On behalf of Agilyx

Product Carbon Footprint of Styrene from Depolymerization of Waste Polystyrene

June 2025

Client:	**Agilyx**
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On behalf of Sphera Solutions, Inc., and its subsidiaries

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List of Acronyms

BTX	Benzene, Toluene, and Xylenes
CFP	Carbon Footprint of a Product
EoL	End-of-Life
GaBi	Ganzheitliche Bilanzierung (German for holistic balancing)
GHG	Greenhouse Gas
GWP	Global Warming Potential
GWPt	Net Total Global Warming Potential
ISO	International Organization for Standardization
LCA	Life Cycle Assessment
LCA FE	LCA for Experts (fka GaBi)
LCI	Life Cycle Inventory
LCIA	Life Cycle Impact Assessment
LHV	Lower Heating Value
MLC	Managed LCA Content
PCF	Product Carbon Footprint
PS	Polystyrene

Glossary

Product Carbon Footprint (PCF)

A life cycle study that only quantifies a single impact category: climate change (ISO, 2019).

Declared Unit

An amount of a product, typically mass-based, that is used a reference unit for a partial PCF (ISO, 2019).

Partial Product Carbon Footprint

A PCF that does not include all the stages in a product's life cycle. They are most commonly cradle-to-gate assessments (ISO, 2019).

Life Cycle

A view of a product system as "consecutive and interlinked stages … from raw material acquisition or generation from natural resources to final disposal" (ISO 14040:2006, section 3.1). This includes all material and energy inputs as well as emissions to air, land and water.

Life Cycle Assessment (LCA)

"Compilation and evaluation of the inputs, outputs and the potential environmental impacts of a product system throughout its life cycle" (ISO 14040:2006, section 3.2)

Life Cycle Inventory (LCI)

"Phase of life cycle assessment involving the compilation and quantification of inputs and outputs for a product throughout its life cycle" (ISO 14040:2006, section 3.3)

Life Cycle Impact Assessment (LCIA)

"Phase of life cycle assessment aimed at understanding and evaluating the magnitude and significance of the potential environmental impacts for a product system throughout the life cycle of the product" (ISO 14040:2006, section 3.4)

Life Cycle Interpretation

"Phase of life cycle assessment in which the findings of either the inventory analysis or the impact assessment, or both, are evaluated in relation to the defined goal and scope in order to reach conclusions and recommendations" (ISO 14040:2006, section 3.5)

Functional Unit

"Quantified performance of a product system for use as a reference unit" (ISO 14040:2006, section 3.20)

Allocation

"Partitioning the input or output flows of a process or a product system between the product system under study and one or more other product systems" (ISO 14040:2006, section 3.17)

Closed-loop and Open-loop Allocation of Recycled Material

"An open-loop allocation procedure applies to open-loop product systems where the material is recycled into other product systems and the material undergoes a change to its inherent properties."

“A closed-loop allocation procedure applies to closed-loop product systems. It also applies to open-loop product systems where no changes occur in the inherent properties of the recycled material. In such cases, the need for allocation is avoided since the use of secondary material displaces the use of virgin (primary) materials.” (ISO 14044:2006, section 4.3.4.3.3)

Foreground System

“Those processes of the system that are specific to it … and/or directly affected by decisions analyzed in the study.” (JRC, 2010, p. 97) This typically includes first-tier suppliers, the manufacturer itself and any downstream life cycle stages where the manufacturer can exert significant influence. As a general rule, specific (primary) data should be used for the foreground system.

Background System

“Those processes, where due to the averaging effect across the suppliers, a homogenous market with average (or equivalent, generic data) can be assumed to appropriately represent the respective process … and/or those processes that are operated as part of the system but that are not under direct control or decisive influence of the producer of the good….” (JRC, 2010, pp. 97-98) As a general rule, secondary data are appropriate for the background system, particularly where primary data are difficult to collect.

Critical Review

“Process intended to ensure consistency between a life cycle assessment and the principles and requirements of the International Standards on life cycle assessment” (ISO 14044:2006, section 3.45).

Comparative Assertion

An “environmental claim regarding the superiority or equivalence of one product versus a competing product that performs the same function.” (ISO 14044:2006, section 3.45) Such claims cannot be made on the basis of PCF studies because they only focus on a single environmental impact: global warming potential.

Executive Summary

ES.1 Company Background

Agilyx uses advanced recycling technology to convert post-use plastics into high-value, virgin-equivalent products. Styrenyx, its proprietary advanced recycling technology via catalyst-free depolymerization, recycles polystyrene waste back into the styrene monomer for use in high-quality products.

ES.2 Goal and Scope Definition

To better understand the global warming potential (GWP) of their styrene monomer, Agilyx commissioned Sphera Solutions, Inc. (“Sphera”) to perform a cradle-to-gate product carbon footprint (PCF) of its styrene production. The GWP associated with Agilyx’s styrene is also compared to the GWP associated with producing virgin styrene from fossil resources. The study has been conducted according to the requirements of the International Organization for Standardization (ISO) 14067:2019-02 (ISO, 2019).

The functional unit for this cradle-to-gate PCF is the production of 1 kg of styrene monomer. Agilyx styrene is produced from post-consumer waste polystyrene along with a blend of benzene, toluene, and xylenes (BTX) and pyrolysis oil co-products. In the baseline scenario, co-product allocation is considered using lower heating value for both the recycled and virgin styrene. Scenario analyses also explored allocation by mass and C content as well as system expansion where the pyrolysis oil goes through hydrocracking to produce naphtha, for which it receives a credit. The BTX blend co-product also receives a credit for mixed BTX in that scenario.

Since Agilyx’s advanced recycling process is multi-functional: it produces products and treats post-use waste polystyrene, it is necessary to somehow consider the additional function associated with waste treatment. In the base case, upstream waste management credits are provided for the US national average treatment of polystyrene in US municipal solid waste.

Primary data for Agilyx styrene was provided by Agilyx to represent a potential full-scale facility operating in 2025, and secondary data was provided by Sphera’s 2025.1 Managed Life Cycle Assessment Content (MLC). Primary data on inputs, yields, energy use, and waste were developed by Agilyx using rigorous engineering calculations based on actual recorded results and experience from the operation of a 3,300 ton per year pilot facility over many years. Virgin styrene production was modeled using the US styrene production from ethylbenzene dehydrogenation in the MLC 2025.1 database. The reference year for the dataset is 2023, and documentation can be found online at https://lcadatabase.sphera.com/2024/xml-data/processes/7e44071f-b9d2-4845-b6a0-2010bb10968d.xml.

ES.3 Results

Figure ES-1 shows the contributions to the Agilyx styrene compared to the virgin styrene in the baseline scenario. Agilyx styrene reduces cradle-to-gate GWP by 43% compared to virgin styrene (0.97 kg CO_2 eq/kg styrene) when including conventional waste management credits and reduces GWP by 27% (0.61

kg CO_2 eq/kg styrene) when the credits are excluded. Electricity is the largest contributor to total GWP for Agilyx styrene. Electricity contributes 1.02 kg CO_2 eq/kg styrene, which represents 62% of the total GWP burdens of 1.65 kg CO_2 eq/kg styrene (i.e., total GWP excluding credits). Thermal energy is the next largest contributor (0.31 kg CO_2 eq/kg styrene; 19% of GWP burdens), and the waste polystyrene feedstock is the third largest contributor (0.16 kg CO_2 eq/kg styrene). Other raw materials, direct emissions, transport, water, and waste management contribute 9% to the total GWP burdens (0.15 kg CO_2 eq/kg styrene).

The upstream waste management credit reduces the total GWP burdens by ~21%. While this is a significant reduction, it must be noted that the Agilyx styrene reduces GWP by 27% even without these credits.

For the virgin styrene, the ethylene and benzene feedstock contribute 74% to the total GWP of 2.26 kg CO_2 eq./kg styrene. Thermal energy is the next largest contributor at 23%, while electricity and other burdens contribute ~3%.

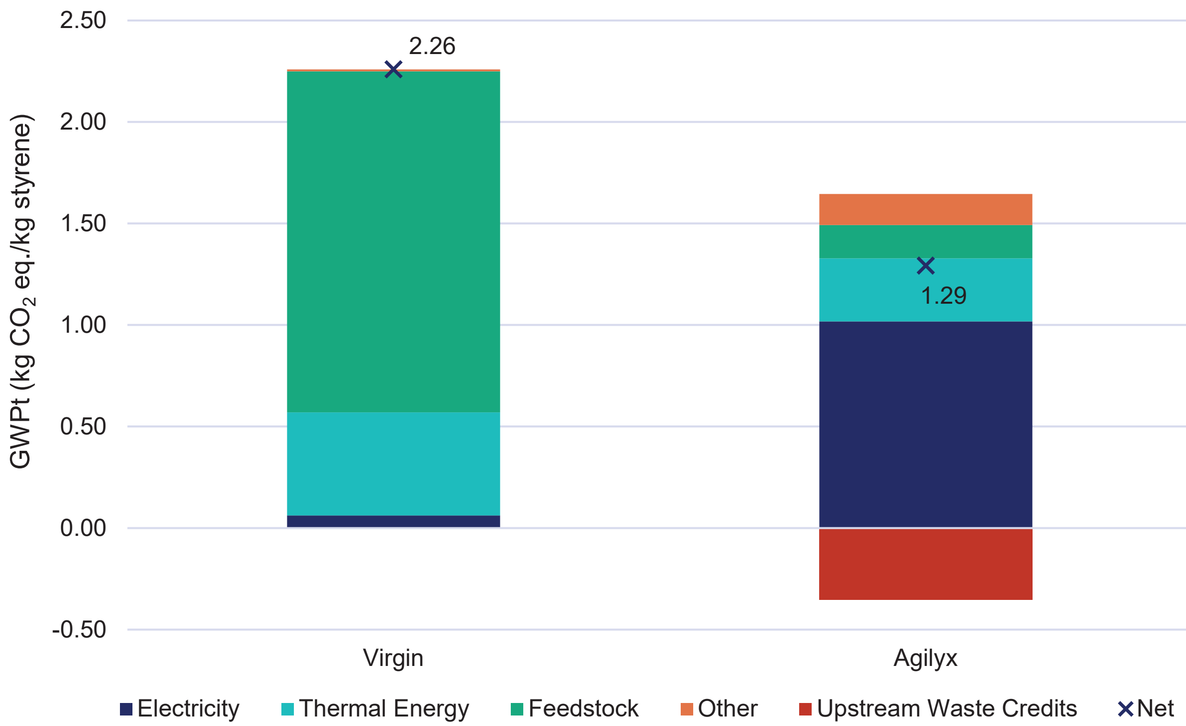


Figure ES-1: Contributions to net total GWP for Agilyx styrene compared to virgin styrene

ES.3.1 Scenario Analysis

Five scenario analyses were performed to compare results between different sets of assumptions or modeling choices:

1. Electricity Source: Used wind electricity instead of grid electricity for both virgin and Agilyx styrene production
2. Thermal Energy Source: Used biogas and wind electricity for thermal energy instead of natural gas for Agilyx styrene

3. Conventional Waste Management: Credits were provided for diverting 100% post-use polystyrene waste from landfill and 100% from incineration instead of 82% landfill, 17.1% incineration, and 0.9% mechanical recycling in the base case
4. Co-Product Allocation: Used mass and carbon content for co-product allocation instead of lower heating value (LHV) in the base case
5. System Expansion: Provided credits for BTX mixture and pyrolysis oil co-products instead of using allocation based on LHV in the base case

The electricity (section 4.3.1) source scenario analysis found that switching to wind electricity could reduce the total GWP from Agilyx styrene by 77%, however, the use of wind electricity in the case of virgin styrene only reduced the total GWP by <3%. The thermal energy (section 4.3.2) source scenario analyses showed that Agilyx can reduce their total GWP burdens by an additional 17% by using biogas instead of natural gas for thermal energy, and by an additional 23% by using wind electricity to produce thermal energy.

The results of the conventional waste management credit scenario analysis (section 4.3.3) indicate that even if Agilyx's waste polystyrene feedstock is all diverted from a landfill, the recycled styrene still outperforms virgin styrene by ~27%. However, diverting polystyrene meant for incineration with energy recovery can decrease the Agilyx styrene total GWP by 129%. This negative GWPt should not be interpreted to mean that Agiylx styrene is carbon negative. It only indicates that incinerating post-use polystyrene waste leads to more GWPt than converting it into styrene via Agilyx's process.

The co-product allocation scenarios (section 4.3.4) showed that the choice of physical attribute for co-allocation has a negligible effect on the results. Finally, the system expansion scenario (section 4.3.5) was developed where all the produced pyrolysis oil is hydrotreated to produce naphtha and an associated credit from virgin naphtha was applied, while the BTX blend receives a credit from virgin mixed BTX. In this scenario, the recycled styrene still outperforms virgin styrene by 25% (0.57 kg CO_2 eq./kg styrene). These last three scenarios provide confidence that Agilyx styrene outperforms virgin styrene under a variety of assumptions.

