WHITE PAPER

TRACEABILITY FOR CIRCULAR AND RENEWABLE PLASTICS

Dr. Jeroen Wassenaar
Circular & Renewable Plastics Manager
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Qenos

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Find out how sustainable plastics can be traced through the supply chain using mass balance.
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Traceability of recycled or biobased inputs through plastic supply chains is an important element in the substantiation of claims for sustainable plastic products and packaging. Internationally accepted protocols require all entities in the value chain that process or own sustainable content to communicate the sustainable attributes from one link in the chain to the next under an independently certified framework. Certified chain of custody schemes employing mass balance accounting enable the co-processing of sustainable inputs with conventional feedstock, enabling existing facilities to enter and build scale in circular markets. Whilst a level of global harmonisation of traceability frameworks is desirable, sufficient flexibility is required to incentivise participation and investment in each country or region.

TRACEABILITY IS GAINING INCREASING ATTENTION FOR PRODUCTS WITH SPECIFIC SUSTAINABILITY CREDENTIALS. FROM BIOFUELS TO FAIR TRADE CHOCOLATE TO CIRCULAR PLASTICS, TRACEABILITY PLAYS A CRUCIAL ROLE IN PROVING THAT RAW MATERIALS FROM A SPECIFIC ORIGIN END UP IN A PARTICULAR PRODUCT, THEREBY SUPPORTING SUSTAINABILITY CLAIMS. AS GOVERNMENTS AROUND THE WORLD TRANSITION FROM VOLUNTARY TARGETS TO MANDATORY REQUIREMENTS FOR SUSTAINABLE PRODUCT AND PACKAGING DESIGN, TRACEABILITY CERTIFICATION BECOMES A NECESSITY.

WHY CHAIN OF CUSTODY TRACEABILITY IS ESSENTIAL FOR SUSTAINABLE PLASTICS

Sustainable plastics (in the context of this white paper) refers primarily to circular (recycled) and renewable (biobased) plastics but may also include plastics based on CO_2 or renewable hydrogen. These plastics may offer specific sustainability attributes such as a reduced carbon footprint, diversion of waste from landfill, or contribute to the protection of biodiversity. Typically, such products are more expensive to produce and command a premium over conventional plastics. With an increased focus on sustainability over recent years, it is expected that demand for sustainable plastics will outstrip supply for the foreseeable future [Wassenaar 2023a].

Chain of custody traceability enables materials to be traced through the supply chain from the point of origin to the final product. This provides certainty about the material's provenance as well as transparency over the entire supply chain. Chain of custody traceability underpins the legitimacy of sustainability claims and lends support to the application of green premiums. Some schemes may also focus on other sustainability characteristics such as adherence to modern slavery prevention laws and sustainable land use .

A WHOLE OF SUPPLY CHAIN APPROACH

Supply chains for plastics can be highly complex and typically involve a variety of different participants across various geographies. This applies equally for circular and renewable plastics even with the focus on localised models for circularity. An example of a supply chain for circular polyethylene (PE) packaging is shown in Figure 1. For additional technical background on circular plastics derived through pyrolysis based chemical (advanced) recycling, please refer to our previous white paper [Wassenaar 2022].

Every step of a traceable supply chain in which material changes ownership is accompanied by a traceability declaration containing important sustainability characteristics such as the country of origin, raw material category (e.g. circular or bio), type of recycling operations (e.g. chemical or mechanical), pre- or post-consumer plastic waste status, greenhouse gas emissions, and the chain of custody option (e.g. mass balance). Most of these characteristics are preserved through the supply chain and communicated to the next entity in the chain via a traceability declaration. This declaration allows the last entity in the chain before the consumer, typically a brand owner, to make an accurate claim based on the sustainability characteristics forwarded through the chain. Traceability declarations may be held by each entity, allowing one-up one-down traceability without necessarily disclosing all participants in the supply chain.

THE ROLE OF THIRD-PARTY CERTIFICATION

Integrity and harmonisation of traceability declarations is ensured through third-party certification. Certification typically involves periodic on-site audits for compliance with scheme rules by an accredited certification body. Examples of chain of custody certification schemes used for circular and renewable plastics with some of their key characteristics are shown in Table 1. The scope of mandatory supply chain participation varies for different schemes. Whilst ISCC PLUS and REDCert[2] require the full supply chain to be certified, other schemes focus only on recycling facilities e.g the Association of Plastic Recyclers (APR).

