

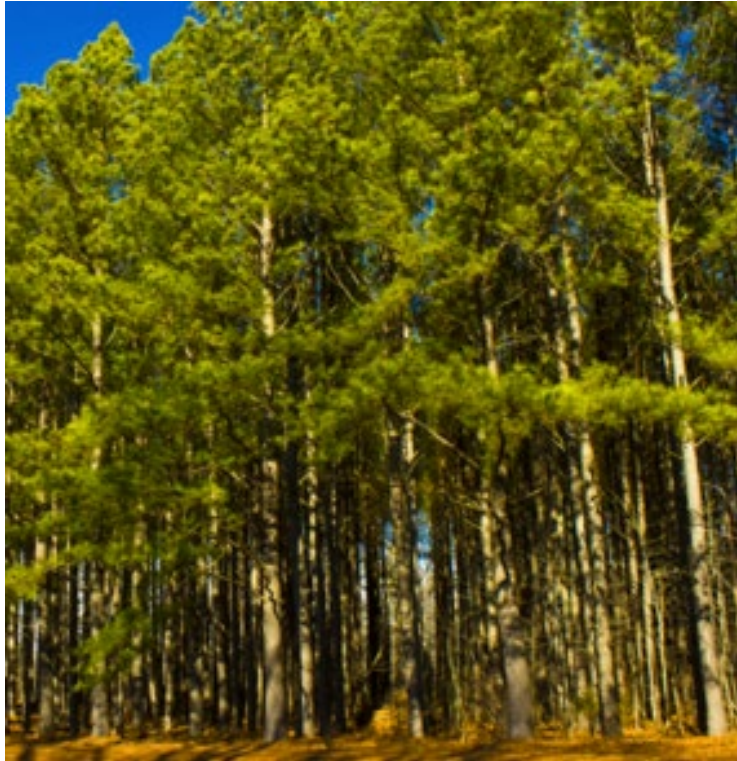
# Anellootech



**November 2022**

# Alternative Feedstocks to Petroleum

## Biomass



## Plastic Waste

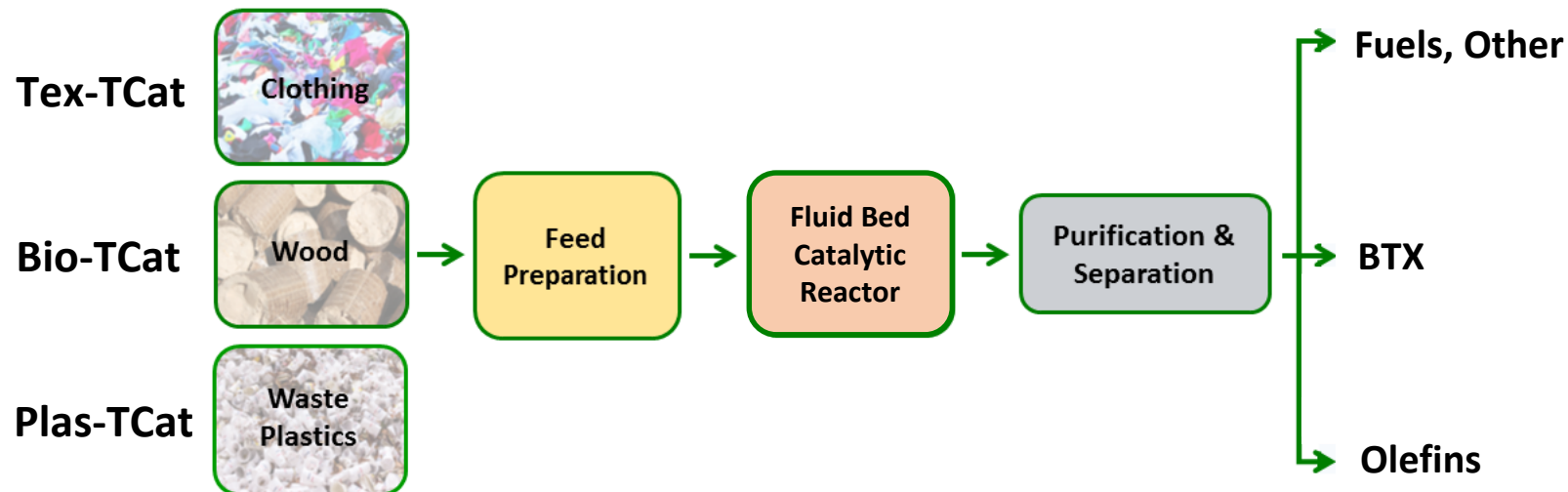


## Textile Waste



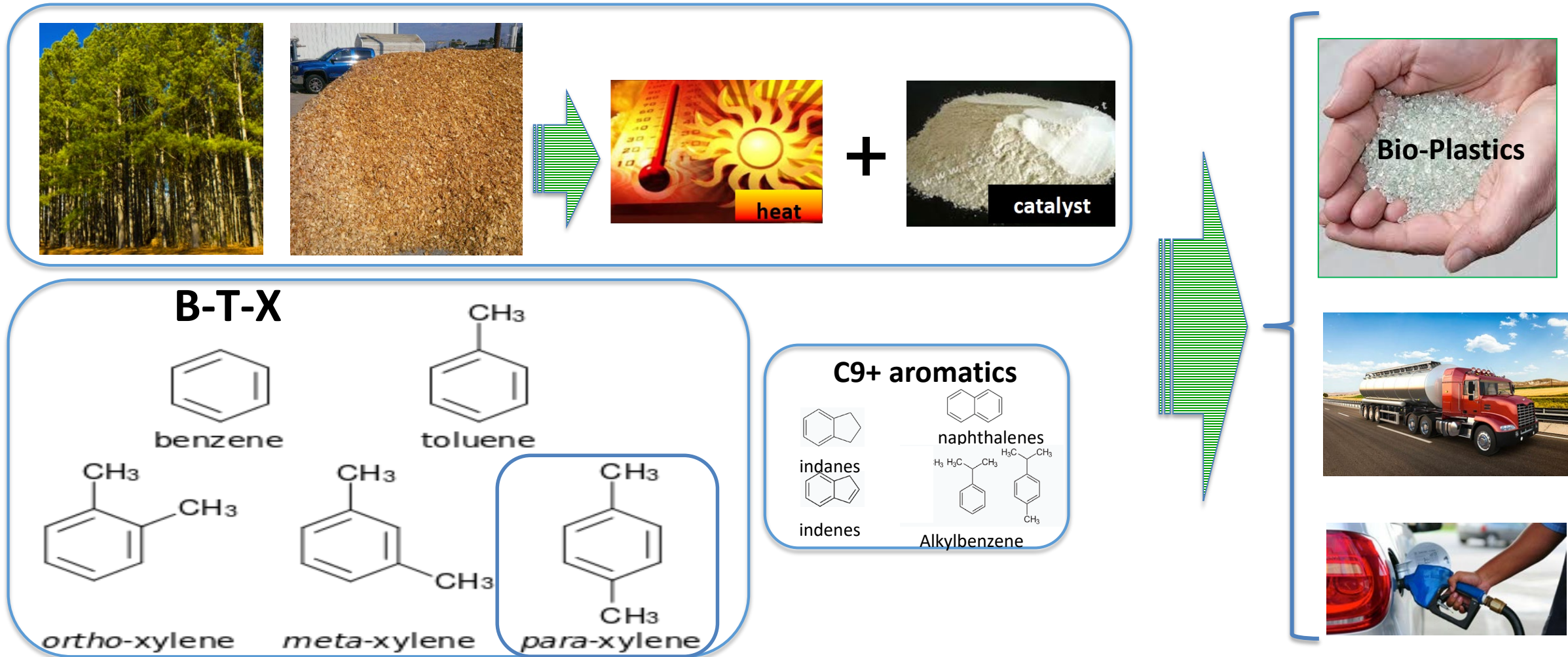
# Anellotech Technology Suite

- Developed Bio-TCat to convert biomass into petrochemicals to replace fossil-based fuels and chemicals with identical renewable materials
- Working on Plas-TCat to convert waste plastics into petrochemicals to enable recycling of mixed waste plastics
- Basis for Tex-TCat, conversion of waste textiles as feedstock



# Bio-sourced aromatics for virgin plastics and fuels

## The Bio-TCat™ Process --- Thermal Catalytic Biomass Conversion



# Developed with \$85 million cash and in-kind support from industrial R&D and brand owner partners

Anellotech

- ✓ Program Management
- ✓ Research & Development
- ✓ Pilot Plants



- ✓ Process Development
- ✓ Modeling & Hydrodynamics
- ✓ Scale-Up

**SUNTORY**  
FOLLOW YOUR NATURE



Johnson Matthey

**INTERCAT**<sup>SM</sup>

- ✓ Catalyst Technologies
- ✓ Formulations
- ✓ Catalyst Supply

**Axens**  
Powering integrated solutions

- ✓ Process & Plant Design
- ✓ Technology Licensing & Marketing
- ✓ Start-Up & Operations Support

**TOYOTA TSUSHO**

# 7,500 hours of pilot plant testing



- Commercial yield and catalyst life
- Regularly completing sustained 24/7 runs; 7,500+ hours on stream operations since Feb'18
- Demonstration of major continuous process operations, recycle loops
- Feedstock -- loblolly pine SE USA forests
- Operates inside OSHA PSM compliant commercial chemical facility

# Bio-TCat Development Completion Milestone

## 100% bioPET Bottle made by Suntory from Bio-TCat Paraxylene



Georgia-grown loblolly pine



TCat-8 Pilot Unit (Silsbee, TX)



BTX Product



Prototype 100% bioPET bottle with PX from TCat-8

# ANELLOTECH WINS PLASTICS INDUSTRY ASSOCIATION BIOPLASTICS INNOVATION AWARD

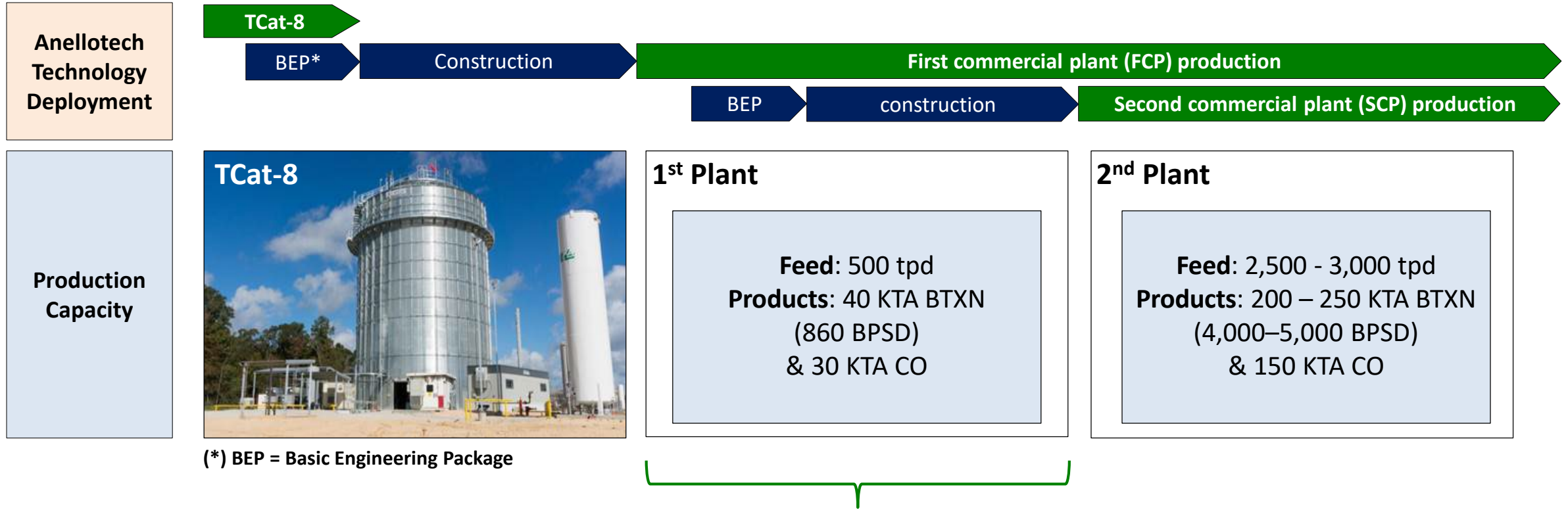
THU SEPTEMBER 15, 2022

Washington, D.C.—The Plastics Industry Association (PLASTICS) today announced sustainable technology company, Anellotech, as the winner of PLASTICS' 2022 Innovation in Bioplastics Award. The announcement came as part of PLASTICS' annual, online #BioplasticsWeek awareness and education event.