ES.3.2 Sensitivity Analysis

Sensitivity analyses were performed on electricity and thermal energy demand (section 4.4) to test the sensitivity of the results towards changes in these parameter values. The analyses showed that electricity demand would need to increase by ~80% per kg styrene for Agilyx styrene to be outperformed by virgin styrene in GWP, while thermal energy would need to increase by ~267% for Agilyx styrene to be outperformed by virgin styrene. Given their much lower contributions, potentially uncertain inputs such as transportation distances or raw material demand would have to increase by much more to breakeven with virgin styrene. Therefore, the conclusion that Agilyx styrene reduces GWPt compared to virgin styrene is relatively insensitive to uncertainty in these input values.

ES.3.3 Uncertainty Analysis

Uncertainty analysis was performed to test the robustness of the results towards the combined parameter uncertainty. The analysis showed that Agilyx styrene is very likely to outperform virgin styrene in terms of GWP even when 50% uncertainty is simultaneously applied to all key model parameters (e.g., feedstock, raw materials, energy demand, and transportation distances) using uniform distributions. Agilyx styrene outperformed virgin styrene by 21% to 65% (0.47 to 1.46 kg CO_2 eq./kg styrene) across the 90th percentile range of the 25,000 iterations.

ES.4 Conclusions and Recommendations

Based on the analyses, assumptions, limitations, and data quality, it is likely that Agilyx styrene is associated with a significantly lower net total GWP compared to virgin styrene. This conclusion holds under a variety of scenarios, assumptions, and over a large range of uncertain input values. The analysis indicates that Agilyx can improve the GWP performance of their styrene by using low-carbon sources of electricity and thermal energy and by preferentially siting facilities where polystyrene waste is predominantly incinerated.

Additional insights into the environmental sustainability of Agilyx styrene could be developed by extending the scope of this analysis to cradle-to-grave and by including additional environmental impacts in a full life cycle assessment. The accuracy of the study could be improved for specific facilities by knowing the specific energy sources and how the waste polystyrene feedstock would otherwise be managed. Additionally, repeating this analysis once a full-scale facility has been in operation will improve the accuracy of the results and conclusions.

ES.5 Potential Future Implications

The US produced approximately 4.68 million metric tons of virgin styrene in 2019 (Statista, 2023), and based on the virgin styrene results from this analysis, that amount of styrene is associated with the emission of ~10 million metric tons of CO_2 eq. Therefore, there is a significant opportunity to reduce the net total GWP from virgin styrene production. An Agilyx facility that produces 33,000 metric tons of styrene annually could reduce net total GWP by ~27,700 metric tons of CO_2 eq compared to virgin styrene. This is equivalent to removing approximately 6,460 average US gasoline cars off the road for the year (~3.11 million gallons of gasoline) or the amount of CO_2 sequestered by over 450,000 tree seedlings over a decade (US EPA, 2024). Therefore, there is significant potential for Agilyx styrene to reduce net total GWP by replacing virgin styrene production.

1. Goal of the Study

Agilyx uses catalyst-free depolymerization to convert post-use plastics into high-value, virgin-equivalent products. To better understand the global warming potential (GWP) of their styrene monomer produced from waste polystyrene, Agilyx commissioned Sphera Solutions, Inc. (“Sphera”) to perform a cradle-to-gate product carbon footprint (PCF) of their production process. The GWP associated with Agilyx’s styrene is compared to that of virgin styrene from fossil resources.

The main audience for this PCF study includes Agilyx’s internal stakeholders, customers, potential investors, and the public. The results will be used to identify hotspots in the manufacturing processes and facilitate informed decision-making related to raw materials, supply chain, energy use, and unit processes and operations by Agilyx’s internal stakeholders. Agilyx is also looking to compare the potential global warming impacts associated with its recycled styrene to virgin styrene for marketing purposes.

As a comparative footprint study, this PCF can only be used as the basis of comparing the global warming potential of Agilyx recycled styrene to generic virgin styrene (e.g., Agilyx recycled styrene reduces global warming potential by X% compared to generic virgin styrene from cradle-to-gate). These specific comparisons are consistent with the goal and scope of the study, and they do not constitute comparative assertions of overall environmental superiority or equivalence as defined by ISO 14044 (ISO, 2006). PCF studies cannot be used as the basis for this type of comparative assertion because they only consider a single impact category: global warming potential. This study would need to evaluate "a comprehensive set of environmental issues" and be reviewed by a panel of at least three expert reviewers to form the basis of this type of comparative assertion according to ISO 14044 (ISO, 2006).

The study has been conducted according to the requirements of the International Organization for Standardization (ISO) 14067:2019 (ISO, 2019) and has undergone independent critical review in accordance with ISO 14071:2024 (ISO, 2024) by Adisa Azapagic of ETHOS Research.

The Critical Review Statement can be found in Annex A, and the critical review report containing the review comments and responses is available from Agilyx upon request.

2. Scope of the Study

The following sections describe the general scope of the project to achieve the stated goals. This includes, but is not limited to, the identification of specific product systems to be assessed, the product function(s), functional unit and reference flows, the system boundary, allocation procedures, and cut-off criteria of the study.

2.1. Product System

Agilyx accepts post-use plastic waste and converts it into products (Figure 2-1). Their styrene system takes waste polystyrene uses catalyst-free depolymerization to convert it into styrene monomer, benzene, toluene, and xylenes (BTX), and pyrolysis oil. The purity of styrene monomer is ≥99.8%, and it is suitable for food grade products and packaging.

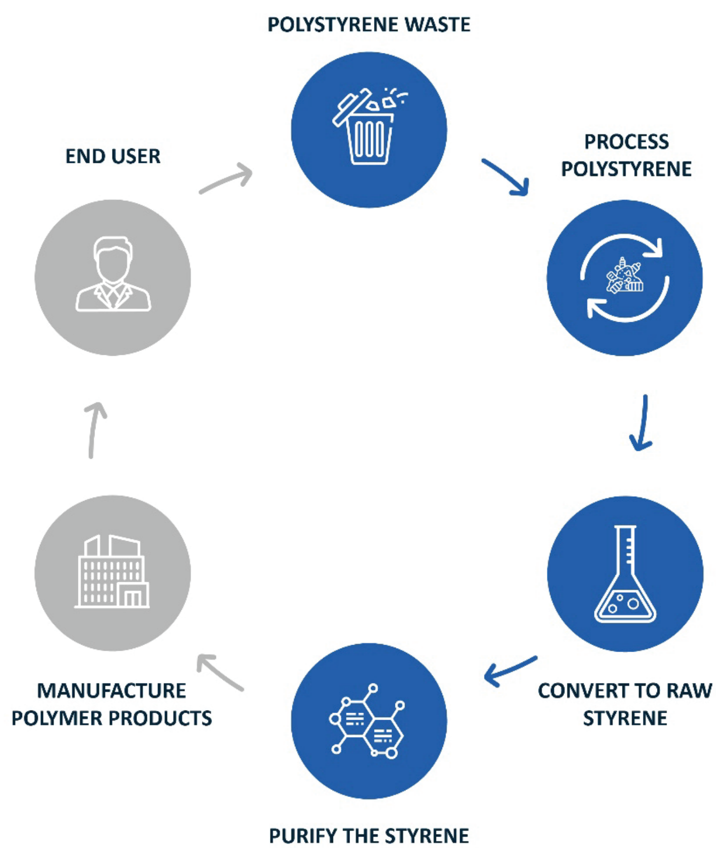


Figure 2-1: Overview of Agilyx and Technip Energies system for converting post-use polystyrene waste into styrene (conversion to products and use are not included in the system boundary)

2.2. Product Function and Declared Unit

Styrene monomer is primarily used as a raw material for chemical production, primarily polystyrene and acrylonitrile butadiene styrene. Since the system boundary is cradle-to-gate, the declared unit for this study is

the production of 1 kg of styrene monomer

This declared unit is selected since it serves as the relevant unit to capture the potential climate change impact of different processes involved in producing 1 kg of styrene. The reference flow is therefore the same as the declared unit.

In addition, Agilyx's styrene production system provides a second function, which is the management of post-consumer polystyrene waste. The specific mass of polystyrene waste varies based on the allocation of co-products, but for the baseline scenario, 1.21 kg of post-consumer polystyrene waste are managed per kg of styrene monomer produced. This additional functionality has been addressed through the use of subtractive system expansion, which provides a credit to Agilyx's styrene monomer production for how the polystyrene waste would have been otherwise managed. This ensures that the virgin and Agilyx styrene product systems are both providing the same functions. A subtractive approach was used because the mass of waste managed varies based on the underlying assumptions of the model regarding yields and co-product allocation.

There is no omission of any additional functions in comparisons made in this study.

2.3. System Boundary

This study is a cradle-to-gate PCF study which refers to life cycle stages from the extraction of raw materials to the manufacturing of products (i.e., styrene) before shipping. A cradle-to-gate boundary was used because the two types of styrene and their associated life cycles are identical after the point of manufacture. Additionally, the cradle-to-gate emissions are likely to account for the large majority of GWP associated with both products over their entire life cycles. Construction of capital equipment, maintenance/operation of support facilities are assumed to contribute negligibly to GWP and are thus excluded.

Table 2-1: System boundaries

Included	Excluded
✓ Collection, transport, sorting, and shredding of polystyrene waste	× Construction of capital equipment
✓ Raw materials production	× Maintenance and operation of support equipment (e.g., employee facilities)
✓ Transportation of raw materials to manufacturing site	× Human labor and employee commute
✓ Use of auxiliary materials, water, and energy during manufacturing	× Virgin polystyrene production
✓ Emissions to air, water, and soil during manufacturing	

2.3.1. Time Coverage

The models are intended to represent the production of styrene in 2024, and the results are considered to be valid until significant technological changes occur.

2.3.2. Technology Coverage

The study is intended to be representative of Agilyx's styrene production from waste polystyrene via catalyst-free depolymerization and virgin styrene production from dehydrogenation of ethylbenzene.

2.3.3. Geographical Coverage

The study is intended to represent styrene production in the US.

2.4. Allocation

2.4.1. Multi-output Allocation

Multi-output allocation follows the requirements of ISO 14044, section 4.3.4.2 (ISO, 2006). When allocation becomes necessary during the data collection phase, the allocation rule most suitable for the respective process step is applied and documented along with the process in Chapter 3. Agilyx's styrene production system creates two additional co-products: a blend of benzene, toluene, and xylenes (BTX) and pyrolysis oil. In the baseline scenario, allocation is based on carbon content, but additional physical properties are tested as well (i.e., mass and energy content). The percent of burdens allocated to each co-product based on each allocation parameter is shown Table 2-2. Across the three properties, there is <1.5% difference between the amount of burdens and credits allocated to the styrene.

Allocation is considered to be preferable to system expansion despite the hierarchy provided by ISO14044 for managing co-products because of the uncertainty associated with the substitution of pyrolysis oil. This is consistent with the Together for Sustainability (TfS) guidelines (section 5.2.9) guidelines which require that a substituted co-product "directly replaces an alternative product with a dedicated production process on the market.", and that there must be a "consensus for a production path of the displaced product." (Together for Sustainability, 2024) Since this is not true for pyrolysis oil, allocation was selected to address co-products. Additionally, the ratio of the economic value of the co-products is <5, which according to TfS guidelines (section 5.2.9) indicates that allocation based on physical properties should be applied (Together for Sustainability, 2024). It should be noted that this study does not claim compliance with the TfS guidelines, their reasoning for how to consider co-products is just being used to further explain the choices made in this study.

Table 2-2: Percent of burdens allocated to each co-product based on different physical properties

Co-Product	Mass (kg)	C Content (kg C/kg)	LHV (MJ/kg)	Percent Allocated		
				Mass	C	LHV
Styrene	1	0.92	40.5	62.7	62.4	61.8
BTX	0.229	0.93	40.7	14.3	14.4	13.8
Pyrolysis Oil	0.367	0.93	41.8	23.0	23.2	24.4

Allocation of background data (energy and materials) taken from Sphera's Managed LCA Content (MLC) 2025.1 databases is documented in (Sphera, 2024) and available at https://lcadatabase.sphera.com/dataset-documentation-download/.

2.4.2. End-of-Life Allocation

End-of-life allocation follows the requirements of ISO 14044, section 4.3 (ISO, 2006). Such allocation approaches address the question of how to assign impacts from virgin production processes to material that is recycled and used in future product systems.

While this is a cradle-to-gate study, there are still waste streams produced during manufacturing and there are potential energy credits from incinerating the waste polystyrene as part of the conventional waste management. In this study, we used a value-corrected substitution approach (also known as 0:100, closed-loop approximation, recyclability substitution or end of life approach), which provides a credits for the recovery of materials and energy at the end-of-life. However, to avoid double-counting the benefits of recycled content, waste materials may carry some of their initial primary burden to the next product system. With value-correction, waste materials without a market value do not carry this burden, nor would they get a credit at the end-of-life. However, those end-of-life recycling credits are not relevant to this study because none of the produced waste streams are recycled at end-of-life.

2.5. Cut-off Criteria

No cut-off criteria are defined for this study. As summarized in section 2.3, the system boundary was defined based on relevance to the goal of the study. For the processes within the system boundary, all available energy and material flow data were included in the model. In cases where no matching life cycle inventories were available to represent a flow, proxy data were applied based on conservative assumptions regarding environmental impacts.

The choice of proxy data is documented in Chapter 3. The influence of these proxy data on the results of the assessment has been carefully analyzed and is discussed in Chapter 5.

