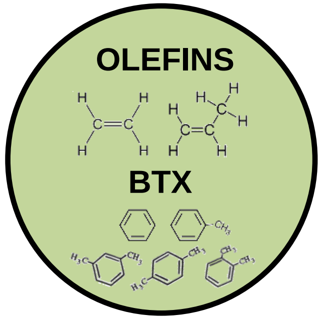
Anellotech



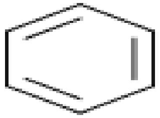


Bio-sourced aromatics for virgin plastics and fuels

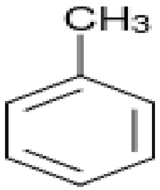
The Bio-TCat™ Process --- Thermal Catalytic Biomass Conversion

+

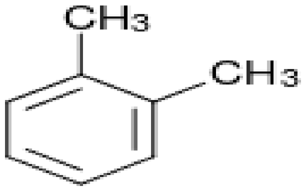
B-T-X



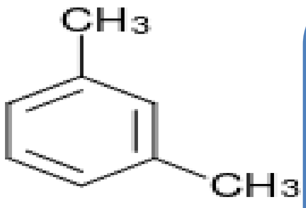
benzene



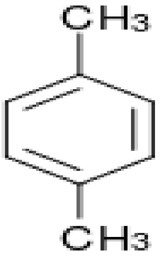
toluene



ortho-xylene

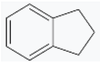


meta-xylene

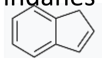


para-xylene

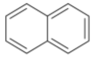
C9+ aromatics



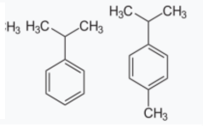
indanes



indenes



naphthalenes



Alkylbenzene

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

Anellotech

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

IFP Energies nouvelles

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

SUNTORY
FOLLOW YOUR NATURE

JM Johnson Matthey
INTERCAT

- ✓ 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

1st Commercial Plant Planning Underway

Anellotech Technology Deployment

TCat-8

BEP* → Construction → **First commercial plant (FCP) production**

BEP → construction → **Second commercial plant (SCP) production**

Production Capacity

(*) BEP = Basic Engineering Package

1st Plant

Feed: 500 tpd
Products: 40 KTA BTXN
(860 BPSD)
& 30 KTA CO

2nd Plant

Feed: 2,500 - 3,000 tpd
Products: 200 – 250 KTA BTXN
(4,000–5,000 BPSD)
& 150 KTA CO

Basic engineering work for the 1st Plant completed; site, funding TBD

1st Commercial Plant Planning

Process Design Study performed by Axens

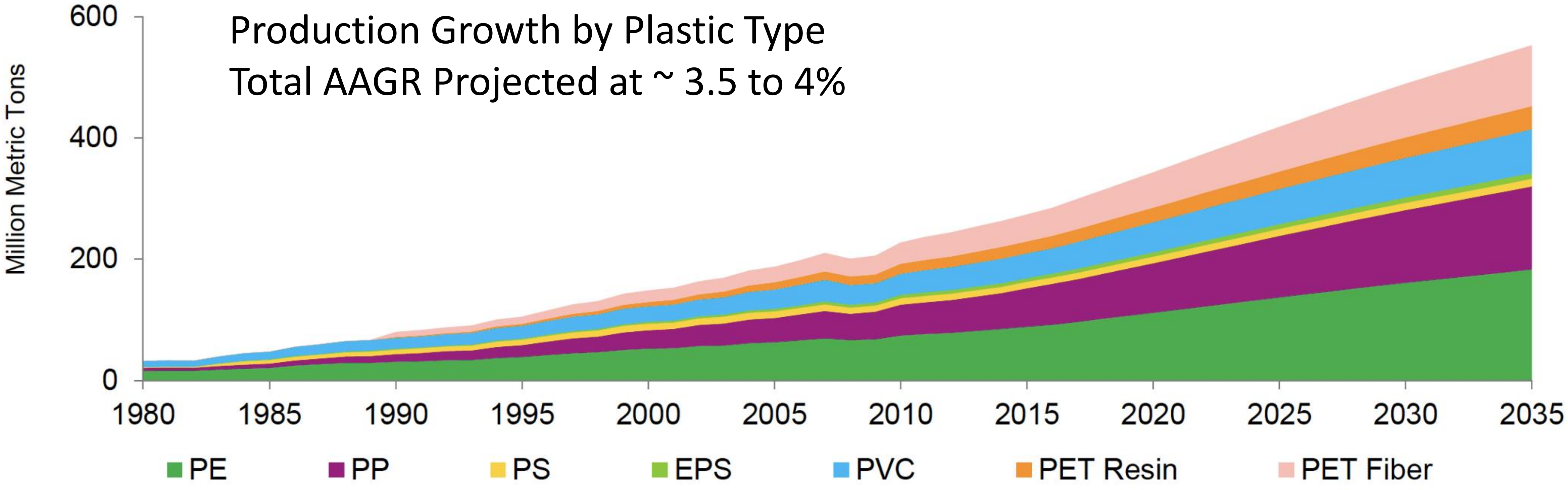
(500 TPD)