Anellotech won the award for the development of the first 100% bioPET (polyethylene terephthalate) bottle made from loblolly pine and other biomass feedstocks, potentially lessening the industry's reliance on petroleum and natural gas as feedstocks. PET is a widely used plastic most often seen by consumers in plastic beverage bottles.



# 1<sup>st</sup> Commercial Plant Planning Underway



**Basic engineering work for the 1<sup>st</sup> Plant completed; site, funding TBD**

# 1<sup>st</sup> Commercial Plant Planning

## Process Design Study performed by Axens

*(500 TPD)*

- *Basis of design*
- *Unit description, Operating Conditions*
- *Heat & Material Balances*
- *Catalyst & Chemical Specifications*
- *Utility Summary*
- *Effluent Summary*
- *Material specifications*
- *Sized equipment list*
- *Drawings (PFD, PIDs)*
- *Data Sheet of main equipment*
- *Cost estimate*
- *Pre-Hazop*

# Commercial Vectors

Today: 500 TPD Feed Plant

- Licensing for fuels or chemicals
- Wood (pine) feedstocks

Next: 2,500-10,000 TPD Plants

- Agricultural residue feedstock (i.e. sugar cane bagasse)
- Eucalyptus

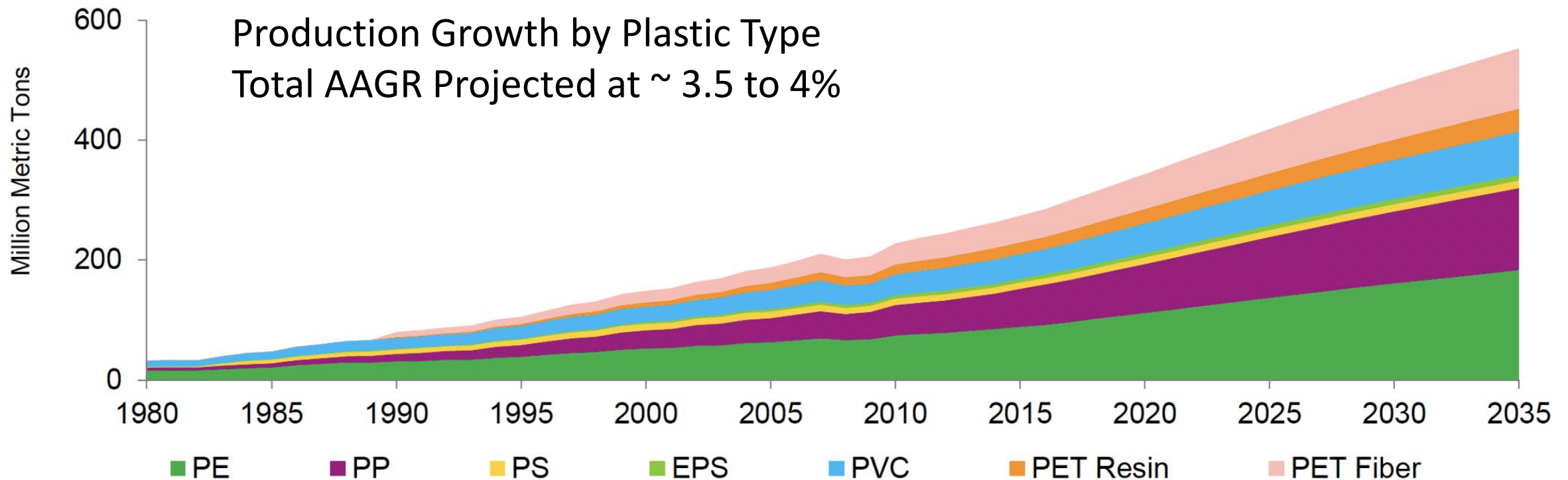
# Anellotech

Plas-TCat™

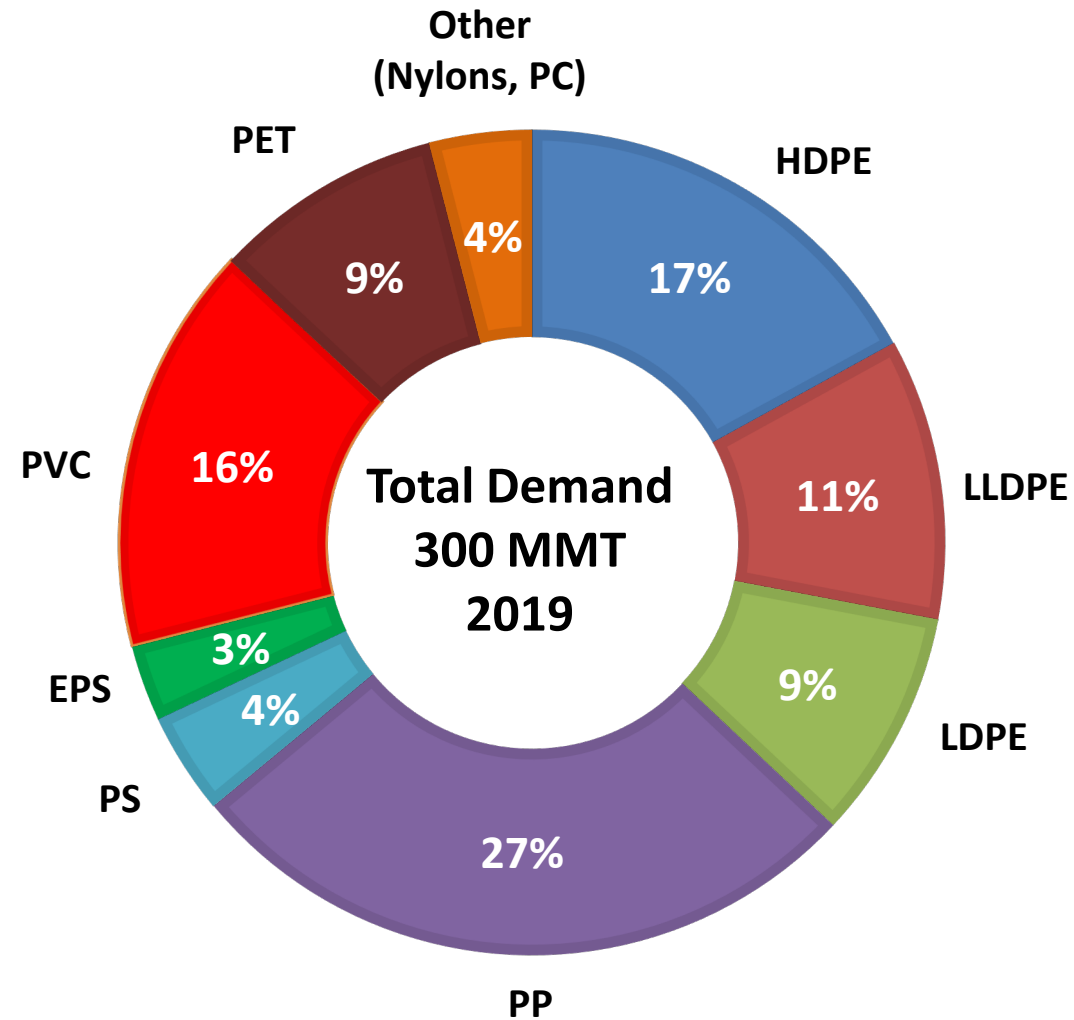


# Huge, Growing Plastics Recycling Challenge

400+ million tons/year production by 2030



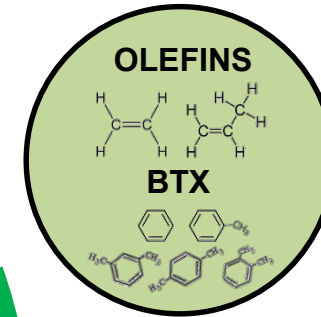
# Global plastics demand by type of polymer



Anellotech aims to convert large volumes of mixed waste plastics...



...directly into valuable chemicals (using new technology Plas-TCat)...  
... not fuels!



