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Thermolysis of plastic waste: Reactor comparison

Muhammad Saad Qureshi

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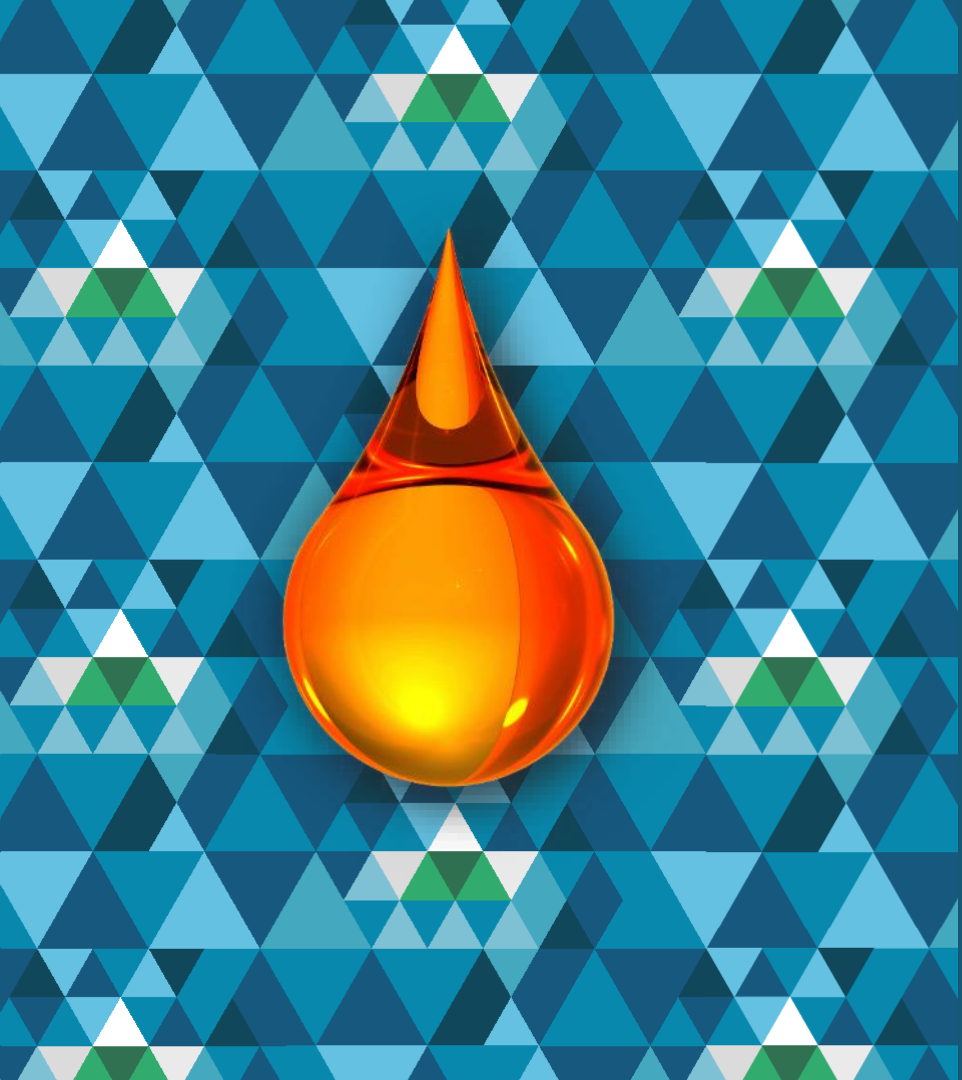


Thermolysis of plastic waste:

Reactor comparison

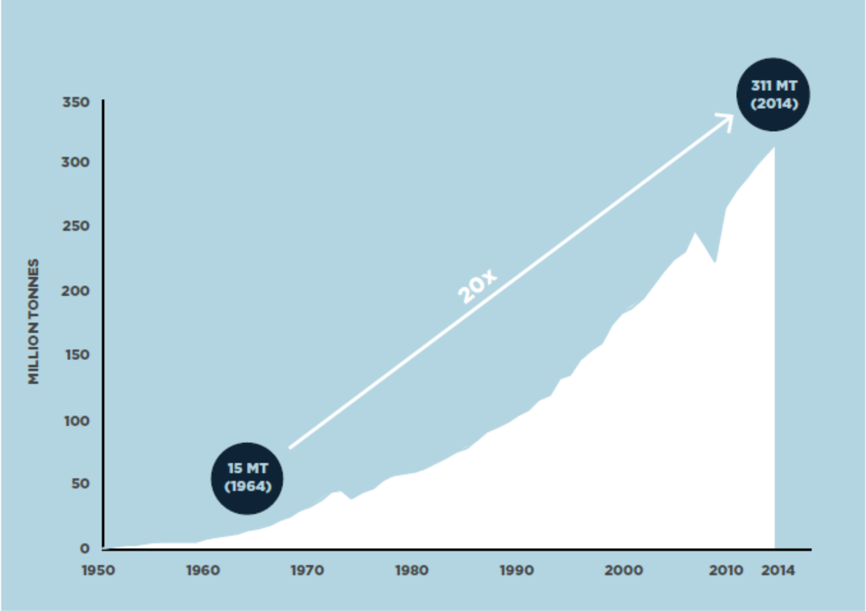
Muhammad Saad Qureshi
Christian Lindfors
Anja Oasmaa

Pyroliq 2019, Cork, Ireland

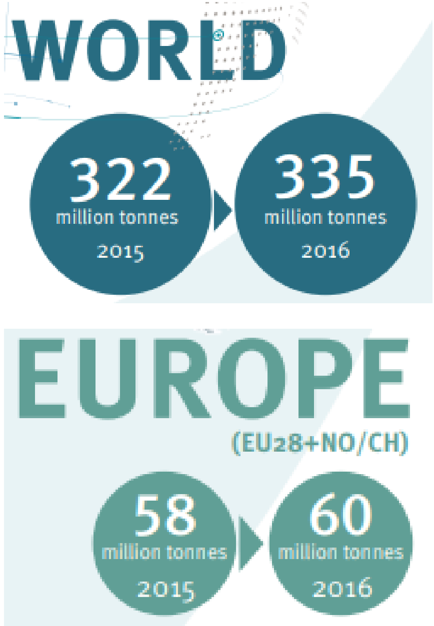
Contents

- Thermolysis of plastic waste
- Common types of reactors
- Commercial systems
- Factor affecting product spectrum
- Lessons learnt

Plastic demand



Note: Production from virgin fossil-based feedstock only (does not include bio-based, greenhouse gas-based or recycled feedstock).
Source: PlasticsEurope, *Plastics – the Facts 2013* (2013); PlasticsEurope, *Plastics – the Facts 2015* (2015).