- *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*

Plas-TCat™

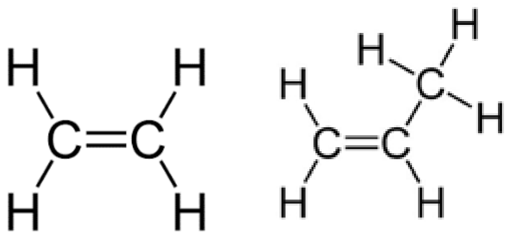
Huge, Growing Plastics Recycling Challenge

400+ million tons/year production by 2030



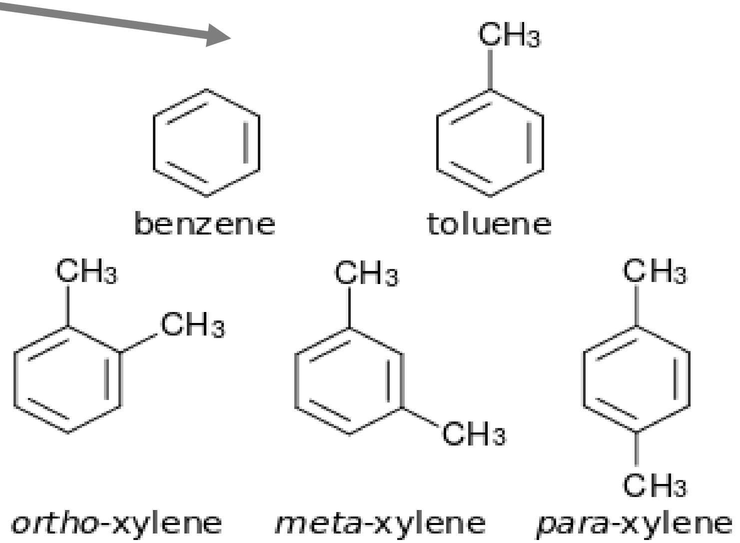
Plas-TCat™

Olefins



ethylene **propylene**

