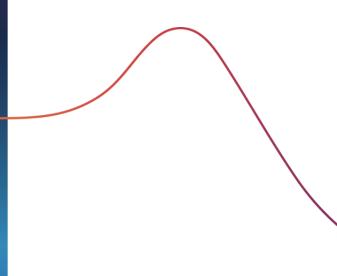# SBTi CHEMICALS SECTOR PATHWAYS SYNTHESIS REPORT

Version 1.0

December 2025

ABOUT SBTi

The Science Based Targets initiative (SBTi) is a corporate climate action organization that enables companies and financial institutions worldwide to play their part in combating the climate crisis. We develop standards, tools and guidance which allow companies to set GHG emissions reductions targets in line with what is needed to keep global heating below catastrophic levels and reach net-zero by 2050 at the latest. The SBTi is incorporated as a UK charity, with a subsidiary SBTi Services Limited, which hosts target validation services (together with SBTi, the "SBTi Group").

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VERSION HISTORY

Version	Change/update description	Release date	Effective dates
1.0	• Publication of the initial version of the SBTi Chemicals Sector Pathways Synthesis Report	December 2, 2025	December 2, 2025

CONTENTS

1. INTRODUCTION

This document provides a summary of how the Science Based Targets initiative (SBTi) has developed the pathways described in the SBTi Chemical Sector Pathways and Implementation Criteria document (pathways criteria document). Included in this document is development background on the following pathways and data:

- Emissions scenario selection for setting activity-specific emissions intensity pathways for primary chemical production, to be used in conjunction with the Sectoral Decarbonization Approach (SDA).

- Development of activity-specific emissions intensity pathways for primary chemicals based on direct emissions, electricity, and production values for the total chemicals sector, and for ammonia, methanol, and high value chemicals (HVCs). The International Energy Agency (IEA) Net Zero by 2050 (NZE) Scenario (IEA, 2021a) forms the basis of the calculations, and this has been supplemented by other IEA sources such as the World Energy Outlook Report (IEA, 2023a), the Net Zero Roadmap: A Global Pathway to Keep the 1.5°C Goal in Reach (IEA, 2023b) and the Ammonia Technology Roadmap Report (IEA, 2021b).

- The development of the activity-specific pathway for scope 1 greenhouse gas (GHG) emissions from non-primary chemical production activities.

- The development of the activity-specific pathway and target-setting method for scope 1 emissions of N_2O from nitric acid production activities.

- The development of the activity-specific pathway for scope 3 category 11 emissions of N_2O from the use-phase of sold nitrogen fertilizers.

- The development of the activity-specific pathway and target-setting method for the sourcing of alternative sources of carbon as feedstocks.

2. BACKGROUND ON TECHNICAL DEVELOPMENT

2.1 Emissions scenario selection for setting primary chemicals activity-specific pathways

The SBTi has developed 1.5°C-aligned emissions intensity convergence pathways for ammonia, methanol, and HVCs, which together constitute approximately 70% of direct CO_2 emissions from the chemicals sector. Emissions scenarios that are granular at the chemical product level were needed to establish the chemical-specific emissions intensity convergence pathways. Specifically, projections of emissions, electricity consumption, and product demand to 2050 that are consistent with a 1.5°C emissions budget were needed for each chemical group. The SBTi researched many scenarios that included data for the chemicals sector as a part of the larger model framework or as the primary sectoral focus of the model, in order to assess the availability and suitability of the data for developing pathways.

Based on this research, the SBTi chose to use data from the IEA's Net Zero by 2050 (NZE) report (IEA, 2021a) and other related publications to develop the chemical-specific pathways. This IEA model was chosen for the following primary reasons:

- The IEA's NZE is a scenario produced by the IEA's Global Energy and Climate model, which includes detailed "technology-rich" modeling for primary chemicals, which includes emissions, electricity consumption, and demand projections until 2050.

- The IEA has published the data from the 2021 version of the NZE scenario in various topic-specific reports, such as the *Global Hydrogen Review*, which provide transparency into the underlying model results.

- The IEA's NZE scenario has been used as the basis for sector-specific emissions intensity convergence pathways in existing SBTi sectoral guidance, including guidance for the cement and iron and steel sectors. This ensures consistency in the modeling approach across sectoral resources.

- The SBTi has established CO_2 emissions budgets to 2050 at the sectoral level, which were published in the paper *Pathways to Net-Zero: SBTi Technical Summary* (SBTi, 2021). These budgets were developed based on the 2021 IEA NZE Report, therefore using this model for chemical-specific emissions intensity pathways ensures consistency with the upper bound of the sectoral CO_2 budget.

- The SBTi has included the IEA NZE as part of the envelope of scenarios that have been used to develop our cross-sector emissions reduction pathway.

- The IEA is an internationally recognized research organization with a high level of credibility within the chemicals sector and broader climate community.

Table 1. Summary of data used to develop activity-specific pathways for each primary chemical

CATEGORY	PARAMETER	BASELINE 2020	2030	2040	2050
Whole sector	Direct emissions (Gt CO_2)	1.296	1.199	0.654	0.066
	Electricity (EJ)	0.66	1.6		
	Production - primary chemicals (Mt)	529	641	686	688
Ammonia	Heat and process-related emissions (Gt CO_2)	0.450	0.340	0.145	0.020
	Electricity (EJ)	0.29	0.72	2.52	4.32
	Production - *Non-energy uses only* (Mt)	185	205	220	230
	Production - *All uses* (Mt)	185	283	424	560
	Electricity-related emissions (Gt CO_2)	0.033	0.020	0.013	0.001
	Total emissions (Gt CO_2)	0.483	0.360	0.158	0.021
	Emissions intensity - *Non-energy uses only* (Mt CO_2 / Mt ammonia)	**2.61**	**1.76**	**0.72**	**0.09**
	Emissions intensity - *All uses* (Mt CO_2 / Mt ammonia)	**2.61**	**1.27**	**0.37**	**0.04**
Methanol	Heat and process-related emissions (Gt CO_2)	0.222	0.222	0.134	0.012
	Electricity (EJ)	0.29	0.72	1.26	1.80
	Production (Mt)	99	127	136	133
	Electricity-related emissions (Gt CO_2)	0.033	0.020	0.006	0.000
	Total emissions (Gt CO_2)	0.255	0.242	0.140	0.012
	Emissions intensity (Mt CO_2 / Mt methanol)	**2.59**	**1.91**	**1.03**	**0.09**
HVCs	Heat and process-related emissions (Gt CO_2)	0.251	0.251	0.151	0.014
	Electricity (EJ)	0.08	0.16	0.30	0.58
	Production (Mt)	245	309	330	325
	Electricity-related emissions (Gt CO_2)	0.010	0.004	0.002	0.000
	Total emissions (Gt CO_2)	0.261	0.255	0.153	0.014
	Emissions intensity (Mt CO_2 / Mt HVCs)	**1.06**	**0.83**	**0.46**	**0.04**

Table legend:

- **Green** – Values provided by IEA in published reports.
- **Amber** – Values not directly provided, but calculated from IEA values in published reports.
- **Blue** – Values interpolated or estimated from already reported IEA values for other years, supplemented with other sources where noted.
- **No color** – Values directly calculated using the above data.

