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(71) Applicant: **BASF SE** [DE/DE]; Carl-Bosch-Strasse 38,
67056 Ludwigshafen am Rhein (DE).

(72) Inventors: **BADRI, Tara**; 470 Launch Circle, Naples,
Florida 34108 (US). **LU, Marcelo Rocha**; 128 Beach
Road, Singapore 189773 (SG). **RAUDA SALAZAR, Eliz-
abeth**; Insurgentes Sur 975, Ciudad de Mexico, 03710
(MX). **GONZALEZ GASPAS, Areli**; Insurgentes Sur

975, Ciudad de Mexico, 03710 (MX). **SCHWABE, Hen-
ning**; Glücksteinallee 25, 68163 Mannheim (DE). **GRAF,
Nicole**; Pfalzgrafenstraße 1, 67061 Ludwigshafen am Rhein
(DE).

(74) Agent: **BASF IP ASSOCIATION**; BASF SE GBI - C006,
67056 Ludwigshafen (DE).

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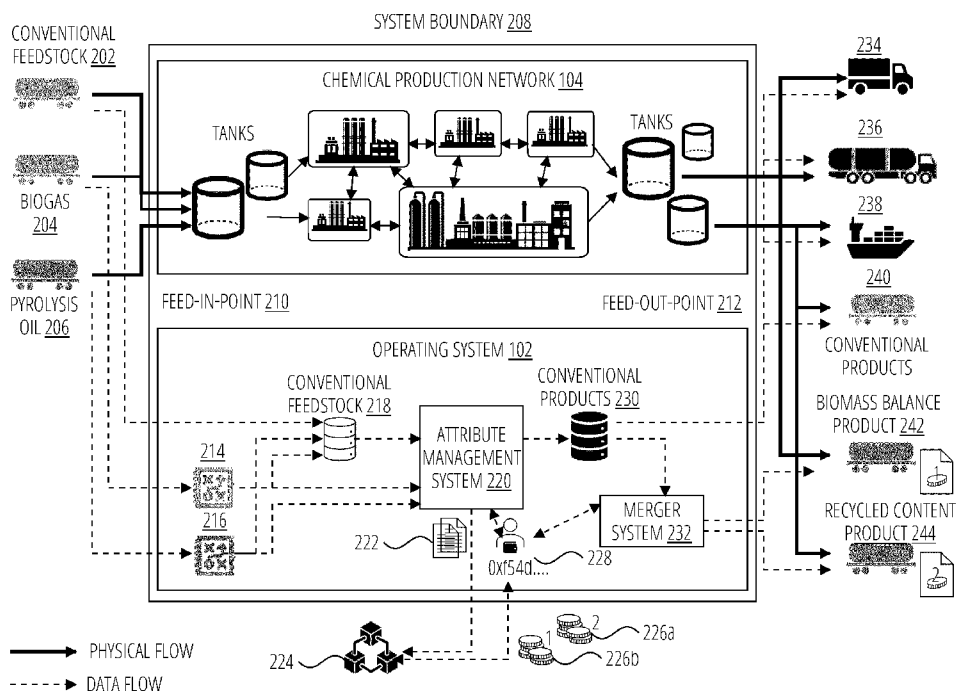


FIG. 2

(57) Abstract: Disclosed are methods, apparatuses, and systems for producing at least one chemical product associated with one or more environmental attribute(s) and for assigning at least one environmental attribute to at least one chemical product produced by a chemical production network.

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BALANCING OF ENVIRONMENTAL ATTRIBUTES IN CHEMICAL PRODUCTION NETWORKS

TECHNICAL FIELD

The present disclosure relates to methods, apparatuses and systems for managing and attributing at least one environmental attribute associated with input material(s) to one or more chemical product(s).

TECHNICAL BACKGROUND

In supply chains the environmental impact of each supply chain participant is of great interest. Transparency between the participants can aid collective reduction of environmental impacts to combat climate change. However, data sharing of environmental impact data is hindered by the lack of common data standards and the lack of trusted data platforms. In addition, the highly specific and centralized setup of data systems today makes exchange and sharing for collective action laborious. Hence, there is a need to develop metrics quantifying the environmental impact of produced products, to simplify data standards relating to environmental impact and to broadly enable a secure exchange of supply chain data relating to the environmental impact.

SUMMARY OF THE INVENTION

Disclosed is in one aspect a computer-implemented method for attributing at least one environmental attribute associated with an input material to one or more chemical products(s), wherein the one or more chemical products(s) are produced by a chemical production network using the input material(s), wherein the chemical production network chemically converts input materials via chemical intermediates to chemical products that exit the chemical production network, the method comprising:

- providing input material data associated with the input material to an operating system of the chemical production network;
- determining environmental attributes associated with the input material based on the provided input material data;
- creating one or more token(s) linked to at least one determined environmental attribute at an address associated with a distributed ledger network, wherein the address is associated with the operating system of the chemical production network;
- providing a chemical product identifier associated with the chemical product and optionally at least one target environmental attribute;
- based on the chemical product identifier and optionally the target environmental attribute, selecting at least one attribution rule for attributing token(s) linked to one or more environmental attributes(s) associated with input material(s) to chemical product(s);

- determining via the at least one attribution rule units of token(s) linked to one or more environmental attribute(s); and
- assigning the determined units of token(s) linked to the one or more environmental attribute(s) to the chemical product identifier.

5 Disclosed is in a further aspect a computer-implemented method for attributing at least one environmental attribute associated with an input material to one or more chemical products(s), wherein the one or more chemical products(s) are produced by a chemical production network using the input material(s), wherein the chemical production network chemically converts input materials via chemical intermediates to chemical products that exit the chemical production network, the method comprising:

- 10
- providing input material data associated with the input material to an operating system of the chemical production network;
 - determining environmental attributes associated with the input material based on the provided input material data;
 - based on the determined environmental attributes, determining at least one address associated with
- 15 a distributed ledger network and holding units of token(s) linked to one or more of the determined environmental attribute(s);
- allocating units of at least one of the token(s) to a further address associated with the operating system of the chemical production network;
 - providing a chemical product identifier associated with the chemical product and at least one target
- 20 environmental attribute;
- based on the chemical product identifier and the target environmental attribute, selecting at least one attribution rule for attributing token(s) linked to one or more environmental attributes(s) associated with input material(s) to chemical product(s);
 - determining via the at least one attribution rule at least one address holding units of token(s) linked
- 25 to one or more environmental attribute(s); and
- assigning units of at least one of the tokens linked to the one or more environmental attribute(s) to the chemical product identifier.

Disclosed is in yet a further aspect a computer-implemented method for monitoring environmental impact of one or more chemical product(s), wherein the one or more chemical products(s) are produced by a

30 chemical production network using the input material(s), wherein the chemical production network chemically converts input materials via chemical intermediates to chemical products that exit the chemical production network, the method comprising:

- providing input material data associated with the input material to an operating system of the chemical production network;
- 35
- determining environmental attributes associated with the input material based on the provided input material data;

- creating one or more token(s) linked to at least one determined environmental attribute at an address associated with a distributed ledger network, wherein the address is associated with the operating system of the chemical production network;
- providing a chemical product identifier associated with the chemical product and optionally at least one target environmental attribute;
- based on the chemical product identifier and optionally the target environmental attribute, selecting at least one attribution rule for attributing token(s) linked to one or more environmental attributes(s) associated with input material(s) to chemical product(s);
- determining via the at least one attribution rule units of token(s) linked to one or more environmental attribute(s); and
- assigning the determined units of token(s) linked to the one or more environmental attribute(s) to the chemical product identifier.

Disclosed is in yet a further aspect a computer-implemented method for monitoring environmental impact of one or more chemical product(s), wherein the one or more chemical products(s) are produced by a chemical production network using the input material(s), wherein the chemical production network chemically converts input materials via chemical intermediates to chemical products that exit the chemical production network, the method comprising:

- providing input material data associated with the input material to an operating system of the chemical production network;
- determining environmental attributes associated with the input material based on the provided input material data;
- based on the determined environmental attributes, determining at least one address associated with a distributed ledger network and holding units of token(s) linked to one or more of the determined environmental attribute(s);
- allocating units of at least one of the token(s) to a further address associated with the operating system of the chemical production network;
- providing a chemical product identifier associated with the chemical product and at least one target environmental attribute;
- based on the chemical product identifier and the target environmental attribute, selecting at least one attribution rule for attributing token(s) linked to one or more environmental attributes(s) associated with input material(s) to chemical product(s);
- determining via the at least one attribution rule at least one address holding units of token(s) linked to one or more environmental attribute(s); and
- assigning units of at least one of the tokens linked to the one or more environmental attribute(s) to the chemical product identifier.

Disclosed is in yet a further aspect a computer-implemented method for attributing at least one environmental attribute associated with an input material to one or more chemical products(s), wherein the one or more chemical products(s) are produced by a chemical production network using the input material(s), wherein the chemical production network chemically converts input materials via chemical intermediates to chemical products that exit the chemical production network, the method comprising:

- providing multiple input material(s) associated with one or more environmental attribute(s) to the chemical production network, including a first input material and a second input material;
- providing a first input material data associated with the first input material and a second input material data associated with the second input material;
- providing units of token(s) associated with the one or more environmental attribute(s) of the first input material and the second input material, wherein the units of token(s) are stored in an address associated with a distributed ledger network and wherein the address is associated with an operating system of the chemical production network;
- providing a chemical product identifier associated with the chemical product and at least one target environmental attribute;
- based on the chemical product identifier and the target environmental attribute, selecting at least one attribution rule for attributing token(s) linked to one or more environmental attributes(s) associated with input material(s) to chemical product(s);
- determining via the at least one attribution rule at least one address holding units of token(s) linked to one or more environmental attribute(s); and
- assigning units of at least one of the tokens linked to the one or more environmental attribute(s) to the chemical product identifier.

Disclosed is in yet a further aspect a computer-implemented method for monitoring environmental impact of one or more chemical product(s), wherein the one or more chemical products(s) are produced by a chemical production network using the input material(s), wherein the chemical production network chemically converts input materials via chemical intermediates to chemical products that exit the chemical production network, the method comprising:

- providing multiple input material(s) associated with one or more environmental attribute(s) to the chemical production network, including a first input material and a second input material;
- providing a first input material data associated with the first input material and a second input material data associated with the second input material;
- providing units of token(s) associated with the one or more environmental attribute(s) of the first input material and the second input material, wherein the units of token(s) are stored in an address associated with a distributed ledger network and wherein the address is associated with an operating system of the chemical production network;

- providing a chemical product identifier associated with the chemical product and at least one target environmental attribute;
- based on the chemical product identifier and the target environmental attribute, selecting at least one attribution rule for attributing token(s) linked to one or more environmental attributes(s) associated with input material(s) to chemical product(s);
- determining via the at least one attribution rule at least one address holding units of token(s) linked to one or more environmental attribute(s); and
- assigning units of at least one of the tokens linked to the one or more environmental attribute(s) to the chemical product identifier.

Disclosed is in yet another aspect, an apparatus for assigning or attributing at least one environmental attribute associated with input material(s) to one or more chemical product(s), wherein the one or more chemical products(s) are produced by a chemical production network using the input material(s), wherein the chemical production network chemically converts input materials via chemical intermediates to chemical products that exit the chemical production network, the apparatus comprising:

- an environmental attribute determination module configured to
 - receive input material data associated with the at least one input material and
 - determine environmental attributes associated with the at least one input material;
- a distributed ledger application configured to create one or more token(s) linked to at least one determined environmental attribute at an address associated with the distributed ledger, wherein the address is associated with an operating system of the chemical production network,
- an attribution module configured to provide at least one attribution rule for attributing token(s) linked to one or more environmental attributes(s) associated with input material(s) to chemical product(s);
- a data provider configured to provide at least one chemical product identifier associated with the chemical product and at least one target environmental attribute for the chemical product; and
- an outbound allocator configured to
 - select based on the chemical product identifier and the target environmental attribute at least one attribution rule,
 - determine via the at least one attribution rule at least one address holding units of token(s) linked to one or more environmental attribute(s), and
 - assign units of at least one of the tokens linked to the one or more environmental attribute(s) to the chemical product identifier.

Disclosed is in yet another aspect, an apparatus for assigning or attributing at least one environmental attribute associated with input material(s) to one or more chemical product(s), wherein the one or more chemical products(s) are produced by a chemical production network using the input material(s), wherein the chemical production network chemically converts input materials via chemical intermediates to chemical products that exit the chemical production network, the apparatus comprising:

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- an environmental attribute determination module configured to
 - receive input material data associated with the at least one input material and
 - determine environmental attributes associated with the at least one input material;
 - a distributed ledger application configured determining - based on the determined environmental attributes - at least one address associated with a distributed ledger network and holding units of token(s) linked to one or more of the determined environmental attribute(s) and to allocate units of at least one of the token(s) to a further address associated with the operating system of the chemical production network,
 - an attribution module configured to provide at least one attribution rule for attributing token(s) linked to one or more environmental attributes(s) associated with input material(s) to chemical product(s);
 - a data provider configured to provide at least one chemical product identifier associated with the chemical product and at least one target environmental attribute for the chemical product; and
 - an outbound allocator configured to
 - select based on the chemical product identifier and the target environmental attribute at least one attribution rule,
 - determine via the at least one attribution rule at least one address holding units of token(s) linked to one or more environmental attribute(s), and
 - assign units of at least one of the tokens linked to the one or more environmental attribute(s) to the chemical product identifier.
- Disclosed is in yet another aspect, an apparatus for monitoring environmental impact of one or more chemical product(s), wherein the one or more chemical products(s) are produced by a chemical production network using the input material(s), wherein the chemical production network chemically converts input materials via chemical intermediates to chemical products that exit the chemical production network, the apparatus comprising:
- an environmental attribute determination module configured to
 - receive input material data associated with the at least one input material and
 - determine environmental attributes associated with the at least one input material;
 - a distributed ledger application configured to create one or more token(s) linked to at least one determined environmental attribute at an address associated with the distributed ledger, wherein the address is associated with an operating system of the chemical production network,
 - an attribution module configured to provide at least one attribution rule for attributing token(s) linked to one or more environmental attributes(s) associated with input material(s) to chemical product(s);
 - a data provider configured to provide at least one chemical product identifier associated with the chemical product and at least one target environmental attribute for the chemical product; and
 - an outbound allocator configured to

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- select based on the chemical product identifier and the target environmental attribute at least one attribution rule,
- determine via the at least one attribution rule at least one address holding units of token(s) linked to one or more environmental attribute(s), and
- 5 ○ assign units of at least one of the tokens linked to the one or more environmental attribute(s) to the chemical product identifier.

Disclosed is in yet another aspect, an apparatus for monitoring environmental impact of one or more chemical product(s), wherein the one or more chemical products(s) are produced by a chemical production network using the input material(s), wherein the chemical production network chemically
10 converts input materials via chemical intermediates to chemical products that exit the chemical production network, the apparatus comprising:

- an environmental attribute determination module configured to
 - receive input material data associated with the at least one input material and
 - determine environmental attributes associated with the at least one input material;
- 15 • a distributed ledger application configured determining - based on the determined environmental attributes - at least one address associated with a distributed ledger network and holding units of token(s) linked to one or more of the determined environmental attribute(s) and to allocate units of at least one of the token(s) to a further address associated with the operating system of the chemical production network,
- 20 • an attribution module configured to provide at least one attribution rule for attributing token(s) linked to one or more environmental attributes(s) associated with input material(s) to chemical product(s);
- a data provider configured to provide at least one chemical product identifier associated with the chemical product and at least one target environmental attribute for the chemical product; and
- an outbound allocator configured to
 - 25 ○ select based on the chemical product identifier and the target environmental attribute at least one attribution rule,
 - determine via the at least one attribution rule at least one address holding units of token(s) linked to one or more environmental attribute(s), and
 - assign units of at least one of the tokens linked to the one or more environmental attribute(s) to
30 the chemical product identifier.

Disclosed is in yet another aspect, a digital operating system of a chemical production network, wherein the chemical production network chemically converts input materials via chemical intermediates to chemical products that exit the chemical production network, the digital operating system comprising:

- an environmental attribute determination module configured to
 - 35 ○ receive input material data associated with the at least one input material and
 - determine environmental attributes associated with the at least one input material;

- a distributed ledger application configured to create one or more token(s) linked to at least one determined environmental attribute at an address associated with the distributed ledger, wherein the address is associated with an operating system of the chemical production network,
- an attribution module configured to provide at least one attribution rule for attributing token(s) linked to one or more environmental attributes(s) associated with input material(s) to chemical product(s);
- a data provider configured to provide at least one chemical product identifier associated with the chemical product and at least one target environmental attribute for the chemical product; and
- an outbound allocator configured to
 - select based on the chemical product identifier and the target environmental attribute at least one attribution rule,
 - determine via the at least one attribution rule at least one address holding units of token(s) linked to one or more environmental attribute(s), and
 - assign units of at least one of the tokens linked to the one or more environmental attribute(s) to the chemical product identifier.

Disclosed is in yet another aspect, a digital operating system of a chemical production network, wherein the chemical production network chemically converts input materials via chemical intermediates to chemical products that exit the chemical production network, the digital operating system comprising:

- an environmental attribute determination module configured to
 - receive input material data associated with the at least one input material and
 - determine environmental attributes associated with the at least one input material;
- a distributed ledger application configured determining - based on the determined environmental attributes - at least one address associated with a distributed ledger network and holding units of token(s) linked to one or more of the determined environmental attribute(s) and to allocate units of at least one of the token(s) to a further address associated with the operating system of the chemical production network,
- an attribution module configured to provide at least one attribution rule for attributing token(s) linked to one or more environmental attributes(s) associated with input material(s) to chemical product(s);
- a data provider configured to provide at least one chemical product identifier associated with the chemical product and at least one target environmental attribute for the chemical product; and
- an outbound allocator configured to
 - select based on the chemical product identifier and the target environmental attribute at least one attribution rule,
 - determine via the at least one attribution rule at least one address holding units of token(s) linked to one or more environmental attribute(s), and
 - assign units of at least one of the tokens linked to the one or more environmental attribute(s) to the chemical product identifier.

In yet another aspect disclosed is a computer element, in particular a computer program product or a computer readable medium, with instructions, which when executed on one or more computing node(s) are configured to carry out the steps of any of the methods disclosed herein. In yet another aspect disclosed is a computer element, in particular a computer program product or a computer readable medium, with instructions, which when executed by a processor cause any of the apparatuses disclosed herein to perform any of the methods disclosed herein.

Disclosed is in yet another aspect the use of the chemical product associated with one or more environmental attribute(s) as provided by any of the methods disclosed herein and/or produced by a chemical production network as provided by any of the methods disclosed herein to produce at least one discrete product or at least one end product of a product supply chain associated with the one or more environmental attribute(s). Disclosed is in yet another aspect a method for producing at least one discrete product or at least one end product of a product supply chain associated with the one or more environmental attribute(s), wherein the chemical product associated with one or more environmental attribute(s) as provided by any of the methods disclosed herein and/or produced by a chemical production network as provided by any of the methods disclosed herein is provided and/or used to produce the at least one discrete product or at least one end product of a product supply chain associated with the one or more environmental attribute(s).

In yet another aspect the present disclosure relates to a computer element with instructions, which when executed on one or more computing node(s) is configured to carry out the steps of the method(s) of the present disclosure or configured to be carried out by the apparatus(es) of the present disclosure.

Any disclosure, embodiments and examples described herein relate to the methods, the systems, apparatuses, chemical products and computer elements lined out above and below. Advantageously, the benefits provided by any of the embodiments and examples equally apply to all other embodiments and examples.

Embodiments

The methods, apparatuses, systems and computer elements disclosed herein provide an efficient way to track environmental attributes in chemical processing and provide chemical products with positive environmental impact through the value chain. By converting environmental attributes of input material(s) to units of token(s), such environmental attributes can be virtually balanced on a distributed ledger and can be efficiently assigned via attribution rules to chemical products produced in chemical production networks. Specifically for chemical networks that produce more than one chemical product from more than one input material via interconnected, connected and non-connected production chains, the use of token(s) in combination with attribution rules allows to reliably assign environmental attributes in line with the physical setup of the chemical production network and to tailor the units of token(s) (e.g. digital

assets) associated with the chemical product to the needs of customers. The virtual balancing using token(s) and associated meta data structure further allows to decouple the complexity in material flow of chemical production networks while still allowing to tailor environmental impact to each chemical product. This way the environmental impact of the produced chemical product can be determined in line with the physical set up of the chemical production network and the tailored needs of customers. Moreover, the environmental property of the chemical products produced by the chemical production network can be made transparent to customers further processing the chemical products. By providing chemical product identifiers associated with at least one environmental attribute, the environmental attributes to be allocated to the product and as such the number of token(s) and associated units attached to the chemical product can be adjusted to customer needs.

By using attribution rules, environmental attributes associated with input materials can be efficiently attributed to chemical products. Specifically for chemical networks that produce more than one chemical product from more than one input material via interconnected, connected and non-connected production chains, the use of attribution rules allows to reliably adjust the attribution mechanisms in line with the physical setup of the chemical production network. The use of tokens for balancing environmental attributes further allows to abstract the complexity of chemical production networks while still allowing to assign environmental impact to chemical products. This way the environmental impact of the produced chemical product can be determined in line with the physical set up of the chemical production network. Moreover, the environmental property of the chemical products produced in the chemical production network can be made transparent to customers further processing the chemical products. By providing a chemical product identifier associated with at least one target environmental attribute the environmental attributes to be allocated to the product and as such the number of token(s) and associated units attached to the chemical product may even be adjusted to customer needs.

By using token(s) and associated units linked (or assigned, attributed, allocated, attached) to a chemical product, customers can easily select sustainable products (e.g., products with renewable, bio-based, sustainable origin and/or a recycled content). They can use the token(s) and associated units to identify ways to make the value chain more sustainable. The token(s) also provide(s) a way for chemical production networks to speed the transformation of the use of sustainable feedstocks as input materials and the production of chemical products at least partly based on sustainable materials. Specifically for chemical networks that produce more than one chemical product from more than one input material via interconnected, connected and non-connected production chains, the use of token(s) enables the attribution of environmental attributes in line with the physical setup of the chemical production network. The use of token(s) enables the abstraction of the complexity of chemical production networks while still allowing to assign environmental impact to chemical products. This way the environmental impact of the produced chemical product(s) can be determined in line with the physical set up of the chemical production network. Moreover, the environmental property of the chemical products produced in the

chemical production network can be made transparent to customers further processing the chemical products. By providing token(s) and associated units with a chemical product identifier associated with at least one target environmental attribute the environmental attributes may even be adjusted to customer needs.

5 The token may be a representation of environmental attribute(s) of a physical asset, such as input material and/or chemical product, and can be exchanged among participants of a distributed ledger network and recorded in the distributed ledger. The token may be associated with units. Said units may specify a quantitative measure of the environmental attribute(s) the token is linked to, such as the amount of sustainable origin content, recycled content, renewable content and/or bio-based content of the
10 chemical product. Said units may specify a quantitative measure of the environmental attribute(s) the token is linked to, such as the amount of sustainable origin input material, recycled input material, renewable input material and/or bio-based input material entering the chemical production network. The token may specify a qualitative measure of the environmental attribute(s) the token is linked to, such as the sustainable origin, recycled, renewable and/or bio-based of the input material(s). The token may be
15 a fungible token (e.g. an asset that is not unique and mutually interchangeable). The token may be a non-fungible token (e.g. an asset that is unique). This may allow to uniquely link a token and hence the environmental attribute(s) the token is associated with to a particular order of a produced chemical product.

The environmental attribute associated with the input material may be a digital asset. The environmental
20 attribute may digitally specify the environmental impact of the input material. The environmental attribute may relate to a carbon footprint. The environmental attribute may relate to a renewable, a bio-based and/or a recycled content e.g., of the input material. The environmental attribute may relate to a sustainable origin of the input material. The environmental attribute may include a qualitative data point relating to the type of impact e.g., in view of the input material. The environmental attribute may specify
25 a type such as sustainable origin, recycled, renewable and/or bio-based. The qualitative data point may be converted to a quantitative measure such as token units. The environmental attribute may include a quantitative data point relating to the type of impact e.g., in view of the input material. The environmental attribute may specify a sustainable origin, recycled, renewable and/or bio-based content. The environmental attribute may include further environmental characteristics of the input material(s).

30 Environmental attribute(s) may refer to any property or characteristic related to the environmental impact. Such property may be a property or characteristic of an input material(s) and/or a chemical product(s). The environmental attribute may indicate an environmental performance of an input material(s), the chemical production network and/or chemical product(s). The environmental attribute may indicate certifications which document coherence to existing industry standards, in particular standards with
35 respect to the environmental impact. The environmental attribute may be derived from properties of the

input material(s), the chemical production network and/or the chemical product(s). The environmental attribute may be associated with the environmental impact of one or more material(s) at any stage during their lifecycle. The stages of the material or product lifecycle may include the stages of providing raw material, producing products, such as intermediate products or end products, using products, treating
5 end-of-life products, recycling end-of-life products, disposing end-of-life products, reusing components from end-of-life products or any subset of stages. The environmental attribute may be tracked through any activity of one or more entities participating at any stage of the lifecycle of one or more material(s) or product(s). Environmental attributes associated with any activity of one or more entities participating at any stage of the lifecycle of one or more input material(s) or product(s) may be accumulated or
10 aggregated. The environmental attribute(s) may be specified or may be produced or derived from any activity of one or more entities participating at any stage of the lifecycle of input material(s) or product(s).

The environmental attribute may include one or more characteristic(s) that are attributable to environmental or sustainability impact of the input material(s), chemical product(s), intermediate product(s) and/or end product(s). The environmental attribute may include environmental, technical,
15 recyclability or circularity characteristics(s) associated with the environmental impact of the input material(s), chemical product(s), intermediate product(s) and/or end product(s).

Environmental characteristic(s) may specify or quantify ecological criteria associated with the environmental impact of an input material, intermediate product, and/or a chemical product. Environmental characteristic(s) may be or may be produced or derived from measurements taken during
20 the lifecycle of input material(s), chemical product(s), intermediate product(s) and/or end product(s). Environmental characteristic(s) may for example include impact categories such as carbon footprint, greenhouse gas emissions or global warming potential, primary energy demand, cumulative energy demand, biotic and abiotic resource consumption, air emissions, stratospheric ozone depletion potential, ozone formation, terrestrial and/or marine acidification, water consumption, water depletion, water
25 availability, water pollution, noise pollution, freshwater and/or marine eutrophication potential, human carcinogenic and/or non-carcinogenic toxicity, photochemical oxidant formation, particulate matter formation, terrestrial, freshwater and/or marine ecotoxicity, ionizing radiation, agricultural and/or urban land occupation, land transformation, land use, indirect land use, deforestation, biodiversity, mineral resource consumption, and/or fossil resource consumption. Environmental characteristic(s) may be
30 calculated from combinations of one or more environmental characteristics. Environmental characteristic(s) may for example include material or product characteristics related to the production of the material or product like recycled content, bio-based content, renewable content, bio based, produced using sustainable vegetable oil, vegan, halal, kosher, palm oil-free, natural or the like.

Technical characteristic(s) may specify or quantify material or product performance at least indirectly
35 associated with the environmental impact. Technical characteristic(s) may for example include product

composition data, bill of materials, product specification data, product component data, product safety data, application property data, application instructions or product quality data. Technical characteristic(s) may be or may be produced from measurements taken during the lifecycle of one or more material(s) or product(s). Technical characteristics may be determined at any stage of the material or product lifecycle and may characterize the material or product performance for such stage or up to such stage. Technical characteristic(s) may for example include composition data, input in the production process, bill of materials, product or material specification data, product or material component data, product or material safety data, application property data, application instructions or product or material quality data. Technical characteristic(s) may for example include physical, chemical or further properties of the material or product.

Circularity characteristic(s) may specify or quantify the material or product life cycle characteristics associated with circular uses. Circularity characteristic(s) may be or may be produced from measurements taken during the lifecycle of one or more material(s) or product(s). Circularity characteristic(s) may be or may be produced from circular data recorded in one or more prior lifecycle(s) including reuse. Circularity characteristics may be determined at any stage of the material or product lifecycle and may characterize the reuse or recycling performance for such stage or up to such stage. Circularity characteristic(s) may relate to technical, mechanical, chemical and/or biological recycling. Circularity characteristic(s) may for example include recycling data, reuse rate, recycling rate, recycling loops, reuse reused product performance, reused material or product quality or the like. Further circularity material characteristics may be derived by combining circularity characteristic(s).

Recyclability characteristic(s) may specify or quantify the material or product life cycle characteristics associated with recycling uses. Recyclability characteristic(s) may include the composition of the material including specifically tailored constituents making the material suitable for recycling. Recyclability characteristic(s) may be or may be produced from measurements taken during the lifecycle of one or more materials or product(s). Recyclability characteristic(s) may be or may be produced from recycling data recorded in one or more prior lifecycle(s). Recyclability characteristics may be determined at any stage of the material or product lifecycle and may characterize the recycling performance for such stage or up to such stage. Recyclability characteristic(s) may for example include recycling data, recyclability data, efficiency of recycling or the like.

The input material may comprise any indiscrete material, e.g., may be a continuous volume of solid or liquid material. The input material may include starting material used in any process performed in the chemical production network to produce the chemical product. The input material may be a chemical material, such as a natural, organic or inorganic chemical material. The input material may be a virgin material, e.g. an input material that has not undergone a previous production-and-use cycle, in particular, has not been processed and/or used. The input material may be a recycled material having undergone

at least one recycling step. The input material may be selected from petrochemical feedstocks, such as naphtha crude oil, and natural gas, or intermediates from such feedstocks that in turn require a certain amount of naphtha, crude oil, and natural gas. The input material may be selected from natural feedstocks, such as vegetable oils, biologicals like enzymes, and/or naturally occurring inorganic or organic chemical materials, or intermediates from such feedstocks that in turn require a certain amount of vegetable oils, biologicals and/or naturally occurring inorganic or organic chemical materials. Input material may include conventional vegetable oil(s), non-conventional vegetable oil(s) or both. Non-conventional vegetable oil(s) may include vegetable oil(s) having a sustainable origin. Input material may include feedstock for a hydrolysis plant. Input material may include, for example sustainably produced vegetable oil (sustainable vegetable oil), such as sustainable palm oil, sustainable palm kernel oil, sustainable coconut oil, sustainable rapeseed oil, sustainable soybean oil or combinations thereof. Palm oil and palm kernel oil may be produced from the fruit of the palm oil tree. Palm oil may be produced by milling the fruits of the palm oil tree. Palm kernel oil may be produced by crushing the palm kernels. The sustainable origin of the vegetable oil may be associated with its production. In particular, the sustainable origin may be associated with the growth of the plants used to produce the vegetable oil. Input material may be provided to at least one hydrolysis plant or any plant of the production chain for downstream products such as fatty acids, fatty alcohols, ethoxylated fatty acids, ethoxylated fatty alcohols, soaps or the like. The input material may comprise or be any input material entering the chemical production network and provided at any entry point of the chemical production network. The input material may be any material entering the system boundary of the chemical production network.

Chemical products may include or be any material produced by the chemical production network using at least one input material. The chemical product may comprise or be any chemical product produced by the chemical production network and provided at any exit point of the chemical production network. The chemical product or output material may be produced from input materials by the chemical production network. The chemical product or output material may comprise any material leaving the system boundary of the chemical production network. The chemical product may be produced from the input material(s) via one or more chemical and/or physical processes. Hence, chemical intermediate products produced from input materials may be used to produce the chemical product(s) or output material(s). Chemical processes may include chemical reactions. Chemical reactions may include any chemical reaction commonly known in the state of the art in which the reactants are converted to one or more different chemical products. Chemical reactions may involve the use of catalysts, enzymes, bacteria, etc. to achieve the chemical reaction between the reactants. Physical processes may include mixing, separation and/or extrusion.

Chemical production networks may include multiple types of production processes for producing different chemical products from input materials. The chemical production network may include a complex production network producing multiple chemical products in multiple production or value chains. A

production or value chain may include one or more process(es) configured to produce one chemical product or chemical product class from one or more input material(s). The chemical production network may include connected, interconnected and/or non-connected production chains. The production chains included in the chemical production network may be defined by the physical system boundary of the chemical production network. The system boundary may be defined by location or control over production processes. The system boundary may be defined by the site of the chemical production network. The system boundary may be defined by production processes controlled by one entity or multiple entities jointly. The system boundary may be defined by the value chain with staggered production processes to an end product, which may be controlled by multiple entities jointly or separately. The chemical production network may include a waste collection and sorting step, a recycling step such as pyrolysis, a cracking step such as steam cracking, a production step to produce chemical products or intermediates from provided inbound material(s), a separation step to separate intermediates of one process step and further processing steps to convert such outputs to chemical product(s) leaving the system boundary of the chemical production network. The chemical production network may produce from input materials multiple intermediates and from intermediates one or more chemical products. Input material may enter the chemical production network at entry points. Chemical products may leave the production network at exit points (or feed-out points).

The chemical production network may comprise one or more entry points at which input materials are provided to the chemical production network. Input material may include fossil material, non-fossil material or both. Fossil input material may include crude oil, natural gas or coal. Non fossil input material may include renewable material, bio-based material or recycled materials. Input material may include feedstock for a gasification plant, a steam cracker, a synthesis gas plant or a hydrolysis plant. Input material may include synthesis gas produced from fossil feedstock, non-fossil feedstock or both. Input material may include for example pyrolysis oil from recycled waste, syngas produced from recycled waste, naphtha produced from bio-based material (bio-naphtha), methane from bio-based material (bio-methane), biogas produced from the decomposition of organic materials or combinations thereof. Input material may include, for example sustainably produced vegetable oil (sustainable vegetable oil), such as sustainable palm oil, sustainable palm kernel oil, sustainable coconut oil, sustainable rapeseed oil, sustainable soybean oil or combinations thereof. Input material may be provided to at least one gasification plant, steam cracker, synthesis gas plant, hydrolysis plant or any plant of the production chain for downstream products such as nitrogen, ammonia, methanol, ethylene, propylene, sulfur, fatty acids, fatty alcohols, ethoxylated fatty acids, ethoxylated fatty alcohols, soaps or the like.

The input material associated with one or more environmental attribute(s) provided to the entry point of the chemical production network may include recycled input materials including, but not limited to, recycled pyrolysis oil, recycled pyrolysis gas, recycled synthesis gas, recycled hydrogen, recycled naphtha, recycled methane, recycled ethane, recycled propane, recycled chemicals or combinations

thereof. Recycled chemicals may include, but may not be limited to, recycled ammonia, recycled methanol, recycled ethylene, recycled propylene, recycled benzene, recycled toluene, recycled xylene or combinations thereof. In the context provided here recycled input material may include any material that at least in part includes recycled content and/or is at least in part produced from recycled content. The recycled content may be physically and/or chemically traceable.

The input material associated with one or more environmental attribute(s) provided to the entry point of the chemical production network may include renewable input materials including, but not limited to, renewable pyrolysis oil, renewable pyrolysis gas, renewable synthesis gas, renewable hydrogen, renewable naphtha, renewable methane, renewable ethane, renewable propane, renewable chemicals or combinations thereof. Renewable chemicals may include, but may not be limited to, renewable ammonia, renewable methanol, renewable ethylene, renewable propylene, renewable benzene, renewable toluene, renewable xylene or combinations thereof. In the context provided here renewable input material may include any material that at least in part includes renewable content and/or is at least in part produced from renewable content. The renewable content may be physically and/or chemically traceable.

The input material associated with one or more environmental attribute(s) provided to the entry point of the chemical production network may include bio-based input materials including, but not limited to, bio-based pyrolysis oil, bio-based pyrolysis gas, bio-based synthesis gas, bio-based hydrogen, bio-based naphtha, bio-based methane, bio-based ethane, bio-based propane, bio-based chemicals or combinations thereof. Bio-based chemicals may include, but may not be limited to, bio-based ammonia, bio-based methanol, bio-based ethylene, bio-based propylene, bio-based benzene, bio-based toluene, bio-based xylene or combinations thereof. In the context provided here bio-based input material may include any material that at least in part includes bio-based content and/or is at least in part produced from bio-based content. The bio-based content may be physically and/or chemically traceable.

The input material associated with one or more environmental attribute(s) provided to the entry point of the chemical production network may include input materials having a sustainable origin. The origin may refer to the geographical denomination that stands for the production and harvesting zone of the input material (e.g. the plant used to produce the input material, such as the vegetable oil). The origin may be deemed sustainable if the origin of the inbound material is deemed to comply with the established sustainability requirements for the respective inbound material. Such sustainability requirements may include biodiversity, carbon stock, peatland and/or land use change. Biodiversity requirements may include protection of primary forest and other (primary) wooded land, namely forest and other wooded land of native species, where there is no clearly visible indication of human activity and the ecological processes are not significantly disturbed. Biodiversity requirements may include protection of nature protection areas designated by law or by the relevant competent authorities for nature protection

purposes. Biodiversity requirements may include protection of rare, threatened or endangered ecosystems or species recognized by international agreements, or included in lists drawn up by intergovernmental organizations or the International Union for Conservation of Nature (IUCN). Carbon Stock Requirement may include protection of wetlands, e.g. namely land that is covered with or saturated by water permanently or for a significant part of the year and/or continuously forested areas namely land spanning more than one hectare with trees higher than five meters and canopy cover of more than 30% or trees able to reach those thresholds in situ and/or lands spanning more than one hectare with trees higher than five meters and a canopy cover between a given range, or trees able to reach those thresholds in situ, unless evidence is provided. Peatland requirement may include that raw material intended for vegetable oil production shall not be made from land that was peatland in a specific earlier date. Land Use Change Requirement (LUC Requirement) may refer to the need of minimizing emissions of greenhouse gases caused by changes in land use since a particular year. Land use change should be understood as referring to changes in terms of land cover between the six land categories used by the IPCC (forest land, grassland, cropland, wetland, settlements and other land) plus a seventh category of perennial crop. Input material having a sustainable origin may include conventional vegetable oil(s), non-conventional vegetable oil(s) or both as listed above. The sustainable origin may be traceable by data, such as certificates, certifying the fulfillment of defined sustainability requirements. For example, the sustainable origin of the palm kernel oil and palm oil may be proven by an RSPO (round table on sustainable palm oil) certificate. The origin of the vegetable oil may be documented by storing data associated with each step in the vegetable oil supply chain, for example within a distributed ledger network. Steps in the vegetable oil supply chain may include plantation, milling, transportation and refining. Data acquired for each step may be checked with respect to certain criteria to ensure that no fraudulent data is stored, and that the origin of the vegetable is documented correctly. Such data may be associated with the certificate to allow verification of the sustainable origin.

The chemical production network may include identity preserving or segregated production chains. Identity preserving or segregated in this context may refer to the environmental attributes of the input materials being preserved or segregated in the production chains. Examples are bio-based, renewable or recycled input materials used to produce the chemical product without fossil content. Further examples are fossil input materials used to produce the chemical products with fossil content. Examples are input materials having a sustainable origin used to produce the chemical product with sustainable origin content. Further examples are input materials having a non-sustainable origin used to produce the chemical products with non-sustainable origin content. Chemical production networks may include non-identity preserving or non-segregated production chains. Non-identity preserving or non-segregated in this context may refer to input materials associated with environmental attributes being mixed. For example, non-identity preserving or non-segregated in this context refers to input materials associated with environmental attributes being mixed with fossil input materials or with input materials having non-sustainable origin in the production chains. Examples are fossil and renewable input materials mixed to

produce the chemical product with fossil and renewable content. Further examples are input materials having sustainable and non-sustainable origin being mixed to produce the chemical product with sustainable and non-sustainable origin content.

