

Plastic's Potential

Supporting a Truly Circular Economy

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INTRODUCTION

Increasing global production and consumption of plastics is leading to accumulation of waste plastic in landfills and the environment, leading to societal, ecological, and economic challenges.

Plastics recycling rates remain low globally with only less than 10% of plastics that has ever been recycled and the rest sent to landfill or incineration [1]. The plastic pollution is also visible in water with estimated 8 million tons of plastic waste entering ocean waters every year [2]. The market value of all plastic is expected to reach 750B USD per year by 2025 [3] and well over 100B USD annually is assumed to be lost because of the waste that is not - but should be - recycled.

Plastic production and consumption are expected to double in next 20 years. If we want to achieve ambitious recycling and net-zero emission goals, the recycling rate (both mechanical AND chemical) must increase, and the unmanaged waste stream will need to disappear.

ADVANCED RECYCLING TECHNOLOGIES

Consumer demand, sustainability commitments and net zero carbon ambitions from industry and the public sector are already driving plastics recycling growth. It's estimated that for packaging only ca. 12 million tons of additional recycling capacity will be needed by 2030 in Europe and the US alone – with ca. 70 million tons of capacity worldwide. Commercialization of advanced (also called chemical) recycling is a crucial milestone to close this capacity gap.

Advanced recycling technologies process end-of-life and contaminated plastic waste that can be further refined to produce virgin polymers and chemicals. These technologies are not expected to compete with mechanical recycling that requires very clean and mono-material feedstock. Rather, chemical and mechanical recycling are expected to complement one another. Targeted feedstocks for chemical or advanced recycling are waste that cannot be mechanically recycled, usually due to contamination.

KBR's Hydro-PRT is a differentiated, stable, and scalable technology, based on a unique patented process from Mura Technology, using supercritical water (SCW) to convert plastic waste feedstock into commercial hydrocarbon liquid and gas products that can be used to produce new polymers delivering a truly circular economy.

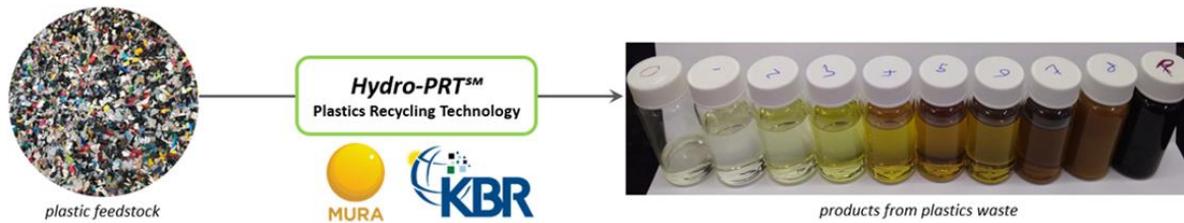


Figure 1. Plastic waste conversion to a mix of hydrocarbon products.

This unique plastic waste conversion process, called hydrothermal liquefaction, has been studied for over 10 years, supported by a demonstration plant since 2014. The first commercial facility is under construction, and start-up is expected by the end of 2022.

The differentiation of this process is a consequence of using SCW as a heating medium that is mixed with the plastic waste injected into the plastic melt stream. This direct contact heat transfer provides more efficient heat transfer and homogeneous reaction conditions. This guarantees more efficient and more homogeneous (i.e., with no temperature gradient) heat transfer when compared with other advanced recycling processes (e.g., pyrolysis) where plastic waste is heated by the reactor itself. As a result, the following differentiating factors should be highlighted:

- High-product yields: a negligible amount of char or unwanted by-products, combined with the ability to control reaction conditions contribute to high liquid products yields.
- Feedstock versatility: the ability to process mixed composite polymers, flexible and rigid plastics, and insensitivity to organic contaminants such as paper, card and biomass means the Hydro-PRT process can convert a wider range of waste plastic feedstocks.
- Scalability: the direct heat transfer between the plastic and the heating medium (SCW) leads to an efficient heat transfer mechanism. Scale up is a simpler process, not limited by vessel size.
- Product stability: the water surrounding the plastic in the hydrothermal reactors helps to calm the conversion reactions and limit unwanted cross linking of reaction products, producing a higher yield of a far more consistent and stable product.
- Product quality: the distillation of products allows for ready separation of fine solids and particulates into the heavy wax residue and water from the naphtha fraction. This provides high quality product oils (naphtha, distillate gas oil and heavy gas oil [HGO]) with low solids and water content. It also has a low chloride content, with most chlorides partitioning to the water phase rather than product oils.
- Operational flexibility: the process has a high degree of process control, allowing products with different distillation ranges to be produced. Operators can modify the products by altering operating parameters and plastic feedstock composition.