**ANELLOTECH'S VISION**  
Efficient, economic,  
large-scale recycling of  
mixed waste plastics

- Polystyrene
- Polyethylene
- Polypropylene
- Polycarbonate
  - Nylon
  - PET
- ...and many more



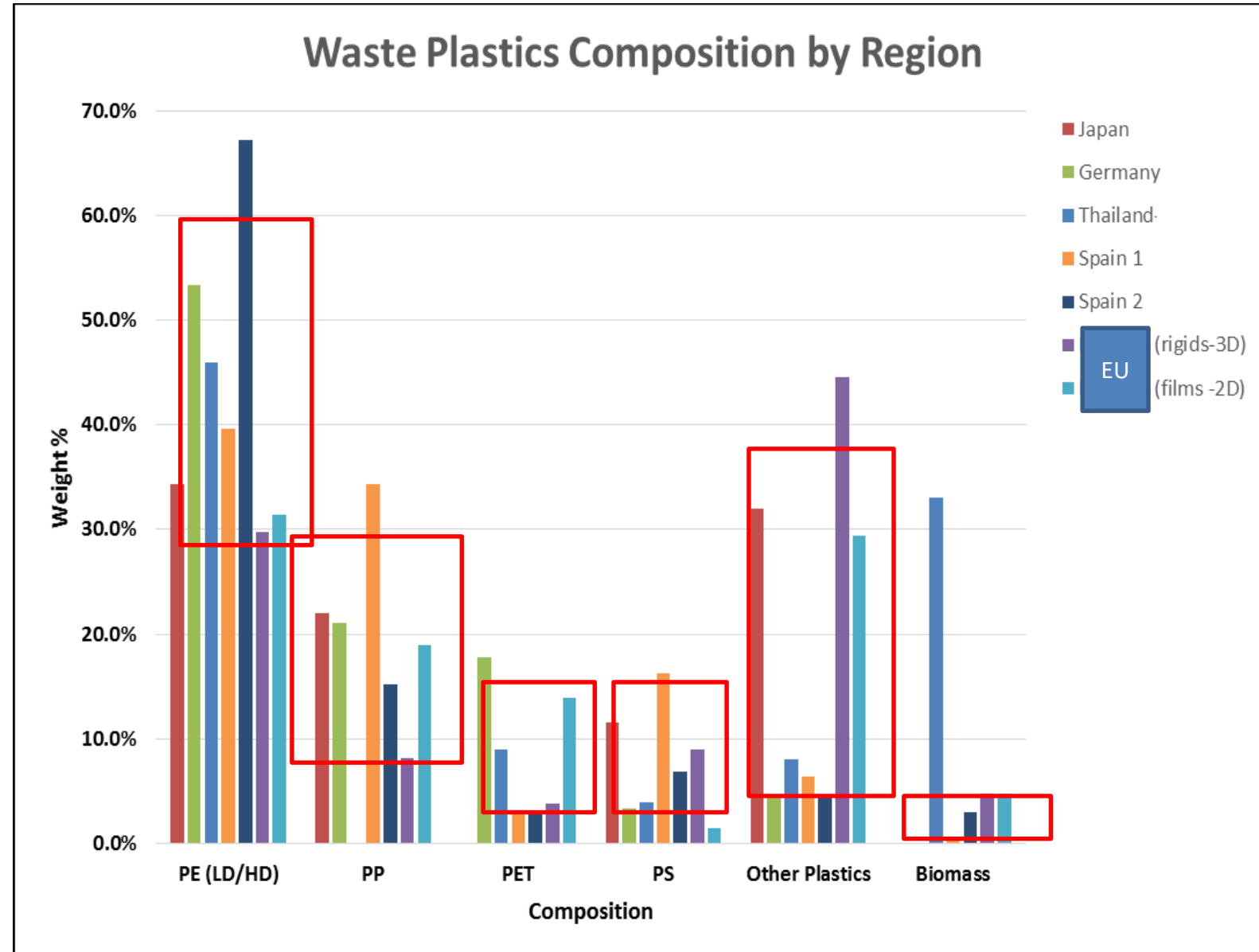
...that are the same ones that manufacturers buy to produce the plastics...

...widely used today in packaging and other products.



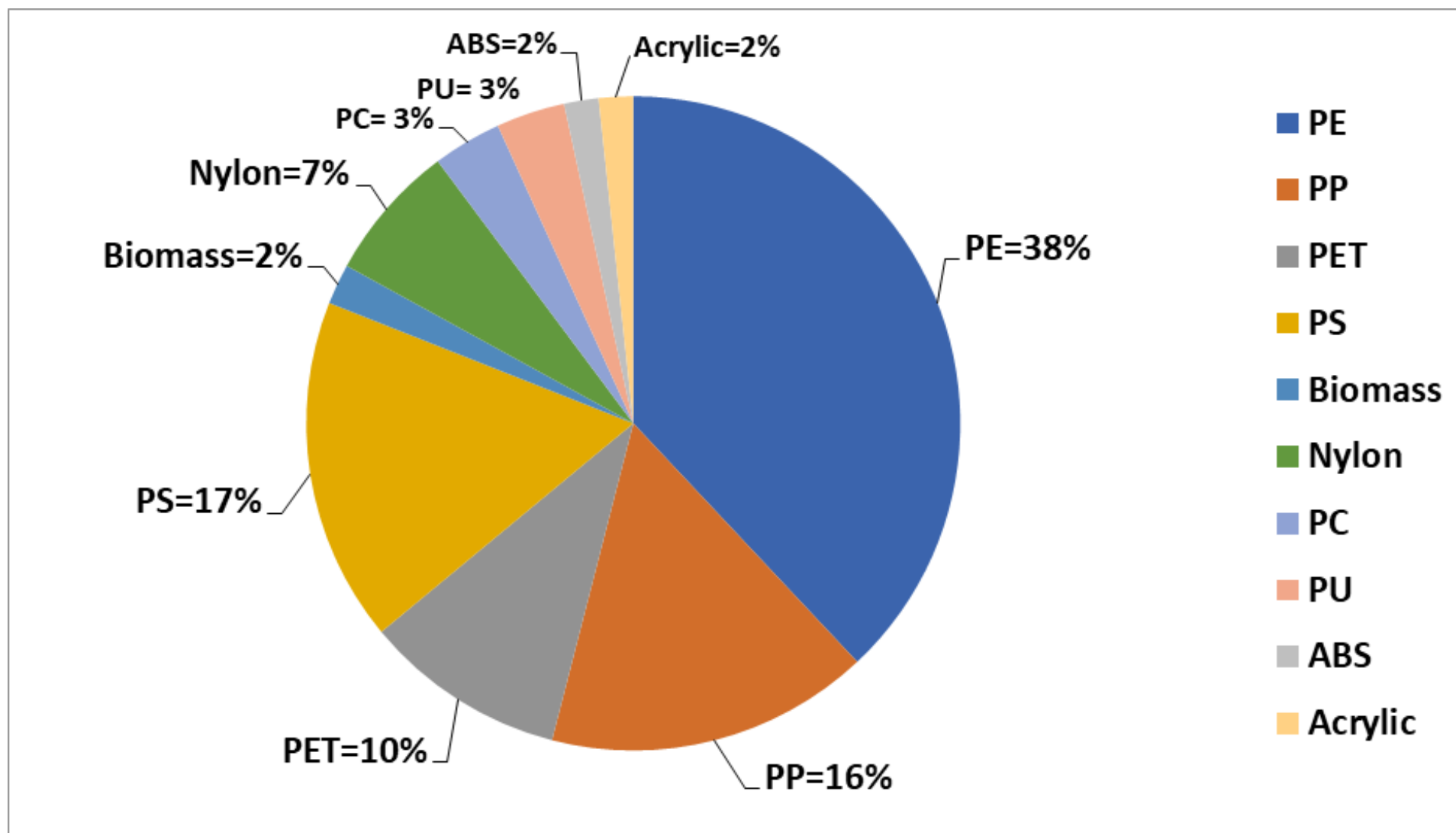
# Plas-TCat Development: Design Window

- Addresses a Broad Range of Plastic Solids Waste (PSW) Composition
- Based on the analysis of composition of Plastic Solid Wastes in different regions, a window of PSW composition has been selected.
- Plastic mixtures with high and low polyolefin (PO) concentration define the operational window.
- The midpoint of the window is the Base Case