Creating the token(s) linked to at least one determined environmental attribute at an address associated with the distributed ledger network may include generating transaction data and providing the generated transaction data to the distributed ledger network. The transaction data may include a new token object that defines a token name, a token description, a token symbol, the number of decimals to which each unit of the token can be sub-divided, an initial quantity (e.g. initial units) of the token, an address associated with the operating system and token control function(s) defining one or more functions of the token, such as minting functions, burning functions, transfer functions, approve functions and/or balancing functions. The new token object may be generated based on existing token templates. The token templates may include templates corresponding to (1) fungible assets (i.e., assets that are not unique and mutually interchangeable) with variable supply, (2) fungible assets with fixed supply, (3) non-fungible assets (i.e., assets that are unique) with variable supply, and (4) non-fungible assets with fixed supply. The token templates may include control functions. Use of a token template to generate the transaction data may simplify the token creation process and ensures that the generated token(s) contain all required token control functions to allow desired handling of the token.

The transaction data may include a first address associated with the operating system, a second address associated with the operating system and a quantity of tokens to be transferred. The transaction data may be provided to the distributed ledger network as previously described. Upon execution of the transaction, the quantity of the token specified in the transaction data is transferred from the first address to the second or further address. Hence, the balance of the first address decreased by the quantity specified in the transaction data while the balance of the second address increases by the same quantity. This allows to transfer previously minted units of a token to a further address.

The transaction data may be signed by a private key associated with the operating system. The generated transaction data may be provided to a node of the distributed ledger network for deployment (e.g. creation) of the token. The token may be created at the address specified in the transaction data. Hence, after successful deployment of the token, the balance of the address specified in the transaction data holds a token in a quantity specified in the transaction data. The generated transaction data may be provided to a node of the distributed ledger network for transfer to the specified units of the token to from the specified first address to the specified second address.

The distributed ledger network may be a peer-to-peer network with a plurality of nodes. Each node may comprise a peer-to-peer application in the form of a decentralized ledger. Each node may comprise a peer-to-peer application in the form of a shared database. Each node may comprise the same peer-to-peer application. The decentralized ledger may be configured to store data, e.g. tokens and associated

units, transfers of token units, creation of tokens and associated units, burning of token units, etc., with certain proofs or signatures. The decentralized ledger may further be configured to store computer code in the form of executable means. In particular, an executable means can be invoked by a transaction to the (unique) communication address of the executable means in so called 'smart contracts'. This
5 executable means may be processed on the plurality of node(s) of the peer-to-peer network. That executable means (e.g. smart contracts) or processing logic may be stored and executed in so called 'crypto conditions' of the Interledger protocol (ILP) such that not necessarily all code of an executable means need be stored in a smart contract such as Ethereum smart contract. Alternatively, the executable means (smart contract) may be stored and executed on a decentral computation market (e.g. Ethereum
10 Computation Market, Trubit, Golem, Cryplets Microsoft).

The decentralized ledger or shared database may be readable by participating entities (participants), such as any entity of a product ecosystem including raw material manufacturers, chemical product manufacturers, part manufacturers, assembly manufacturers, end-product manufacturers, end-product users, end-of-life product collectors and recyclers, of the peer-to-peer network. The decentralized ledger
15 or shared database may be readable at least by a part of the participants of the peer-to-peer network. The decentralized register, at least the public part (i.e. may be without private contracts) may be read at least by each participant of the peer-to-peer network. Peer-to-peer network nodes may send messages to or write messages to the peer-to-peer application. A message or transaction sent to an executable means may start the execution of a code of the executable means while using data (transaction criterions
20 and/or other data) stored in the executable means. For instance, sending transaction data indicating generation of new units of a previously generated token to such executable means may result in generation (e.g. minting) of further units of such a token.

Information among peer-nodes may be exchanged by a peer-to-peer messaging system. This means a peer node may send a message to another peer node to submit an information or to trigger an action.
25 Messages may be clear text, signed, hashed, time-stamped and/or encrypted. This means that not all data exchanged among peer nodes need be stored on the decentralized register.

The peer-to-peer application might be built upon the following elements: peer-to-peer network comprising Consensus System/Protocol, Data Structure, Merkle Trees, Public Key Signatures and/or Byzantine Fault Tolerance. It may replicate data based on a consensus principle. It may be auditable and traceable. The
30 peer-to-peer application may be a decentralized ledger comprising at least two blocks coupled to each other (e.g. a block chain). The block chain may be a decentralized, peer-to-peer-based register in which tokens linked to environmental attribute(s) may be created, transferred and burned (e.g. transferred to an address not being associated with a private key). The block chain may be a permissionless block chain. The block chain may be permissioned. The block chain may be public. The blockchain may be a
35 consortium block chain. The block chain may be a private block chain. Alternatively, the peer-to-peer

application may be formed by multiple block chains which are connected via mechanisms, such as side chains or smart contracts. A peer-to-peer node may run one or more different block chain client(s). Data of the peer-to-peer application may be stored on the “decentral ledger technology”. The decentralized ledger may store (encrypted) data storage accessible via the internet, such as in decentral data storage, object store and database (e.g. Interplanetary File System (IPFS) or storj), or in a distributed Blockchain database (e.g. BigChainDB). Access to encrypted data by third party entities may be managed via an access means formed as one or more smart contract(s) on the block chain.

The transaction data may be generated and sent to the distributed ledger network via a peer-to-peer module. The peer-to-peer module may provide an interface module, such as an application programming interface (API), and a decentral application for communication with the computer nodes of the peer-to-peer network or the peer-to-peer application, such as a block chain or a smart contract on the block chain, e.g. the peer-to-peer module may not comprise the peer-to-peer application and may not be a node of the peer-to-peer network. This allows reducing the required processing power of the peer-to-peer module. For instance, such a peer-to-peer module can either send clear text or encrypted information or generate a secure connection (e.g. tunnel) to a peer-to-peer gateway (or so called “remote node”) in order to communicate with the peer-to-peer network. The decentral application of software may comprise local algorithms at least configured to create and transmit data, such as the transaction data, to the peer-to-peer application via the API. The decentral application (so called “Dapp”) is at least configured to generate and transmit said data. For instance, the peer-to-peer module might be a so called “light node” or a decentral application (DAPP) connected to a remote node. Data and messages may be signed or encrypted. Data and messages may be transmitted via a cryptographically secured tunnel or a secured internet connection to a peer-to-peer node running the peer-to-peer application, such as the block chain. To securely deploy an executable means and or data into a device a trusted execution environment, such as Intel SGX or TPM or Direct Anonymous Attestation module, may be integrated with a peer-to-peer module.

Alternatively, the peer-to-peer module may be a peer-to-peer node comprising at least a part of the peer-to-peer application. For instance, the peer-to-peer module may comprise the total data content of the peer-to-peer application. The peer-to-peer module may comprise the decentral application, the API and the peer-to-peer application, such as the block chain or decentral ledger.

The peer-to-peer network may comprise one or more validating peers or full node(s). Such validating nodes may be configured to perform a validation process, e.g. creating new entries in the distributed ledger or shared database. The peer-to-peer network node may further comprise one or more observing nodes. The observing nodes may be configured to validate transactions to establish a trust level but does not validate all transactions which is done by the validating peer. The peer-to-peer network may comprise one or more mining nodes. Such mining nodes may participant in the proof-of-work consensus algorithm.

Such mining nodes may append new blocks to the blockchain upon solving the mathematical problem associated with the proof-of-work algorithm.

Data stored on the distributed ledger may be stored in clear text. Data stored on the distributed ledger may be encrypted and the keys may be handled via the distributed ledger. Transactions of units of tokens may be stored in clear text on the block chain. Privacy preserving, secure transactions or execution of computer code may be achieved with cryptographic tools, such as zero knowledge (zk) proofs or zk Succinct Non-interactive Arguments (zk-SNARK). Transactions or algorithms may be separated into two parts: an executable means (e.g. a smart contract) on the distributed ledger and a further executable means (e.g. a private contract). A privacy preserving protocol may ensure the privacy of data and the correctness of code execution (SNARK verification may be done via the smart contract on chain). The private contract computation may be done by a set of nodes, off-chain computers or done in measured launch environment or a secure hardware enclave for attestation and sealing that cannot be manipulated by other software code running on the devices. Alternatively, secure Multi-Party-Computing (sMPC) systems may be used for transactional privacy. Examples for privacy preserving protocols and computation include HAWK and MIT Enigma. Use of zero knowledge proof (zk Proofs) allows to verify that the algorithm is executed correctly in a private contract without disclosing the input data to the verifying party. zk Proofs may be stored in and/or validated by the peer-to-peer application. In addition, selective privacy may be achieved by sharing keys to decrypt transactions for reporting and auditing purposes.

The address holding token(s) linked to environmental attribute(s) may be considered a virtual balancing account that stores data related to environmental attributes in the form of token(s) and associated units. The address may thus be used for balancing environmental attributes. The address may be associated with the operating system. The address may be associated with the chemical product network. The address may be associated with the entity operating the chemical production network. The address may be associated with metadata identifying the environmental attributes linked to token(s) and associated units allocated to the address. The address may be associated with metadata identifying the production chain the address is associated with. The address may be associated with metadata identifying the input or chemical product the address is associated with. The metadata may be stored in a database associated with the operating system and may be used to determine a suitable address for allocating units of token(s) to a chemical product identifier. The address may be part of a virtual balancing system including multiple addresses. The address may hold units of token(s) for transaction. Units of token(s) and hence environmental attributes linked thereto may be transferred to (e.g. added) or from (e.g. deducted) the address. The address may be associated with an allocation scheme such as segregated allocation, non-segregated allocation like book and claim, mass balance with free attribution, mass balance without free attribution or combinations thereof.

The at least one attribution rule may specify the allocation scheme associated with the address. The at least one attribution rule may specify the attribution of environmental attributes associated with input materials and the chemical production network to environmental attributes associated with chemical products. The at least one attribution rule may depend on a chemical product identifier and an environmental attribute. The at least one attribution rule may include instructions for attributing environmental attributes of input materials via token(s) and associated units to at least one address associated with the operating system. The at least one attribution rule may include instructions for transferring units of token(s) linked to environmental attributes from at least one address. The at least one attribution rule may include instructions for linking units of tokens linked to environmental attribute(s) to chemical products or chemical product identifiers. Such linking may comprise transfer of said units of token(s) from the address such that the balance of the address is reduced by the transferred units. This ensures that units of token(s) and hence environmental attributes allocated to a produced chemical product are no longer available in the virtual accounting system, hence ensuring that the environmental attributes of input materials represented by the units of token(s) are only used once for assignment to the chemical product

The at least one attribution rule may be associated with environmental attribute types that relate to certified or non-certified environmental attributes. The at least one attribution rule may be associated with environmental attribute types that relate to input material dependent environmental attributes. The at least one attribution rule may be associated with environmental attribute types that relate to chemical network or production chain dependent environmental attributes. The at least one attribution rule may be associated with environmental attribute types that relate to chemical product dependent environmental attributes. The at least one attribution rule may be associated with environmental attribute types that relate to certified or non-certified environmental attributes. The at least one attribution rule may be associated with environmental attribute types that relate to environmental attributes certified under specific certification schemes. The at least one attribution rule may be associated with environmental attribute types that relate to environmental attributes adhering to specific attribution schemes.

The at least one attribution rule may be associated with at least one chemical production network producing the at least one chemical product(s). The at least one attribution rule may be associated with at least one chemical production network including one or more production chains. The at least one attribution rule may be associated with at least one chemical production network including one or more process steps converting input material(s) to one or more intermediate(s) and/or one or more chemical product(s). The at least one attribution rule may be associated with at least one process setup of the chemical production network.

The at least one attribution rule may be associated with at least one attribution scheme specifying the balancing or environmental attributes. The at least one attribution rule may be associated with at least

one segregated or non-segregated attribution scheme. The at least one attribution rule may be associated with at least one non-segregated attribution scheme. The at least one attribution rule may be associated with one or more non-segregated attribution schemes, such as a mass balance scheme with free attribution, a mass balance scheme without free attribution or a book-and-claim scheme.

- 5 The at least one attribution rule may be associated with at least one input material characterized by at least one environmental attribute type. The at least one attribution rule may be associated with at least one input material entering the chemical production network. The at least one attribution rule may be associated with at least one input material used to produce one or more chemical product(s).

- 10 The at least one attribution rule may be associated with at least one chemical product characterized by at least one environmental attribute type. The at least one attribution rule may be associated with at least one chemical product type exiting the chemical production network. The at least one attribution rule may be associated with at least one chemical product type produced from one or more input material(s).

The at least one attribution rule may be associated with token(s). The at least one attribution rule may be associated with environmental attribute types.

- 15 The token(s) and the at least one attribution rule may be associated at least in part with corresponding metadata. The token(s) and the at least one attribution rule may be associated with corresponding metadata. The token(s) and the at least one attribution rule may be associated with partially corresponding metadata. The set of metadata associated with a token and the at least one attribution rule may match in all data points of the meta data. The set of metadata associated with a token and the
- 20 at least one attribution rule may relate to at least one environmental attribute type, at least one chemical production network, at least one production chain, at least one attribution scheme, at least one input material type, at least one chemical product type or combinations thereof. The input material type may relate to characteristics of input material such as recycled material, biobased material, sustainable-origin material or renewable material. The input material type may relate to the material and its use or entry
- 25 points such as pyrolysis oil for input to a steam cracker or syngas plant, bio-gas for input to a steam cracker or syngas plant, sustainable origin vegetable oil for input to a hydrolysis plant. The input material type may relate to the geographic origin of the input material. The input material type may relate to the production process of the input material, such as mechanically or chemically recycled material.

- The attribution rule may include instructions to determine one or more address(es) accessible (e.g. usable
- 30 for transferring units of token(s)) for the at least one chemical product. The at least one attribution rule may include instructions to determine one or more address(es) accessible for the at least one chemical product and/or the units of token(s) accessible for the at least one chemical product. The attribution rule may be associated with metadata signifying the one or more address(es) accessible for the at least one chemical product. The attribution rule may include instructions to verify or validate the one or more

address(es) accessible for the at least one chemical product. The attribution rule may include instructions to determine, verify and/or validate the one or more address(es) accessible for the at least one chemical product. For determination of the one or more address(es) accessible for the at least one chemical product, the attribution rule may be associated with the chemical product or chemical product type.

- 5 The attribution rule may include instructions to determine the input material(s) used to produce the chemical product. The attribution rule may include instructions to access a bill of material comprising input material data, chemical product data and process data. From the bill of material, the environmental attribute types and hence the units of token(s) accessible for the at least one chemical product may be determined. From the environmental attribute types, the one or more address(es) accessible for the at
10 least one chemical product may be determined.

- The attribution rule may include instructions to match the metadata of the token(s) with the chemical product type corresponding to the chemical product. For determination of the one or more address(es) accessible for the at least one chemical product, the attribution rule may be associated with the production chain. The attribution rule may include instructions to match the metadata of the token(s) with the
15 production chain. Such metadata matching may be executed for any combination of metadata associated to the token(s) and attribution rules as lined out above.

- For verification of the one or more address(es) accessible for the at least one chemical product, the attribution rule may be associated with the chemical product type and one or more address(es). On verification the one or more address(es) accessible for the at least one chemical product may be
20 determined and compared to the one or more address(es) associated with the attribution rule. For verification of the one or more address(es) accessible for the at least one chemical product, the attribution rule may be associated with the chemical product type and one or more token(s). On verification the one or more address(es) holding token(s) accessible for the at least one chemical product may be determined and compared to the one or more token(s) associated with the attribution rule.

- 25 For validation of the one or more address(es) accessible for the at least one chemical product, the attribution rule may be associated with the chemical product type and one or more address(es). For validation of the one or more address(es) accessible for the at least one chemical product, the attribution rule may be associated with the chemical product type and one or more token(s). On validation the metadata and/or the balance of the one or more address(es) accessible for the at least one chemical
30 product may be checked to be validly accessible.

The chemical product may be produced by the chemical production network to which the input material(s) associated with one or more environmental attribute(s) were provided. The chemical product may be produced by a production chain of the chemical production network to which the input material(s)

associated with one or more environmental attribute(s) were provided. The chemical product may be produced from the input material(s) associated with one or more environmental attribute(s).

The chemical product may include one or more identifier(s) relating to the chemical product. The identifier may relate to a chemical product class, a specific chemical product and/or properties of the chemical product such as environmental properties. The identifier may include a unique number uniquely associated with the chemical product class, the specific chemical product and/or the properties of the chemical product. The identifier may include one or more specific identifier(s), such as chemical product class identifier, specific chemical product identifier and/or property of the chemical product identifier. Such specific identifier(s) may be uniquely linked to the chemical product. For example, one or more property identifier(s) may be uniquely linked to the chemical product identifier. The chemical product identifier may be uniquely linked to the specific chemical product. This way the chemical product can be uniquely linked to a digital twin of the chemical product specifying specific properties of the chemical product.

The chemical product identifier may include one or more identifier(s) relating to one or more environmental attribute(s). The identifier may include an environmental attribute identifier, such as a unique environmental attribute identifier, relating to environmental attribute(s) assignable to chemical products. The environmental attribute identifier may relate to the chemical product class or the specific chemical product. For example, the environmental attribute identifier may relate to recycled content, bio-based content and/or renewable content as environmental attribute, each having their own unique each having their own unique material identifier. The specific environmental attribute or a specific combination of environmental attributes may be related to the unique environmental attribute identifier.

The chemical product identifier may include, be linked to or be related to a batch and/or order number, such as a unique batch and/or order number. The batch number may be linked to the physical entity of produced chemical product batches. The order number may be linked to the transaction specifying the shipment of the chemical product batch from the producer of the chemical product to the user further processing the chemical product.

The chemical product identifier is associated with a product specification for the chemical product.

The chemical product identifier and target environmental attribute may be provided in response to receiving data related to an order associated with the chemical product. The order data may be received from a chemical product consumer. Order data may include an indication that the chemical product should be associated with at least one environmental attribute. The chemical product identifier may be provided based on the order data. Triggering provision of the chemical product identifier and target environmental attributes allows to assign environmental attributes via units of tokens linked to said attributes to the produced chemical product if requested by a customer, thus ensuring that the produced chemical product

fulfils the needs of the customer with respect to environmental attributes while avoiding an automatic assignment process of environmental attributes based on input materials used to produce the respective chemical products. This allows to provide chemical products being associated with the required environmental attribute(s) while maintaining a flexible supply of input materials and production of the chemical products based on available input material(s).

In an embodiment, the environmental attribute associated with the input material relates to or is associated with a renewable, a bio-based and/or a recycled content and/or a sustainable origin. For example, input material from organic waste may be associated with the environmental attributes recycled and bio-based. Input material from organic waste may be bio-based and recycled input material. Input material having a sustainable origin may be associated with the environmental attribute sustainable origin. Further for example, input material from wooden waste may be associated with the environmental attributes recycled, bio-based and renewable. Input material from wooden waste may be bio-based, renewable and recycled input material. In the context provided here renewable, a bio-based and/or a recycled input material may include any material that at least in part includes renewable, a bio-based and/or a recycled content and/or is at least in part produced from renewable, a bio-based and/or a recycled content. The renewable, a bio-based and/or a recycled content may be physically and/or chemically traceable. The sustainable origin may be traceable by data acquired along the supply chain associated with the input material. The environmental attribute associated with the input material, such as vegetable oil, may be associated with the production of the input material. The production of the input material may include the growth of plants, the harvesting, the transport, the milling and/or the refining. The sustainable origin may be traceable by data acquired during production of the input material. For instance, data on at least part of the production steps involving the production of the input material may be stored on a distributed ledger network. Such data may include data on the geographic location of the growth of plants used to produce the input material, such as the vegetable oil. Such data may include data on the harvesting of such plants. Such data may include data on the transport of such harvested plants or parts thereof to a mill. Such data may include data on the treatment of the harvested plants or parts thereof, such as data on milling process, data on crushing process and/or data on a refinery process. Prior to storing such data on the distributed ledger network, such data may be validated. This may ensure that only correct data is stored on the distributed ledger network, hence avoiding storage of incorrect data which may be used for incorrect certification afterwards. For instance, data relating to a sustainable origin may be checked with respect to location data associated with the growth of the plants prior to storing a sustainable origin for such plants and vegetable oils produced therefrom.

In an embodiment, the environmental attribute is associated with or corresponds to certificate data being indicative of a production of the input material, such as the vegetable oil, according to predefined production criteria. Predefined production criteria may include different areas of impact of the input material production. Such areas may be defined by different data points, such as data points associated

with prosperity, people and nature. Data points associated with prosperity may include data on ethical and transparent behavior, data on legal operation and respecting of rights. Data points associated with people may include data associated with respect of human rights and community, data on support of smallholder inclusion, data on respect of workers' rights and conditions. Data points associated with nature may include data on protection of ecosystems and environment. Predefined production criteria may include the above mentioned biodiversity, carbon stock, peatland and/or land use change.

In an embodiment, the input material data includes data associated with the production of the input material. Data associated with the production of the input material, such as vegetable oil, may include data associated with growth of the input material or plants used to produce the input material, data associated with the harvesting of the plants used to produce the input material, data associated with processing of the harvested plants used to produce the input material, data associated with transport of harvested plants, data associated with the transport of processed plants, data associated with the transport of the input material or a combination thereof. Data associated with the growth of the plants used to produce the input material may include location data associated with the field the plants were grown on. Data associated with the production of the input material may be stored on a distributed ledger network. This allows to track and trace the production steps of the input material. This also allows to proof sustainable origin of the input material. For instance, such data may be used to obtain a certificate certifying the sustainable origin of the input material. If such data is verified prior to storage on the distributed ledger network, this may improve the trust associated with said data and hence may allow to use such data to obtain certificates.

In an embodiment, the input material data may include a measured or determined physical and/or chemical property of the input material, data associated with the delivery of the input material, an input material identifier, a LOT number, a batch number, certificate data or a combination thereof. The inbound material identifier may comprise any identifier uniquely associated with the inbound material. The inbound identifier may relate to one specific physical entity of the inbound material such as a batch or a packaged material. The inbound identifier may relate to a group of physical entities of the inbound material such as batches or packaged material of a material produced from one production chain or site, such as a production chain or site included in the chemical production. The inbound material identifier may be associated with continuous or semi-continuous stream of inbound material fed to the chemical production. The identifier may refer to a stream of the inbound material, e.g. over a certain time period or from a certain supplier, fed to the chemical production. The LOT number may be assigned to the inbound material on production of said materials. The LOT number may refer to an identification number assigned to a particular quantity or lot of inbound material from a single manufacturer. LOT numbers can typically be found on the outside of the packaging of the inbound material. The order number may be assigned to the transfer of a certain physical entity, quantity or group of inbound material(s) to the chemical production network. The order number may be assigned to the inbound material transfer. The order number may

relate to the inbound material producer identity and the entity operating the chemical production network. certificate certifying the environmental attribute. The certificate data may include the certificate type, the allocation scheme, the environmental attribute, the quantity of inbound material associated with the environmental attribute, the amount of inbound material, the producer identifier, inbound material
5 identifier or combinations thereof. The certificate may be generated by a certifying authority and may indicate that the inbound material fulfils the requirements associated with said certificate. For example, the certificate may certify at least one environmental attribute of the inbound material, such as its sustainable origin.

In an embodiment, the input material data may be provided via a physical identifier attached to the
10 physical entity of the input material. The physical identifier may include a code, such as a bar code, a QR code, an embossed code, an RFID tag, a marker, etc.. The physical identifier may be associated with a decentral identifier. The decentral identifier may comprise any unique identifier uniquely associated with the input material(s). The decentral identifier may include a Universally Unique IDentifier (UUID) or a Digital IDentifier (DID). The decentral identifier may be issued by a central or decentral identity issuer.
15 The decentral identifier may be linked to authentication and/or authorization information. Via the decentral identifier and its unique association with the input material producer and input material data , access to the input material data may be controlled by the input material producer. This contrasts with central authority schemes, where identifiers are provided by such central authority and access to data is controlled by such central authority. Decentral in this context refers to the usage of the identifier in
20 implementation as controlled by the data owner, such as the input material producer.

The input material suppliers and the chemical product producer may be part of a product ecosystem. The product ecosystem may include different stages including manufacturing, use and re-use. In these stages one or more ecosystem participant(s) may contribute to the manufacture, use or re-use of the product. For example, the manufacturing stage may include raw material manufacturers, chemical product
25 manufactures and/or end-product manufacturers. Further for example, the use stage may include a product user, product maintainers and/or product distributors. Further for example, the re-use stage may include collectors, sorters, dismantlers, recyclers, restorers and/or re-furbishers.

The participants of the product ecosystem may be connected via a decentral network. The decentral network may include computing nodes associated with participants of the product ecosystem and may
30 be configured to perform data transactions. The computing nodes associated with participants of the product ecosystem may be associated with producers, users or re-users of physical products, such as input material producers, chemical product producers, intermediate product producers, end product producers, end product users, used product users or product re-users. The data transactions may be based on a transaction protocol including authentication and/or authorization mechanism(s). Based on
35 the authentication and/or authorization mechanism(s) a peer-to-peer communication between computing

nodes associated with participants of the product ecosystem may be established. The chemical product manufacturer may access input material data via a decentral data consuming network node configured to access data at a decentral data providing network node based on decentral identifiers. For instance, the decentral data consuming network node may access input material data at a decentral data providing network node associated with the input material producer. The input material data may be accessed upon or after entry of the input material to the chemical production network. The input material data may be stored on a dedicated storage associated with the decentral data providing network node. The dedicated storage and hence access to the input material data may be under control of the input material data owner, such as the input material producer.

In an embodiment, determining the environmental attributes associated with the input material comprises determining the amount of the input material. In case more than one input material is provided, the amount of at least part of the provided input materials may be determined. The determination may be based on a bill of materials, a sales receipt, a recipe and/or any of a wide range of digital documents (e.g., input material data) associated with receipt of input material(s). An operating system may parse the input material data to determine the amount of input material that was received. The “amount” of the input material may refer to the volume, amount of substance, and/or mass of the input material. The amount of input material entering the chemical production network may be stored in one or more input material storages, such as tanks and/or warehouses. The input material storage(s) may be connected to one or more production plants of the chemical production network, for example via pipes allowing continuous or batch-wise supply of input material to the respective plant.

In an embodiment, determining the environmental attributes associated with the input material further comprises determining a value associated with the input material. In case more than one input material is provided, the value for at least part of the input materials may be determined. For example, the operating system may compute the difference in cost between a sustainable input material and the corresponding equivalent fossil input material to determine the value associated with the input material. The value may be based on average price, actual price, market price or other suitable values to determine the cost of the equivalent amount of fossil input materials. The operating system may store and track the amounts and values corresponding to sustainable input materials. For example, the values may be stored in digital inventories associated with the token(s).

In an embodiment, the environmental attributes associated with the input material may be determined via a virtual production process. Virtual production may refer to receiving input material data for a sustainable input material (e.g. a recycled input material, renewable input material, bio-based input material, input material with sustainable origin) and producing environmental attributes (based on the sustainable input material) and also generating conventional input material data (e.g., data describing the corresponding amount and/or value of the conventional input material). The virtual production process may be performed

by a virtual production module configured to receive input material data associated with the at least one input material and to produce environmental attributes associated with the at least one input material. The virtual production module may further be configured to determine an amount of the input material. The virtual production module may further be configured to determine a value associated with the input material.

In an embodiment, the token(s) decouple the material flow of the input material(s) through the chemical production network from the environmental attributes associated with said input materials. Decoupling of the environmental attribute(s) via the tokens from the physical flow of input material(s) within the chemical production allows to flexibly assign such environmental attribute(s) to chemical product(s) produced from such input material(s) irrespective of the environmental attribute(s) associated with the particular input material(s) used for the production of a particular product. This way, environmental attribute(s) can be assigned in line with target environmental data provided by customers of the chemical product irrespective of the environmental attribute(s) associated with the input material(s) supplied to the chemical production. By flexible allocation of environmental attribute(s) to chemical product(s), the environmental attribute(s) can be more efficiently allocated, since allocation is more independent of the supply of input material(s) associated with environmental attribute(s) requested by the customer(s).

In an embodiment, the determined environmental attributes may be verified. Verification may include verifying the determined environmental attribute "sustainable origin" of the input material, such as the vegetable oil. Verifying may include determining a decentral identifier associated with the received input material. The decentral identifier may be used to gather data associated with the environmental attribute of the input material from a peer-to-peer network as previously described. The gathered data may be used to validate the determined environmental attributes. For instance, the gathered data may be used to validate whether the determined sustainable origin is indeed sustainable or not. The gathered data may be compared to databases storing certificate data associated with the origin of vegetable oils. The gathered data may be compared to geographic data to determine whether the sustainable origin claimed according to the certificate data is true or not. The gathered data may be compared to a rule set associated with the certificate data. For instance, the rule set may include rules to be fulfilled for a certificate to be valid.

Verifying may include determining a digital asset associated with the received input material, such as the vegetable oil, based on the provided input material data. The digital asset may correspond to a non-fungible token associated with the input material. The digital asset may be used to determine production data associated with the received input material. For instance, the digital asset may be linked to one or more further digital assets, such as tokens, each digital asset representing a production step, such as growing, harvesting, transport, milling, crushing or refining. The further digital assets may be stored on a distributed ledger network and may be used to verify the sustainable origin of the input material. The data

associated with the further digital assets may be gathered and may be used to verify the determine environmental attribute as previously described.

In an embodiment, the token(s) relate to or is/are associated with one or more characteristic(s) of the input material associated with one or more environmental attribute(s). The token(s) may relate to one or more characteristic(s) of the input material that are attributable to environmental impact of the input material and the chemical product produced by the chemical production network. The characteristic(s) of the input material may include, and may not be limited to, an input material type, a waste stream type, a biomass type, a renewable type, an origin type, an allocation scheme, or combinations thereof. By specifying the characteristics of the input material, the environmental attribute and characteristics of input materials used to produce the chemical product may be tracked with more granularity. This enables a system to track the environmental attributes and characteristics of the input material more granularly. More granular tracking via the token(s) in return enables allocation of units of token(s) linked to environmental attributes to chemical products that are tailored to customer needs.

In an embodiment, the token(s) relate(s) to or is/are associated with an input material type, a waste stream type, a biomass type, a renewable type, an origin type, an allocation scheme, or combinations thereof. The virtual balancing system or the token(s) may be associated with metadata specifying the input material associated with one or more environmental attribute(s). The metadata may specify the input material associated with one or more environmental attribute(s) provided to the entry point of the chemical production network. The input material type may include, and may not be limited to, pyrolysis oil, pyrolysis gas, vegetable oil, palm oil, palm kernel oil, coconut oil, synthesis gas, hydrogen, naphtha, methane, ethane, propane, chemicals, or combinations thereof. Chemicals may include, but may not be limited to, ammonia, methanol, ethylene, propylene, benzene, toluene, xylene, fatty acids, fatty alcohols or combinations thereof.

In an embodiment, the token(s) may be associated with metadata specifying an input material type, a waste stream type, a biomass type, a renewable type, an origin type, an allocation scheme, or combinations thereof. As one example, recycled pyrolysis oil produced from plastics waste may be provided to the chemical production network as input material. The metadata may specify the input material type pyrolysis oil, the environmental attribute type recycled, the waste stream type mixed plastics waste, specific end product waste, post-consumer waste or pre-consumer waste, and/or the allocation scheme non-segregated scheme such as mass balance. As another example, bio-based naphtha may be provided to the chemical production network as input material. The metadata may specify the input material type naphtha, the environmental attribute type bio-based, the biomass type palm oil and/or the allocation scheme non-segregated scheme such as mass balance. As another example, bio-based methane may be provided to the chemical production network as input material. The metadata may specify the input material type methane, the environmental attribute type bio-based, the biomass type

waste from agriculture and/or the allocation scheme non-segregated scheme such as mass balance. As another example, sustainable palm oil and/or palm kernel oil may be provided to the chemical production network as input material. The metadata may specify the input material type palm oil/palm kernel oil, the environmental attribute type sustainable origin and/or the allocation scheme non-segregated scheme such as mass balance.

In an embodiment, the token(s) is/are associated with input material types including pyrolysis oil, pyrolysis gas, synthesis gas, hydrogen, r-chemicals, bio-naphtha, bio-methane, sustainable palm oil, sustainable palm kernel oil. In an embodiment, the token(s) is/are associated with pyrolysis or gasification and the waste stream the pyrolysis oil, pyrolysis gas, synthesis gas, hydrogen or r-chemicals is produced from.

In an embodiment, the token(s) is/are associated with bio-naphtha or bio-methane and the renewable stream the bio-naphtha or bio-methane is produced from. In an embodiment, the token(s) is/are associated with a hydrolysis. In an embodiment, the token(s) is/are associated with vegetable oil types sustainable palm oil, sustainable palm kernel oil or sustainable coconut oil. In an embodiment, the token(s) is/are associated with a hydrolysis of the vegetable oil.

In an embodiment, the token(s) relate(s) to or is/are associated with waste stream types. The waste stream types may be linked to at least the environmental attribute recycled. The waste stream types may relate to one or more waste materials or waste categories. Waste categories may include, and are not limited to, non-synthetic waste such as animal waste, vegetable or wooden waste, or synthetic waste, such as textile waste, paper waste, plastics waste, or rubber waste. The waste stream types may relate to the origin of the waste, such as the end-of-life product, the producer of the end-of-life product, the geolocation of the end-of-life product, the habitat of the end-of-life product, the consumer of the end-of-life product, or combinations thereof and may not be limited thereto. For example, in the case of recycled as environmental attribute and pyrolysis oil as input material type the waste type may specify plastics waste from tires. mixed plastics waste from packaging or mixed plastics waste from ocean cleanup.

In an embodiment, the token(s) relate(s) to or is/are associated with biomass types or renewable types. The biomass type may be linked to at least the environmental attribute bio-based or renewable. The biomass type may relate to one or more raw materials the input material is produced from. Raw materials may include, and are not limited to, agricultural waste, manure, municipal waste, plant material, sewage, green waste, food waste, natural occurring fats, natural occurring oils, mixtures of natural occurring fats and oils, cooking oil, or animal fats. The biomass type may relate to the origin of the biomass, such as the producer of the biomass, the geolocation of the biomass, the habitat of the biomass, the consumer of the biomass, or combinations thereof and may not be limited thereto. For example, in the case of bio-based as environmental attribute and bio-naphtha as input material type the biomass type may specify oils and fats from plants (vegan). Further for example, in the case of bio-based as environmental attribute and biogas as input material type the biomass type may specify municipal waste.

In an embodiment, the token(s) is/are associated with metadata specifying the relationship between the input material(s) associated with one or more environmental attribute(s) and the chemical product. In another embodiment the relationship relates to the chemical production network, one or more production chain(s), one or more chemical product(s), one or more chemical product classes or combinations thereof. The relationship may relate to the chemical production network. For example, the input material(s) associated with one or more environmental attribute(s) may be provided to the chemical production network producing the chemical product. The relationship may relate to one or more production chain(s) of the chemical production network producing the chemical product. For example, the input material(s) associated with one or more environmental attribute(s) may be provided to one or more production chain(s) of the chemical production network producing the chemical product. The relationship may relate to one or more chemical product class(es) produced by the chemical production network. For example, the input material(s) associated with one or more environmental attribute(s) may be provided to one or more production chain(s) of the chemical production network producing the chemical product class(es). The relationship may relate to one or more chemical product(s) produced by the chemical production network. For example, the input material(s) associated with one or more environmental attribute(s) may be provided to one or more production chain(s) of the chemical production network producing the one or more chemical product. The relationship may relate to the chemical production network, one or more production chain(s), one or more chemical product(s), one or more chemical product classes or combinations thereof. By tagging with the relationship metadata the input materials may be physically and/or chemically traceable. The metadata may be derived from a digital twin of the chemical production network (or a portion of the chemical production network). The metadata may be derived from a digital twin of the chemical production network (or a portion thereof) and a production schedule.

In one embodiment, creating token(s) includes generating transaction data and providing the generated transaction data to the distributed ledger network. Generating transaction data includes determining the units of token based on the determined environmental attributes. The units of token may be determined based on a rule set. The rule set may define correlations between an input material, an environmental attribute of the input material, an amount of input material and the associated units of a token. The input material may be identified in the rule set via the input material identifier. The environmental attribute may be identified via an environmental attribute identifier. The rule set may include correlations for several input materials and/or for several environmental attributes and/or for several amounts of input material. For instance, the rule set may define that a predefined amount, such as a kilogram or a ton, of a predefined inbound material, such as palm oil, associated with a predefined environmental attribute, such as sustainable origin, may represent defined units of the token "sustainable origin". The rule set may define correlations between environmental unit(s) associated with a defined amount of input material and the units of the token. The rule set may define rules to determine the environmental unit(s) from the determined environmental attributes. For instance, the rule set may define rules to convert a determined environmental attribute to said environmental unit(s) based on the amount of inbound material provided

to the chemical production network. The environmental unit(s) may relate to a methane equivalent, an energy property such as heating value, a number of carbon atoms or any other suitable measure for the environmental impact of the environmental attribute.

By converting the environmental attribute(s) of inbound material to units of token(s), said token(s) may act as a digital environmental currency and may be used to transfer the environmental attribute(s) associated with said token(s) chemical products produced by the chemical production network as described later on. The digital environmental currency may allow to decouple the material flow of the input material(s) through the chemical production network from the environmental attributes associated with said input materials and may allow to allocate such environmental attributes to chemical products produced by said chemical production network fully or at least partially independent of material flows. Hence, the token(s) may be balanced independent from the physical flow of inbound material(s) used during production of chemical product(s) by the chemical production network. The token(s) linked to the respective environmental attribute(s) may be balanced based on the system boundary of the chemical production network. The token(s) linked to the respective environmental attribute(s) may be balanced based on the input material(s) entering the system boundary of the chemical production network and the produced chemical product(s) exiting the chemical production network.

In an embodiment, the target environmental attribute may relate to or be associated with a renewable, a bio-based, recycled and/or sustainable origin content. The target environmental attribute may further be related to or associated with metadata specifying an input material type, a waste stream type, a biomass type, a renewable type, an origin type, an allocation scheme, or combinations thereof. Based on such metadata, the metadata associated with or related to the token(s) may be matched, and addresses holding matching token(s) may be selected. The units of matching token(s) may be transferred from the selected addresses, for example as described later on. The transferred units may be assigned to the chemical product, for example as described later on. Owing to the token(s) and associated metadata granular target environmental attributes can be achieved.

In an embodiment, assigning determined units of token(s) to the chemical product identifier comprises retiring the determined units of token(s) and creating one or more further token(s) specifying the retired units of the token(s), the one or more environmental attributes linked to the token(s) and the provided chemical product identifier. Retiring the units of token(s) may include transferring said units to an address not associated with a private key (e.g. burning said units of token). Retiring the units of token(s) may include transferring said units to an address not associated with, e.g. not being under control of, the chemical production network/operating system/entity operating the chemical production network. The address may be associated with a third party creating the one or more further token(s). Transfer of said token units may include generating transaction data specifying the address the units are to be transferred to, the units to be transferred and the provided chemical product identifier. The transaction data may be

generated by a decentral application. The decentral application may be configured to provide the generated transaction data to a distributed ledger network. Creating one or more further token(s) may include generating transaction data specifying the retired units of token(s), the one or more environmental attributes linked to token(s) associated with the retired units and the provided chemical product identifier and providing the generated transaction data to the distributed ledger network for creating the one or more further token(s). The transaction data may be generated by the operating system. The transaction data may be generated by a third party on behalf of the entity operating the chemical production network.