Scope 1 and 2 data calculation process

The basis for the primary chemicals heat- and process-related CO_2 emissions and production data described below is the IEA's 2021 NZE report (IEA, 2021a), and certain accompanying reports. The IEA has subsequently published data from newer outputs of the NZE scenario in their World Energy Outlook 2023 Report (IEA, 2023a) and Net Zero Roadmap: A Global Pathway to Keep the 1.5°C Goal in Reach Report (IEA, 2023b). The SBTi has chosen to use emissions and production data from the 2021 NZE Report (IEA, 2021a) and not the more recent reports because:

- Some data that was available in the 2021 NZE (IEA, 2021a) report and accompanying reports is not available in the 2023 reports (IEA, 2023b), specifically data from the IEA's 2021 Ammonia Technology Roadmap (ATR) (IEA, 2021b) that has been used to inform the pathways for both ammonia and other primary chemicals.

- The SBTi has chosen not to selectively update the data based on what is available in the 2023 NZE reports (IEA, 2023b), except where noted below, as this would introduce inconsistencies within pathways and between pathways.

- The chemical sector production data in the 2023 NZE Report (IEA, 2023b) includes production from refineries, which are outside the scope of the pathways.

- Based on differences found in the available data, modeled projections for heat- and process-related CO_2 emissions from primary chemicals between the published 2021 NZE Report (IEA, 2021a) and the 2023 Report (IEA, 2023b) are relatively minor. Published primary chemical emissions data in 2020 and 2030 from the 2023 NZE Report, compared to the 2021 data (presented as part of the emissions intensity pathways above), are shown in Table 2. The 2023 NZE data was taken from the 2023 NZE Report and the most recent IEA chemicals industry webpage (IEA, 2023c).

Table 2. Comparison of relevant data between 2021 and 2023 IEA NZE reports

CHEMICAL	SCENARIO DATA	2020 DIRECT CO_2 EMISSIONS (GT)	2030 DIRECT CO_2 EMISSIONS (GT)
Whole sector	2021 NZE Reports	1.296	1.199
	2023 NZE Reports	1.329*	1.150
Ammonia	2021 NZE Reports	0.450	0.340

CHEMICAL	SCENARIO DATA	2020 DIRECT CO_2 EMISSIONS (GT)	2030 DIRECT CO_2 EMISSIONS (GT)
(Non-energy purposes only)	2023 NZE Reports	0.422	0.311
Methanol	2021 NZE Reports	0.222	0.222**
	2023 NZE Reports	0.234	0.209
HVCs	2021 NZE Reports	0.251	0.251**
	2023 NZE Reports	0.244	0.248

*The value shown here is for 2021. The 2023 NZE Report does not publish 2020 emissions data for the whole sector.
**As described below, emissions from methanol and HVCs production in 2030 have been set equal to 2020, even though the 2021 NZE Scenario projects minor increases in direct emissions for these products.

The differences in cumulative emissions between the 2021 NZE data and the 2023 NZE data from 2020 to 2030 are less than 8% across all primary chemicals. Differences were found between the reports in the baseline emissions for 2020, but for consistency purposes the SBTi has chosen to use the same 2021 NZE data set for the baseline year, as described above. These minor differences in emissions between the NZE scenario versions propose a minor risk of inconsistency between the primary chemical activity-specific pathways and the current IEA modeling. However, the lack of published primary chemical emissions and production data for 2040 and 2050 in the 2023 NZE Report led us to choose the 2021 NZE as our basis for the development of the pathways, because 2040 and 2050 data for ammonia was available and could be used to inform pathways for the other chemicals. The SBTi will evaluate new scenario data in the future and will update the activity-specific pathways if warranted.

For electricity consumption data, the SBTi has based this mainly on IEA's 2023 WEO report for ammonia and methanol production in 2020, 2030, and 2050 (IEA, 2023a) and the current IEA chemicals webpage for total electricity used for the production of primary chemicals in 2020 and 2030 (IEA, 2023c). The IEA had not provided this information in their 2021 publications described above; therefore, the SBTi has chosen to use the more recent reports. Since there is no significant difference in total production values in the chemical sector between the 2021 and 2023 NZE iterations, the SBTi has assumed electricity consumption in the 2023 NZE Report (IEA, 2023b) to be comparable to those in the 2021 version (IEA, 2021a), and thus compatible with the primary chemical emissions and production values described above. The emissions intensity in tCO_2 / MWh for each year in the SBTi's SDA Pathway for the Power Sector (as of the publication of this document) was used to convert electricity usage to electricity-related emissions for each year.

As described above, data from several reports from the IEA have been used to develop primary chemical emissions intensity pathways. In most cases, these reports were published using data from the NZE scenario in 2021; therefore, the SBTi has assumed consistency in data between the reports. Cases where more recent data was used to supplement the 2021 NZE information are described above.

Total chemical sector

This includes primary chemicals and non-primary chemicals, except where noted.

- Heat- and process-related emissions: **All years** from the 2021 NZE Report, Annex A table A.4 (IEA, 2021a).

- Electricity (only used for primary chemicals): The **2020** and **2030** values are from the IEA chemicals webpage, the "Energy" graph (IEA, 2023d). The 2040 and 2050 values haven't been calculated as they are not required for our assessment and are not provided by the IEA in the 2023 publications.

- Production (only used for primary chemicals): **All years** from the 2021 IEA NZE Report, page 200 (IEA, 2021a).

Ammonia for non-energy purposes only

- Heat- and process-related emissions: The **2020** value is from the IEA ATR report, page 9, and the **2030**, **2040,** and **2050** values are estimated from the ATR report, Figure 2.1 (IEA, 2021b).[1]

- Electricity: The **2020** (assumed to be the same as electricity use in 2022, as little to no change in electrification is assumed), **2022, 2030,** and **2050** values are from the WEO 2023 report, Figure 3.6 (IEA, 2023a). The **2040** value is calculated as the average of the 2030 and 2050 values.

- Production: The **2020** and **2050** values are from the IEA ATR report, page 62. Values for **2030** and **2040** are estimated from the ATR report, Figure 2.5 (IEA, 2021b).

Data for heat- and process-related emissions and production in years not shown in Table 1 were calculated based on linear interpolation between the years shown. Data for electricity usage in years not shown in Table 1 were calculated based on linear interpolation between the years shown, modified with an assumption that there is no increase in electricity-related emissions from the prior year. This has been done to prevent temporary increases in total emissions from electricity generation that occur due to rapid increases in electricity usage projected due to a rise in the use of electrolysis to produce hydrogen.

Ammonia for all purposes

- Heat- and process-related emissions: Assumed to be the same as heat- and process-related emissions from the pathway for ammonia production for non-energy purposes. This is because the IEA has modeled all future ammonia used as an energy carrier as coming from production based on low-emissions hydrogen, as

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[1] The IEA modelling approach for ammonia doesn't consider CO_2 generated during ammonia production but converted to urea to be emitted under scope 1.

shown in Figure 3.21 in the IEA NZE 2023 report (IEA, 2023b)[2]. This assumes that emissions from ammonia produced via low-emissions hydrogen from fossil fuels with high-capture Carbon Capture, Utilization, and Storage (CCUS) technology are minimal, when in reality some direct emissions will occur due to incomplete capture rates. The SBTi may investigate refinements to this approach in future work.

- Electricity: Assumed to be the same as electricity-related emissions from the pathway for ammonia production for non-energy purposes. This is because any ammonia produced for use as an energy carrier is assumed to be based on low-emissions hydrogen, thus using low-emissions sources of electricity.

