Product Stewardship

Sphera® Managed LCA Content (MLC)

Refinery LCA Model
2026

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Abbreviations

ETBE	Ethyl-Tertiary-Butyl-Ether
FCC	Fluid Catalytic Cracking
H_2S	Hydrogen Sulfide
HFO	Heavy Fuel Oil
ISO	International Organization for Standardization
LCA	Life Cycle Assessment
LCI	Life Cycle Inventory
LFO	Light Fuel Oil
LP	Linear Programming
LPG	Liquefied Petroleum Gas
MDO	Marine Diesel Oil
MGO	Marine Gas Oil
MTBE	Methyl-Tertiary- Butyl- Ether
NCV	Net Calorific Value (synonym for LHV = Lower Heating Value)
RON	Research Octane Number
UCO	Used Cooking Oil
ULSFO	Ultra Low Sulfur Fuel Oil
VGO	Vacuum Gas Oil
VLSFO	Very Low Sulfur Fuel Oil
VOC	Volatile Organic Compound
Wt.%	Weight Percentage

Background – How a Refinery Works

Crude oil refineries are complex plants. The combination and sequence of many processes is usually very specific to the characteristics of the crude oil and the refinery products to be delivered. Available crude oil quality, the market demand for specific refinery products, as well as product requirements set by authorities and customers determining the configuration and complexity of a refinery.

Simple hydro-skimming refineries can process only a few crude oil qualities and produce few high-quality products. Complex refineries with many conversion plants can process different crude oil types and produce different product slates.

Crude oil refinery activities begin with the input of crude oil. After desalting, crude oil is fed to the distillation column for atmospheric distillation (fractionation of the crude oil by separation according to density/boiling/condensation areas). The light ends (gases) go up to the head of the column and are further treated at the gas treatment system to recover refinery gas, methane and ethane, for the use as refinery fuel and liquefied petroleum gas (LPG), propane and butane, as marketable products. This light product separation occurs in almost every refinery. These gases can also be used in a steam reforming process to produce hydrogen, which is mainly necessary for desulfurization processes, hydrocracking and, to a lesser extent, the isomerization unit.

The straight-run naphtha of the atmospheric distillation, which is taken in the upper trays of the column are often divided and fed to three different processes. 1) In some refineries, smaller quantities of light naphtha fraction are fed to the chemical sweetening process. Depending on the specification, some sweetened naphtha is directly blended to the gasoline. 2) The middle fraction is sent to the isomerization unit where the aliphatic paraffins are converted into iso-paraffins with a high-octane value. Often there is a de-iso-pentanizer (distillation) downstream to increase the yield of iso-components. These iso-paraffins are very valuable components for gasoline production with a high Research Octane Number (RON). 3) After desulfurization, the heavy naphtha fractions are sent to the reformer for catalytic transformation from aliphatic paraffins to iso-paraffins and from cyclo-paraffins to aromatic compounds. The catalytic reformer produces hydrogen as well (the only process at the refinery which produces hydrogen besides additional plants like steam reforming and/or electrolysis). The output products of the isomerization and the catalytic reforming processes are blended to premium or regular gasoline at the gasoline blending system while naphtha is sold as feedstock to the chemical downstream industry.

Aromatics from the catalytic reformer unit are processed in the so-called aromatics unit, producing benzene, toluene, xylene and cyclohexane. In addition, hexane and heptane are produced.

Kerosene is often directly obtained from the atmospheric distillation and is treated separately from the rest of the middle distillates fraction. The main portion of the middle distillates produced in the atmospheric distillation is processed at the hydrofiner to desulfurize diesel, light fuel oil (LFO), marine gas oil (MGO) and marine diesel oil (MDO). The desulfurized products are fed to the middle distillate blender. The residue from the atmospheric distillation can be sold as a product and/or is fed to the vacuum distillation to produce light vacuum gas oil, vacuum gas oil (VGO) and vacuum residue. VGO can be sold as a product as well.

At some refineries, a portion of the atmospheric residue is processed at the visbreaking unit (mild thermal cracking). Small amounts of atmospheric residue are sometimes introduced directly into the heavy fuel oil (HFO) blending system and the asphalt-blowing process. The light vacuum gas oil, as a product of the vacuum distillation, is further processed at the hydrofiner (hydrotreatment), is desulfurized, and sent to the middle distillate blender.

Some of the vacuum distillate yield, which has been taken from the middle trays of the vacuum distillation, is processed at the base oil production unit to produce group I base oil and waxes (paraffins).

Group II and III base oils are produced from the vacuum distillate treated in a hydrocracker, and dewaxing and hydrofinishing units.

However, most of the vacuum distillate is fed either to a catalytic cracker, such as a fluid catalytic cracking (FCC) - sometimes first desulfurized - or a hydrocracker, where the feeds are converted into shorter chains by molecule restructuring (cracking). The products are gases, gasoline, middle distillates and heavy cycle gas oils (components of HFO). The gases of the catalytic cracking are treated in an alkylation and polymerization unit to manufacture additional valuable gasoline components.

Co-processing, the simultaneous processing of bio feedstocks (e.g., used cooking oil (UCO)) and circular feedstocks (e.g., pyrolysis oil) with fossil feedstocks, like crude oil and VGO, can be implemented in refinery units like FCC, hydrotreaters and hydrocrackers.

Butylene of the FCC is further used together with external supplied methanol or often (bio-) ethanol to produce Methyl-Tertiary-Butyl-Ether (MTBE) respectively Ethyl-Tertiary-Butyl-Ether (ETBE), a product used as octane booster for gasoline. The naphtha of the FCC must be treated in a special desulfurization process to reduce its sulfur content.

The vacuum residues are processed in a coking process, which produces gases, gasoline, middle distillates, and heavy fuel oil. An additional product of the coking unit is petroleum coke, which is typically purified and sold as a product. The vacuum residue, like some of the atmospheric residue, is also used as feed to the visbreaking unit, which also produces gases, naphtha, middle distillates, and heavy fuel oil.