Plastic demand by sector - Europe

Plastics Europe – Plastic facts 2017

Plastic waste come in all shapes and sizes and usually not alone…

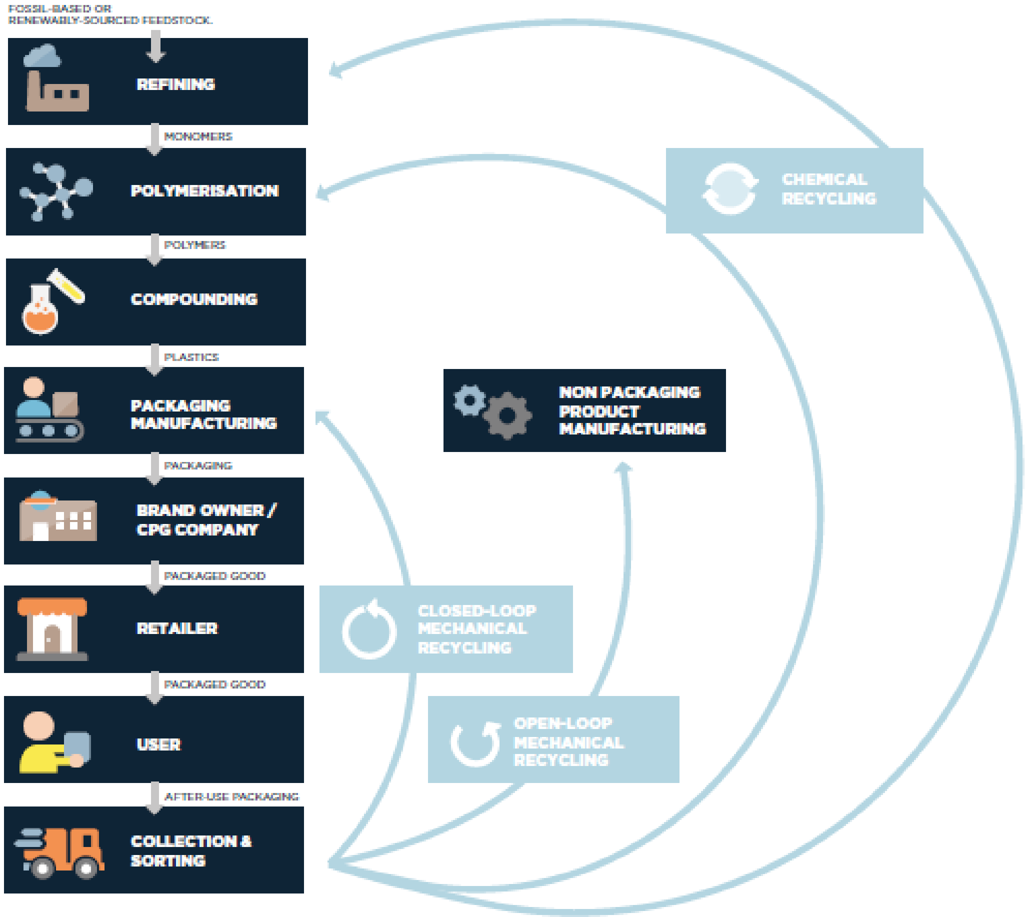


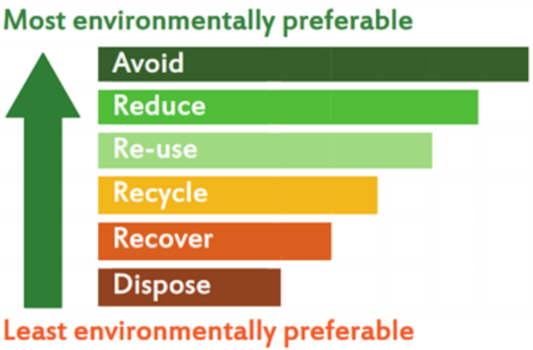





Picture credits: Google images

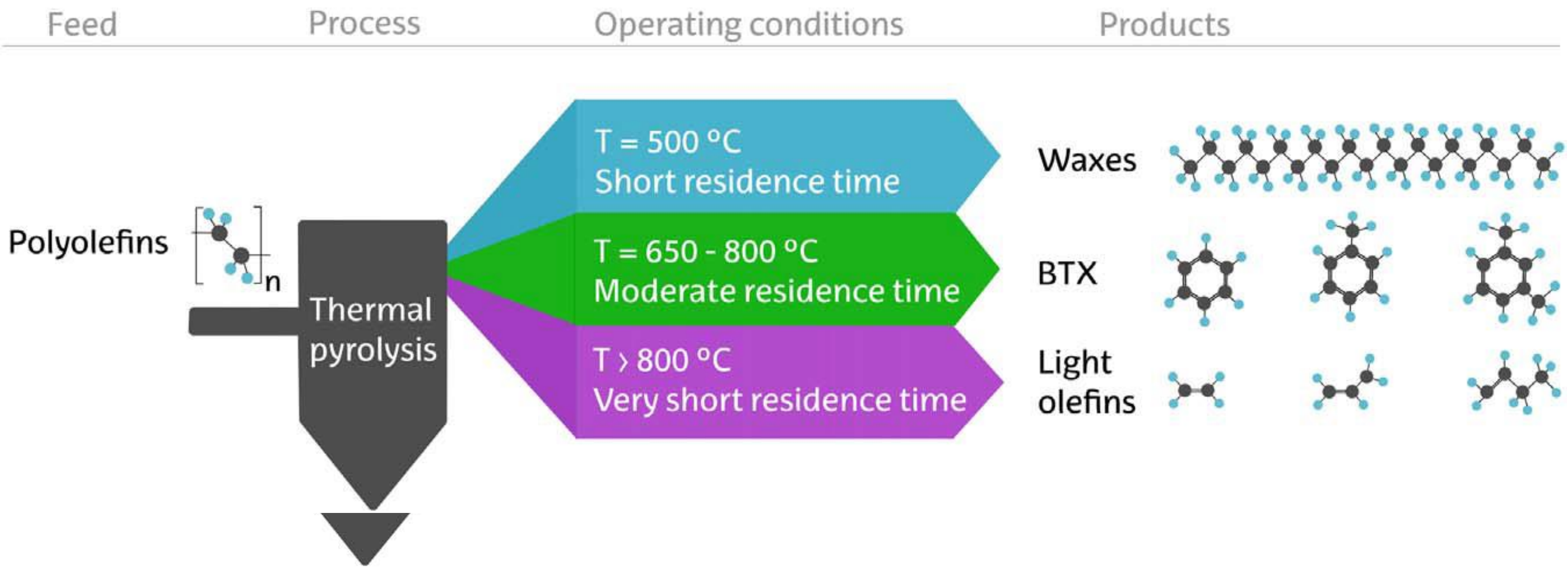
Plastic recycling options





New plastics economy 2016– Ellen Mc Arthur Foundation

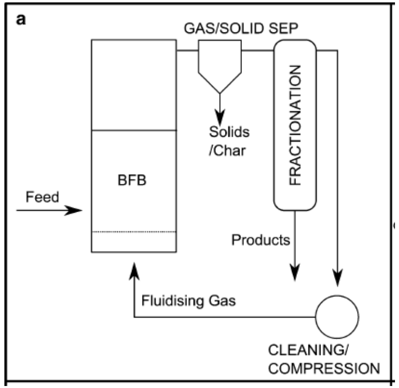
Typical thermolysis products



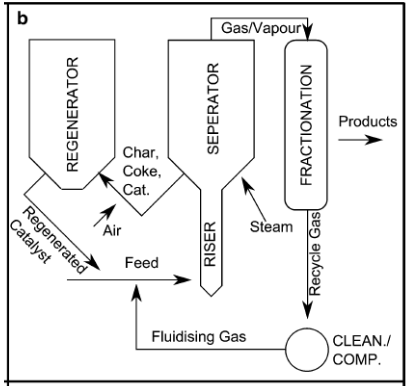
Conditions for the selective production of waxes, BTX (Benzene, Toluene and Xylene) and light olefins from polyolefins by thermal cracking.

