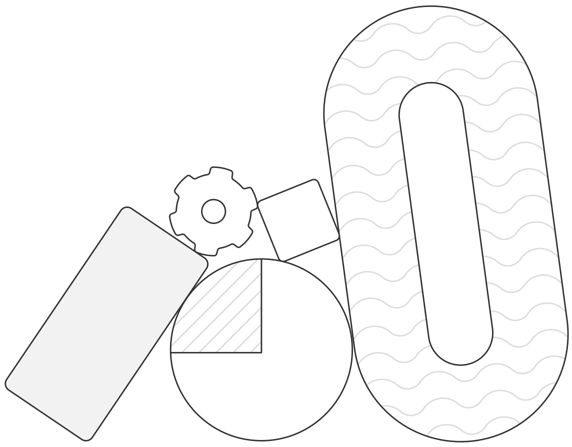
- Low-range power price: 30 USD/MWh
- High power price: (unpublished) renewable electricity costs from the MMMCZCS
- CapEx overrun for capture: 25%
- Capture efficiency: 80%
- Capture discount rate: 10%
- Project lifetime: 25 years
- Operational and maintenance cost: annually 4% of CapEx
- Capture CapEx financed: 50%

The capture CapEx model is based on real-world projects.

## $CO_2$ concentrations

The % $CO_2$ assumed for each source was as follows:

- Waste to energy: 11%
  - 50% of $CO_2$ emissions from waste-to-energy are assumed to be biogenic
- Pulp and paper mills: 13%
  - 80% of $CO_2$ emissions reported from pulp and paper are assumed to be the capturable biogenic portion from the chimney of the recovery boiler
- Bio-ethanol: 84%
- Biogas: 37.5%
- Biomass power: 11%



## $CO_2$ transport

We assumed that pipelines and trucks were used for $CO_2$ transport, depending on which was less expensive for each interconnection. The transport discount rate was 7%.

- Pipeline assumptions:
  - $CO_2$ is transported as a gas
  - Temperature for compression: 300K
  - $CO_2$ inlet pressure for pipelines: atmospheric
  - $CO_2$ outlet pressure for pipelines: 40 bar
  - Steel cost: $1.23/kg
  - For pipelines, one compressor is needed for every 250 km
  - Lifetime of the pipeline: 50 years

- Truck assumptions:
  - Truck capacity: 22 tonnes
  - Capacity factor: 40%
  - Operating expense for trucks: $3.06/km

We excluded rail as a $CO_2$ transport option, as this infrastructure typically does not exist in the relevant locations. Shipping of $CO_2$ was also excluded, giving preference to pipelines as the longer-term option. Additionally, multiple interviewees expressed that they did not expect shipping of $CO_2$ to be the most economical way of producing e-fuels.

## Other assumptions

- We do not limit $CO_2$ availability based on the age of the emitting plant. However, it should be remembered that existing plants are not near start of life and would not offer the payback necessary to invest in on-site $CO_2$ capture.

- We do not calculate the cost of e-fuel production itself, since this study only focuses on the $CO_2$ costs of capture and transport. This accordingly means that we do not consider the cost of e-hydrogen (renewable electricity and transport of water to site).

- Transport of e-fuels to port or storage is not considered in the cost; neither do we consider the optional cost of producing e-fuels in proximity to a port and, therefore, transporting $CO_2$ feedstock from more distant locations.

## A.2 Additional results

Figure A2: Global volume estimates (million tonnes per year) of biogenic $CO_2$, with indicated adjustments, according to the methodology of the report. Out of approximately 0.5 billion tonnes per year from the database of point sources, more than one-third is excluded by the algorithm on the basis of threshold size and maximum transport distance. With this exclusion under these assumptions, the algorithm yields a raw availability of biogenic $CO_2$ for e-fuel production. However, further contributions to global potential were estimated by two additions: (1) re-inclusion of sites in proximity to the generated hubs, and (2) by estimation of pulp mill production that might have eluded the database. Finally, from this net 367 million tonnes per year estimate of potential, we demonstrate an example of how the cost curve could be used to further constrain availability estimates, by illustrating the effect of an arbitrary cap of $120 on acceptable capture and transport cost.