Depending on the sulfur content of the crude oil and further hydrotreatment, fuel oils with different sulfur contents can be produced, e.g., ultra-low sulfur fuel oil (ULSFO) (0.1 wt.% sulfur), very low sulfur fuel oil (VLSFO) (0.5 wt.% sulfur), heavy fuel oils (HFO) with sulfur contents ranging from 0.3 up to 2.5 wt.% sulfur, and untreated bunker oil (>2.5 wt.% sulfur).

Hydrogen sulfide (H_2S) from all hydrotreatment (desulfurization) units is converted to elemental sulfur at the sulfur recovery unit (Claus process).

Refineries require heat, steam and electricity for its operation. This energy is most often produced onsite at a refinery power plant and boilers/incinerators using refinery fuels such as refinery/fuel gas, LFO, HFO, petroleum coke and sometimes liquefied petroleum gas (LPG). Smaller amounts of the energy are produced using purchased natural gas and/or biomethane, or steam and/or electricity are directly purchased from external sources outside the refinery system boundary.

Carbon capture and storage (CCS) technology can be applied in the steam reformer and/or in the boilers and power plants of the refinery.

A simplified flow chart of a refinery is shown in Figure 1. The arrangement of these units varies between the refineries and few, if any, employ all of these units.

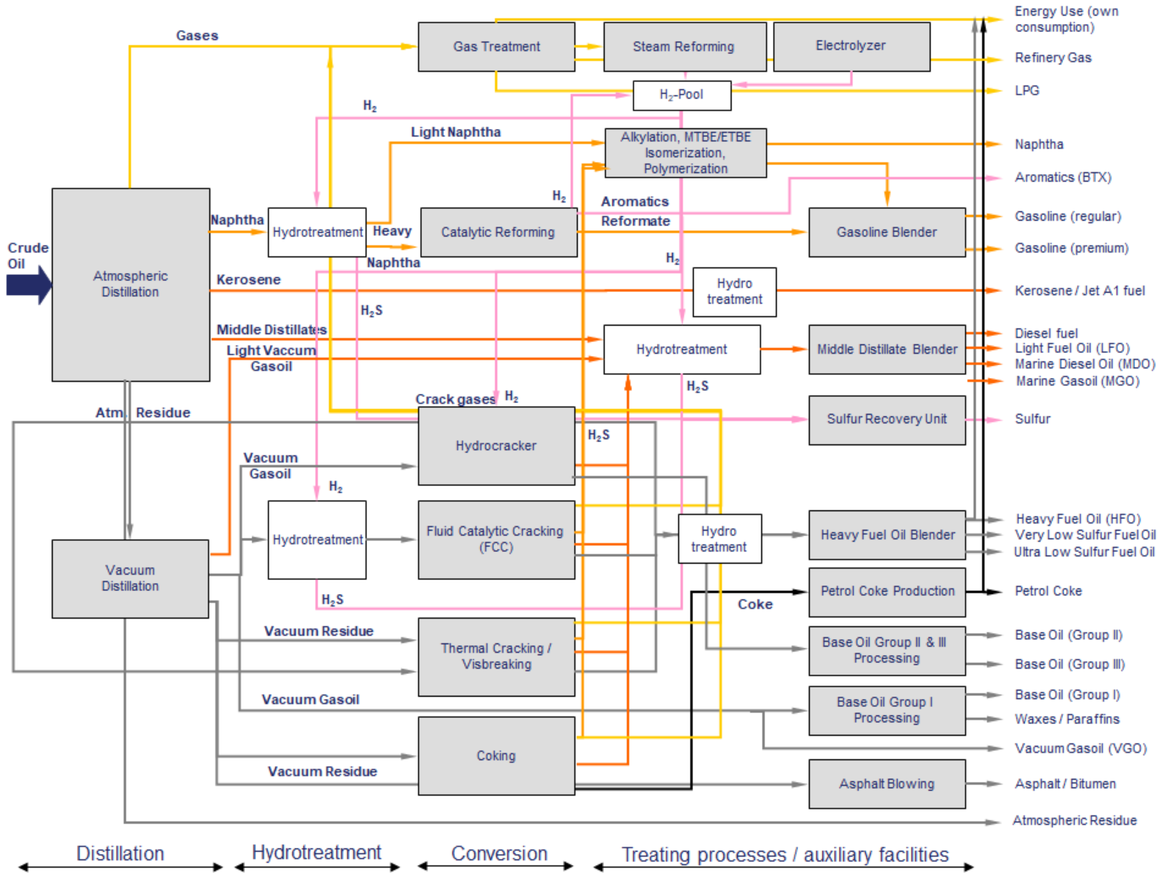

Figure 1 Simplified Flow Chart of a Refinery

The Sphera LCA Refinery Model 2026

Modelling Approach

Due to the interlinkages within a refinery, all refinery products and all units within the refinery must be considered when analyzing the environmental performance of refinery products.

The “Sphera LCA Refinery Model” is a generic, parameterized LCA model which describes the conversion of crude oil into finished refinery products. The model follows an attributional modelling approach, i.e. analyzing an average liter of diesel, gasoline, etc. produced, instead of looking at marginal changes in the system if e.g., the gasoline or diesel production is increased/decreased (consequential modelling). Further information about attributional and consequential modelling approaches can be found in the study “Attributional vs. Consequential LCA” published by the European Council for Automotive R&D (EUCAR) [1].

“Generic” means that the model provides a suite of different refinery processes which can be turned on and off. “Parametrized” means that the model is fully adjustable to different input properties, output slates, fuel specifications, and refinery operations schemes, etc. The following key parameters can be adapted, among others:

- Crude oil input, other feedstock inputs (e.g., VGO, bio and circular feedstocks), and refinery product output slates,
- Properties of crude oil, other feedstocks and refinery products (such as density and sulfur content),
- Layout and sequence of different distillation, conversion and upgrading processes,
- Energy consumption data (heat, steam, electricity) for each refinery unit,
- Energy supply (energy sources and fuels produced within the refinery and/or purchased/imported from external sources),
- Carbon capture and storage (CCS) for refinery and/or steam reformer, and
- Emission inventory of the refinery.