DOI: 10.1016/j.rser.2017.01.142

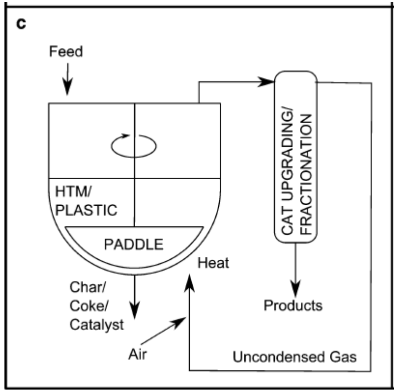
Common reactors for plastic thermolysis



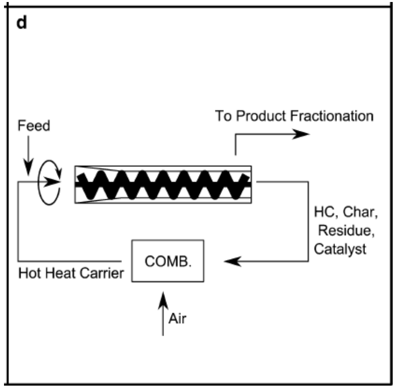
Fluidized bed



Fluid catalytic cracking



CSTR reactor

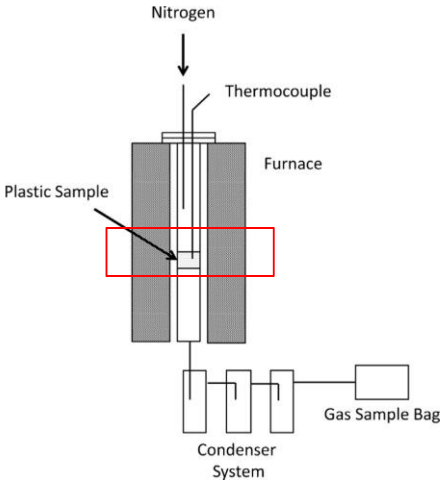


Screw reactor

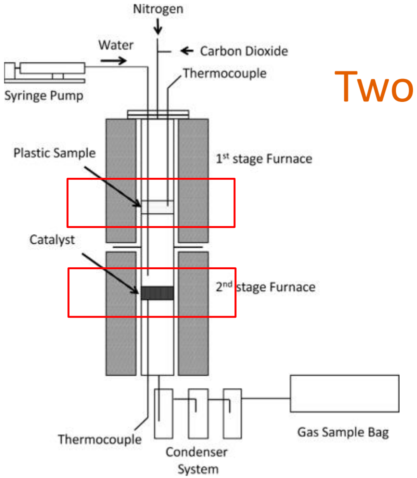
DOI 10.1007/s12649-011-9067-5

1. Fixed bed reactors

Single stage



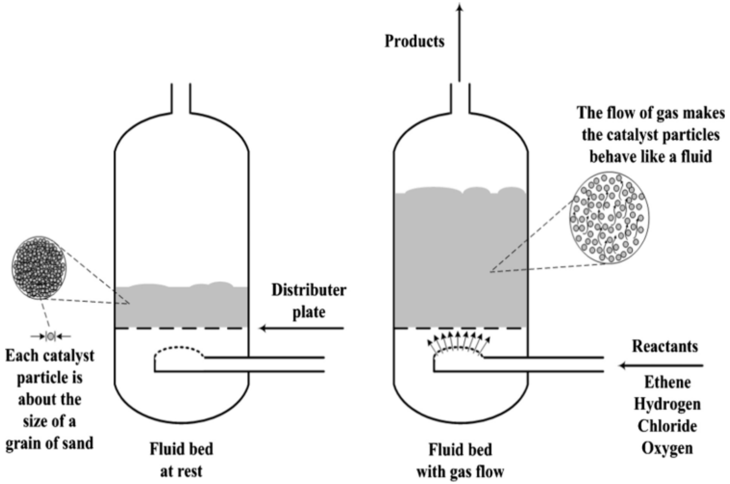
Two stage

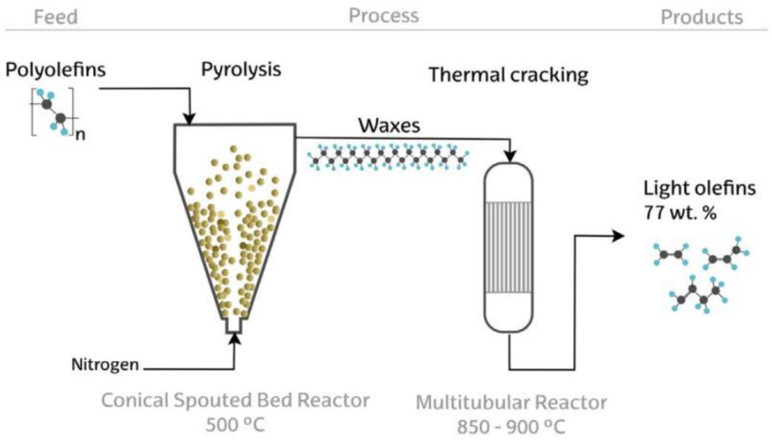


Advantages	Disadvantages
Simple construction and easy to build	Temperature controls are difficult
Economical operation and maintenance of the unit	Batch operation and scale up issues
Two staged process for selective productions	Bed channelling causes uneven distribution of products
Both thermal and catalytic processes are possible	Coke deposition causes blockages and increase pressure drop

SAAD, J.M., NAHIL, M.A. and WILLIAMS, P.T., 2015. *Influence of process conditions on syngas production from the thermal processing of waste high density polyethylene.*

2. Fluidized bed reactors



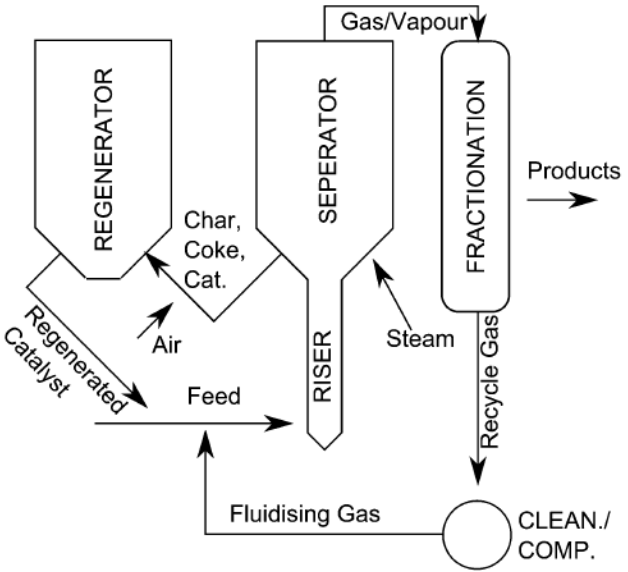


Advantages	Disadvantages
High heat and mass transfer and solid mixing regimes	Complex design and operation
Significant versatility on gas residence times	Bed defluidization may occur
Liberty in product distribution – residence time	Melt plastic attaches to the surface of the bed particles.
Continuous operation possible (scalable)	A pilot plant is often necessary for scale up