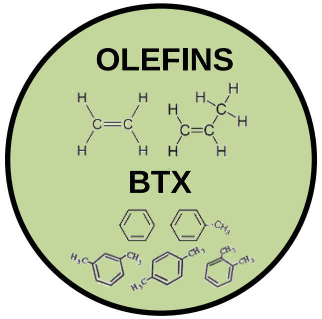
B-T-X



Anellotech aims to convert large volumes of mixed waste plastics…

Plas-TCat™

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



ANELLOTECH'S VISION

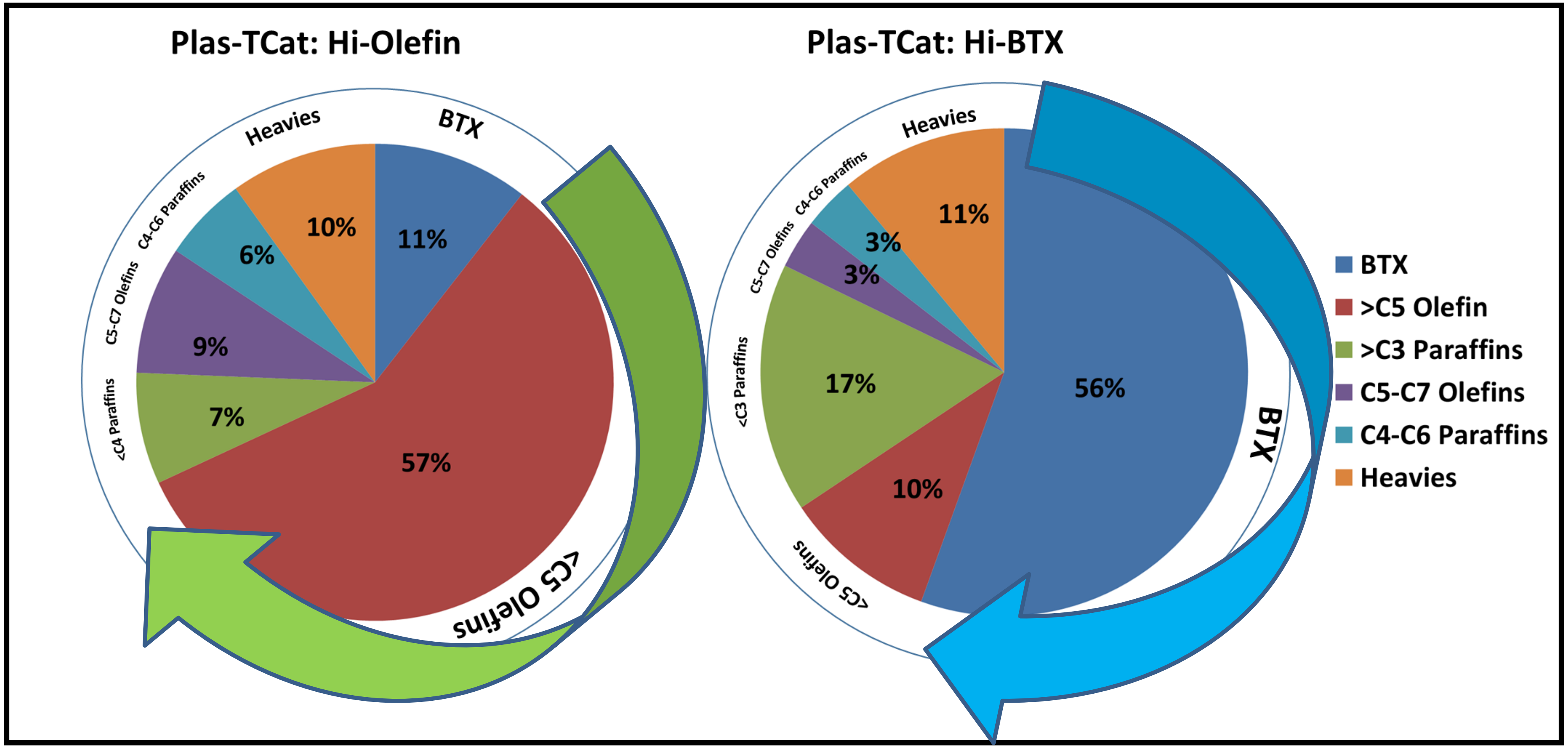
Efficient, economic, large-scale recycling of mixed waste plastics