The one or more further token(s) may specify a value associated with the input material, wherein the value associated with the input material is related to a difference in cost between the input material and a corresponding amount of fossil input material. The value may be provided in the transaction data

The one or more further token(s) may uniquely specify the chemical product with the combination of the chemical product identifier, the one or more environmental attributes and retired units of the token(s). Hence, the one or more further token(s) may be non-fungible token(s) uniquely specifying the chemical product via the chemical product identifier.

The one or more further token(s) may specify or be associated with metadata. The one or more further token(s) may contain a digital representation pointing to the metadata or parts thereof. This allows to store metadata of the token(s) off chain, hence allowing to update or change the metadata without having to burn and mint another token. For instance, the one or more non-fungible tokens may include a link pointing to an off chain storage location of the meta data.

The one or more further token(s) may be created at an address associated with the chemical production network. The one or more further token(s) may be created at an address associated with a third party and may be transferred to an address of the chemical production network. Upon transfer of the chemical product associated with said one or more token(s) to a chemical product consumer, the one or more token(s) may be transferred to an address (e.g. address associated with the distributed ledger network) associated with the chemical product consumer.

In another embodiment, assigning determined units of token(s) to the chemical product identifier comprises transferring the determined units to a further address associated with the distributed ledger network, the further address being associated with the provided chemical product identifier. The further address may further be associated with the operating system of the chemical production network. For instance, further addresses may be associated with metadata indicating the provided chemical product identifier and such metadata may be used to determine the further address. The further address may further be associated with the recipient of the produced chemical product.

In yet another embodiment, assigning determined units of token(s) to the chemical product identifier comprises locking the determined units by transferring said units to a vault address associated with the distributed ledger network, wherein the determined units are transferred by generating transaction data including the determined units and locking data associated with the chemical product identifier and sending the transaction data to the distributed ledger network to lock the determined units, and wherein the locked units can be unlocked and transferred from said vault address using the locking data. The vault address corresponds to an executable means which may be invoked by sending the transaction to said (unique) communication address of the executable means. The transaction allows to look the determined units token(s) using a secret. The secret may, for example, be a hash value of the chemical product identifier. The produced chemical product associated with said chemical product identifier may be provided to a consumer. The chemical product may be associated with a physical identifier having encoded a decentral identifier. The decentral identifier may be used to access chemical product data from a decentral data providing network node of the chemical product producer as described previously. The chemical product data may include the secret used to look the units of token(s). The chemical product consumer may use the secret to generate transaction data including the secret and the vault address and may provide the transaction data to the distributed ledger network for unlocking the units (e.g. transferring said units to an address of the distributed ledger network associated with the chemical product consumer).

In an embodiment, assigning the determined units of token(s) to the chemical product identifier includes,

- checking the balance of addresses holding token(s) associated with the determined token units and assigning the determined units of token(s) from the associated address to the chemical product identifier if the balance is sufficient, and/or
- checking that the respective token(s) are associated with input material(s) used to produce the chemical product and assigning the determined units of token(s) from addresses holding said units to the chemical product identifier if the respective token(s) is/are associated with input material(s) used in the production chain of the chemical product.

Input material(s) used to produce the chemical product may include input material(s) associated with environmental attributes at the entry to the chemical production network. Input material(s) used to produce the chemical product may include input material(s) associated with environmental attribute(s) and input material(s) not associated with environmental attribute(s). The respective environmental attributes may be decoupled from the material flow by generating token(s) and associated units.

Assignment of determined units of token(s) to the chemical product identifier may be performed prior to, during or after production of the chemical product. Creation prior to production ensures that the environmental attributes requested by a customer can be associated with the produced chemical product. Moreover, this allows to determine the remaining units of token(s) and hence environmental attributes

available for allocation to produced chemical products independent from the production, hence ensuring that customer needs with respect to environmental attributes associated with an ordered product can be fulfilled.

In an embodiment, providing input material data associated with the input material may include providing a first input material data associated with the first input material and providing a second input material data associated with the second input material. In yet another embodiment, the method further comprises providing at least one token linked to one or more environmental attribute(s) of the first input material and the second input material. In another embodiment, assigning the determined units of token(s) to the chemical product identifier may include generating one or more further token(s) that specify the chemical product identifier, the determined units of token(s) and the one or environmental attribute(s) of at least one of the first input material and the second input material.

BRIEF DESCRIPTION OF THE DRAWINGS

In the following, the present disclosure is further described with reference to the enclosed figures. The same reference numbers in the drawings and this disclosure are intended to refer to the same or like elements, components, and/or parts.

FIG. 1 illustrates an example of a chemical production network producing one or more chemical product(s) from one or more input material(s) in connection with an operating system including an attribute management system.

FIG. 2 illustrates an example of a chemical production network producing one or more chemical product(s) from one or more input material(s) in connection with an operating system including an attribute management system for two or more environmental attributes.

FIG. 3 illustrates a virtual production system for producing sustainable chemical products by decoupling the environmental attributes of incoming sustainable inputs and producing balancing units.

FIG. 4 illustrates a merger system for producing sustainable chemical products by combining environmental attributes represented by units of tokens with conventional product data.

FIG. 5A illustrates a merger system for producing sustainable chemical products involving the use of non-fungible tokens.

FIG. 5B illustrates a merger system for producing sustainable chemical products involving the use of addresses associated with environmental attributes.

- FIG. 5C illustrates a merger system for producing sustainable chemical products involving the use of a vault address to look and unlock units of tokens linked to environmental attributes.
- FIGs. 6A-6C illustrate a part of a chemical production network producing various chemical product(s) from sustainable and non-sustainable inbound material(s).
- 5 FIGs. 7A-7C illustrate a part of a chemical production network producing multiple chemical product(s) from fossil and non-fossil input material(s).
- FIGs. 8A-8C illustrate examples of allocation schemes allocating the use of renewable or bio-based input materials to chemical products of the chemical production network.
- FIG. 9 illustrates an example of a chemical production network with different allocation schemes.
- 10 FIG. 10 illustrates a first example of a method for assigning at least one environmental attribute to at least one chemical product produced by a chemical production network.
- FIG. 11 illustrates a further example of a method for assigning at least one environmental attribute to at least one chemical product produced by a chemical production network.
- 15 FIG. 12A illustrates a first example of an apparatus for producing at least one chemical product associated with one or more environmental attribute(s) including an example method for assigning at least one environmental attribute to the at least one produced chemical product.
- FIG. 12B illustrates a further example of an apparatus for producing at least one chemical product associated with one or more environmental attribute(s) including an example method for assigning at least one environmental attribute to the at least one produced chemical product.
- 20 FIG. 13 illustrates a first example of the converting environmental attributes associated with input material to balancing units and assignment to chemical products.
- FIG. 14 illustrates a second example of the converting environmental attributes associated with input material to balancing units and assignment to chemical products.
- 25 FIGs. 15A, 15B illustrate examples of data structures for assigning environmental attributes from the balancing account to the chemical product identifier.
- FIG. 16 illustrates examples of token(s) and associated metadata.

- FIG. 17 illustrates an example of a rule set for generating units of token(s) or allocating units of token(s) linked to environmental attribute(s) based on environmental attributes associated with input material(s).
- FIG. 18 illustrates examples of attribution rules for assigning units of token(s) to a chemical product identifier based on an attribution rule.
- FIG. 19 illustrates examples of attribution rule instructions for determining units of at least one token linked to one or more environmental attributes.
- FIG. 20 illustrates examples of attribution rule instructions for a compatibility check of token units.
- FIG. 21A illustrates a first example of a participant network of a product ecosystem associated with a decentral peer-to-peer network for exchange of input material data.
- FIG. 21B illustrates an exchange of input material data associated with input material provided to a chemical production network via a decentral peer-to-peer network.
- FIG. 22A illustrates a further example of a participant network of a product ecosystem associated with a decentral peer-to-peer network for exchange of environmental attributes associated with produced products.
- FIG. 22B illustrates an exchange of token(s) linked to environmental attributes and being associated with a chemical product provided by the chemical production network to a chemical product consumer via a decentral peer-to-peer network.

DETAILED DESCRIPTION

- FIG. 1 illustrates an example of a chemical production network 104 producing one or more chemical product(s) from one or more input material(s) in connection with an operating system including an attribute management system 102. For producing one or more chemical product(s) different input materials (feedstocks) may be provided as physical inputs from material providers or suppliers. The chemical products produced from the input materials may have one or more properties related to the environmental impact of the input materials or the chemical products produced from the input materials, that may be signified by the environmental attributes.

The chemical production network 104 may include multiple interlinked processing steps. The chemical production network 104 may be an integrated chemical production network with connected or interconnected production chains. The chemical production network 104 may include multiple different production chains that have at least one intermediate product in common. The chemical production network 104 may include multiple stages of the chemical value chain. The chemical production network

104 may include the producing, refining, processing and/or purification of gas or crude oil or vegetable oil. The chemical production network 104 may include a stream cracker, or a syngas plant or a hydrolysis plant connected to multiple production chains that output chemical products from the effluent of the steam cracker or syngas plants or the hydrolysis plant. The chemical production network 104 may include multiple production chains that produce from one or more input material(s) chemical products that exit the chemical production network 104. The chemical production network 104 may include multiple tiers of a chemical value chain. The chemical production network 104 may include physically connected or interconnected supply chains and/or production sites. The production sites may be at the same location or at different locations. In the latter case, the production sites may be connected or interconnected by means of dedicated transportation systems such as pipelines, supply chain vehicles, like trucks, ships or other cargo transportation means.

The chemical production network 104 may chemically convert input materials via chemical intermediates to one or more chemical product(s) that exit the chemical production network. The chemical production network 104 may convert input material(s) by way of chemical conversion to one or more chemical product(s).

The input material(s) may be fed into the chemical production network 104 at any entry point. The input material(s) may be fed into the chemical production network 104 at the start of the chemical production network 104. Input materials may for example make up the feedstock of a steam cracker. Input materials may for example make up the feedstock of a hydrolysis plant. The input material may include a bio-based, a recycled, a renewable, a fossil input material and/or an input material having a sustainable origin for the manufacture of chemical intermediates and chemical products.

The chemical production network 104 may include multiple production steps. The production steps included in the chemical production network 104 may be defined by the system boundary of the chemical production network 104. The system boundary may be defined by location or control over production processes. The system boundary may be defined by the site of the chemical production network 104. The system boundary may be defined by production processes controlled by one entity or multiple entities jointly. The system boundary may be defined by a value chain with staggered production processes to an end product, which may be controlled by multiple entities separately. The chemical production network 104 may include a waste collection and sorting step, a recycling step such as pyrolysis, a cracking step such as steam cracking, a hydrolysis step, a separation step to separate outputs of one process step and further processing steps to convert such outputs to a chemical product leaving the system boundary of the chemical production network 104.

The operating system 102 of the chemical production network 104 may monitor and/or control the chemical production network 104 based on operating parameters of the different processes. One process step monitored and/or controlled may be the feed of input materials or the discharge of chemical products.

Another process step monitored and/or controlled may be the attributing of at least one environmental attribute associated with an input material to one or more chemical products(s) produced via the chemical production network 104. Yet another process step monitored and/or controlled may be the tokenization of environmental attributes associated with input material(s) entering the system boundary of the chemical production network. Yet another process step monitored and/or controlled may be the management of tokens linked to environmental attributes associated with input material(s) and tokens linked to chemical product(s) produced by the chemical production network 104.

The operating system 102 may be configured to access data related the inputs material(s), the process(es) and/or the chemical product(s) produced by the chemical production network 104. The operating system 102 may be configured to convert a recycled, renewable, or bio-based content of the one or more input material(s) used in the chemical production network to balancing units. The operating system 102 may be configured to determine environmental attributes associated with the input material(s) to environmental attribute(s). The operating system 102 may be configured to determine units of token(s) using the determined environmental attributes. The operating system 102 may be configured to generate transaction data and to provide the generated transaction data to a distributed ledger network for creating tokens and associated token units linked to the environmental attribute(s) or for transferring units of token(s) linked to the environmental attributes to a specified address. The operating system 102 may be configured to allocate units of token(s) from an address associated with the distributed ledger network and the operating system 102 to the at least one chemical product.

The operating system 102 may be configured to manage tokens and associated token units related to the input material and chemical products produced by the chemical production network 104. In particular, the operating system 102 may be configured to determine token units associated with the use of input materials impacting the environmental property/attribute of the chemical products produced by the chemical production network 104. The operating system 102 may be configured to determine token units associated with the chemical product(s) and the environmental property of the chemical product(s). This way the operating system 102 may be configured to allocate tokens and associated token units to one or more addresses or to transfer token units from the one or more addresses to deduct said units from the total balance of said addresses. The token units may be viewed as a credit that may be deposited in an address (e.g., a digital inventory) or deducted from an address related to the input material and chemical products of the chemical production network 104.

The operating system 102 may be configured to convert environmental attributes associated with input materials to token units and/or to assign token units to produced chemical product(s) and to manage token creation/token unit transfer as well as assignment of token units to chemical product(s).

FIG. 2 illustrates an example of a chemical production network 104 producing one or more chemical product(s) from one or more input material(s) in connection with an operating system 102 including an

attribute management system 220 to manage two or more environmental attributes. Chemical production network 104 is described above with reference to FIG. 1.

Operating system 102 may be a digital operating system configured to collect, store, manage and interpret a wide range of production and/or business data for chemical production network 104. Operating system 102 may be part of an Enterprise Resource Planning (ERP) system. Alternatively, operating system 102 may be partly implemented in an ERP system and partly implemented in one or more additional systems coupled with an ERP system. Operating system 102 may also be implemented in one or more systems outside of an ERP system.

Input materials 202-206 may be provided to chemical production network 104 at the feed-in-point 210. The input materials may include conventional fossil feedstock 202 (e.g., naphtha) as well as sustainable input materials 204-206. The sustainable input materials 204-206 may include renewable input materials (such as biogas and/or bio-naphtha) and/or recycled input materials (e.g., pyrolysis oil) and/or input materials having a sustainable origin (e.g. sustainable palm oil, sustainable palm kernel oil, sustainable coconut oil). After they are delivered to chemical production network 104, the conventional input materials 202 and the sustainable input materials 204-206 may be combined (e.g., by being fed into the same tank) as they enter the chemical production process.

Input material data for sustainable input material 204 may be provided to operating system 102 at 214. Similarly, input material data for sustainable input material 206 is provided to operating system 102 at 216. For example, the goods receipt (and/or a BOM and/or a chemical production recipe) including the input material data for each of the sustainable input materials may be electronically provided to operating system 102 when sustainable materials 204-206 are delivered to chemical production network 104. Operating system 102 may receive input material data 214-216 through an interface to a local or a remote database or an ERP system, in particular its supply chain module, or any computing system or apparatus, such as a centralized or decentralized computing system or apparatus including processing and storage. operating system 102 may receive input material data via a decentral network, such as described in the context of FIG. 21A and FIG. 21B. The input material data for each input material may hence be gathered from an ERP system or any computing system or apparatus, such as a centralized or decentralized computing system or apparatus including processing and storage. In some cases, the input material data of each input material is gathered through an interface to more than one database. It therefore may be necessary to convert the information retrieved from different databases into a single format to allow further processing. In particular, the input material data obtained from databases may be attributed to the input material via the identification of an input material in the database that has to be translated to the identification of the input material of the process data used in the process according to the present disclosure.

Operating system 102 may initiate a virtual production step after it receives the input material data for sustainable materials 204-206. Virtual production may refer to receiving input material data for a sustainable input material and producing environmental attributes (based on the sustainable input material) and also generating conventional input material data (e.g., data describing the corresponding amount and/or value of the conventional input material).

For example, with reference to FIG. 2 and FIG. 3, operating system 102 may initiate virtual production process 300 when it receives input material data for sustainable input material(s) (e.g., 214-216). Using input material data 214-216, virtual production process 300 may parse the input material data and apply a corresponding recipe. For example, virtual production process 300 may determine the volume (or mass) and type of sustainable input material that was received from the input material data. It may then apply virtual production step(s) 304 to the sustainable input material 302. Virtual production step(s) 304 may “produce” or generate both environmental attributes 306 and conventional input material 308. The amount of conventional input material 308 (virtually) generated may be equal to the amount of sustainable input material 302.

Referring again to FIG. 2, after the virtual production process, operating system 102 may credit digital inventory (which may also be referred to as a virtual balancing account) 218 with the amount of conventional feedstock that was created by the virtual production process(es). Operating system 102 may determine the amount (e.g., volume and/or mass) and the value of sustainable input material 204-206, respectively. For example, operating system 102 may parse input material data 214 to determine the amount of sustainable input materials 204 that was received. Similarly, operating system 102 may parse input material data 216 to determine the amount of sustainable input material 206 that was received. Operating system 102 may then provide such data to attribute management system 220.

Attribute management system 220 may determine token units based on the environmental attributes. For instance, attribute management system 220 may determine token units based on a rule set correlating the environmental attributes to token units. Attribute management system 220 may convert the environmental attributes to balancing units. Attribute management system 220 may determine token units based on the balancing units. Balancing units may be determined based on a conversion factor. The conversion may include a conversion factor that takes account of the chemical difference between fossil-based input materials, such as naphtha and methane, and non-fossil input materials, such as pyrolysis oil. The conversion factor may relate to the lower heating value of the pyrolysis oil in relation to the lower heating value of naphtha or methane. The conversion factor may include the ratio of the lower heating value of pyrolysis oil to naphtha or methane. This way the chemical difference between the fossil and the renewable input material can be considered.

For instance, attribute management system 220 may determine token units based on a rule set correlating balancing units to token units. Attribute management system 220 may generate transaction data 222 and

provide the generated transaction data 222 to a distributed ledger network 224, such as distributed ledger network 224 described in the context of FIG. 5A to FIG. 5C and FIG. 22A. The distributed ledger network 224 may be a permissioned distributed ledger network. Hence, access to the distributed ledger network may be controlled by the organization operating the distributed ledger network. For instance, access to the distributed ledger network as well as access to data stored within the distributed ledger network may be based on access policies. This may avoid that transactions associated with token generation performed upon entry of the input material are visible by each participant of the product ecosystem, hence avoiding that other participants of the product ecosystem gain insights on production processes performed within the chemical production network. The transaction data 222 may be generated based on the determined token units. The distributed ledger network 224 may be a blockchain as described in the context of 22A. The distributed ledger network 224 may process the received transaction data. Upon successful completion of the transaction associated with the transaction data 222, token units 226a, 226b may be generated at an address of an account 228 of the distributed ledger network 224 associated with operating system 102. The token units 226a may be associated with environmental attribute(s) associated with a first sustainable input materials. The token units 226b may be associated with environmental attribute(s) associated with a second sustainable input materials. Upon successful completion of the transaction associated with the transaction data 222, token units may be transferred from a first address of the distributed ledger network 224 to a second address associated with account 228 of the operating system 102.

The address associated with account 228 may be considered as a virtual balancing account or digital environmental attribute inventory. The address may hold credits in the form of token units associated with one or more environmental attributes. Since token(s) may be associated with metadata indicating the environmental attribute they are associated with, tokens may be differentiated from each other via their metadata. Hence, tokens associated with different environmental attributes may be present in one address, thus reducing the need of different addresses for tokens associated with different environmental attributes and hence reducing the complexity of the virtual balancing system.

Operating system 102 or attribute management system 220 may determine a value associated with the token units assigned to the address of account 228. For example, operating system 102 or attribute management system 220 may compute the difference in cost between sustainable input materials 204-206 and corresponding equivalent fossil input materials to determine the value of the token units. Operating system 102 may use average price, actual price, market price or other suitable values to determine the cost of the equivalent amount of fossil input materials. Operating system 102 may store and track the values corresponding to sustainable input materials in digital inventories (not shown). For example, the token units assigned to the address of account 228 may be associated with digital inventories which include the value information corresponding to sustainable inputs 204-206.

Operating system 102 may include a merger system 232 to create sustainable chemical products by combining token units with data stored in conventional product digital inventories. With reference to FIG. 2, FIG. 4 and FIG. 5A to FIG. 5C, operating system 102 may processes an order for a product 234-244 received from a customer. If the customer purchased a conventional chemical product 234-240, operating system 102 may process the purchase using conventional product digital inventory 230.

If, however, the customer purchased a sustainable chemical product (e.g. a chemical product associated with one or more environmental attribute(s)), operating system 102 may direct merger system 232 to combine token units assigned to address 228 with conventional product data stored in digital inventory 230. Merger system 232 may generate one or more further token(s) (see FIG. 5A) that define(s) (or specify/ies) a sustainable product from the combination of token units and conventional product data (e.g., using combining or bundling logic 406-408). For example, merger system 232 may create a sustainable product as shown by FIG. 5A to FIG. 5C. Similarly, merger system 232 may create a circular product as shown by FIG. 5A to FIG. 5C. Thus, operating system 102 enables chemical production network 104 to efficiently create multiple sustainable products from multiple input materials including sustainable input materials that are combined with fossil input materials in a large interconnected chemical production network.

FIG. 5A illustrates a merger system for producing sustainable chemical products involving the use of non-fungible tokens. The merger system 232 may be part of the operating system 102 described in the context of FIG. 2. Operating system 102 may receive order data associated with the order of a chemical product by a customer. The order data may include data being indicative of the chemical product to be purchased, such as a chemical product id and/or name and/or order number, and environmental attributes to be associated with the ordered chemical product. Operating system 102 may parse the order data to determine the data related to the chemical product and the target environmental attributes. Operating system 102 may generate a chemical product identifier associated with the ordered chemical product. Operating system 102 may provide the chemical product identifier and the target environment attributes to merger system 232.

Merger system 232 may select, based on the provided target environment attributes, at least one attribution rule for attributing units of token(s) linked to one or more environmental attributes to the chemical product. Merger system 232 may determine the units of token(s) based on the attribution rule(s). The units of token(s) may be determined by combining or bundling logic 406, 408 of merger system 232.

Merger system 232 may generate, for the determined units of each token transaction data 508, 510. The transaction data may include a new token object that defines the determined units of the respective token, the environmental attribute(s) associated with the respective token, the provided chemical product identifier, an address associated with the operating system and token control function(s) defining one or more functions of the respective token, such as minting functions, burning functions, transfer functions,

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approve functions and/or balancing functions. The new token object may be generated based on existing token templates. The transaction data may be signed with a private key associated with operating system 102. The transaction data may be generated by a decentralized app running on merger system 232. With reference to FIG. 22A, merger system 232 may be a peer-to-peer module comprising an API configured to provide an interface to a peer-to-peer node of the decentralized ledger network 224. With reference to FIG. 22A, merger system 232 may be a peer-to-peer node comprising the peer-to-peer application described previously. Merger system 232 may provide the transaction data to decentralized ledger network 224. Decentralized ledger network 224 may be a peer-to-peer network as described in the context of FIG. 22A. Decentralized ledger network 224 may be a blockchain network. One or more nodes of the decentralized ledger network may validate the received transaction data and may append a new block to the existing blockchain including said transaction data. Validation may include checking the signature of the transaction data. Validation may result in creation of the one or more further tokens 526, such as non-fungible tokens, at the address specified in the transaction data (e.g. address 506).

The transaction data 508, 510 may include the determined units of each token, the environmental attributes associated with the respective token, the provided chemical product identifier and an address associated with a third party. At least part of the transaction data, such as the determined units of each token and the address associated with the third party may be provided to the distributed ledger network 224 as previously described. Further parts of the transaction data may be provided to the third party generating the one or more token(s) on behalf of the entity operating the chemical production network 104. For example, the further parts may include the chemical product identifier. Based on the received units of token(s) as well as the further parts of the transaction data, the third party may create transaction data to generate the one or more further token(s) as described above. The created one or more further token(s) 526 may be assigned to an address of the third party and may be transferred from said address to address 506 associated with operating system 102. The one or more further token(s) may be created directly at address 506.

The one or more non-fungible tokens 526 may be uniquely associated with the chemical product via the chemical product identifier as illustrated in FIG. 5A. The one or more non-fungible tokens 526 may be provided as digital assets upon providing the physical chemical product 242, 244 to the chemical product consumer having ordered said chemical product. Providing the non-fungible tokens 526 may include transferring the non-fungible token(s) from address 506 associated with operating system 102 to an address associated with the chemical product consumer via a transaction recorded within the decentralized ledger network 224.

FIG. 5B illustrates a merger system for producing sustainable chemical products involving the use of addresses associated with environmental attributes. In contrast to the example of FIG. 5A, merger system 232 may transfer the determined units of token(s) to an address 516, 518 associated with the chemical

product identifier 520, 522. The address may be associated with account 228. For instance, a plurality of addresses may be generated based on the seed phrase associated with account 228. Each generated address may be associated with a chemical product identifier. The linking between generated address 516, 518 and chemical product identifier may be stored in a database of merger system 232 (not shown).

5 Upon receiving the chemical product identifier, merger system 232 may gather the respective address from said database and may generate transaction data to transfer the units of token(s) from the address associated with account 228 to address 516, 518, respectively. The transaction data may include the units of token(s) and address 516 or 518, respectively. The transaction data may be provided to the distributed ledger network 224 for execution of the transaction. The transaction data may be generated
10 by a decentralized app running on merger system 232 as described in the context of FIG. 5A. The distributed ledger network may include

The distributed ledger network 224 may be a permissioned distributed ledger network as described in the context of FIG. 2. This allows to ensure the required level of privacy and security concerning the generation of token(s) linked to environmental attributes associated with input materials since such token
15 generation provides insights into production processes performed within the chemical production network which are desired to be kept confidential by the entity operating such chemical production network.

Upon providing the physical chemical product 242 to the customer, the units of token assigned to address 516 may be transferred to an address associated with the customer of chemical product 242. Likewise, the units of the token assigned to address 518 may be transferred to an address associated with the
20 customer of chemical product 244.

FIG. 5C illustrates a merger system for producing sustainable chemical products involving the use of a vault address to look and unlock units of tokens linked to environmental attributes. In contrast to the example illustrated in FIG. 5B, merger system 232 may lock determined units of token(s) at a vault address 532. The vault address may comprise an executable means which may be invoked by a
25 transaction to the (unique) communication address of the executable means, e.g. to the vault address 532. The executable means may allow to lock units of token(s) using a secret. The secret may, for example, include a hash of the chemical product identifier.

For locking of the determined units of the token, merger system 232 may generate transaction data 528, 530. The transaction data may be generated by a decentralized app running on merger system 232 as described in the context of FIG. 5A. The transaction data may include the determined units of the token, the secret and the vault address. The transaction data may be provided to the distributed ledger network 224 as described previously. Upon execution of the transaction associated with the transaction data, the
30 units of token will be deducted from the address associated with account 228 and will be locked at the vault address 532.

The secret as well as the vault address to unlock the units of tokens may be provided to the customer, for example using a product passport as described in the context of FIG. 21A and FIG. 21B. Using the secret, the customer may generate transaction data to unlock the units of tokens locked at the vault address 532. Hence, the digital asset associated with the physical chemical product 242, 244 may be provided via the secret and the vault address to the customer of the chemical product.

The distributed ledger network 224 may be a permissioned distributed ledger network as described in the context of FIG. 2. This allows to ensure the required level of privacy and security concerning the generation of token(s) linked to environmental attributes associated with input materials since such token generation provides insights into production processes performed within the chemical production network which are desired to be kept confidential by the entity operating such chemical production network.

The principles illustrated in FIG. 5A to FIG. 5C ensure that units of tokens representing environmental attributes which are allocated to chemical products are deducted from the available units of tokens generated from environmental attributes associated with input materials. Hence, it may be ensured that the order of the customer regarding a chemical product and its environmental attributes may be fulfilled. Additionally, the remaining environmental attributes are made transparent via the balance of token units allocated to the address of account 228.

FIG. 6A to FIG. 6C illustrate a part of a chemical production producing various chemical products from sustainable and non-sustainable inbound materials.

The chemical production network 104 may comprise a system boundary 208. The chemical production network 104 may comprise a hydrolysis plant 602 or plant for hydrolysis of received inbound material. A sustainable material stream may feed the hydrolysis plant 602. The sustainable material stream may include material having a sustainable origin and being hydrolysable. The sustainable origin of the material may be proven by certificate data contained in the input material data associated with the sustainable material, certifying the sustainable origin of said material as described above. The certificate may have been issued by a certifying authority. Moreover, a non-sustainable material stream may feed the hydrolysis plant 602. The non-sustainable material may, chemically speaking, be the same material as the sustainable material. However, the non-sustainable material may not have a sustainable origin. For example, the sustainable material stream may include sustainable palm oil or palm kernel oil or coconut oil, while the non-sustainable material stream may include conventional palm oil or palm kernel oil or coconut oil (e.g. palm oil or palm kernel oil or coconut oil not being certified as being sustainable).

Palm oil may be extracted from the flesh of the Palm fruit. Palm Kernel Oil may be extracted from the seeds or kernels of the Palm fruit. Fresh fruit bunches (FFB) of oil palm may be harvested by palm oil companies from plantations or may be supplied to said companies from third party suppliers. The harvested FFB may then be transported to mills to extract Crude Palm Oil (CPO). The Crude Palm Oil

may be extracted from the fresh Palm fruit flesh by pressing and centrifugation. The Crude Palm Oil extraction may be done with the fresh Palm fruit to avoid the deterioration of Palm Oil. The palm kernels resulting from the milling process may be transported to crushing companies. Said companies may crush the palm kernels and extract palm kernel oil. Said crude palm kernel oil may then be transported to traders.

The oil extracted from the fruits and/or kernels, such as CPO and crude palm kernel oil, may be traded by traders. Said traders may buy oil extracted by mills and/or crushers and may sell said oil to refineries or chemical product producer. The chemical product producer may operate a chemical production network, such as chemical production network 104 described in the context of FIG. 1 and FIG. 2. The chemical product producer may produce chemical product(s) using the oil provided by traders, for example as described in the context of FIG. 6A to FIG. 6C. The received oil may be associated with oil data, such as described in the context of FIG. 2. The oil data may include certificate data. The certificate data may indicate that the production of the oil (e.g. plantation, transport, milling, crushing, refining) has been performed according to predefined production criteria. Such production criteria may include the previously mentioned criteria. Certificate data may be generated by independent authorities which ensure that the criteria for certification are fulfilled and may be provided to producers of the palm oil and palm kernel oil. For example, the oil data may include RSPO (round table on sustainable palm oil) certificate data. The oil data may be gathered by chemical product producer, for example as described in the context of FIG. 21A and FIG. 21B.

The refinery may refine the vegetable oil, such as CPO and crude palm kernel oil, by various processes to remove unwanted impurities which may adversely affect the physical appearance, quality, oxidative stability and/or shelf life of the vegetable oil. Refining may include the steps of bleaching, deodorizing/de-acidification and fractionating to obtain oil fractions, such as palm olein and stearin. The refined products may then be transported to chemical product producer as previously described.

The hydrolysis effluent exiting the hydrolysis plant 602 may comprise hydrolyzed material, such as fatty acids and glycerol. The hydrolyzed material, such as fatty acids, may be used as feedstock for various plants, depending on the desired chemical product to be obtained. Part of the hydrolyzed material may be fed into one or more subsequent plants, depending on the chemical products to be produced, while the other part (e.g. glycerol) may be sold as chemical product or as intermediate to produce further chemical products, such as polymers. For example, part of the hydrolyzed material may be fed into a hydrogenation plant 604, which hydrogenates the fed material. In case the hydrolyzed material is a fatty acid, the hydrogenation will result in fatty alcohols. Such hydrogenated material may be used as feed for the cracker described in relation to FIG. 7A to FIG. 7C below or may be fed to a sulfatation plant 606 to obtain sulfonated products. For example, if fatty alcohols are fed into the sulfatation plant 606, fatty

alcohol sulfonates are obtained as chemical products, which may be used as anionic surfactants in cosmetics and detergents.

Part of the hydrogenated material may also be fed into an ethoxylation plant 608 to obtain ethoxylated materials and/or into an esterification plant to obtain esterified material. The output from the ethoxylation plant 608 may be fed into the sulfatation plant 606 to obtain ethoxylated and sulfonated chemical products, such as ethoxylated fatty alcohol sulfonates usable as anionic surfactants in cosmetics and detergents.

Part of the hydrolyzed material may be fed into an ethoxylation plant 608 to obtain ethoxylated material. For example, the fatty acids obtained from hydrolyzing palm oil may be ethoxylated to obtain fatty acid ethoxylates which may be used as nonionic surfactants in cosmetics and detergents.

Part of the hydrolyzed material may be fed into an esterification plant 610 to obtain esterified material. For example, the fatty acids obtained from hydrolyzing palm oil may be esterified to obtain fatty acid esters, which may be used to produce biodiesel and a variety of other chemical products.

Part of the hydrolyzed material may be fed into a neutralization plant 612 to obtain soaps. For example, the fatty acids obtained from hydrolyzing palm oil may be neutralized to obtain fatty acid soaps. These soaps may be supplied as chemical products or as intermediate chemical products to produce cosmetics.

Based on the sustainable origin content of the hydrolysis plant 602 effluent, the fatty acids from the hydrolysis plant 602 effluent and any chemical products produced from any component of such effluent may contain sustainable origin content. For example, the fatty alcohol ethoxylates may contain sustainable origin content. Further for example, the fatty alcohol may contain sustainable origin content. Further for example, chemical products produced from the fatty acid or fatty alcohol may contain sustainable origin content. This way the sustainable origin content may be contained in the produced chemical intermediates, chemical product(s), or end products.

FIG. 6A illustrates an embodiment for a system boundary 208 of the chemical production network 104, which includes the hydrolysis step. The sustainable and non-sustainable material streams form the entry point into the chemical production network 104. The chemical end products produced from the chemical production network 104 form the exit point out of the chemical production.

FIG. 6B illustrates another embodiment for the system boundary 208 of the chemical production network 104, which excludes the hydrolysis step. The fatty acid feed forms the entry point into the chemical production network 104. The chemical products form the exit point out of the chemical production network 104.

FIG. 6C illustrates another embodiment for the system boundary 208 of the chemical production network 104, which excludes the hydrolysis step and the hydrogenation, ethoxylation, esterification and neutralization steps. The fatty alcohol effluent produced at least in part from fatty acids forms the entry point into the chemical production network 104. The chemical products form the exit point out of the chemical production network 104. The chemical production networks 104 and the system boundaries 208 illustrated in FIG. 6A to FIG. 6C are examples and should not be considered limiting.

In the examples shown in FIG. 6A to FIG. 6C, the sustainable origin content may be the environmental attribute of the respective input material. In FIG. 7A, the sustainable origin vegetable oil is the input material to the chemical production network 104 including the hydrolysis plant 602. The environmental attribute associated with such vegetable oil may include the environmental attribute type such as sustainable origin and a type such as vegetable oil. The environmental attribute may be separated from the material flow through the chemical production network 104 on entry of the vegetable oil. Units of token(s) may be generated or allocated to an address associated with the operating system 102 (see FIG. 2). In FIG. 7B, the fatty acid is the input material to the chemical production network 104 excluding the hydrolysis plant 602. The environmental attribute associated with such fatty acid may include the environmental attribute type such as sustainable origin, the material type such as fatty acid and the input type such as vegetable oil. The environmental attribute may be separated from the material flow through the chemical production network 104 on entry of the fatty acid to the chemical production network 104. Units of token(s) may be generated or allocated to an address associated with the operating system 102 (see FIG. 2). In FIG. 7C, the fatty alcohol effluent produced from fatty acids or the effluent from the ethoxylation plant 608 is the input material to the chemical production network 104 excluding the hydrolysis plant 602, the hydrogenation plant 604, the ethoxylation plant 608, the esterification plant 610 and the neutralization plant 612. The environmental attribute associated with such effluent may include the environmental attribute type such as sustainable origin, the material type such as effluent produced from fatty acids and the input type such as vegetable oil. The environmental attribute may be separated from the material flow through the chemical production network 104 on entry of the cracked effluent to the chemical production network 104. Units of token(s) may be generated or allocated to an address associated with the operating system 102 (see FIG. 2). By separating the environmental attribute from the material flow of the chemical production network, a reliable and simple assignment of environmental attributes to the chemical products produced by the chemical production network can be realized. By way of tokens linked to environmental attributes, the environmental attributes can be collected as units of token(s) on entry to the chemical production network at one or more addresses associated with the operating system 102. On exit of chemical products, the units of token(s) collected on entry can be assigned to such products and withdrawn from the the address they were created at or transferred to on entry of of the input material to the chemical production network. Thus, it can be ensured 1) that only environmental attributes are assigned to chemical products that entered the chemical production network

and 2) that are not already assigned to another chemical product. As a result, the positive environmental impact is only counted once and can be tracked from entry to exit of the chemical production network.

FIG. 7A to FIG. 7C illustrate a part of a chemical production network 104 producing multiple chemical product(s) from fossil and non-fossil input material(s).

- 5 The chemical production network 104 may comprise a pyrolysis plant 702 for pyrolysis of recycled waste. A waste stream may be fed to the pyrolysis plant 702. Waste stream may include plastics, rubber (including tires), textiles, wood, biowaste, modified celluloses, wet laid products, and any other material suitable for pyrolysis. The recycled waste stream may include a stream containing at least in part post-industrial, or post-consumer, or both post-industrial and post-consumer materials. A post-consumer
- 10 material may be a material that has been used at least once for its intended application for any duration of time regardless of wear, or has been sold to an end use customer, or which is discarded by any person or entity other than a manufacturer or business engaged in the manufacture or sale of the material. A post-industrial material may be a material that has been created and has not been used for its intended application or has not been sold to the end use customer or discarded by a manufacturer or any other
- 15 entity engaged in the sale of the material. Examples of post-industrial materials include rework, regrind, scrap, trim, out of specification materials, and finished materials transferred from a manufacturer to any downstream customer (e.g., manufacturer to wholesaler to distributor) but not yet used or sold to the end use customer. The waste stream may be isolated as one type of waste stream with specific waste material, or it may be a stream of mixed wastes.
- 20 Examples of plastics as a waste stream include high density polyethylene and copolymers thereof, low density polyethylene and copolymers thereof, polypropylene and copolymers thereof, other polyolefins, polystyrene, polyvinyl chloride (PVC), polyvinylidene chloride (PVDC), polyesters including polyethylene terephthalate, co-polyesters and terephthalate co-polyesters (e.g. containing residues of 2,2,4,4-tetramethyl-1,3-cyclobutanediol, CHDM cyclohexanedimethanol, neopentyl glycol monomers, or
- 25 propylene glycol), polyethylene terephthalate, polyamides, poly(methyl methacrylate), polytetrafluoroethylene, acrylonitrile butadiene styrene (ABS), polyurethanes, cellulose and derivatives thereof such as cellulose acetate, cellulose diacetate, cellulose triacetate, cellulose propionate, cellulose butyrate; regenerated cellulose such as viscose and rayons, epoxy, polyamides, phenolic resins, polyacetal, polycarbonates, polyphenylene-based alloys, polypropylene and copolymers thereof,
- 30 polystyrene, styrenic compounds, vinyl based compounds, styrene acrylonitrile, thermoplastic elastomers, urea based polymers and/or melamine containing polymers.

