MURA TECHNOLOGY

WHITE PAPER

The Above-Ground Carbon Reservoir

Unlocking Waste Plastics as a Strategic Sovereign Resource

November 2026



Introduction

Net zero does not eliminate society's need for carbon. It changes where that carbon should come from, how long it remains in productive use and which products it should serve.

The energy transition is advancing through renewable energy, electrification and hydrogen. A parallel molecular transition is less developed. Fuels, polymers, solvents, coatings, pharmaceuticals and many functional materials still require carbon atoms. **For these sectors, the practical objective is not blanket decarbonisation but defossilisation: reducing the extraction of new fossil carbon while circulating carbon already present in the economy.**

Waste plastics occupy a distinctive position in this transition: they are concentrated hydrocarbon materials whose carbon and hydrogen have already been extracted, refined and manufactured into products. When these materials can no longer be retained through reuse or high-quality mechanical recycling, their molecular inventory should not automatically be destroyed by incineration or diluted into low-value outlets. It should be recovered and directed toward the highest technically and economically justified use.

The strategic question is therefore not whether the world will continue to use carbon as a resource, but where that carbon will come from.

Circular carbon can come from biomass, animal or plant fats and oils, captured carbon dioxide and end-of-life materials. Each will have a role, but waste plastics represent a uniquely concentrated and underutilised reservoir. **What was a waste management liability can, with suitable conversion technologies, become a sovereign strategic resource.**

As a feedstock, waste plastics are already aggregated and collected in population centres, requiring no additional land for feedstock cultivation. This feedstock offers logistical efficiencies and, with its molecular advantages, provides a potentially cost-competitive route to circular molecules. For countries that require carbon to support domestic manufacturing, the carbon resource embedded in waste plastic becomes a strategic sovereign asset to reduce reliance on international supply chains. The European Commission's Joint Research Centre (JRC) has calculated that the PPWR rules alone will create demand for an estimated 0.5-1 million tonnes annually of advanced recycled materials, significantly exceeding the EU's existing advanced recycling capacity of approximately 150,000-190,000 tonnes.[1]

Lowering the cost, increasing accessibility

How the attributes of waste plastics can help reduce the green premium

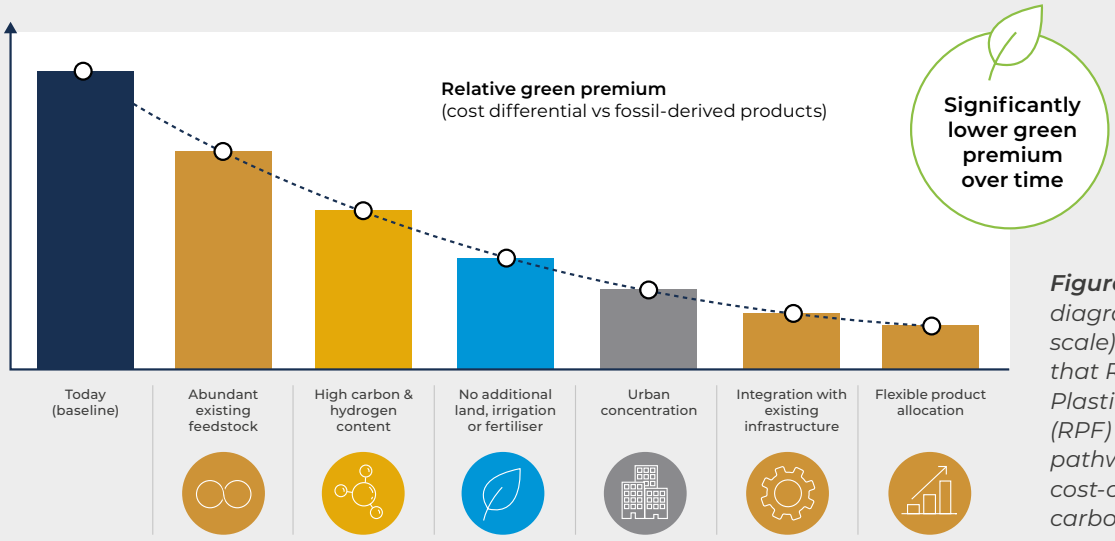


Figure 1: *Illustrative diagram (not to scale) showing that Recovered Plastic Feedstock (RPF) provides a pathway to more cost-competitive carbon molecules*