Both thermal and catalytic processes are possible	Attrition of particle can be serious in CFB
Maintaince costs are moderate	Capital costs are higher for CFB than BFB

ANUAR SHARUDDIN, S.D., ABNISA, F., WAN DAUD, W.M.A. and AROUA, M.K., 2016. *A review on pyrolysis of plastic wastes.*

3. Fluid Catalytic Cracking (FCC)

- Widely used in conventional refinery (VGO to gasoline)
- Two zones in the reactor
  - Hot particulate catalyst contact with feed creating cracking products and coked catalyst
  - Catalyst is regenerated by burning
  - Hot catalyst is recycled to the riser for additional cracking of feed
- Feedstocks are cracked to gaseous components and further separated to fuel gas,
- Large energy requirement
- Good solid polymer mixing

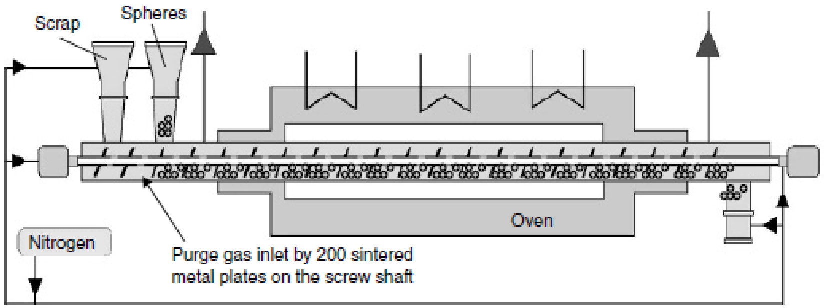


Schematic FCC unit

BUTLER, E., DEVLIN, G. and MCDONNELL, K., 2011. Waste polyolefins to liquid fuels via pyrolysis: review of commercial state-of-the-art and recent laboratory research.

4. Screw/Auger kiln reactors

- Typically made up of tubular reactor and a screw conveyor.
- Residence time can by varied by the varying the speed of the screw and length of the reactor
- Spheres (metal/ceramic) avoid coke build up and improves heat transfer.
- High amounts of thermoset materials (e.g. WEEE) can be pyrolyzed
- Efficient removal of chlorine from the mixed waste
- Selective zone heating from outside.
- Several Rotary kiln commercial process are online (feedstocks biomass, municipal solid waste, Tires, shredder light fractions, WEEE, cables etc.)