Thus, the “Sphera LCA Refinery Model” can be used to either analyze a specific or a country-/region-specific average refinery. The model calculates average environmental inventories for refinery products. The default refinery datasets of Sphera’s MLC databases represent country-/region-specific averages.

System Boundary

The “Sphera LCA Refinery Model” considers crude oil and other feedstock inputs (quantities of other feedstocks depend on the refinery or country under consideration). Natural gas and/or biomethane are either used at a steam reforming process to produce hydrogen, and/or are used as fuels at the refinery power plant. Most refineries have an electricity grid connection and purchase either electricity for daily operation, use the connection as a backup or even sell electricity to the grid. All options can be handled by the model. Methanol and (bio-) ethanol are used to produce MTBE/ETBE, and water is used to produce steam, as a cooling absorbent or for washing purposes. Hydrogen is considered as a special case, since in some refineries, hydrogen is produced (and sold), while other refineries purchase hydrogen. The “Sphera LCA Refinery Model” can handle both ways. Model outputs include the refinery products as well as emissions.

The considered main inputs and outputs of the “Sphera LCA Refinery Model” are shown in Figure 2.

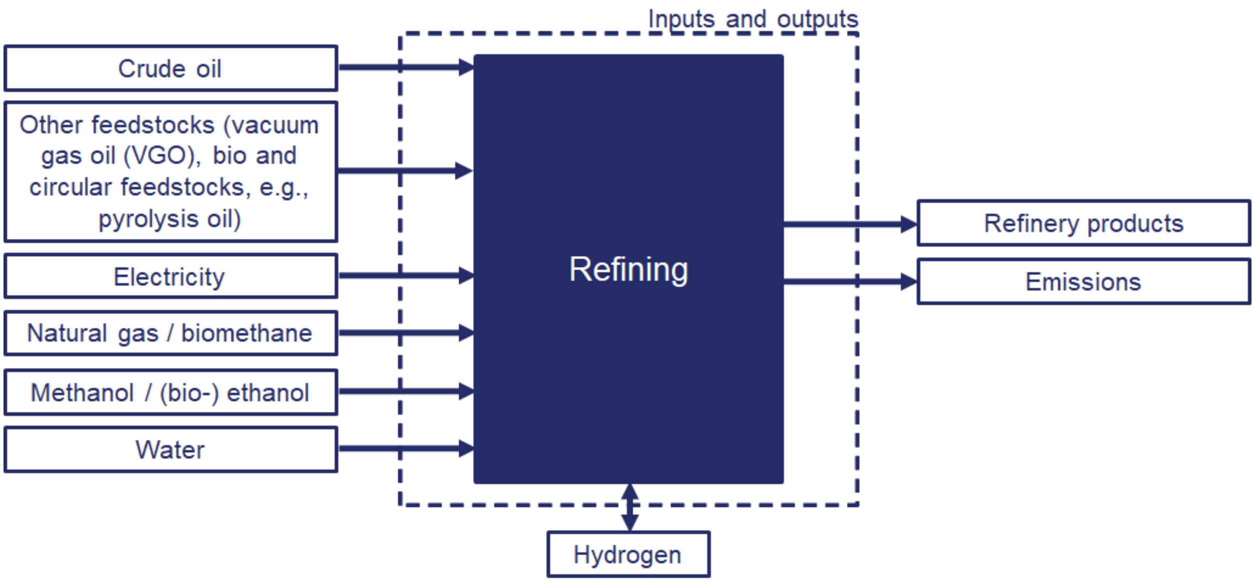

Figure 2 Considered Refinery Inputs and Outputs

Model Outline

The "Sphera LCA Refinery Model" is based on a detailed mass balance. The mass balance of the whole refinery is developed by considering the crude oil input, other feedstock inputs (e.g., VGO, bio and circular feedstocks), the refinery output spectrum, as well as the processing capacity of each unit process (including its utilization) and the process unit output shares. The screenshot of the schematic of the "Sphera LCA Refinery Model" is shown in Figure 3.