2.6. Selection of LCIA Methodology and Impact Categories

As this is a PCF study, the only impact category under investigation is climate change, which is broken down into five sources as required by ISO 14067 (ISO, 2019) and shown in Table 2-3.

The global warming potential impact category is assessed based on the current IPCC characterization factors taken from the 6th Assessment Report (IPCC, 2023) for a 100-year timeframe as this is currently the most commonly used metric. It should be noted that there is no scientific justification for selecting this over other timeframes. The global warming potential results include the photosynthetically bound carbon (also called *biogenic carbon removals*) in the background datasets, however there is no biogenic carbon in either the recycled or virgin styrene, so this only potentially applies to the background datasets.

Global warming potential results further include emissions from direct land use change which are calculated using Sphera's own land use change tool. It follows the recommendations of the European Commission, using the PAS 2050 methodology (BSI, 2012). It is also in accordance with the GHG Protocol Land Sector and Removals Guidance Draft from 2022 (WRI, 2022). For more information, please refer to (Sphera, 2024) available at https://lcadatabase.sphera.com/dataset-documentation-download/. Finally, greenhouse gas (GHG) emissions from aircraft are also separately reported according to ISO 14067:2019 section 6.4.9.7 (ISO, 2019). However, there is no transport by aircraft in the foreground system.

Table 2-3: Reported GHG emissions

Category	Description
Aircraft GHG Emissions	Fossil and biogenic GHG emissions from aircraft transportation.
Biogenic GHG Emissions	Emissions of biogenic CO_2 and CH_4.
Biogenic GHG Removals	Removal of CO_2 and CH_4 from the atmosphere by plants.
GHG Emissions from Direct Land Use Change	GHG emissions associated with direct land use change (i.e., changes in carbon stocks in soil and biomass) within the last 20 years.
Fossil GHG Emissions	All other GHG emissions, which are primarily from fossil fuel combustion.
Total GWP	Sum of all GHG emissions

It shall be noted that the above impact categories represent impact *potentials*, i.e., they are approximations of environmental impacts that could occur if the emissions would (a) actually follow the underlying impact pathway and (b) meet certain conditions in the receiving environment while doing so. In addition, the inventory only captures that fraction of the total environmental load that corresponds to the declared unit (relative approach). GWP results are therefore relative expressions only and do not predict actual impacts, the exceeding of thresholds, safety margins, or risks.

2.7. Interpretation to be Used

The results of the LCI and LCIA were interpreted according to the Goal and Scope. The interpretation addresses the following topics:

- Identification of significant findings, such as the main process step(s), material(s), and/or emission(s) contributing to the overall results
- Evaluation of completeness, sensitivity, and consistency to justify the exclusion of data from the system boundaries as well as the use of proxy data.
- Conclusions, limitations and recommendations

2.8. Data Quality Requirements

The data used to create the inventory model shall be as precise, complete, consistent, and representative as possible with regards to the goal and scope of the study under given time and budget constraints.

- Measured primary data are considered to be of the highest precision, followed by calculated data, literature data, and estimated data. The goal is to model all relevant foreground processes using measured or calculated primary data.

- Completeness is judged based on the completeness of the inputs and outputs per unit process and the completeness of the unit processes themselves. The goal is to capture all relevant data in this regard.
- Consistency refers to modelling choices and data sources. The goal is to ensure that differences in results reflect actual differences between product systems and are not due to inconsistencies in modelling choices, data sources, emission factors, or other artifacts.
- Reproducibility expresses the degree to which third parties would be able to reproduce the results of the study based on the information contained in this report. The goal is to provide enough transparency with this report so that third parties are able to approximate the reported results. This ability may be limited by the exclusion of confidential primary data and access to the same background data sources.
- Representativeness expresses the degree to which the data matches the geographical, temporal, and technological requirements defined in the study's goal and scope. The goal is to use the most representative primary data for all foreground processes and the most representative industry-average data for all background processes. Whenever such data were not available (e.g., no industry-average data available for a certain country), best-available proxy data were employed.

An evaluation of the data quality with regard to these requirements is provided in Chapter 5 of this report.

2.9. Type and Format of the Report

In accordance with ISO 14067:2019 (ISO, 2019)reporting requirements this document aims to report the results and conclusions of the LCA completely, accurately and without bias to the intended audience. The results, data, methods, assumptions, and limitations are presented in a transparent manner and in sufficient detail to convey the complexities, limitations, and trade-offs inherent in the LCA to the reader. This allows the results to be interpreted and used in a manner consistent with the goals of the study.

2.10. Software and Database

The LCA model was created using LCA for Experts (LCA FE) 10.9 Software system for life cycle engineering, developed by Sphera Solutions Inc. The MLC 2025.1 LCI database provides the life cycle inventory data for several of the raw and process materials obtained from the background system.

2.11. Critical Review

The international standard ISO 14071:2024 (ISO, 2024) outlines that an independent expert or panel of experts shall perform the critical review. The primary goals of such a critical review are to provide an independent evaluation of the study and to provide input to the study authors on how to improve the quality and transparency of the study. The benefits of employing a critical review are to ensure that:

- the methods used to carry out the PCF study are consistent with ISO 14044 (ISO, 2006) and ISO 14067 (ISO, 2019),
- the methods used to carry out the PCF study are scientifically and technically valid,
- the data used are appropriate and reasonable in relation to the goal of the study,
- the interpretations reflect the limitations identified and the goal of the study, and

- the study report is transparent and consistent.

For this study, the critical review was conducted by Adisa Azapagic of ETHOS Research.

The reviewer was contracted to perform the critical review as an independent expert. Her review comments shall not be construed to represent the positions of their affiliated organizations.

The review was performed according to ISO 14071:2024 (ISO, 2024) on critical reviews. The independent expert provided feedback on the methodology, assumptions, and interpretation. The draft report was subsequently updated through two rounds of revisions, and a final copy submitted to the reviewer along with responses to comments.

The Critical Review Statement can be found in Annex A.

3. Life Cycle Inventory Analysis

3.1. Data Collection Procedure

Primary data were collected using customized data collection templates, which were sent out by email to the respective data providers in the participating companies. Upon receipt, each questionnaire was cross-checked for completeness and plausibility using mass balance, stoichiometry, as well as internal and external benchmarking. If gaps, outliers, or other inconsistencies occurred, Sphera engaged with the data provider to resolve any open issues.

Wherever feasible, the coefficient of variation was established for the different inputs and outputs, either across different data providers or across the reported time period if a breakdown into smaller increments (e.g., 12 months) was available.

3.2. Agilyx Styrene Production

3.2.1. Overview of Product System

Figure 3-1 shows the process flow diagram for the production of Agilyx’s styrene monomer. Post-use waste polystyrene is collected, sorted, shredded, and transported to the Agilyx facility. The prepared waste polystyrene is received in bulk and off-loaded into a feed delivery system. This system feeds the waste polystyrene into a pre-melt system prior to depolymerization, which produces styrene oil and co-products. The styrene oil, BTX, and pyrolysis oil are then cooled and separated. Finally, the styrene oil is purified to produce a styrene monomer with 99.8% purity. The process also generates solid char, oily wastewater, and additional wastewater for appropriate treatment and/or disposal. While there are potentially beneficial uses for the char, Agilyx has not found a market for it partially due to the limited volume that is produced. Additionally, considering the char a waste also means that no burdens are allocated to it, and burdens associated with landfilling the char are included. Therefore, this assumption is conservative when comparing Agilyx’s recycled styrene to virgin styrene.

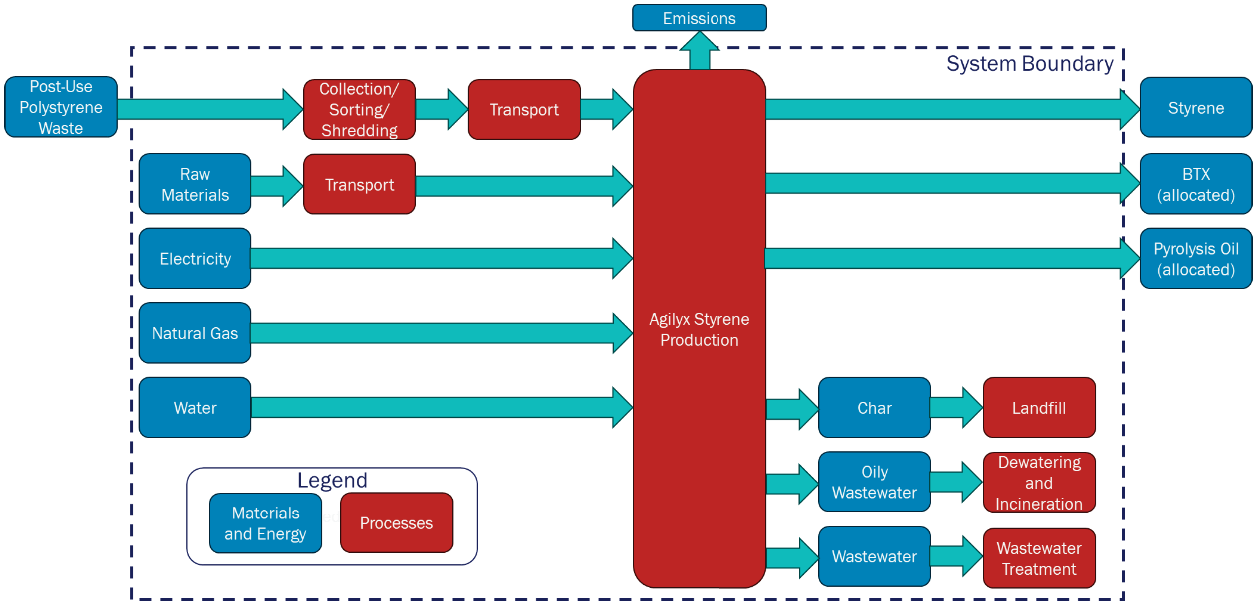


Figure 3-1: Process flow diagram for Agilyx styrene production

3.2.2. Manufacturing

Table B-1 shows the unallocated inputs and outputs associated with the production for 1 kg of styrene, and Table 3-1 shows the values used for allocation. In the baseline scenario, lower heating value is used. However, the effects of using mass and carbon content are also assessed in scenarios, and the differences in results are <1%.

Primary data on inputs, yields, energy use, and waste were developed by performing rigorous engineering calculations based on actual recorded results and experience from the operation of a 3,300 ton per year pilot facility over many years. The work was a collaborative effort led by Agilyx utilizing Worley, a globally recognized engineering, procurement, and construction firm, numerous equipment manufacturers, and permitting authorities.

Table 3-1: Co-product allocation factors for the baseline results and scenarios

Product	Lower Heating Value (MJ/kg)	Mass Out (kg)	Carbon Content (kg C/kg)
Styrene	40.5	1.00	0.92
BTX	40.7	0.229	0.93
Pyrolysis oil	41.8	0.367	0.93
		Percent Allocated	
Product	**Lower Heating Value**	**Mass**	**Carbon Content**
Styrene	61.8	62.7	62.4
BTX	13.8	14.3	14.4
Pyrolysis oil	24.4	23.0	23.2

3.2.3. Waste Polystyrene Collection and Processing

Prior to the manufacturing stage described in section 3.2.2, the system boundary begins with the collection of post-consumer polystyrene waste at the waste generators. The waste is transported an assumed average of 20 miles to a feed processing facility that performs additional sorting and shredding. The 20 mile distance is based on the assumed distance used in the US EPA's WAste Reduction Model (WARM) (US EPA, 2023). After processing, the shredded polystyrene is transported 10 miles to the Agilyx facility. Sorting uses 0.108 MJ of electricity and 0.0619 MJ of diesel per kg of output polystyrene (Sphera, 2023), while shredding requires 0.719 MJ of electricity per kg of polystyrene (Plastic Odyssey, 2024).

3.2.4. End-of-Life

The styrene production process creates three primary waste streams: plastic char, oily wastewater, and wastewater. The char is disposed in a landfill. The oily wastewater is dewatered and incinerated, and the wastewater is sent via sewers to a municipal wastewater treatment facility.

3.2.5. Conventional Post-Use Styrene Waste Management Credits

Since Agliyx's advanced recycling system provides two functions: production of styrene and management of waste polystyrene, it is necessary to consider how potential environmental credits and burdens should be allocated to each product system. To address these multiple functionalities, a credit is provided for how the waste would have been managed if it were not recycled by Agilyx. Figure 3-3 shows the process flows for the conventional waste management system, while Figure 3-4 shows the relationship between the functionalities of the credits and the two product systems based on their functions. Essentially, the virgin styrene product system produces 1 kg of styrene monomer, and the conventional waste management system manages 1.21 kg of post-use waste polystyrene. However, the recycled styrene system produces 1 kg of styrene monomer and manages 1.21 of post-use waste polystyrene, so it provides the same function as the two other systems combined. This conventional waste management credit is implemented in the model by subtracting GWPt from managing the polystyrene waste from the GWPt associated with Agilyx styrene.