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

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

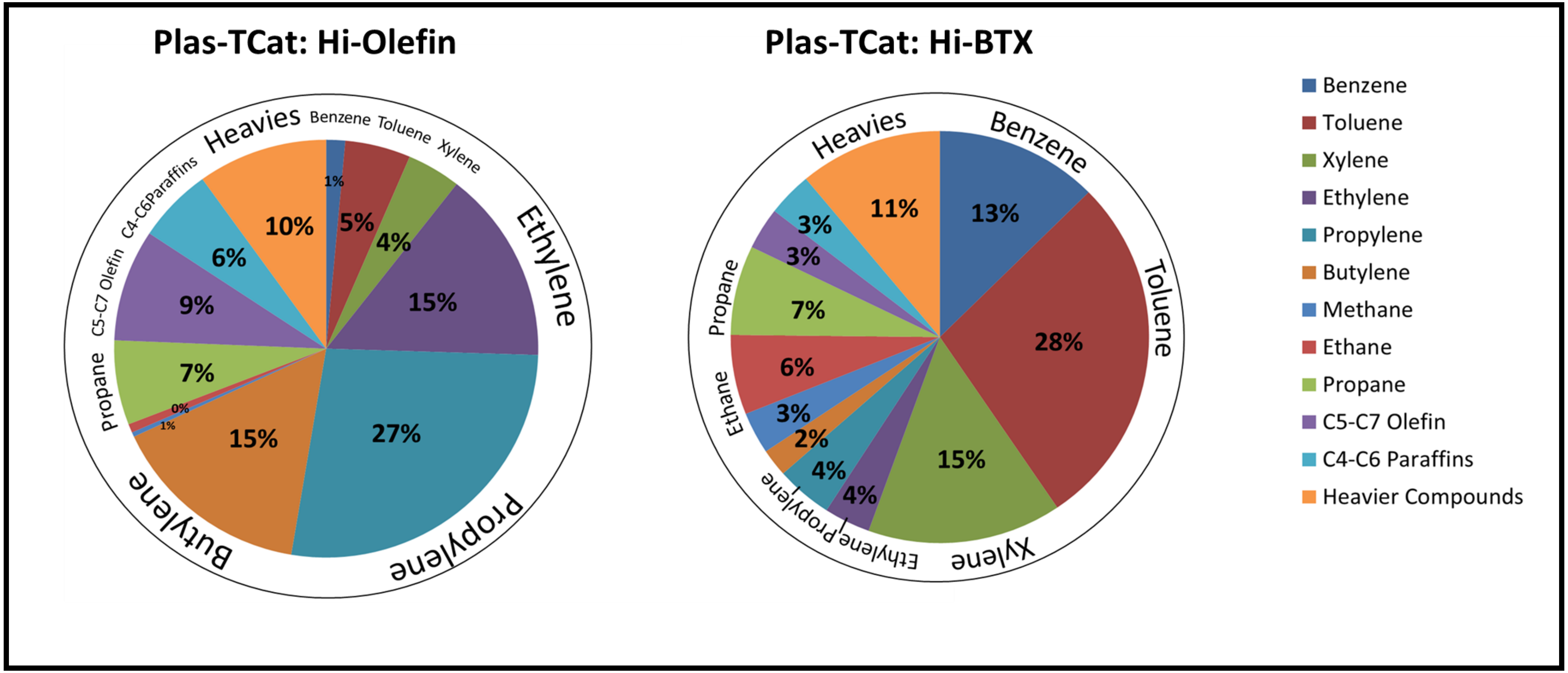
…widely used today in packaging and other products.