- Modular design: modular delivery of a complete hydrothermal conversion unit will save project time and costs and reduce project risks. At this moment, standardized production capacities of 20,000 and 50,000 tons/year per train are designed. Higher capacities can be reached by utilizing multiple trains.
- Well-studied and demonstrated technology: the technology has been successfully demonstrated on a pilot scale since 2014. A 20 thousand ton per year commercial scale plant utilizing the process is under construction by ReNew ELP in Wilton, UK - scheduled to start-up in 2022. Using end-of-life plastic as feedstock, this plant will produce gas and liquid hydrocarbon cracker feedstock alongside intermediate products. It will eventually process over 80 thousand tons of plastic waste feedstock with additional three 20 kta trains added later.

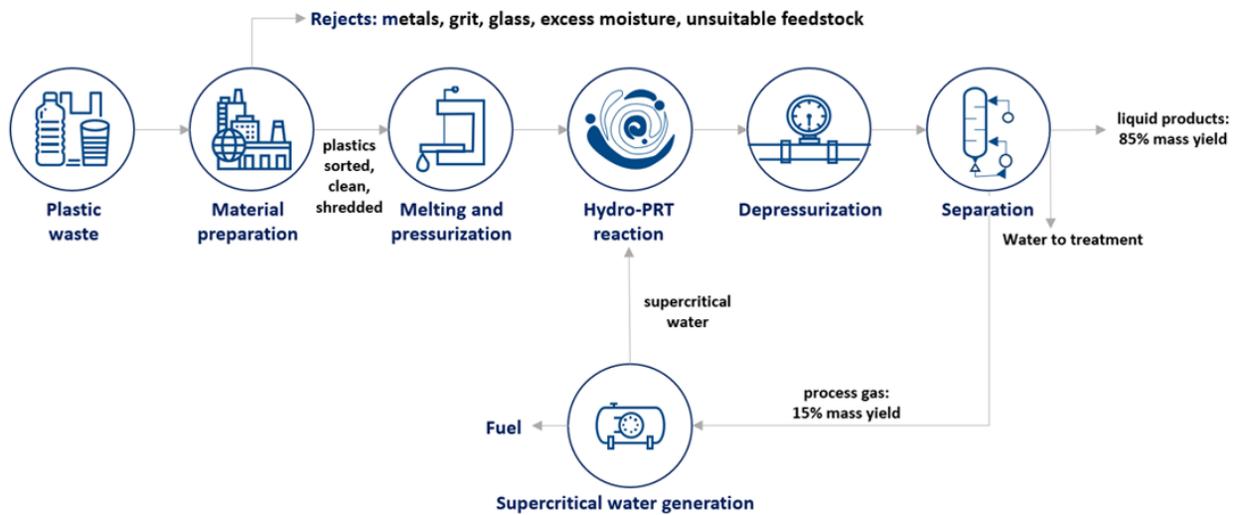


Figure 2. A scheme of the Hydro-PRT process from plastic waste to product separation step.

The Hydro-PRT reaction is the heart of the plastics recycling process. However, to ensure continuous operation, high yields and good product quality additional processes have been designed - both upstream and downstream from the Hydro-PRT reactor – to offer a holistic approach.

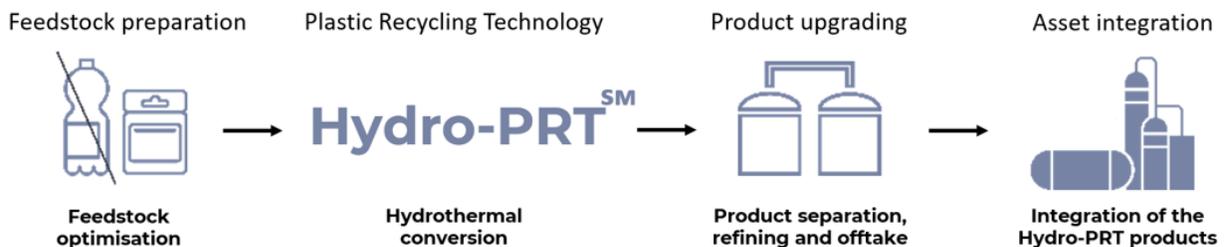


Figure 3. A holistic Hydro-PRT approach – optimizing the feedstock and upgrading the products

FEEDSTOCK

Before entering the reactor, feedstock should be optimized in a sorting process to minimize unwanted feedstock contaminants. This step takes place in the Material Preparation Plant (MPP). The operational benefits of an MPP include:

- Protection of downstream equipment: the MPP protects the extruder(s) and other critical downstream equipment from wear and tear, thereby increasing uptime.
- Optimization of operating conditions: reducing the variance of the feedstock, thereby allowing a better control to achieve optimal operating conditions and yield.
- Feedstock accessibility – bridging the gap between the waste specification available in the market and the Hydro-PRT process specification, unlocking more plastics streams for processing.
- Product yield – removing non-target materials, thereby increasing the product yield of the technology.
- Product quality – non-polyolefins introduce heteroatoms into the process, which will need to be removed via further hydrotreatment steps to achieve a high product quality.
- Cost optimization – non-target materials may affect liquid yields and quality which may have a negative effect on process economics. It can be cheaper to remove non-target materials via the MPP rather than accepting a reduced yield and lower product quality.

The targeted waste plastic feedstock stream, before entering the MPP, should consist of high polyolefin content to guarantee high hydrocarbon product yields. The key differentiator of the Hydro-PRT is feedstock flexibility as some impurities and unwanted materials are tolerated, including paper, cardboard, textile, or leather as well as non-polyolefinic polymers such as PS, PET, or PA. The content of chlorinated polymers should be minimized to maintain low halogens concentrations in the product. The feedstock does not require any drying step and can contain some moisture content. For the most optimal MPP design, specifics of the waste stream should be determined on a case-by-case basis – including composition, origin, and size of the components. The expected sources for Hydro-PRT feedstock could be post-consumer waste plastic (PCR), Materials Recovery Facility (MRF) residue or industrial waste and plastics intended for waste-to-energy incineration or landfills. Desired feedstock will be predominantly polyolefinic to reduce introduction of heteroatoms and maintain high product quality.



Figure 4. A visualization of the main part of the Hydro-PRT plant with tubular verticals reactor in the center.

PRODUCTS

The Hydro-PRT products consist of approximately 15% gas and 85% liquid hydrocarbon mix. The liquid hydrocarbons (Figure 5) can be separated by boiling temperatures into preferred fractions. Lighter fractions can be used as feedstock for production of new circular plastics or other chemicals while heavier ones can be processed further in refineries or used for base oil and wax production or fuel blendstock. The heavy wax oil can serve as an asphalt additive or coker feedstock.

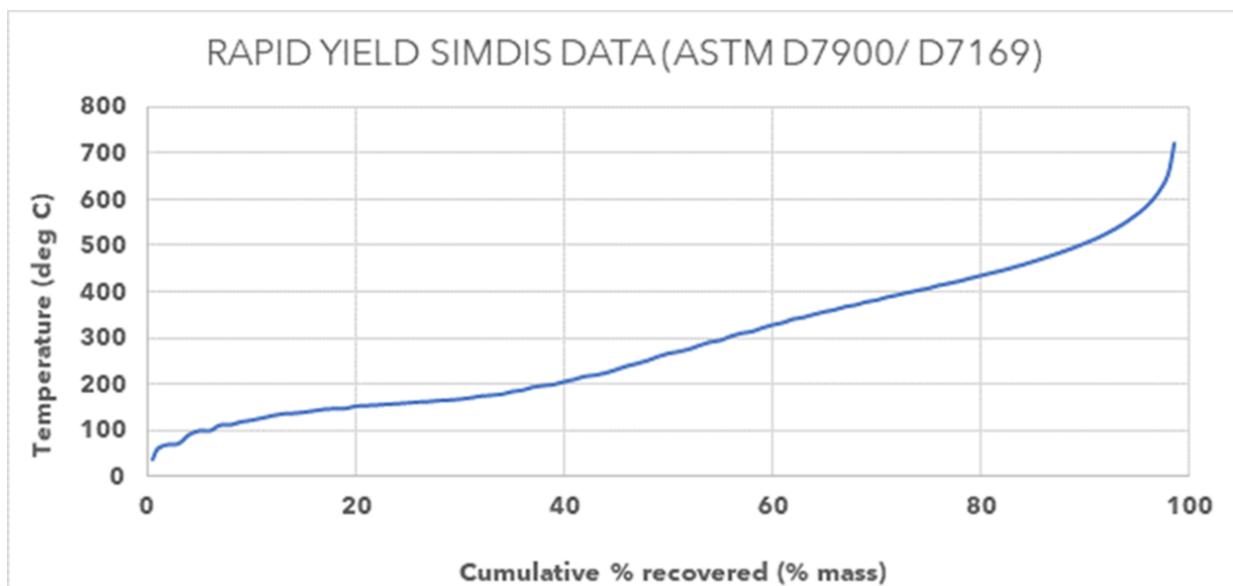


Figure 5. The boiling curve for a typical mix of liquid hydrocarbon products from the Hydro-PRT process.