- Production: Ammonia for use as an energy carrier is assumed to be the sum of ammonia only used for power generation and as a maritime fuel. The **2020** values are the same as the pathway for ammonia used for non-energy purposes, as the IEA has not modeled any ammonia production for use as an energy carrier in 2020. The **2050** value is the sum of production for power generation and maritime fuel from the IEA ATR report, chart in Box 2.2, page 72. The **2030** and **2040** values for production for power generation are calculated based on linear interpolation between 2020 and 2050. The **2030** and **2040** values for production of ammonia for maritime fuel are calculated based on the energy use from ammonia as a liquid maritime fuel from the IEA NZE 2021 report, Table A.2. Energy use is converted to ammonia production in 2030 and 2040 using the ratio between energy usage in the maritime sector in 2050 and total ammonia produced for the maritime sector in 2050, as calculated above. This assumes all ammonia used as a liquid fuel outside the electricity generation sector is used in the maritime sector.

Data for heat- and process-related emissions and production in years not shown in Table 1 were calculated based on linear interpolation between the years shown. Data for electricity usage in years not shown in Table 1 were calculated based on linear interpolation between the years shown, modified with an assumption that there is no increase in electricity-related emissions from the prior year. This has been done to prevent temporary increases in total emissions from electricity generation that occur due to rapid increases in electricity usage projected due to a rise in the use of electrolysis to produce hydrogen.

Methanol

- Heat- and process-related emissions: The **2020** value is recorded from the IEA's direct CO_2 emissions from primary chemical production in the Net Zero Scenario, 2015-2030 (IEA, 2021c). The **2030** value is assumed to be the same as the 2020 value. Although the 2030 CO_2 emissions from methanol in the 2021 NZE Report (IEA, 2021a) showed minor increases from 2020, the SBTi has assumed no emissions increase to prevent backsliding. Note that the 2023 NZE Report supports

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[2] The IEA defines low-emissions hydrogen as "hydrogen which is produced through water electrolysis with electricity generated from a low-emissions source such as renewables or nuclear, or biomass or from fossil fuels equipped with CCUS technology. Production from fossil fuels with CCUS is included only if upstream emissions are sufficiently low, if capture, at high rates, is applied to all CO_2 streams associated with the production route, and if all CO_2 is permanently stored to prevent its release to the atmosphere." (IEA, 2023b)

this rationale (IEA, 2023b), with reductions in CO_2 emissions from methanol shown.[3] The **2040** and **2050** values are assumed to have the same ratio against the total chemical sector emissions (minus ammonia) as 2020 values.

- Electricity: The **2020** (assumed to be the same as electricity used in 2022, as little to no change in electrification is assumed), **2022, 2030,** and **2050** values are from the WEO 2023 Report, Figure 3.6 (IEA, 2023a). The **2040** value is calculated as the average of the 2030 and 2050 values.

- Production: The **2020** value is calculated by dividing the 2020 emissions (see above) by the methanol production emission intensity value provided in Figure 1.7 in the ATR (2.2 tCO_2 / t) (IEA, 2021b). The **2030** value is based on the indexed values provided in IEA's Expansion in primary chemical production in the Net Zero Scenario, 2000-2030 graphic, published in 2021 (IEA, 2021d). This value is calculated as an index against the calculated 2020 value. The **2040** and **2050** values are calculated by assuming the same ratio against the total primary chemical production values (minus ammonia) as the 2030 values in the 2021 NZE Report (IEA, 2021a). The SBTi notes that 2020 and 2030 ratios are similar in the 2021 NZE Report. Additionally, this ratio between methanol and total primary chemical production remains the same in 2030 and 2050 in the CTS scenario provided in the IEA Future of Petrochemical Report – Methodological Annex in Table A8 (IEA, 2018).

Data for heat- and process-related emissions and production in years not shown in Table 1 were calculated based on linear interpolation between the years shown. Data for electricity usage in years not shown in Table 1 were calculated based on linear interpolation between the years shown, modified with an assumption that there is no increase in electricity-related emissions from the prior year. This has been done to prevent temporary increases in total emissions from electricity generation that occur due to rapid increases in electricity usage projected due to a rise in the use of electrolysis to produce hydrogen.

HVCs

- Heat- and process-related emissions: The **2020** value is recorded from the IEA's direct CO_2 emissions from primary chemical production in the Net Zero Scenario, 2015-2030 (IEA, 2021c). The **2030** value is assumed to be the same as the 2020 value. Although the 2030 CO_2 emissions from HVCs in the 2021 NZE Report showed minor increases from 2020, the SBTi has assumed no emissions increase to prevent backsliding. Note that the 2023 NZE (IEA, 2023b) Report supports this rationale, with CO_2 emissions from HVCs increasing only 1.7% from 2020 to 2030.[4] The **2040** and **2050** values are assumed to have the same ratio against the total chemical sector emissions (minus ammonia) as the 2020 values.

- Electricity: The **2020** and **2030** values are calculated by subtracting the total electricity required to produce ammonia and methanol from the total electricity from primary chemical production in those years. Minimal electrification is assumed for the

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production of HVCs, therefore the same rate of increase in electricity between 2020 and 2030 is maintained for **2040** and **2050**.

- Production: The **2020** value is calculated by dividing the 2020 emissions (see above) by the HVCs production emission intensity value provided in Figure 1.7 in the Ammonia Technology Roadmap (1 tCO$_2$ / t) (IEA, 2021b). The **2030** value is based on the indexed values provided in IEA's Expansion in primary chemical production in the Net Zero Scenario, 2000-2030 graphic, published in 2021 (IEA, 2021d). This value is calculated as an index against the calculated 2020 value. The **2040** and **2050** values are calculated by assuming the same ratio against the total primary chemical production values (minus ammonia) as the 2030 values in the 2021 NZE Report (IEA, 2021a). The SBTi notes that 2020 and 2030 ratios are similar in the NZE Report. Additionally, this ratio between HVCs and total primary chemical production remains the same across 2030, 2040, and 2050 in the CTS scenario provided in the IEA Future of Petrochemical Report – Methodological Annex in Table A8 (IEA, 2018).

Data for heat- and process-related emissions, electricity usage, and production in years not shown in Table 1 were calculated based on linear interpolation between the years shown.

2.2 Pathway development for scope 1 emissions from non-primary chemical production

As described above, the IEA NZE scenario includes direct emissions projections for the entire chemicals sector, which encompasses both primary chemical and non-primary chemical production. However, the modeling methodology used for non-primary chemicals is, with some exceptions, significantly different from the technology-rich model used for primary chemicals. As a result, projections of non-primary chemical production are not included in the IEA's reports on the NZE scenario. Additionally, the sector produces thousands of different non-primary chemicals, manufactured with a wide variety of process types. This high level of diversity in product and process types makes the establishment of a single emissions intensity pathway for all non-primary chemicals impractical.

The SBTi has thus established a pathway for absolute direct emissions from the production of non-primary chemicals using the IEA NZE scenario. This scenario was chosen to ensure consistency with the primary chemical pathways described above. The non-primary chemical pathway was developed based on the difference between the reported emissions from the whole of the sector, and the sum of the emissions from each primary chemical group. For methanol and HVC, the actual emissions projections for 2030 from the scenario were used rather than the modified values described above. Table 3 includes the direct emissions from the whole of the sector, direct emissions from production of each primary chemical, the resulting direct emissions pathway for non-primary chemicals, and the percent reduction in absolute emissions for the non-primary chemical category from the reference base year of 2020.