The pyrolysis effluent exiting the pyrolysis plant 702 may comprise pyrolysis oil. The pyrolysis oil may be used as feedstock for a steam cracker/syngas plant 704. The pyrolysis oil may be fed to the steam cracker/syngas plant 704 as recycled feedstock together with a non-recycle or conventional feedstock

35 (e.g., propane, ethane, naphtha and/or natural gasoline). In addition, or alternatively to the recycled

feedstock, bio-based feedstock may be fed to the steam cracker/syngas plant 704. For example, bio-naphtha may be produced through hydrogenation of bio-based material such palm oil and tallow and provided as feedstock to the steam cracker/syngas plant 704. In further embodiments pyrolysis wax, pyrolysis gas, pyrolysis char, or synthesis gas may be provided to the steam cracker/syngas plant 704 as feedstock.

The cracker unit of steam cracker/syngas plant 704 may include a steam cracker that breaks saturated hydrocarbons down into smaller, often unsaturated, hydrocarbons. Steam crackers are facilities in which fossil feedstock such as naphtha, liquefied petroleum gas (LPG), ethane, propane, or butane and/or non-fossil feedstock is thermally cracked through the use of steam in steam cracking furnaces or electric furnaces to produce lighter hydrocarbons.

The output effluent of the cracker unit may be a recycled and/or bio-based content effluent containing light olefins, C4 products and heavy cracker products such C5, C6, C7, C8, C9, C10 products or mixtures. The recycled and/or bio-based content cracked effluent may be subjected to separation in a separation train. The recycled or bio-based content effluent can be separated in different fractions containing recycled or bio-based content from the recycled or bio-based content of the cracked effluent.

The light olefins fraction may include ethylene and propylene. Ethylene may be used to produce polyethylene, ethylene chloride and ethylene oxide. Polyethylene, ethylene chloride or ethylene oxide may be chemical intermediates used to produce chemical product(s) that exit the chemical production network. Polyethylene, ethylene chloride or ethylene oxide may be chemical product(s) that exit the chemical production network. Polyethylene, ethylene chloride or ethylene oxide may be used for producing packaging as end product, for plastic processing or for producing end products in construction and textile production. Propylene may be used to produce polypropylene, propylene oxide, acrylic acid, or other chemical derivatives. Propylene and its derivatives may be chemical intermediates used to produce chemical product(s) that exit the chemical production network. Propylene and its derivatives may be used for producing packaging as end product, for producing furniture as end products or for producing end products in automotive production.

The C4 fraction may contain a gas mixture comprising C4 olefins from which butadiene and isobutene may be extracted. The residue, a mixture of butene and butanes, may be used as chemical intermediate for further production processes of the chemical production network. Butadiene and its derivatives may be chemical intermediates used to produce chemical product(s) that exit the chemical production network. Butadiene and its derivatives may be chemical product(s) that exit the chemical production network. Butadiene and its derivatives may be used for producing end products such as tires, papers, plastics, rubber, petroleum, lube, or perfumes. Isobutene (Isobutylene) and its derivatives may be chemical intermediates used to produce chemical product(s) that exit the chemical production network. Isobutene

(Isobutylene) and its derivatives may be chemical product(s) that exit the chemical production network. Isobutene (Isobutylene) and its derivatives may be used for producing butyl rubber and for polyisobutylene for end products such as tires, papers, plastics, rubber, petroleum, lube, or perfumes.

The heavy cracker fraction may contain 5-12 hydrocarbon atoms (e.g., C5 non-aromatics, C7/C8 mixtures, C9). C5 non aromatics may be chemical intermediates used to produce further chemical intermediate(s) such as cyclopentane- and n/i pentane mixtures or chemical product(s) that exit the chemical production network. C9 fraction, not hydrogenated or hydrogenated, C7/8 mixtures or xylol-mixtures may be chemical intermediates used to produce further chemical intermediate(s) such as hydrocarbon resins, used as a blending component for premium gasoline or used for the production of benzene.

Residues like pyrolysis oil from ethylene production may be used as chemical intermediate for the production of carbon black, as an auxiliary material in the chemical industry, as a raw material for distillation of naphthalene and indene.

Based on the recycled and/or bio-based content of the cracked effluent, the fractions from the cracked effluent and any chemical products produced from any component of such effluent may contain recycled and/or bio-based content. For example, the light olefin fraction may contain recycled and/or bio-based content. Further for example, the ethylene or propylene fraction may contain recycled and/or bio-based content. Further for example, chemical products produced from the ethylene or propylene fraction may contain recycled and/or bio-based content. This way the recycled and/or bio-based content may be contained in the produced chemical intermediates, chemical product(s), or end products.

FIG. 7A illustrates an embodiment for a system boundary 208 of the chemical production network 104, which includes the pyrolysis step. The waste stream forms the entry point into the chemical production network 104. The chemical end products form the exit point out of the chemical production network 104.

FIG. 7B illustrates another embodiment for the system boundary 208 of the chemical production network 104, which excludes the pyrolysis step. The pyrolysis oil and the fossil feed form the entry point into the chemical production network 104. The chemical end products form the exit point out of the chemical production network 104.

FIG. 7C illustrates another embodiment for the system boundary 208 of the chemical production network 104, which excludes the pyrolysis step and the cracking step. The cracker effluent produced at least in part from pyrolysis oil forms the entry point into the chemical production network 104. The chemical end products form the exit point out of the chemical production network 104. The chemical production networks 104 and the system boundaries 208 illustrated in FIG. 7A to FIG. 7C are examples and should not be considered limiting.

In the examples shown in FIG. 7A to FIG. 7C, the recycled and/or bio-based content may be the environmental attribute of the respective input material. In FIG. 7A, the waste stream is the input material to the chemical production network 104 including the pyrolysis plant 702. The environmental attribute associated with such waste stream may include the environmental attribute type such as recycled and the waste type such as mixed plastics waste. The environmental attribute may be separated from the material flow through the chemical production network 104 on entry of the waste stream. Units of token(s) may be generated or allocated to an address associated with the operating system 102 (see FIG. 2). In FIG. 7B, the pyrolysis oil is the input material to the chemical production network 104 excluding the pyrolysis unit. The environmental attribute associated with such pyrolysis oil may include the environmental attribute type such as recycled, the material type such as pyrolysis oil and the waste type such as mixed plastics waste. The environmental attribute may be separated from the material flow through the chemical production network 104 on entry of the pyrolysis oil to the chemical production network 104. Units of token(s) may be generated or allocated to an address associated with the operating system 102 (see FIG. 2). In FIG. 7C, the cracked effluent produced from pyrolysis oil is the input material to the chemical production network 104 excluding the pyrolysis plant 702 and the cracker steam cracker/syngas plant 704. The environmental attribute associated with such effluent may include the environmental attribute type such as recycled, the material type such as effluent produced from pyrolysis oil and the waste type such as mixed plastics waste. The environmental attribute may be separated from the material flow through the chemical production network 104 on entry of the cracked effluent to the chemical production network 104. Units of token(s) may be generated or allocated to an address associated with the operating system 102 (see FIG. 2). By separating the environmental attribute from the material flow of the chemical production network, a reliable and simple assignment of environmental attributes to the chemical products produced by the chemical production network can be realized. By way of tokens linked to environmental attributes, the environmental attributes can be collected as units of token(s) on entry to the chemical production network at one or more addresses associated with the operating system 102. On exit of chemical products, the units of token(s) collected on entry can be assigned to such products and withdrawn from the address they were created at or transferred to on entry of the input material to the chemical production network. Thus, it can be ensured 1) that only environmental attributes are assigned to chemical products that entered the chemical production network and 2) that are not already assigned to another chemical product. As a result, the positive environmental impact is only counted once and can be tracked from entry to exit of the chemical production network.

In the context of this example a pyrolysis unit followed by a steam cracker unit is shown. This is not to be considered limiting. The concepts disclosed herein equally apply to equivalent chemical value/production chains such as syngas plant-based value/production chains.

FIG. 8A to FIG. 8C illustrate examples of allocation schemes allocating the use of renewable or bio-based input materials to chemical products of the chemical production network.

As illustrated in FIG. 1 to FIG. 7C, chemical production networks can comprise complex interconnected production sites that chemically convert one or more input materials via chemical processing to one or more chemical products. To account for the use of recycled or renewable or bio-based or sustainable origin content in chemical production, allocation rules may be used. This way recycled, renewable or bio-based or sustainable origin content of input materials may be allocated to chemical products. The renewable content may be based on input material from renewable sources. The renewable content may comprise bio-based input materials produced from living organisms such as different types of crops, wood, or algae. The recycled content may comprise any recycled material used in production of new materials. This may include any recycled bio-based or bio-based materials e.g., as produced from chemical or mechanical recycling. The sustainable origin content may include material from sustainable origin. The sustainable origin may be certified by certification data as described previously.

Accounting principles for allocating the use of recycled or renewable content are for example defined in ISO 22095. Four different chain of custody models may be used: Identity preservation models, segregated models, mass balance models, or book and claim models.

FIG. 8A illustrates an example of a dedicated or segregated production network. The production network comprises a first production chain for producing the chemical product(s) from fossil material(s) materials and a second production chain for producing the chemical product from bio-based input material(s). The first and the second production chain are not interconnected. The first and the second production chains produce fossil-based and bio-based or recycled or sustainable origin chemical product(s), respectively. Example for such dedicated production environments include fermentation or chemical transformation, such as polyethylene production from sugar cane, bio-poly lactic acid (PLA) production from corn, bio-succinic acid, or bio-butanediol (BDO).

FIG. 8B illustrates an example of a complex production network. In contrast to the production network of FIG. 8A the fossil-based input material(s) are co-fed and mixed with bio-based or recycled input materials. Non-sustainable origin material(s) are co-fed and mixed with sustainable origin materials. The production network produces via one or more chemical process chain(s) with intermediates one or more material outputs or products. For the sake of simplicity FIG. 6B illustrates the mass balancing approach for one chemical process chain producing one chemical product or product. In the mass balancing model, the physical mixing or co-feeding of bio-based or recycled input material with conventional fossil input materials is accounted for. Here the feed into the production network and the feed of output products form a system boundary. The mass balance of input and chemical products connects the used bio-based or recycled input material to the produced output product. Mass balance allows to keep track of the total amount of input material (e. g. recycled or bio-based or bio-based materials) throughout the production network and allows for allocation to chemical products. Materials with different sets of specified characteristics may be mixed. E. g. recycled or bio-based feedstock replaces an equivalent amount of

fossil feedstock at the beginning of the value chain (input material) and is allocated to a product (chemical product) in such a manner that the input and output match. For this model, the proportion of the input with specified characteristics might only match the initial proportions on average and will typically vary across different outputs. This means that e.g., recycled and fossil input materials are mixed and that the chemical or technical proportions in each chemical product are not tracked.

Mass balance may include conversion factors to ensure the amount of input material is correlated with the amount of chemical product. The calculation may be made over a pre-defined or specified time period. Mass balance may be based on a balancing unit such as mass, energy, or carbon.

FIG. 8C illustrates a complex production network associated with a book and claim scheme. In a book and claim scheme, the characteristic renewable or recycled input material is not linked to the actual material flows. Book & Claim allows to de-couple a specific characteristic, such as renewable, from the physical product and to transfer the characteristic separately via a dedicated registry in the form of a digital asset. This approach may be used for renewable energy. Book and claim may be based on a book and claim accounting unit such as kilowatt-hours for electricity.

In identity preservation models or segregated approaches as illustrated in FIG. 8A renewable, recycled or bio-based input materials may not be mixed with fossil input material. In mass balance or book and claim approaches as illustrated in FIG. 8B and FIG. 8C renewable or recycled or bio-based materials with fossil input material may be mixed. In view of the increasing number of different sources for more sustainable chemical production and the number of allocation schemes, an efficient and robust operation system for operating complex production networks like chemical production networks is required.

FIG. 9 illustrates an example of a chemical production network with different allocation schemes.

The chemical production network may include multiple production chains with different allocation schemes. The system boundary of the chemical production network may be defined by the entry points to the chemical production network and the exit points from the chemical production network. The production chains may be defined by the chemical product(s) produced via such production chains. The production chain logic may be based on process data associated with process steps from input material(s) to chemical product(s). For each production chain an allocation scheme may be applicable (and the application allocation scheme may be assigned to the production chain). In addition for each production chain a balancing system (e.g., a virtual balancing account) may be applicable or the production chain logic may be embedded in the attribution rules.

FIG. 10 illustrates a first example of a method for assigning at least one environmental attribute associated with an input material to at least one chemical product produced from said input material by a chemical production network. The chemical production network may be the chemical production

network 104 described in the context of FIG. 1 and FIG. 2. The method may be performed by operating system 102 described in the context of FIG. 1 and FIG. 2. The input material may be a fossil input material. The input material may be recycled input material. The input material may be a bio-based input material. The input material may be an input material described in the context of FIG. 2. The environmental attribute may be associated with the production of the input material, such as vegetable oil. The environmental attribute may be associated with or correspond to certificate data being indicative of a production of the input material according to predefined production criteria. The predefined production criteria may relate to the plantation of the vegetable from which the input material, such as the vegetable oil, is produced. The predefined production criteria may relate to the transport of the harvested input material and/or the input material. The production criteria may relate to the production of the input material from the harvested vegetable. The production criteria may relate to the refinement of crude input material.

In block 1002, input material data associated with the input material received from an input material supplier (see for example FIG. 6) may be provided to the operating system of the chemical production network. The input material data may be provided as described in the context of FIG. 2.

In block 1004, environmental attributes associated with the input material may be determined based on the provided input material data. The environmental attributes may be determined by parsing the provided input material data. The environmental attributes may be determined as described in the context of FIG. 2. In case input material data for a first input material and input material for a second input material is provided, the environmental attributes may be determined based on the first input material data and the second input material data. The environmental attributes may be determined as described in the context of FIG. 2.

The determined environmental attributes may be verified. This may ensure that the environmental attributes are correctly determined and avoids generation of token(s) for environmental attributes not associated with the vegetable oil. Hence, correct determination of environmental attributes for vegetable oils entering the chemical production network may be ensured, thus ensuring correct attributing of environmental attributes from vegetable oils entering the chemical production network to chemical products produced by said chemical production network at least in part from said vegetable oils.

Verification may include verifying the sustainable origin of the input material. Verifying may include determining a decentral identifier associated with the received input material, for example as described in the context of FIG. 21B. The decentral identifier may be used to gather data associated with the environmental attribute of the input material from a peer-to-peer network, for example as described in the context of FIG. 21B. For instance, data associated with the environmental attribute may be gathered from at least part of the participants involved in the production of the input material. For instance, the participant(s) may be associated with a decentral peer-to-peer network configured to transfer data associated with the production of the input material between participants of the peer-to-peer network.

The chemical product producer may gather via a decentral data consuming network node data associated with the production of the input material from said participants. The gathered data may be used to validate the determined environmental attributes. For instance, the gathered data may be used to validate whether the determined sustainable origin is indeed sustainable or not. The gathered data may be compared to
5 databases storing certificate data associated with the origin of the input material. The gathered data may be compared to geographic data to determine whether the sustainable origin claimed according to the certificate data is true or not. The gathered data may be compared to a rule set associated with the certificate data. For instance, the rule set may include rules to be fulfilled for a certificate to be valid.

Verifying may include determining a digital asset associated with the received input material based on
10 the provided input material data. The digital asset may correspond to a non-fungible token associated with the input material, for example as described in the context of FIG. 22B. The digital asset may be transferred to chemical product producer upon receipt of the input material at the entry point of the chemical production network. The digital asset may be transferred to an address of a distributed ledger network associated with the operating system. The digital asset may be used to determine production
15 data associated with the received input material. For instance, the digital asset may be linked to one or more further digital assets, such as tokens, each digital asset representing a production step, such as growing, harvesting, transport, milling, crushing or refining. The further digital assets may be stored on a distributed ledger network and may be used to verify the sustainable origin of the input material. The data associated with the further digital assets may be gathered and may be used to verify the determine
20 environmental attribute as previously described.

In block 1006, one or more token(s) linked to at least one determined environmental attribute may be created at an address associated with a distributed ledger network. The address may further be associated with the operating system 102 of the chemical production network 104. The token(s) may be created as described in the context of FIG. 2 and FIG. 5A to FIG. 5C. The tokens may be created using
25 one or more attribution rules as described in the context of FIG. 17.

In block 1008, a chemical product identifier associated with the chemical product and optionally at least one target environmental attribute may be provided. The chemical product identifier may be provided based on order data associated with an order of the chemical product received from a customer. The order data may include data being indicative of the chemical product. Such data being indicative of the
30 chemical product may include a chemical product ID, a chemical product name, an order number or a combination thereof. The order data may further include the target environmental attribute desired by the customer. The order data may be received by operating system 102. Operating system 102 may parse the order data to determine the data being indicative of the chemical product and/or the target environmental attribute. Based on the result of the data parsing, operating system 102 may determine
35 the chemical product identifier. The chemical product identifier may be associated with an environmental

attribute, for example as described in FIG. 15A. Based on the parsed data, the operating system 102 may provide an environmental attribute identifier associated with the target environmental attribute, for example as described in the context of FIG. 15B. The environmental attribute identifier and/or the chemical product identifier may be associated with a defined units of the token.

- 5 In block 1010, at least one attribution rule for attributing token(s) linked to one or more environmental attributes(s) associated with vegetable oil(s) to chemical product(s) may be selected based on the chemical product identifier and optionally the target environmental attribute. The attribution rule may be an attribution rule as described in FIG. 18 to FIG. 20. The attribution rule may define the units of token(s). The attribution rule in combination with the amount of chemical product may define the units of token(s).
- 10 In block 1012, at least one address holding units of token(s) linked to one or more environmental attribute(s) may be determined via the at least one selected attribution rule. The address may be associated with the operating system 102. The token(s) assigned to said address may be tokens generated in block 1010. This block may further include determining the units of token(s) to be assigned to the chemical product identifier. The units of token may be determined based on the selected attribution
- 15 rule. The units of token(s) may be determined based on the amount of chemical product and the chemical product identifier. The units of token(s) may be determined based on the amount of chemical product and the environmental attribute identifier.

- In block 1014, units of at least one of the tokens linked to the one or more environmental attribute(s) may be assigned to the chemical product identifier. Assignment may be performed as described, for example,
- 20 in the context of FIG. 5A to FIG. 5C. Assignment may include
- checking the balance of addresses holding token(s) associated with the determined token units and assigning the determined units of token(s) from the associated address to the chemical product identifier if the balance is sufficient, and/or
 - checking that the respective token(s) are associated with input material(s) used to produce the
- 25 chemical product and assigning the determined units of token(s) from addresses holding said units to the chemical product identifier if the respective token(s) is/are associated with input material(s) used in the production chain of the chemical product.

- FIG. 11 illustrates a further example of a method for assigning at least one environmental attribute associated with an input material to at least one chemical product produced from said input material by
- 30 a chemical production network. The chemical production network may be the chemical production network 104 described in the context of FIG. 1 and FIG. 2. The method may be performed by operating system 102 described in the context of FIG. 1 and FIG. 2. The input material may be an input material as described in the context of FIG. 10. The environmental attribute may be associated with the production of the input material, such as vegetable oil. The environmental attribute may be associated with or
- 35 correspond to certificate data being indicative of a production of the input material according to predefined

production criteria. The predefined production criteria may relate to the plantation of the vegetable from which the input material, such as the vegetable oil, is produced. The predefined production criteria may relate to the transport of the harvested input material and/or the input material. The production criteria may relate to the production of the input material from the harvested vegetable. The production criteria may relate to the refinement of crude input material.

In block 1102, input material data associated with the vegetable oil received from an input material supplier (see for example FIG. 6) may be provided to the operating system of the chemical production network. The input material data may be provided as described in the context of FIG. 2.

In block 1104, environmental attributes associated with the input material may be determined based on the provided input material data. The environmental attributes may be determined by parsing the provided input material data. The environmental attributes may be determined as described in the context of FIG. 2. The determined environmental attribute may be validated. This may ensure that the environmental attributes are correctly determined and avoids generation of token(s) for environmental attributes not associated with the input material. Hence, correct determination of environmental attributes for input materials entering the chemical production network may be ensured, thus ensuring correct attributing of environmental attributes from input materials entering the chemical production network to chemical products produced by said chemical production network at least in part from said input materials. Verification may be performed as described in FIG. 10.

In block 1106, at least one address holding units of token(s) linked to one or more of the determined environmental attribute(s) may be determined based on the environmental attributes. The address may further be associated with the operating system 102 of the chemical production network 104. The address may be determined by mapping attribution rules to determined environmental attributes. For instance, the determined environmental attributes may be mapped to attribution rules illustrated in FIG. 17.

In block 1108, units of at least one of the token(s) may be allocated to a further address associated with the operating system 102 of the chemical production network 104. The further address may be a further address associated with account 224 of the operating system 102. The further address may serve as a balance to determine the amount of token units available for allocation to produced chemical products. Use of a further address may avoid repeated generation of token units upon entry of vegetable oil to the chemical production network.

In block 1110, a chemical product identifier associated with the chemical product and optionally at least one target environmental attribute may be provided. The chemical product identifier and optionally target environmental attribute may be provided as described in the context of FIG. 10.

In block 1112, at least one attribution rule for attributing token(s) linked to one or more environmental attributes(s) associated with vegetable oil(s) to chemical product(s) may be selected based on the chemical product identifier and optionally the target environmental attribute. The attribution rule may be an attribution rule as described in FIG. 18 to FIG. 20. The attribution rule may define the units of token(s).

5 The attribution rule in combination with the amount of chemical product may define the units of token(s).

In block 1114, at least one address holding units of token(s) linked to one or more environmental attribute(s) may be determined via the at least one selected attribution rule. The address may be associated with the operating system 102. This block may further include determining the units of token(s) to be assigned to the chemical product identifier. The units of token may be determined based on the
10 selected attribution rule. The units of token(s) may be determined based on the amount of chemical product and the chemical product identifier. The units of token(s) may be determined based on the amount of chemical product and the environmental attribute identifier.

In block 1116, units of at least one of the tokens linked to the one or more environmental attribute(s) may be assigned to the chemical product identifier. Assignment may be performed as described, for example,
15 in the context of FIG. 5A to FIG. 5C.

FIG. 12A illustrates a first example of an apparatus for producing at least one chemical product associated with one or more environmental attribute(s) including an example method for assigning at least one environmental attribute to the at least one produced chemical product. The apparatus for producing the chemical product may correspond to chemical production network 104 described in the context of FIG. 1 and FIG. 2. The method may be performed by operating system 102 of chemical production network 104.
20 The operating system 102 may be operating system 102 of FIG. 2.

On the physical layer, input material(s) may be provided as physical inputs to the chemical production network 104. The chemical production network 104 may produce one or more chemical product(s) from the provided input materials, for example products described in the context of FIG. 6A to FIG. 7C. The
25 produced chemical products may be provided at exit points of the chemical production network 104. The produced chemical products may be provided to a chemical product consumer 2106 (see for example FIG. 21A and FIG. 22A).

On the virtual layer, operating system 102 may perform blocks 1208 to 1218 illustrated in FIG. 12A. Blocks 1208 to 1218 may correspond to the method illustrated in FIG. 10. Hence, operating system 102
30 may perform - on the virtual layer - the method illustrated in FIG. 10.

FIG. 12B illustrates a further example of an apparatus for producing at least one chemical product associated with one or more environmental attribute(s) including an example method for assigning at least one environmental attribute to the at least one produced chemical product. The apparatus for

producing the chemical product may correspond to chemical production network 104 described in the context of FIG. 1 and FIG. 2. The method may be performed by operating system 102 of chemical production network 104. The operating system 102 may be operating system 102 of FIG. 2.

On the physical layer, input material(s) may be provided as physical inputs to the chemical production network 104. The chemical production network 104 may produce one or more chemical product(s) from the provided input materials, for example products described in the context of FIG. 7A to FIG. 7C. The produced chemical products may be provided at exit points of the chemical production network 104. The produced chemical products may be provided to chemical product consumer 2106 (see for example FIG. 21A and FIG. 22A).

On the virtual layer, operating system 102 may perform blocks 1230 to 1240 illustrated in FIG. 12B. Blocks 1230 to 1240 may correspond to the method illustrated in FIG. 11. Hence, operating system 102 may perform - on the virtual layer - the method illustrated in FIG. 11.

Based on the non-limiting example of FIG. 13 bio-based and recycled feedstock may be provided to the steam cracker. For illustrative purposes the following input materials may be provided to the steam cracker in the following amounts:

- 3 kg recycled input material such as pyrolysis oil produced from mixed plastics waste,
- 5 kg bio-based input material such as bio-naphtha from vegetable oil that is kosher and vegan,
- 92 kg of naphtha.

On providing these input materials to the steam cracker, the input materials enter the chemical production network. The environmental attributes of the recycled and bio-based input materials may be determined as described in the context of FIG. 2, FIG. 9 and FIG. 10. Based on the determined environmental attributes, units of token(s) linked to such environmental attributes may be determined and transaction data may be generated for such determined units of token(s) as described in the context of FIG. 2, FIG. 9 and FIG. 10. Upon execution of the transaction associated with such transaction data by a distributed ledger network, units of tokens may be created at or may be assigned to an address associated with the operating system 102 of the chemical production network 104. The units of tokens may be determined based on the amount of respective input material. In the example, the environmental attribute pyrolysis oil from recycled mixed plastics waste may correspond to 3 units of a recycled token and the environmental attribute bio-naphtha from bio-based food waste may correspond to 5 units of a bio-based token. In this example a simplified weight-based approach is used for illustrative purposes only. Other approaches may be based on energy, atom counting such as carbon atoms, molecule counting such as methane, or include losses that occur in production.

In more elaborate embodiments the token units may be determined based on a more complex conversion factor taking chemical and/or physical differences between input materials and their associated yield into

account. The conversion factor may quantify the differences in chemical and/or physical properties of replacing fossil input material(s) by non-fossil input material(s). The conversion factor may relate the use of conventional input material(s) to the use of input material(s) associated with one or more environmental attribute(s). The conversion factor may depend on carbon atoms, methane molecules, energy properties, process properties or any other suitable factors for quantifying the environmental impact of the environmental attribute. For instance, the lower or higher heating value (LHV, HHV) of the fossil and the non-fossil input material may be considered. Further for instance, material losses that occur in the processing of the fossil or the non-fossil input material may be considered. Further for instance, exempted steam cracker products, intermediates or production chains may be considered. Further for instance, only pre-selected production chains may be considered. This way the environmental impact of the non-fossil input materials may be quantified with reference to fossil input materials.

The steam cracker may produce cracker products, which may be further processed and chemically converted. In the illustrative example, 20 kg ethylene as cracker product, 30 kg polyamide and 50 kg polystyrene may be provided to the exit point of the chemical production network. Since for the production of such products 3kg recycled and 5kg bio-based input materials were used, the token units stored in the address associated with operating system 102 may be assigned to such chemical products. For instance, 3 units of the recycled token may be assigned to polyamide, which corresponds to 10% recycled content, and 5 token units of the bio-based token may be assigned to polystyrene, which corresponds to 10% bio-based content.

Based on the non-limiting example of FIG. 14 sustainable origin feedstock may be provided to the hydrolysis plant 602. For illustrative purposes the following input materials may be provided to the hydrolysis plant 602 in the following amounts:

- 90 kg sustainable origin input material such as sustainable palm oil,
- 10 kg non-sustainable origin input material, such as non-sustainable palm oil.

On providing these input materials to the hydrolysis plant 602, the input materials enter the chemical production network. The environmental attributes of the sustainable origin input materials may be determined as described in the context of FIG. 2, FIG. 9 and FIG. 10. Based on the determined environmental attributes, units of token(s) linked to such environmental attributes may be determined and transaction data may be generated for such determined units of token(s) as described in the context of FIG. 2, FIG. 9 and FIG. 10. Upon execution of the transaction associated with such transaction data by a distributed ledger network, units of tokens may be created at or may be assigned to an address associated with the operating system 102 of the chemical production network 104. The units of tokens may be determined based on the amount of respective input material. In the example, the environmental attribute sustainable origin from sustainable palm oil may correspond to 90 units of a sustainable origin token. In this example a simplified weight-based approach is used for illustrative purposes only. Other

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approaches may be based on energy, atom counting such as carbon atoms, molecule counting such as methane, or include losses that occur in production.

The hydrolysis plant 602 may produce fatty acids, which may be further processed and chemically converted. In the illustrative example, 10 kg fatty acid as hydrolysis plant 602 product, 40kg fatty alcohol ethoxylates 1408 and 50kg fatty acid ethoxylates 1410 may be provided to the exit point of the chemical production network. Since for the production of such products 90kg sustainable origin input materials were used, the token units stored in the address associated with operating system 102 may be assigned to such chemical products. For instance, 40 units of the sustainable origin token may be assigned to fatty alcohol ethoxylate, which corresponds to 100% sustainable origin content, and 50 token units of the sustainable origin token may be assigned to fatty acid ethoxylates, which likewise corresponds to 100% sustainable origin content.

For illustration purposes and to further explain the methods for assigning units of tokens from the address to the chemical product identifier as described in the context of FIG. 2 to FIG. 12B, FIG. 15A and FIG. 15B illustrate examples of data structures for assigning units of tokens from the address to the chemical product identifier.

Based on the non-limiting example of FIG. 7A to FIG. 7C bio-based and recycled feedstock may be provided to the steam cracker, converted to the token units of as shown in FIG. 13 and allocated to the address as described in the context of FIG. 2, FIG. 9 and FIG. 10. The address has in this example a balance of 3 units of the recycled token and 5 units of the bio-based token.

For assignment of such token units to the chemical product, the chemical product identifier may be provided. The chemical product identifier may be associated with the chemical product provided to the exit point of the chemical production network. The chemical identifier may relate to the chemical product specification. The chemical identifier may relate to the chemical product specification and the environmental attribute.

As shown in FIG. 15A, the chemical identifier may relate to the chemical product specification polyamide or polystyrene and the environmental attribute 10% recycled or bio-based content. The chemical product identifier may be provided for pre-defined chemical products associated with pre-defined environmental attribute(s). In this embodiment, the number of token units required for the respective chemical products is pre-defined and a further conversion of token units to respective environmental attribute(s) is not required. This way the management of input materials and chemical products with environmental attributes is less dynamic and can be simplified.

As shown in FIG. 15B, in addition to the chemical identifier an environmental attribute identifier may be provided. The chemical identifier may relate to the chemical product specification polyamide or

polystyrene. The chemical product identifier may be provided for pre-defined chemical products. The environmental attribute identifier may relate to the environmental attribute 10% recycled or bio-based content. The environmental attribute identifier may be linked to the chemical product identifier. The environmental attribute identifier may be provided for pre-defined environmental attribute types. For assignment, the token units may be assigned to the environmental attribute identifier and the chemical product identifier as described in the context of FIG. 5A to FIG. 5C. In this embodiment, the number of token units required for the respective chemical products is not pre-defined and can be flexibly assigned. This way chemical products with environmental attributes tailored to customer needs can be provided.

The chemical product identifier may be uniquely linked to the physical entity of the chemical product. In one embodiment, the batch identifier and the order identifier may be provided and/or linked to chemical product identifier. This way the chemical product identifier may be uniquely linked to the physical entity of the chemical product exiting the chemical production network. In other embodiments the chemical identifier may be linked to the physical entity of the chemical product by way of a physical identifier with encoded chemical product identifier and physically connected to the chemical product. For example, a tag or a QR code may be physically connected to the chemical product and the chemical product identifier may be encoded into the tag or QR code. This way the chemical product identifier may be uniquely linked to the physical entity of the chemical product exiting the chemical production network.

For illustration purposes and to further explain the methods for managing units of tokens as described in the context of FIG. 2 to FIG. 12B, FIG. 16 illustrates examples of tokens to manage the allocation and assignment of environmental attributes. Based on the non-limiting example of FIG. 13 bio-based and recycled feedstock may be provided to the steam cracker. Material data related to the bio-based and recycled feedstock and the respective environmental attributes may be provided to operating system 102 configured to determine units of tokens and to generate transaction data for creation of token units or allocation of token units to address of account 228. In the simplest example, the environmental attribute pyrolysis oil from recycled mixed plastics waste may correspond to 3 units of a recycled token and the environmental attribute bio-naphtha from bio-based vegetable oil may correspond to 5 units of a bio-based token. The tokens may be associated with metadata signifying the units, a logo, decimals, the environmental attribute type, the input material type, waste stream type, biomass type. As for example shown in FIG. 16, the tokens may be associated with metadata relating to environmental attribute type recycled or bio-based, input material type pyrolysis oil, bio-naphtha or bio-gas, input material origins tires, mixed plastics waste, vegetable oil or food waste, respectively.

For allocation of the 3 token units and the 5 token units to the address associated with account 228, the metadata of the tokens may be matched with the determined environmental attributes based on the input material data. Once a match in metadata is found the respective token units are allocated to the address. Hence in the example, the 3 token units recycled token may be transferred from an address to the address

of account 228 and the 5 token units bio-based token may likewise be transferred to the address of account 228.

If metadata provided via the environmental attribute associated with the input material does not correspond to any metadata of existing units of tokens, a new token associated with such metadata may be created as described in the context of FIG. 2 to FIG. 12B. Alternatively, or additionally, units of tokens associated with the greatest match in metadata may be transferred. Here greatest may refer to the maximal number of matching metadata points, in particular token metadata points matching at least in part with environmental attribute metadata points. For example, the environmental attribute may provide more metadata than any token. In such a scenario the units of a token with metadata points matching at least in part with metadata points of the environmental attribute may be transferred.

FIG. 17 illustrate examples of attribution rules for attributing at least one environmental attribute to a token.

Possible inbound attribution rules 1 to 5 mapping environmental attributes to tokens are illustrated in FIG. 17. The attribution rule may depend on the environmental attribute type such as recycled input material. The attribution rule may depend on the environmental attribute type such as recycled input material and the input material type such as recycled input material and pyrolysis oil based on plastics waste. The attribution rule may depend on the environmental attribute type such as recycled input material and production chain such as the ethanol production chain. The attribution rule may depend on the environmental attribute type such as recycled input material and the attribution scheme such as mass balance with and without free attribution. The attribution rule may depend on the environmental attribute type such as recycled input material and the chemical product type such as polyurethane.

Based on such attribution rules the environmental attributes registered on entry to the system boundary may be converted to units of token(s) associated with the respective environmental attribute(s). Environmental attribute types may include bio-based, recycled, renewable or the like.

FIG. 18 illustrate examples of attribution rules for assigning or attributing at least one environmental attribute to a chemical product id based on an attribution rule.

Possible outbound attribution rules 1 to 5 mapping units of tokens to a chemical product are illustrated in FIG. 18. The attribution rule may depend on the environmental attribute type such as recycled input material. The attribution rule may depend on the environmental attribute type such as recycled input material and the input material type such as recycled input material and pyrolysis oil based on plastics waste. The attribution rule may depend on the environmental attribute type such as recycled input material and production chain such as the ethanol production chain. The attribution rule may depend on the environmental attribute type such as recycled input material and the attribution scheme such as mass

balance with and without free attribution. The attribution rule may depend on the environmental attribute type such as recycled input material and the chemical product type such as polyurethane.

Based on such attribution rules the units of tokens created at or transferred to the address of account 228 may be assigned to respective chemical products. Environmental attribute types may include bio-based, recycled, renewable or the like.

FIG. 19 illustrate examples of attribution rule instructions for selecting at least one account.

Similar to FIG. 17 and FIG. 18, the input materials are provided to the chemical production network and chemical products are produced by the chemical production network. On registration of the input materials, environmental attributes associated with the input materials are converted to units of tokens as described herein and in the context of FIG. 12A and FIG. 12B.

FIG. 19 illustrates attribution rule instructions configured to select units of token(s). Depending on the chemical product and the input materials such chemical product is produced from different token(s) may be accessible for the chemical product. The input materials may be determined from a bill of materials including the recipe for the production chain up to the chemical product. The production chain may include the input materials that enter the system boundary of the chemical production network at any stage. From the input materials used to produce the chemical product the accessible tokens associated with such input material types may be determined.

For each accessible token, accessible token units may be determined from the address balance and the input material type used to produce chemical product. Such determination may result in one or more tokens being accessible for the chemical product and the target environmental attribute. For example, the target environmental attribute may refer to pyrolysis oil irrespective of the waste stream. The token(s) for pyrolysis oil from different waste streams may hence be accessible. Depending on the respective address balance one or more combinations of token(s) may be accessible. One combination of accessible tokens may be selected for example based on the combination with the highest address balance. This way the environmental attributes required by other stricter target environmental attributes may still be fulfillable.

On providing the chemical product, the token units from the address may be assigned to the chemical product identifier. This way the chemical product can be uniquely associated with the target environmental attribute via the chemical product identifier.

FIG. 20 illustrate examples of attribution rule instructions for the compatibility check of tokens.

Similar to FIG. 17 to FIG. 19, the input materials are provided to the chemical production network and chemical products are produced by the chemical production network. On registration of the input materials

units of token(s) are allocated to the address of account 228 as described herein and in the context of FIG. 12A and FIG. 12B.

FIG. 20 illustrates attribution rule instructions configured to check compatibility between attribution schemes. Depending on the tokens accessible to accommodate the target environmental attribute different attribution schemes may apply. For instance, one token may be associated with a book and claim scheme, while another token may be associated with a segregated scheme. Further for instance, one token may be associated with a mass balance scheme, while another token may be associated with a segregated scheme. Further for instance, one token may be associated with a mass balance scheme with free attribution, while another token may be associated with a mass balance scheme without free attribution. The different attribution schemes may be mutually exclusive. The different attribution schemes may be compatible with each other in the sense that token units associated with a first attribution scheme may be combined with token units associated with a second attribution schemes and vice versa. The different attribution schemes may be compatible with each other in the sense that token units of first token associated with a first attribution scheme may only be combined with token units of a second token associated with a second attribution schemes. A reverse combination may be excluded. Similarly, the attribution rule associated with the target environmental attribute may be compatible or not compatible with the tokens. Compatibility rules specifying the compatibility of different attribution schemes associated with respective tokens may be provided from a data base. Compatibility rules specifying the compatibility of different attribution schemes associated with respective tokens may relate to accounts and/or the target environmental attribute. The target environmental attribute and/or the tokens may include respective metadata specifying the attribution scheme. Depending on such compatibility rules the compatible combination of accessible tokens and/or target environmental attribute may be determined by matching the metadata. This way it can be ensured that the target environmental attribute includes only compatible environmental attributes.

FIG. 21A illustrates an example embodiment of a decentral network environment. The decentral network environment may include a decentral participant network 2130. The decentral participant network 2130 may include one or more decentral network participants 2102 to 2114. The decentral network participants may be part of a product ecosystem including chemical products. The product ecosystem may include production chains to produce an end-product. The product ecosystem may include recycling chains to recycle at least part of an end-of-life product. The product ecosystem may include a raw input material supplier 2104, a chemical product producer 2102, a chemical product consumer 2106, an OEM 2108, an end-product user 2110 an EOL product collector 2112 and a recycler 2114. The decentral participant network 2130 may be a chemical supply chain. The product ecosystem may allow to use materials resulting from recycling of end-of-life products to produce new products, such as chemical products. The product ecosystem may be associated with the production and/or recycling of physical products. The

product may be a chemical product, an intermediate chemical product, a component, a component assembly, an end product, an end-of-life product or a recycled product.

The participant(s) of the decentral participant network 2130 may be associated with the production the product and/or recycling of the product. The decentral network participant 2102 to 2114 may refer to a manufacturer of physical products, such as input material supplier 2104, chemical product producer 2102, chemical product consumer 2106, OEM 2108, a user of physical goods, such as end-product user 2110, and/or a participant of a recycling chain associated with the physical product, such as EOL product collector 2112 and recycler 2114. The decentral network participant may be associated with a decentral participant identifier. The decentral participant identifier may uniquely identify the decentral network participant within the decentral participant network 2130.