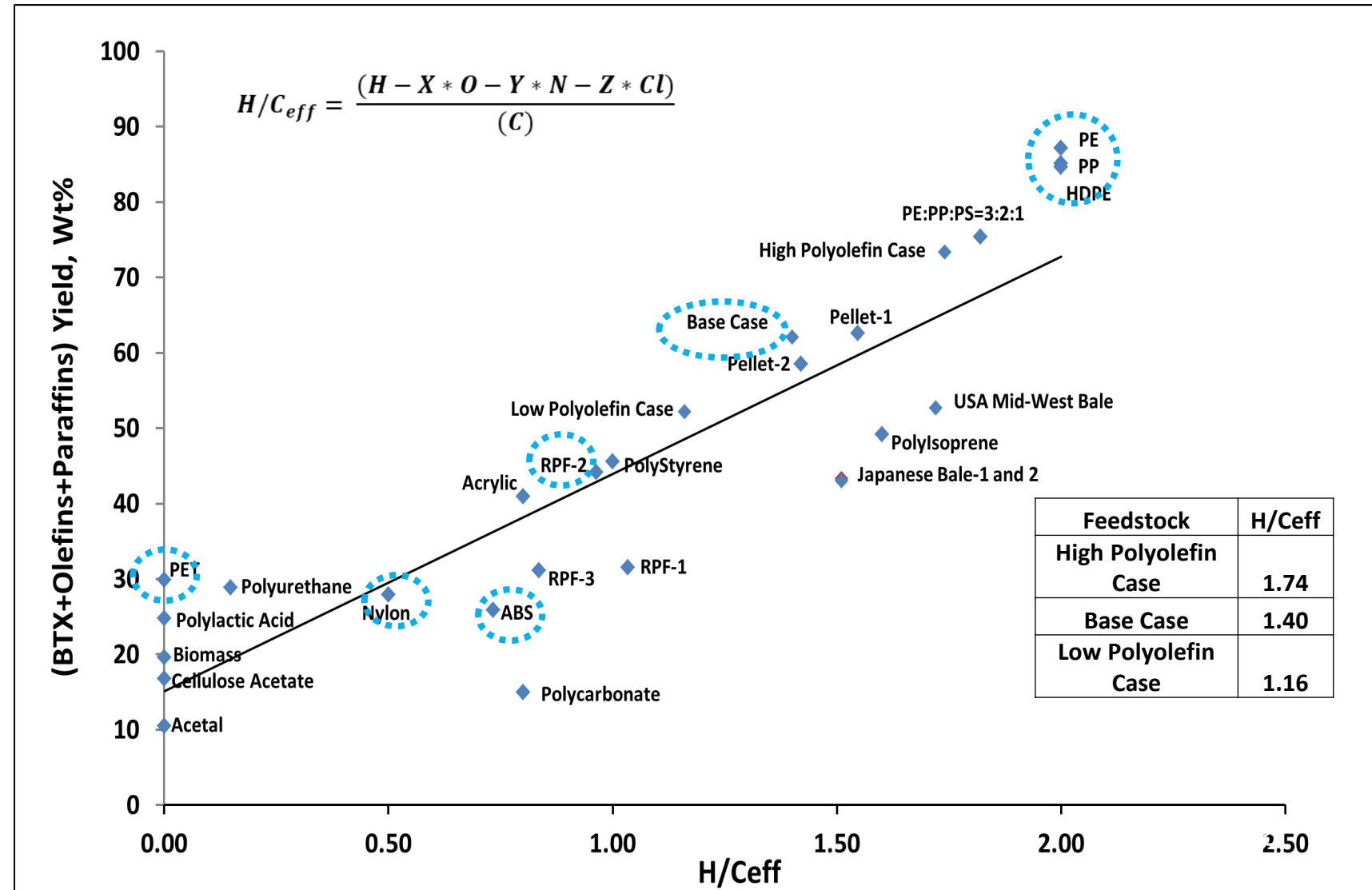


# Plas-TCat Base Case Feedstock Composition



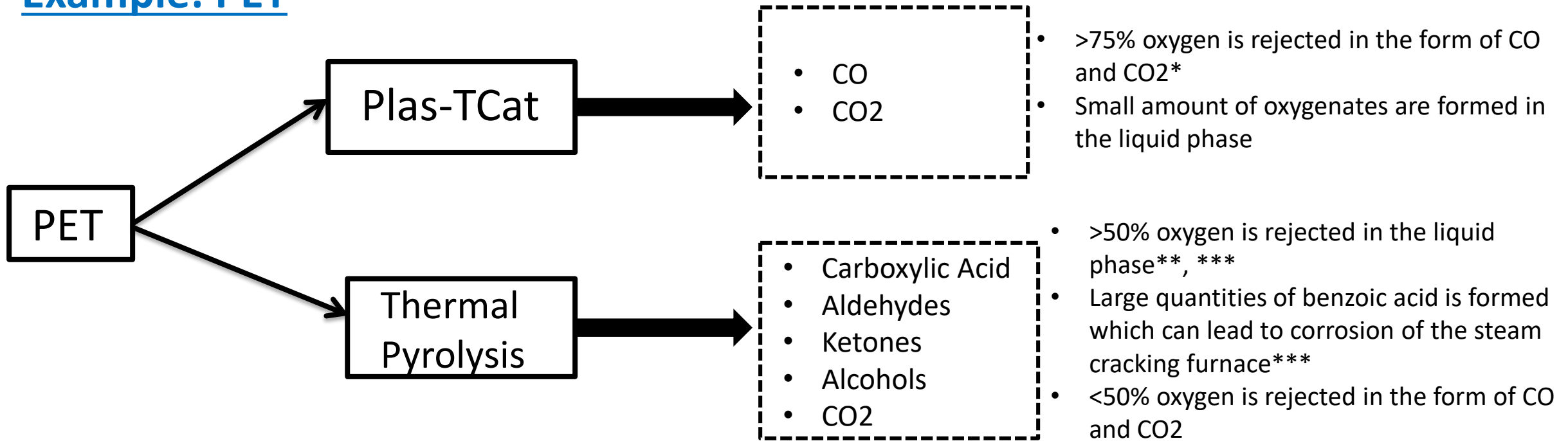
# Plas-TCat Product Yield vs $H/C_{eff}$ Ratio

- $H/C_{eff}$  ratio can be used to predict the yield of valuable products: BTX+Olefins+Paraffins
- In general, the higher the  $H/C_{eff}$  ratio, the higher the product yield.
- Poly-olefins such as polyethylene and polypropylene contain only H and C and their  $H/C_{eff}$  ratio is 2.
- Product yield from poly-olefins is higher than plastics containing heteroatoms because hydrogen reacts with oxygen to make water, hydrogen combines with nitrogen to make nitriles and ammonia and hydrogen reacts with chlorine to make hydrochloric acid. These side reactions reduce  $H/C_{eff}$  ratio



Heteroatoms (N, O, S, Cl, etc.) rejected by Plas-TCat mainly in Gas Phase for easy separation. Potential positive LCA impact (vs. thermal pyrolysis)

## Example: PET



## Plas-TCat Advantage

- Low Upgrading Cost: Minimal hydro treating is required to remove heteroatoms from the liquid phase.
- Favorable LCA: Overall CO<sub>2</sub> footprint is low because of small amount of fossil hydrogen is required to remove heteroatoms from the liquid phase as they are rejected in the gas phase

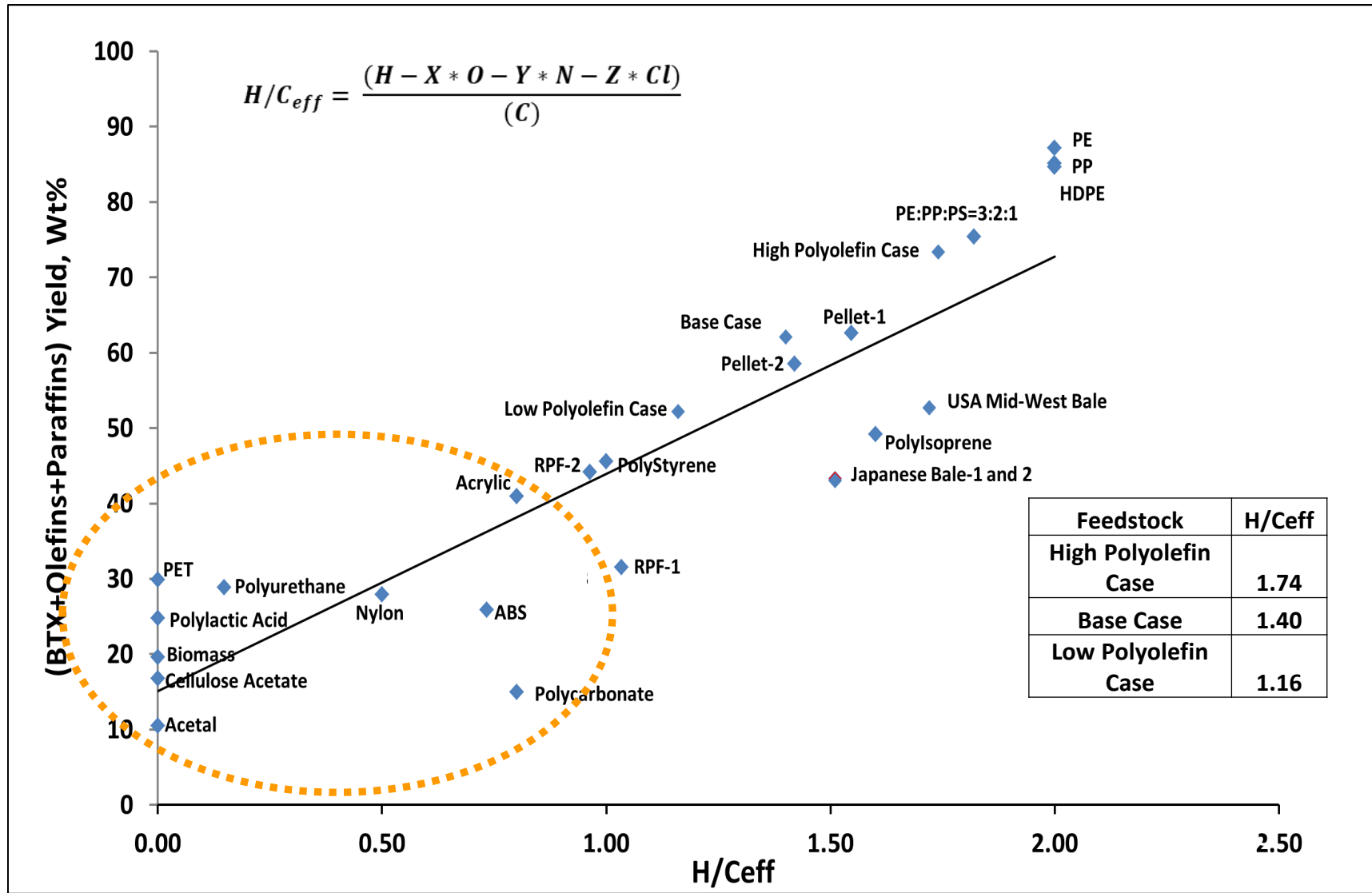
\*Anellotech Lab Data

\*\*Elizabeth A. Williams & Paul T. Williams, "The Pyrolysis of Individual Plastics and a Plastic Mixture in a Fixed Bed Reactor", *J. Chem. Tech. Biotechnol.* 70, 9-20 (1997)

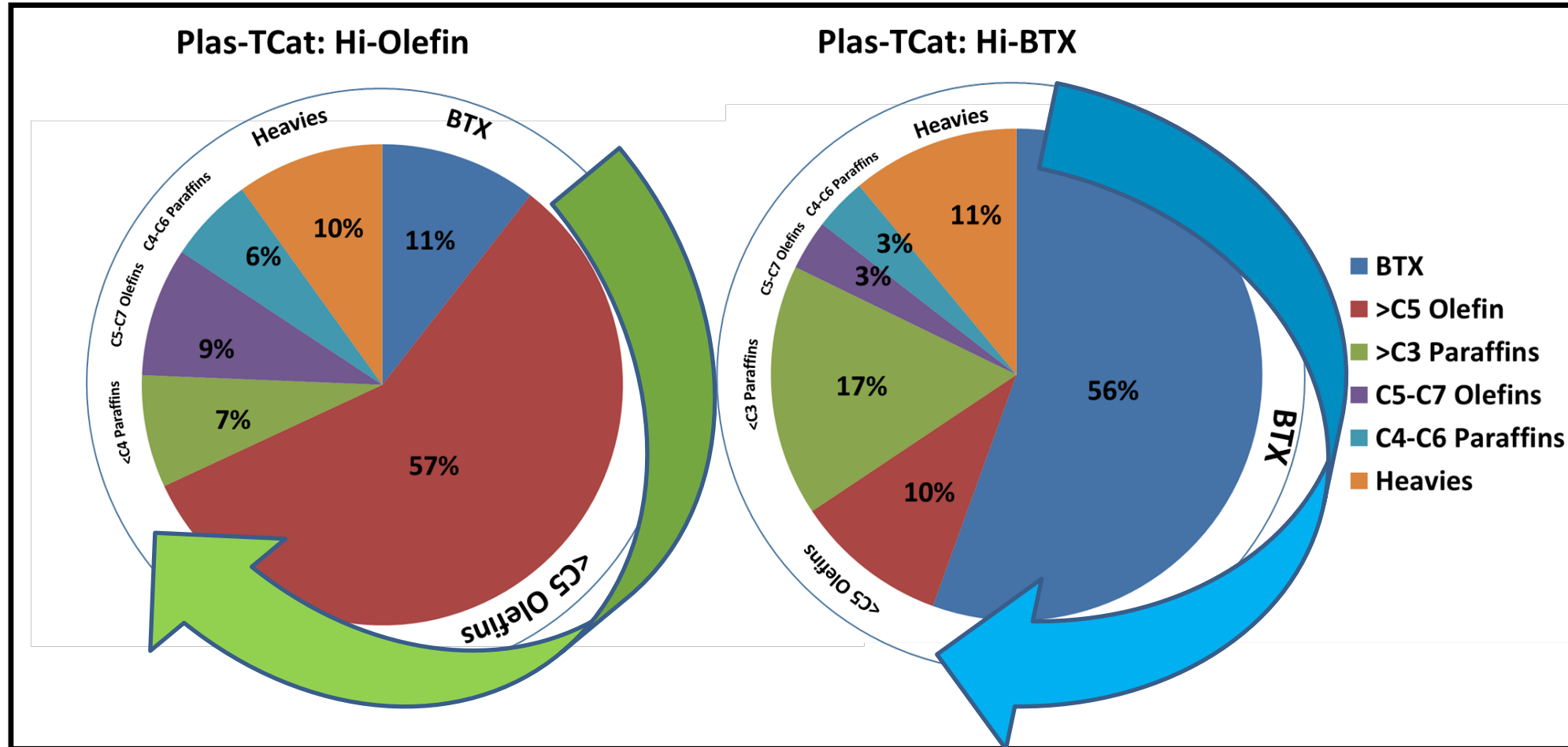
\*\*\*Brems A, Baeyens J, Vandecasteele C, Dewil R, Polymer Cracking of Waste Polyethylene Terephthalate to Chemicals and Energy, *Journal of Air and Waste Management Association*, 61, 721-731 (2011)

# Plas-TCat converts No. 7 plastics (including nylon, ABS, polycarbonate, polyurethane) directly into valuable chemicals

- Most No. 7 plastics contain heteroatoms such as nitrogen and oxygen in their chemical structure
- Plas-TCat converts these heteroatom containing plastics (such as PET, Acrylic, Nylon, Polyurethane, ABS, Polycarbonates, etc.) directly into BTX, olefins and paraffins.
- Due to the process wide tolerance of waste plastic feedstocks, minimal upfront sorting is needed.