For mechanically recycled plastics, certified chain of custody schemes have not yet found widespread adoption. In many cases recycled material can be distinguished from virgin resin through colour, odour or chemical composition. However, as the market for high quality food grade mechanically recycled plastics matures, certified traceability schemes are emerging. In North America, the PCR certification by the APR is increasingly adopted whilst in Europe the Recyclass certification is gaining traction. For globally sourced mechanically recycled plastics the Global Recycled Standard (GRS) published by the Textile Exchange is becoming increasingly referenced.

> MASS BALANCE IS CRITICAL IN THE CREATION OF SUSTAINABLE PLASTICS AS IT ALLOWS THE USE OF EXISTING PETRO-CHEMICAL PLANTS AND CO-PROCESSING WITH CONVENTIONAL FEEDSTOCK TO PRODUCE CIRCULAR-ATTRIBUTED AND BIO-ATTRIBUTED PLASTICS.

For chemically recycled and biobased plastics produced under mass balance accounting, certified chain of custody is critical for system integrity and the credibility of claims. ISCC PLUS has emerged as the leading system, with most suppliers and converters of such materials certified to this scheme. Whilst other schemes are available, they have not yet found widespread adoption for plastics.

It is important to note that a number of certification schemes will not currently accept certificates and declarations from other schemes. This limits the interoperability of such schemes and encourages the widespread adoption of only a few schemes. This situation may evolve over time as mandatory national or international frameworks are established. For example, the Renewable Energy Directive (RED II) in the European Union has set up recognition criteria which certification schemes for biofuels need to meet. This enables mutual recognition of certificates by participating schemes under the framework [EC 2023].

Traceability information is held by each certified entity in the supply chain and audited periodically. The use of blockchain technologies is currently being piloted as a means of holding all traceability information in a decentralised encrypted data repository, facilitating verification of material flows and sustainability characteristics for auditors whilst maintaining confidentiality of the data [Circularise 2022].

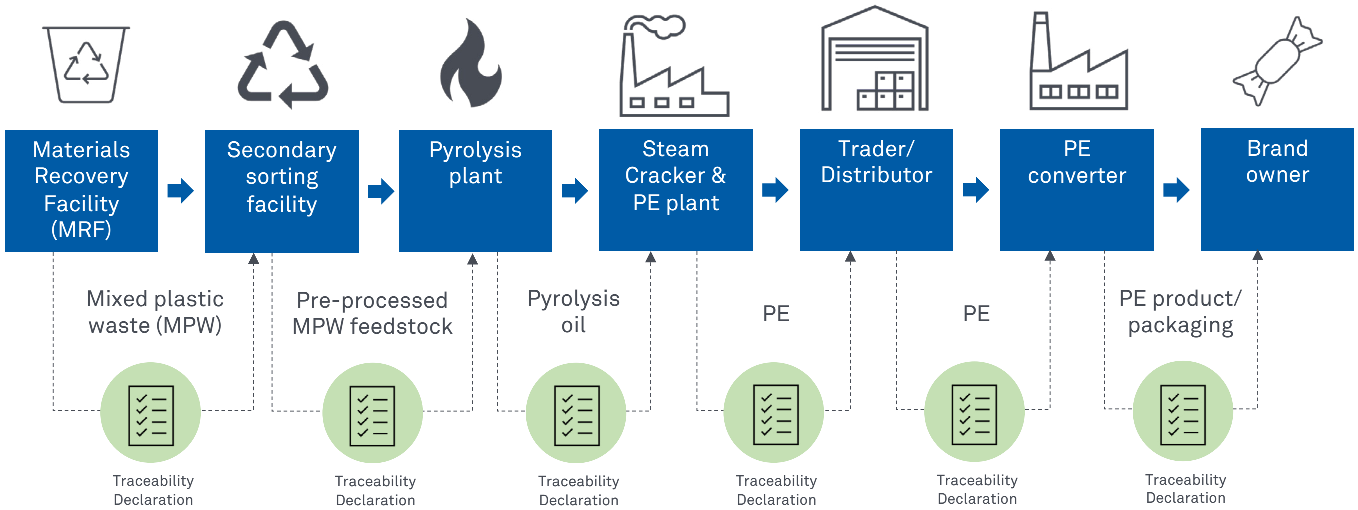


Figure 1. Example of traceability in a supply chain for circular polyethylene via pyrolysis