The participant(s) of the decentral participant network 2130 may be connected via material flow 2136. The material flow 2136 may correspond to the flow of product from one participant of the decentral participant network 2130 to the downstream participant of the decentral participant network 2130. The material flow 2136 may refer to a continuous or a discontinuous flow of product. The flow of product may include any means of transportation suitable to transport the product from a participant to the downstream participant. The means of transportation may include pipes, containers, barrels, packages. The material flow 2136 may be associated with raw materials used to produce the chemical product, such as virgin raw materials. The raw materials may be provided to the chemical product manufacturer for producing chemical product(s) and/or intermediate chemical product(s) (not shown).

At least part of the participants of the decentral participant network 2130 may be associated with decentral participant network nodes 2116 to 2128. The decentral participant nodes 2116 to 2128 may be under control of the respective decentral participant associated with the respective decentral participant node. The decentral participant nodes 2116 to 2128 may form decentral network 2134. The decentral network 2134 may be a peer-to-peer communication network. The decentral network 2134 may be configured to perform data transactions 2132. The data transactions 2132 may be based on a transaction protocol including authentication and/or authorization mechanism(s). Based on the authentication and/or authorization mechanism(s) a peer-to-peer communication between decentral network nodes 2116 to 2128 associated with decentral network participants 2102 to 2114 may be established. The one or more authentication mechanism(s) may be associated with or linked to a decentral identifier as described in the context of FIG. 21B. The one or more authentication mechanism(s) associated with the decentral identifier may be accessible by a decentral data providing network node and/or a decentral data consuming network node as described in the context of FIG. 21B. The decentral configuration allows for more efficient use of computing resources and strengthens control by the data owners of the decentral network.

Data transactions between decentral network participant nodes may be based on a decentral identifier associated with respective product data to be accessed, for example as described in the context of FIG. 21B. The decentral identifier may be uniquely associated with the physical entity of the product and associated product data. The decentral identifier may uniquely identify the respective product within the decentral network. The decentral identifier may be associated with further decentral identifier(s), such as decentral identifier(s) of product(s) used to produce the product. This may allow to track the product(s) used to produce a product, such as an end-product. The decentral identifier may be included in a digital access element associated with the product, for example as described in the context of FIG. 21B.

The data flow 2132 (e.g. transactions) between decentral network participant nodes may be directly or indirectly associated with the material flow 2136 between the decentral network participants. For instance, data flow 2132 may be directly associated with material flow 2136 if data associated with an input material provided from the input material supplier 2104 to the chemical product producer 2102 is accessed by a decentral data consuming network node associated with said chemical product producer 2102. For instance, data flow 2132 may be indirectly associated with material flow 2136 if data associated with a chemical product produced by chemical product producer 2102 is accessed by a decentral data consuming network node associated with recycler 2114.

The decentral participant nodes 2116 to 2128 may be decentral computing nodes. The decentral computing node may be any device or system that includes at least one physical and tangible processor, and a physical and tangible memory capable of having thereon computer-executable instructions that are executed by a processor. The memory may take any form and depends on the nature and form of the computing node.

At least part of the decentral participant nodes 2116 to 2128 may be decentral data providing network nodes. At least part of the participant nodes 2116 to 2128 may be decentral data consuming network nodes. A participant of the decentral participant network 2130 may be associated with a decentral data providing network node and/or a decentral data consuming network node depending on whether data is provided to downstream participants and/or consumed from upstream participants. For instance, input material supplier 2104 may be associated with a decentral data providing network node configured to provide input material data to a downstream participant (e.g. chemical product producer 2102) for example as described in the context of FIG. 21B. In addition to or alternatively, chemical product producer 2102 may be associated with a decentral data consuming network node configured to access data associated with a recycled input material produced by an upstream participant (e.g. recycler 2114).

The decentral network 2134 may include further decentral network nodes. The further decentral network nodes may be decentral infrastructure service nodes (not shown in FIG. 21A). The decentral infrastructure service nodes may not be associated with a participant of the product ecosystem. The decentral infrastructure service nodes may provide services for decentral participant nodes 2116 to 2128, such as

verifying the identity of the decentral network participant nodes 2116 to 2128 prior to performing a data exchange. The decentral network participant nodes 2116 to 2128 may be associated with or include certificate(s), such as X.509 certificate(s). The certificate(s) may be associated with decentral infrastructure service node(s) including e.g. a certificate issuing service and/or a dynamic provisioning service providing dynamic attribute tokens (e.g. OAuth Access Tokens). This way the decentral network participant nodes 116 to 124 possess a unique identifier embedded in a X.509 certificate that identifies the respective decentral network participant node 2116 to 2128. The information required to verify the certificate may be provided via an authentication registry associated with the certificate issuing service and/or a dynamic provisioning service. For instance, in the IDSA Reference Architecture Model, Version 3.0 of April 2019, a decentral data providing network node associated with a data owner, a Certification Authority (CA), a Dynamic Attribute Provisioning Service (DAPS) and a decentral data consuming network node associated with a data consumer are used to verify the identity prior to performing a data exchange (not shown).

FIG. 21B illustrates an exchange of input material data associated with input material provided to a chemical production network via a decentral peer-to-peer network. Access to the input material data twin data may be requested by a decentral data consuming service associated with a participant of the decentral network 2130 (see FIG. 21A). The participant may be a chemical product producer 2102 receiving input materials from an input material supplier 2104 and/or a recycler 2114 (see FIG. 21A). The input material 202 may be associated with a digital twin including input material data. The digital twin may include a decentral identifier and input material data. The input material data may comprise one or more environmental attributes associated with the input material. For instance, input material, such as pyrolysis oil, received from recycler 2114 may be associated with the environmental attribute "recycled" and waste type "tires". The environmental attribute "recycled" and the waste type "tires" may be contained within the input material data. The input material may be associated with a digital access element generated upon or after production of the input material. The digital access element may be associated with the digital twin or the part thereof. The digital access element may contain a decentral passport identifier and digital twin location data. The decentral passport identifier may correspond to or be associated with the decentral identifier of the digital twin. The digital twin location data may include digital representation(s) pointing to the digital twin or parts thereof. The digital access element may further include or relate to authentication and/or authorization information linked to the decentral passport identifier. The authentication and/or authorization information may be provided for authentication and/or authorization of the decentral data providing network node 2118 and/or the decentral data consuming network node 2116. The digital access element may be provided to a decentral registry 2150. Decentral registry 2150 may store decentral passport identifier(s) and associated digital twin location data.

The input material 202 as produced by input material supplier 2104 and/or recycler 2114 may be provided in association with the digital access element to chemical product producer 2102. The chemical product

producer 2102 may process the input material to produce further chemical products, for example as described in the context of FIG. 2. The input material 202 may be connected to a code, such as a bar code or QR-code, having encoded the decentral passport identifier. The chemical product producer 2102 may read the code through a code reader 2138. The code reader 2138 may be a smartphone running a code reading application, such as a QR code reader app. The data obtained by the code reading application may be used to determine the decentral passport identifier. The data obtained by the code reading application may be used to determine the decentral identifier. The data obtained by the code reading application may be used to determine the input material identifier. The data obtained by the code reading application may be used to determine the digital twin location data. The decentral passport identifier, decentral identifier, input material identifier and digital twin location data may be determined by code reader 2138. For instance, the decentral passport identifier determined by the code reader 2138 may be a DID and the code reader 2138 may be configured to retrieve the associated DID document containing the decentral digital twin identifier and the digital twin location data, for example using a DID resolver. In another instance, the input material identifier is determined by code reader 2138 and used to retrieve the decentral passport identifier and associated digital twin location data, for example from a database, decentral registry 2150. Hence, code reader 2138 may be configured to retrieve the digital access element containing the decentral passport identifier and digital twin location data from decentral registry 2150. Code reader 2138 may be configured to provide the decentral passport identifier and/or the decentral identifier to a database, such as database 218, associated with chemical product producer 2102. Code reader 2138 may be configured to provide the determined decentral passport identifier, decentral identifier and digital twin location data to decentral data consuming network node 2116.

Code reader 2138 may be configured to display determined/retrieved data on a user interface as illustrated by reference sign 2140. The user interface may display the determined decentral passport identifier (PP identifier), the determined decentral identifier (DT identifier) and the determined digital twin location data (DT location). In this embodiment, the decentral passport identifier and the decentral identifier differ from each other. In another embodiment, the decentral passport identifier is equal to the decentral identifier. The user interface may further display the determined input material identifier (IP identifier). The user interface may also allow to initiate retrieval of the digital twin or a part thereof based on the decentral passport identifier and the digital twin location data as described in the following. This process may be initiated by the button denoted "Access DT". Upon pressing said button, code reader 2138 may send a request to access the digital twin or the part thereof to decentral data consuming network node 2116.

Decentral data consuming network node 2116 may generate a request to access the digital twin data. Decentral data consuming network node 2116 node may generate the request based on the data received from code reader 2138. For instance, decentral data consuming network node 2116 may generate the request based on the decentral digital twin identifier received from code reader 2138. Decentral data

consuming network node 2116 may generate the request based on the decentral passport identifier and/or decentral identifier provided to database 218. For example, decentral data consuming network node 2116 may be configured to retrieve the decentral identifier and digital twin location data from decentral registry 2150 based on the decentral passport identifier stored in database 218. The request generated by decentral data consuming network node 2116 may include the decentral identifier and the decentral participant identifier of the chemical product producer 2102 associated with decentral data consuming network node 2116. The request may include one or more actions to be performed on the digital twin data. Decentral data consuming network node 2116 may be configured to determine the decentral data providing network node 2118 associated with the digital twin based on the digital twin location data provided by code reader 2138 or retrieved from decentral registry 2150.

Decentral data consuming network node 2116 may sent the request to access the digital twin data to the determined decentral data providing network node 2118 as signified by arrow 2142. The decentral data providing network node 2118 may be associated with the input material supplier 2104. The decentral data providing network node 2118 may be associated with recycler 2114. The decentral data providing network node 2118 may be associated with the chemical production producing the input material. The decentral data providing network node 2118 may be associated with the data owner of the digital twin. In addition to the request, authentication and/or authorization information may be provided by decentral data consuming network node 2116.

The request may be authenticated. Access to the input material data may be authorized based on access policy data associated with the input material data. This allows to filter decentral data consuming network nodes requesting access based on the decentral participant identifier(s) associated with said network nodes and requested actions to be performed on the accessed data. If the request is not authorized, e.g. if decentral data consuming network node 2116 is not authorized to access the digital twin data, the peer-to-peer communication channel will be terminated by decentral data providing network node 2118 and no input material data will be provided.

If the request is authorized, decentral data providing network node 2118 may initiate contract negotiations with decentral data consuming network node 2116 prior to providing input material data. Decentral data providing network node 2118 may provide an electronic contract to decentral data consuming network node 2116. The electronic contract may include one or more authorization rule(s) associated with the decentral identifier. This allows the data consumer to determine access and usage conditions associated with the desired data. Decentral data providing network node 2118 and decentral data consuming network node 2116 may be configured to negotiate an electronic contract and to sign the negotiated electronic contract. Use of the electronic contract ensures that the decentral data consuming network node and further systems handling the digital twin are complying to one or more authorization rule(s) associated with the digital twin. Upon signature of the electronic contract, input material data may be gathered and

access rights may be applied to the gathered data as signified by arrows 2144 and 2146. The input material data resulting from applying access rights to gathered input material data may be provided by decentral data providing network node 2118 to decentral data consuming network node 2116 as signified by arrow 2148.

- 5 The input material data provided by decentral data providing network node 2118 may be stored in database 218 associated with the decentral data consuming network node 2116 according to the access data as signified by arrow 2154.

Through the decentral identifier, input material data can be uniquely associated with the input material. Through the decentral network, the digital twin or a part thereof may be transferred between input material
10 supplier 2104 and/or recycler 2114 and chemical product producer 2102 in a standardized and secure way, allowing input material supplier 2104 and/or recycler 2114 to control access to the input material data by multiple decentral data consuming network nodes existing within the decentral network. This way, the input material data including environmental attributes can be shared with unique association to the input material and without central intermediary directly between the participants of the product ecosystem
15 2130. This allows for transparency of digital twins and standardized and secure sharing of environmental attributes within the product ecosystem 2130.

FIG. 22A illustrates a further example of a participant network of a product ecosystem associated with a decentral peer-to-peer network for exchange of environmental attributes associated with produced products. The participant network may be a decentral participant network 2216. The decentral participant
20 network 2216 may include one or more decentral network participants 2104 to 2114. The decentral network participants may be part of a product ecosystem including chemical products as described in the context of FIG. 21A.

The participant(s) of the decentral participant network 2216 may be associated with the production the product and/or recycling of the product. The decentral network participant 2104 to 2114 may refer to a
25 manufacturer of physical products, a user of physical goods and/or a participant of a recycling chain associated with the physical product, such as described in the context of FIG. 21A. The decentral network participant may be associated with an account of distributed ledger network 224. Each account may be associated with at least one unique address. The account and hence also the address may uniquely identify the decentral network participant within the decentral participant network 2216.

- 30 The participant(s) of the decentral participant network 2216 may be connected via material flow 2220 as described in the context of FIG. 21A.

At least part of the participants of the decentral participant network 2216 may be associated with decentral participant network nodes 2202 to 2214. The decentral participant nodes 2202 to 2214 may form

distributed ledger network 224. Distributed ledger network 224 may be a peer-to-peer network. The peer-to-peer network may not comprise a central instance and/or third party organization. Each node 2202 to 2214 of peer-to-peer network 224 and/or each participant 2104 to 2114 may be connectable at least to every other node of peer-to-peer network 224 and/or participant of decentral participant network 2216.

5 For instance, at least one physical standard network (wired and/or wireless) may be used for connection. For communicating via the at least one physical standard network suitable transceiver modules may be arranged in the respective entities/devices. Nodes 2202 to 2214 may have equal rights which may distinguishes them from a server-client structure.

Nodes 2202 to 2214 may comprise a peer-to-peer application. The same peer-to-peer application may be implemented on each node 2202 to 2214, e.g. each node may comprise the same content and the same code (including one or more executable means) may be executed on each node. The peer-to-peer application may preferably be a distributed ledger, such as a blockchain. The distributed ledger may be inspected by all participants 2104 to 2114 of the peer-to-peer network 224. In one example, each of nodes 2202 to 2214 may store the (entire) distributed ledger, such as the blockchain. In another example,

15 only part of the distributed ledger may be provided on a node (light node).

The peer-to-peer application may be configured to create token(s) linked to environmental attribute(s) associated with input materials. The peer-to-peer application may be configured to transfer token(s) linked to environmental attribute(s) associated with input materials between participants of the decentral network 2216.

Participants 2104 to 2114 may run a peer-to-peer application on nodes 2202 to 2214. At least part of the participants 2104 to 2114 may be connected with peer-to-peer network 224 via peer-to-peer modules. The peer-to-peer module may be configured to communicate at least with the peer-to-peer network 224, i.e. the nodes 2202 to 2214 of the peer-to-peer network 224. Hence, the peer-to-peer modules may be a participant of the peer-to-peer network 224. The peer-to-peer module may not comprise the peer-to-peer application. Such a peer-to-peer module may be configured to provide access to the peer-to-peer application, e.g. via an API (application programming interface). Such a peer-to-peer module (also a node or light node) may comprise a decentral application and at least an API. Hence, such a peer-to-peer module may have access or may be connected to a "gateway" running a node, such as node 2202 to 2214, of the peer-to-peer network (so called remote node). The peer-to-peer module may be configured to generate transaction data, for example as described in the context of FIG. 2 and FIG. 5A to FIG. 5C. The peer-to-peer module may be configured to sign the generated transaction data, for example with a private key associated with the respective participant of network 2216. The peer-to-peer module may be configured to provide generated transaction data to peer-to-peer network 224 for processing. The peer-to-peer module may be configured to query peer-to-peer network 224 for data. For instance, the peer-to-peer module may be configured to retrieve data from peer-to-peer network 224, such as token units

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stored in one or more addresses associated with the peer-to-peer module (e.g. addresses of the respective participant running the peer-to-peer module).

The peer-to-peer network 224 may be configured to perform data transactions 2218. Such data transactions 2218 may be associated with material flows 2220 between participants of the decentral participant network 2216. Data transactions 2218 may include data transactions between peer-to-peer modules and the peer-to-peer network 224. For instance, peer-to-peer modules may be configured to generate transaction data and provide the generated transaction data to peer-to-peer network 224. The transaction data may be associated with the creation of one or more token(s) as described in the context of FIG. 2 and FIG. 5A. The transaction data may be associated with the transfer of token units as described in the context of FIG. 5B and FIG. 5C. Data transactions 2218 may include data transactions between peer-to-peer nodes 2202 to 2214. For instance, a data transaction received by a node of peer-to-peer network 224 may be broadcasted to at least part of the other nodes of peer-to-peer network 224. Each transaction provided to peer-to-peer network 224 may contain a signature. For instance, the transaction data may be signed using a private key associated with the respective participant of network 2216. Prior to processing a transaction, the transaction may be validated by checking the signature of the transaction for example by comparing the signature with valid signatures stored e.g. in the peer-to-peer application. A part of nodes 2202 to 2214 may conduct the validation process. If the transaction is valid, it may be further processed, for example it may be included in a further block of the blockchain. It shall be understood that other means than signatures (e.g. communication addresses, certificates, etc.) may be used for a validation process or authentication process, respectively.

The peer-to-peer application may be a block chain. However, the following remarks can be easily transferred to other peer-to-peer applications, such as a Directed Acyclic Graph (DAG). A directed acyclic graph, such as IOTA or Tangle, means that blocks (or nodes of the graph) are coupled to each other via directed edges. Thereby, direct means that the (all) edges have (always) a same direction similar to time. In other words, it is not possible to step back. Eventually, acyclic means that loops do not exist.

The block chain may be a permissionless or permissioned block chain. The block chain may be a public, a consortium or a private block chain. The peer-to-peer application may be formed with multiple block chains which are connected via mechanisms, such as side chains or smart contracts. Interoperability among block chains may be established.

The block chain may be formed by at least two interconnected blocks. The first block may also be called genesis block. Each block (except for the first block) may refer to each previous block. A new block may be created by a computationally intensive process (for example, so called "mining" or through another appropriate process, such as voting) and will be particularly provided to all nodes 2202 to 2214 of the peer-to-peer network.

The block chain may be configured to receive transactions, such as transactions associated with creation of token(s) linked to environmental attributes associated with input materials and/or transactions associated with the transfer of token units linked to such environmental attributes. The transactions may be received from a peer-to-peer module as previously described. The block chain may be configured to validate received transactions. The block chain may be configured to save transactions, such as validated transactions, in new blocks of the block chain. For instance, the new block may be appended to existing blocks of the block chain. The block chain may at least be configured to control and manage environmental attributes associated with input materials, for example as described in the context of FIG. 2, FIG. 5A, FIG. 5B and FIG. 5C.

In particular, a (newly) received transaction may be validated, saved and published in the current block of the block chain. The published transaction may be ready by at last part of the participants of the peer-to-peer network. Alternatively or additionally, data of a transaction may be stored in a registry storage e.g. on a decentral file service or distributed block chain database controlled by the block chain.

Only a part of the entire nodes of peer-to-peer network 224 may be configured to store the peer-to-peer application and/or only a part of the nodes of peer-to-peer network 224 may be configured to execute the algorithms of a smart contracts. Since the validation/verification requires a considerable computational effort, it may be advantageous for reasons of efficiency, if only a part of the nodes 2202 to 2214 perform the execution of executable means and/or validation algorithm(s) and/or authentication algorithm(s).

Validation, analytics and optimization may be done on-chain or off-chain, as described hereinbefore. Off-chain validation, analysis and/or optimization can be managed by the peer-to-peer application, like the code on the block chain. Powerful means, in particular, a high computing power. In other words, a valid entry in the peer-to-peer application, such as a block chain, is assumed if (only) a part of the peers 2202 to 2214 come to a positive result. It shall be understood that only a single, especially particularly powerful peer can perform the validation, analytics and/or optimization process while further nodes may be configured as monitoring nodes.

Similarly, in a further (not shown) embodiment, a particularly large peer-to-peer network may be divided in two or more clusters. In a corresponding peer-to-peer network, for example, a validation may only be carried out by the members of one cluster (e.g. sharding of a block chain to improve the scalability). In a further embodiment, the peer-to-peer application may be formed using multiple block chains. These block chains are connected via frameworks such as sidechains or smart contracts or interledger.

FIG. 22B illustrates an exchange of token(s) linked to environmental attributes and being associated with a chemical product provided by the chemical production network to a chemical product consumer via a decentral peer-to-peer network.

The input material supplier 2104 may provide the input materials such as bio-gas or pyrolysis oil. The environmental attributes of the input material may be provided through the data providing service connected to the decentral network as described in the context of FIG. 21A and FIG. 21B. The chemical product producer 2102 may produce the chemical product from the input material(s) provided to the chemical production network. The input material supplier 2104 may access the environmental attributes associated with the input material through a data consuming service connected to the decentral network as described in the context of FIG. 21B. The chemical product producer may manage the environmental attributes via token(s) linked to such environmental attributes as described in the context of FIG. 2 to FIG. 12B. The chemical product producer may assign units of tokens linked to environmental attributes associated with the input materials or associated with the chemical production network such as the carbon footprint, to the chemical products as described in the context of FIG. 2 to FIG. 12B. Linking of units of the token to the chemical product identifier of the polyamide may include generating a non-fungible token, for example as described in the context of FIG. 5A and FIG. 13. The non-fungible token may be generated by a third party on behalf of the entity operating the chemical production network producing the polyamide (see for example FIG. 5A). The non-fungible token may comprise data, such as NFT data 2232. The NFT data 2232 may be recorded in the distributed ledger and may include the chemical product identifier, a batch ID, an order ID and the environmental attribute (e.g. 10% recycled). The NFT data 2232 may be linked with further metadata, for example via a pointer contained in the NFT data 2232 (not shown). Such further metadata may be stored off-chain. Such further metadata may include a code printed on the packaging of the chemical product. Such metadata may include safety data sheets and/or technical data sheets and or further documents associated with the transport of a chemical product. Such further metadata may be accessed via the NFT.

The non-fungible token may be owned by chemical product producer 2102 as signified by a transaction creating said NFT at the address associated with chemical product producer 2102 or transferring said NFT to the address associated with the chemical product producer 2102. The transaction may be stored in a block of the peer-to-peer network 224.

The chemical product 244 as produced by chemical product producer 2102 may be provided in association with the NFT to chemical product producer 2102. Upon providing the chemical product 244 to chemical product consumer 2106, chemical product producer 2102 may generate transaction data to transfer to NFT associated with said chemical product 244 to chemical product consumer 2106. The transaction data may be generated by a peer-to-peer module associated with chemical product producer 2102. The transaction data may include the address associated with the chemical product consumer 2106 as well as data being indicative of the NFT to be transferred. The transaction data may be signed by a private key associated with chemical product producer 2102. The transaction data may be provided to the peer-to-peer network 224, such as node 2202. Peer-to-peer network 224 may validate the received transaction as described in the context of FIG. 22A. Peer-to-peer network 224 may store the received

transaction in a new block of the block chain. Upon storing the received transaction in a new block of the block chain, ownership of the NFT has been transferred from chemical product producer 2102 to chemical product consumer 2106.

In the example of FIG. 22B an NFT may be generated by the OEM 2108 for the produced end product. Such NFT may be provided to further participants of the product ecosystem, such as product end-product user 2110. The end product specific NFT may contain one or more environmental attribute(s) associated with the end product. The one or more environmental attribute(s) associated with the end-product may at least in part be derived from environmental attribute(s) associated with the chemical product(s) used to produce the end-product. Hence, the NFT associated with the end-product may be linked to the NFT associated with chemical product 244.

This way the environmental attributes of input materials, chemical products and any products produced from chemical products may be tracked through the value chain up to the end product. By tracking the environmental attributes of materials in such way the information can be made transparent across the value chain while the information flow can be controlled by the participants in the supply chain. Overall, such tracking enables tracking of positive environmental impact by individual supply chain participants, which makes positive environmental impacts transparent and attributable to individual supply chain participants.

The present disclosure has been described in conjunction with preferred embodiments and examples as well. However, other variations can be understood and effected by those persons skilled in the art and practicing the claimed invention, from the studies of the drawings, this disclosure and the claims.

Any steps presented herein can be performed in any order. The methods disclosed herein are not limited to a specific order of these steps. It is also not required that the different steps are performed at a certain place or in a certain computing node of a distributed system, i.e. each of the steps may be performed at different computing nodes using different equipment/data processing.

As used herein “determining” also includes “initiating or causing to determine”, “generating” also includes “initiating and/or causing to generate” and “providing” also includes “initiating or causing to determine, generate, select, send and/or receive”. “Initiating or causing to perform an action” includes any processing signal that triggers a computing node or device to perform the respective action.

In the claims as well as in the description the word “comprising” does not exclude other elements or steps and the indefinite article “a” or “an” does not exclude a plurality. A single element or other unit may fulfill the functions of several entities or items recited in the claims. The mere fact that certain measures are recited in the mutual different dependent claims does not indicate that a combination of these measures cannot be used in an advantageous implementation.

Any disclosure and embodiments described herein relate to the methods, the systems, devices, the computer program element lined out above and vice versa. Advantageously, the benefits provided by any of the embodiments and examples equally apply to all other embodiments and examples and vice versa.

All terms and definitions used herein are understood broadly and have their general meaning.

- 5 Any disclosure and embodiments described herein are mere examples for implementing the method, the system or application device disclosed herein and shall not be considered limiting.

CLAIMS

1. A computer-implemented method for attributing at least one environmental attribute associated with an input material to one or more chemical products(s), wherein the one or more chemical products(s) are produced by a chemical production network using the input material(s), wherein the chemical production network chemically converts input materials via chemical intermediates to chemical products that exit the chemical production network, the method comprising:
- 5
- providing input material data associated with the input material to an operating system of the chemical production network;
 - determining environmental attributes associated with the input material based on the provided input material data;
 - 10 - creating one or more token(s) linked to at least one determined environmental attribute at an address associated with a distributed ledger network, wherein the address is associated with the operating system of the chemical production network;
 - providing a chemical product identifier associated with the chemical product and optionally at least one target environmental attribute;
 - 15 - based on the chemical product identifier and optionally the target environmental attribute, selecting at least one attribution rule for attributing token(s) linked to one or more environmental attributes(s) associated with input material(s) to chemical product(s);
 - determining via the at least one attribution rule units of token(s) linked to one or more environmental attribute(s); and
 - 20 - assigning the determined units of token(s) linked to the one or more environmental attribute(s) to the chemical product identifier.
2. A computer-implemented method for attributing at least one environmental attribute associated with an input material to one or more chemical products(s), wherein the one or more chemical products(s) are produced by a chemical production network using the input material(s), wherein the chemical production network chemically converts input materials via chemical intermediates to chemical products that exit the chemical production network, the method comprising:
- 25
- providing input material data associated with the input material to an operating system of the chemical production network;
 - 30 - determining environmental attributes associated with the input material based on the provided input material data;
 - based on the determined environmental attributes, determining at least one address associated with a distributed ledger network and holding units of token(s) linked to one or more of the determined environmental attribute(s);
 - 35 - allocating units of at least one of the token(s) to a further address associated with the operating system of the chemical production network;

- providing a chemical product identifier associated with the chemical product and at least one target environmental attribute;
 - based on the chemical product identifier and the target environmental attribute, selecting at least one attribution rule for attributing token(s) linked to one or more environmental attributes(s) associated with input material(s) to chemical product(s);
 - determining via the at least one attribution rule at least one address holding units of token(s) linked to one or more environmental attribute(s); and
 - assigning units of at least one of the tokens linked to the one or more environmental attribute(s) to the chemical product identifier.
3. The computer-implemented method of claim 1 or 2, wherein determining the environmental attributes associated with the input material comprises determining the amount of the input material.
4. The computer-implemented method of claim 1 or 3, wherein determining the environmental attributes associated with the input material further comprises determining a value associated with the input material.
5. The computer-implemented method of any one of claims 1 to 4, wherein the token(s) decouple the material flow of the input material(s) through the chemical production network from the environmental attributes associated with said input materials.
6. The computer-implemented method of any one of claims 1 to 5, wherein the environmental attributes associated with the input material are determined via a virtual production process.
7. The computer-implemented method of any one of claims 1 to 6, wherein creating one or more token(s) linked to at least one determined environmental attribute at an address associated with the distributed ledger network includes creating transaction data including at least one of the determined environmental attributes, a token symbol, the token supply, the token decimals, the address associated with the operating system or a combination thereof, and providing the created transaction data to the distributed ledger network.
8. The method of any one of claims 1 to 7, wherein assigning units of the at least one of the tokens to the chemical product identifier comprises generating transaction data and providing the generated transaction data to a distributed ledger for creating one or more further token(s) specifying retired units of the token(s), the one or more environmental attributes linked to the token(s) and the provided chemical product identifier.
9. The computer-implemented method of any one of claims 1 to 8, wherein the chemical product identifier is associated with a product specification for the chemical product

10. The computer-implemented method of claim 1, further comprising providing multiple input material(s) associated with one or more environmental attribute(s) to the chemical production network, including a first input material and a second input material.
11. The computer-implemented method of claim 10, wherein providing input material data associated with the input material further comprises:
- providing a first input material data associated with the first input material; and
 - providing a second input material data associated with the second input material.
12. The computer-implemented method of claim 11, further comprising:
- providing units of token(s) associated with the one or more environmental attribute(s) of the first input material and the second input material, wherein the units of token(s) are stored in an address associated with a distributed ledger network and wherein the address is associated with an operating system of the chemical production network.
13. The computer-implemented method of claim 12, wherein assigning or attributing the one or more environmental attribute(s) to the chemical product identifier comprises creating on the distributed ledger a digital asset that includes the chemical product identifier and the one or environmental attribute(s) associated with the units token(s).
14. An apparatus for assigning or attributing at least one environmental attribute associated with input material(s) to one or more chemical product(s), wherein the one or more chemical products(s) are produced by a chemical production network using the input material(s), wherein the chemical production network chemically converts input materials via chemical intermediates to chemical products that exit the chemical production network, the apparatus comprising:
- an environmental attribute determination module configured to
 - receive input material data associated with the at least one input material and
 - determine environmental attributes associated with the at least one input material;
 - a distributed ledger application configured to create one or more token(s) linked to at least one determined environmental attribute at an address associated with the distributed ledger, wherein the address is associated with an operating system of the chemical production network,
 - an attribution module configured to provide at least one attribution rule for attributing token(s) linked to one or more environmental attributes(s) associated with input material(s) to chemical product(s);
 - a data provider configured to provide at least one chemical product identifier associated with the chemical product and at least one target environmental attribute for the chemical product; and
 - an outbound allocator configured to

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- select based on the chemical product identifier and the target environmental attribute at least one attribution rule,
- determine via the at least one attribution rule at least one address holding units of token(s) linked to one or more environmental attribute(s), and
- assign units of at least one of the tokens linked to the one or more environmental attribute(s) to the chemical product identifier.

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15. The apparatus of claim 14, wherein the environmental attribute determination module is further configured to

- determine an amount of the input material; and/or
- determine a value associated with the input material.

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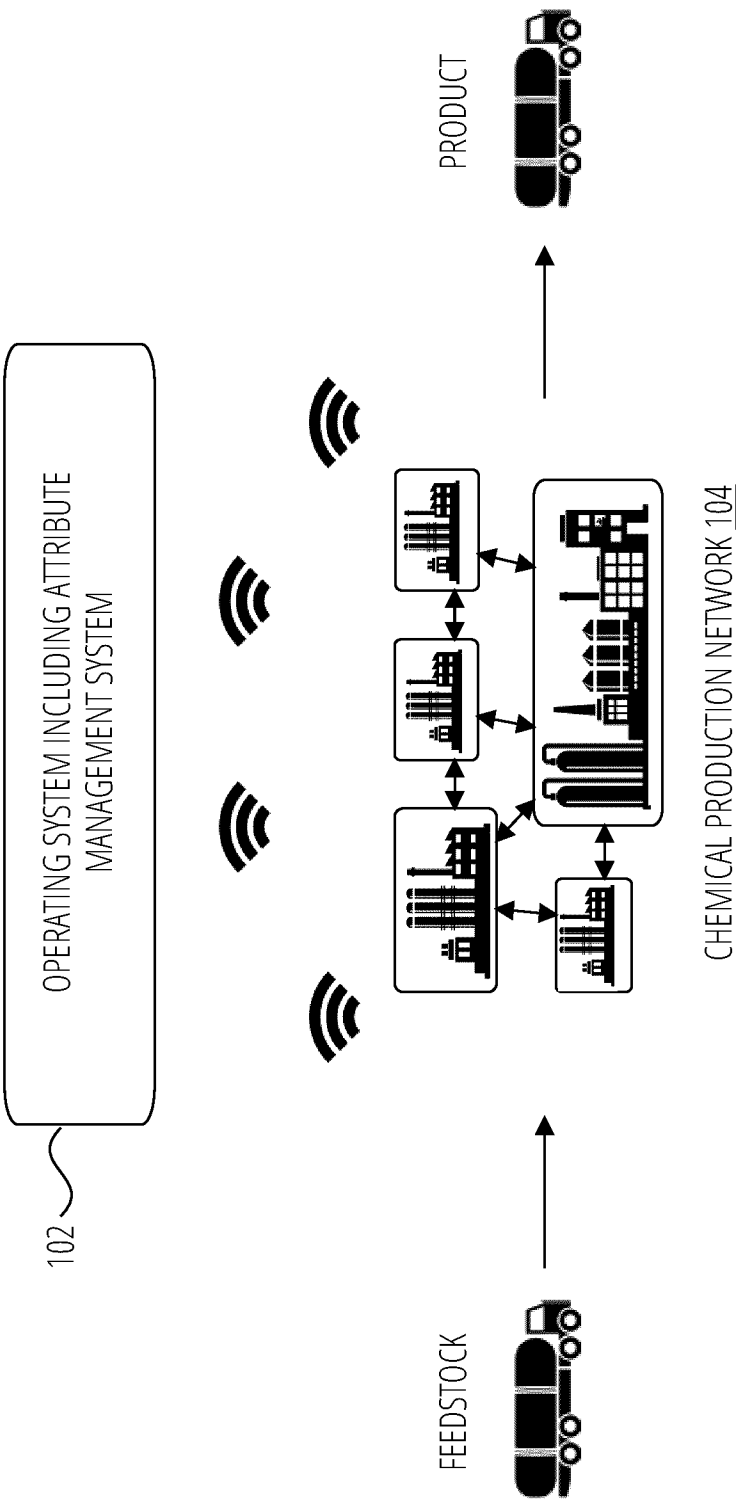