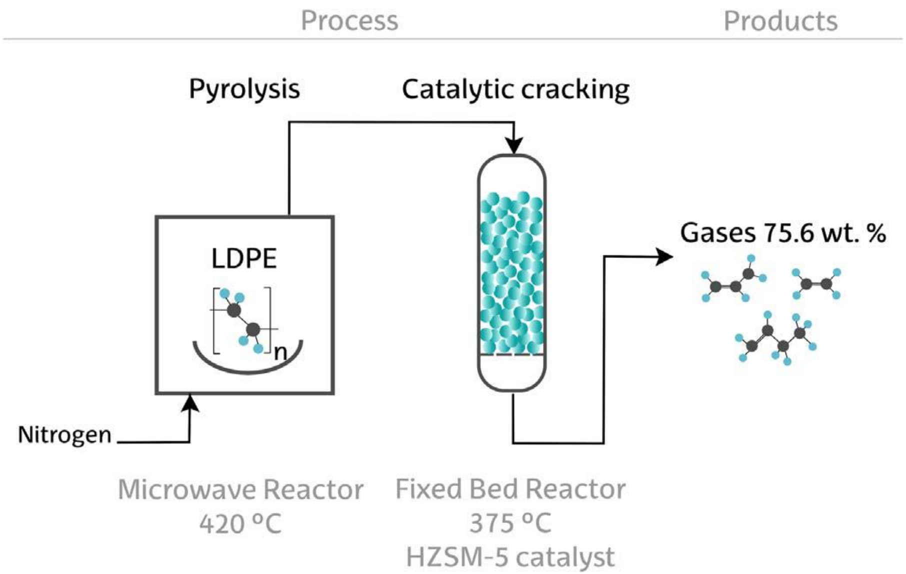


Haloclean process

HORNUNG, A. and SEIFERT, H., 2006; 2006. Rotary Kiln Pyrolysis of Polymers Containing Heteroatoms. *Feedstock Recycling and Pyrolysis of Waste Plastics.* John Wiley & Sons, Ltd, pp. 549-567.

5. Microwave thermolysis

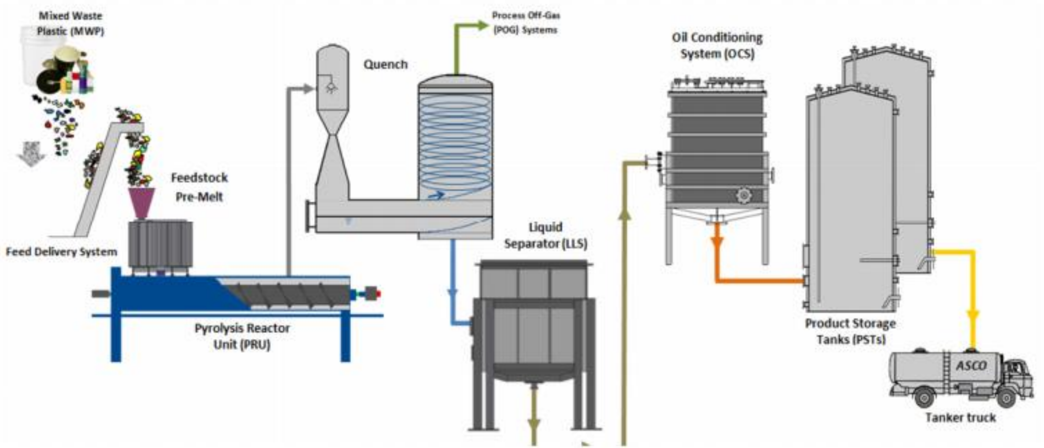
- Attractive for efficient heat transfer
- Plastic has to be mixed with heat adsorbent such as graphitic carbon or inorganic oxides
- Temperatures can reach up to 1000 °C
- Short residence time
- Poor mixing
- Scale up is questionable



LOPEZ, G., ARTETXE, M., AMUTIO, M., BILBAO, J. and OLAZAR, M., 2017. Thermochemical routes for the valorization of waste polyolefinic plastics to produce fuels and chemicals. A review. *Renewable and Sustainable Energy Reviews,* 73, pp. 346-368

Commercial systems

Agilyx (USA) – Screw reactor

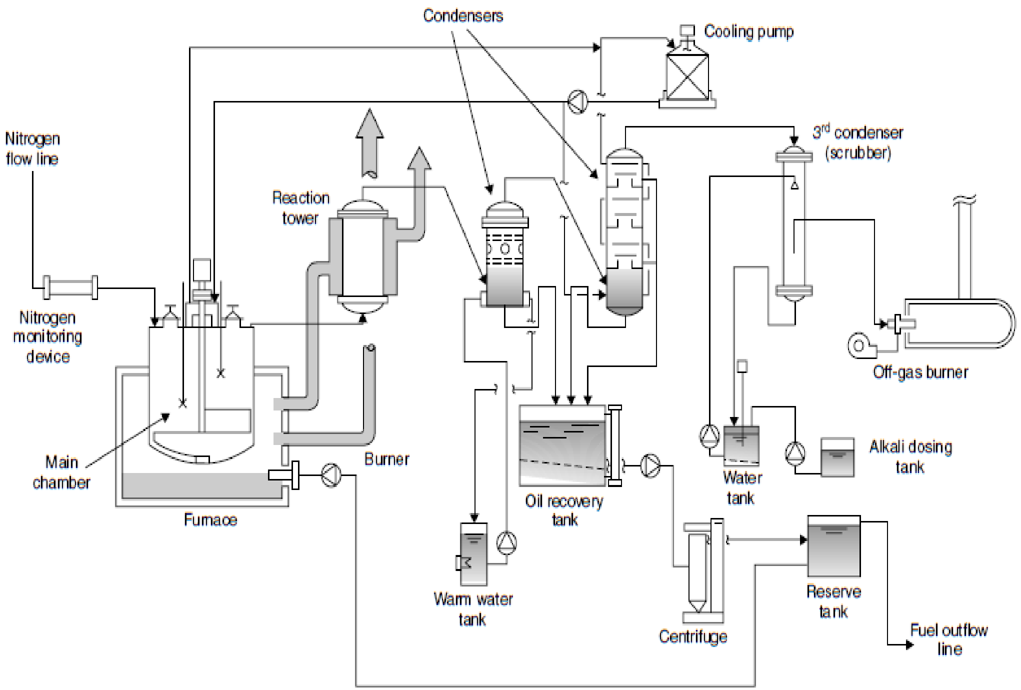


Schematic flow diagram of the Agilyx process

- Continuous non-catalytic
- Self cleaning dual screw reactor
- Currently operational 10 TPD, pilot scale
- Light sweet synthetic crude is the main product sold to a refinery

