

Chemical recycling as an alternative source of feedstock (but not only for petrochemistry)

Thermochemical Methods of Chemical Recycling – Feedstock Source

Main outputs for further use:

Pyrolysis → pyrolysis oil and BTX (replacement for aromatic fractions from coal tar).

Gasification → syngas for olefins, methanol and RCF / RFNBO fuels.

Current situation:

- Global plastics production ~460–520 Mt/year.
- EU: 18 operating units (289 kt/year), ~2.8 Mt/year planned.
- Key players: ExxonMobil, Neste, BASF ChemCycling, BioBTX.

Circular chemistry and petrochemistry – **from waste to basic Chemicals.**

Plastic waste and the needs of its material recycling

Global plastic **waste production** (~350 Mt/year) - EU (~43 Mt/year).

Realistically low rate of **actual recycling** - approx. 9% (currently mainly mechanical).

EU targets (50% recyclable plastic packaging by 2030) – requirements to increase recycling rates.

Mandatory recycled content (2030 - 30% PET, 10% FCM outside PET and 35% for other packaging), requirements for recyclability - the increasing role of thermochemical methods as a complement to mechanical recycling.

Mechanical recycling fails for mixed, contaminated and degraded plastics (PE, PP, PS, PET mixtures).

Growing volume of "**missing plastics**" – waste that cannot be efficiently sorted or mechanically recycled.

Overview of thermochemical methods

Pyrolysis (oil, BTX) and gasification (syngas)

Advantageous sources for chemicals and petrochemicals.

Main advantage - processing of mixed and contaminated plastic waste, which will not be processed by mechanical recycling.

The main goal is material recovery (plastic-to-chemicals) instead of incineration or landfilling.

Pyrolysis → pyrolysis oil (drop-in raw material into petrochemical or BTX fraction).

Gasification → syngas (CO+H₂) for the synthesis of basic chemicals and fuels.

Compared to depolymerization, thermochemical methods are more versatile for polyolefins and mixed plastics.

Promoting the circular economy: **replacing fossil raw materials** (diesel, aromatic hydrocarbons) with recycled carbon.

Pyrolysis: Principle and Outputs

Thermal decomposition of plastics without access to oxygen at 400-600 °C.

Particularly advantageous for polyolefins (PE, PP), polystyrene (PS) and mixed plastics.

Main outputs:

- Pyrolysis oil (60-80% yield) – raw material for petrochemicals.
- Pyrolysis gas (10-15% - light hydrocarbons for possible energy use).
- Char / solid residue (1-5% - carbon).

Options for further processing of the oil:

- Direct use as drop-in feedstock to steam cracker.
- Catalytic treatment → BTX (benzene, toluene, xylenes) – replacement of aromatic hydrocarbons e.g. from coal tar.

Advantage:

- High flexibility and compatibility with existing petrochemical plants.

Integration of pyrolysis oil and BTX fraction in petrochemical production

Pyrolysis oil after treatment (hydrotreatment, distillation) serves as a drop-in raw material for crackers.

Main petrochemical routes:

- Steam cracking → ethylene, propylene and other olefins (basic monomers for plastics)
- Catalytic aromatization – insitu x ex-situ (zeolites e.g. HZSM-5, Ga/Zn modifications) → BTX fraction

BTX made of plastics replaces traditional aromatic hydrocarbons from coal tar.

Application - production of polystyrene, PET, dyes, solvents, pharmaceuticals.

BTX represent key petrochemical raw materials (~40% of petrochemical volume, market value ~USD 200 billion/year).

Examples of technologies: ICCP (BioBTX/Agilyx), Sulzer GT-BTX, Encina.