For the conventional waste management credits, US average management of polystyrene was assumed as a baseline (US EPA, 2020). This includes 17.1% of the polystyrene being incinerated, 82% being landfilled, and the remaining 0.9% being mechanically recycled. The incinerated polystyrene is used to create electricity and steam. Credits are provided for the produced electricity and steam using a substitution approach in the baseline scenario. Credits are also provided for the secondary polystyrene produced via mechanical recycling. To be clear, these energy and recycling credits reduce the total credit that Agilyx receives from conventional waste management. The mechanical recycling is included to minimize additional assumptions and because it is slightly more conservative to include it rather than exclude it.

Table 3-2: Conventional waste management for post-consumer polystyrene

Treatment Process	Percent Managed
Landfill	82.0%
Incineration	17.1%
Mechanical Recycling	0.9%

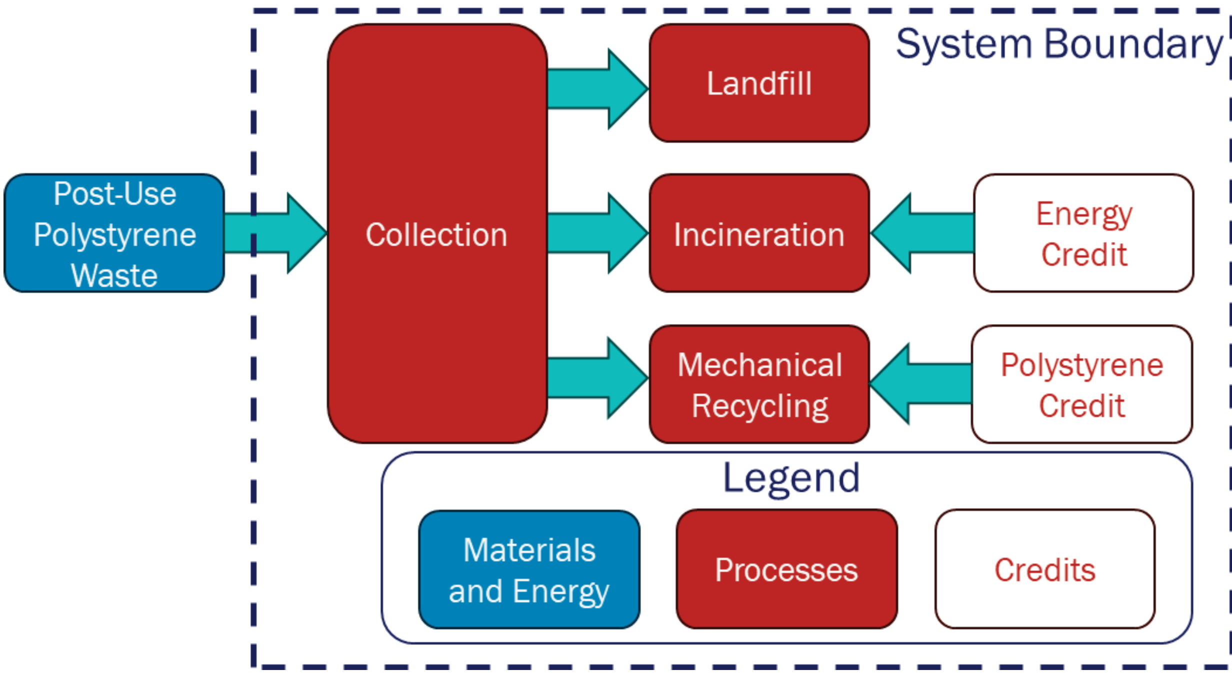


Figure 3-2: Process flow diagram for conventional waste management credits

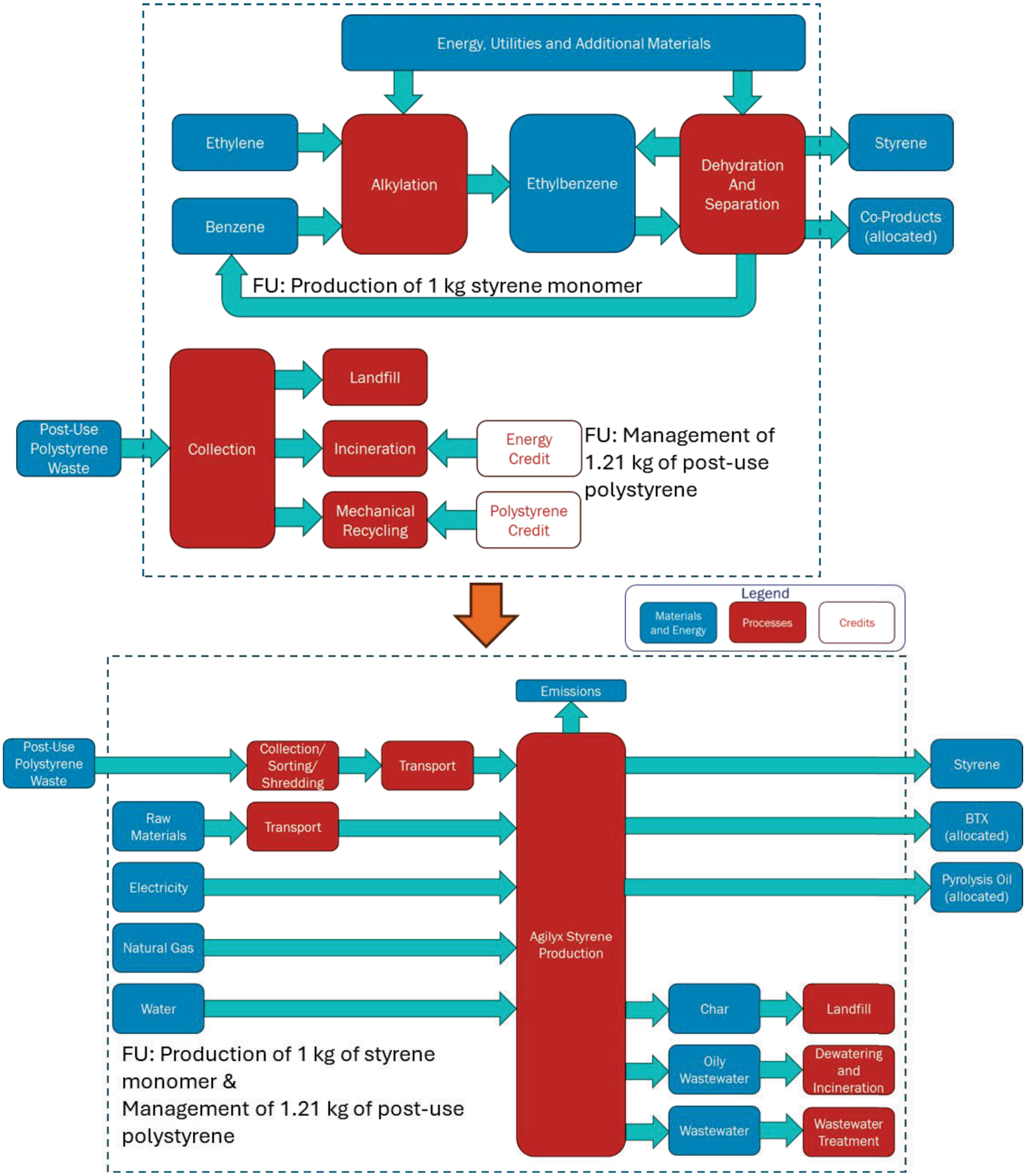


Figure 3-3: Diagram showing how the virgin styrene system with the upstream waste management system provide the same functionality as the recycled styrene system

3.3. Virgin styrene

Virgin styrene production was modeled using the MLC 2025.1 dataset shown in Table 3-3 (Sphera, 2023). Figure 3-2 shows the process flow diagram for virgin styrene. First, ethylene and benzene are alkylated in the presence of an aluminum silicate catalyst to produce ethylbenzene. Next, the ethylbenzene is mixed with steam and dehydrated. Finally, the benzene, ethylbenzene, and styrene are separated, and the benzene and ethylbenzene are recycled. Allocation between the styrene and the other co-products in the foreground system is based on lower heating value. The reference year for the data is 2023, so it should reasonably represent the reference year of 2024.

Table 3-3: Styrene dataset documentation

Material/ Process	Location	Dataset	Data Provider	Reference Year
Styrene monomer	US	US: Styrene (EBSM dehydro-genation)	Sphera	2023

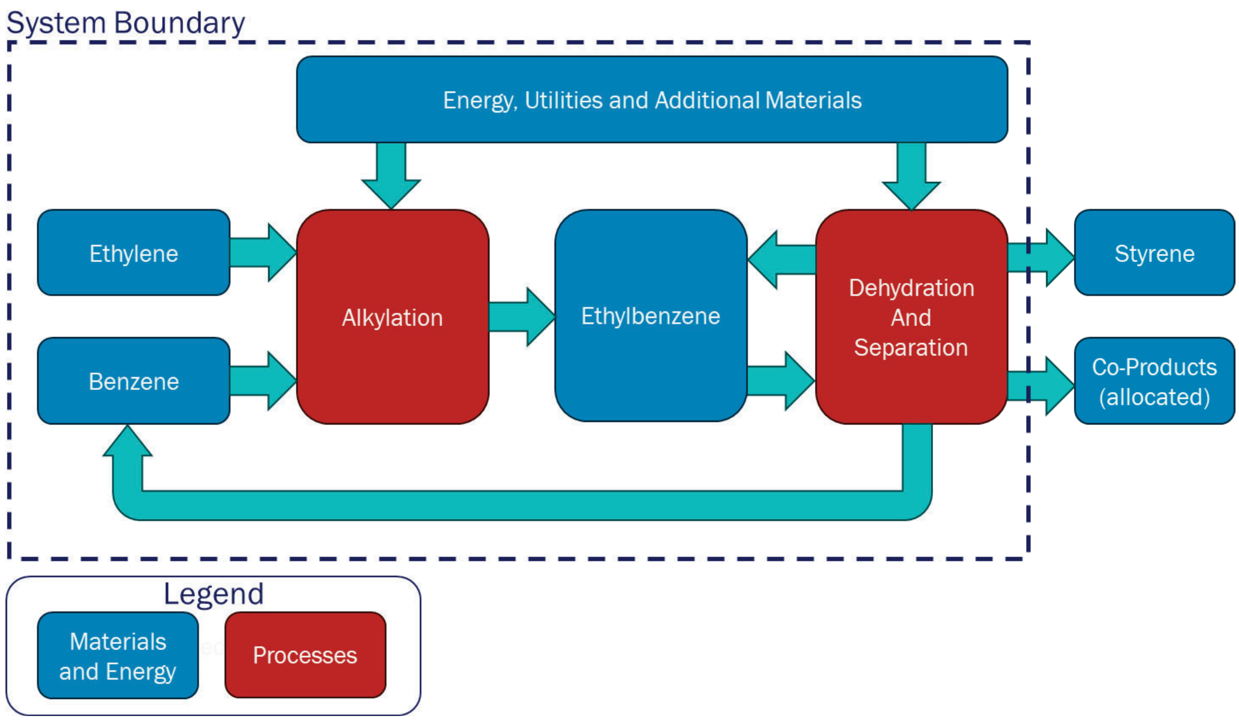


Figure 3-4: Process flow diagram for virgin styrene

3.4. Background Data

Documentation for all MLC datasets can be found online at https://lcadatabase.sphera.com.

3.4.1. Fuels and Energy

National/regional averages for fuel inputs and electricity grid mixes were obtained from the MLC 2025.1 databases. Table 3-4 shows the most relevant LCI datasets used in modeling the product systems. Electricity consumption was modeled using national/regional grid mixes that account for imports from neighboring countries/regions. The datasets are from 2021 and 2022, so they should be able to reasonably represent the 2024 reference year.

Table 3-4: Key energy datasets used in inventory analysis

Energy	Dataset	Data Provider	Reference Year	Proxy?[a]
Grid Electricity	US: Electricity grid mix - RFCW	Sphera	2022	No
Wind Electricity[b]	US: Electricity from wind power	Sphera	2021	No
Natural gas	US: Natural gas mix	Sphera	2021	No
Process Steam	US: Process steam from natural gas 90%	Sphera	2022	No
Technical Heat - Conventional	US: Thermal energy from natural gas	Sphera	2022	No
Technical Heat - Renewable[b]	US: Thermal energy from biogas	Sphera	2022	No

a. Geo: Geographical; Tech: Technological
b. Dataset only used in scenario analysis

3.4.2. Raw Materials and Processes

Data for upstream and downstream raw materials and unit processes were obtained from the MLC 2025.1 database. Table 3-5 shows the most relevant LCI datasets used in modeling the product systems. These datasets are from 2021 to 2024, so they should reasonably represent the 2024 reference year.