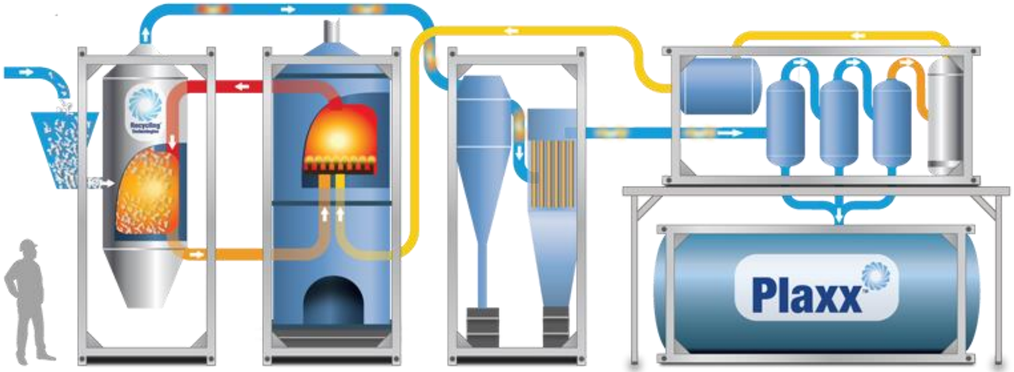
Plastic energy (Spain) - CSTR

- Thermal degradation in STR
- Moderate temp (320-425°C)
- Vapor phase upgrading at 220°C
- Several plants in Japan, Ireland, UK and Spain
- 20 TPD available



SCHEIRS, J., 2006; 2006. Overview of Commercial Pyrolysis Processes for Waste Plastics. *Feedstock Recycling and Pyrolysis of Waste Plastics.* John Wiley & Sons, Ltd, pp. 381-433.

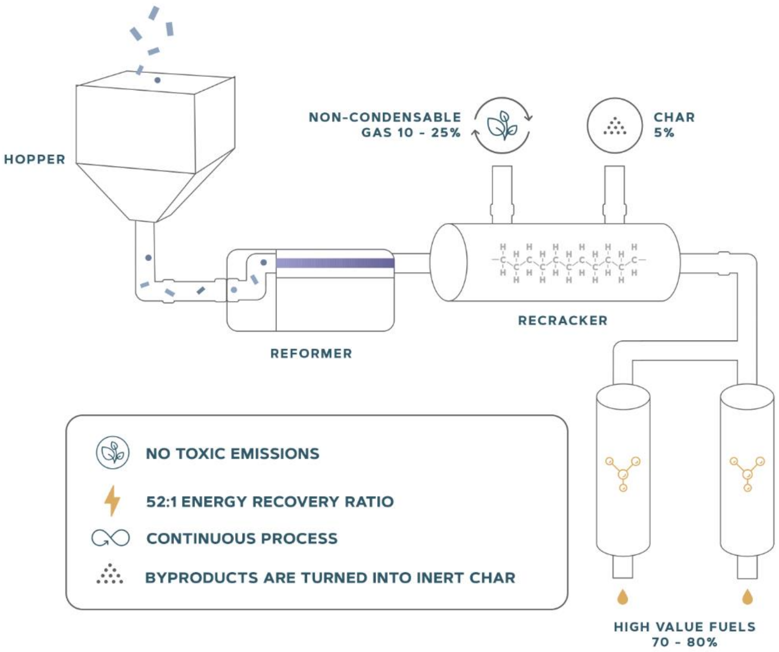
Recycling technologies (UK) – Circulating Fluidized bed



- Advanced fluidized bed reactor, the RT7000, uses thermal depolymerization
- residual plastic waste from material recycling facilities (MRFs) as feedstock
- Plaxx™ is a hydrocarbon product, low sulphur alternative to heavy fuel oil (HFO).
- Dry weight capacity 7000 tpa

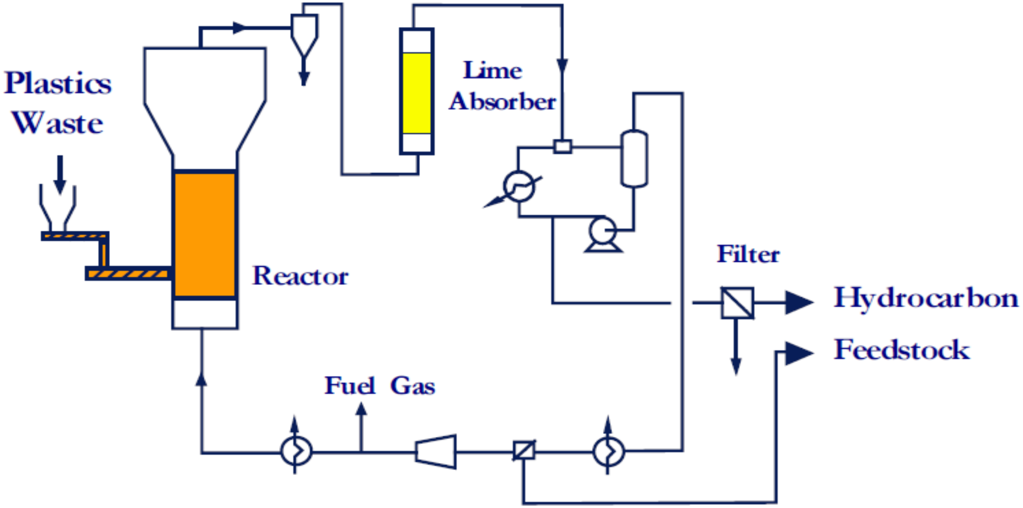
Renewlogy (USA) – Auger / Kiln reactor

- Plastic is dried and shredded
- Auger/kiln reactor
- Easy control over product
- Output ranging from wax to crude-like oil to diesel-quality oil.
- Renewlogy– Nova Scotia Canada set up a large plastic conversion system at their site in 2017
- 10 TPD modules



Patent: https://patentimages.storage.googleapis.com/d3/eb/d9/f0bdabcecda720/US20170218278A1.pdf