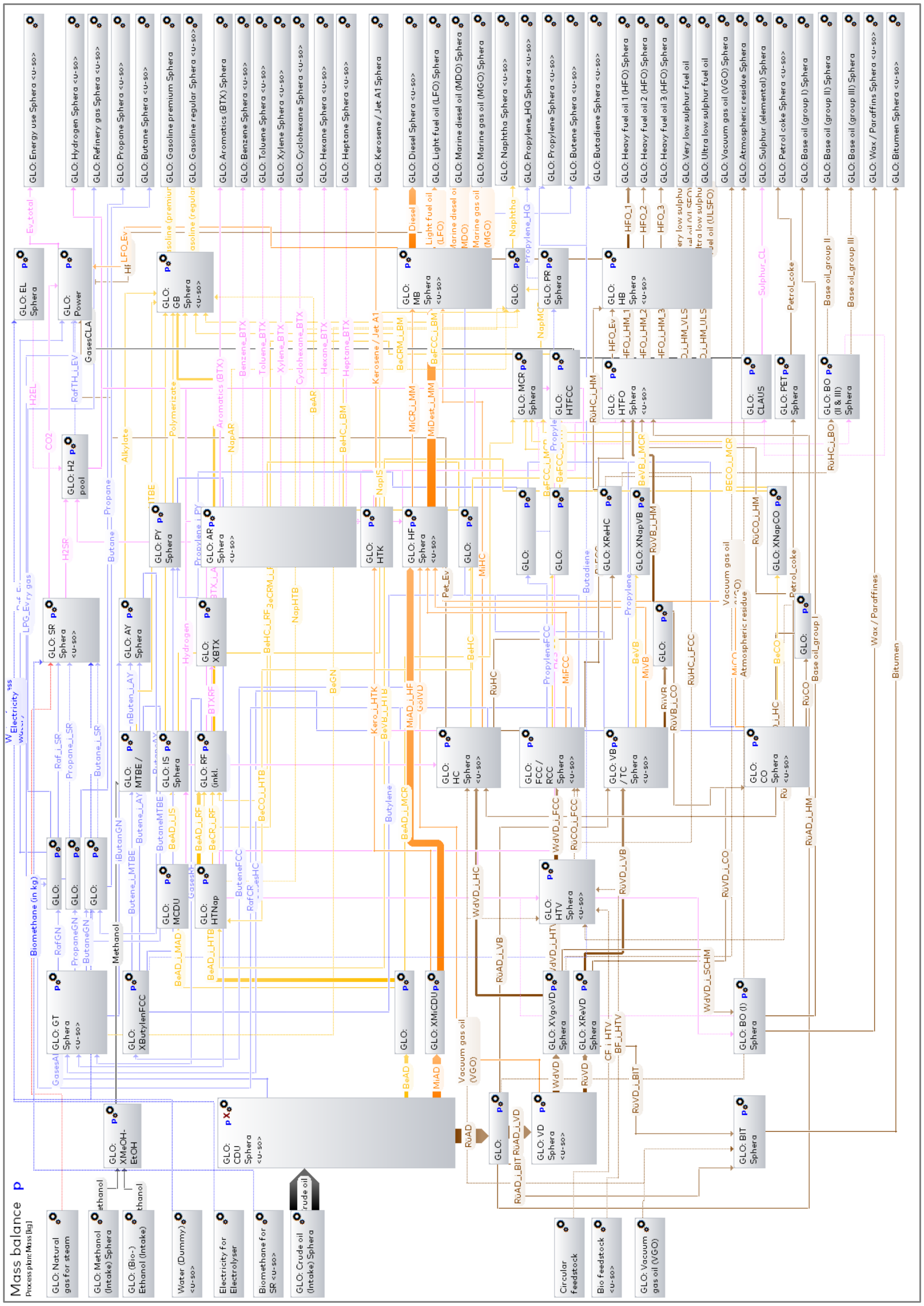

Figure 3 Screenshot of the “Sphera LCA Refinery Model” – Mass Balance (Sankey Diagram)

Since the mass balance of the hydrocarbons is modelled through the whole refinery, the sulfur balance is also modelled using an average distribution pattern. Thereby, the sulfur content of each hydrotreatment unit input and output is determined by knowing the feedstock type (VGO, naphtha, FCC gasoline, diesel, etc.) and its production pathway (produced at atmospheric distillation unit, FCC, etc.), and the defined output specification, i.e. sulfur limit in the product. This method is used to calculate the amount of hydrogen required in the desulphurization units, and thus, the hydrogen demand of the whole refinery.

The heat, steam and electricity demand of each unit process is quantified. Please note that some unit processes do not need heat, steam or electricity. If so, these model input parameters are set to zero or if the unit process is even delivering heat due to its exothermic nature, the model can handle it by using negative model input parameter values, which are then credited to the process and hence its outputs. Based on the heat, steam and electricity input values, the energy balance of the refinery is calculated.

Certain amounts of produced fuels are used at the refinery power plant (and boilers) to convert the fuel into heat, steam and/or electricity. In the “Sphera LCA Refinery Model”, the fuels used can be determined. Either refinery fuels, such as refinery/fuel gas, LPG, LFO, HFO and petroleum coke, can be used or purchased fuels from external sources such as natural gas and/or biomethane. The power plant conversion efficiencies can be specified as well. In addition, the share between onsite produced electricity and purchased electricity can also be adjusted.

The “Sphera LCA Refinery Model” calculates the allocation factors for each refinery product dependent on the individual way through the refinery and allows the allocation of the total refinery emissions from the commonly used power plant (bubble) to the different products. More details on the allocation method applied can be found in section “Allocation”.

Embedded emissions related to the infrastructure of the refinery (plant construction), the use of catalysts as well as consumption of fuel additives are not considered in the model.

Please note, that the “Sphera LCA Refinery Model” is a model that calculates the environmental impact of refinery products. Even though the model calculates the results based on the underlying mass balance and considers the energy, sulfur, and hydrogen balance, the model is not a classical linear programming (LP) model, simulating operation pattern or optimizing the outcome towards certain criteria. It is a Life Cycle Assessment (LCA) model quantifying the environmental footprint of a certain static state, in practice mostly an annual average of the refineries of a specific country or region.

Functional Unit

The “Sphera LCA Refinery Model” itself refers to 1 kg of crude oil input i.e. all mass flows (intermediates and products) within the refinery model are quantitatively related to the input.

However, to have comparability among different products within a refinery or across several refineries, all refinery products are re-scaled to 1 kg of the corresponding product, e.g., 1 kg of diesel and 1 kg of gasoline.

The overview of the “Sphera LCA Refinery Model” is shown in Figure 4.