Table 3-5: Key material and process datasets used in inventory analysis

Material/ Process	Dataset	Data Provider	Reference Year	Proxy?[a]
4-*tert*-Butlycatechol	DE: Resorcin (1,3-Dihydroxybenzene)	Sphera	2024	Geo/Tech
Bleach	US: Sodium hypochlorite solution	Sphera	2024	No
Boiler/Cooling water	US: Tap water from groundwater	Sphera	2024	No
BTX[b]	US: Aromatics (BTX) at refinery	Sphera	2021	No
Corrosion inhibitor	US: Hydrazine	Sphera	2024	Tech
Diesel	US: Diesel mix at filling station	Sphera	2021	No
Dispersant	GLO: Dispersing agent (anionic dispersant and ethoxylate non ionic mixture)	Sphera	2024	No
DNPB	RER: Nitrochlorobenzene (approximation)	Sphera	2024	Geo/Tech
Ethylbenzene	RER: Ethyl benzene (vapour phase alkylation, zeolite catalysed)	Sphera	2024	Geo
Hazardous wastewater treatment	RER: Hazardous waste (water content >90%) in waste incineration plant	Sphera	2024	Geo
Helium	US: Helium (liquid)	Sphera	2024	No
Hydrogen	US: Hydrogen at refinery	Sphera	2021	No
Naphtha[b]	US: Naphtha at refinery	Sphera	2021	No

Material/ Process	Dataset	Data Provider	Reference Year	Proxy?[a]
Polymerization inhibitor	CH: Hydroxytetramethylpiperidin (HTMP) 65%	Sphera	2024	Geo/Tech
Process water	US: Process water from groundwater	Sphera	2024	No
Polystyrene incineration	US: Polystyrene (PS) in waste incineration plant (0% H2O content)	Sphera	2024	No
Polystyrene landfilling	US: Plastic waste on landfill, post-consumer	Sphera	2024	No
Polystyrene recycling	US: Plastic recycling (clean scrap)	Sphera	2024	No
Polystyrene mechanical recycling credit	US: Polystyrene granulate (PS) (approximation)	Sphera	2024	No
Quicklime	US: Lime (CaO; quicklime lumpy)	Sphera	2024	No
Sulfuric acid	US: Sulphuric acid (96%)	Sphera	2024	No
Wastewater treatment	US: Municipal wastewater treatment (mix)	Sphera	2024	No

a. Geo: Geographical; Tech: Technological
b. Dataset only used in system expansion scenario analysis

3.4.3. Transportation

Average transportation distances and modes of transport are included for the transport of the raw materials, operating materials, and auxiliary materials to production and assembly facilities. It should be noted that no air transport is use in the foreground systems.

Sphera's MLC databases (CUP 2025.1) were used to model transportation. Truck transportation within the United States was modeled using US truck transportation datasets based on data from EPA's SmartWay program (https://www.epa.gov/smartway). SmartWay collects fleet data -- including truck class, fuel consumption, miles driven, etc. -- from various US carriers and aggregates the data to generate average carbon dioxide (CO_2) emissions for each carrier. Emissions for this dataset are then calculated by averaging emissions for all carriers classified under the given SmartWay vehicle category.

Other emissions are calculated based on EPA MOVES data (https://www.epa.gov/moves). An appropriate MOVES truck type is identified and corresponding emission factors in grams per mile obtained from the model. Emission factors are separated for short (less than 200 miles) and long haul (above 200 miles) as the latter accounts for "hoteling", i.e., the hours spend in idle mode during breaks.

Diesel consumption is back-calculated from SmartWay CO_2 emissions while factoring in biodiesel content from the US Energy Information Administration (EIA) Annual Energy Review under the assumption that diesel is the primary fuel consumed by SmartWay carriers. The fraction of biodiesel calculated from EIA data is also used to split SmartWay CO_2 emissions into fossil and biogenic CO_2.

Fuels were modeled using geographically appropriate datasets. Fuel and transport datasets are from 2021 and 2023, which means they should be able to reasonably represent the reference year of 2024.

Table 3-6: Transportation and road fuel datasets

Mode / fuels	Geographic Reference	Dataset	Data Provider	Reference Year	Proxy?
Class 8 (refuse truck)	US	Truck - LTL/dry van (EPA SmartWay)	Sphera	2023	No
Class 8 (tanker)	US	Truck - tanker (EPA SmartWay)	Sphera	2023	No
Diesel	US	Diesel mix at filling station	Sphera	2021	No

3.5. Life Cycle Inventory Analysis Results

ISO 14044 defines the Life Cycle Inventory (LCI) analysis result as the "outcome of a life cycle inventory analysis that catalogues the flows crossing the system boundary and provides the starting point for life cycle impact assessment" (ISO, 2006). As the complete inventory comprises hundreds of flows, Table 3-7 only displays carbon dioxide and methane emissions which represent >99.3% of the total GWP for both the virgin and baseline Agilyx styrene.

Table 3-7: LCI results of Agilyx styrene (kg)

Emission	Feedstock	Electricity	Thermal Energy	Other	Upstream Credits
Carbon dioxide, fossil	0.153	0.953	0.261	0.109	-0.390
Methane, fossil	0.000496	0.00315	0.00171	0.00136	0.00141

4. PCF Results

This chapter contains the results for the global warming categories defined in section 2.6. It shall be reiterated at this point that the reported impact results represent impact potentials, i.e., they are approximations of environmental impacts that could occur if the emissions would (a) follow the underlying impact pathway and (b) meet certain conditions in the receiving environment while doing so. In addition, the inventory only captures that fraction of the total environmental load that corresponds to the chosen declared unit (relative approach).

PCF results are therefore relative expressions only and do not predict actual impacts, the exceeding of thresholds, safety margins, or risks.

4.1. Overall Results

Table 4-1 shows the GWP results for the virgin and Agilyx styrene. The results indicate that the net total GWP (GWPt) associated with virgin and Agilyx styrene is 2.26 kg CO_2 eq./kg of styrene and 1.29 kg CO_2 eq./kg of styrene, respectively. Therefore, the cradle-to-gate GWPt for Agilyx styrene is 43% (0.97 kg CO_2 eq./kg of styrene) lower than virgin styrene. Additionally, fossil GHG emissions account for 99.9% and 99.7% of GWPt for the virgin and Agilyx styrene, respectively. Therefore, the rest of the results will focus on GWPt with the understanding that the large majority of the impacts are from fossil GHG emissions. The biogenic removals and emissions are primarily related to the use of biofuels in the background system (e.g., biodiesel in the diesel mix and electricity or thermal energy from biomass or biogas).

Table 4-1: Overall GWP results for virgin and Agilyx styrene (kg CO_2 eq./kg styrene)

	Virgin	Agilyx		
Category	**Styrene Production**	**Styrene Production**	**Waste Management Credit**	**Total**
Aircraft GHG emissions	**1.38E-08**	1.88E-08	2.50E-09	**2.13E-08**
Biogenic GHG emissions	**0.0117**	0.0299	0.00329	**0.03321**
Biogenic GHG removals	**-0.0092**	-0.0270	-0.00314	**-0.03013**
GHG emissions from direct land use change	**4.37E-04**	5.60E-04	8.54E-05	**6.45E-04**
Fossil GHG emissions	**2.26**	1.64	-0.353	**1.29**
Net Total GWP (GWPt)	**2.26**	1.65	-0.353	**1.29**

4.2. Contribution Results

Figure 4-1 shows the contributions to the Agilyx styrene compared to the virgin styrene. Electricity is the largest contributor to GWPt for recycled styrene. Electricity contributes 1.02 kg CO_2 eq/kg styrene, which represents 62% of the total GWP burdens of 1.65 kg CO_2 eq/kg styrene (i.e., GWPt excluding credits). Thermal energy is the next largest contributor (0.31 kg CO_2 eq/kg styrene; 19% of GWP burdens), and the waste polystyrene is the third largest contributor (0.17 kg CO_2 eq/kg styrene). Other raw materials, direct emissions, transport, water, and waste management contribute 9% to the total GWP burdens (0.15 kg CO_2 eq/kg styrene).

The upstream waste management credit reduces the total GWP burdens by ~21%. While this is a significant reduction, it must be noted that the Agilyx styrene leads to 27% less GWP than virgin styrene even without these credits.

For the virgin styrene, the ethylene and benzene feedstock contribute 74% to the total GWP of 2.26 kg CO_2 eq./kg styrene. Thermal energy is the next largest contributor at 23%, while electricity and other burdens contribute ~3%.

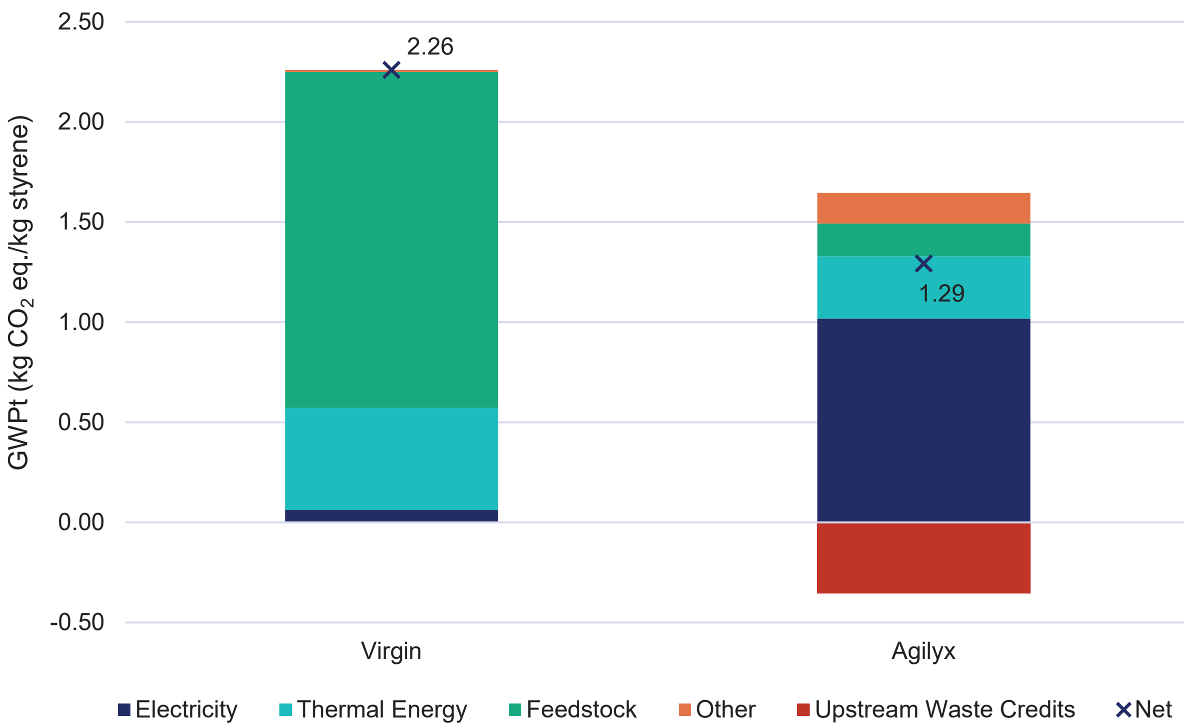


Figure 4-1: Contributions to GWPt for Agilyx styrene compared to virgin styrene

4.3. Scenario Analysis

Several scenario analyses were performed to better understand the potential changes to the results and conclusions.

4.3.1. Electricity Source

Since electricity from the grid was the largest contributor to GWPt, the use of wind electricity was evaluated to see how it changed the results (Figure 4-2). When virgin and Agilyx styrene are both produced with wind electricity, the GWPt associated with the Agilyx styrene is 87% lower than virgin (1.9 kg CO_2 eq/kg styrene).

The results indicate that switching to wind electricity reduces the GWPt by 1.00 kg CO_2 eq/kg styrene and reduces the total GWP burden by 61% compared to Agilyx styrene produced using grid electricity.

For the virgin styrene system, switching to wind electricity only reduces the GWPt by 0.061 kg CO_2 eq./kg styrene (2.6%) because electricity contributes much less to the production of virgin styrene. Therefore, shifting to cleaner sources of electricity will increase the GWPt benefits of recycled styrene relative to virgin styrene.