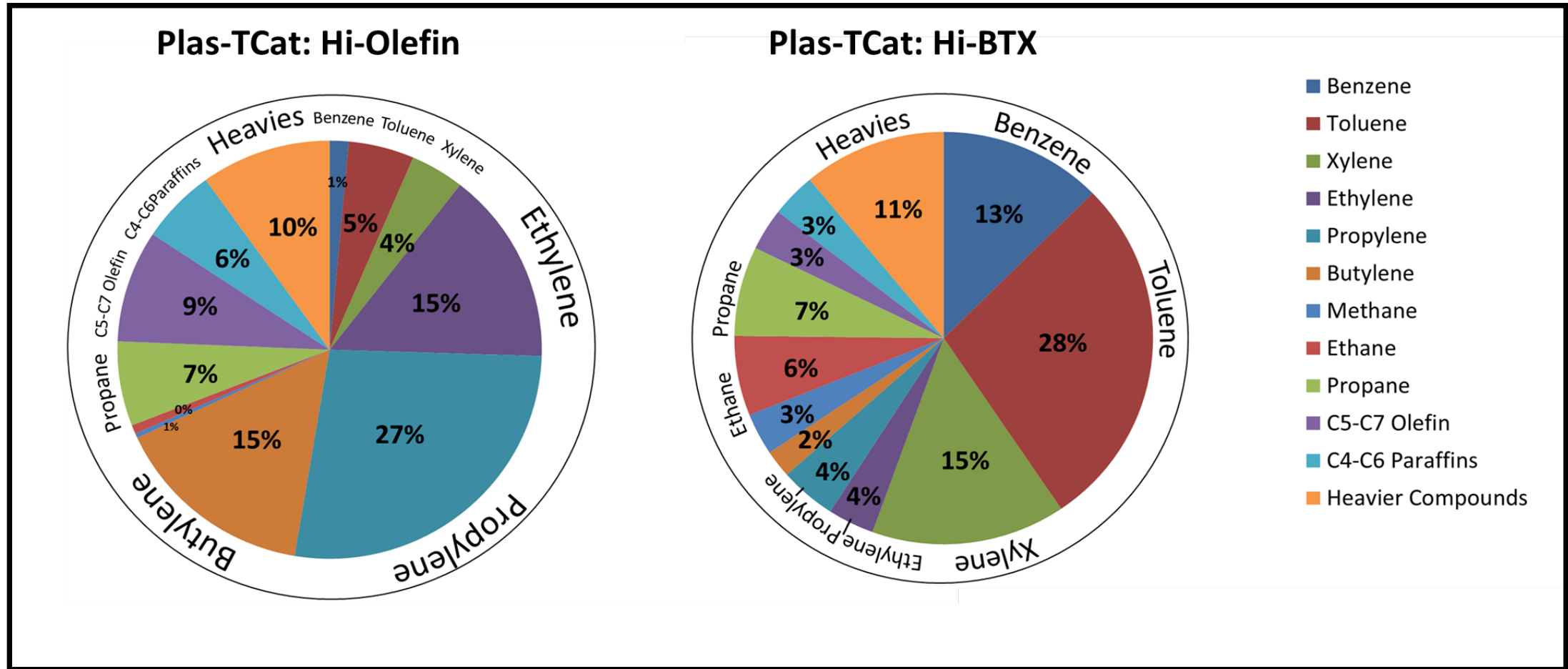


# Plas-TCat reactor outlet products from Polyethylene feed can be controlled to give High Yield Olefins or High Yield BTX



For illustrative, qualitative use only. These lab results are to be validated in long-duration studies in a fully integrated TCat-8 Pilot Plant. Detailed review of experimental conditions, catalyst and other factors can be shared to fully assess this data

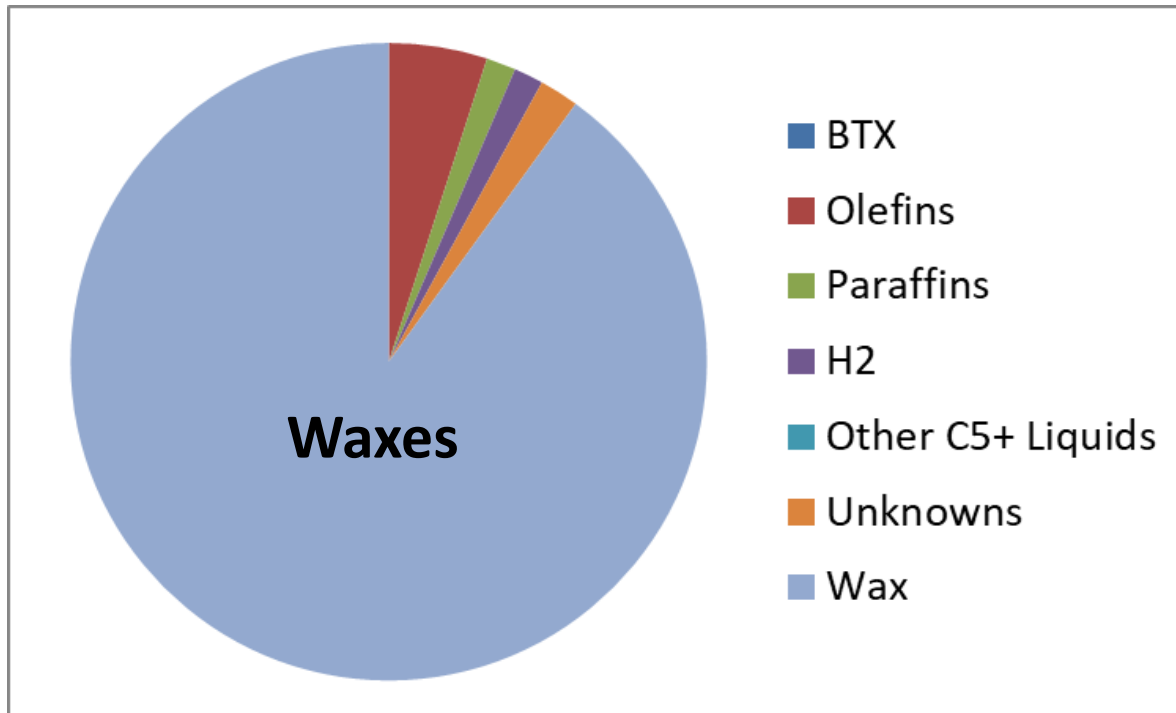
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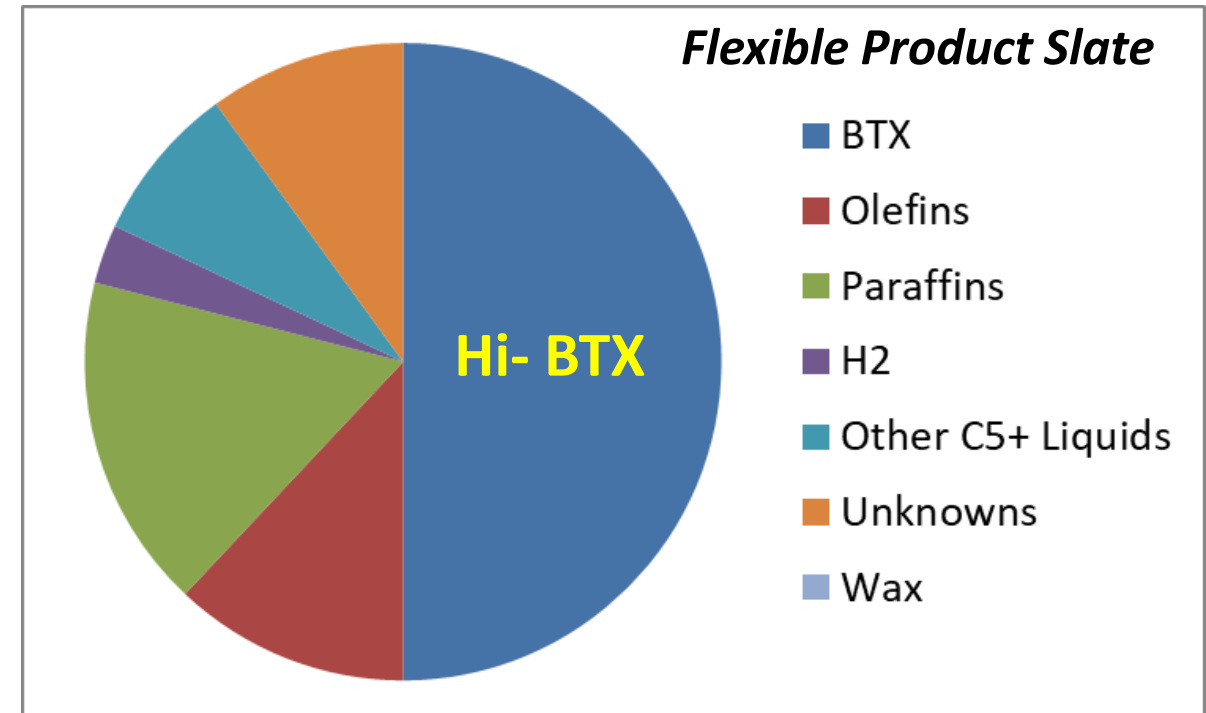
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# Contrast Plas-TCat with non-catalytic pyrolysis, which produces predominantly waxes needing further upgrading