FIG. 1

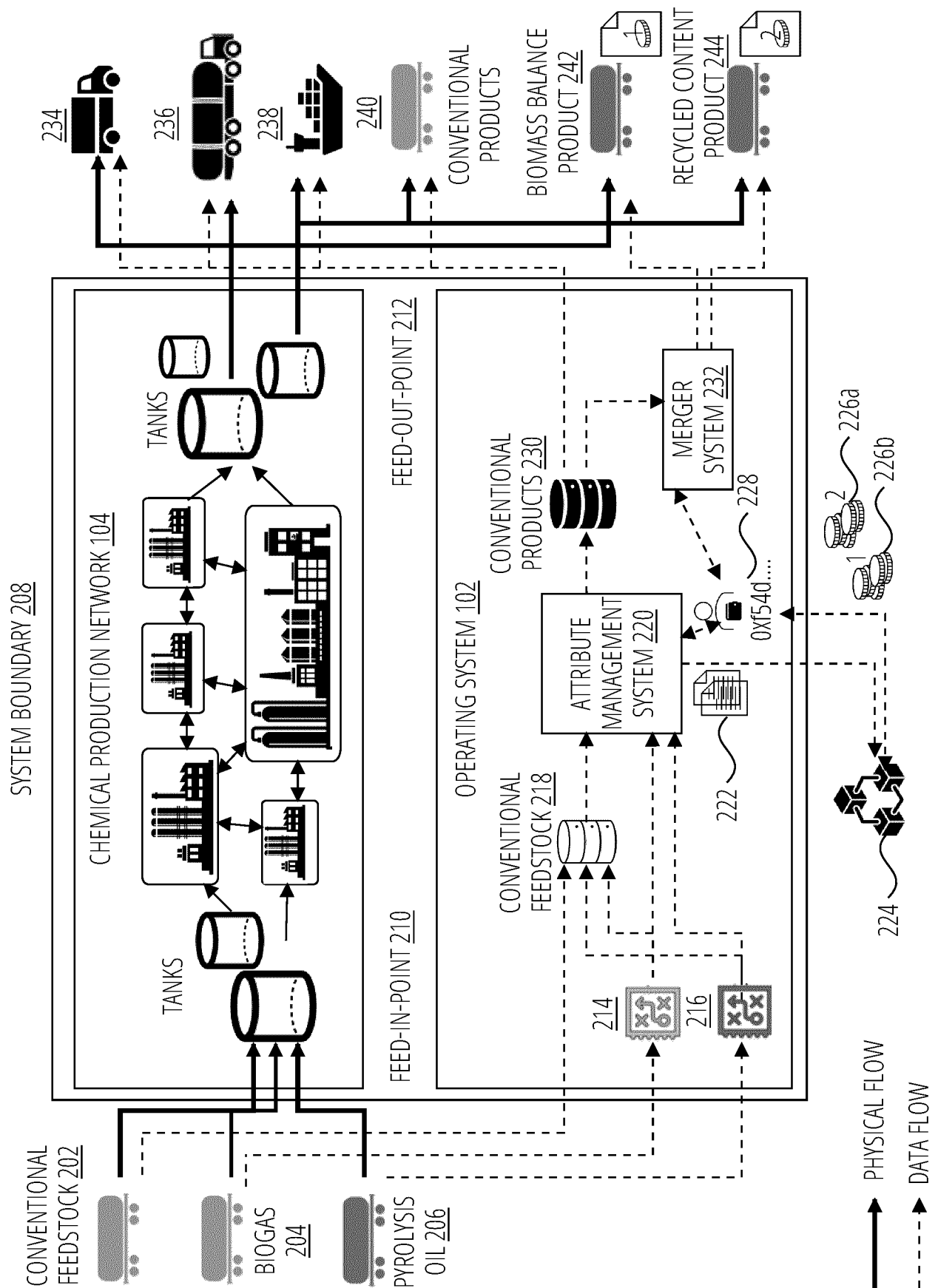


FIG. 2

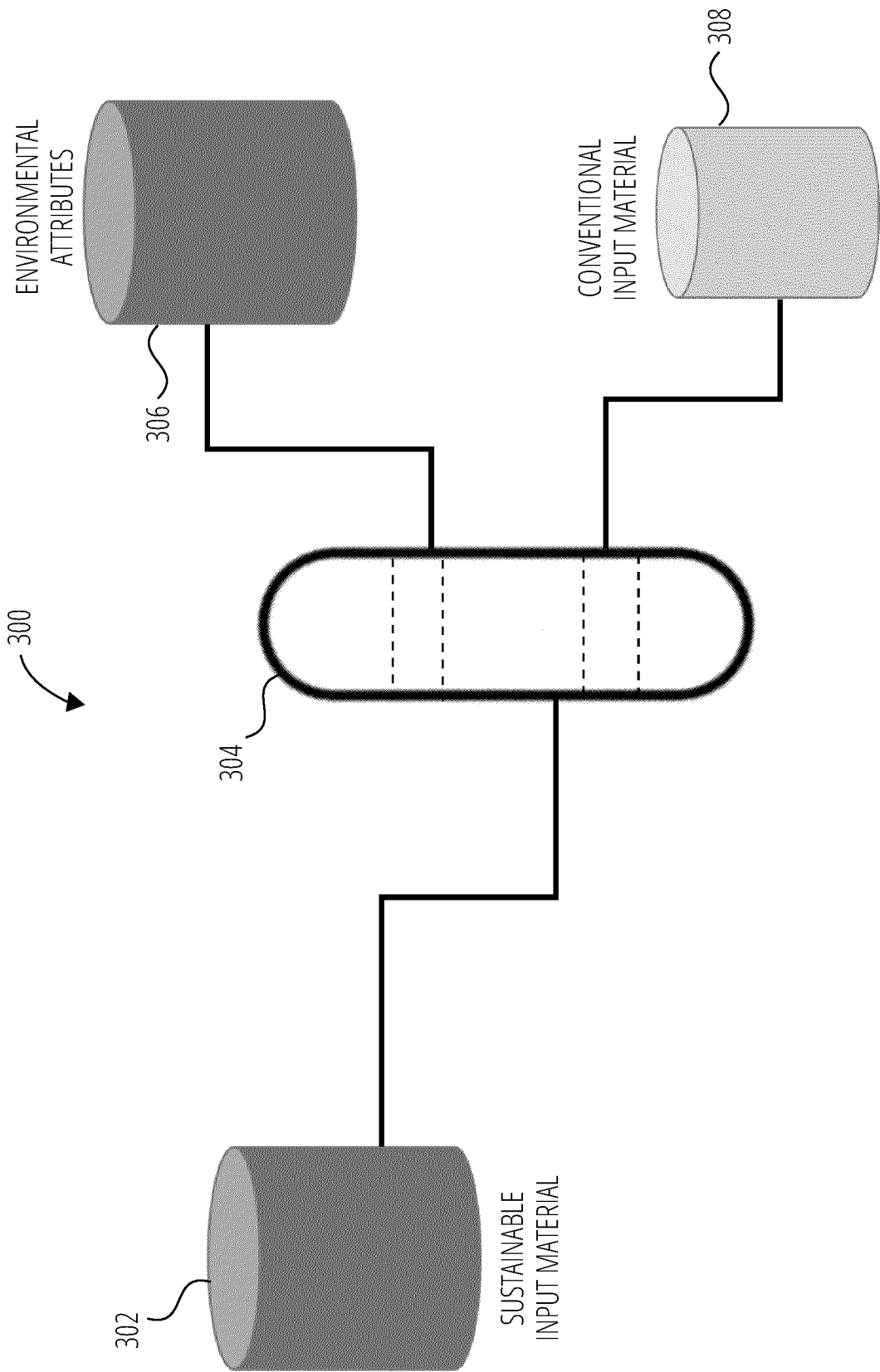


FIG. 3

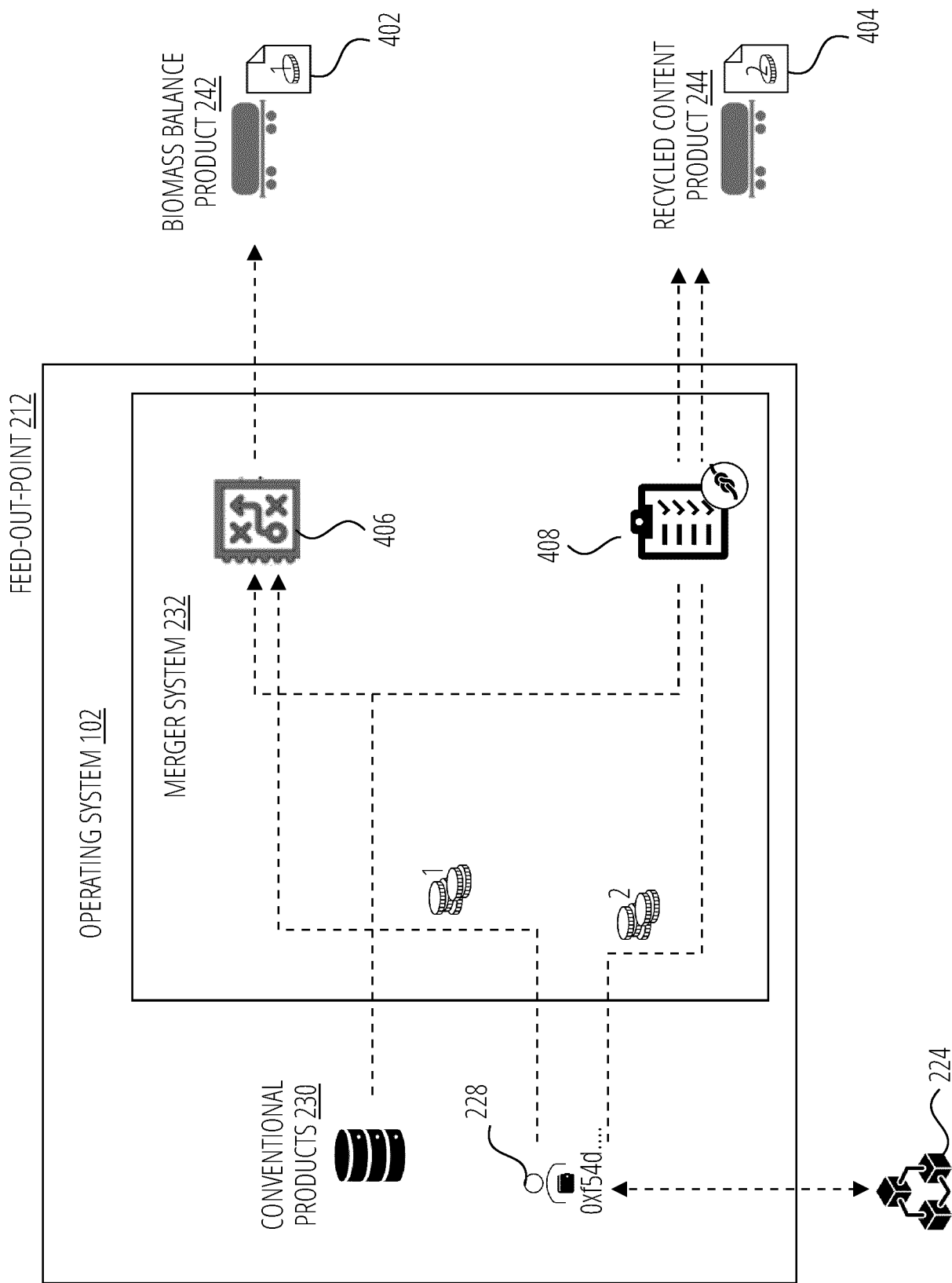


FIG. 4

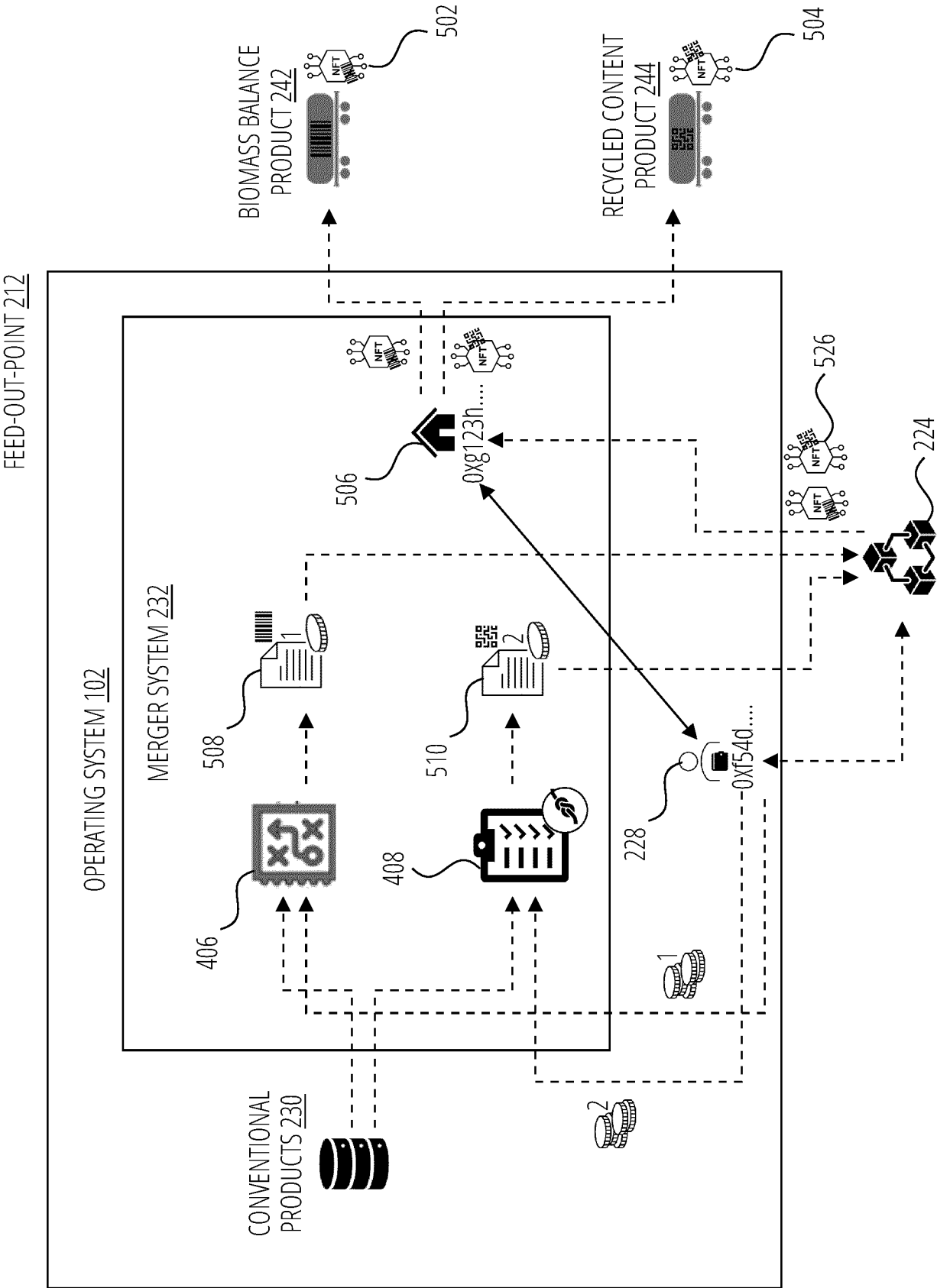


FIG. 5A

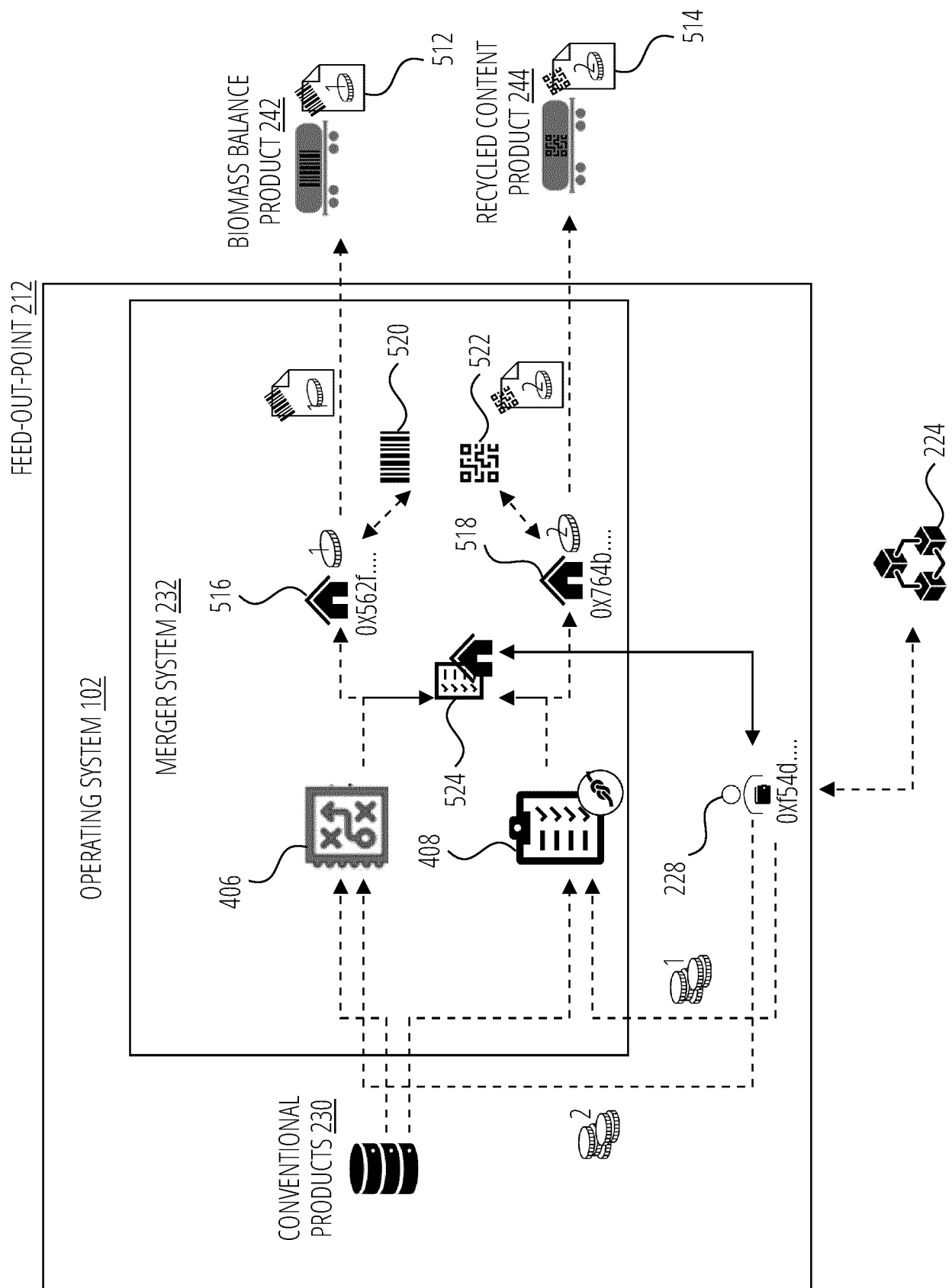


FIG. 5B

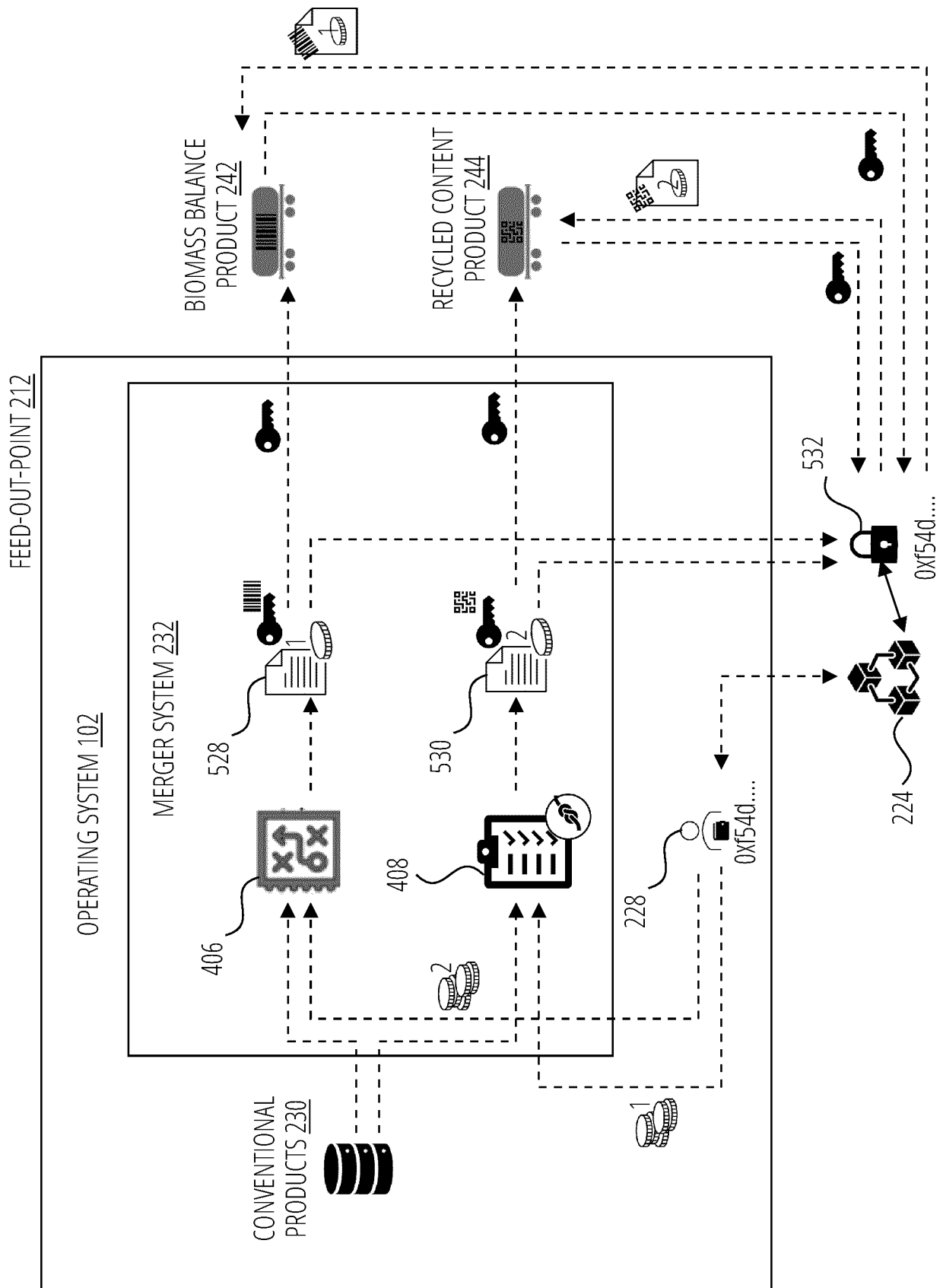


FIG. 5C

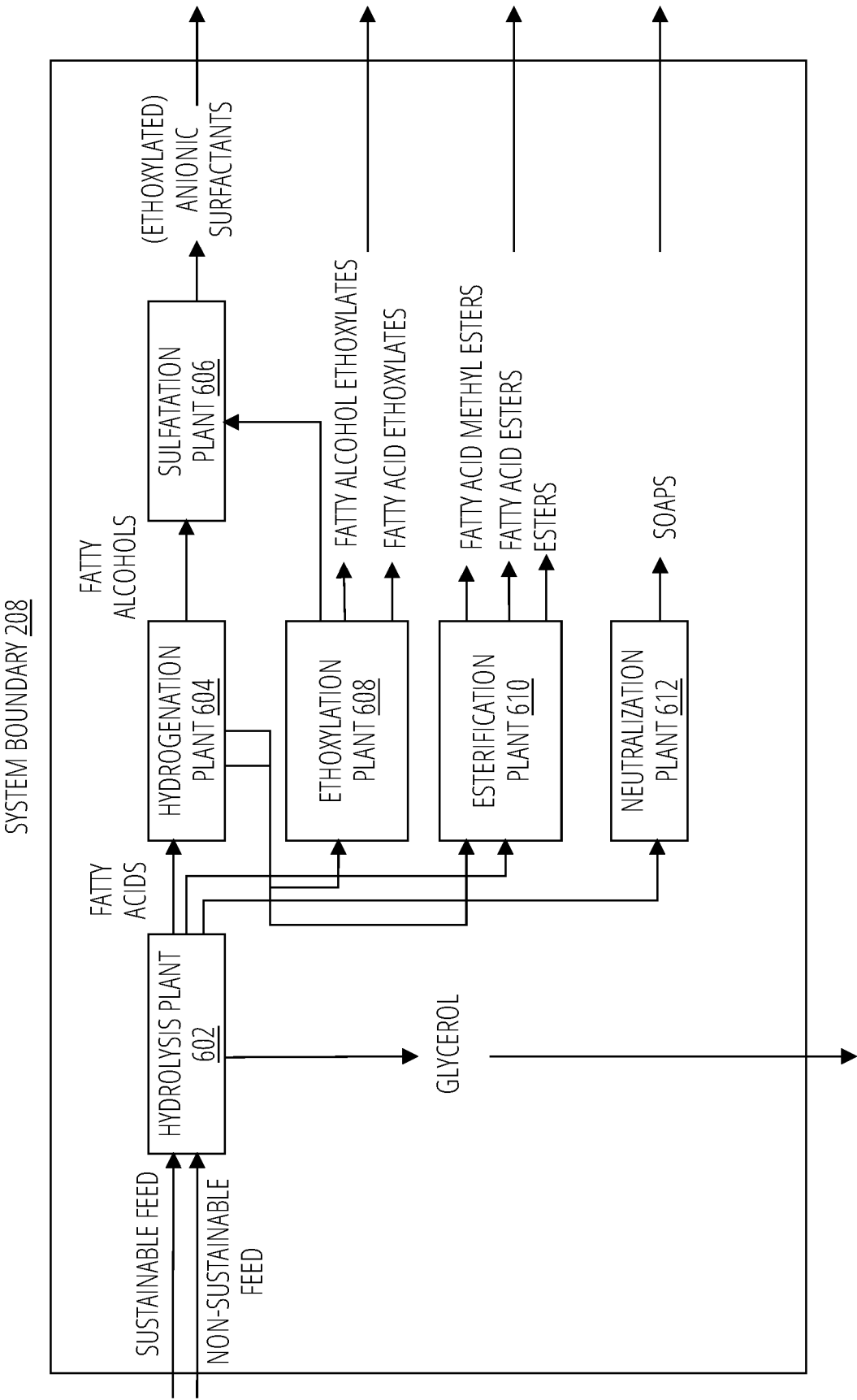


FIG. 6A

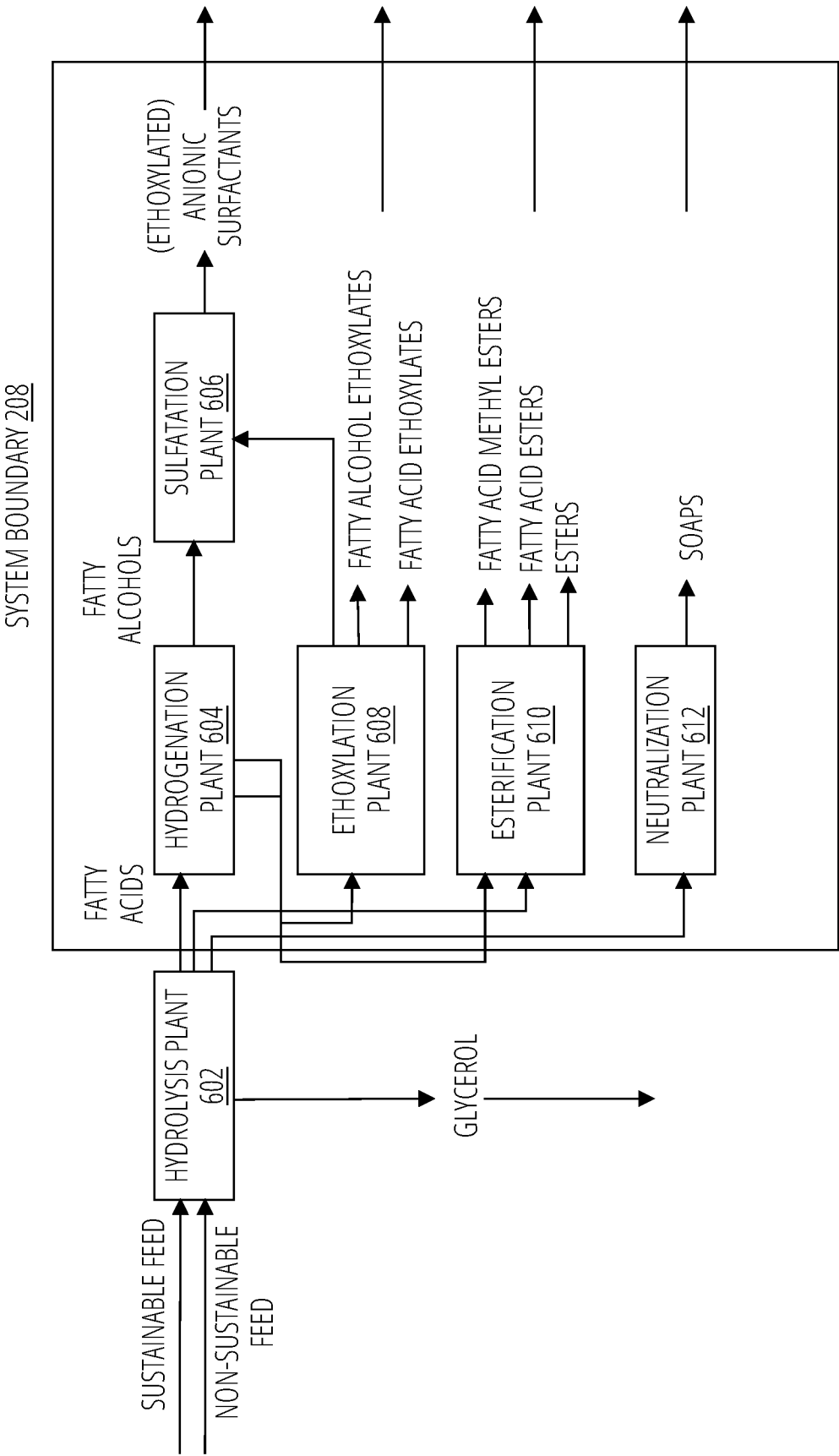


FIG. 6B

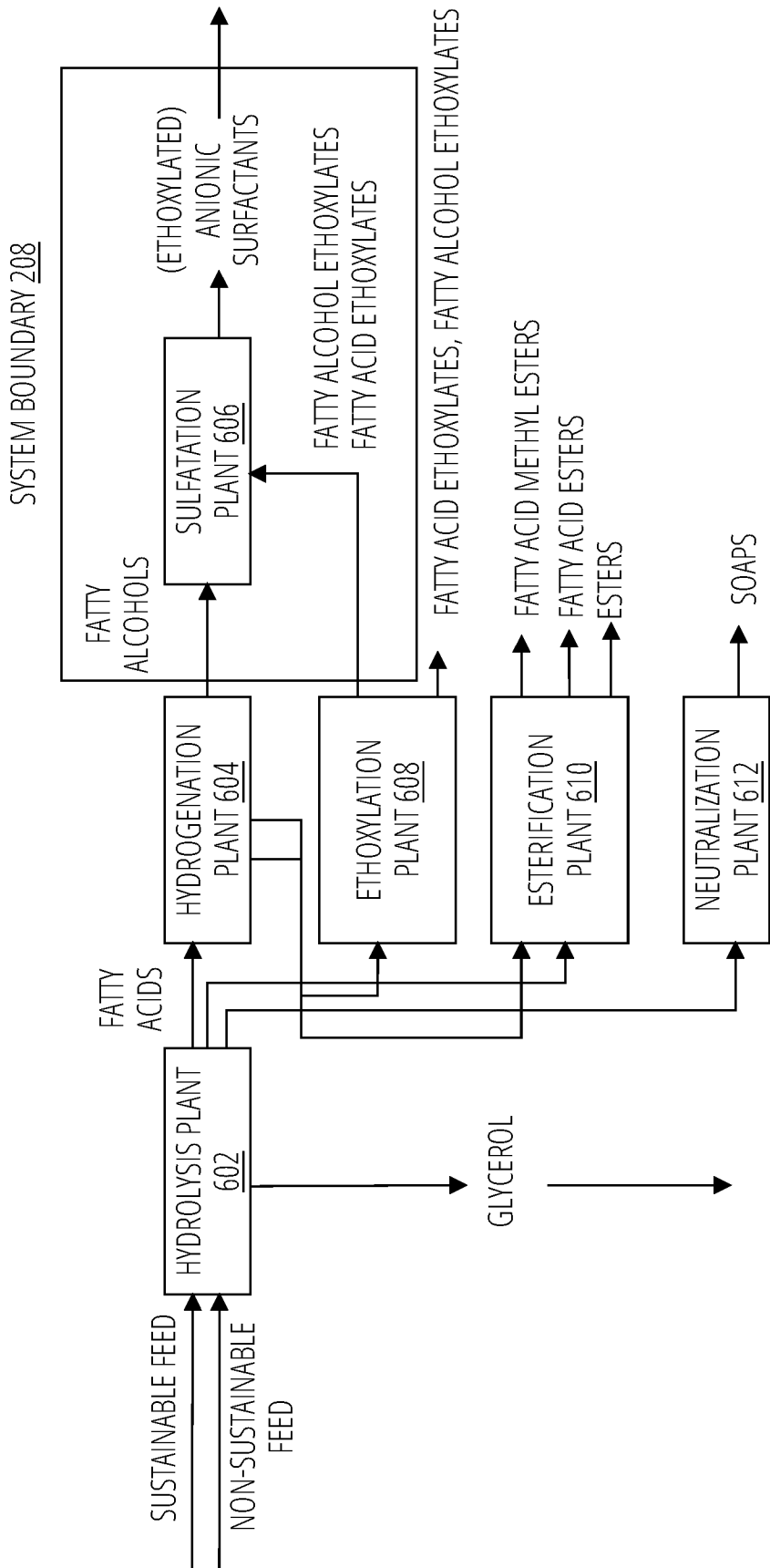


FIG. 6C

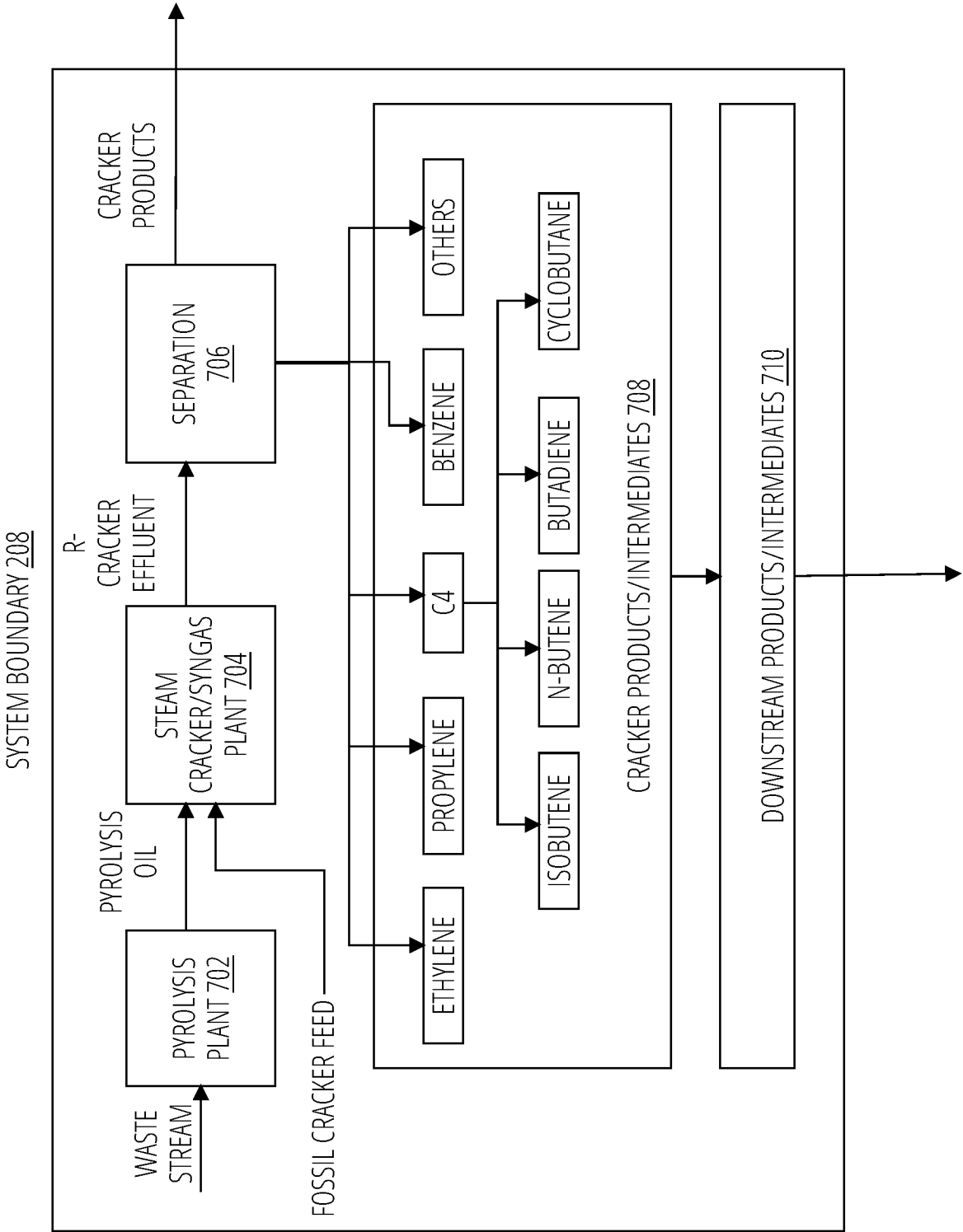


FIG. 7A

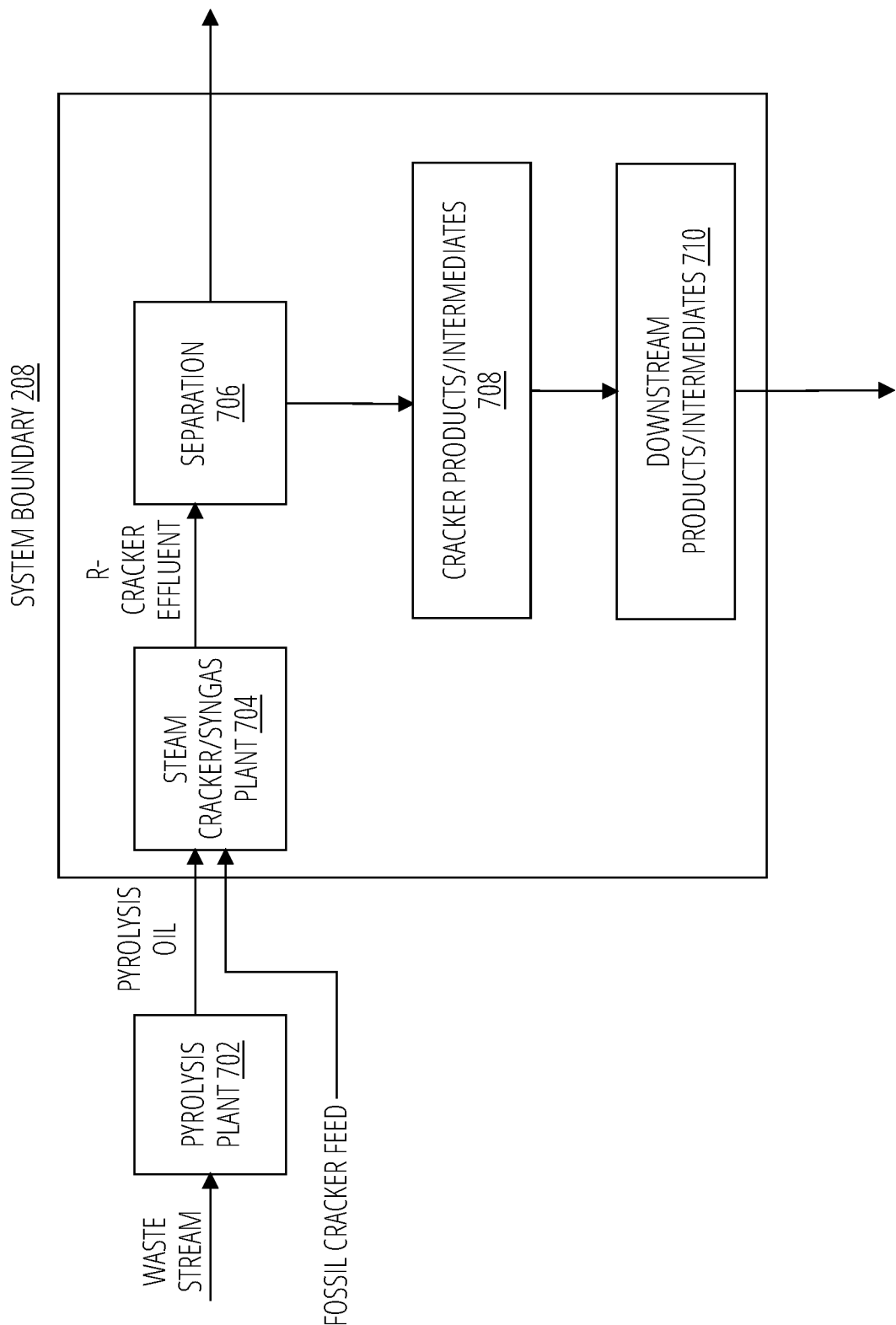


FIG. 7B

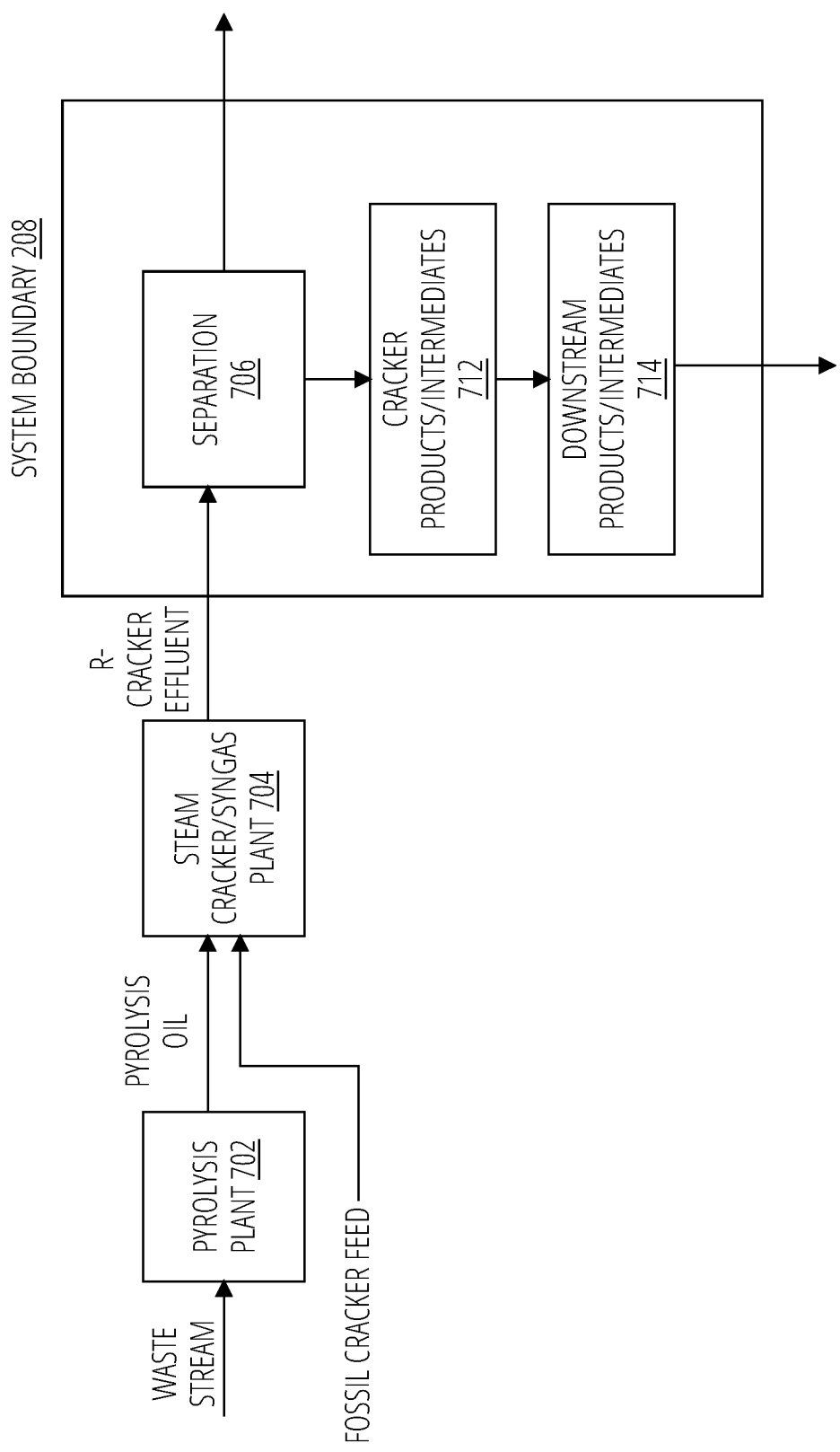
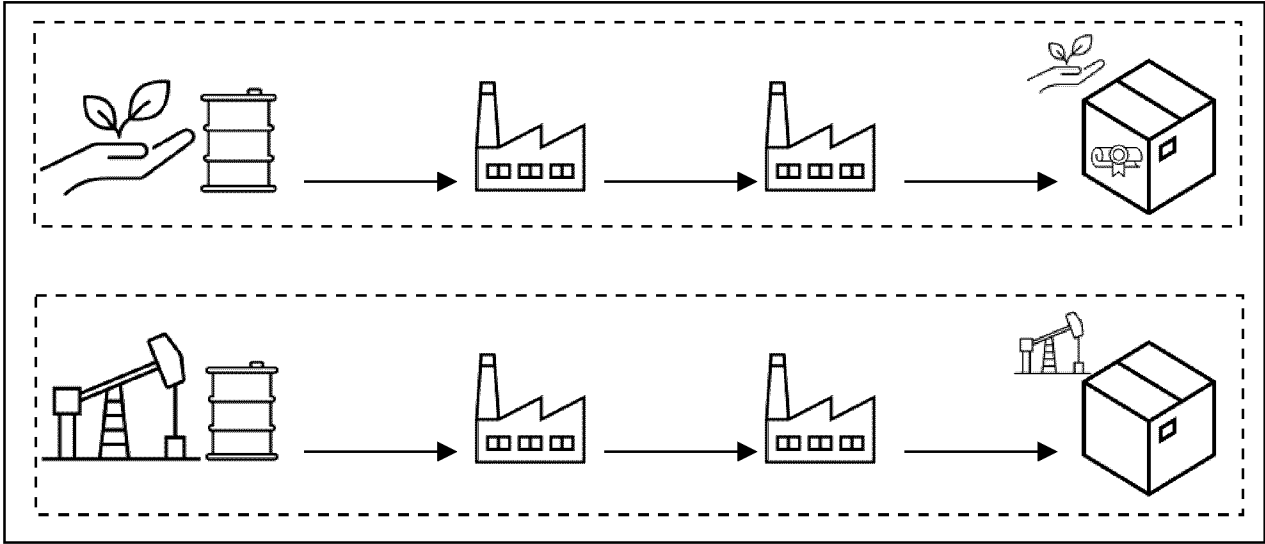
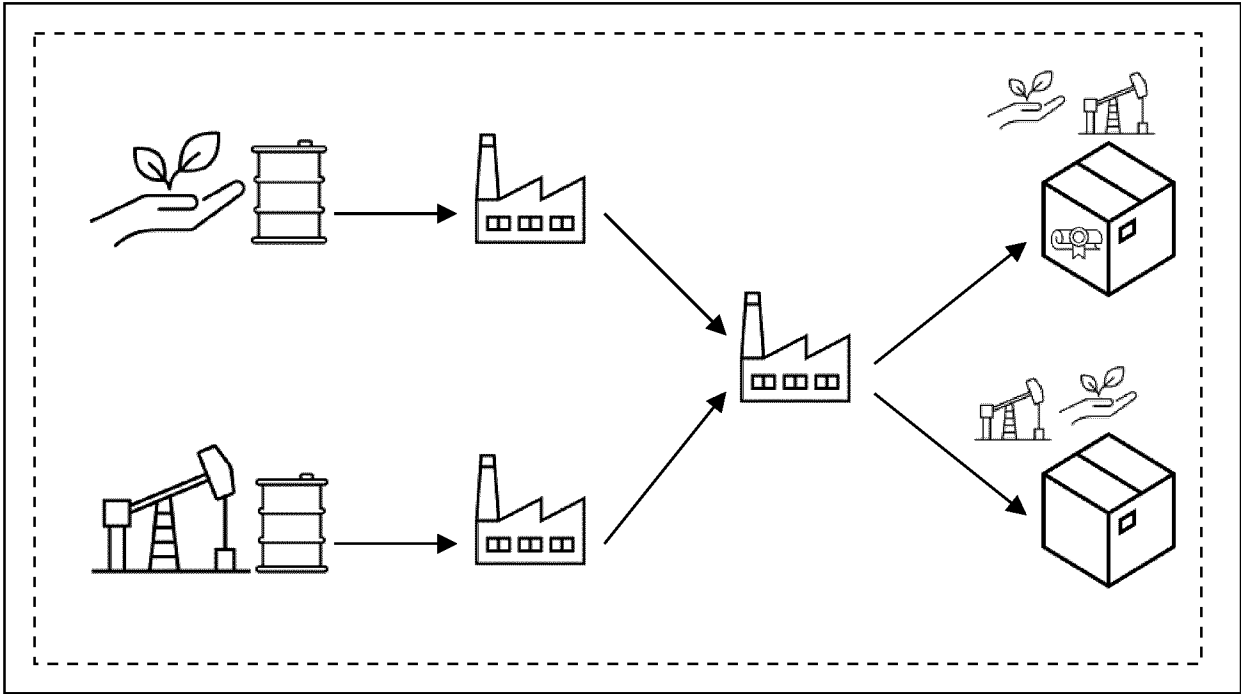


FIG. 7C



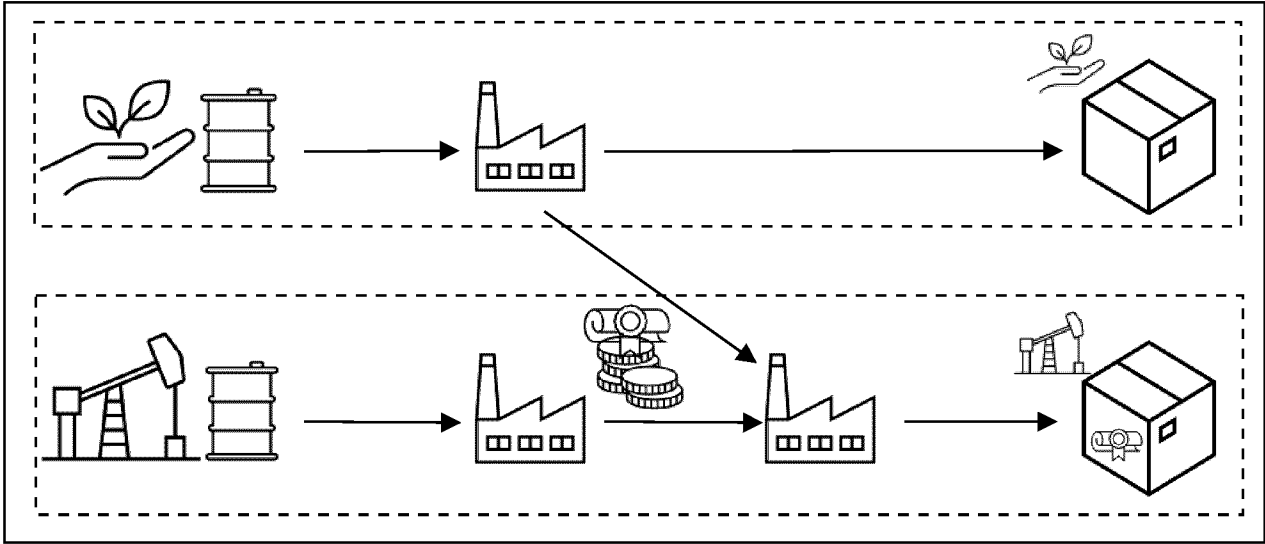