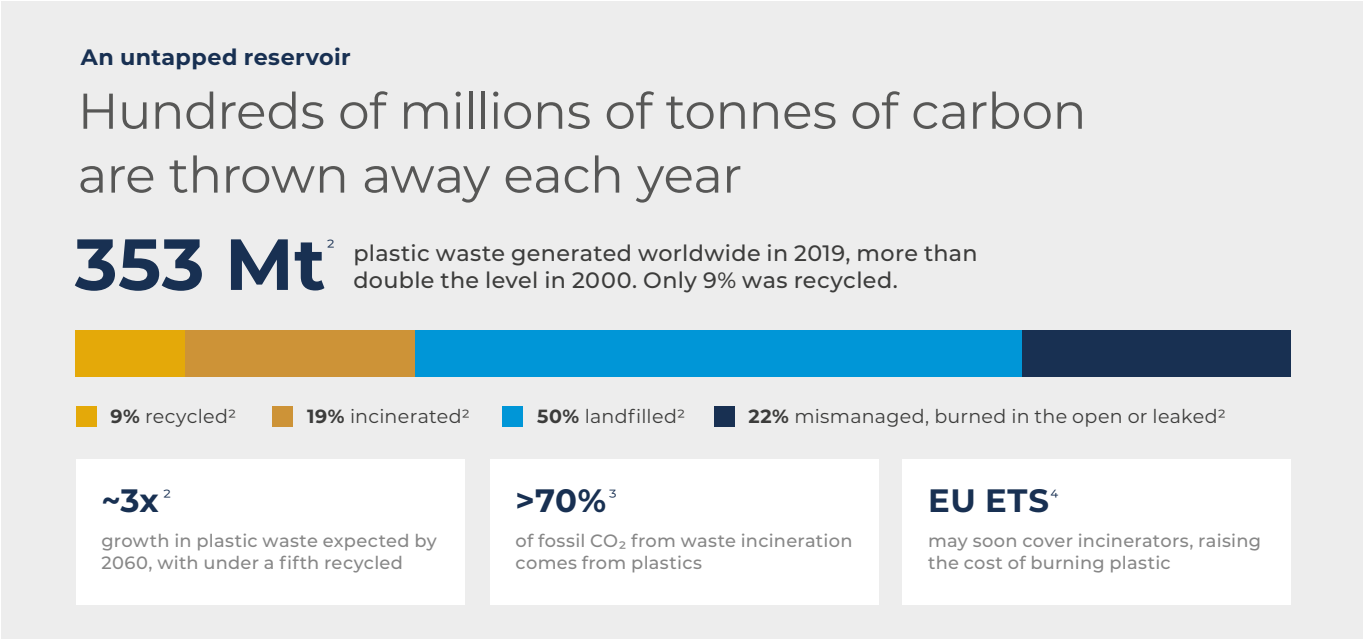


Figure 2: *Waste plastics are both an abundant and underutilised source of carbon*

But environmental performance alone will not deliver industrial-scale adoption. Circular carbon must also become economically competitive. Early low-carbon products almost always require a green premium over conventional fossil alternatives, especially when Scope 3 emissions are not valued or accounted for when comparing circular and virgin fossil molecules. While regulation, mandates and customer commitments can support initial deployment, truly large-scale adoption will depend on progressively reducing the premium through technological advances, scale, industrial integration and supportive market conditions. Waste plastics have several attributes that could support the long-term objective to minimise the green premium associated with recycled products:

- the feedstock already exists in abundance and does not have to be cultivated
- high carbon and hydrogen content can support strong potential product yields
- there is no incremental requirement for agricultural land, irrigation or fertilisers
- urban concentration may reduce collection and aggregation distances
- projects can potentially be integrated with established waste, refinery and petrochemical infrastructure
- products may be compatible with existing storage, distribution and manufacturing systems
- flexible product allocation can direct recovered molecules towards the markets offering the highest value

The above-ground carbon reservoir

Mura thinks of waste plastic as an urban carbon mining resource. This approach treats end-of-life plastic as an above-ground carbon reservoir and organises technology choices around a cascading principle: preserve products when possible, preserve polymers when practical, recover monomers where selective depolymerisation is viable, and recover molecular carbon from difficult mixed or contaminated streams. Energy recovery is the final option, not the default destination.

These recycled carbon molecules are selected and engineered to provide high functionality, strategic relevance and strong value per unit of carbon. Depending on feedstock and market, they may include circular naphtha and olefin precursors, aromatic intermediates, speciality solvents, lubricant components and carefully justified sustainable fuel components. Hydrothermal processing deserves serious consideration within this portfolio because hot compressed or supercritical water can provide an intense reaction environment for heterogeneous, difficult-to-recycle streams. Its potential strengths include feedstock flexibility, rapid heat transfer, direct liquid hydrocarbon production and possible integration with existing refinery and petrochemical assets. Nevertheless, Hydrothermal Liquefaction (HTL) should not be declared universally superior. Its case must be established feedstock-by-feedstock against pyrolysis, gasification, solvolysis and mechanical routes using consistent carbon, energy, environmental and economic boundaries.

Whilst the environmental benefits are clear, quantifiable and auditable, the expansion of advanced recycling capacity must have the commercial model at its core. Critical to long-term success, as in any production industry, must be to minimise the cost of producing circular carbon molecules. Projects should be assessed by carbon retention, product quality, displacement of virgin fossil feedstock, hydrogen and energy demand, impurity management, scale-up risk and credible market access. Policy should reward verified and certified recycled carbon outcomes with the certainty needed to enable investment decisions.