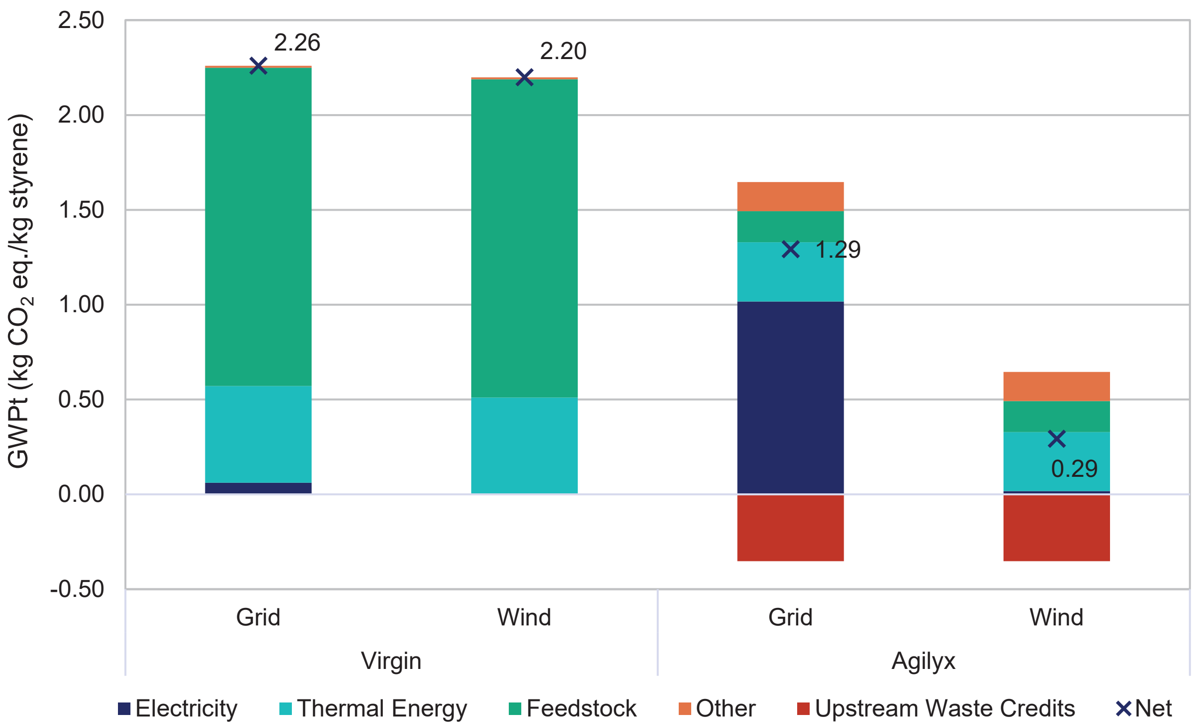


Figure 4-2: GWPt results when switching to wind electricity from grid electricity

4.3.2. Thermal Energy Source

Since thermal energy from natural gas was the next largest contributor to GWPt for the Agilyx styrene, the use of biogas (Figure 4-3) and electricity powered by wind (Figure 4-4) were evaluated to see how they may further improve the GWPt from Agilyx styrene. The results indicate that switching to biogas from natural gas reduces the GWPt by 0.22 kg CO_2 eq./kg styrene, which reduces the total GWP burden by 17% from the baseline, and an additional 75% from the wind electricity scenario. Using wind electricity with an electrified boiler and heating system reduces the GWPt burden by an additional 0.081 kg CO_2 eq/kg styrene (6% of the baseline total GWP burden). Therefore, use of renewable fuels and electrification can further reduce the GWPt of Agilyx styrene.

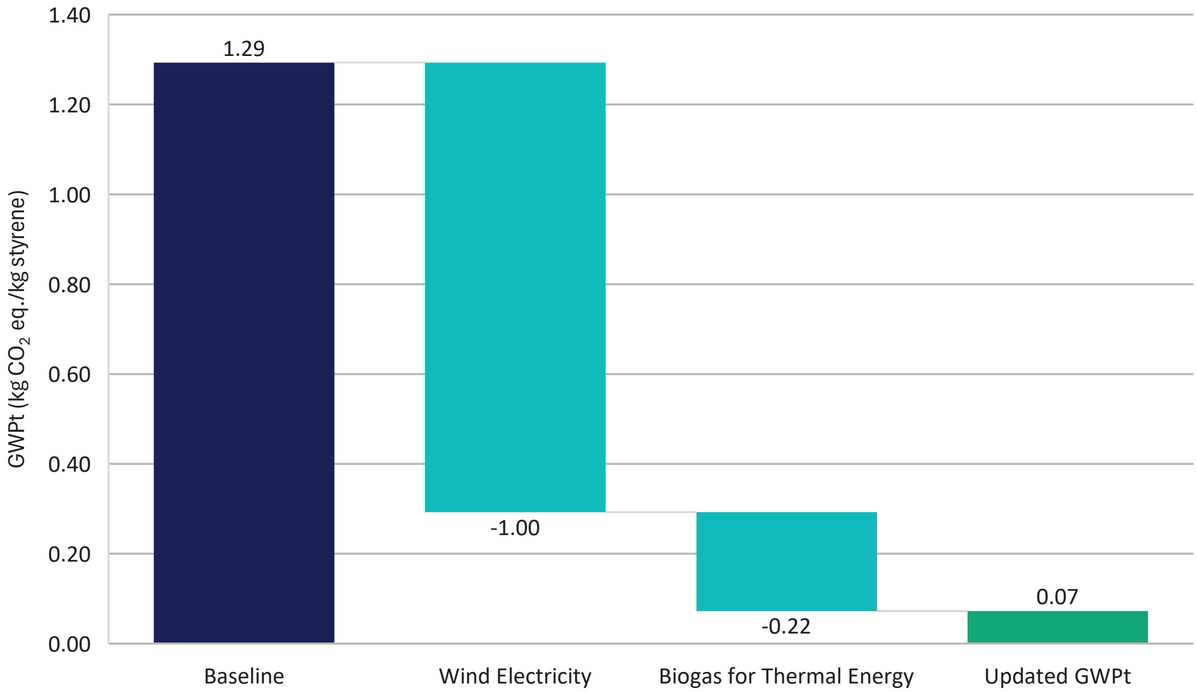


Figure 4-3: Potential reductions in GWPt from switching to wind electricity and biogas for thermal energy

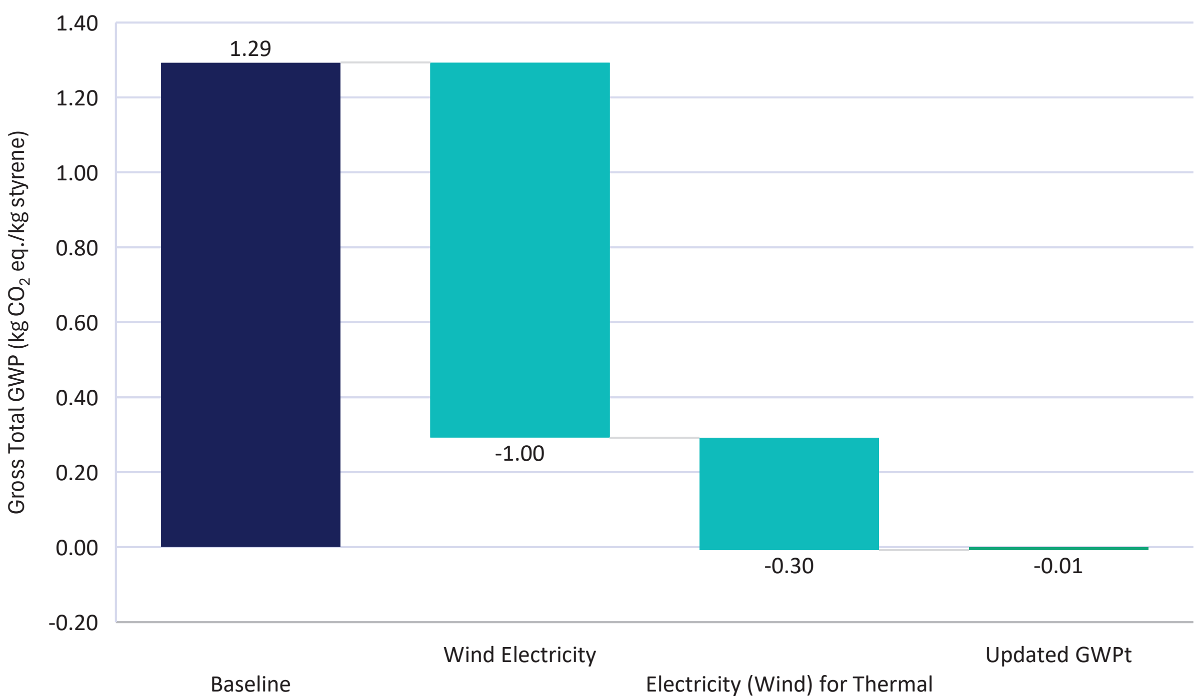


Figure 4-4: Potential reductions in GWPt from switching to wind electricity and using that wind electricity to provide thermal energy

4.3.3. Conventional Waste Management

The baseline system uses the US national mix for polystyrene waste management for the conventional waste management system as described in section 3.2.5. However, there are significant differences in the GWPt from incinerating polystyrene and landfilling it. Figure 4-5 shows the results when all the waste polystyrene is landfilled and when it is all incinerated compared to the baseline virgin and Agilyx styrene.

The results indicate that using a landfill almost completely removes the credit because polystyrene does not anaerobically biodegrade, therefore the only credits are for collection and the equipment and materials used at the landfill. Therefore, if all the polystyrene were to be landfilled, the GWPt increases by 25% (0.32 kg CO_2 eq./kg styrene). However, even if all the waste is diverted from landfill, the Agilyx styrene reduces GWPt compared to virgin styrene by 29% (0.64 kg CO_2 eq/kg styrene).

Alternatively, if all the polystyrene were to be diverted from incineration with energy recovery, the upstream waste management credit would increase by a factor of 5.7, which leads to a negative GWPt of -0.38 kg CO_2 eq./kg styrene. However, caution should be applied when interpreting this value since it does not mean Agilyx styrene produces negative greenhouse gas emissions. It just means that using waste polystyrene to produce styrene using Agilyx's system leads to lower greenhouse gas emissions than incinerating it.

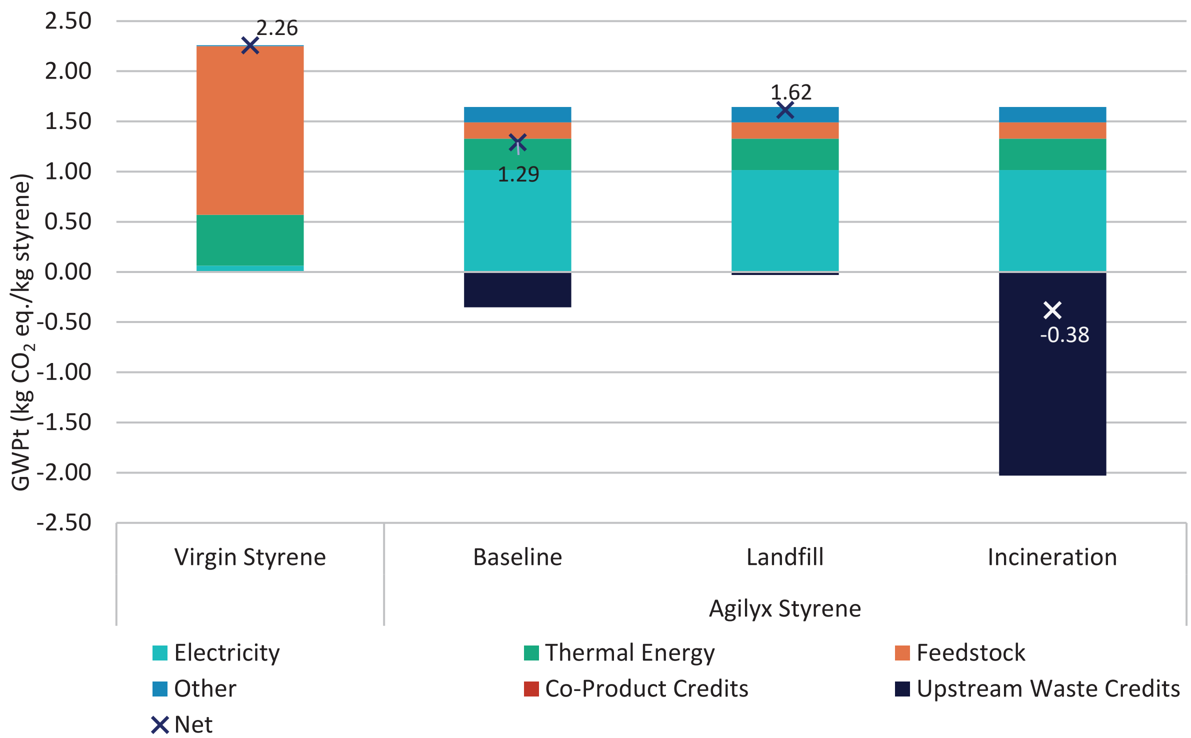


Figure 4-5: Comparison of different sources of upstream waste management credits

4.3.4. Co-Product Allocation

Allocation by LHV was chosen because it is a reasonable physical metric for the quality of the different co-products produced via depolymerization. However, other types of physical allocation are also available. In this scenario analysis the carbon content and mass were used as alternative allocation schemes to test how this modeling assumption affected the results. The percent of burdens and credits allocated to each co-product are shown in Table 2-2, and the GWPt results for each are shown in Figure 4-6.