TABLE 1. SUMMARY OF SELECTED RECYCLED OR RENEWABLE PLASTIC CONTENT VERIFICATION SCHEMES ADAPTED FROM HANN 2022, EUNOMIA 2021 AND INDEPENDENT RESEARCH.

	ISCC PLUS	REDcert^2	APR	GRS	Recyclass	RSB
Publishing/ certifying organisation	International Sustainability & Carbon Certification System GmbH	REDcert GmbH	Association of Plastic Recyclers	Textile Exchange	Plastics Recyclers Europe	Roundtable on Sustainable Biomaterials Association
Geographic scope	Global	Global	North America	Global	Europe	Global
Supply chain scope	Full supply chain	Full supply chain	Recycling facility	Recyclers, Manufacturers, brands, retailers, traders	Product and semi-finished product	Full supply chain
Recognition of other schemes	None	ISCC PLUS, RSB, UL, SCS	Unclear	None	EuCert Plast	None
Mass balance allowed	Yes	Yes	Yes	No	No	Yes
Allocation of co-products	Free and fuel use excluded	Free	Unclear	N/A	N/A	Unclear
Credit transfer allowed between sites within same corporate entity, conditions	Yes, in same country or sharing inland border	Yes, if less than 2,000km apart	No	N/A	N/A	Yes, no geographic limitations

MASS BALANCE

Mass balance is a chain of custody approach with a long track record used by many industries such as forestry, cocoa and aluminium, to track the attribution of sustainable origin products in complex manufacturing and distribution systems where products with different characteristics are blended and physical segregation is impractical. For example, fairtrade orange juice is processed together with non-fairtrade inputs and the resulting amount of fairtrade product is calculated and traced based on an audited and 3rd party certified mass balance.

Mass balance is critical in the creation of sustainable plastics as it allows the use of existing petrochemical plants and co-processing with conventional feedstock to produce circular-attributed and bio-attributed plastics. This means that the capital investment required to produce such sustainable materials is significantly reduced, enabling existing facilities to enter and build scale in circular markets.

Circular and fossil feedstock is physically mixed and processed into products in the example in Figure 2. Physically, all products will contain a proportion of circular content governed by the ratio of the circular and conventional feedstock and any process losses that may occur. Mass balance bookkeeping allows the attribution of circular content to a specific proportion of the products produced in the process, allowing claims of circular content up to 100%. Importantly, no more circular product can be claimed then the amount of circular feedstock used whilst accounting for any process losses. Importantly, it must be chemically possible for the circular feedstock to end up in the product that is claimed as circular.

A mass balance is confined to a specific time period in which the sustainable feedstock is processed and sustainable products are sold. The maximum period will be defined by the certification scheme but is typically up to 3 months. The processing of sustainable feedstock will generate mass balance credits based on a conversion factor that takes process losses into account. Mass balance credits are then depleted by selling product claimed as sustainable. Some schemes allow credit balances to go negative during a mass balance period but at the end of the period the credit balance must be positive. Positive credit balances may then be transferred to the next period if certification is maintained.

Mass balance credits are site specific, however some schemes will allow the transfer of credits between sites of the same corporate entity under certain conditions. ISCC PLUS for example allows credit transfer for the same type of product if both sites are in the same country or share an inland border, and both sites hold a valid certificate.

It should be noted that mass balance is one of three approaches to chain of custody management relevant to sustainable plastics. The other two approaches are physical segregation and controlled blending and are typically used for mechanically recycled plastics where recycled material is not mixed with virgin or blended at a known proportion without any chemical reaction taking place. The approach used for chain of custody impact the claims that businesses in the supply chain can make. Whilst physically segregated mechanically recycled plastics can be claimed as having recycled content or being derived from plastic waste, circular plastics produced via chemical recycling using mass balance must be referred to as recycled-attributed material according to the latest guidance by ISCC PLUS and Plastics Europe [PE 2023]. Similarly biobased plastics that use mass balance should be referred to as bio-attributed material. This nomenclature ensures that sustainability claims are transparent to end users.