Recovered plastics have a molecular advantage

The world has a waste management challenge that needs to be restated as a strategic resource opportunity.

Plastic is central to modern life, and its consumption is projected to rise, with over 350 million tonnes of plastic waste being generated each year and less than 10% of this being recycled. But this waste material is a concentrated store of hydrocarbon molecules - these molecules being the world's most versatile carbon platform with one molecular framework supporting myriad end-use applications.

The same carbon molecules can generate dramatically different economic value depending on how they are used, but the key principle is to preserve carbon before burning. **To treat every hydrocarbon molecule as a reusable carbon asset.**

Table 1 below illustrates the molecular advantage of plastics. It closely mirrors the composition of virgin fossil oils in both carbon and hydrogen, but importantly, has an advantage over most other renewable or waste-based feedstock in oxygen content.

Plastic has a carbon advantage

Polyolefin-rich plastic waste is among the most carbon-dense solid feedstocks available for thermochemical conversion. In post-consumer packaging, carbon accounted for 84.3–85.5 wt% of the material[6]. The liquid products replicate this density, with pyrolysis oils containing 85.3-86.3 wt% carbon[7]. This places plastic waste within the carbon range of crude oil (about 83–87 wt%[8]). It is clearly above lignocellulosic biomass (about 40–55 wt%) and at or above most coals (about 60-85 wt%, dry basis[9]) (see Table 1). Waste plastics have a high carbon utilization index, defined as the mass of carbon that is retained in the recycled products. This is enhanced when using a high efficiency conversion technology, such as HTL. **HTL of waste plastics utilising Mura's Hydro-PRT® technology is differentiated from pyrolysis due to the use of supercritical water.**

Plastic has a hydrogen advantage

The hydrogen content of polyolefin waste is about 14 wt%. This matches the stoichiometric limit of a $(CH_2)_n$ chain (14.4 wt%, calculated) and is two to three times that of coal or biomass (Table 1). Plastics (the data here is for pure polyolefins as impurities and fillers are highly variable quantities) therefore have the highest hydrogen/carbon ratio of the feedstocks compared here, about 2.0 against about 1.6–1.7 for biomass and oil and about 0.7 for coal (calculated from the midpoints of the ranges in Table 1). Waste plastics have a high hydrogen utilization index, defined as the reciprocal of the mass of hydrogen required per tonne of product for any post-production hydrotreatment. On a mass balance basis, we have calculated that to achieve full saturation and removal of olefins requires circa 5 kg of hydrogen per tonne of oil produced by HTL of recovered plastics[10].

Plastic has near-zero oxygen content

Oxygen is the third main difference between plastics and other solid feedstocks. Polyolefin waste contains only 0.3 wt% oxygen in rigid PP and mixed-polyolefin fractions and 1.6 wt% in PE films, and the carbon and hydrogen together account for at least 98 wt% of the material. Pyrolysis oils contain less than 0.1–0.2 wt% oxygen, since oxygen leaves mainly as CO and CO_2. Compared with other feedstocks, plastic waste has an oxygen/carbon ratio of about 0.003–0.014, versus about 0.09 for coal and about 0.6 for biomass (calculated from the midpoints in Table 1). This matters because oxygen lowers heating value, promotes soot, and forms corrosive and fouling acids[11], and because steam crackers limit oxygen to about 100 ppm in the feed and 5 ppm in ethylene and propylene.

Non polyolefin plastics such as PVC, PET and nylon will increase oxygen content and, whilst they can be processed, the additional oxygen content will add to post-treatment costs.

	Coal	Crude oil	Biomass	Polyolefin waste
Carbon	60–85	83–87	40–55	84–86
Hydrogen	3.0–5.5	10–14	5.5–7.5	13.9–14.2
Oxygen	3–15	0.05–2	30–45	0.3–1.6

Table 1. *Elemental composition (wt%) of polyolefin waste compared with coal, crude oil and biomass[12]*

But what about contaminants?

Mixed plastic waste contains contaminants including halogens, nitrogen compounds, metals, particulates and oxygenates that can cause corrosion, catalyst deactivation, fouling and coke formation. Halogens, particularly chlorine from PVC, are the most problematic, often exceeding petrochemical specifications, while nitrogen and metal contaminants further impair downstream processing. Consequently, feedstock preparation to remove upstream of processing, or alternately post processing of oils such as product upgrading are required to produce petrochemical-grade products which can then be used freely in downstream applications.