The feedstock from plastic waste will count as fully circular and sustainable only if it can replace fossil-equivalent feedstock. After the PRT reactor, in order to substitute fossil feedstock without any limitations, the product quality can be improved via a simple upgrading process. This will adapt the products to the specifications of the downstream assets, like steam crackers, and can be accomplished via hydroprocessing of the products - similar to existing solutions for naphtha and gas oil upgrading. Dilution of Hydro-PRT products in usually much larger virgin feedstock streams can also be considered.

Additionally, integration of the Hydro-PRT products into refineries and crackers to produce new plastics, fuels and chemicals can be supported using sustainable technologies. This would ensure full process circularity and the creation of new polymers from plastic waste. Score™ is a high yield ethylene steam-cracking technology capable of upgrading heavy feeds and converting them into chemicals rather than fuels. Maxofin™ is an advanced fluid catalytic cracking (FCC) process to increase propylene yield from traditional FCC feedstocks. ROSE® is used to maximize the recovery of high-quality products from residues from bottom of the barrel byproducts and other feedstocks. Lastly, the Veba Combi-Cracker (VCC™) is a slurry phase hydrocracking/hydrogenation process for converting petroleum residues at very high conversion rates into high-quality distillates or synthetic crude oil.

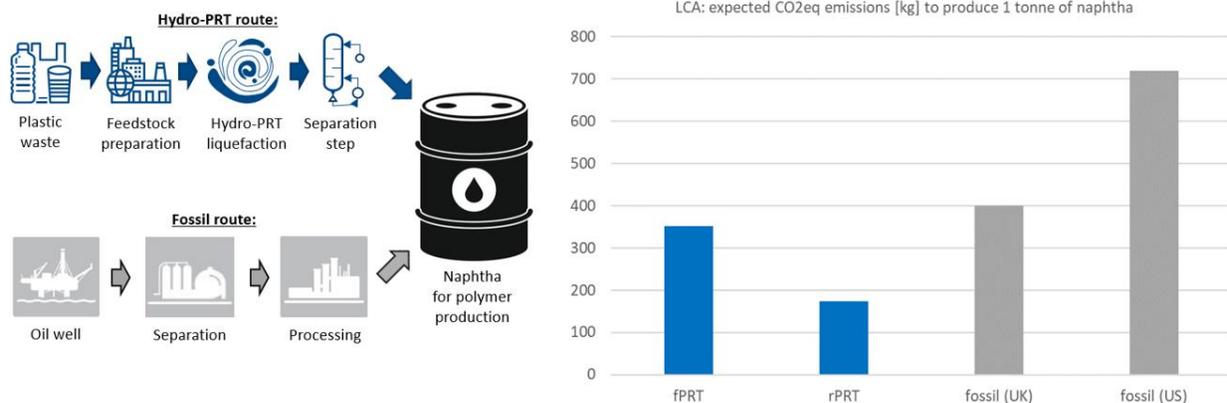


Figure 6. Carbon emissions for 1 tonne of naphtha produced from fossil feedstock (grey, UK method vs. US method) compared to Hydro-PRT feedstock (blue) using energy from fossil sources (fPRT) and renewable sources (rPRT). NOTE: for fossil-derived scenarios 20-50% CO₂eq should be added to account for methane fugitive emissions from oil wells.

SUMMARY

The differentiated Hydro-PRT process has the potential to play a significant role in closing the capacity gap in plastics waste recycling and contributing to the full circularity of plastics. Life cycle analysis (LCA) studies support a circular economy targeting minimized or even net zero greenhouse gas (GHG) emissions. Independent LCA studies on Hydro-PRT are about to be published demonstrating the clear environmental benefits of the technology. Utilizing this process to recycle contaminated, mixed plastics waste into new polymers is the path forward in order to achieve a circular economy, reducing plastics carbon footprint and the use of fossil-sourced feedstocks.

The net zero carbon sustainable strategies are focusing on fuel-exempt applications such as the production of plastics or other chemicals. Recycling plastics waste via the Hydro-PRT process generates no hazardous waste. The minimal waste produced falls out into the heaviest hydrocarbon product, which can be used in the construction industry, for example.

Through a licensing business model, KBR's Hydro-PRT allows customers to design, build, and operate an all-encompassing plastic recycling plant that has the capacity to take mixed and contaminated plastic waste feedstock and integrate it into existing assets.

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