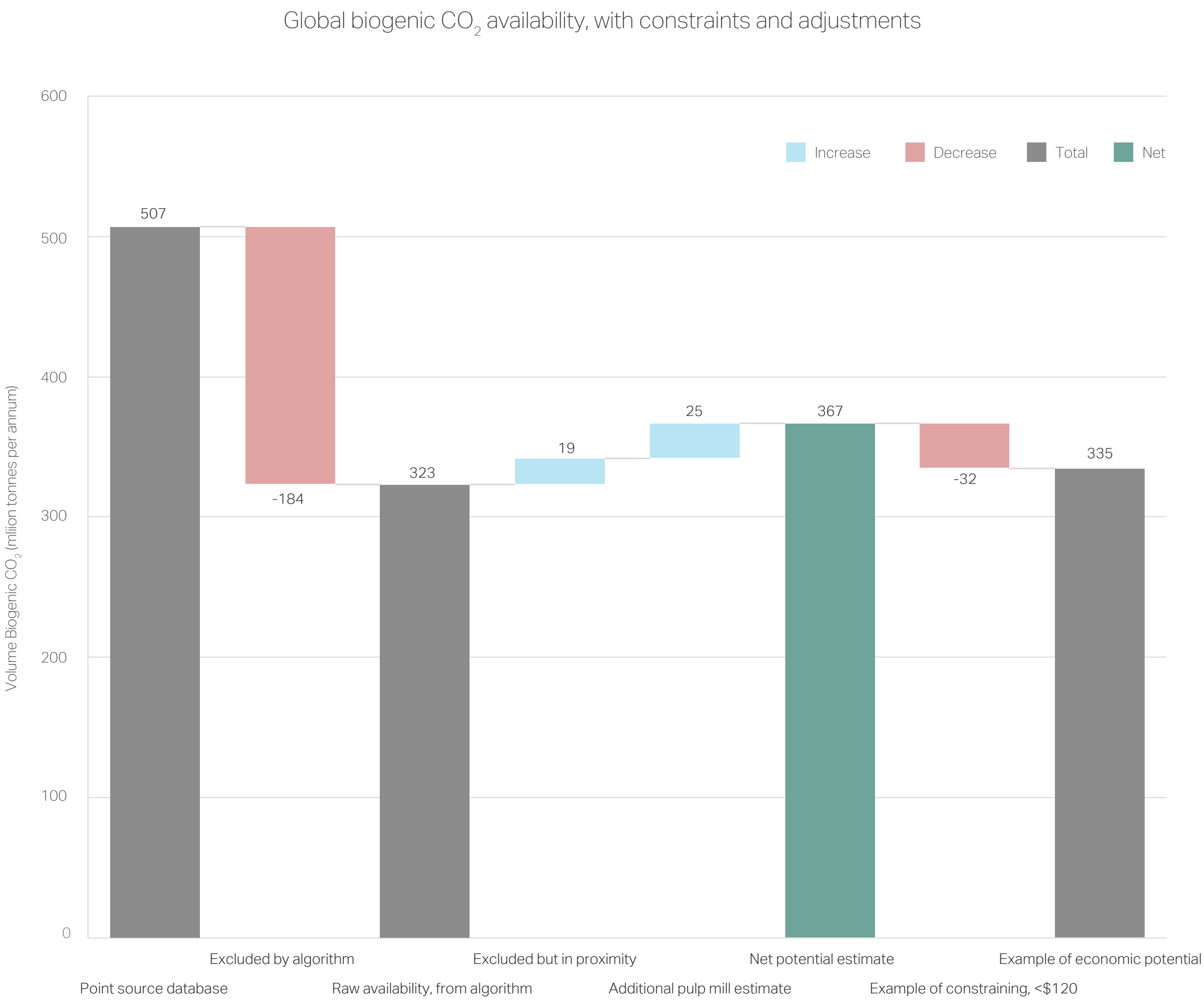


Figure A3: Number of theoretical collection sites, and the calculated cost of $CO_2$ for each site. For comparison, the range of reported full costing of $CO_2$ supply is indicated to the left of the Y-axis.