BP process (Hamburg) – Fluidized bed reactor

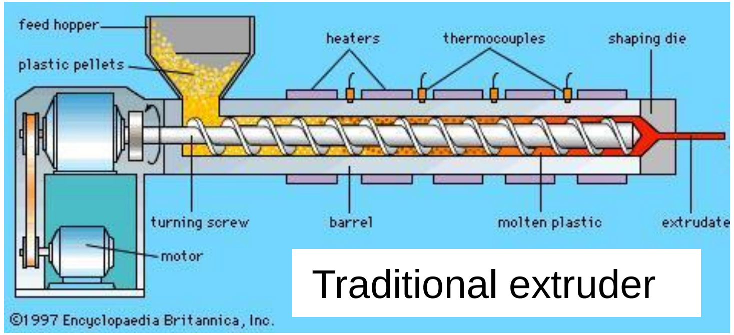


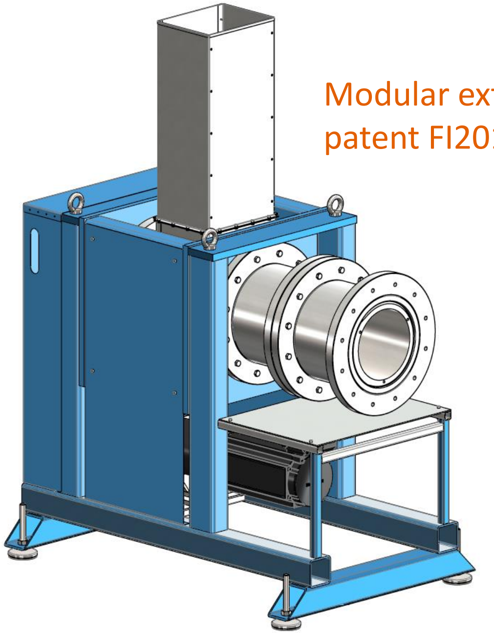
Schematic representation of the BP process.

- Low temperature (500° C) thermal fluidized bed process
- Dechlorination using lime absorber
- Light and heavy wax was the main product
- (50 kg/h) plant no longer operational

LOPEZ, G., ARTETXE, M., AMUTIO, M., BILBAO, J. and OLAZAR, M., 2017. Thermochemical routes for the valorization of waste polyolefinic plastics to produce fuels and chemicals. A review. *Renewable and Sustainable Energy Reviews,* 73, pp. 346-368

Integrated material pretreatment to thermolysis





Modular extruder, VTT patent FI20165640

- Heterogenous feed including foils which otherwise are difficult to process
- Processing to granules or straight to thermolysis as melt compound

Plastic waste › **Pretreatment** › Thermolysis › Upgrading › Products

Contact: Juha.mannila@vtt.fi

Reactor comparison for plastic thermolysis

VTT

	Temp. control	Heat transfer	Particle size flexibility	Residence time flexibility	Process flexibility	Thermal mode operation	Catalytic mode operation	Value of obtained products	Scale-up flexibility	Economic feasibility
Fixed Bed	Red	Red	Orange	Orange	Red	Orange	Orange	Green	Red	Orange
BFB	Orange	Green	Orange	Orange	Green	Green	Green	Green	Orange	Orange
CFB	Orange	Green	Orange	Orange	Green	Green	Orange	Green	Orange	Red
Rotary kiln	Red	Red	Orange	Green	Orange	Green	Orange	Orange	Orange	Orange
Melting vessel	Red	Red	Orange	Green	Orange	Green	Orange	Orange	Orange	Red
Extruder	Orange	Red	Red	Red	Green	Orange	Orange	Green	Green	Orange

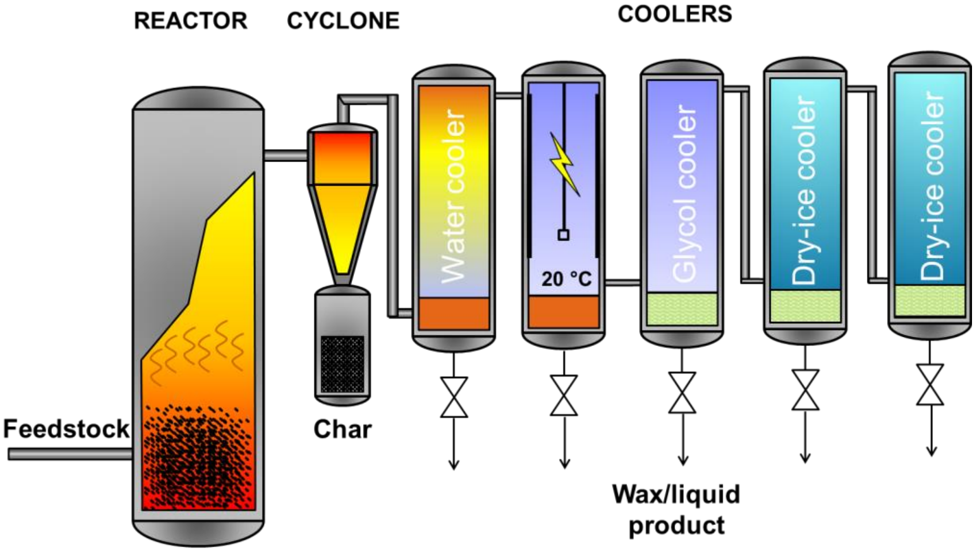
Green = good   Orange = sastisfactory   Red = Poor

U. Arena, M.L. Mastellone, Fluidized Bed Pyrolysis of Plastic Wastes, in: Feedstock Recycling and Pyrolysis of Waste Plastics, John Wiley & Sons, Ltd, 2006; 2006, pp. 435-474.