Table 3. Summary of pathway data for direct emissions from non-primary chemical production activities

CATEGORY	PARAMETER	BASELINE 2020	2030	2040	2050
Whole sector *(W)*	Direct emissions (Gt CO_2)	1.296	1.199	0.654	0.066
Ammonia *(A)*	Direct emissions (Gt CO_2)	0.450	0.340	0.145	0.020
Methanol *(M)*	Direct emissions (Gt CO_2)	0.222	0.245	0.134	0.012
HVCs *(H)*	Direct emissions (Gt CO_2)	0.251	0.259	0.151	0.014
Non-primary chemicals *(= W - A - M - H)*	**Direct emissions (Gt CO_2)**	**0.373**	**0.355**	**0.224**	**0.020**

The emissions data for the non-primary chemical pathway shown in Table 3 includes only direct non-process CO_2 emissions. Emissions from the generation of electricity used in the relevant chemical production activities are not included. Data for emissions in years not shown in Table 3 were calculated based on linear interpolation between the years shown.

2.3 Development of target-setting metrics for nitric acid production

The SBTi has established the target emissions intensity metric of 0.5 kg N_2O / t Nitric Acid based on an assumed unabated emissions intensity of 9.0 kg N_2O / t Nitric Acid [(NACAG, 2023), (Joerss, 2023), (WRI, 2015)] and an assumed annual average abatement percentage of around 95% from the use of tail-gas abatement technologies [(NACAG, 2023), (IPCC, 2007)].

The SBTi has chosen to set a requirement to reach this threshold value to ensure that companies who have not yet taken abatement measures will be incentivized to do so, without creating an obligation for companies who have already implemented abatement measures to invest further, while still ensuring that these emissions are covered by a company's overall emissions reduction target.

2.4 Pathway development for N_2O emissions in scope 3 category 11 from the use-phase of sold nitrogen fertilizers

The SBTi, with input from members of the project's EAG, explored source-specific emissions scenarios to develop a science-based trajectory that could be used by fertilizer manufacturers to set 1.5°C-aligned emissions reduction targets on emissions of N_2O in the use-phase (scope 3 category 11).

The SBTi used the following qualitative criteria to guide assessment of studies that specifically address emissions of N_2O from the use of synthetic N-fertilizers:[5]

- Provide a realistic representation of the potential reduction in emissions until 2050 resulting from different measures that fertilizer companies can take.
- Be compliant with a scenario that limits global warming to a maximum of 1.5°C.
- Be based on recent and credible scientific research.
- Provide transparent underlying data and calculations.

The SBTi identified three studies which focused on the key levers to reduce N_2O emissions from fertilizers from the field (Gao & Serrenho, 2023), Systemiq (Systemiq, 2022), and McKinsey & Co (McKinsey & Co, 2020). The key mitigation levers relevant for N_2O considered in these studies include minimizing the demand and use of N-fertilizers while maintaining crop production sufficient to meet global food demand, thus ensuring food security. Maximizing the nitrogen use efficiency (NUE) of N-fertilizers[6] is a key strategy to achieve optimized fertilizer application while maintaining adequate and equitable food supply. Increasing NUE can be achieved by:

- Applying the "4R" N management principle (i.e., applying the right N source at the right rate, time, and place); and
- Use of Enhanced Efficiency Fertilizers (EEFs).

The use of nitrification inhibitors (NIs) is another lever to mitigate N_2O emissions from the field. NIs are chemicals that prevent bacteria from performing the nitrification and denitrification reactions that generate N_2O.

The three studies each include consideration in their model that meeting future food demand is a necessity that cannot be compromised by reductions in N_2O emissions from N-fertilizers. Gao & Serrenho (2023) rely on projected crop demand and N-fertilizer demand from the Food and Agriculture Organization of the United Nations (FAO) against which their mitigation levers are measured. McKinsey & Co rely on mitigation scenarios from the IPCC's 2018 report, *Global Warming of 1.5°C*, which considers trade-offs and synergies with the sustainable development goals (SDGs). Gao & Serrenho (Gao & Serrenho, 2023) separately modeled 2020-2030, while the annual emissions reduction from Systemiq and McKinsey & Co was derived based on their 2020-2050 modeling.

Because these three studies examine only a single source of emissions within the broader land sector, it is difficult to definitively conclude their alignment with the 1.5°C level of ambition that the SBTi has recognized for the land sector (Anderson et al., 2022). The McKinsey & Co study claims alignment with the upper end of required reductions and is higher than the top of the interquartile range for emissions reductions from agriculture in the low-overshoot scenarios from the Integrated Assessment Modeling (IAM) Consortium that underpins IPCC's 2018 report, *Global Warming of 1.5°C* (IPCC, 2018). For this reason, the

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[5] These criteria were established for the specific purpose of evaluating scenarios dealing with emissions of N_2O from fertilizer use in the field. They are not representative of the evaluation of scenarios for other SBTi work, for which more general principles are currently in development.
[6] Nitrogen use efficiency is the fraction of N input that is harvested as product in the crop.

SBTi considers the McKinsey & Co pathway and other, more ambitious pathways, to be consistent with a 1.5°C level of ambition.

Many other emissions scenarios for the land sector model N_2O emissions from fertilizer use, such as those summarized by Roe et al. (Roe, et al., 2019); however, these models typically lack the resolution on mitigation options for individual emission source types such as N_2O emissions from synthetic fertilizer. These models can provide additional insight into the role of land sector N_2O emissions mitigation in global models; therefore, in addition to the studies described above, the SBTi also evaluated the envelope of scenarios assessed in the sixth Assessment Report (AR6) of the IPCC in order to broaden our dataset and ensure our methods are informed by a more diverse range of scenarios.

The AR6 database contains 1,202 scenarios selected from multi-model and individual modeling studies. Together, these scenarios represent an ensemble of possible futures defined, among other factors, by a range of technological and socio-economic conditions. To navigate this complexity, to restrict the scenario space, and to ensure internal consistency in scenario assessment, the SBTi adopted six broad principles to guide the selection of scenarios. Here, the SBTi used the principles to derive strict criteria for scenario selection. The principles are outlined below, while the precise criteria applied to scenario selection are provided in Table 4.

Ambitious: SBTi criteria should drive action and transformative decarbonization in line with the ambition required to limit warming to 1.5°C. Ambition is the primary principle for pathway selection, as it relates directly to SBTi's primary goal of driving action in the private sector to reduce emissions. In this analysis, the SBTi began our scenario selection by including only scenarios in the AR6 database that limit warming to 1.5°C with a 50% or greater likelihood, with low or no overshoot of the 1.5°C temperature goal. Scenarios in this category (category C1) are the most ambitious scenarios assessed by the IPCC.

Responsible: SBTi criteria should incentivize a transition to net zero that emphasizes low risk of adverse outcomes for broader sustainability goals. For pathways, specifically, the principle of responsibility dictates that they rest on drivers of climate mitigation that are conservative, emphasizing low risk of adverse outcomes for broader sustainability goals, including relevant SDGs and planetary boundaries. The SBTi addressed this principle through several criteria related to sustainability. First, within the C1 category, scenarios were excluded that exceeded the sustainability limits of bioenergy in primary energy consumption in any year before and by 2050. This threshold reflects current scientific consensus on the amount of bioenergy that can be sustainably produced while minimizing detrimental impacts on food production, livelihoods, and biodiversity (Frank et al., 2021). The SBTi excluded scenarios where large-scale bioenergy carbon capture and storage (BECCS) deployment poses risks to biodiversity, livelihoods, and carbon balance, often exceeding sustainability thresholds for land use as highlighted by recent IPCC reports and other literature (IPCC, 2021; Creutzig et al., 2021). To ensure alignment with precautionary limits, a threshold was applied of 3 $GtCO_2$ per year for BECCS deployment in any year between 2020 and 2050 (Warszawski et al., 2021).