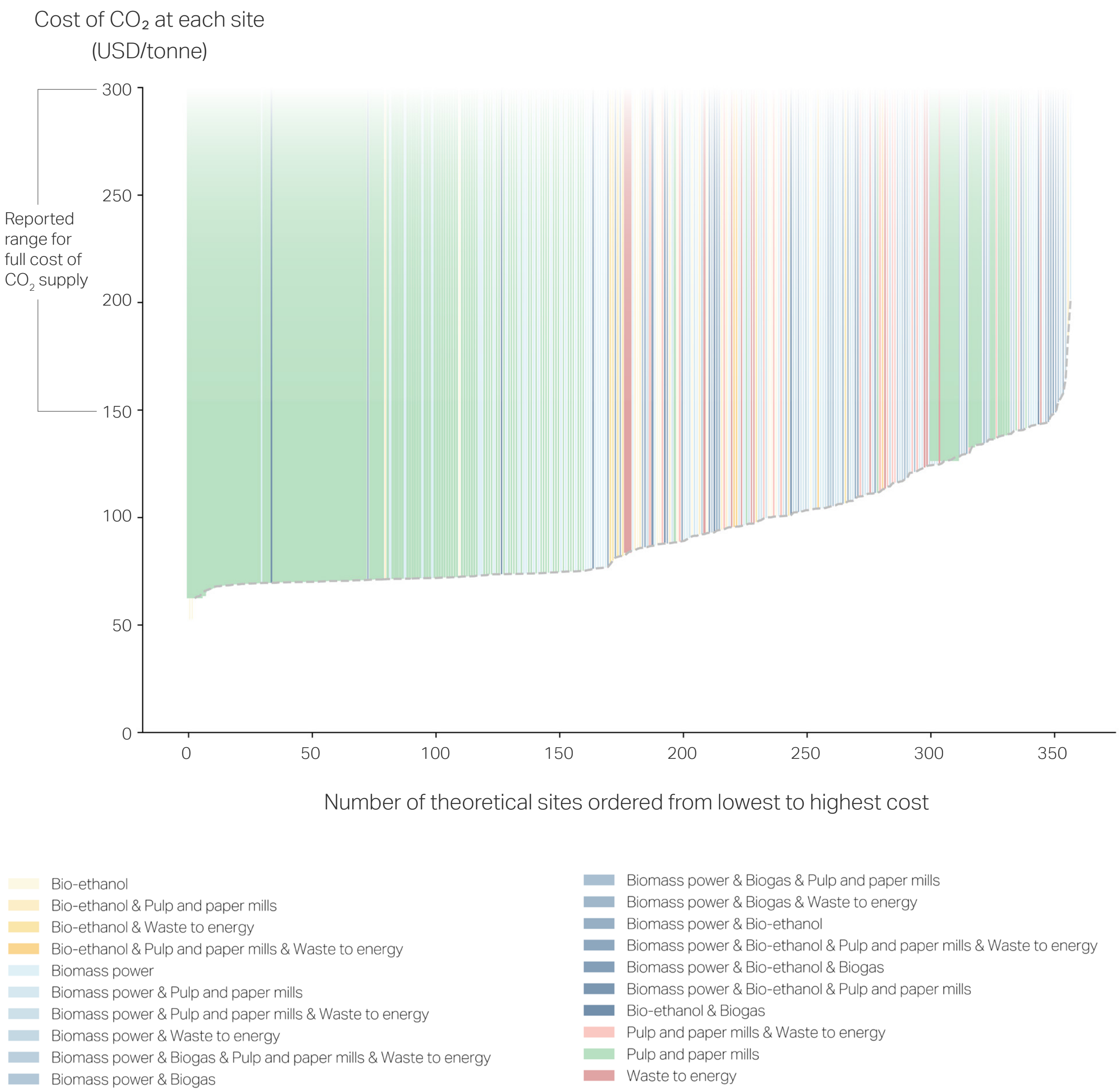
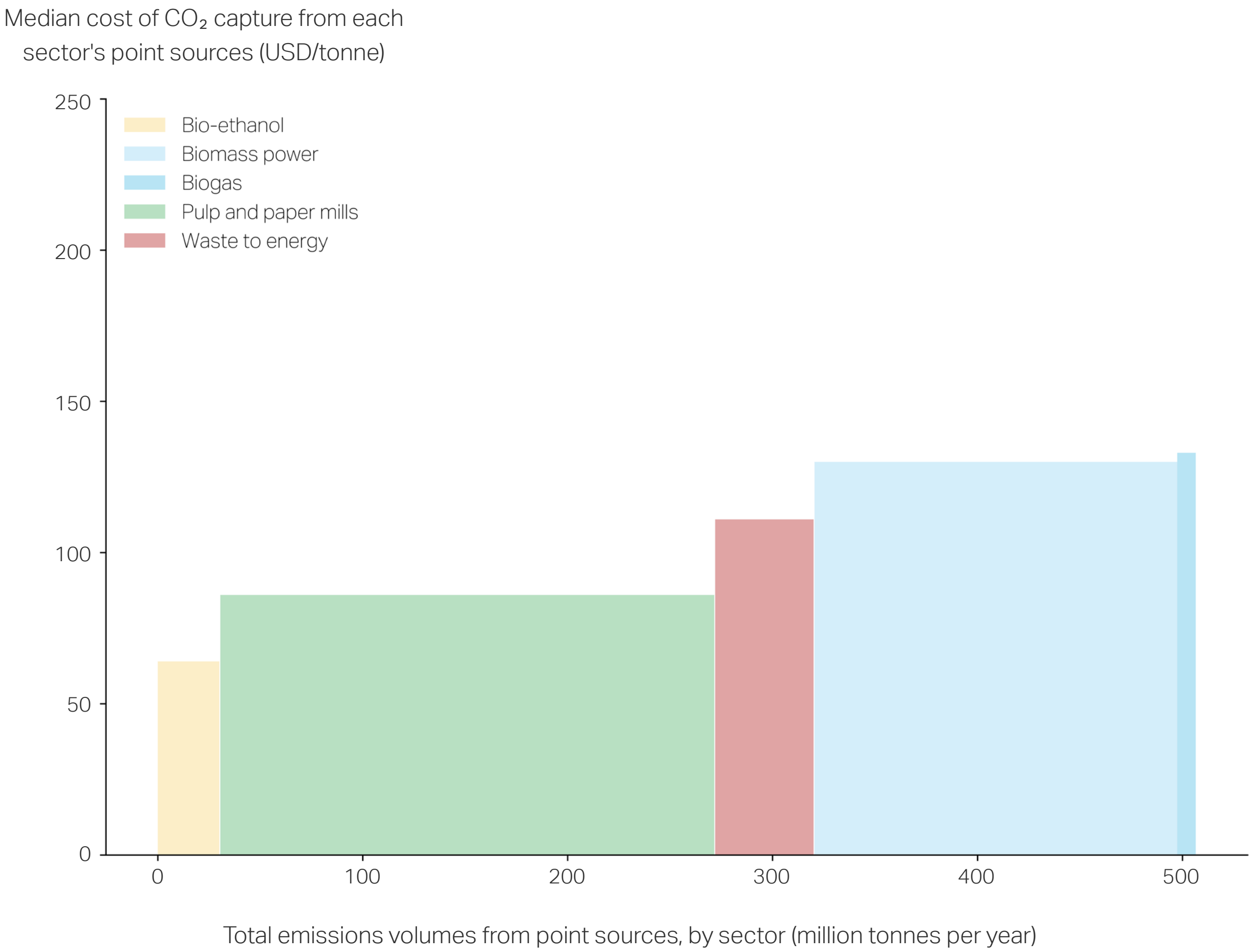


Figure A4: Median capture cost and total volumes for biogenic $CO_2$, sorted by median capture costs of the five sectors. Transport cost is not included, and $CO_2$ volumes have not been restricted by size or transport distance. These data help to represent the magnitude of potential impact from pulp mills, as a sector with larger volumes of relatively low-cost $CO_2$, which is needed to help the e-fuels industry reach scale.



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