Recovered plastic feedstock: structurally advantaged and growing in scale

Waste plastic is a resource that exists today and at scale. The growth in plastics correlates closely with growth in GDP per capita, population and urbanisation, while society is increasingly urbanised. According to the United Nations' World Urbanization Prospects 2025, 45% of the global population currently lives in cities, roughly 3.7 billion people, with two-thirds of global population growth to 2050 expected to occur in cities, further concentrating waste generation and opportunities for resource recovery.

It is estimated that 2.56 billion tonnes of municipal solid waste (MSW) was generated in 2022, projected to grow to 3.86 billion tonnes by 2050 under a business-as-usual scenario, with c. 12.5% of MSW being plastics[13]. This demographic concentration creates what might be termed an urban carbon nexus:

1. Products and fuels are consumed within and between population centres
2. Used plastics are collected and aggregated through municipal and commercial waste systems
3. Transport, aviation and maritime infrastructure is commonly located in or near the same urban-industrial regions
4. Refineries, petrochemical plants, ports, storage terminals and distribution systems are often already connected to these markets

Waste plastics therefore do not require the creation of a new supply chain or the dedication of land to feedstock production. The material already exists, is already concentrated around consumers and is increasingly subject to organised collection.

A city of one million people can generate around 75,000 tonnes of post-consumer plastic waste each year. Recovering the non-mechanically recyclable fraction could provide around 45,000 tonnes of feedstock, with the potential to produce approximately 250,000 barrels of recycled hydrocarbon products. This illustrates the scale of the carbon resource already concentrated within urban waste streams, and the opportunity to return that carbon to productive use. This is illustrated in Figure 3 where, for simplicity we show the energy content for use cases, but these molecules can also and preferably would be used in production of new packaging plastics.

Clearly, improvement to waste management is needed in many jurisdictions including in logistics and preparation; mixed plastics still require segregated collection, sorting, preprocessing and quality control. Nevertheless, aligning recycled-carbon production with established urban waste systems and nearby industrial infrastructure offers the potential to reduce transport distances, avoid feedstock aggregation from dispersed areas and improve security of supply. Collection, sorting and preparation remain important cost considerations, with competing demand for suitable waste streams from other recovery and recycling pathways. Europe currently has only around 150,000-190,000 tonnes of advanced recycling capacity[15], compared with 13.2 million tonnes of

Land-use independence

No farmland, no food competition, and supply that scales

Feedstock	Land-use risk	Competes with food	Water use	Scalability
Waste plastics	Very low	No	Very low	High ~3x by 2060
Used cooking oil, tallow	Very low	No	Very low	Limited
Farm and forestry residues	Medium	No	Very low	Medium to high
Corn ethanol	Medium	High	Medium	High
Soy, palm oil	High	Moderate to high	Medium	Medium to high

Table 2: *Qualitative comparison of alternative carbon feedstocks[14]*

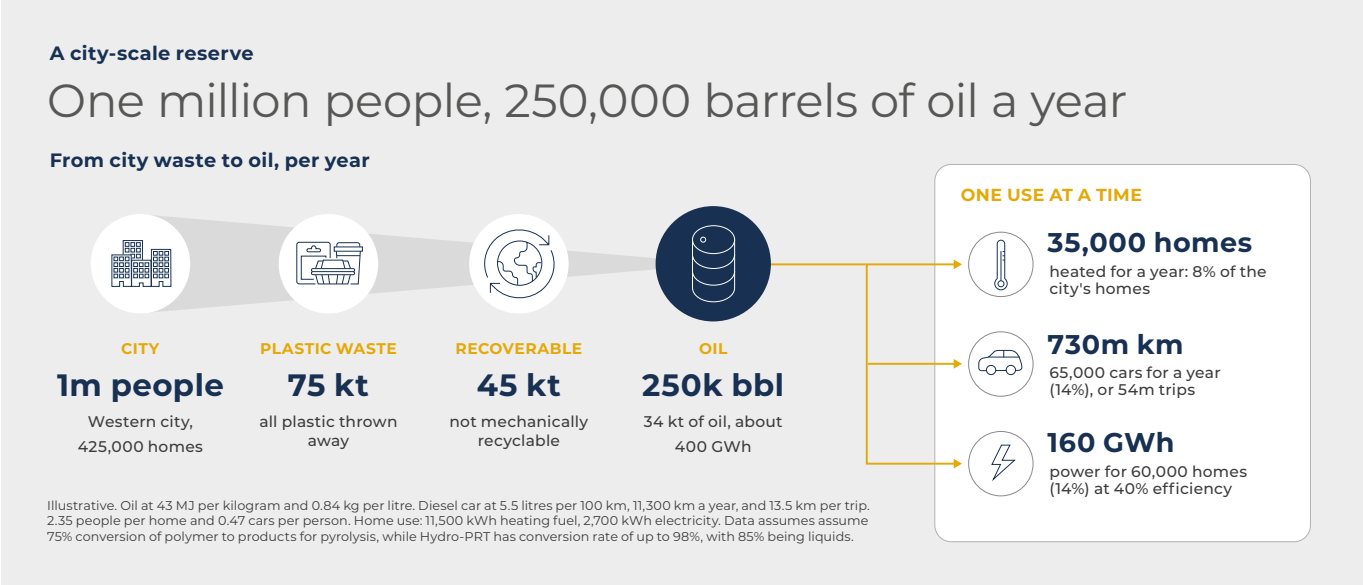


Figure 3: *Illustrative annual hydrocarbon recovery potential, based on energy uses rather than new plastic production, from non-mechanically recyclable plastic waste generated by a high GDP city of one million people*