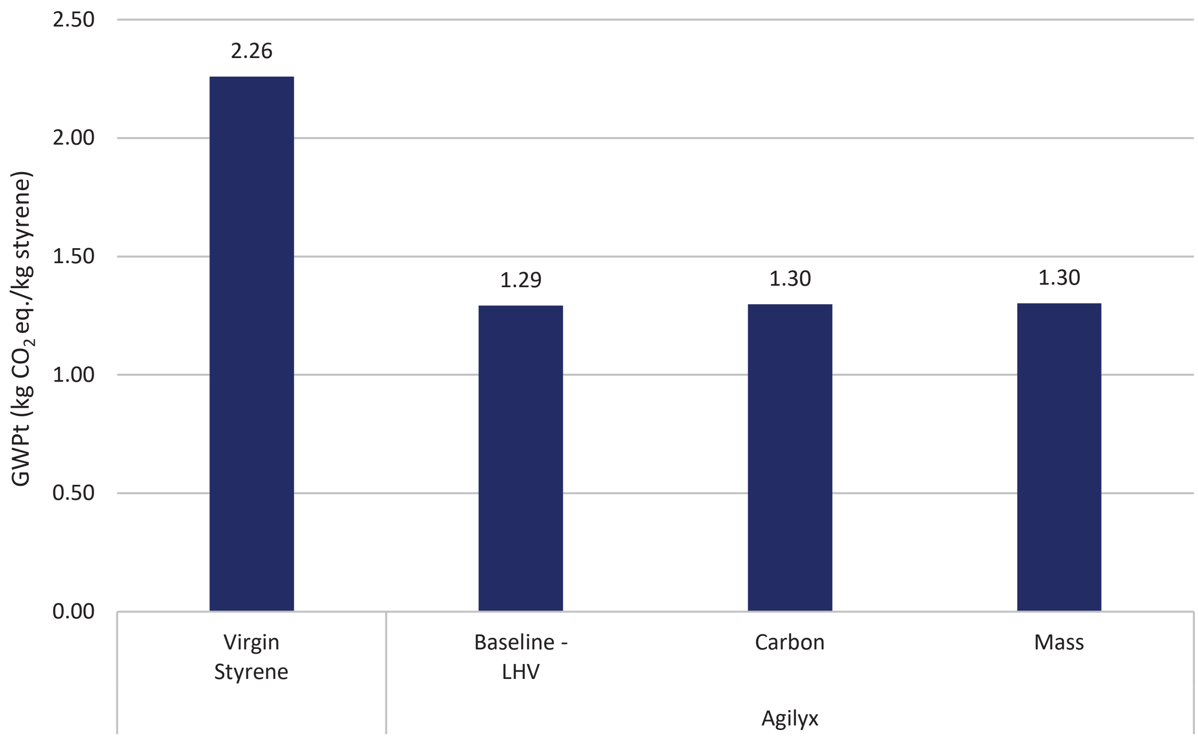


Figure 4-6: Comparison of different allocation parameters

The results show that regardless of the physical allocation parameter chosen, the GWPt changes by <1%, which is expected because the respective carbon contents and LHVs per unit mass of the three co-products are all similar. Therefore, the choice of physical allocation parameter does not meaningfully alter the results or conclusions.

4.3.5. System Expansion

According to ISO 14044, sub-division and system expansion are both preferred over allocation to address multiple co-products from a process (ISO, 2006). However, allocation based on LHV was selected based on the significant uncertainty associated with the point of substitution for the pyrolysis oil. The pyrolysis oil can be used in multiple ways depending on the user. For this example, it was assumed that the pyrolysis oil was hydrotreated to produce a drop-in naphtha replacement, and then a credit for conventional fossil naphtha is provided. The blended BTX co-product is also given a credit for conventional fossil BTX.

The results for this simplified system expansion scenario compared to the baseline alternatives are shown in Figure 4-7. The system expansion scenario essentially increases each of the contributors by ~61% and then provides a credit of 0.39 kg CO_2 eq./kg styrene due to the co-products. The system expansion scenario still reduces GWPt by 25% (0.57 kg CO_2 eq./kg styrene) compared to virgin styrene.

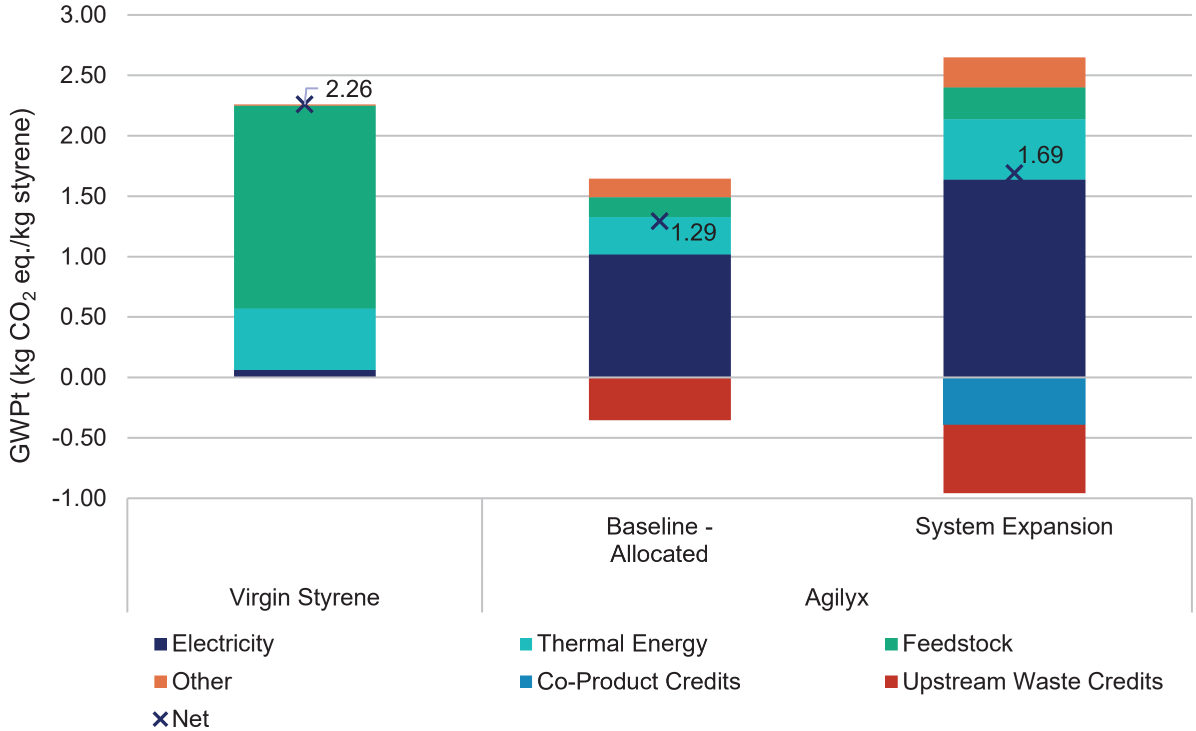


Figure 4-7: Comparison of system expansion scenario with the baseline virgin and Agilyx scenarios

4.4. Sensitivity Analysis

Since electricity and thermal energy contribute ~81% to the total GWP burden, they were the focus of sensitivity analysis. Figure 4-8 shows how the baseline GWPt for Agilyx styrene as the demand for electricity and thermal energy change for 1 kg of styrene. The results indicate that the electricity demand would need to increase by ~95% for virgin styrene to have a lower GWPt than Agilyx styrene, whereas thermal energy would need to increase by ~410% per kg styrene for Agilyx styrene to be outperformed by virgin styrene. Given their much lower contributions, potentially uncertain inputs such as transportation distances or raw material demand would have to increase by much more to breakeven with virgin styrene. Therefore, the conclusion that Agilyx styrene reduces GWPt compared to virgin styrene is relatively insensitive to uncertainty in these input values.

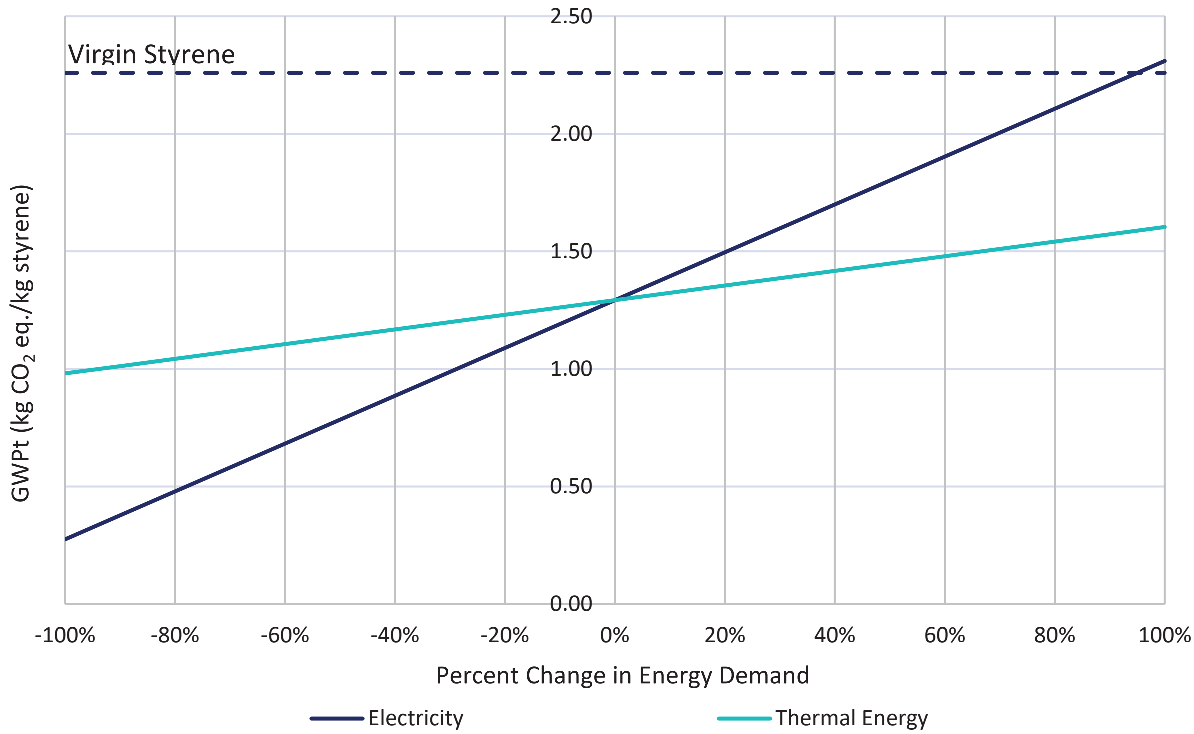
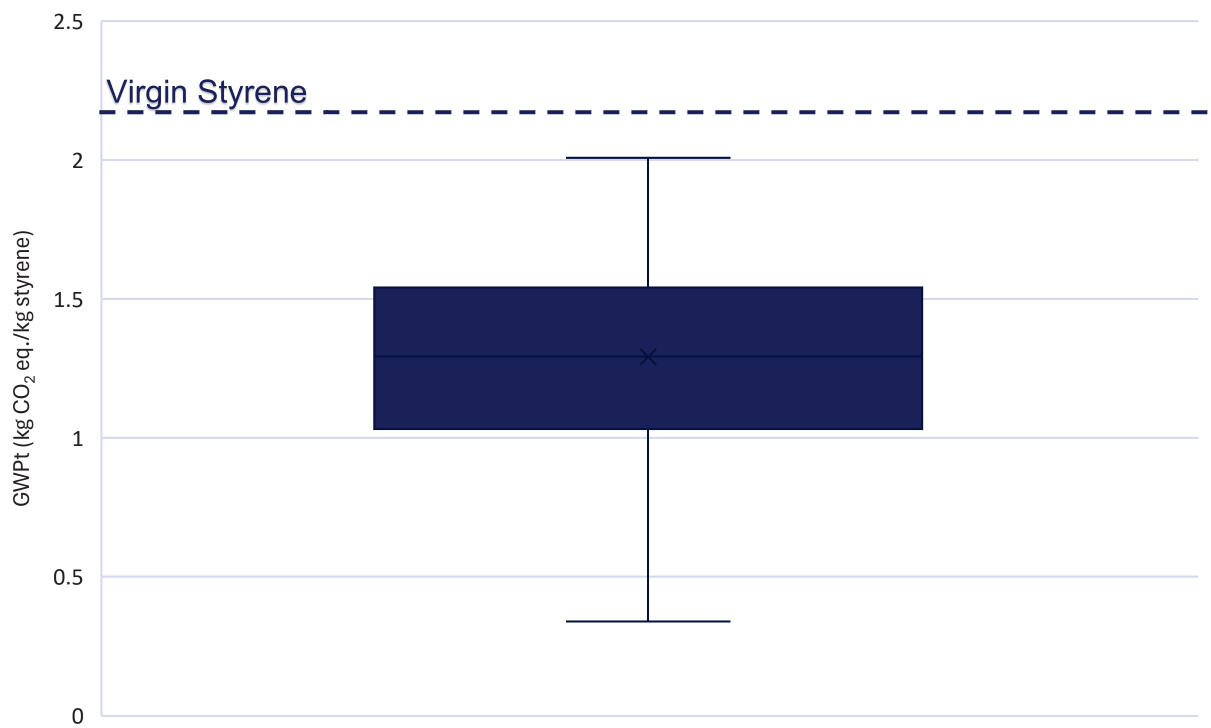


Figure 4-8: Changes in Agilyx styrene GWPt based on changes in electricity and thermal energy demand

4.5. Uncertainty Analysis

To further test the uncertainty of the results and conclusions, a 25,000 iteration Monte Carlo analysis was performed. Given the lack of additional data points or information on the underlying distributions, uniform distributions were used. All feedstocks, raw materials, water, energy demands, waste generation, and transportation distances were simultaneously varied by up to ±50%. However, co-product yields and credits were fixed. This is meant to be a conservative assumption where increasing feedstocks and raw materials does not actually increase yield.