ATTRIBUTION MODELS

Attribution describes what can and cannot be counted as sustainable in the mass balance chain of custody approach to the production of circular-attributed and bio-attributed plastics. Attribution rules differ depending on scheme or region, reflecting the evolution of regulatory frameworks and objectives.

By one definition [Hann 2022], there are 5 levels of attribution as outlined in table 2.

The chemical reactions that occur in the production of industrial chemicals such as plastics are often highly complex and generate typically more than one product. Whilst it is straightforward to account for losses such as exhaust gas or effluent, the accounting for valuable co-products can make attribution of mass balance credits more complicated.

Figure 3 shows the example where 10t of certified circular pyrolysis oil is co-processed with 90t of virgin naphtha in a steam cracker to produce monomers for plastic production.

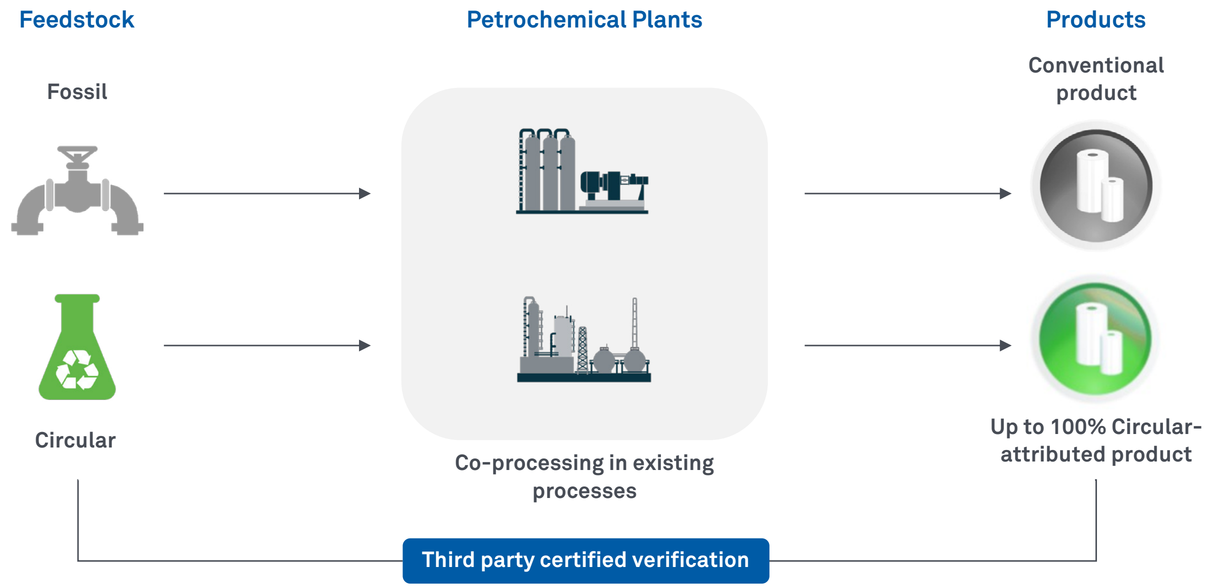


Figure 2. **Mass balance attribution of circular content from feedstock to products**