mechanical recycling capacity[16]. With regulatory demand for recycled packaging content estimated at 0.5-1 million tonnes annually, expanding domestic advanced recycling could reduce import dependence, strengthen industrial resilience and improve security of supply.

This is a central economic advantage. The supply of recoverable carbon and the demand for sustainable carbon molecules can increasingly be brought together with the same geographic and carbon nexus.

As demand for Sustainable Aviation Fuels (SAF), Recycled Carbon Fuels (RCF) and circular products grows, the limit becomes the supply of waste-based feedstocks and their collection and processing costs.

Conversion Technology

Hydro-PRT® belongs to one of the most versatile categories of advanced recycling technologies, capable of processing mixed streams of contaminated plastic waste streams. Other technologies within this category include pyrolysis and gasification.

While **Hydro-PRT**, pyrolysis and gasification all recover carbon from waste plastics, they do so in fundamentally different ways. **Hydro-PRT** and pyrolysis preserve much of the carbon in the form of hydrocarbons, such as oils and waxes. In contrast, gasification breaks hydrocarbons down into simple molecules, primarily carbon monoxide (CO) and hydrogen (H_2), producing a synthetic gas (syngas) stream. This syngas is then used as a building block for the manufacture of new chemicals and products. Rather than preserving hydrocarbon molecules, gasification effectively destroys them and rebuilds new products from syngas.