SYSTEM BOUNDARY 208

FIG. 8A



SYSTEM BOUNDARY 208

FIG. 8B



SYSTEM BOUNDARY 208

FIG. 8C

SYSTEM BOUNDARY 208

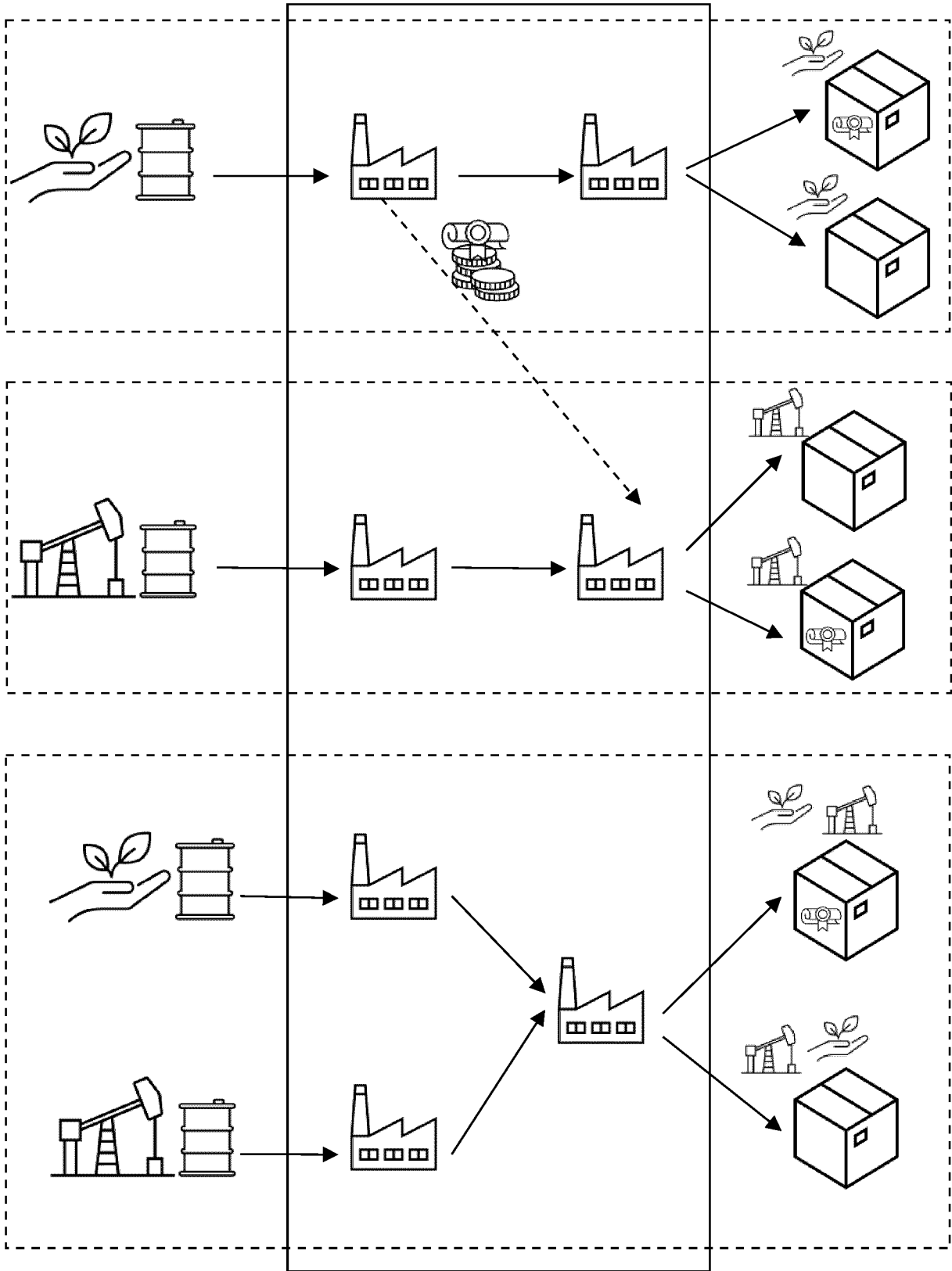


FIG. 9

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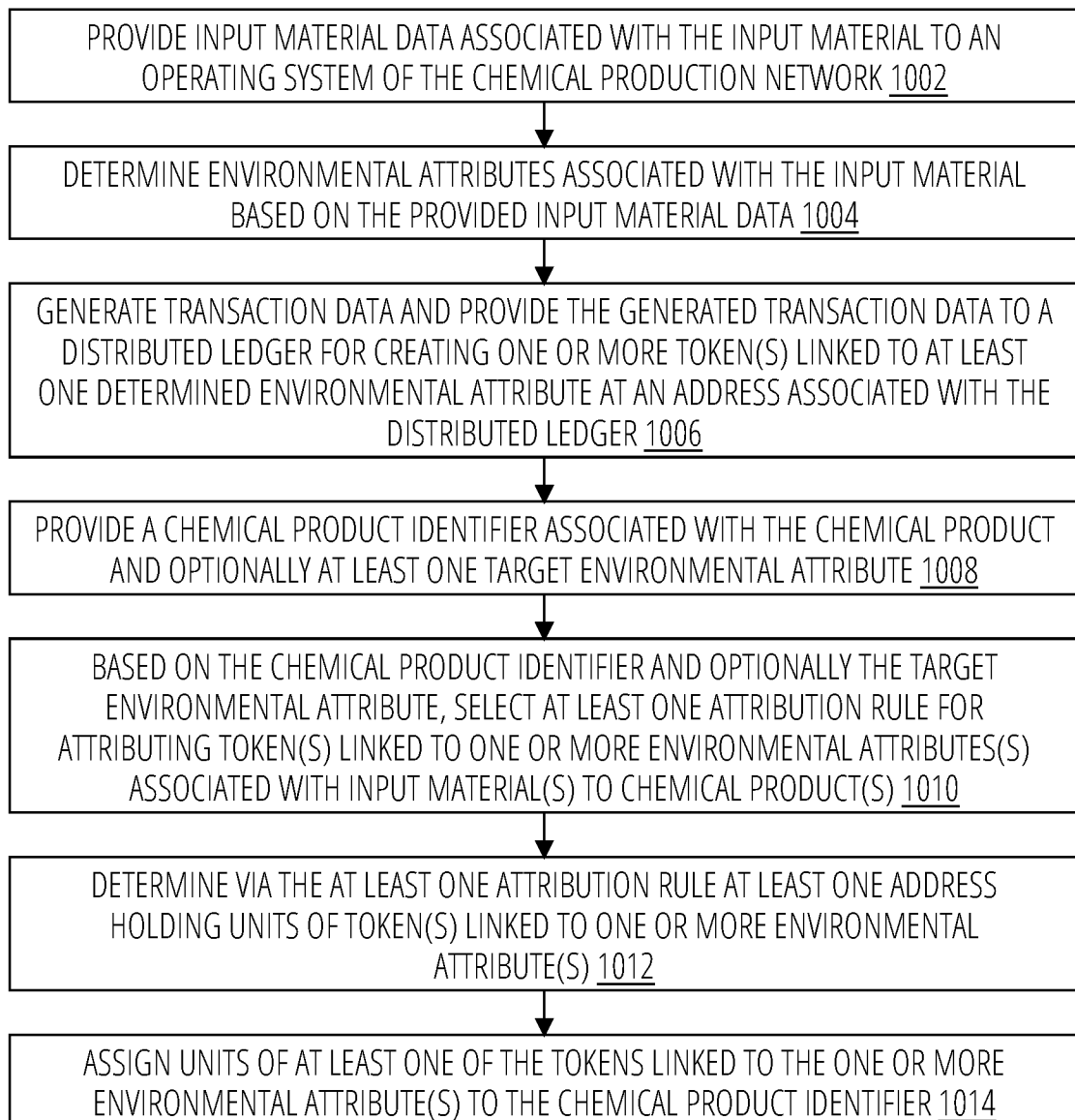


FIG. 10

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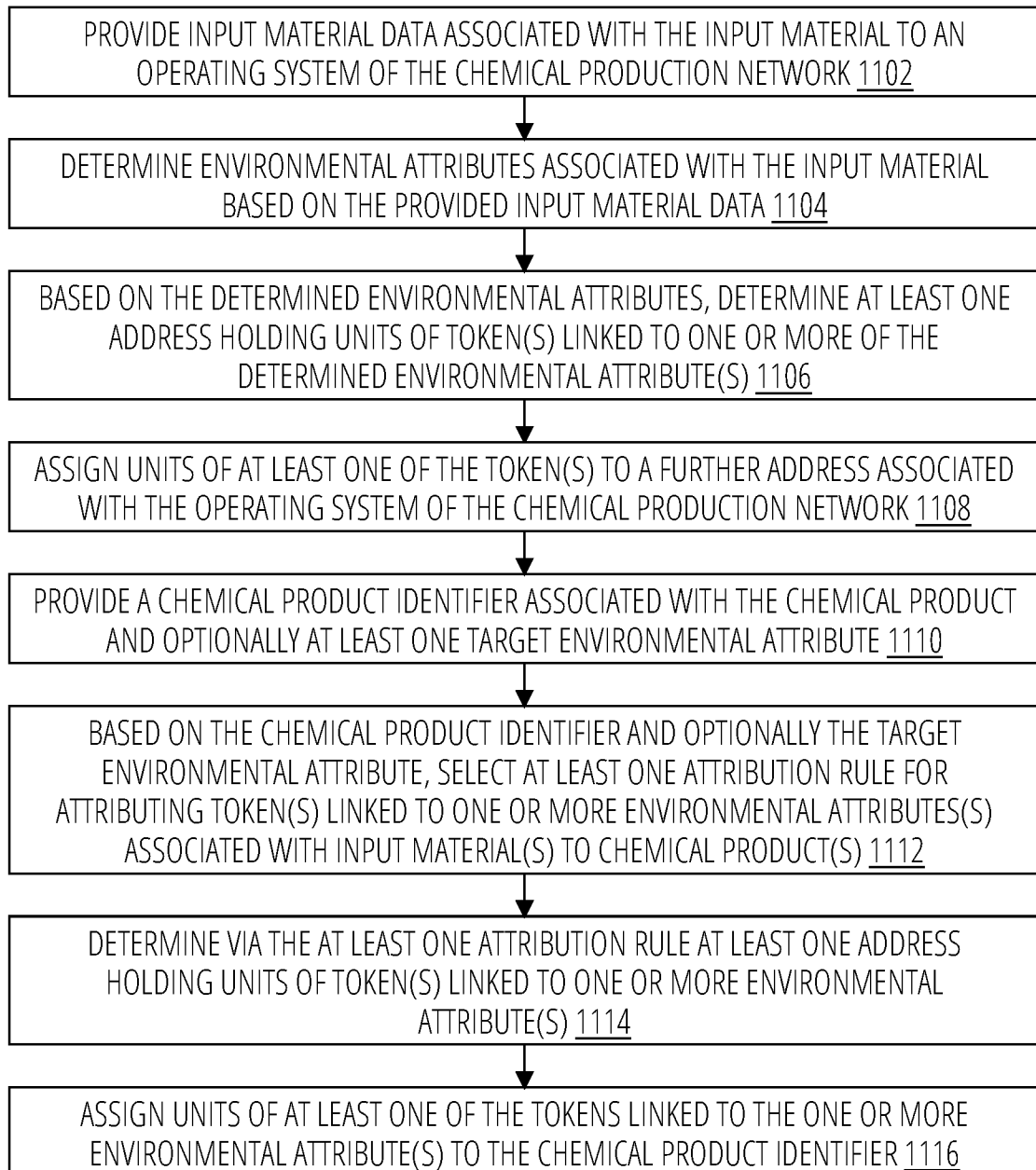


FIG. 11

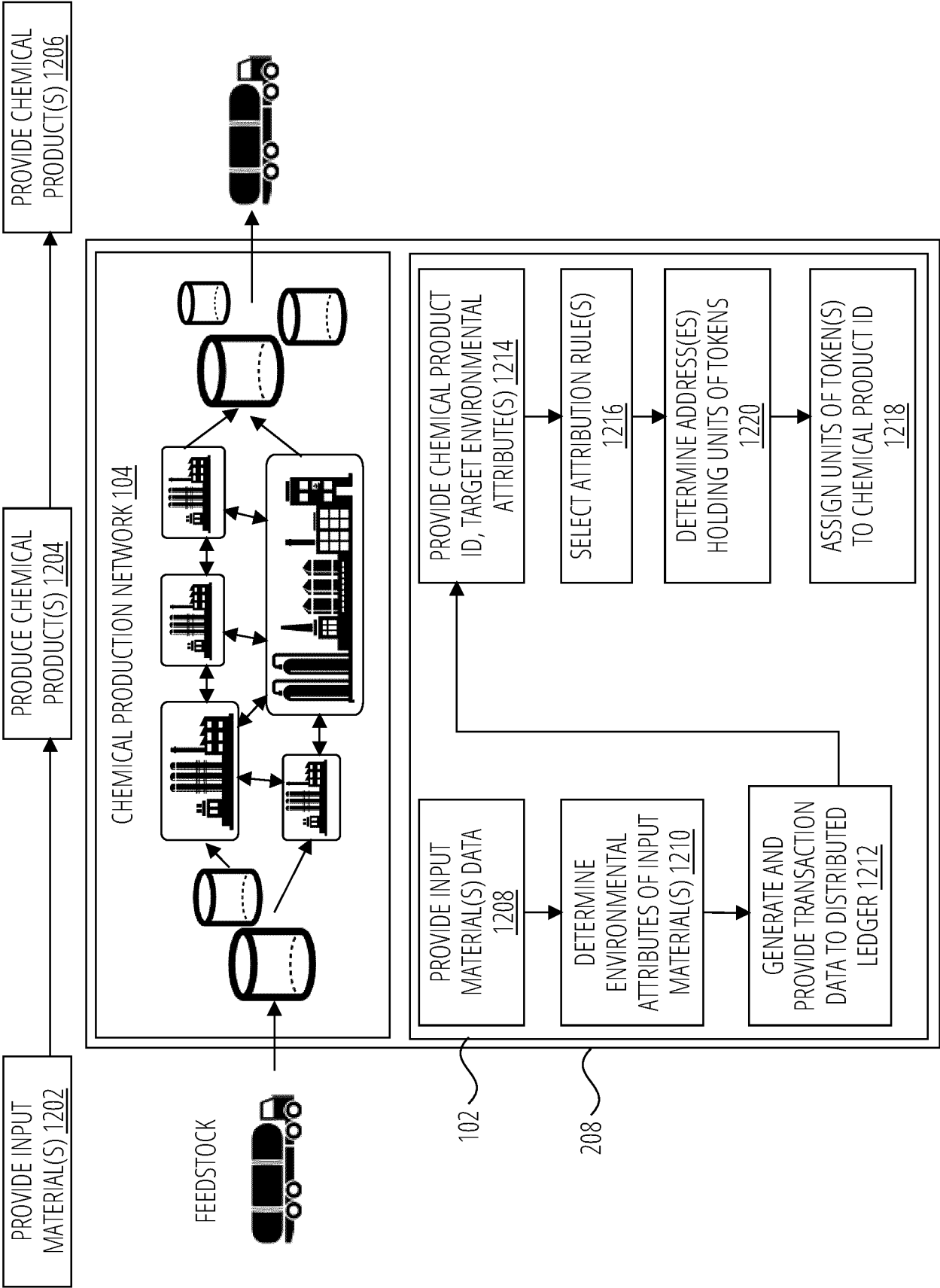


FIG. 12A

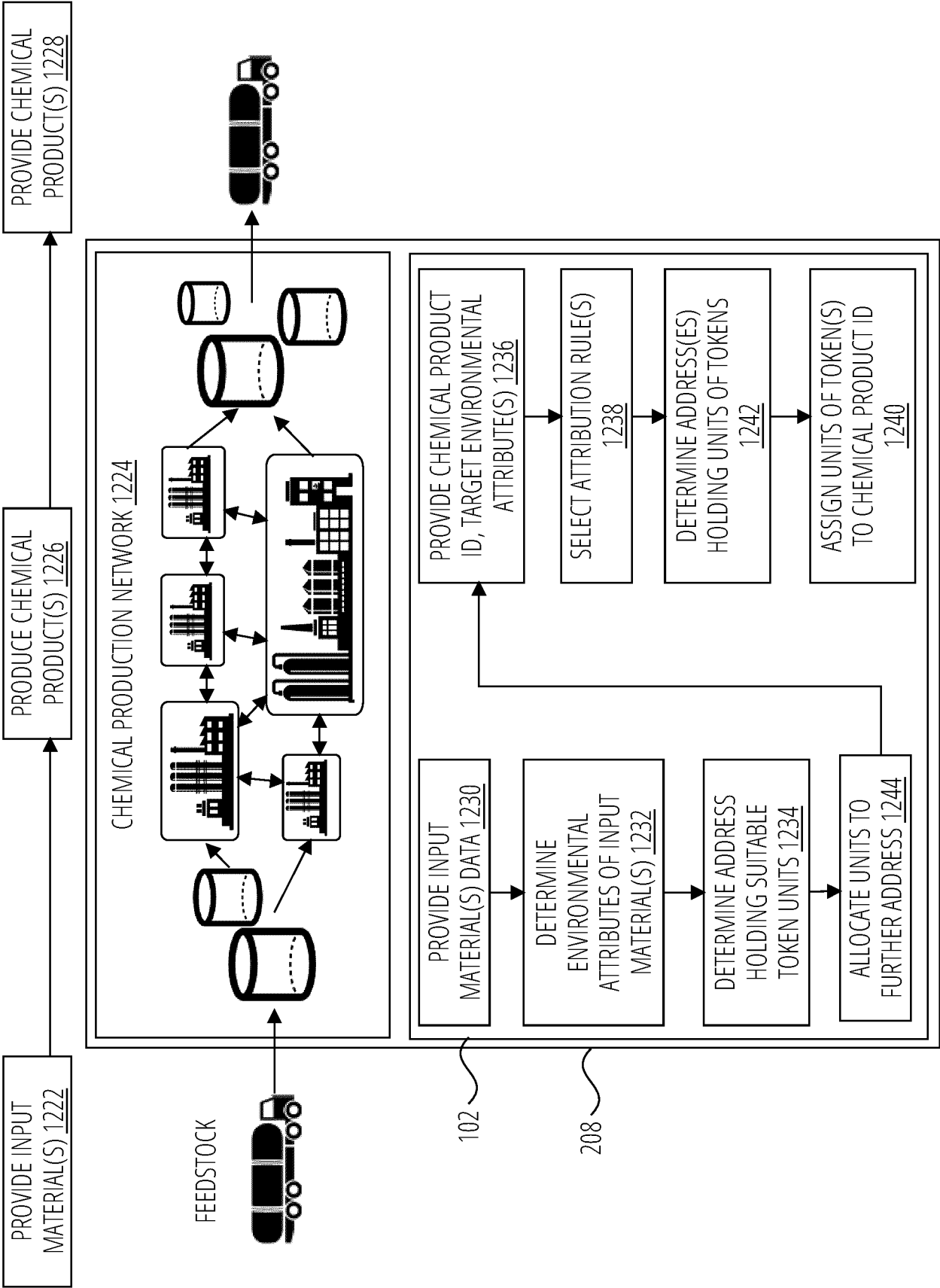


FIG. 12B

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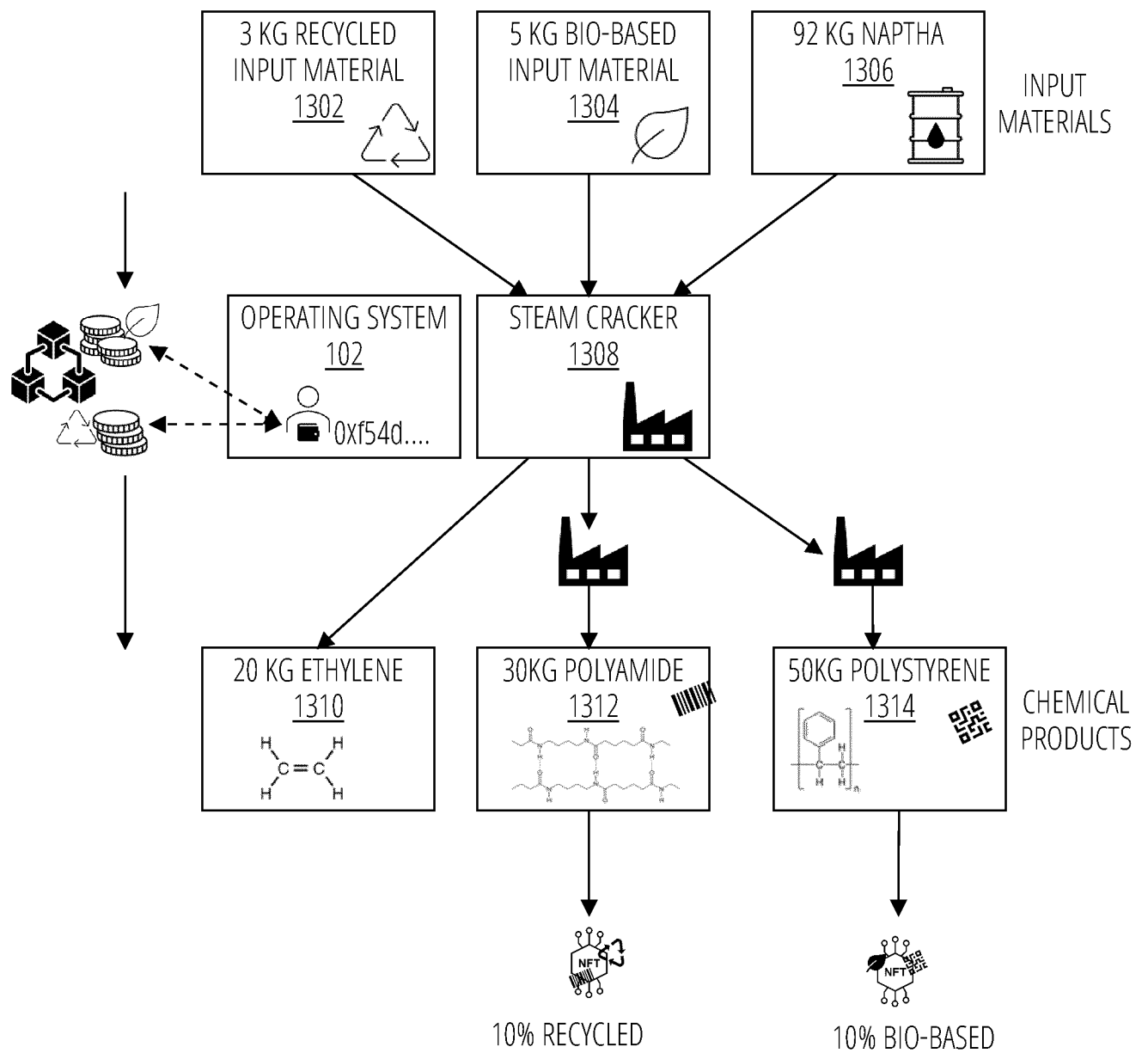


FIG. 13

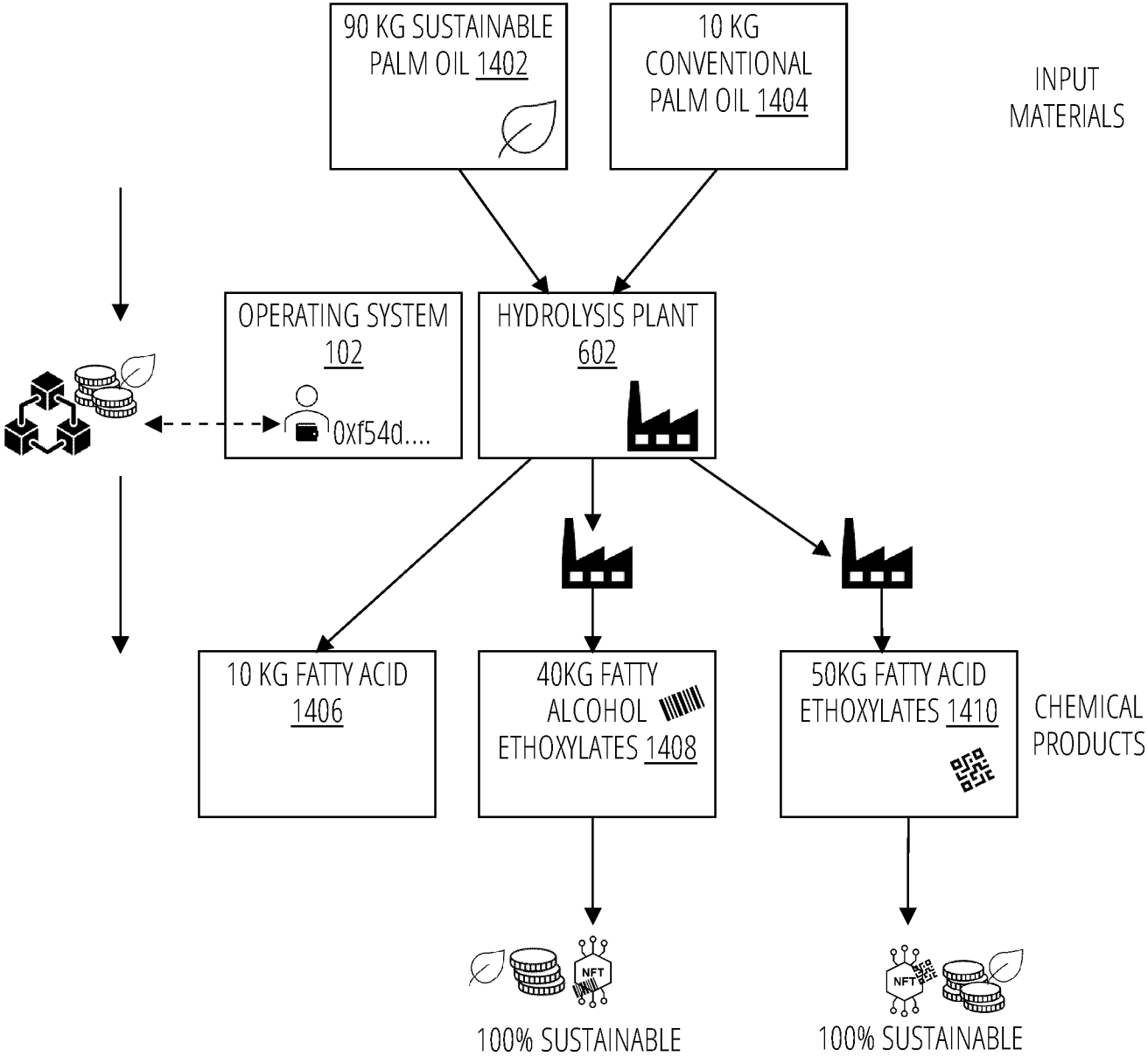


FIG. 14

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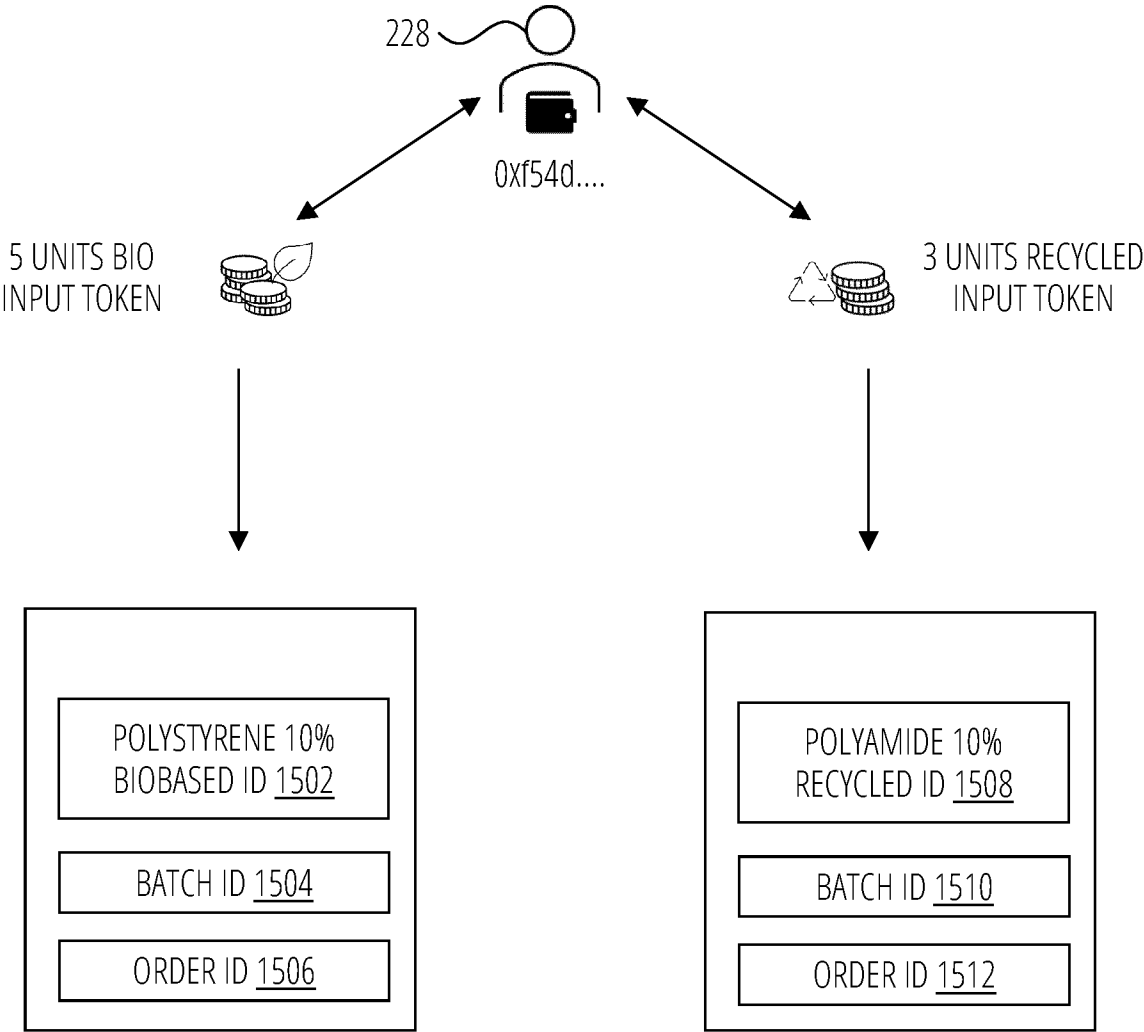