TABLE 2. MASS BALANCE ATTRIBUTION RULES RELEVANT TO SUSTAINABLE PLASTICS

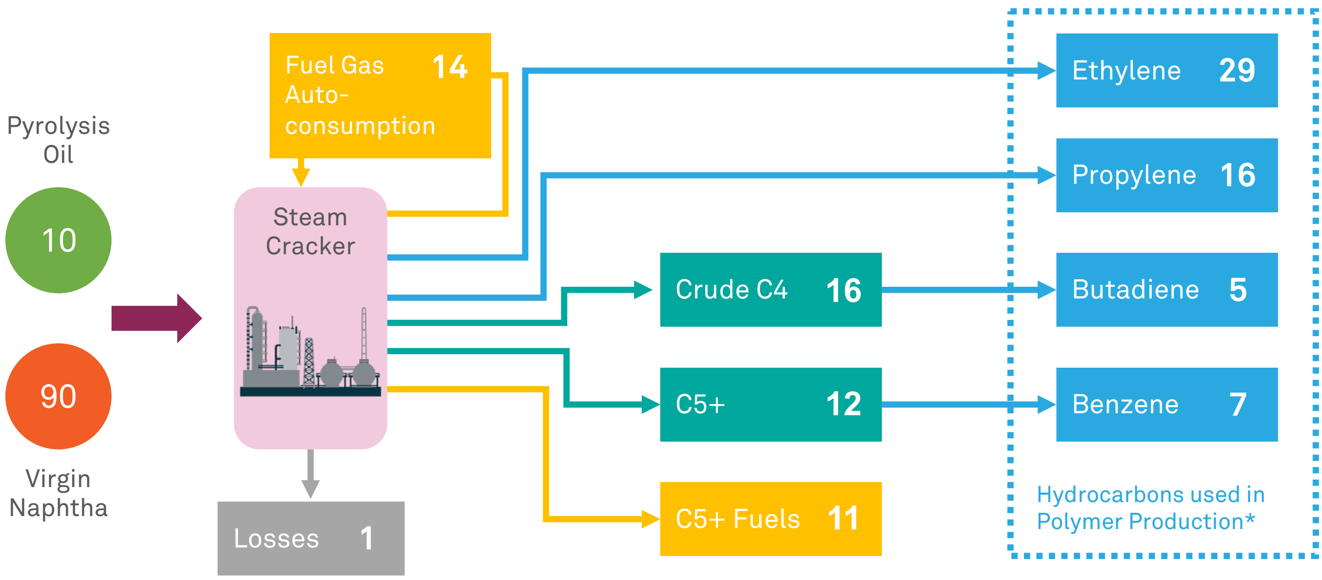
Attribution level	Permitted inclusions
A Proportional	Sustainable content can only be attributed on a proportional basis, i.e. in proportion to the physical yield of the specific output
B Polymers only	Sustainable content is accrued for all outputs that are raw materials for polymer manufacture, and then attributed freely amongst these outputs
C Fuel use excluded	Sustainable content is accrued for all outputs that are not used as fuel either internally or sold on to third parties, and then attributed freely amongst these outputs
D Auto consumption excluded	Sustainable content is accrued for all outputs that are not used as internal fuel to power the conversion process, and then attributed freely amongst these outputs
E Free	Sustainable content is accrued for all outputs except for process losses (waste), and then attributed freely amongst these outputs

The resulting ethylene, propylene, butadiene and benzene will be mainly used for the production of polymers and rubbers, though they may also be used in the manufacture of other important industrial chemicals. The process will also yield other hydrocarbons as part of the crude C4 and C5+ fractions that will be used in the manufacture of other chemicals (C4 and C5+ refers to the number of carbon atoms within the molecule). A proportion of the C5+ fraction is not suitable for chemical manufacturing but is typically used as a blend stock for gasoline and other fuels. Fuel gas (predominantly methane and hydrogen) is typically used as fuel in the furnace of the steam cracker which operates at a process temperature of 800-900°C. Process losses in the steam cracking process are minimal as the process has been optimised over many decades to extract as much value as possible out of the reactants.

The most straightforward attribution model is the free attribution (E in Table 2) of mass balance credits accrued across all products, accounting for process losses. This would mean that 99% of the mass of certified pyrolysis oil input (9.9t) can be attributed to the product(s) of choice, for example ethylene. At the other end of the spectrum sits the proportional attribution (A) that does not allow the attribute of mass balance credits from one product to another. In that case only 2.9t of certified circular ethylene can be claimed, 1.6t of circular propylene, 0.5t of circular butadiene, etc. An in between position is the fuel use excluded (C, aka fuels exempt) model that excludes accrual of mass balance credits on co-products that are used exclusively for fuel. This model would allow attribution of 7.3t (2.9t ethylene + 1.6t propylene + 1.6t crude C4 + 1.2t C5+) of mass balance credits to be allocated to the product(s) of choice in the example in Figure 3. Further variations include the polymers only (B) and auto-consumption excluded (D) approaches.