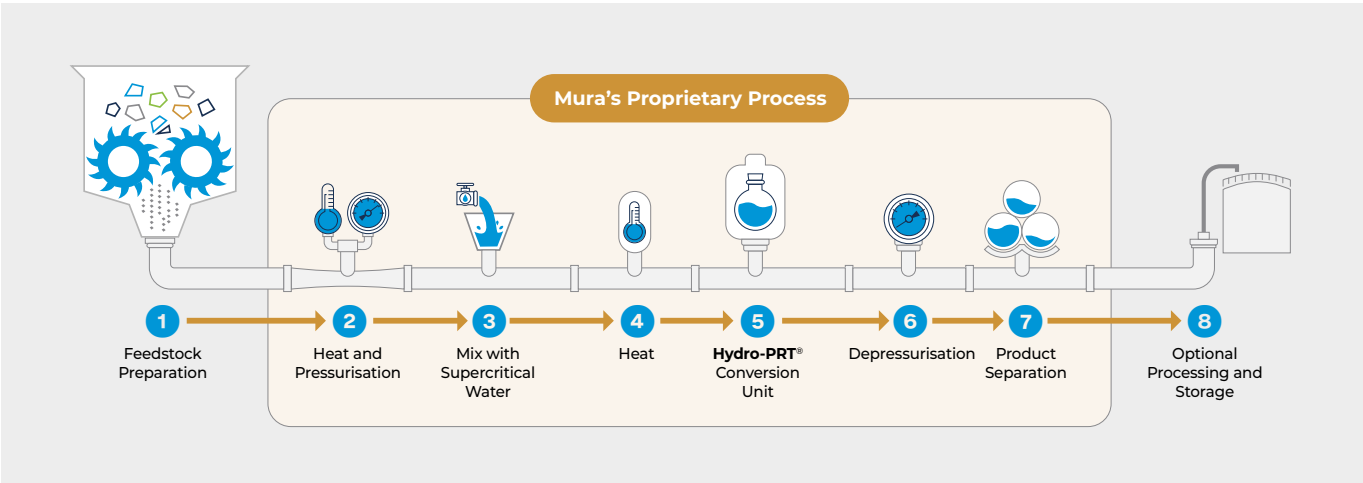


Figure 4: *Schematic of Mura's proprietary process,* ***Hydro-PRT***

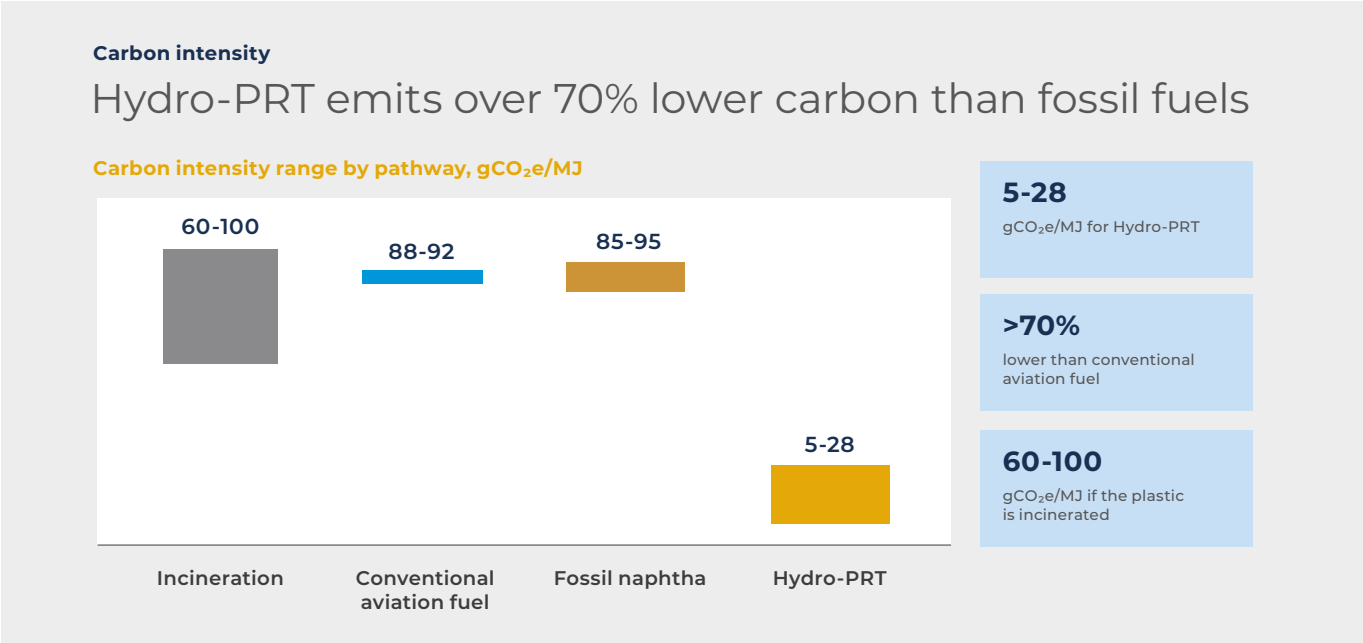


Figure 5: *Regulatory test: EU recycled carbon fuels must beat a 94 CO_2e/MJ fossil baseline by 70%.* ***Hydro-PRT****'s whole range passes*

Hydro-PRT provides significant opportunity to decarbonise the transport sector with emissions in the range of 5 – 28 g CO_2 eq. MJ, representing a saving of circa 70% when compared to fossil fuels and SAF, rising to over 80% when including the fuel in use and avoided incineration emissions outlined in the EU recycled carbon fuels LCA methodology (ISCC EU/RED III).[17]

Although **Hydro-PRT** and pyrolysis are both based on similar free-radical cracking chemistry, **Hydro-PRT** operates in the presence of water, providing several advantages. **Hydro-PRT** uses supercritical water (SCW) as a reaction medium during the conversion process. SCW is a highly diffusive solvent with exceptional heat transfer properties, enabling highly efficient plastic cracking. Direct contact heat transfer between the SCW and plastic feedstock creates a highly reactive and controllable environment in which water and plastics interact throughout the conversion process. This promotes rapid reaction rates and high conversion efficiencies while stabilising valuable hydrocarbon products.

In addition to acting as a solvent and heat transfer medium, supercritical water helps control reaction pathways and facilitates the removal of unwanted contaminants from the process. As a result, **Hydro-PRT** can achieve higher conversion rates and produce greater yields of high-quality liquid hydrocarbon products compared with conventional pyrolysis technologies.

Valorising carbon through advanced recycling

Advanced recycling is increasingly recognised as a strategic component of a circular plastics economy, particularly for flexible, multi-layer packaging streams that are difficult to recycle mechanically. Flexible plastics contain highly refined hydrocarbons that have already undergone extraction, refining and polymerisation. Compared with energy recovery, advanced recycling preserves material value rather than merely recovering calorific energy.

Unlike incineration, advanced recycling retains carbon molecules in circulation and enables their reuse in future products, supporting the principle of keeping materials at their highest value for as long as possible. The JRC concluded that plastic waste management should prioritise material recovery in line with the waste hierarchy and recognised an important role for advanced recycling where mechanical recycling is not technically (or economically) feasible.[18,19]

Recovery of carbon molecules is maximised when mechanical and advanced recycling complement each other[20]. Advanced recycling converts mixed plastic waste into hydrocarbon feedstocks that can readily re-enter existing petrochemical infrastructure, displacing fossil-derived naphtha and reducing dependence on newly extracted oil and gas resources. Liquid hydrocarbon yield should not be equated with recycled material yield. The proportion qualifying as recycled content depends on the final application and applicable regulatory accounting rules. Outputs used as fuels are treated separately from plastic-to-plastic recycling.