## Non-Catalytic Pyrolysis



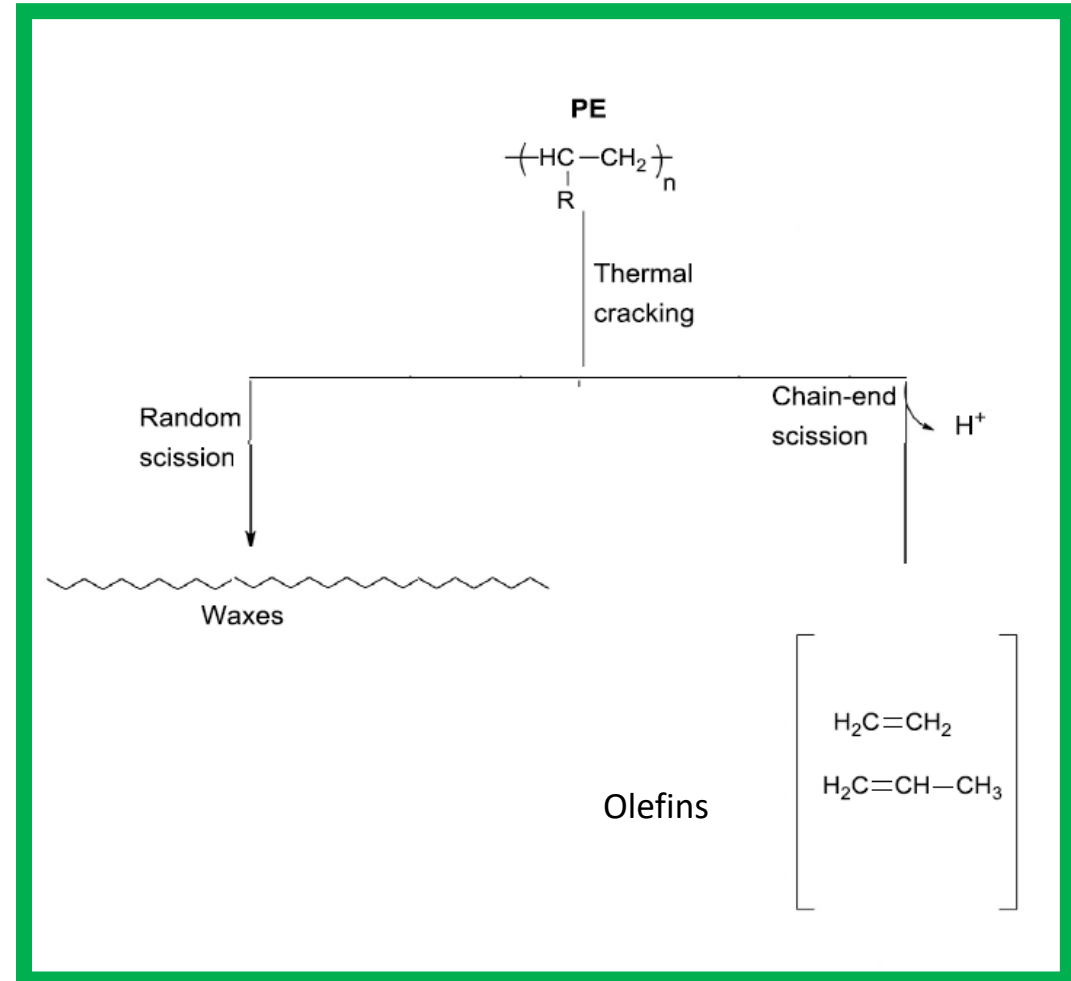
## Plas-TCat Catalytic Process (Hi-BTX)



For illustrative, qualitative use only. These lab results are to be validated in long-duration studies in a fully integrated TCat-8 Pilot Plant. Detailed review of experimental conditions, catalyst and other factors can be shared to fully assess this data

**While Non-Catalytic Pyrolysis**  
of polyethylene produces a  
broad mix of waxes and  
olefins<sup>(1)(2)</sup>

***Requires upgrading in a  
steam cracker to yield  
upgraded valued product***



<sup>1</sup> Dongting Zhao, Xianhua Wang, James B Miller, George W Huber, "The chemistry and kinetics of polyethylene pyrolysis: A feedstock to produce fuels and chemicals."

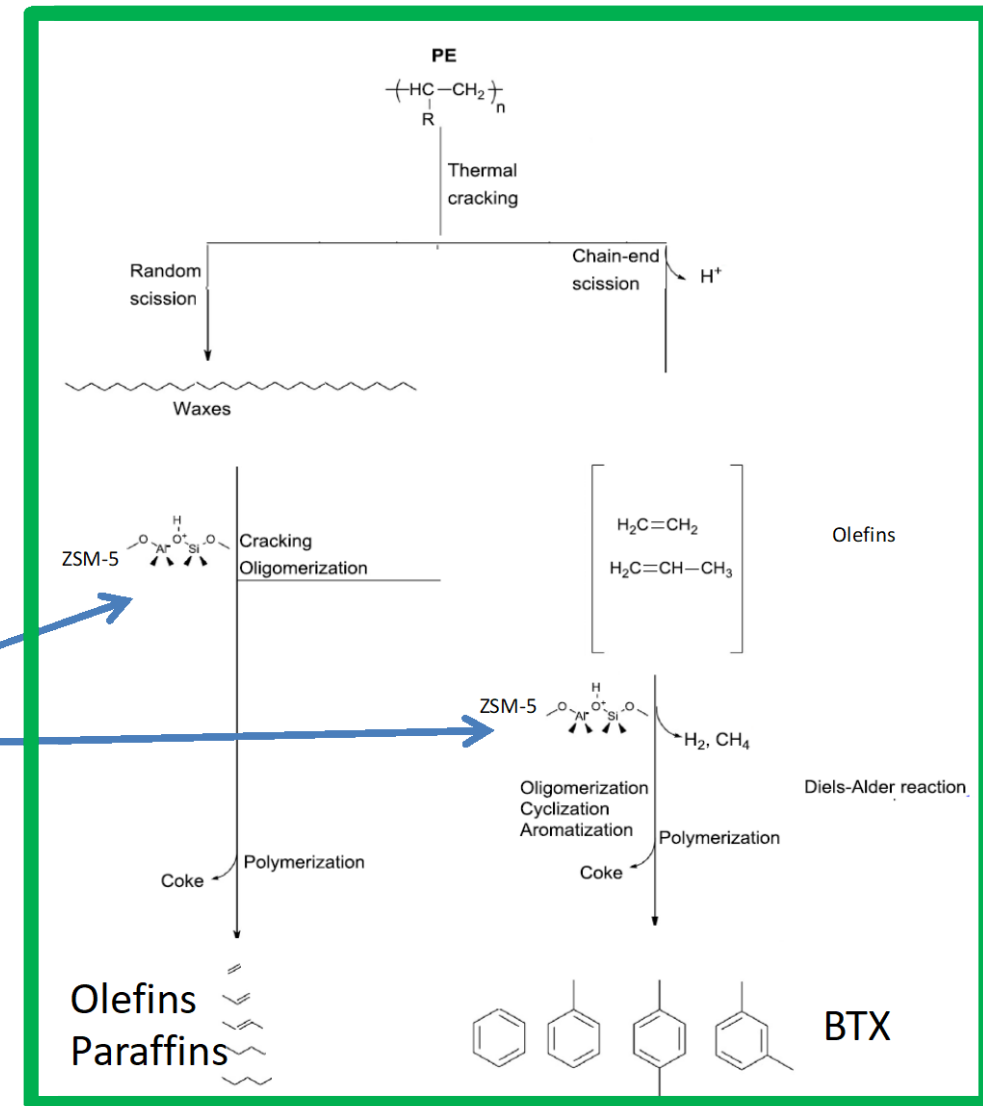
<sup>2</sup> Xuesong Zang, Habwy Lei, Lei Zhu, Moriko Qian, Xiaolu Zhu, Joan Wu, Shulin Chen, "Enhancement of jet fuel range alkanes from co-feeding of lignocellulosic biomass with plastic via tandem catalytic conversion", *Applied Energy*, 173 (2016) 418-430



Plas-TCat Catalytic Pyrolysis yields mainly BTX, ethylene, propylene, paraffins **directly** in one reactor

*Products ready for purification and use to make virgin plastics*

ZSM-5  
Catalyst

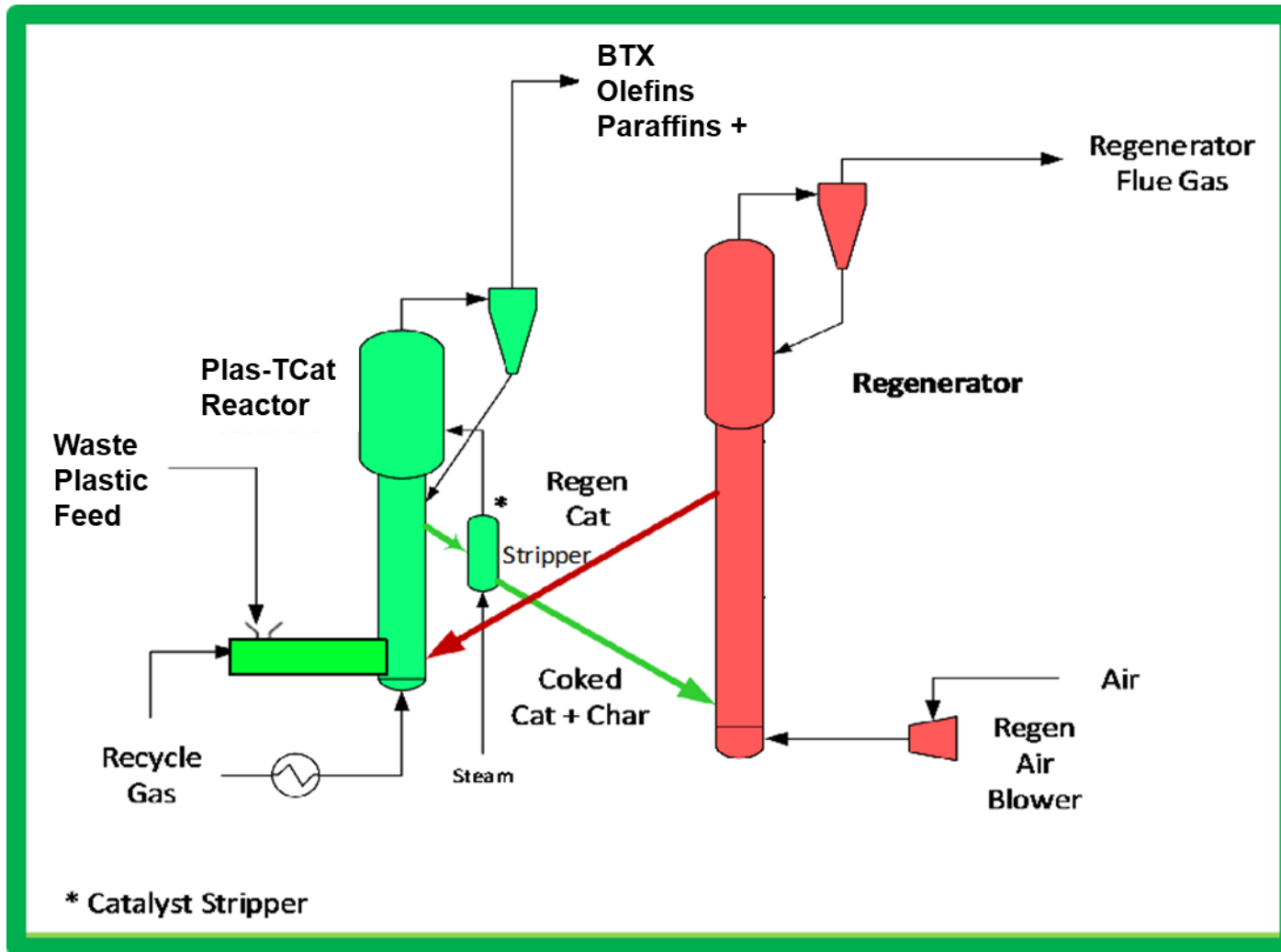


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# Plas-TCat is highly scalable – limited only by feedstock supply