Using a similar rationale, the SBTi eliminated scenarios that included more than 3.6

$GtCO_2$ sequestration per year via afforestation in 2050, reflecting the estimated upper limit of sustainable sequestration by this lever (Fuss et al., 2018).

Rigorous: SBTi criteria should be informed by the best available science, as defined by international consensus bodies like the IPCC, and best practices in climate target setting and climate mitigation at the time of development. The selection of scenarios from the AR6 database reflects the principle of scientific rigor, as only scenarios that successfully passed the IPCC's rigorous vetting assessments were considered.

Actionable: SBTi criteria should offer an actionable framework that provides organizations with clear, measurable, and achievable steps toward meeting their targets, thereby facilitating effective and immediate reductions in emissions. For pathways, specifically, this principle dictates that they should be supported by climate mitigation scenarios that rest on credible narratives on how key socio-economic factors, such as population, economic growth, and rate of technological development, may evolve over time. The SBTi applied this principle primarily according to the deployment of key carbon storage technologies. The SBTi restricted scenarios according to the total amount of CO_2 captured and permanently stored in geological formations (CCS), eliminating scenarios that featured a cumulative CCS capacity deployment higher than 214 $GtCO_2$ between 2010 and 2050. This restriction reflects broad concern over the plausibility and feasibility of large-scale CCS deployment along biophysical, infrastructural, and market-related lines (van de Ven et al., 2023).[7] The SBTi also ruled out scenarios exhibiting deployment of novel CDR (i.e., removal of CO_2 via BECCS, DAC, and enhanced weathering) greater than 2.3 Mt in the year 2020, representing their current yearly deployment level based on the most recent estimates (Smith et al., 2023).

Robust: SBTi criteria should be rigorous and impartial, safeguarding the independence of the development process, and enabling credible and evidence-based claims throughout the target-setting and implementation journey. For pathways, this principle necessitates that pathways should be internally consistent and exhibit coherent logic. The SBTi applied the principle of robustness in two ways: first, scenarios were examined that include mitigation through land sinks according to their compatibility with existing SBTi guidance for the land sector[8] (Anderson et al., 2022). This restriction was implemented by calculating cumulative CO_2e emissions from agriculture, forestry, and other land use (AFOLU) for each scenario over the 2020-2050 time period and comparing this to the land-based emissions in the SBTi FLAG pathway. No constraint was applied on the upper limit of land-based emissions.

Transparent: SBTi criteria should make all relevant information publicly available, and be documented in a way that supports balanced, multi-stakeholder involvement in their construction and use. This principle implies that SBTi standards must rest on methods, scenarios, and positions that are transparently documented, including explicit statements of assumptions. As such, the SBTi only selected scenarios for inclusion if their underlying scenario data were publicly available.

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[7] This reflects a simplified assumption that 75% of the volume of oil and gas basins, and 25% of the volume of saline aquifers, could be deployed for CO_2 storage. For more details about how this heuristic was derived, see supplementary material of van de Ven et al. (2023).

[8] The SBTi forestry, land, and agriculture (FLAG) pathway is based on the summary of land-based mitigation potential in 1.5°C scenarios described by Roe et al. (2019).

To analyze the remaining emissions pathways for N_2O emissions from the use of N-fertilizers in the AR6 scenarios, the SBTi focused on the variable for N_2O emissions from soil management practices in the agriculture sector, classified in the AR6 dataset as *Emissions|N2O|AFOLU|Agriculture|Managed Soils.*

Upon applying the principles-driven filtering criteria to the C1 scenarios category of the AR6, and limiting to scenarios that report the emissions of N_2O from managed soils in the agriculture sector, nine scenarios were found to meet all criteria, originating from two main model families. The number of scenarios satisfying each filter is shown in Table 4.

Table 4. Filtering criteria applied to the AR6 scenario database, and the number and percentage of C1 scenarios satisfying each individual criterion. When applied together, nine scenarios satisfied all criteria. Scenarios in the C1 category are the most ambitious scenarios assessed by the IPCC and exhibit low or no overshoot of the 1.5°C temperature goal

FILTERING CRITERION	VALUE	REFERENCE	NUM. (%) OF C1 SCENARIOS MEETING CRITERION
Maximum primary energy from bioenergy in any year between 2010-2050	<100 EJ	Frank et al., 2021	30 (31%)
Maximum CO_2 removed via BECCS in any year between 2010-2050	<3 Gt CO_2	Warszawski et al., 2021	35 (36%)
Maximum CO_2 removed via afforestation in 2050	<3.6 Gt CO_2	Fuss et al., 2018	80 (82%)
Total cumulative CO_2 permanently stored in geological deposits, 2010-2050	<214 Gt CO_2	van de Ven et al., 2023	83 (86%)
Maximum CO_2 removed via novel CDR in 2020	<2.3 Mt CO_2	Smith et al., 2023	92 (95%)
Total cumulative AFOLU emissions, 2020-2050	>-99.54 Gt CO_2e	Anderson et al., 2022	95 (98%)

The nine scenarios remaining from this analysis are listed in Table 5.

Table 5. Scenarios meeting all filtering criteria

MODEL	SCENARIO NAME
MESSAGEix-GLOBIOM_1.1	EN_NPi2020_500
MESSAGEix-GLOBIOM_1.1	EN_NPi2020_600_DR1p
MESSAGEix-GLOBIOM_1.1	EN_NPi2020_600_DR2p

MESSAGEix-GLOBIOM_1.1	EN_NPi2020_600_DR3p
MESSAGEix-GLOBIOM_1.1	EN_NPi2020_600_DR4p
MESSAGEix-GLOBIOM_1.1	EN_NPi2020_600_COV
REMIND-MAgPIE 2.1-4.2	EN_NPi2020_600f_COV
REMIND-MAgPIE 2.1-4.2	SusDev_SDP-PkBudg1000
REMIND 2.1	LeastTotalCost_LTC_brkLR15_SSP1_P50

The MESSAGEix-GLOBIOM integrated assessment model (IAM) consists of the energy model MESSAGEix and the land use model GLOBIOM. GLOBIOM provides a detailed representation of the agricultural, forestry, and bio-energy sectors, including modeled emissions from these sectors. Emissions from crop sources in GLOBIOM include N_2O from both synthetic and organic fertilizers (IBF-IIASA, 2023). Relevant mitigation options referenced in the GLOBIOM model include improved fertilization practices and the use of nitrification inhibitors (Frank et al., 2018).

The REMIND-MAgPIE 2.1-4.2 framework is a coupling of the energy-economy model REMIND and the agricultural production model MAgPIE. MAgPIE includes a nitrogen module that estimates N_2O emissions from managed soils, among other sources (Dietrich et al., 2019). Relevant mitigation options referenced in the MAgPIE model also include improved fertilization practices and the use of nitrification inhibitors (Lucas et al., 2007).