FIG. 15A

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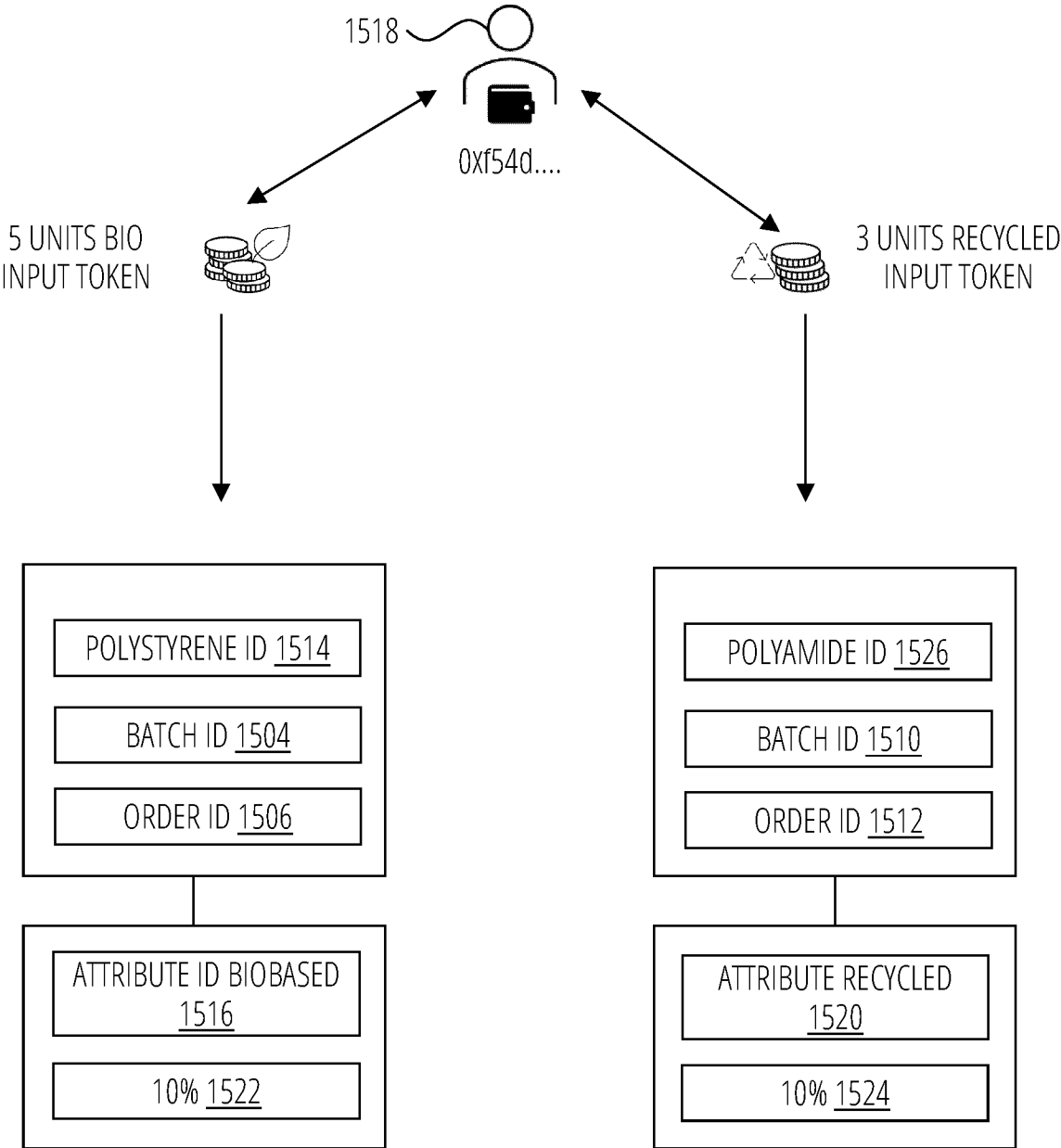


FIG. 15B

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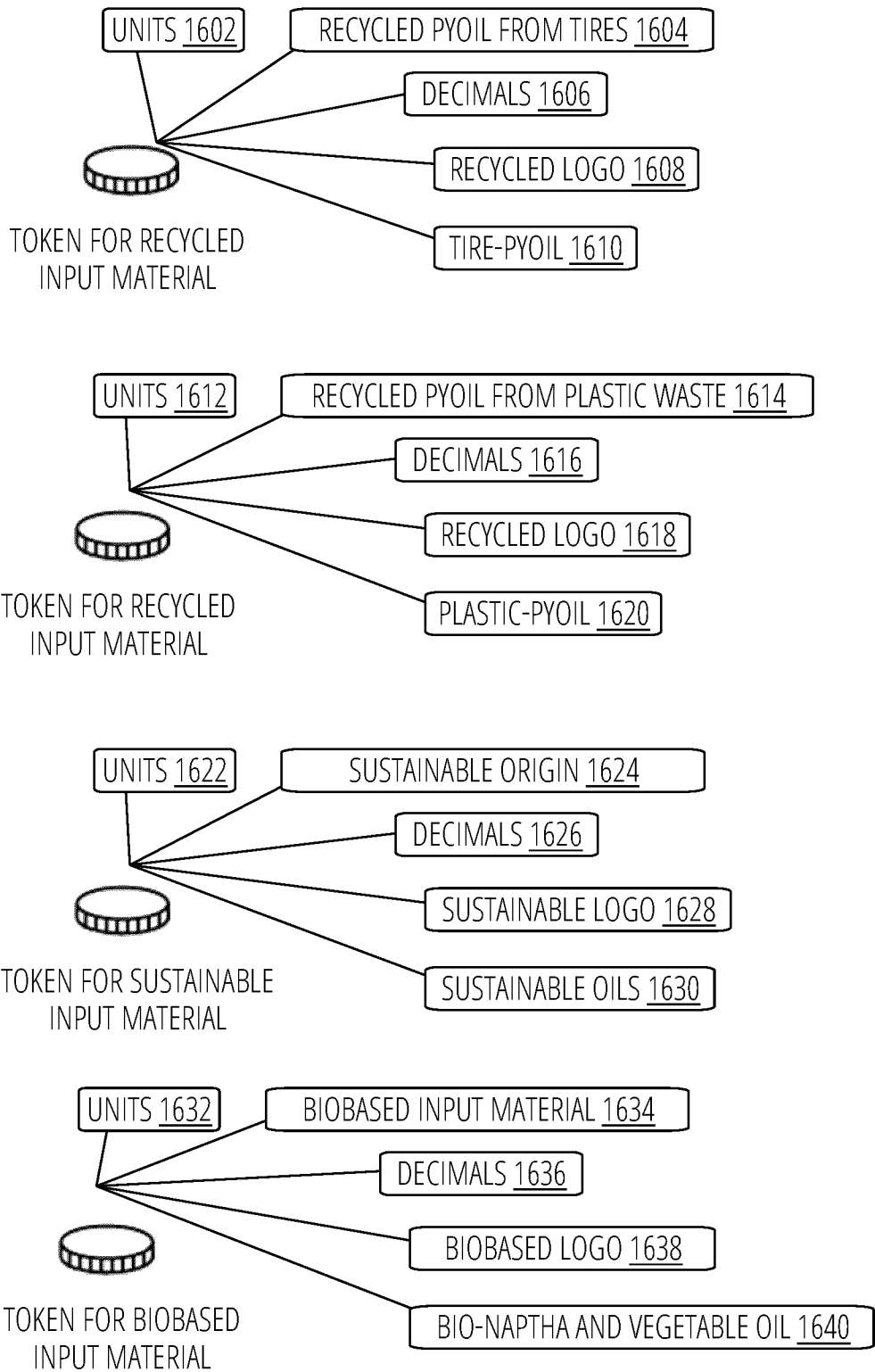


FIG. 16

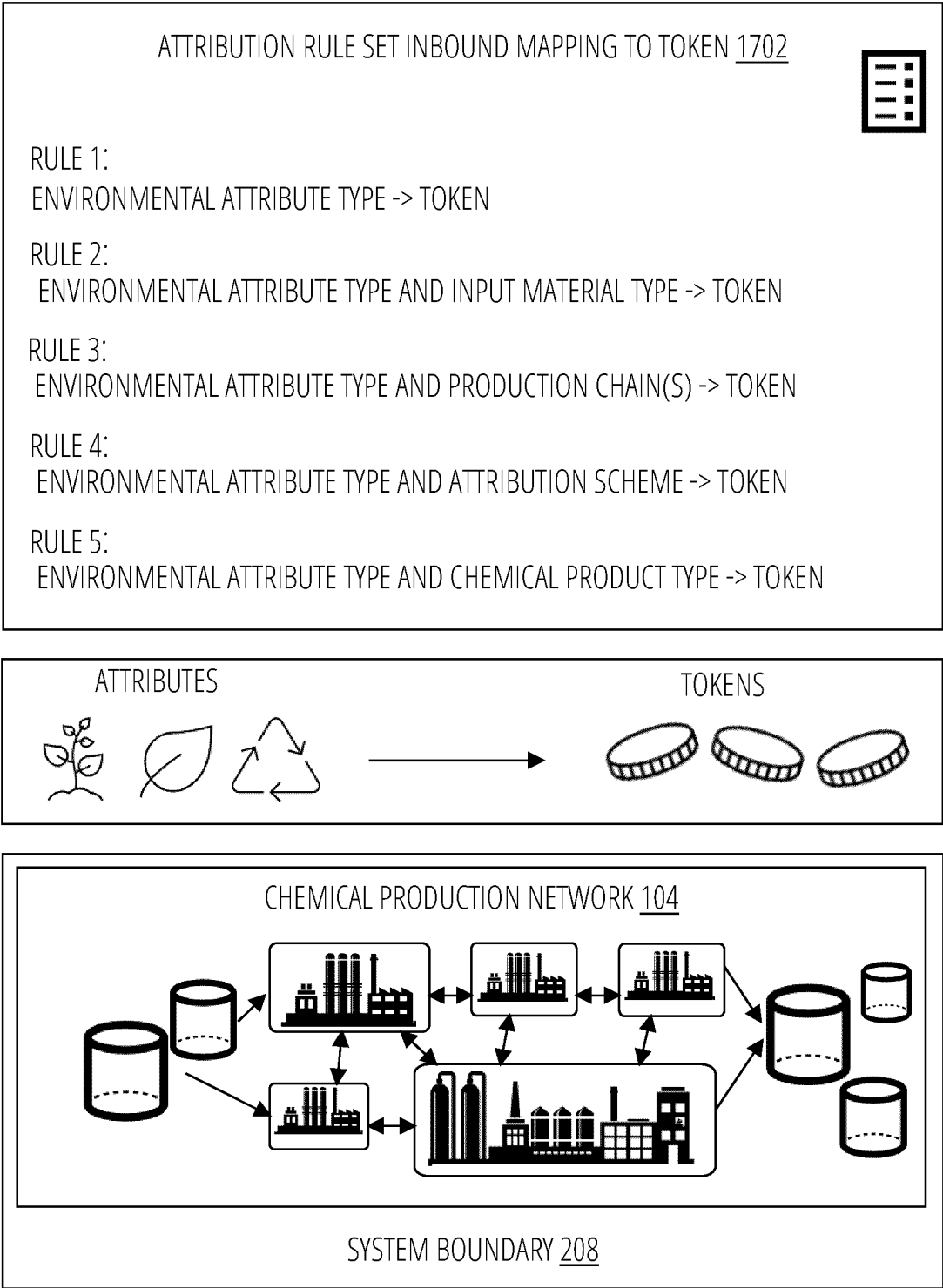


FIG. 17

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ATTRIBUTION RULE SET OUTBOUND MAPPING TO CHEMICAL PRODUCT ID 1802

RULE 1:
ENVIRONMENTAL ATTRIBUTE TYPE -> ID

RULE 2:
ENVIRONMENTAL ATTRIBUTE TYPE AND INPUT MATERIAL TYPE -> ID

RULE 3:
ENVIRONMENTAL ATTRIBUTE TYPE AND PRODUCTION CHAIN(S) -> ID

RULE 4:
ENVIRONMENTAL ATTRIBUTE TYPE AND ATTRIBUTION SCHEME -> ID

RULE 5:
ENVIRONMENTAL ATTRIBUTE TYPE AND CHEMICAL PRODUCT TYPE -> ID

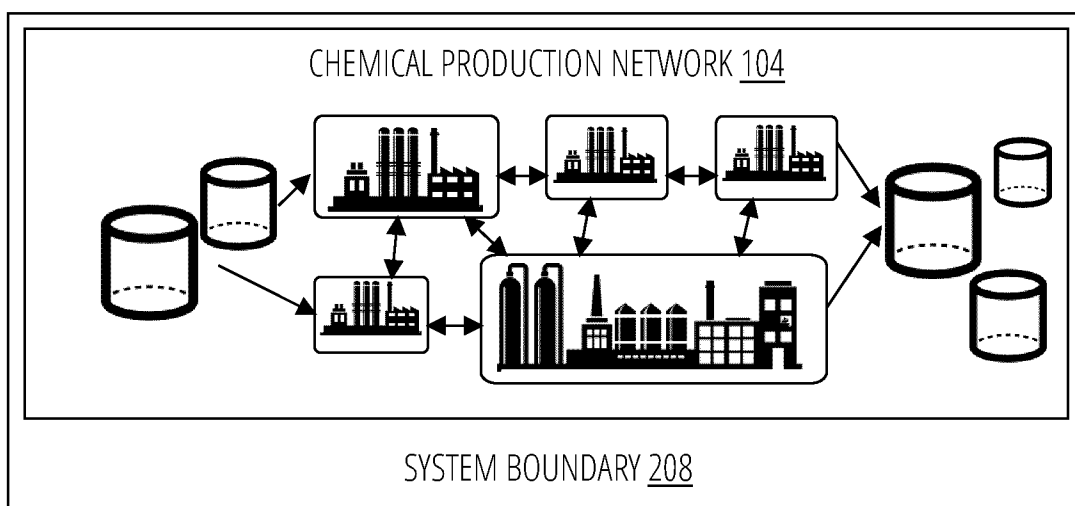
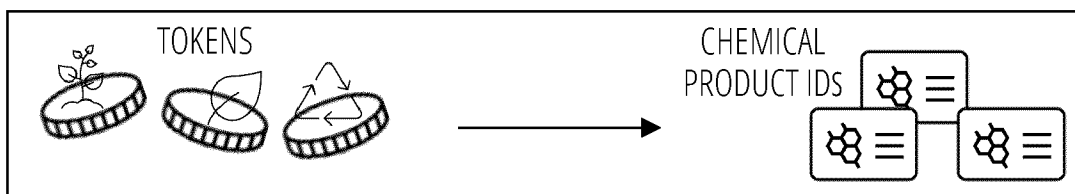


FIG. 18

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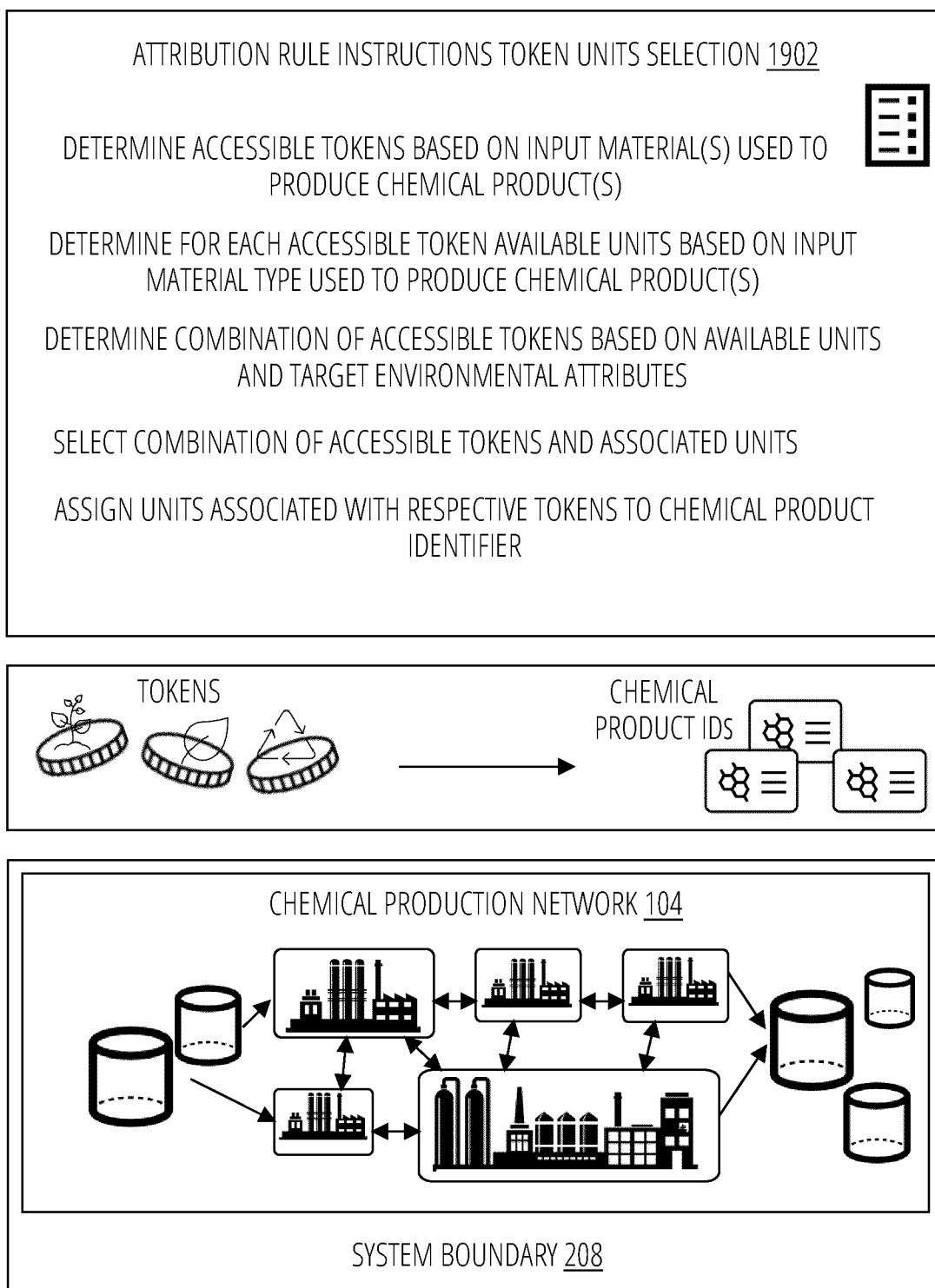


FIG. 19

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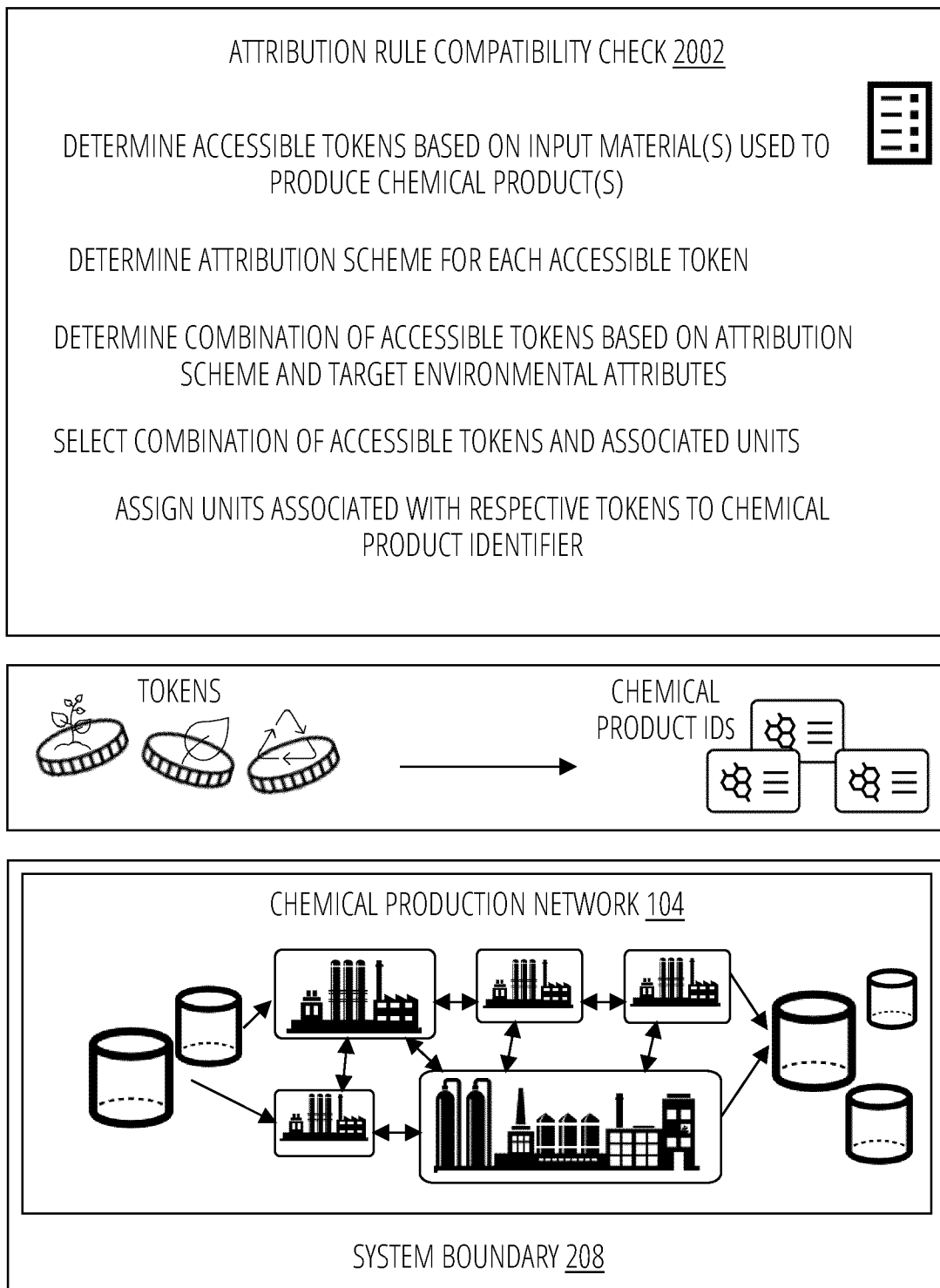


FIG. 20

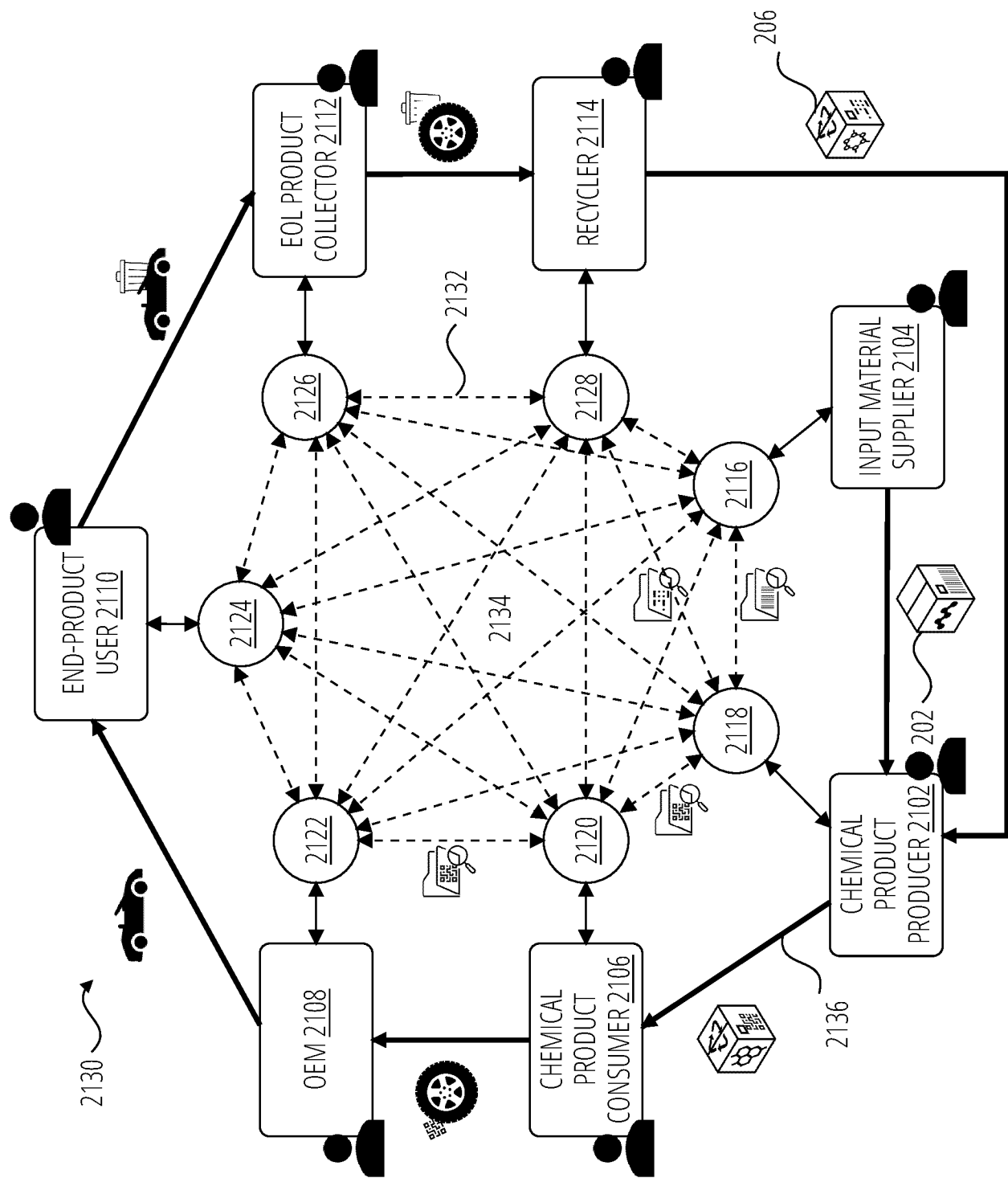


FIG. 21A

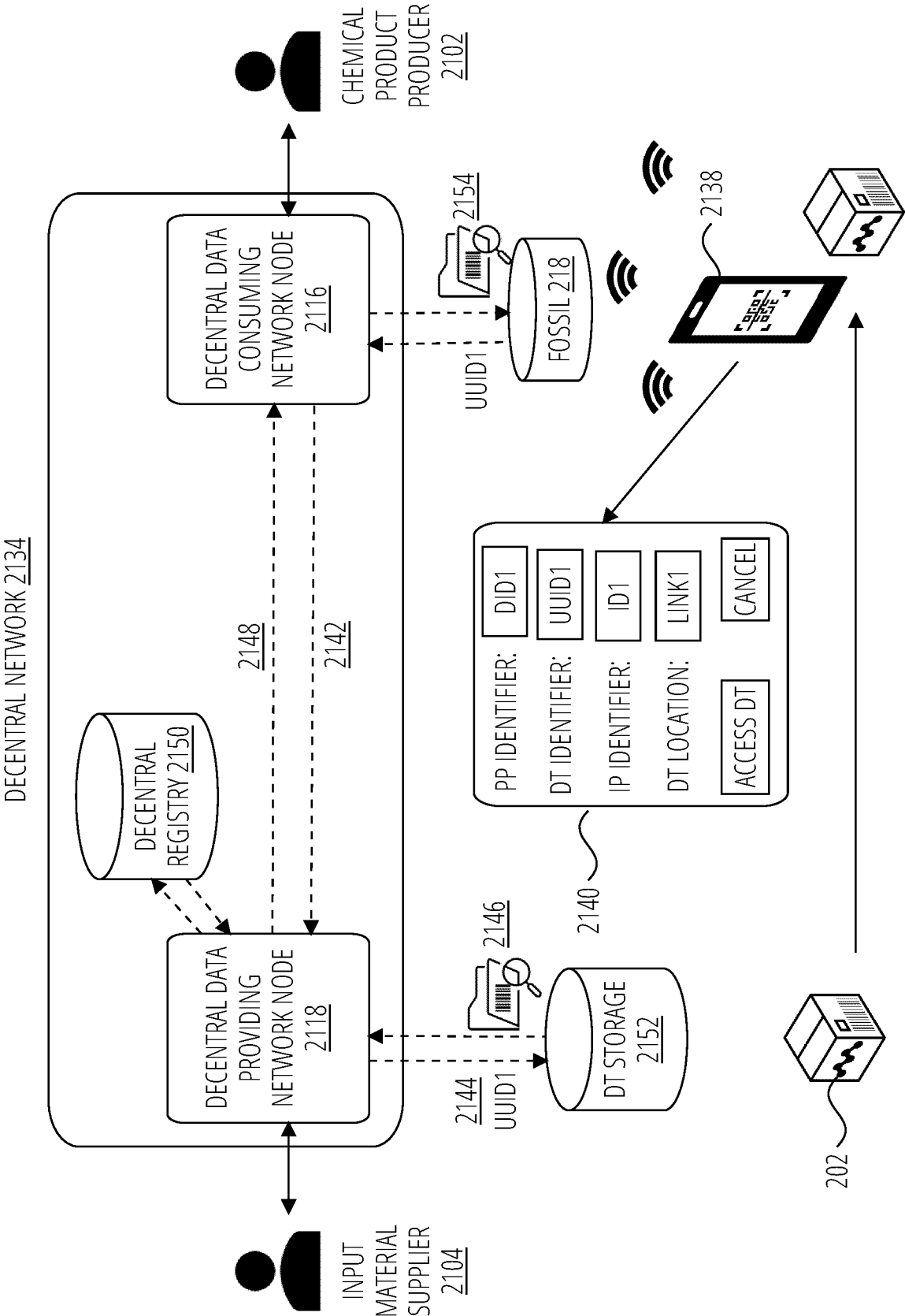


FIG. 21B

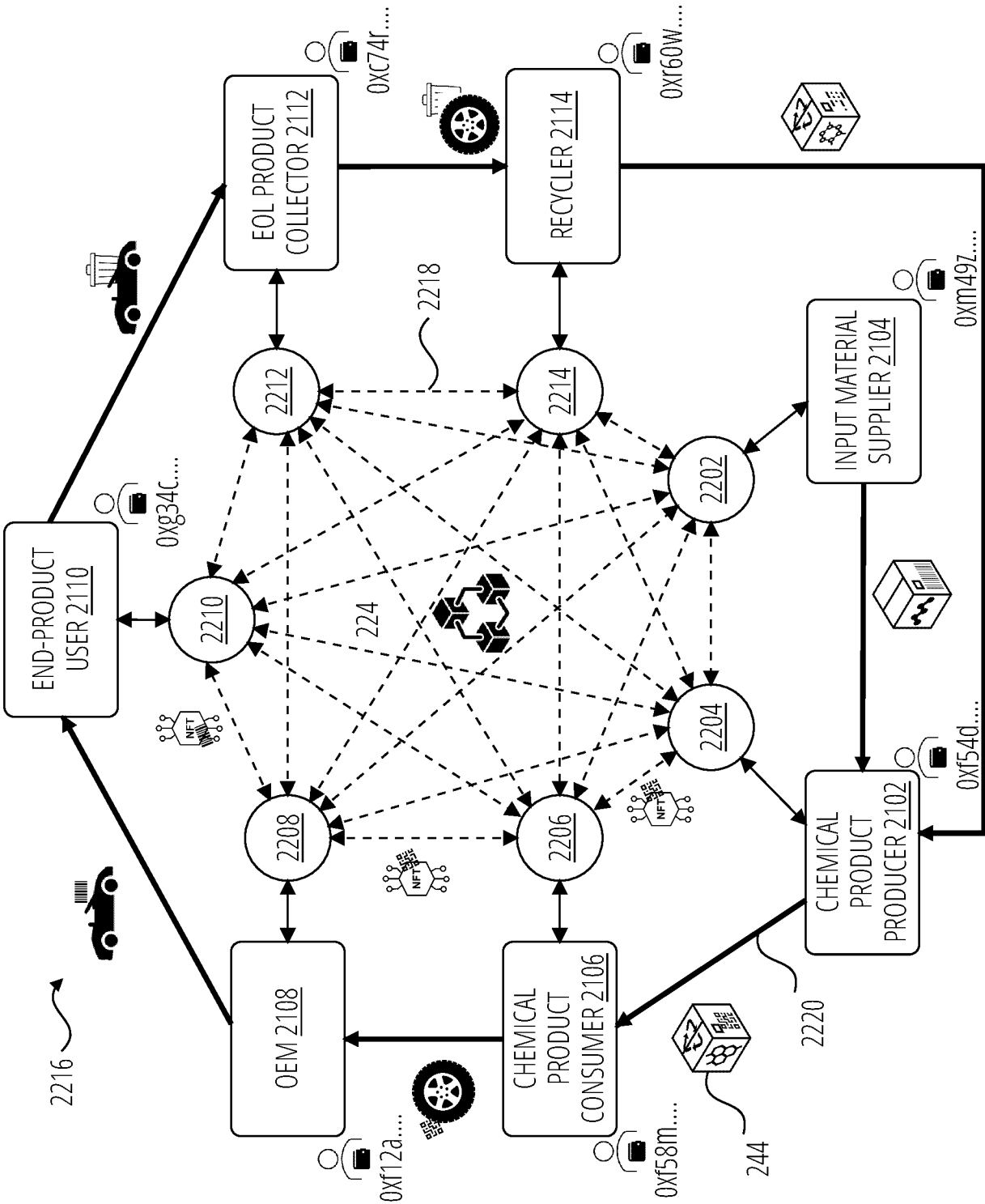


FIG. 22A

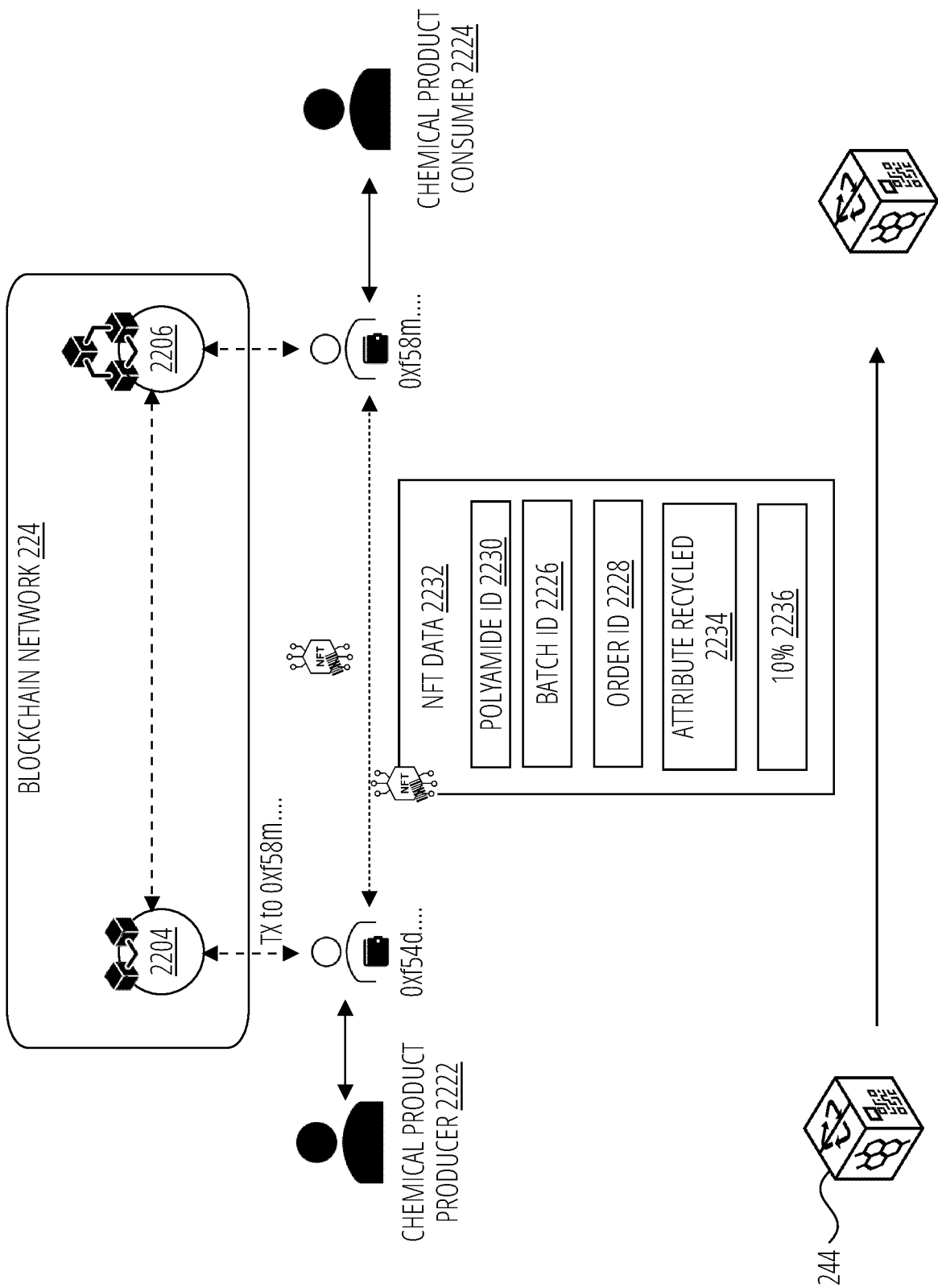


FIG. 22B

INTERNATIONAL SEARCH REPORT

International application No
PCT/EP2024/066780

A. CLASSIFICATION OF SUBJECT MATTER INV. G06Q10/0639 G06Q10/08 G06Q10/30 G06Q50/04 G06Q30/018 ADD.		
According to International Patent Classification (IPC) or to both national classification and IPC		
B. FIELDS SEARCHED Minimum documentation searched (classification system followed by classification symbols) G06Q Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched Electronic data base consulted during the international search (name of data base and, where practicable, search terms used) EPO-Internal		
C. DOCUMENTS CONSIDERED TO BE RELEVANT		
Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	US 2022/237628 A1 (WOLLACK SCOTT WILLIAM [US] ET AL) 28 July 2022 (2022-07-28) paragraphs [0020] - [0074]; figure 5 -----	1 - 15
A	US 2023/130670 A1 (GOGERTY NICK [US] ET AL) 27 April 2023 (2023-04-27) paragraphs [0194], [0205] -----	4, 8, 15
☐ Further documents are listed in the continuation of Box C. ☒ See patent family annex.		
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Date of the actual completion of the international search 17 July 2024		Date of mailing of the international search report 31/07/2024
Name and mailing address of the ISA/ European Patent Office, P.B. 5818 Patentlaan 2 NL - 2280 HV Rijswijk Tel. (+31-70) 340-2040, Fax: (+31-70) 340-3016		Authorized officer Hopper, Eva

INTERNATIONAL SEARCH REPORT

Information on patent family members

International application No
PCT/EP2024/066780

Patent document cited in search report		Publication date	Patent family member(s)	Publication date
US 2022237628 A1	28-07-2022	AU	2020292276 A1	20-01-2022
		CN	114175015 A	11-03-2022
		EP	3983908 A1	20-04-2022
		KR	20220024553 A	03-03-2022
		US	2022237628 A1	28-07-2022
		WO	2020252013 A1	17-12-2020

US 2023130670 A1	27-04-2023	EP	4405881 A1	31-07-2024
		EP	4405885 A1	31-07-2024
		EP	4405886 A1	31-07-2024
		EP	4406213 A1	31-07-2024
		US	2023130670 A1	27-04-2023
		US	2023162204 A1	25-05-2023
		US	2023298042 A1	21-09-2023
		WO	2023049230 A1	30-03-2023
		WO	2023049232 A1	30-03-2023
		WO	2023049233 A1	30-03-2023
WO	2023049234 A1	30-03-2023		