## Industrial Fluid Bed Catalytic Reactor Technology



## Scalable Heat Transfer Solution

### Plas-TCat

- Circulating catalyst provides heat to reactor

### Thermal Pyrolysis

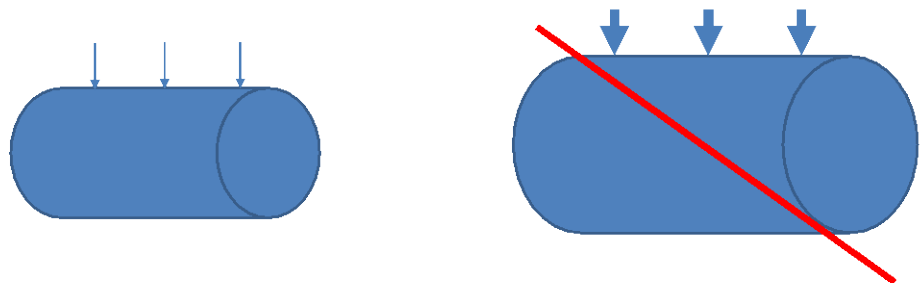
- Heat provided by external heating of reactor walls
- Limits reactor diameter and overall process scale
- Multiple reactor trains required for scale up

# Thermal Pyrolysis Heat Transfer Scale up Dilemma

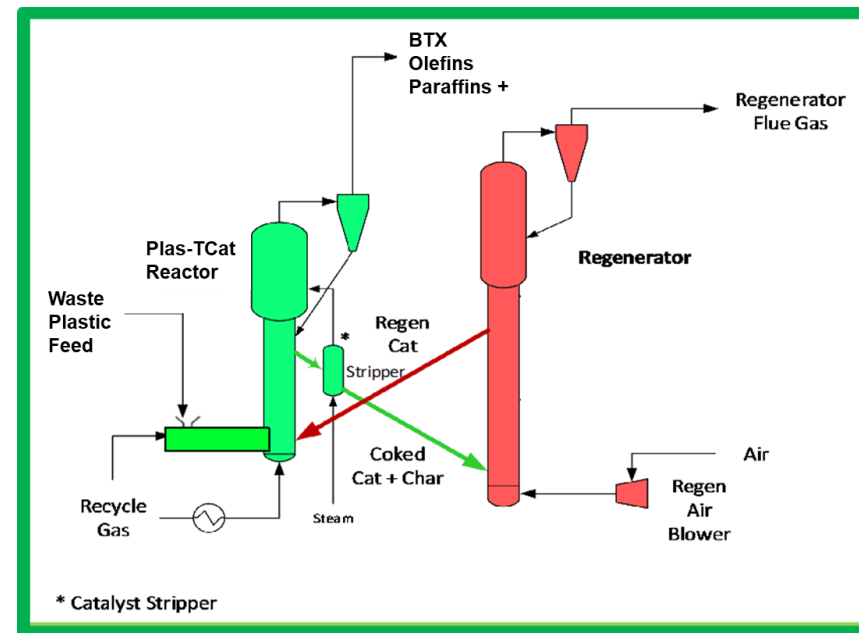
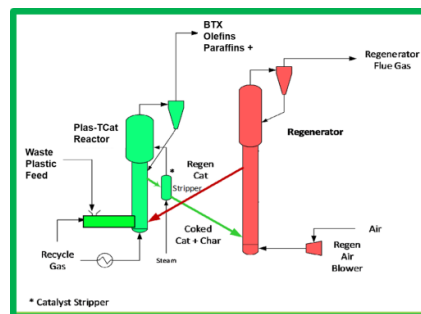
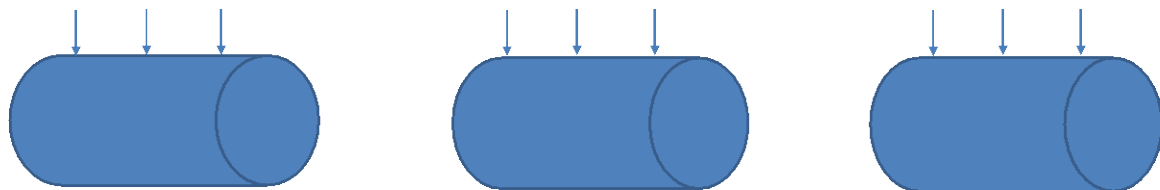
## Thermal Pyrolysis (numbering –up)

## Plas-TCat (single system scale-up)

Scale-up potential has inherent limitations

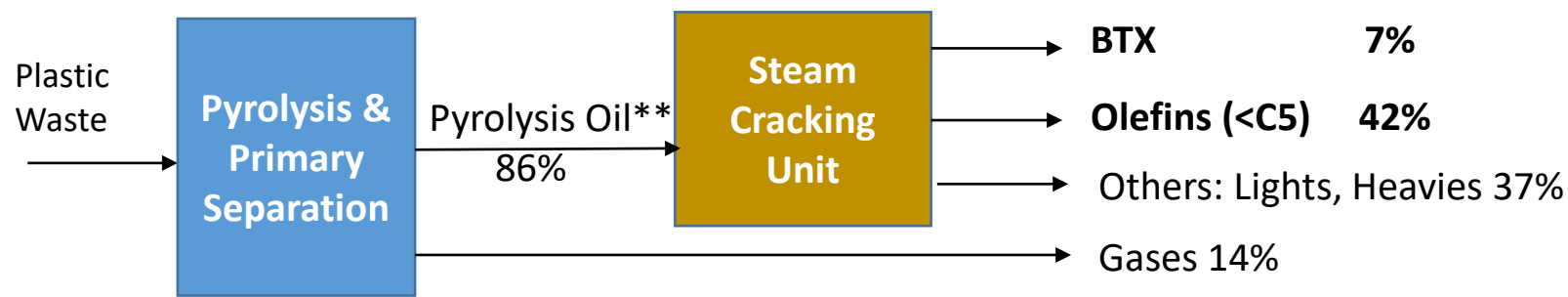


Numbering-up required to reach comparative single system scale for Plas-TCat

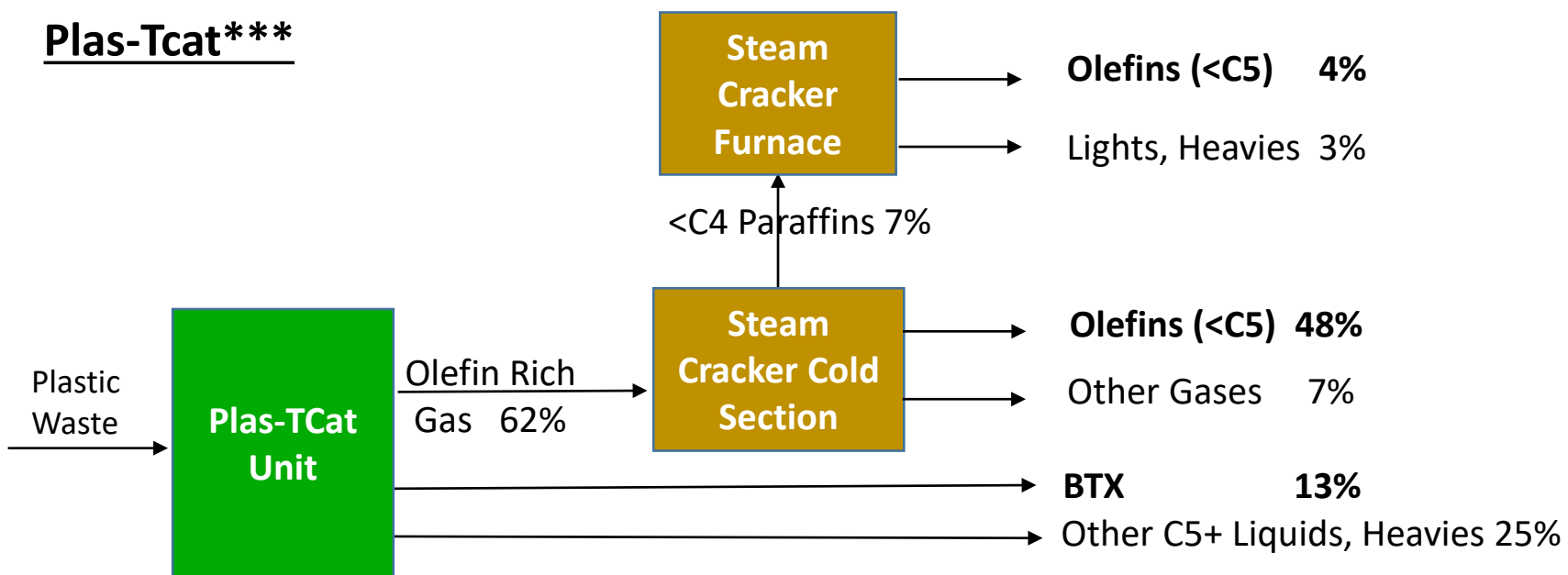


Capex and Opex significantly improved by ability to utilize single reactor larger scale systems

## Non-Catalytic Pyrolysis\*



## Plas-Tcat\*\*\*



## Yields as % of Plastic Waste Feed

### Thermal Pyrolysis

➔ **BTX + <C5 olefins = 49%**  
 7%                      42%

### Plas-TCat Catalytic Pyrolysis

➔ **BTX + <C5 olefins = 65%**  
 13%                      52%

\* Source: Elizabeth A. Williams & Paul T. Williams, "The Pyrolysis of Individual Plastics and a Plastic Mixture in a Fixed Bed Reactor", *J. Chem. Tech. Biotechnol.* 70, 9-20 (1997)

\*\* Assume pyrolysis oil has same avg steam cracker yields as naphtha

\*\*\*Anellotech Lab data

New Joint Venture Company with 12 Japanese Cross-Industry Partners  
to Develop Innovative Anellotech Plas-TCat Plastics Recycling Technology