Academic studies have calculated that more than five barrels of oil extraction can be avoided for every tonne of plastic processed via **Hydro-PRT**, increasing to over seven barrels at larger commercial scales[21]. This contribution is consistent with wider International Energy Agency[22] analyses identifying recycling and alternative feedstocks as key levers for reducing emissions from the chemicals sector.

Evidence from our product

Our distillate is far cleaner than refiners require

Property	DGO spec limit
Boiling point range	130-360 °C
Carbon number range	C1O-C20+
Reduced GHG emissions	under 28.2 CO,e/MJ
Fossil-like blending qualities	density 785 kg/m
Ultra-low metals and halogens	ICP metals 0.l ppm; halogens <1 ppm
Exceptionally low viscosity	3.63 cSt at -20 °C
Excellent cold flow	-44.3 °C freezing point
Near-zero sulphur and oxygen	sulphur 1 ppm; oxygen below detection

Hydrocarbon balance	
63%	paraffins
30%	naphthenes
6%	aromatics
<1%	olefins

Table 3: *Analysis of Mura's Distillate Gas Oil (DGO) after mild hydrotreating, demonstrating low contaminant levels and key hydrocarbon characteristics*

Reducing the green premium

The molecular composition of waste plastics means that, once converted back into its fundamental building blocks, the circular oils require less post-processing than other waste-based feedstocks. However, JRC analysis indicates that significant cost barriers remain. It estimates that pyrolysis-derived naphtha currently costs around 1.5–3.5 times more than virgin naphtha and concludes that incremental innovation and scale alone are unlikely to close this gap in the short to medium term. The JRC identifies supercritical hydrothermal liquefaction as one potential avenue for the technological step change required. Mura's operating data and project models do indicate a significant improvement on production costs of naphtha compared to the JRC published figures for pyrolysis. This is a material cost advantage. Mura's **Hydro-PRT** technology also reduces contaminants to lower levels than other technologies. Mura has shown that its **Hydro-PRT** offtake products can be used in steam-crackers or in recycled fuels with minimal dilution or post-treatment.

Coking levels comparable to fossil naphtha in both radiant and convection sections have been found during steam cracker reactor trials. This represents a significant improvement on traditional pyrolysis oil from a fouling perspective, indicating the potential for **Hydro-PRT** products to be processed in existing steam cracking assets with reduced pre-treatment and dilution requirements, as illustrated in Figure 6.

We believe these features, producing clean oils with minimal post treatment, offer a cost-effective pathway to certified recycled carbon for new plastics and liquid fuels.

This is also why project location and industrial integration matter. Facilities situated close to suitable waste catchments, ports, refineries, chemical complexes and product users can seek to reduce feedstock transport, share utilities and infrastructure simplify product logistics and lower operating costs. Molecular recycling plants should leverage existing waste systems and petrochemical and refining complexes, combined with thoughtful project siting, as a near-term route to competitive operating economics.

In hard-to-abate sectors where electrification will reach its limits, recycled carbon fuels will be an increasingly vital and valuable pathway to defossilise. Feedstock costs for current SAF pathways via HEFA and bio-ethanol feedstocks represent c.30-70% of SAF sales prices[23], whereas feedstock costs for sustainable fuels plastics-derived products via **Hydro-PRT** would represent <20% of sales prices[24].

Financial robustness will require plants to have flexibility to adapt to changing demands of the market, often driven by evolving regulations. Advanced recycling plants will need to be able to produce a range of valuable sustainable hydrocarbons for both circular chemicals and recycled fuels markets to enhance commercial flexibility and reduce

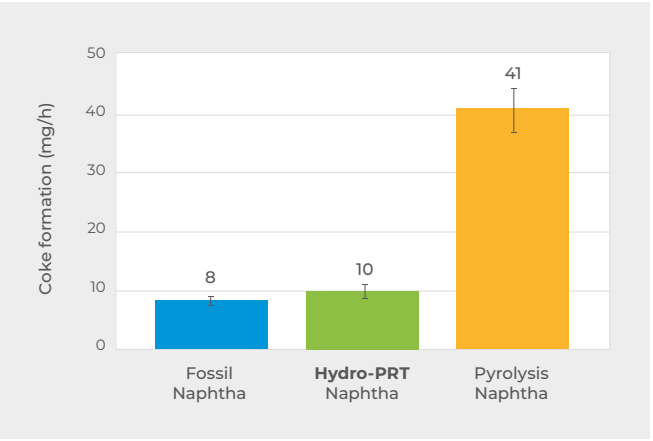


Figure 6: *Comparison of steam cracker coke formation potential for fossil,* ***Hydro-PRT*** *and Pyrolysis generated naphtha*