Plas-TCat 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

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



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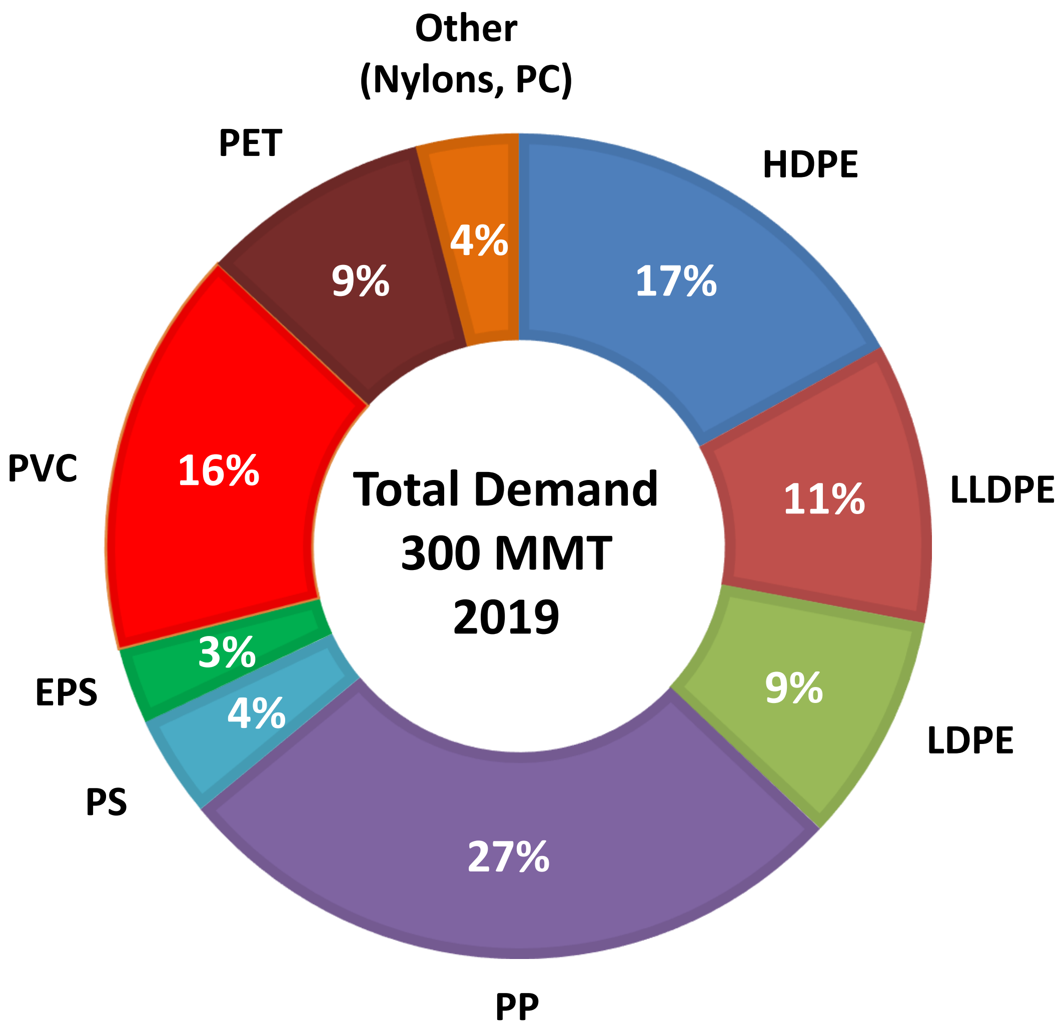
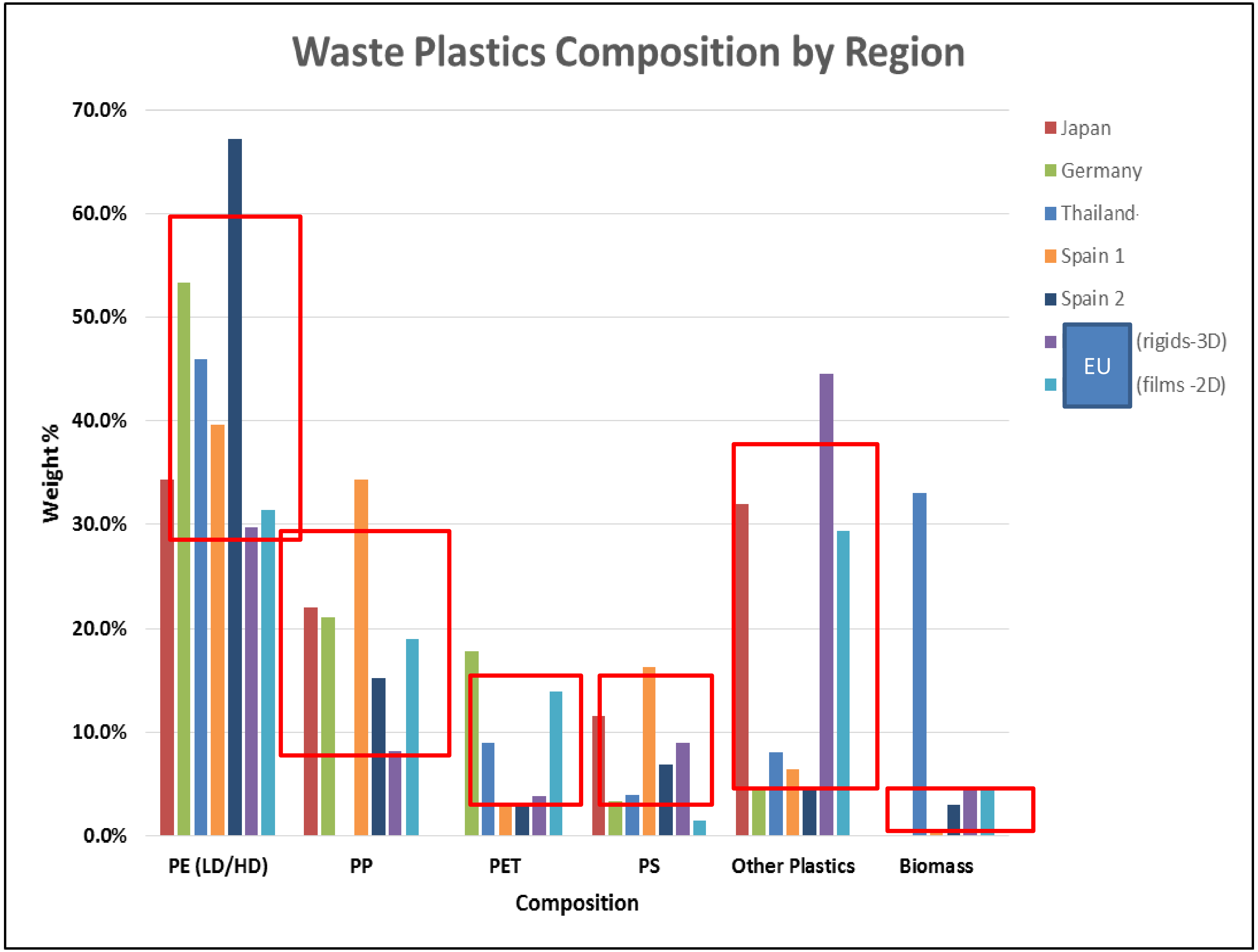
Global plastics demand by type of polymer