June 30, 2020



# R Plus Japan JV Partners

**SUNTORY**

**TOYOBO**  
*Ideas & Chemistry*

**GPI**  
The General Packaging Industry  
**RENGO**

**DNP**

**TOPPAN**

**TOYO SEIKAN GROUP**

**Iwatani**

**Fuji Seal International**

**Asahi**

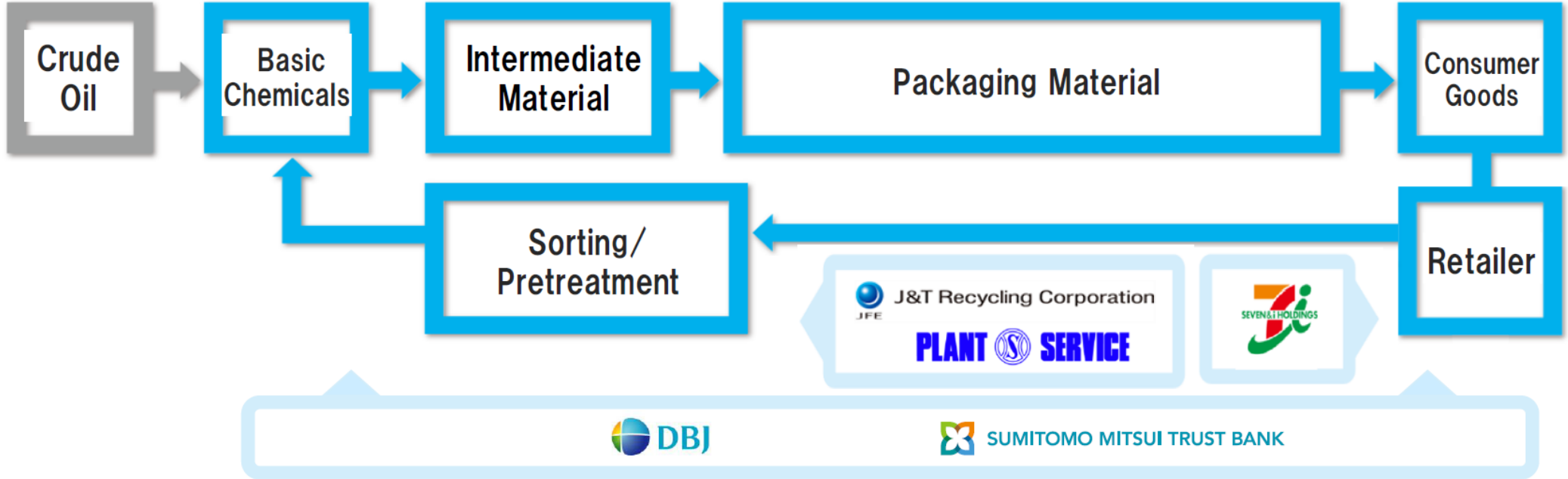
**YOSHINO**  
株式会社吉野工業所



Container Business  
**HOKKAI CAN CO.,LTD**

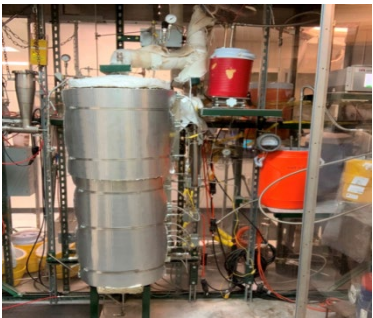


**J&T Recycling Corporation**



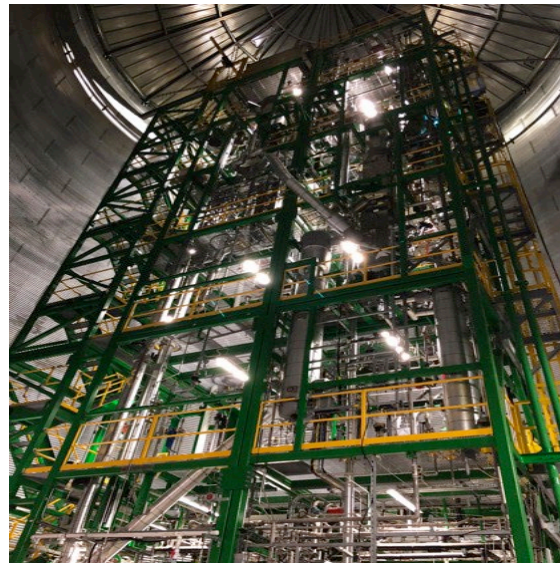
# Plas-TCat Development Program

## Laboratory Fluid Bed Reactors



**Completed**

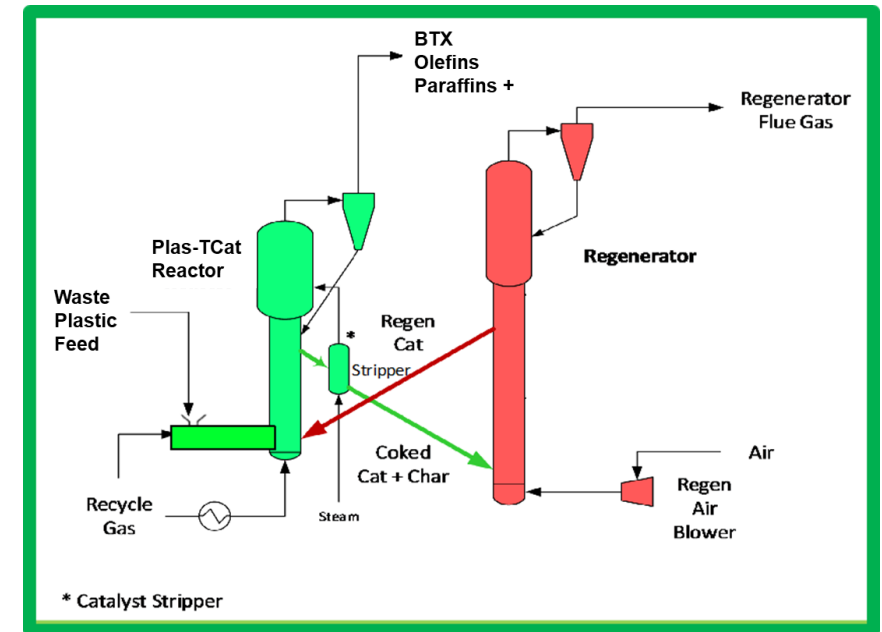
## TCat-8 Pilot Plant ([VIDEO LINK](#))



**2022-2023**

## Future Commercial Plant

### Plas-TCat™

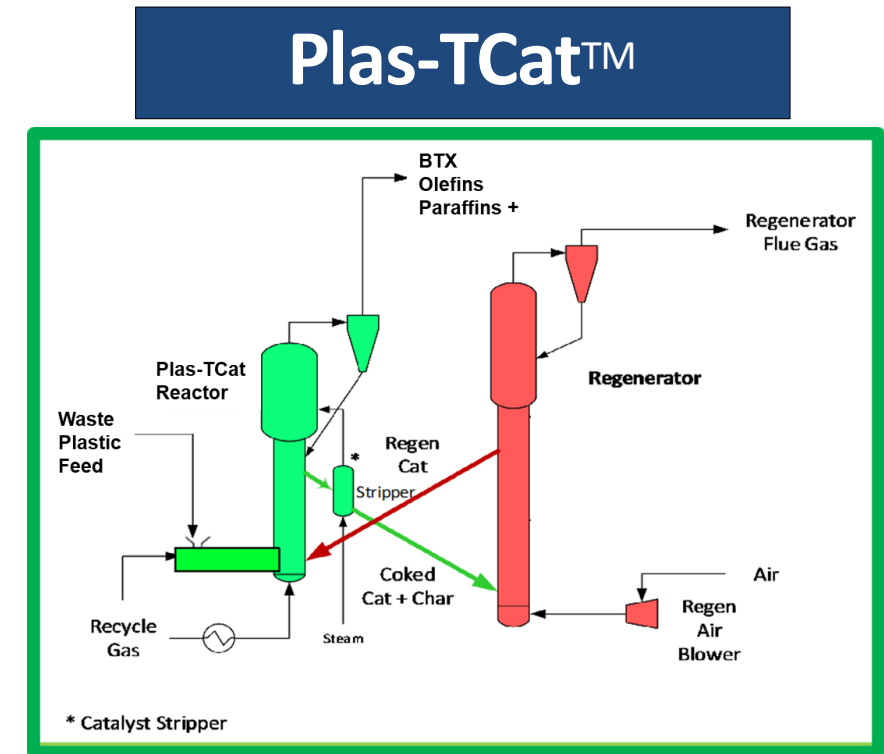


**2027**



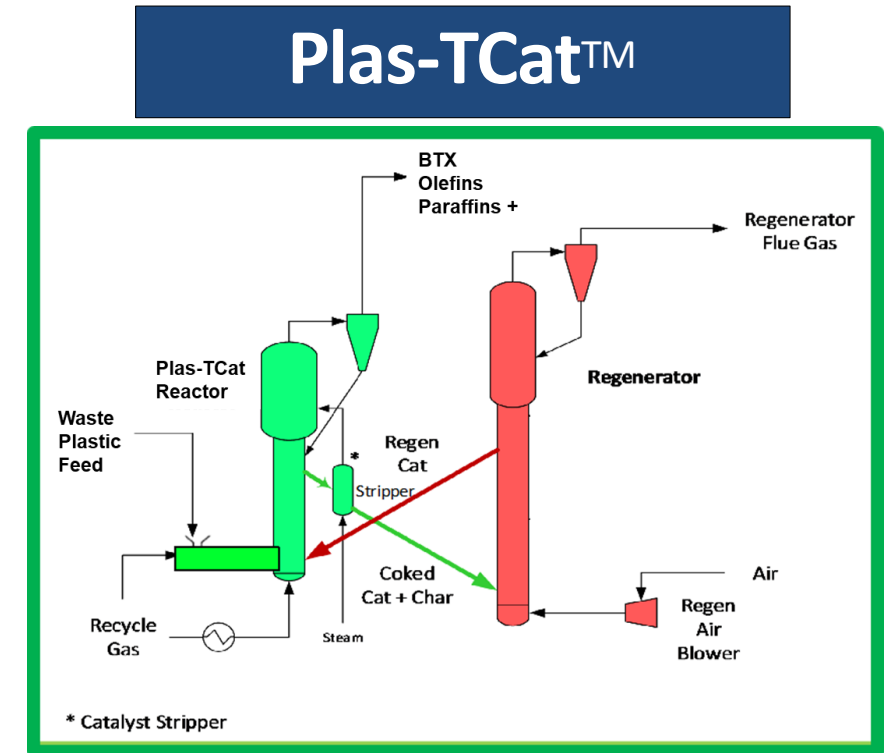
# 6 Reasons that Plas-TCat is a Game Changer

- 1. Plas-TCat process is a new, direct route to olefins and aromatics** from low value plastic waste feedstock
- 2. Competitive economics (double digit IRR%)** using market price feedstock; no tipping fees or product price premiums.
- 3. Makes valuable products from range of feedstocks** at attractive yields
  - Can feed all major plastics due to proprietary catalyst and fluid bed reactor-regenerator system design.
  - Product slate can be controlled to maximize aromatics (BTX) or olefins (ethylene, propylene)
  - Composites, mixed plastics can be used with minimal presorting of feedstocks (other than PVC reduction)
  - Yields can be predicted based on plastic's chemical composition
  - Heteroatoms (O, N, S, Cl) mostly rejected in the form of gases CO, CO<sub>2</sub>, H<sub>2</sub>S, N<sub>2</sub> to nitriles, Cl removed in pretreatment



# 6 Reasons that Plas-TCat is a Game Changer (continued)

4. **No major chemical upgrading** of Plas-TCat products is required
  - Aromatics, C2-C4 olefins and paraffins ready for purification and sale or direct feeding into the downstream steam crackers purification trains.
  - No upgrading is required in ethylene furnaces -- as for thermal pyrolysis output.
  
5. **LCA assessment** (preliminary): potential to reduce CO2 emissions up to 50% vs. monomers from steam crackers.
  
6. **Scalable.** Anticipated commercial plants should exceed 200,000 metric tons/year of olefins and/or BTX production from a single reactor system processing majority polyolefin plastic waste.
  - Reactor scaling is not limited by heat transfer (multiple reactors, in parallel, are not required to scale as in liquid thermal pyrolysis). Hot, regenerated Plas-TCat catalyst serves as a carrier to provide the heat to the reactor.



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