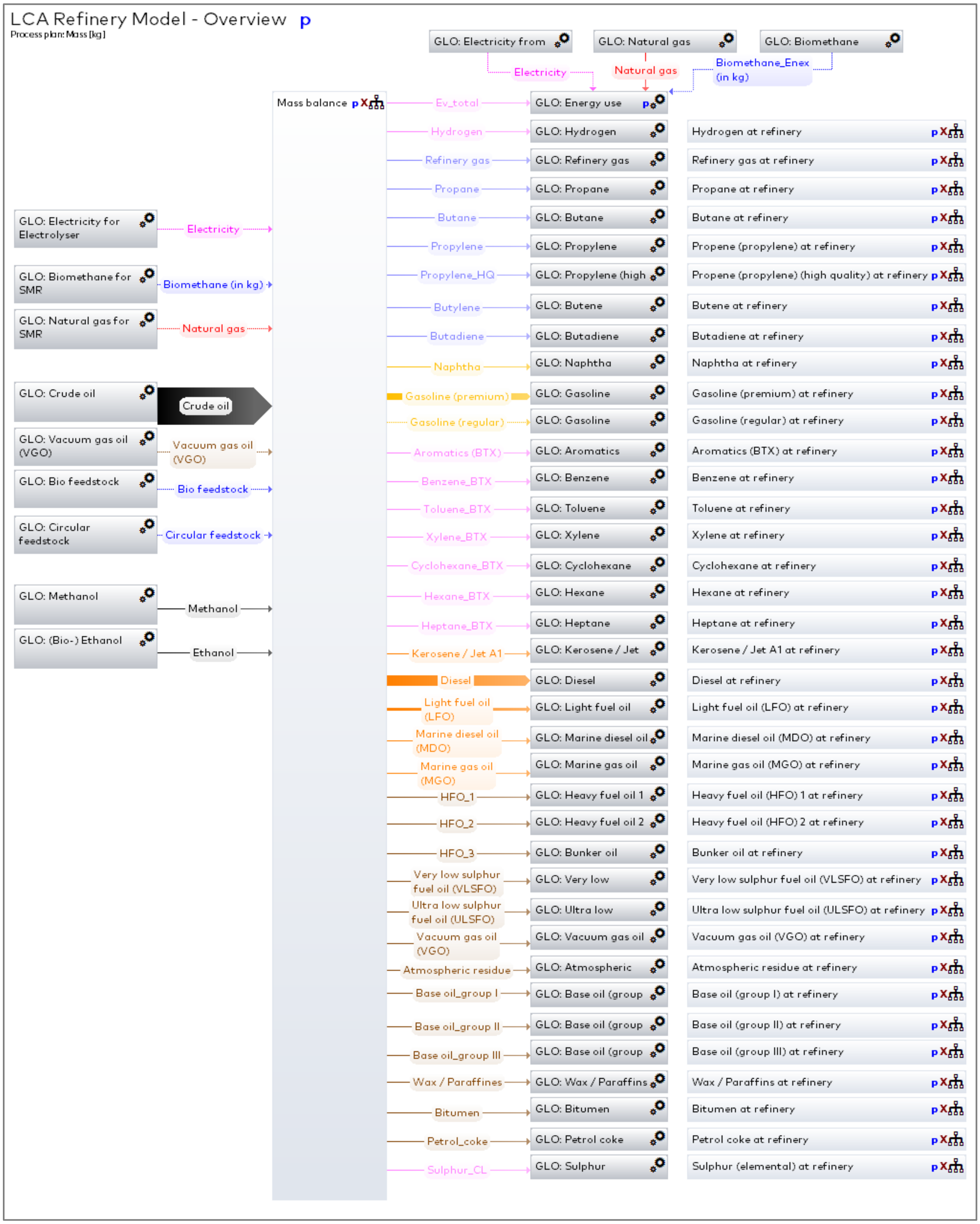

Figure 4 Screenshot of the “Sphera LCA Refinery Model” – Overview (Sankey Diagram)

Allocation

Almost all refinery units (processes) are multi-output processes. Multi-output processes produce two or more products simultaneously. The challenge is to allocate the environmental burden associated with the operation of the process to its products. The ISO standards for life cycle assessment, ISO 14040:2006 [2] and ISO 14044:2006 [3], define allocation as “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.” As nearly every single refinery unit process is a multi-output process, a suitable allocation method needs to be defined for refineries.

Each refinery process handles a hydrocarbon feedstock and consumes a certain amount of heat and steam (both grouped to “thermal energy” in the following), and electricity. In the “Sphera LCA Refinery Model”, steam is converted from kg to MJ by using a conversion factor of 3.05 MJ/kg. In case of the atmospheric distillation the hydrocarbon feedstock is crude oil, while all other refinery units process intermediate feedstocks, which are derived from crude oil and/or other feedstocks like VGO, bio and circular feedstocks (with a few exceptions, like ethanol used for ETBE production).

The environmental burdens associated with the supply of crude oil and other feedstocks and energy use at the refinery (i.e., emissions related to the thermal energy and electricity production) must be allocated to the different refinery products.

In the “Sphera LCA Refinery Model” the environmental burden of each process unit is allocated to its products, and each product is followed individually through the refinery (backpack principle), i.e., the allocation is done at the refinery unit level (allocation to intermediate products) and is based on prorated allocations reflecting the physical input/output relationships (mass and energy yields). The actual distribution of the emissions is done by using allocation factors. Thereby, the sum of the allocated emissions to the refinery products are equal to the emissions before allocation.

Furthermore, all emissions released at the refinery (from heat, steam, and electricity production, individual processes and emissions due to losses) are considered as a bubble and are allocated to the refinery products on a unit process level, with the exception of H_2S which is considered as a by-product.

Hence, the environmental burdens of the following items must be allocated to the refinery products, including:

- The emissions of the refinery (representing all refinery emissions, including the power plant itself, converting plants, decentralized boilers, storage, flaring and diffuse losses),
- The environmental impacts of crude oil and other feedstock supply (i.e., the upstream impacts of crude oil, VGO, UCO, pyrolysis oil, etc.),
- The environmental impacts of purchased electricity from the grid (i.e., electricity purchased which is used in addition to the one produced at the refinery power plant),
- The environmental impacts of natural gas and/or biomethane supply (if natural gas and/or biomethane are purchased),
- The environmental impacts of hydrogen supply (if hydrogen is purchased), and
- The environmental impacts of methanol/ ethanol supply (if MTBE/ETBE is produced).

The following allocation approach is used as default in the “Sphera LCA Refinery Model”:

- Emissions caused by the refinery, purchased electricity from the grid, and natural gas/biomethane supply are allocated to the products following a mass allocation approach.

- Impacts related to the supply of crude oil, and other feedstocks (e.g., VGO, bio and circular feedstocks) are allocated to the products based on their energy content.
- Impacts from methanol/ethanol and hydrogen supply are assigned directly to the applicable products, e.g., methanol/ethanol supply emissions to the produced gasoline, hydrogen to the desulfurized products, like diesel, gasoline, etc.
- No environmental impacts are allocated to H_2S because it is treated as a by-product. Thus, H_2S entering the sulfur recovery unit (Claus process) is considered burden free and only the environmental impacts of the sulfur recovery unit are allocated to the sulfur.

The “Sphera LCA Refinery Model” is able to switch between mass and energy allocation. In addition, it is possible to allocate the impacts related to the bio and circular feedstock supply directly to the products applying “free allocation”, i.e., the free distribution of the impacts among the refinery products. Free allocation is also applicable for the catalytic reformer (as the only refinery unit producing hydrogen as a co-product). Further information about allocation approaches for the catalytic reformer can be found in the study “Attributional vs. Consequential LCA” published by the European Council for Automotive R&D (EUCAR) [1]. It is also possible to apply the sensible heat allocation method used in the study “Eurobitume Life Cycle Assessment 4.0 for Bitumen” published by Eurobitume [4] for the atmospheric distillation and vacuum distillation units in the “Sphera LCA Refinery Model”. The “Sphera LCA Refinery Model” can handle all of these allocation methods.