Key projects and technologies - BTX

BioBTX – PETRA Circular Chemicals Plant (Delfzijl, Nizozemsko)

- Technology: ICCP (Integrated Cascading Catalytic Pyrolysis) – separated pyrolysis + ex-situ catalytic aromatization of vapors (HZSM-5 + Ga/Zn modification)
Capacity: up to 50kt/year mixed plastic waste/year → circular BTX
- Status - planned start of production in 2027
- "Circular Aromatics" project with partners ExxonMobil Chemical Holland, Ketjen, University of Twente – extension and optimization of ICCP for contaminated mixtures
- Collaboration with Zeopore – up to 100% increase in BTX yield thanks to new mesoporous zeolite catalysts

BioBTX + Agilyx

- Combination of Agilyx pyrolysis (for difficult-to-recycle plastics) + BioBTX catalytic conversion
- High quality BTX meeting petrochemical industry specifications

Key projects and technologies - BTX

Encina Development Group

- Catalytic pyrolysis of plastics directly to BTX/P (benzene, toluene, xylenes + propylene)
- Planned projects: Major plants in the USA, Saudi Arabia, India and Southeast Asia
- Status: Some major projects (e.g., in Pennsylvania) canceled/delayed due to funding and local resistance
- Other collaborations with e.g. Blue Planet, BASF

BTX yield in practice:

- Typical: 17-19 wt % (per input material) for mixed waste
- With a high PS/PET content: up to ~37% aromatic oil, of which BTX makes up a significant part.
- With advanced catalysts: the potential to double the yield.

Key projects and technologies- pyrolysis

ExxonMobil (Exxtend™)

- Thermal pyrolysis with ex-situ catalytic treatment of pyrolysis oil and subsequent use in a refinery (integration into steam crackers). Baytown Plant (USA) – doubling production to ~227 kt/year (in 2025), target 454 kt/year globally by 2027; Cracker integration

Quantafuel

- Catalytic pyrolysis, BASF's strategic partner, unit in SKIVE

OMV (ReOil®)

- Thermal pyrolysis PE, PP, PS, plant in Schwechat (16kt/year) – most of the refinery fuel outputs - hydroprocessing / FCC but part also for plastics (processing in Borealis)

Pyrum Innovations

- Dillingen plant (20kt/year), thermal tyre pyrolysis. Supplier for BASF

Key projects and technologies- pyrolysis

Plastic Energy (TAC technologie®)

- Thermal pyrolysis, plants in Seville, Almeria (33 kt/year), joint venture with Sabic – plant in Geleen (20 kt/year), plant with TotalEnergies in Grandpuits (15 kt/year), plan for operation in Ghent (up to 1160 kt/year)

Mura Technology (HydroPRS)

- Hydrothermal proces (Supercritical Liquid), PE/PP, Teesside UK (80 kt/rok)

Wastewise Group

- Thermal pyrolysis, processing 24 kt/year of plastic waste
- Supplier for NESTE

BlueAlp – supplier of modular pyrolysis technologies

- Italy - Pettoranello del Molise (20kt/year, plan to launch 2026)
- Cooperation with Shell – plan for units in NL (30kt/year)
- Belgium – Indaver project Plastics2Chemicals (P2C) in Antwerp, depolymerization of polystyrene and polyolefins for Ineos and TotalEnergies (26 kt/year)

Key projects and technologies – pyrolysis oil processing

Neste

- Treatment of purchased pyrolysis oil (e.g. from Wastewise Group – thermal pyrolysis), unit in Porvoo 150 kt/year
- Cooperation with BASF and Covestro

SHELL

- Treatment of purchased pyrolysis oil, MDU unit in Moerdijk (50 kt/year)

BASF (ChemCycling®)

- External purchase of pyrolysis oils, our own technology of processing into products - Ccycled pyrolysis oil products – sophisticated system of use in production, integration into the process

SABIC (TRUCIRCLE™)

- External purchase of pyrolysis oils, similar to BASF but more focus on customer-specific properties

Gasification: Principle and Outputs

Partial oxidation at 700-800 °C with limited access to oxygen, or decomposition by plasma (1100-1400 °C) to form syngas (syngas: CO + H₂). The composition of Syngas can be controlled, for example, by the input of water vapor.