Figure 4-9 shows a box-and-whisker plot of the results, and Table 4-2 shows summary statistics. The results indicate that even with this large variation in nearly all the model parameters, the Agilyx styrene outperforms virgin styrene in GWPt in all 25,000 iterations. The 95th percentile value is still 21% (0.47 kg CO_2 eq./kg styrene) less than virgin styrene. Additionally, given the symmetric distributions that were used, the resulting distribution is also centered on the baseline value of 1.29 kg CO_2 eq./kg styrene.



x: mean; line: median; box: interquartile range; whiskers: 1.5 x interquartile range

Figure 4-9: Box-and-whisker plot of the uncertainty analysis for Agilyx styrene

Table 4-2: Summary statistics for uncertainty analysis on Agilyx styrene (kg CO_2 eq./kg styrene)

		Percentiles						
Mean	Standard Deviation	5^{th}	10^{th}	25^{th}	50^{th}	75^{th}	90^{th}	95^{th}
1.29	0.31	0.80	0.87	1.03	1.29	1.55	1.71	1.79

5. Interpretation

5.1. Identification of Relevant Findings

In all scenarios assessed, Agilyx styrene reduces GWPt compared to virgin styrene. For both virgin and Agilyx styrene, fossil greenhouse gas emissions contribute >99% of the GWPt. For the baseline Agylix styrene, electricity contributes 62% to the total GWP burdens (1.02 kg CO_2 eq/kg styrene), while thermal energy contributes 19% (0.31 kg CO_2 eq/kg styrene), and the waste polystyrene feedstock contributes 10% (0.16 kg CO_2 eq/kg styrene). Everything else (i.e., transport, raw materials, water, waste management, and emissions control) contributes 9% to the total GWP burdens (0.15 kg CO_2 eq/kg styrene).

Upstream waste credits reduce the total GWP burden by ~21%, but the baseline Agilyx styrene outperforms virgin styrene by 27% even without these credits. With the credits, the Agilyx styrene outperforms virgin styrene by 43%.

5.2. Assumptions and Limitations

There are assumptions and potential limitations of this study:

- Proxy datasets were used for six raw materials and a geographic proxy was used for hazardous waste management of the oily wastewater. However, combined these datasets contribute <1% to the GWPt for Agilyx styrene.
- In the baseline scenario, the BTX and pyrolysis oil co-products were addressed using allocation based on energy content, but other allocation methods and potential system expansion were explored in scenario analyses and were found to change the results by <1%..
- The baseline conventional polystyrene waste management system used a national average mix of landfill (82.0%), incineration (17.1%), and recycling (0.9%). However, a real facility will likely remove waste exclusively from one of these alternatives. Therefore, a scenario analysis (section 4.3.3) was performed.
- The primary data for the Agilyx system were developed using engineering calculations and projections based on a 3,300 ton per year pilot plant that they have operated for several years.

5.3. Results of Sensitivity, Scenario, and Uncertainty Analysis

5.3.1. Scenario Analysis

Scenario analyses were performed to compare results between different sets of assumptions or modeling choices. The electricity (section 4.3.1) and thermal energy (section 4.3.2) source scenario analyses showed that Agilyx could significantly reduce the GWPt of their styrene by utilizing low carbon energy sources.

The conventional waste management scenario analysis (section 4.3.3) showed that even if their polystyrene is all diverted from landfilling, Agilyx styrene still outperforms virgin styrene. However, recovering polystyrene meant for incineration with energy recovery can significantly improve their relative GWPt performance. The co-product allocation scenarios (section 4.3.4) showed that the choice of physical attribute for co-allocation has a negligible effect on the results. Finally, the system expansion scenario (section 4.3.5) showed that using system expansion to address co-products still leads to Agilyx styrene outperforming virgin styrene. These last three scenarios provide confidence that Agilyx styrene outperforms virgin styrene under a variety of assumptions.

5.3.2. Sensitivity Analysis

Sensitivity analyses were performed on electricity and thermal energy demand (section 4.4) to test the sensitivity of the results towards changes in these parameter values. The analyses showed that electricity demand would need to increase by ~95% per kg styrene for Agilyx styrene to be outperformed by virgin styrene, while thermal energy would need to increase by ~410% per kg styrene. Given their much lower contributions, potentially uncertain inputs such as transportation distances or raw material demand would have to increase by much more to breakeven with virgin styrene. Therefore, the conclusion that Agilyx styrene reduces GWPt compared to virgin styrene is relatively insensitive to uncertainty in these input values.

5.3.3. Uncertainty Analysis

Uncertainty analysis was performed to test the robustness of the results towards the combined parameter uncertainty. The analysis showed that Agilyx styrene is very likely to outperform virgin styrene in terms of GWPt even when 50% uncertainty is simultaneously applied to all the key model parameters. The 90^{th} percentile range of the Agilyx styrene was 0.80 to 1.79 kg CO2 eq., which reduces GWPt compared to virgin styrene by 21% to 65% (0.47 to 1.46 kg CO_2 eq./kg styrene).

5.4. Data Quality Assessment

Inventory data quality is judged by its precision (measured, calculated or estimated), completeness (e.g., unreported emissions), consistency (degree of uniformity of the methodology applied) and representativeness (geographical, temporal, and technological).

To cover these requirements and to ensure reliable results, data in combination with consistent background LCA information from Sphera’s 2025.1 MLC database were used. The LCI datasets from the Sphera’s 2025.1 MLC database are widely distributed and used with the LCA FE 10.9 Software. The datasets have been used in LCA models worldwide in industrial and scientific applications in internal as well as in many critically reviewed and published studies. In the process of providing these datasets they are cross-checked with other databases and values from industry and science.

5.4.1. Precision and Completeness

- ✓ **Precision:** As the majority of the relevant foreground data are calculated based on primary information sources of the owner of the technology, precision is considered to be moderate. Seasonal variations/variations across different manufacturers were balanced out by using annual averages. All background data are sourced from Sphera’s 2025.1 MLC databases with the documented precision.

- ✓ **Completeness:** Each foreground process was checked for mass balance and completeness of the emission inventory. No data were knowingly omitted. Completeness of foreground unit process data is considered to be high. All background data are sourced from Sphera's 2025.1 MLC databases with the documented completeness.

5.4.2. Consistency and Reproducibility

- ✓ **Consistency:** To ensure data consistency, all primary data were collected with the same level of detail, while all background data were sourced from the Sphera's 2025.1 MLC databases. Therefore, consistency is considered to be high.
- ✓ **Reproducibility:** Reproducibility is supported as much as possible through the disclosure of input-output data, dataset choices, and modeling approaches in this report. However, due to the use of a confidential annex, third parties may not be able to approximate the results of this study using the same data and modeling approaches. Therefore, reproducibility is considered to be low-to-moderate.

5.4.3. Representativeness

- ✓ **Temporal:** All primary data were collected for the year 2024. All secondary data come from the Sphera's 2025.1 MLC databases and are representative of the years 2021 to 2024. As the study intended to compare the product systems for the reference year 2024, temporal representativeness is considered to be high.
- ✓ **Geographical:** All primary and secondary data were collected specific to the countries or regions under study. Where country-specific or region-specific data were unavailable, proxy data were used. Geographical representativeness is considered to be high.
- ✓ **Technological:** All primary and secondary data were modeled to be specific to the technologies or technology mixes under study. Where technology-specific data were unavailable, proxy data were used. Technological representativeness is considered to be high.

5.5. Model Completeness and Consistency

5.5.1. Completeness

All relevant process steps for each product system were considered and modeled to represent each specific situation. The process chain is considered sufficiently complete and detailed with regards to the goal and scope of this study.

5.5.2. Consistency

All assumptions, methods and data are consistent with each other and with the study's goal and scope. Differences in background data quality were minimized by predominantly using LCI data from the Sphera's 2025.1 MLC databases. System boundaries, allocation rules, and impact assessment methods have been applied consistently throughout the study.

5.6. Conclusions, Limitations, and Recommendations

Based on the analyses, assumptions, limitations, and data quality, it is likely that Agilyx styrene is associated with a significantly lower net total GWP compared to virgin styrene. This conclusion holds under a variety of scenarios, assumptions, and over a large range of uncertain input values.

As a PCF study, only global warming impacts were considered, therefore the conclusions cannot be generalized to other environmental impacts. Additionally, this is a cradle-to-gate study, so it excludes any environmental burdens associated with further processing, distribution, use, and end-of-life that may substantially contribute to the life cycle environmental impacts.

Additional insights into the sustainability of Agilyx styrene could be developed by extending the scope of this analysis to cradle-to-grave and by including additional environmental impacts in a full life cycle assessment. The accuracy of the study could be improved for specific facilities by knowing the specific energy sources and how the waste polystyrene feedstock would otherwise be managed. Additionally, repeating this analysis once a full-scale facility has been in operation will improve the accuracy of the results and conclusions.

The analysis indicates that Agilyx can improve the GWPt performance of their styrene by using low-carbon sources of electricity and thermal energy and by preferentially siting facilities where polystyrene waste is predominantly incinerated.

5.7. Potential Future Implications

The US produced approximately 4.68 million metric tons of styrene in 2019 (Statista, 2023), and based on this analysis that production is associated with the emission of ~11 million metric tons of CO_2 eq. Therefore, there is a significant opportunity to reduce the GWPt from styrene production. An Agilyx facility that produces 33,000 metric tons of styrene annually could reduce GWPt by ~32,000 metric tons of CO_2 eq compared to virgin styrene. This is equivalent to removing approximately 7,460 average US gasoline cars off the road for the year (~3.6 million gallons of gasoline) or the amount of CO_2 sequestered by over 529,000 tree seedlings over a decade (US EPA, 2024). Therefore, there is significant potential for Agilyx styrene to reduce GWPt by replacing virgin styrene production.

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Agilyx Company Background

Agilyx ASA is at the forefront of advanced recycling, converting post-use plastics into high-value feedstock and virgin-equivalent products. Through Cyclyx, its joint venture with ExxonMobil (25%) and LyondellBasell (25%), Agilyx supports the collection and of post-use plastic waste into custom-formulated, high-quality feedstock solutions for global plastic producers. Through Plastyx, its joint venture with Circular Resources (40%), Agilyx provides critical feedstock to the European mechanical and advanced recycling markets. Additionally, Agilyx markets TruStyrenyx, a polystyrene advanced recycling solution that combines its Styrenyx depolymerization technology with Technip Energies' purification process. By advancing from a linear "make-take-waste" model to a circular economy, Agilyx advances the transition to a low-carbon future.

Find out more at www.agilyx.com

Annex A: Critical Review Statement

Critical review statement

for the study

Product carbon footprint of styrene from depolymerisation of waste polystyrene

1. Background

The product carbon footprinting (PCF) study "Product carbon footprint of styrene from depolymerisation of waste polystyrene" was commissioned by Agilyx ("Commissioner") and carried out by Sphera ("Practitioner").

The study was critically reviewed by Adisa Azapagic of ETHOS Research ("Reviewer").

The Reviewer carried out the review as an individual and not as a representative of any organisation. The Reviewer is independent of any party with a commercial or any other interest in the study.

The aim of the review was to ensure that:

- the methods used to carry out the study are consistent primarily with the ISO 14067:2018 standard and with the guidance in the related ISO 14040:2006+A1:2020 and 14044:2006+A1:2018+A2:2020 standards;
- the methods used are scientifically and technically valid given the goal of the study;
- the data used are appropriate and reasonable in relation to the goal of the study;
- the interpretation of the results and the conclusions of the study reflect the goal and the findings of the study; and
- the study report is transparent and consistent.

2. Critical review process

The critical review process involved the following:

- a review of a draft version of the report according to the above criteria and recommendations for improvements to the study and the report; and
- a review of two revised reports, of which the last (V1.0 dated 13 June 2025) became the final report to which this critical review statement refers.

All the comments made by the Reviewer were addressed by the Practitioner. The comments and the responses are available from the Commissioner on request.

The PCF models developed by the Practitioner for the purposes of this project were not reviewed and hence all the findings of the critical review are based solely on the PCF report that was made available to the Reviewer during the course of the critical review.

3. Conclusion of the critical review

The Reviewer can confirm that this study follows the guidance of and is consistent with the the Carbon Footprint of Products standard (ISO 14067: 2018) and, as far as possible, with the Life Cycle Assessment standards (ISO 14040:2006+A1:2020 and 14044:2006+A1:2018+A2:2020) as follows:

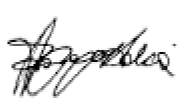
- the methods used are scientifically and technically valid as far as possible given the goal of the study and the assumptions;
- the data used are appropriate and reasonable in relation to the goal of the study;
- the interpretation of the results and the conclusions of the study reflect the goal and the findings of the study; and
- the study report is transparent and consistent, with study limitations clearly stated.

This critical review statement is only valid for the final report as presented to the Reviewer. The statement does not apply to any further reports, including third-party reports, generated subsequently for the purposes of internal or external communication.

4. Communication of the study results

The following aspects should be mentioned when communicating the results of the study to external stakeholders:

- The findings of the study are specific to Agilyx technology for styrene recycling, the supply chains considered and the assumptions made in the study and cannot be generalised beyond that.
- The results of the study are based on the pilot-plant data and may not be representative of a full-scale commercial process.
- No comparative assertions (comparisons) should be made with related technologies or materials.
- This is a carbon footprinting rather than a full LCA study, focusing only on one environmental impact related to greenhouse gas emissions.
- Some of the assumptions affect the results, interpretation and conclusions of the study. Therefore, it is important that these and their influence on the results and conclusions be described transparently, whenever the study or its parts are disclosed to any stakeholders to avoid any potential misinterpretation of the study.
- Whenever a reference is made to the review of the study and its outcome, it should also be mentioned that the Critical Review Statement and Reviewer comments are available upon request.



Adisa Azapagic

June 2025