In order to ensure the consistency of these two modeling frameworks for use in the pathway development, the SBTi compared the reported values in the base year for both N_2O emissions from managed soils and the total use of nitrogen as fertilizer from the scenarios listed in Table 5. For both variables, the REMIND-MAgPIE 2.1-4.2 framework reported values that were significantly higher than the median values from the rest of the C1 scenario dataset, and from the values reported in FAOSTAT (FAO, 2024). A comparison of these values is shown in Table 6.

Table 6. Reported fertilizer use by source

MODEL/SOURCE	SCENARIO	VARIABLE	2020 REPORTED VALUE
REMIND and REMIND-MAgPIE Scenario Results			
REMIND-MAgPIE 2.1-4.2	EN_NPi2020_600f_COV	Fertilizer Use, Nitrogen (Inorganic + organic)	254.7 Tg N
		N_2O Emissions from Managed Soils	7,411.5 kt N_2O
REMIND-MAgPIE 2.1-4.2	SusDev_SDP-PkBudg1000	Fertilizer Use, Nitrogen (Inorganic + organic)	257.9 Tg N

MODEL/SOURCE	SCENARIO	VARIABLE	2020 REPORTED VALUE
		N_2O Emissions from Managed Soils	7,406.7 kt N_2O
REMIND 2.1	LeastTotalCost_LTC_brkLR15_SSP1_P50	Fertilizer Use, Nitrogen (Inorganic + organic)	Not reported
		N_2O Emissions from Managed Soils	7,452.4 kt N_2O
For Comparison:			
Full C1 scenario dataset, excluding REMIND-MAgPIE scenarios (Median)	–	Fertilizer Use, Nitrogen (Inorganic + organic)	124.7 Tg N
		N_2O Emissions from Managed Soils	4,127.1 kt N_2O
FAOSTAT (World Total)	–	Fertilizer Use, Nitrogen (Inorganic only)	114.7 Tg N
		N_2O Emissions from Synthetic Fertilizers + Manure applied to Soils	2,913.3 kt N_2O

To ensure consistency among the included scenarios, the SBTi eliminated the scenarios from the REMIND-MAgPIE model family shown in Table 6 from the final list of scenarios used to calculate the pathway.

To determine near-term pathways for setting targets on emissions of N_2O in scope 3 category 11 from the use of sold N-fertilizers, the SBTi calculated the percentage reduction in relevant N_2O emissions in each of the three independent studies described above (Gao & Serrenho, McKinsey & Co, and Systemiq), and the percentage reduction in N_2O emissions from managed soils in the agriculture sector in the six MESSAGEix-GLOBIOM scenarios shown in Table 5 for the period of 2020-2030. To determine a long-term target-setting pathway, the same calculations were performed on the period 2020-2050.

The near and long-term target-setting pathways have been set based on the median of the percentage reductions from the included studies and scenarios. Near-term targets are based on an absolute reduction method using a reduction of 13% in absolute emissions between 2020 and 2030 from the reference pathway. Net zero targets are based on a reduction in absolute emissions of 17% from 2020 to 2050 from the reference pathway. The calculated percentage reduction values and the resulting median reduction percentage are shown in Table 7.

Table 7. Calculated absolute emissions reduction percentage in N_2O emissions from the fertilizer use-phase

MODEL / STUDY	SCENARIO NAME	% REDUCTION IN N_2O EMISSIONS *2020-2030*	% REDUCTION IN N_2O EMISSIONS *2020-2050*
MESSAGEix-GLOBIOM_1.1	EN_NPi2020_500	17.4%	22.4%
MESSAGEix-GLOBIOM_1.1	EN_NPi2020_600_DR1p	11.0%	13.4%
MESSAGEix-GLOBIOM_1.1	EN_NPi2020_600_DR2p	12.5%	15.3%
MESSAGEix-GLOBIOM_1.1	EN_NPi2020_600_DR3p	12.7%	16.0%
MESSAGEix-GLOBIOM_1.1	EN_NPi2020_600_DR4p	12.7%	16.7%
MESSAGEix-GLOBIOM_1.1	EN_NPi2020_600_COV	11.1%	15.4%
Gao & Serrenho	–	46.3%	76.0%
McKinsey & Co	–	9.0%	27.0%
Systemiq	–	23.3%	69.9%
Median		**13%***	**17%***

*Values conservatively rounded up to two digits.

The SBTi recognizes the importance of establishing a specific pathway for setting targets on N_2O emissions from the use of fertilizers in the field. Additional research on mitigation measures for these emissions in the context of equitable food demand scenarios would provide further insight into source-specific climate-aligned pathways. Additionally, improving the availability of primary data from farming practices up the value chain could provide fertilizer manufacturers more visibility and influence on how their products are being used. This could increase the uptake of optimized fertilizer application methods in all regions and thus reduce the N_2O emissions associated with the use of fertilizers and improve quantification of these reductions. In future work, the SBTi may revisit this target-setting method as part of the review and revision process for this document to incorporate future research.

2.5 Development of target-setting metrics for the sourcing of alternative sources of feedstock carbon.

Scenarios and roadmaps for the chemicals sector's transition towards net zero commonly include a reduction in reliance on virgin fossil feedstocks, and an increase in the usage of alternative feedstocks. Different literature sources provide different projections for the future feedstock mix as well as the dominance of the various alternative feedstocks (bio-based, recycling, and CCU), as is illustrated in Table 4.3 of (Kloo, 2023).

To determine a sector pathway in share of alternative feedstocks for this criteria, the SBTi used the scenarios described in the reports *Planet-compatible pathways for transitioning the*

chemical industry (Meng, et al., 2023), and *Planet Positive Chemicals: Pathways for the chemical industry to enable a sustainable global economy* (Kremer, et al., 2022).

These studies present planet-compatible pathways toward 2050, employing demand-side and supply-side interventions. These pathways were chosen due to the detailed modeling of feedstock types, scope 3 emissions, and availability of data between 2020 and 2050.

The low- and high-circularity demand scenarios (LC and HC), as well as the most economic (ME) and no fossil new build after 2030 (NFAX) supply scenarios, were jointly analyzed to model the rate of increase in alternative feedstock consumption by the chemical sector from 2020 to 2050.

Ultimately, the SBTi has decided to use the LC demand scenario as the basis for the pathway to be conservative regarding re-use and substitution rates.[9] The values for the alternative feedstock pathway were determined as described below. Unless otherwise noted, the scenarios analyzed are the LC-ME and LC-NFAX scenarios.

STEP 1: Determine overall use of different feedstocks for production of the chemicals included in the scenarios for each year.

STEP 2: Determine a representative end-of-life emissions factor in 2050 based on the modeled end-of-life fates for each hydrocarbon chemical (e.g., incineration with and without CCS, recycling, landfilling, etc.).

STEP 3: Determine the end-of-life emissions and the share of carbon (C) that is emitted end-of-life in 2050 for all the produced hydrocarbon chemicals (including urea) in each scenario.

STEP 4: Determine the ratio between the LC-ME and the LC-NFAX scenarios that balances the share of feedstock C of atmospheric origin in 2050 with the share of C that is emitted end-of-life in 2050 from Step 3. Applying a combination of the LC-ME and LC-NFAX scenarios based on this ratio results in shares of alternative feedstocks for the modeled chemicals that are between the modeled shares from the LC-ME and LC-NFAX scenarios.