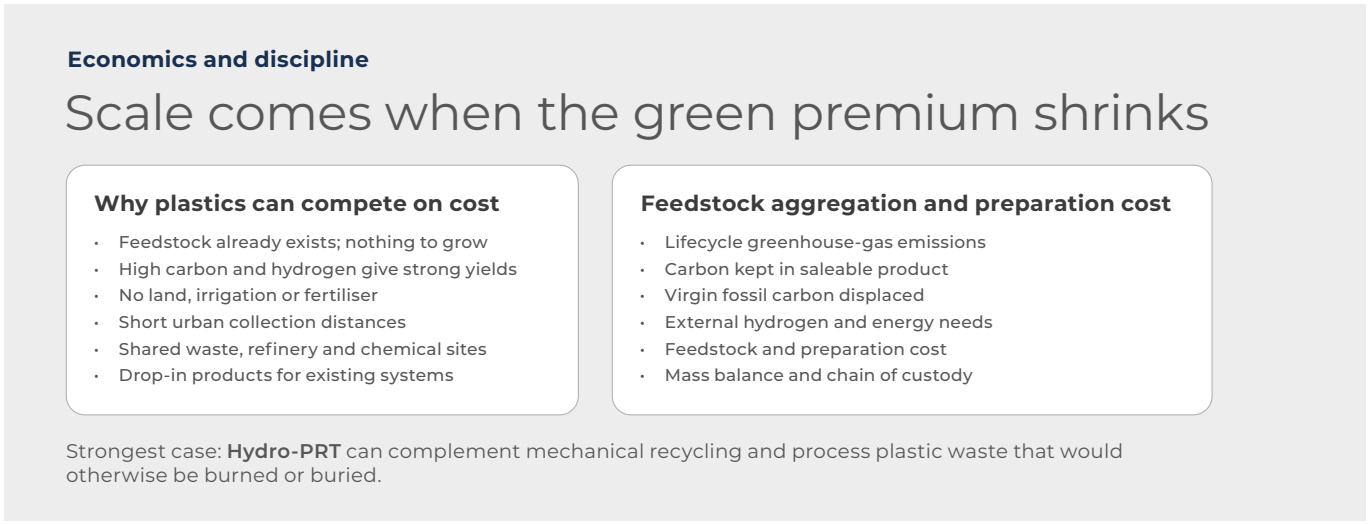


Figure 7: *Key economic and environmental factors influencing the competitiveness of waste plastics as a feedstock and the potential to reduce the green premium*

regulatory risk. This flexibility across offtake channels and end-use markets supports greater economies of scale while reducing market risks for investors.

Plastic feedstocks therefore hold the potential to reduce the price premium of recycled products compared to fossil equivalents in hard-to-abate sectors with a compliance need for sustainable fuels and circular products. This is before accounting for the reduced capital and operating costs for plastics-derived products due to their carbon and hydrogen intensity.

Summary – maximising value of carbon in the economy

The first phase of the energy transition has focused on decarbonising energy: renewable power, grids, batteries and electrification.

The next challenge is defossilising industry.

Modern economies cannot eliminate carbon molecules. Carbon remains essential to plastics, chemicals, aviation and marine fuels, solvents, lubricants and thousands of manufactured products.

The challenge is therefore not to stop using carbon but to transition to circular sources.

Waste plastics represent one of the largest and most underutilised above-ground carbon reservoirs available today. Unlike many alternative renewable feedstocks, waste plastics are highly concentrated hydrocarbons that have already undergone extraction, refining and manufacturing. When reuse and mechanical recycling are no longer technically or economically feasible, recovering embedded molecular value should take precedence over disposal or energy recovery. The objective is not simply improved waste management, but the creation of a circular carbon system that retains valuable molecules in productive use for as long as possible.

This molecular transition requires circular carbon infrastructure, such as **Hydro-PRT**, to recover carbon from mixed and hard-to-recycle plastic waste streams, converting them into hydrocarbon feedstocks that can re-enter existing refinery and petrochemical infrastructure thus reducing transition friction.
By displacing virgin fossil feedstocks, preserving material value and reducing demand for newly extracted oil and gas, advanced recycling can support the circularity objectives embedded in both industrial decarbonisation and defossilisation goals.

However, environmental performance alone will not drive large-scale adoption. Lasting transformation requires sustainable carbon solutions that are commercially competitive. Waste plastics offer a unique combination of abundant supply, high carbon and hydrogen content, urban concentration, infrastructure compatibility and flexible product markets. Combined with strategic project siting and integration into existing industrial ecosystems, these characteristics have the potential to reduce costs, improve resource efficiency and progressively reduce the green premium that continues to constrain many low-carbon technologies.

In summary, decarbonisation is the destination and transforms how the world produces energy.
But defossilisation is the industrial strategy for those parts of the economy where carbon molecules remain essential.

Ultimately, waste plastics should be viewed not as a disposal challenge, but as an abundant, strategic above-ground carbon resource capable of supporting a more resilient and economically sustainable future.

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