In the following, the choice of the default allocation method is described and explained by using examples.

Allocation of Crude Oil

When processing crude oil in a refinery, the emissions of the crude oil supply chain (i.e., emissions from crude oil production, processing and transport to the refinery) must be allocated (attributed) to each refinery product. The environmental burden of the crude oil supply is allocated to the refinery products according to the quantity produced in the unit process and its energy content or in other words, the crude oil consumption is allocated to the products according to its net calorific value (energy). The crude oil consumption $CO_{i,Process}$ (expressed in mass), required for the production of product i, (product i defined by its mass m_i and its net calorific value of NCV_i) of a certain unit process is calculated proportionately to mass, m_i, and its ratio of its net calorific value NCV_i and the average net calorific value, NCV_{avg}, of all products produced in this unit process. The mass, m_i, is calculated with the weight percentage, m_{pi}, of the total mass of all products produced within this unit process.

$$CO_{i,Process} = \frac{\mathrm{m_i}}{\sum_{\mathrm{n=1}}^{\mathrm{i}} \mathrm{m_i}} \cdot m_{Crude\ Oil} \cdot \frac{NCV_i}{NCV_{avg}} = \frac{m_{pi}}{100\%} \cdot m_{Crude\ Oil} \cdot \frac{NCV_i}{NCV_{avg}} \qquad (1)$$

with:

$$NCV_{avg} = \sum_{n=1}^{i} \frac{m_{pi}}{100\%} \cdot NCV_i \qquad (2)$$

Allocation of Thermal Energy

The thermal energy is allocated to the products by mass. The thermal energy consumption, $Th_{Ei,Process}$, needed for the production of product i, with mass, m_i, of the unit process is calculated with the total energy consumption, $Th_{Etot,Process}$:

$$ThE_{i,Process} = \frac{m_i}{\sum_{n=1}^{i} m_i} \cdot ThE_{tot,Process} = \frac{m_{pi}}{100\%} \cdot ThE_{tot,Process} \quad (3)$$

The energy required for the production of a product i corresponds to a value that is relative to its weight percentage of the total mass.

Allocation of Electricity

The electricity is allocated to the products by mass. The electricity consumption, $El_{i,Process}$, required for the production of product i, with mass, m_i, of the unit process is calculated in the same way as the thermal energy consumption with the total consumption of electricity, $El_{tot,Process}$:

$$El_{i,Process} = \frac{m_i}{\sum_{n=1}^{i} m_i} \cdot El_{tot,Process} = \frac{m_{pi}}{100\%} \cdot El_{tot,Process} \quad (4)$$

Allocation Example and Explanations

Figure 5 shows the default allocation of crude oil, thermal energy and electricity for the atmospheric distillation (example). Please note that other refinery feedstocks are neglected in this description to increase readability.

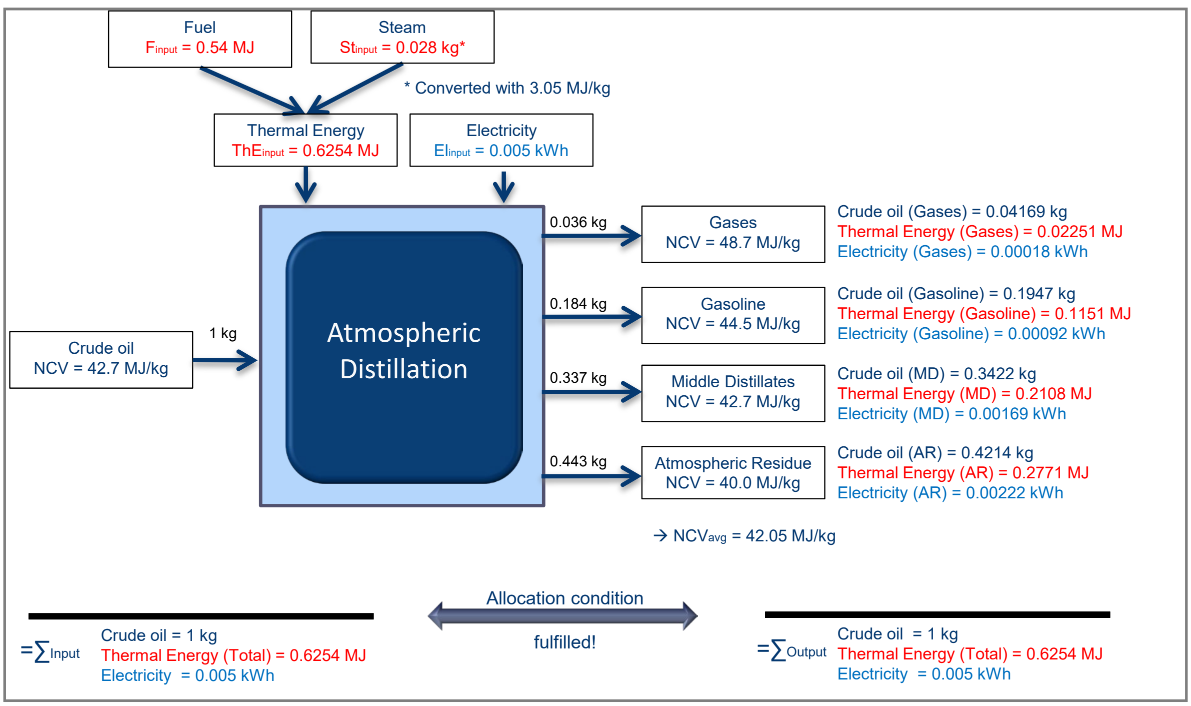

Figure 5 Allocation Example: Atmospheric Distillation

Explanation - Crude Oil Allocation

Figure 5 demonstrates that products with a higher net calorific value than the average (gases, naphtha, middle distillates) result in a higher amount of allocated crude oil consumption compared with products with a lower net calorific value (atmospheric residue).