STEP 5: Add 8% to the obtained alternative feedstock numbers to reflect the additional potential of direct bio-based routes that are not included in the modeled feedstocks in the reference scenarios, and current use of bio-based feedstocks.

A detailed explanation of the method used to determine the alternative feedstock pathway using these steps is provided below.

STEP 1: The yearly overall use of the various types of feedstocks was determined from:

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[9] As a comparison exercise, a combination of the HC-ME and HC-NFAX scenarios was also analyzed, which resulted in comparable values to the LC scenarios for the alternative feedstock target in 2030, 2040, and 2050.

1. Feedstock use (in Mt feedstock) to produce ethylene, propylene, butadiene, benzene, toluene, xylene, methanol, and urea was taken from the reference study's global dashboard file:[10]

   - HVCs produced in refineries are not accounted for in the feedstock share. As IEA projects for their NZE scenario that by 2050 around 32% of total fuels will be alternative fuels (based on energy content, rather than C-content) (IEA, 2023d), chemicals originating from refineries were not deemed to present a major deviation for the downstream chemical companies purchasing HVCs for the minimum target. Thus, production of primary chemicals in the reference study's modeling using the following refinery processes is excluded:
     - Gasoline catalytic reformer.
     - LPG catalytic reformer.
     - Off-gas catalytic reformer.[11]

   - The production of "Ammonium Nitrate" and production of "Ammonia (excluding Derivatives)" are both excluded; the production of ammonia for the conversion to urea (including its subsequent conversion to urea) is included.

2. The feedstock consumption in Mt feedstock from #1 was converted to feedstock consumption in Mt-C by multiplying #1 with the carbon content for each feedstock, which was also taken from the global dashboard file. A value of 0.65 was used for pyrolysis oil.

3. The total feedstock use was determined for each of the following feedstock categories:

   - Virgin fossil feedstock.
   - Bio-based feedstock.
   - Direct Air Capture CO_2 (considered part of CCU-based feedstock).
   - Point Source CO_2 (considered part of CCU-based feedstock).
     - The SBTi's definition of alternative feedstock excludes traditionally produced urea[12] from the CCU feedstock category. Therefore, to consider point source CO_2 used to produce urea:
       - CO_2 from fossil and municipal solid waste (MSW)[13] feedstocks to produce urea doesn't qualify as CCU and thus doesn't contribute to the alternative feedstock target.

       - CO_2 from bio-based feedstocks to produce urea doesn't qualify as CCU but does qualify as bio-based and thus counts toward the alternative feedstock target.

       - Double counting of CO_2 from fossil- or bio-based feedstocks is corrected.

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[10] The Global Dashboard file is provided as part of the supplementary modeling documentation data for the reference study. It is available at https://github.com/systemiqofficial/Pathways-Chemical-Industry.

[11] This also means the impact of a shift from production of High Value Chemicals in refineries to the chemical sector has not been explored.

[12] Traditionally produced urea involves the production of ammonia from fossil-based sources, in which the ammonia and the CO_2 from this ammonia production is captured explicitly to be used as feedstocks to produce urea.

[13] MSW feedstocks do qualify as chemical recycling. Note the origin of the MSW (bio-based or fossil) would only have been relevant for 2050, in which no MSW feedstock is used to produce urea in any of the four assessed scenarios.

- Remaining CO_2 feedstock to produce urea is all assumed to originate from another point source (e.g., the cement sector) and thus counts toward the alternative feedstock target as CCU-based feedstock (but doesn't qualify as CO_2 of atmospheric origin, as seen below).
  - For Point Source CO_2 for methanol:
    - CO_2 feedstock is all assumed to originate from another point source and thus contributes to the alternative feedstock target as CCU-based feedstock (but doesn't qualify as CO_2 of atmospheric origin, as seen below).
- MSW refuse-derived fuel (RDF) and pyrolysis oil together form the 'chemical recycling' feedstocks.
- In line with the reference study's approach to treat depolymerization- and dissolution-recycling as demand reduction, and in view of the expected limited availability of mainly dissolution-recycling options for chemical products, these volumes have been added to the volumes of mechanical recycling.[14]
- Mechanical recycled volumes are:
  - Neither included in the alternative feedstock scope, nor in the calculation of the total amount of feedstocks for Table 9 (target thresholds that exclude mechanically recycled materials).
  - Included in the alternative feedstock scope, as well as in the calculation of the total amount of feedstocks for Table 10 (target thresholds that include mechanically recycled materials).
- Methanol is used as one of the feedstocks to produce HVCs in the reference study's modeling. However, this methanol-as-feedstock is excluded when determining the share of alternative feedstock in the model's outcomes, because the share of alternative feedstock has already been included in the feedstocks to produce this methanol. Toward later years, the feedstocks going into methanol production seem too high to meet the methanol demand, while the amount of feedstocks is too low for the propylene demand and especially for the xylene demand. The SBTi interprets that a relevant share of the methanol in the model is used for the production of mainly xylene during these years.[15]

STEP 2: The end-of-life emission factor (tCO_2 / tC) was determined for 2050 for each of the hydrocarbon chemicals considered by the reference study (ethylene, propylene, butadiene, benzene, xylene, toluene, and methanol), as follows:

1. Determining the total amount of each of these chemicals that end up in waste after increasing re-use and substitution, after mechanical recycling and after dissolution- and depolymerization-recycling.[16]

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[14] Note that the reference study labels these as 'chemical recycling'.

[15] While this is not shown in the numbers for feedstock use for propylene and xylene used, the SBTi is relatively confident about this assumption, as we can approximately replicate the Mt carbon feedstock from figure 2 in (Meng, Wagner, Kremer, & Kanazawa, 2023).

[16] Based on the distribution of waste processing technologies, as the reference study provides for LC-scenarios, specifically in worksheets "Ethylene Recycling LC", "Propylene Recycling LC", "Methanol Recycling LC", "BTX Recycling LC", and "Butadiene Recycling LC".

2. Converting these into end-of-life emissions using the following factors:[17]

- Landfilling / Dumpsite: 0 tCO$_2$ / tC (from the "Scope 3 Yearly" worksheet in the demand model supplemental data file. This is a simplification, assuming negligible emissions from landfilling of durable plastics and ignoring emissions of methane from non-durable waste.

- Leakage into the environment and into oceans: 0 tCO$_2$ / tC (from the "Scope 3 Yearly" worksheet in the demand model supplemental data file. This is a simplification which may require further work in the future.

- Incineration (with or without energy recovery) without CCS: Stoichiometric conversion (all C becomes CO$_2$). While this value is higher than assumed by the reference study, it suggests that, by 2050, emissions will not be attributed to the energy consumer.

- Incineration with CCS: 5% of the emissions without CCS, in line with the "Scope 3 Yearly" worksheet in the demand model supplemental data file.

- Open burning: Stoichiometric conversion (all C becomes CO$_2$). This value is higher than assumed by the reference study.

STEP 3: The overall end-of-life emissions (tCO$_2$) for the hydrocarbon chemicals and urea were determined for each scenario (LC-ME and LC-NFAX) based on their production in 2050[18] by adding:

1. The product from the production of each of the hydrocarbons with their determined end-of-life carbon emissions factor, as described above in step 2 (including urea, amounts are based on numbers in the "Yearly Summary" worksheet in the demand model supplemental data file).

2. End-of-life carbon emissions from urea, obtained by multiplying its production[19] with the stoichiometric emissions factor (44/12) based on the assumption that all urea would be applied as fertilizer and thus emit the embodied CO$_2$.