Outputs:

- Syngas for chemical synthesis (70-85 %)
- Ash / vitrification as a by-product (in the case of plasma, vitrification – slag, 5-10%).

Syngas from plastic gasification (CO+H₂) is a **highly flexible raw material**

- **material use** (chemicals) and energy (**RCF fuels**). Potential for **RFNBOs** when combined with renewable hydrogen.

Advantages of technology:

- High tolerance to contaminants (PVC, halogens, metals) – suitable for highly mixed wastes
- Also applicable to composite materials
- Can be used for biomass and sludge processing

Gasification: Syngas processing

Main petrochemical processing routes:

- Methanol pathway – Methanol synthesis → Methanol-to-Olefins (MTO) process – Output: ethylene, propylene and higher olefins (basic monomers for plastics)
- **Fischer-Tropsch synthesis** – conversion of syngas to liquid hydrocarbons – Output: synthetic diesel, diesel, light fraction for cracking into olefins
- **Ammonia and nitrogen fertilizers** – Haber-Bosch process ($H_2 + N_2$) – An important way for the chemical industry
- **Direct hydrogen production** – Water-Gas Shift reaction + separation → net H_2 for refineries and chemicals

Syngas enables the production of a wide range of basic chemicals from waste plastic.

Recycled Carbon Fuels (RCF) and Renewable Fuels of Non-Biological Origin (RFNBO)

Syngas from plastic gasification can also be used outside of conventional petrochemicals.

Recycled Carbon Fuels (RCF) – defined in EU RED III – fuels made from recycled non-recyclable carbon (plastics) – Count towards the targets of renewable fuels in transport.

Potential for RFNBOs (Renewable Fuels of Non-Biological Origin) – combination of syngas with renewable ("green") hydrogen – production of e-fuels (e-methanol, e-diesel, e-SAF) – fully decarbonized variant.

The importance of gasification in this area:

- Contribution to the decarbonisation of aviation and maritime transport.
- Possibility of higher price premiums and certifications.
- LCA emission savings of up to 70-85% compared to fossil fuels.

Use of thermochemical methods for petrochemistry - summary

Replacing fossil raw materials with recycled carbon

- Pyrolysis oil replaces diesel in cracker.
- BTX replaces coal tar flavorings.
- Syngas replaces syngas from natural gas reforming.

Reducing your carbon footprint

- LCA study: GHG saving 50-75% (pyrolysis) to 70-85% (gasification + RCF).

Drop-in compatibility

- Products meet petrochemical specifications.
- Integration into existing equipment (crackers, reforming units).

Supporting the circular economy + meeting EU legislative goals

- Closing the plastic carbon cycle.
- Meeting the objectives of PPWR, RED III.

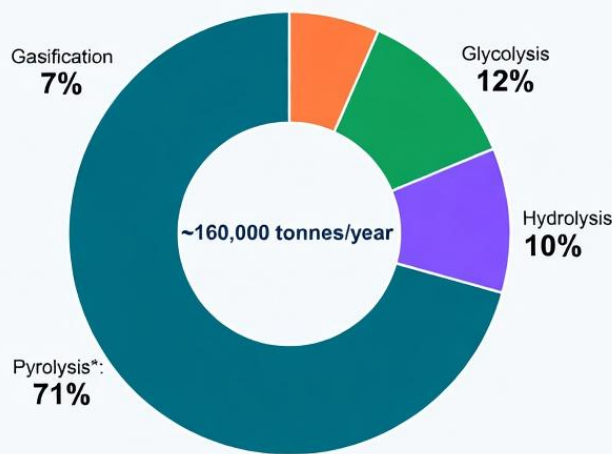
Chemical recycling capacities in the EU

Current status:

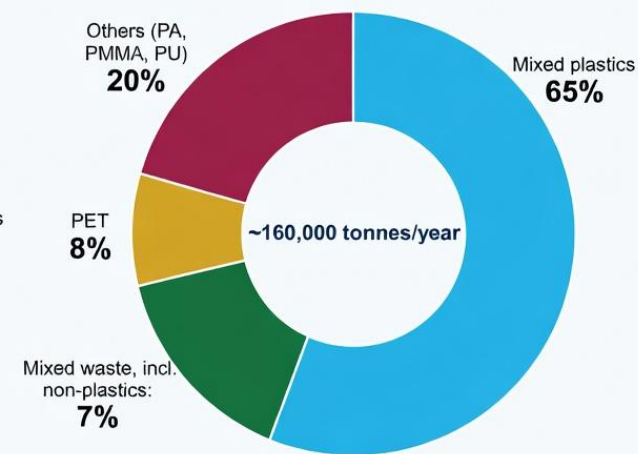
- Operating current capacity: 289 kt/year (18 plants, mainly pyrolysis).
- No commercial gasification at scale, only test units (Enerkem, VTT Bioruukki, Millenium Technologies, PDI).
- Several cancelled projects (Agilyx & NextChem, OMV, Plastic Energy & Virgin Redcar, Quantafuel...).

Chemical recycling capacity in Europe is largely represented by pyrolysis at the moment

Total installed (input) capacity, Europe, operating (as of Apr 2024)
By technology



Total installed (input) capacity*, Europe, operating (as of Apr 2024)
By feedstock



* Includes pyrolysis-based projects (all types, for all relevant polymers), excludes tire pyrolysis

** Includes pyrolysis-based projects (all types, for all relevant polymers), gasification, glycolysis and hydrolysis projects.

Source: ICIS Recycling Supply Tracker – Chemical, 2024

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Challenges and limits of thermochemical recycling projects

Planned units:

- Total planned capacity: ~2.8-3.1 Mt/year by 203.
- Pyrolysis: ~1.95 Mt/year, Gasification: ~0.9 Mt/year.

The most active countries are the Netherlands, Germany, Spain, Belgium, Finland.

Technical challenges:

- Contaminants (Cl, N, metals, oxygen) → required pretreatment and cleaning.
- Deactivating catalysts in BTX production.

Economic challenges:

- High investment costs (CAPEX).
- Competitiveness compared to cheap fossil diesel.

Regulatory and market challenges:

- Mass-balance and RED certification for RCF.
- Project delays (9 EU projects cancelled or suspended).
- Public and market acceptance ("chemical recycling" vs. "plastic-to-energy").

Future and trends

Key trends in Europe:

- By 2030: target of ~3 Mt/year of plastics processed by thermochemical methods.
- Strong growth of pyrolysis + gradual onset of gasification.
- Hybrid systems (pyrolysis + catalytic treatment + MTO).

Legislative support:

- EU Packaging and Packaging Waste Regulation (PPWR).
- RED III – Recycled Carbon Fuels (RCF) Recognition.
- Mandatory recycled content in plastic packaging.

Technological development:

- Advanced catalysts for higher BTX yields (>30% target).
- Better syngas purification and integration with renewable hydrogen (RFNBO).
- Digitization and AI optimization of processes.

Long-term goal:

Circular petrochemicals – most of the olefins and aromatic hydrocarbons will come from recycled plastics.

Conclusion

Thermochemical methods (pyrolysis and gasification) represent a **key technology** for the material recovery of plastic waste.

They enable:

- Production of circular olefins and BTX (substitute for fossil and tar raw materials).
- Production of Recycled Carbon Fuels (RCF) and potentially RFNBOs.
- Significant reduction in dependence on fossil resources.

Current status:

- Rapidly growing number of projects.
- Pyrolysis already in the commercial stage.
- Gasification in the advanced pilot/demonstration phase.

Chemical recycling is not a competitor to mechanical recycling, but a necessary complement to achieving the EU's high recycling targets. It is a way to replace fossil raw materials in chemistry.

Thank you for your attention.

Contact:

Ing. Radek Pjatkan

Česká technologická platforma pro udržitelnou chemii (SUSCHEM CZ)

E-mail: radek.pjatkan@schpcr.cz

tel.: +420 734 829 431

www.suschem.cz



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