For example, from 1 kg of crude oil input, 0.036 kg gases are produced. To produce a specific amount of product (in this case 0.036 kg), a corresponding amount of 0.036 kg of crude oil is necessary. Through allocation, the gases are attributed 0.04169 kg of the crude oil consumption. The atmospheric residue works contrary to those products with a high net calorific value. From 1 kg of crude oil input 0.443 kg atmospheric residue is produced, but the allocation attributes only 0.4214 kg due to its low net calorific value. Therefore, products with higher net calorific value are attributed higher input amounts, and therefore higher environmental impacts (associated with the crude oil supply), than products with a lower net calorific value.

This allocation approach is meaningful, because lighter fractions are usually the preferred refinery products and a lot of effort is undertaken to produce them. This sort of “extra” effort is expressed in slightly higher associated burdens. For instance, a lot of processing steps are in operation, converting heavy fractions to lighter fractions, ultimately to products with a higher calorific value. Note, light products have often a higher market demand and market price as well. As previously mentioned, all products are considered to be main products (outputs) and are taken into account in allocation, but to obtain a certain quantity of lighter fractions requires a significant effort.

The allocation of the crude oil input by net calorific value can also be explained from a physical point of view. The energy content of refinery products represents basically a certain crude oil consumption and due to the predominant energetic applications of refinery products, this allocation approach attributes a corresponding crude oil consumption to the use.

The chosen allocation method is therefore providing a cause oriented attribution of environmental impacts to its products. The physical parameter “net calorific value”” is used instead of the “market value”, since most of the intermediate products are not treated on the market and hence, they simply don’t have any market price. Anyway, due to an assumed correlation between market price and net calorific value (not linear and within limits), the conclusion of both allocation methods should come to similar results and conclusions.

Explanation - Thermal Energy Allocation

The first step to define an adequate allocation method is to clarify the purpose. In case of the refinery, the purpose of heat and steam (thermal energy) usage is to heat the different unit feedstocks to process temperature. The pre-heating phase is the primary energy consumer in most of the refinery unit processes.

Equation (5) describes the relationship between the heat, Q_i, that flows into a system to increase its temperature by ΔT, which depends on the specific heat capacity of the medium, c_i and its mass, m_i. Many substances have a known heat capacity per unit mass.

$$Q_i = m_i \cdot c_i \cdot \Delta T \tag{5}$$

Since heavier fractions have higher specific heat capacities compared with lighter products, more energy is needed to heat them to the same temperature, and in addition higher temperatures are needed for heavier fractions, e.g., in distillation columns, to separate those fractions due to its higher boiling point, i.e., the processing of higher fractions is more energy intensive.

Therefore, an allocation by mass is chosen for the energy consumed. An allocation based on “net calorific value” (as used for the crude oil consumption), would increase the environmental impact associated with the provision of lighter fractions. As a result, the chosen allocation by mass avoids giving heavier products ‘too much advantage’ compared with the allocation of net calorific value. The allocation is considered appropriate and cause oriented.

Explanation - Electricity Allocation

The allocation by mass is used for the electricity consumption as well. The mass of the product is used for the allocation, not - as for the thermal energy consumption – due to the higher specific heat capacities, but rather the higher density of heavier products. The electricity is primarily used to run the equipment, which includes pumps and mixers. The pump performance increases with the density of the medium, so allocation by mass is argued to be sufficiently efficient to demonstrate the higher burden of the heavy fractions.

In general, and independent of the chosen allocation method, the allocation condition must be fulfilled, i.e. the inputs and outputs which have been allocated in a unit process must add up to the inputs and outputs before the allocation were performed and in other words, the sum of allocated inputs and outputs to a process must be equal to the sum of inputs and outputs before allocation. Please see Figure 4.

Allocation: Backpack Principle

To quantify and assess the crude oil, and energy consumption that are essential to produce refinery products, the consideration of the atmospheric distillation alone, as described above, is not enough. Please note that other refinery feedstocks are neglected in this description to increase readability.

Since most of the products pass many processes within the refinery, all refinery processes must be considered, and material and energy efforts must be allocated to the final refinery products. More complex products (which passes many unit processes), such as gasoline, have a high energy consumption (and therefore higher associated environmental impacts) compared with products which pass only a few refinery processes, such as straight-run diesel or vacuum residue which can be used directly as bitumen.

This requirement is achieved through the “Backpack Principle”. Each output (product / intermediate product) of a unit process is assigned a “backpack” of allocated crude oil, thermal energy and electricity consumption. Thereby the backpack (allocated crude oil, thermal energy and electricity consumption of previous unit processes) of the input of the corresponding process and the thermal energy and electricity consumption of the corresponding process are allocated to the products / intermediate products and hence, the backpack continues to accumulate during the product journey through the refinery.

The formula for the allocation of the backpack’s content is the same as for the crude oil, thermal energy and electricity of the atmospheric distillation process as described above. In a respective backpack, a product carries a proportionate amount of the feedstock, as well as a proportionate amount that has been allocated in each unit process.

Note, crude oil is obviously only consumed at the atmospheric distillation, while thermal energy and electricity are also consumed in (all) other refinery unit processes.

Figure 6 outlines the backpack principle at the vacuum distillation, a subsequent process of the atmospheric distillation.