STEP 4: The minimum pathway for the alternative feedstock target in each year in these target-setting criteria was based on a combination of the LC-ME and the LC-NFAX scenarios that would ensure the percentage of overall end-of-life carbon (as CO$_2$) emitted calculated in Step 3 was equal to the percentage of carbon of atmospheric origin in the feedstock[20] by:

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[17] The SBTi is unsure whether the distribution of end-of-life treatment routes is just based on plastics, or also on other products. In absence of other data, the SBTi has applied the distribution between these routes to all production of hydrocarbons, adding uncertainty to the approach taken.

[18] This assumes ultimately each produced hydrocarbon, at some point, reaches end-of-life status; its timing was not considered. In line with our understanding of the reference study's approach, total (fossil+biobased) CO$_2$ emissions are included.

[19] As simplification: To weigh the emission factors of the different feedstocks and products, 100% conversion of C in all feedstocks to product has been assumed; this assumption is not conservative for urea (as the C-conversion efficiency in urea production is likely significantly higher than the C-conversion efficiency in HVC production from naphtha even when considering by-products).

[20] This carbon balancing method is described by the reference study in (Meng, Wagner, Kremer, & Kanazawa, 2023), although the SBTi is unsure whether the reference study applied this rationale of balanced carbon flows to all scenarios. The SBTi has chosen to apply the end-of-life percentages based on *products* to *feedstocks*, thus including the share of feedstock that end up as loss, fuel, or by-product would have a similar[17] emission factor as

1. Determining the percentage of carbon of atmospheric origin in the feedstock as the amount of bio-based carbon + CCU-based carbon from direct air capture[21] for the separate LC-ME and LC-NFAX scenarios.

2. Establishing a percentage of alternative feedstocks in each year using a weighted average of the alternative feedstocks in each of the two scenarios to achieve a balance between CO_2 end-of-life emissions and feedstock carbon of atmospheric origin. In this balanced state, the amount of feedstock C of atmospheric origin = the amount of emitted C at end-of-life. This was done using the following data and method:

Table 8. Parameters used to determine combined alternative feedstock pathway values

PARAMETER	VALUE	NOTES
Percentage of C emitted at end-of-life from total produced hydrocarbon chemicals in the LC-ME scenario in 2050	22 wt.% C	Represents the total C to be balanced by feedstocks of atmospheric origin in the SBTi target threshold calculations.
Percentage of feedstocks of atmospheric origin in the LC-ME scenario in 2050	7.6 wt.% C	Implies there are remaining emissions at end-of-life in this scenario that are not balanced by feedstocks from atmospheric origin.
Percentage of feedstocks of atmospheric origin in the LC-NFAX scenario in 2050	59 wt.% C	Implies there are greater amounts of feedstocks from atmospheric origin than end-of-life emissions in this scenario.

The SBTi combined the LC-ME and LC-NFAX scenarios by assigning a relative weight to each scenario based on how close each scenario's share of feedstocks of atmospheric origin, as summarized in Table 8, is to the 22% of end-of-life CO_2 emissions in the LC-ME scenario. In this case, closer values result in a higher weight:[22]

Weighting for LC-ME scenario = 1- [(22 wt. % C – 7.6 wt. % C) / (59 wt. % C – 7.6 wt. % C)] = 72%

Weighting for LC-NFAX scenario = 1- [(59 wt. % C – 22 wt. % C) / (59 wt. % C – 7.6 wt. % C)] = 28%

The weighted average of the alternative feedstock share from each scenario, using the weighting factors above, was used to determine the minimum alternative feedstock pathway values in each year, prior to the adjustment described below in step 5.

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the share of feedstock that ends up as product; this assumption has been made for simplicity and is not based on either an assessment or expert judgement.

[21] This approach just accounts for removal of CO_2 from the atmosphere into bio-based feedstock and through direct air capture into products. It ignores any upstream emissions for the production of biobased feedstock / DAC. It also doesn't account for any upstream emissions savings by replacing the virgin fossil feedstock. It thus is a highly simplified approach that should not be used for Life Cycle Analyses or GHG emissions accounting. MSW is assumed to be of fossil origin only; volumes are < 1% of total C in LC-ME and LC-NFAX.

[22] This calculation method includes a simplifying assumption of equivalent volume of production between the LC-ME and LC-NFAX scenarios, as both scenarios use the same demand model. In the actual reference study modeling, there are minor differences in total production between the scenarios.

STEP 5: 8% is added to the total feedstock values, as calculated above,[23] now and in future years, to account for bio-based feedstocks currently used in the sector, mainly to make specific chemicals often with molecule structures resembling the molecule structure of biomass. This percentage is based on the currently estimated percentage (Kaehler, 2023) and is assumed to remain constant through the years. The minimum pathway values in Tables 9 and 10 include the 8% bio-based feedstocks values.

The higher alternative feedstock share values based on the LC-NFAX scenario remain as an inspirational alternative feedstock target because:

1. The minimum pathway values are based on a highly simplified approach, e.g., ignoring emissions from non-durable waste from landfilling and upstream emissions from the production of biomass (including indirect land-use change emissions).

2. This approach relies to a high extent on application of CCS on waste incineration and on landfilling, and assumes zero emissions from leakage and landfilling. Thus, higher alternative feedstock shares may be needed.

3. Our understanding of the reference study's modeling suggests a rather limited potential for chemical recycling; therefore, the potential for chemical recycling as a feedstock option may be higher.

4. The current targets ignore the upward potential for growth of direct routes toward bio-based or CCU-based chemicals (without methanol or High Value Chemicals as intermediates).

5. As the reference study modeled the scenario with a relatively low[24] carbon price,[25] the share of alternative feedstocks by 2050 may be higher for scenarios based on a carbon price similar to the carbon price in IEA's NZE scenario.

*Table 9. Alternative feedstock pathway shares by 2030, 2040, and 2050, **excluding** mechanically recycled materials*

SCENARIO	2020	2030	2040	2050
Minimum pathway values (based on the combination of the LC-ME and LC-NFAX scenarios)	0 wt.% C	14 wt.% C	26 wt.% C	42 wt.% C

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[23] With 0% in 2020, 1.6% in 2021, 3.2% in 2022, 4.8% in 2023, 6.4% in 2024, 8% in 2025 and later, this 8% is assumed to be additional production (*not* involving the production of primary chemicals), and the total percentage of alternative feedstocks is thus divided by 1.08.

[24] The carbon price used by the reference study (132 USD / tCO_2) is likely lower than the carbon price applied by IEA in their NZE scenario, ranging from 55 to mostly 180-250 USD / tCO_2 (IEA, 2023c). This infers that the percentages of alternative feedstock projected from the reference study's Most Economic scenarios would be higher if a higher carbon price was utilized.

[25] Carbon price for the reference study can be found in the "Prices and Availability" tab in the "Master Template" file at https://github.com/systemiqofficial/Pathways-Chemical-Industry.

Table 10. Alternative feedstock pathway shares by 2030, 2040 and 2050 including mechanically recycled materials

SCENARIO	2020	2030	2040	2050
Minimum pathway values (based on the combination of the LC-ME and LC-NFAX scenarios)	4 wt.% C	19 wt.% C	34 wt.% C	55 wt.% C

Data for years not shown in Tables 9 and 10 were calculated based on linear interpolation between the years shown.

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