Factors affecting product distribution

- Temperature
  - Lower temperatures (T<700°C) yield solids and waxes/oil whereas higher temperatures favour gas formation
- Pressure
  - The effect of pressure is dominant at lower temperatures and reduces with an increase in temperature
- Heating rate
  - Higher heating rate - bond cleavage, lower heating rate - char formation
- Feedstock composition
  - Varying products with varying feedstocks (PVC and PET unappreciable)
- Residence time
  - Longer residence times light molecular weight hydrocarbons and non-condensable gases
- Reactor type: Different reactors different product distribution

Thermolysis reactor (BFB) - VTT

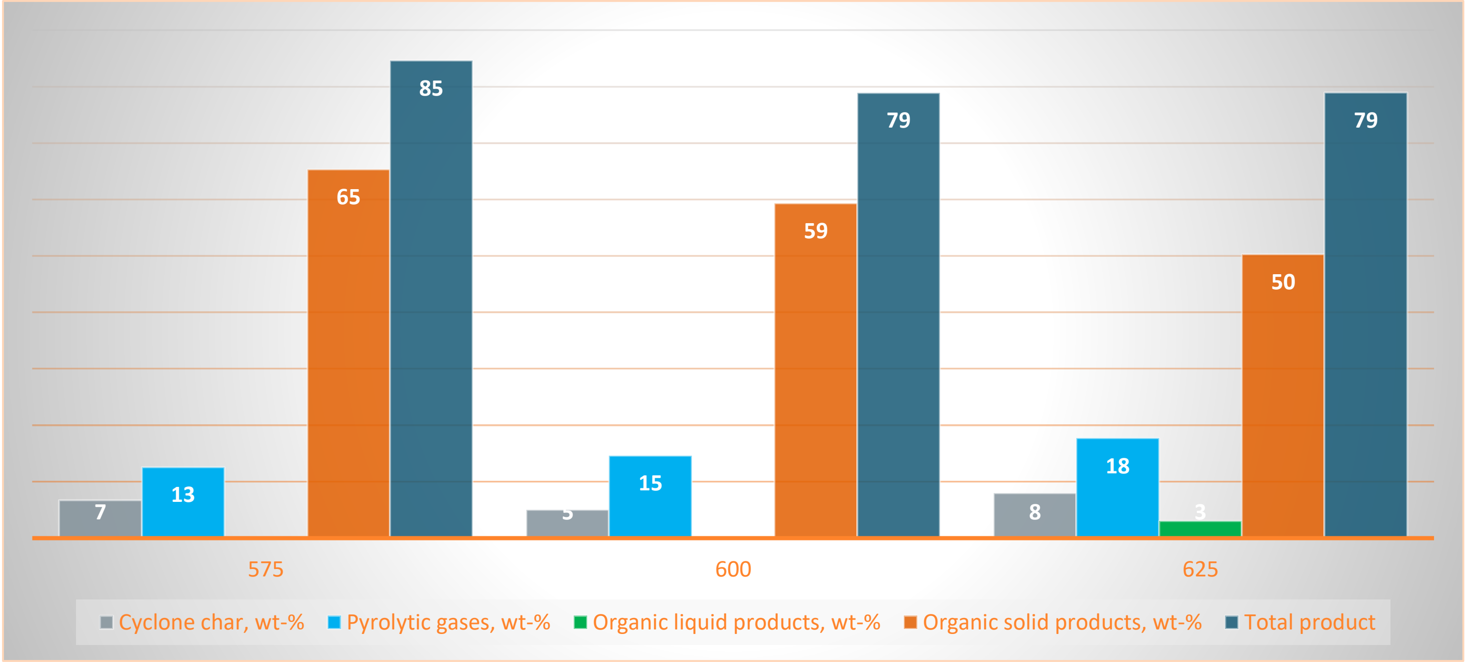


Features:

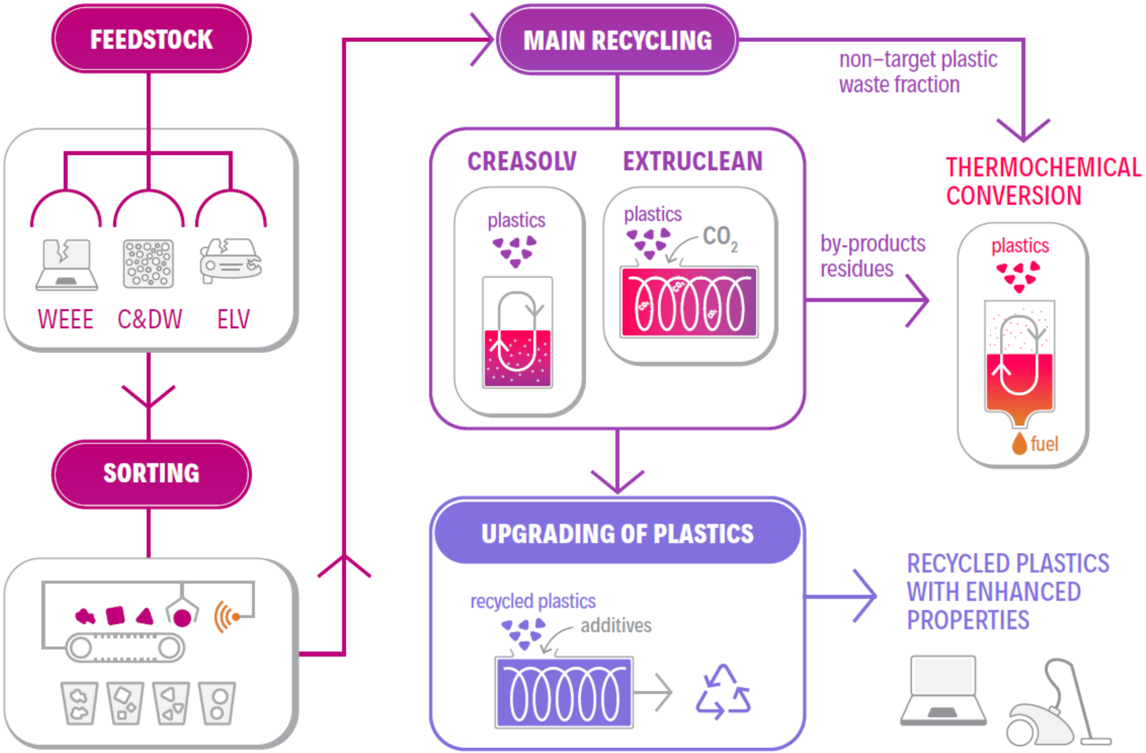
Feed capacity : 1kg/hr
Operating temperatures ~ 500 – 700 C
Feeder : Screw feeder
Condenser: 1 water cooler, 1 glycol cooler, 2 dry ice coolers

Online gas chromatographic analysis

Thermolysis trials- Reject from plastic recycling



NONTOX EU H2020 2019-2021



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