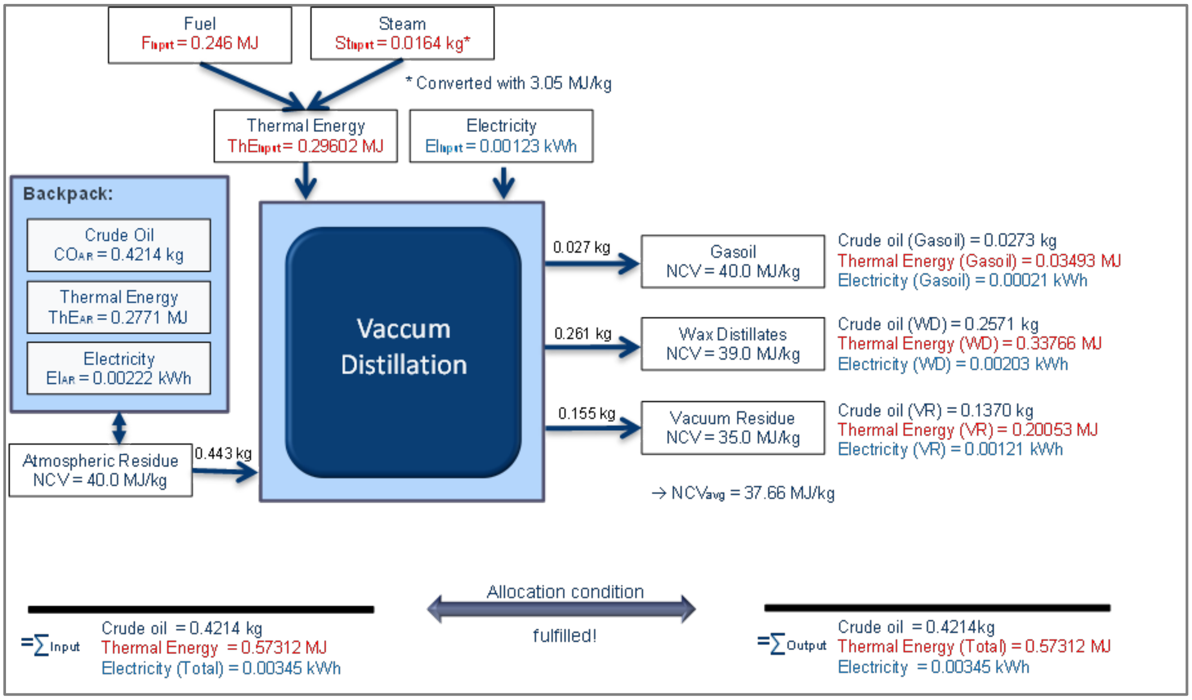

Figure 6 Allocation Example: Vacuum Distillation

To the three products of the vacuum distillation unit (gasoil, wax distillates and vacuum residue) a share of the following is allocated:

- the crude oil (backpack of crude oil consumption accumulated at the atmospheric distillation),
- thermal energy (backpack of thermal energy consumption accumulated at the atmospheric distillation and thermal energy consumption of this process (i.e. vacuum distillation) as well as,
- electricity (backpack of electricity consumption accumulated at the atmospheric distillation and electricity consumption of this process (i.e. vacuum distillation).

The allocated crude oil consumption of subsequent processes to the atmospheric distillation, i.e. at all “downstream processes” is re-distributed to the corresponding products. For thermal energy and electricity consumption, the re-distribution also takes place, but in addition, thermal energy and electricity consumption of the corresponding process is allocated to the products as well. Therefore, the thermal energy and electricity backpack increases according to the thermal energy and electricity required at the corresponding unit process.

For processes with two or more hydrocarbon inputs, the respective input fractions of the backpacks are summed up.

In summary, all subsequent processes of the atmospheric distillation consist of five corresponding inputs: crude oil, thermal energy and electricity of the backpack, as well as thermal energy and electricity at each specific refinery unit process. Note, some unit processes do not need thermal energy / electricity for operation (values set to zero) or are even delivering thermal energy due to its exothermic nature (negative value), which is credited.

Please note that there are significant differences in the thermal energy and electricity consumption of the different refinery unit processes. Also, the production route, i.e. the number of processes a product passes through the refinery, is different from product to product. However, the backpack principle allows that each final refinery product is assigned the environmental impact shares of all processes it passed through the refinery and allows a cause oriented attribution.

For example, a gasoline fraction derived from the atmospheric distillation, which is further processed in a gasoline desulfurization and catalytic reformer, has a smaller backpack than gasoline fractions produced via atmospheric distillation followed by vacuum distillation, vacuum distillate desulfurization, and FCC, because more processes, and especially more energy intensive process, are involved.

This detailed approach following a backpack principle contrasts with simple refinery models, at which the emissions of the whole plant are simply allocated among the final products by static factors (e.g., mass, energy content, market price). These simple allocation approaches do not reflect the complexity of a refinery and do not differentiate between production routes, and such kinds of allocations can’t be classified as cause oriented.

References

[1] European Council for Automotive R&D (EUCAR), “Attributional vs. Consequential LCA,” 2020. [Online]. Available: https://www.eucar.be/wp-content/uploads/2020/08/20200820-EUCAR-Attributional-vs-Consequential-updated-2.pdf. [Accessed January 2026].

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Annex

Table 1: Inputs and Outputs of the “Sphera LCA Refinery Model”:

Inputs of the “Sphera LCA Refinery Model”:	Outputs of the “Sphera LCA Refinery Model”:
• Crude oil • Other feedstocks (VGO, bio and circular feedstocks, e.g., pyrolysis oil) • Electricity • Natural gas / biomethane • Methanol / (bio-) ethanol • Water	• Hydrogen • Refinery gas • Propane • Butane • Propene (propylene) • Butene • Butadiene / C4 cut from FCC • Naphtha • Gasoline (premium) • Gasoline (regular) • Aromatics (BTX) • Benzene • Toluene • Xylene • Cyclohexane • Hexane • Heptane • Kerosene / Jet A1 • Diesel • Light fuel oil (LFO) • Marine diesel oil (MDO) • Marine gas oil (MGO) • Very low sulfur fuel oil (VLSFO) (0.5 wt.% sulfur) • Ultra low sulfur fuel oil (ULSFO) (0.1 wt.% sulfur) • Heavy fuel oils (HFO) (sulfur content ranging from 0.3 to 2.5 wt.% sulfur) • Bunker oil (>2.5 wt.% sulfur) • Base oil (group I) • Base oil (group II) • Base oil (group III) • Vacuum gas oil (VGO) • Atmospheric residue • Wax / paraffins • Bitumen • Petrol coke • Sulfur

Customer Care

For assistance or inquiries regarding Product Name, contact Customer Care:

- Visit the Sphera Customer Network (SCN) at SCN.Spherasolutions.com. To access frequently asked questions and to report any issues using the SCN, you must request a username and password.
- Send an email to customercare@sphera.com