While ISCC PLUS has traditionally only recognised the free attribution approach (E), in the most recent revision of the standard in September 2023 ISCC PLUS also included an energy excluded attribution (C) [ISCC 2023]. The European chemical and plastics industry as well as major brand owners united in the Consumer Goods Forum are advocating for adoption of the fuel use excluded approach by the European Commission to meet recycled content targets under the upcoming Packaging and Packaging Waste Regulation [CEFIC 2023, CGF 2022]. The American Chemistry Council on the other hand supports the free attribution approach to allow the impact of recycling and sustainability to flow where it is most valued by society [ACC 2021].

It is important to recognise that recycled or biobased inputs used for the manufacture of plastics displace fossil fuel derived inputs and avoid the environmental impacts associated with extracting and processing of fossil inputs, regardless of their final use. A free attribution approach has the benefit of allowing industry to utilise existing infrastructure and support



	A	B	C	D	E
Allocated Recycled Ethylene (losses)	2.9 (71%)	5.7 (43%)	7.3 (27%)	8.5 (15%)	9.9 (1%)
Mass Balance Conversion Factor	0.29	0.57	0.73	0.85	0.99

A Proportional
B Polymers Only
C Fuel Use Excluded
D Auto-consumption Excluded
E Free

* Examples of typical output hydrocarbons that are commonly (but not always exclusively) used in polymer production. Benzene can be used as a precursor to styrene used in polystyrene. Butadiene is commonly used in various types of rubber.

Figure 3. Co-product allocation under different attribution rules in the example of co-cracking pyrolysis oil with virgin naphtha. Figure adapted from a report by Eunomia for DG Environment, European Commission [Hann 2022].

investments in new chemical recycling technologies and sustainable supply chains to build market capacity and scale over time. This in turn can assist in meeting national recycling and emission reduction targets. Transparency on the choice and permitted inclusions of the approach used will be important in supporting credible claims and avoiding the perception of greenwashing.

INCORPORATION INTO REGULATORY FRAMEWORKS

The incorporation of traceability and mass balance chain of custody approaches in regulatory frameworks is critical for circular and renewable plastics to contribute to meeting national and international recycling and net-zero targets and regulations. Spain has been the first country in Europe to recognise chemical recycling and mass balance in a law [Aimplas 2022]. Adoption of these concepts into the European Commission's Packaging and Packaging Waste Regulation is imminent, with biobased plastics now included in the draft regulation as counting towards mandated recycled content targets [Tudball 2023].

In Australia, the Department for Climate Change, Energy, the Environment and Water (DCCEEW) has released a discussion paper earlier this year on a national framework for recycled content traceability [DCCEEW 2023a]. In it the department recognises the mass balance approach as appropriate for traceability of recycled content through chemical recycling processes. It does not propose to define settings such as attribution approach under the framework but rather encourages businesses to choose or continue to use a certification scheme that meets their needs. This framework has been endorsed by Australia's environmental ministers and will likely be incorporated in upcoming mandatory packaging design standards that include obligations for the incorporation of recycled content as part of an overhaul of Australia's packaging regulations [DCCEEW 2023b].

CONCLUSION

With increasing demand for sustainable plastic products and packaging, and recycled content targets transitioning into regulatory obligations, supply chain traceability will play an increasingly important role in enabling businesses to make credible claims and accurately report the use of sustainable content. It will also provide for a level playing field based on transparent supply chains, combating false claims and reducing risk of fraud. Mass balance as a chain of custody approach has enabled the accurate tracing of circular and renewable content through complex chemical processes, allowing industry to take advantage of the scale and efficiency of existing virgin plastic manufacturing infrastructure.
Mass balance rules, including attribution models, are unlikely to adhere to a single global model. Whilst a level of global harmonisation of traceability frameworks is desirable, sufficient flexibility is required to incentivise participation and investment in each country or region.

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Qenos Pty Ltd

471 Kororoit Creek Rd
Altona Victoria 3018 Australia

Phone 1800 063 573
ABN 62 054 196 771

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