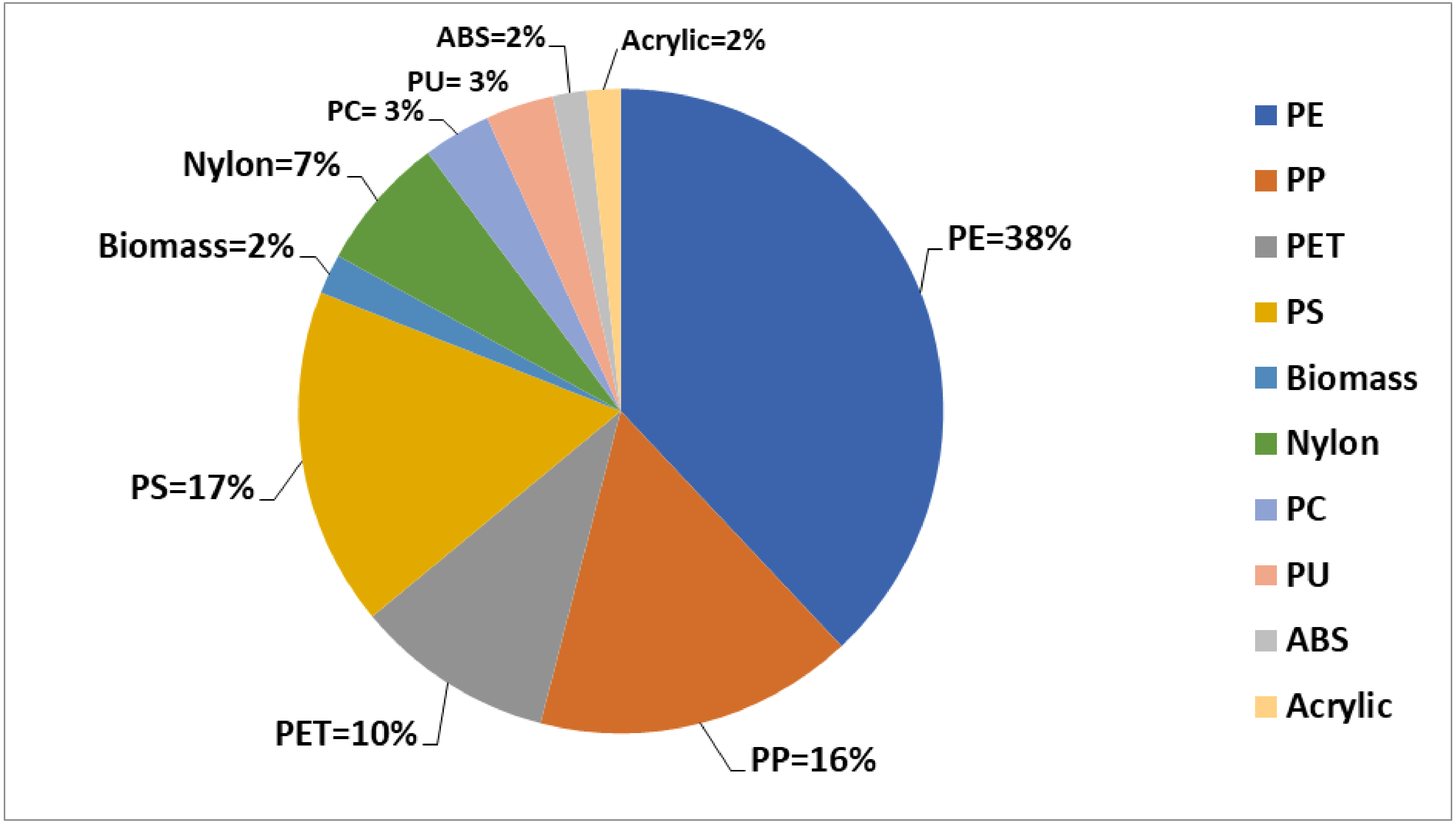


Plas-TCat Development: Design Window

- 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

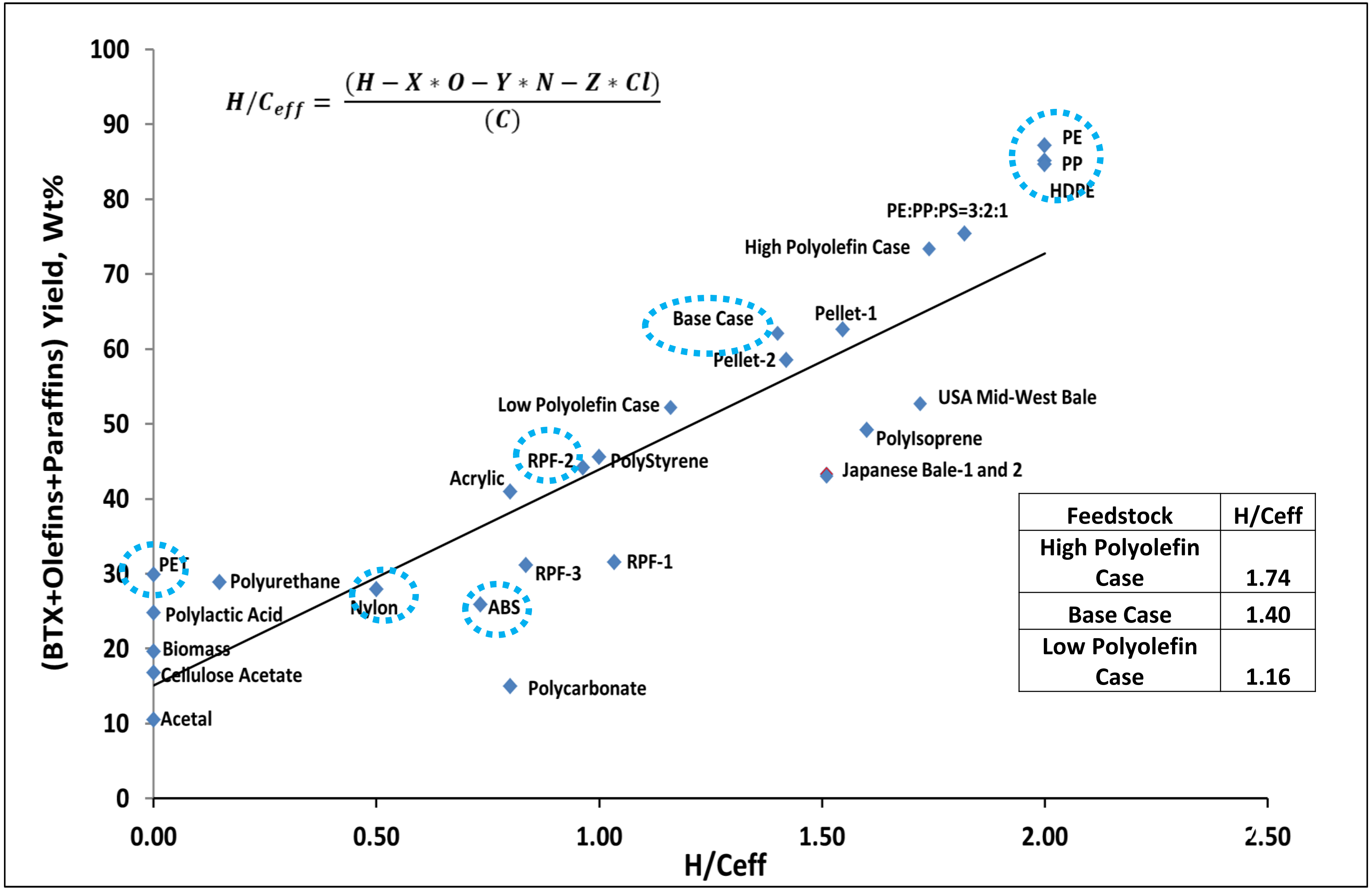


Plas-TCat Base Case Feedstock Composition



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



$$H/C_{eff} = \frac{(H - X * O - Y * N - Z * Cl)}{(C)}$$

Feedstock	H/Ceff
High Polyolefin Case	1.74
Base Case	1.40
Low Polyolefin Case	1.16

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

PET → Plas-TCat →

- CO
- CO_2
- Char

- >75% oxygen is rejected in the form of CO and CO_2*
- Some oxygen is rejected in the form of Char
- Small amount of oxygenates are formed in the liquid phase

PET → Thermal Pyrolysis →

- Carboxylic Acid
- Aldehydes
- Ketones
- Alcohols
- CO_2

- >50% oxygen is rejected in the liquid phase**, ***
- Large quantities of benzoic acid is formed which can lead to corrosion of the steam cracking furnace***
- <50% oxygen is rejected in the form of CO and CO_2

Plas-TCat Advantage

- Low Upgrading Cost: Minimal hydro treating is required to remove heteroatoms from the liquid phase.
- Favorable LCA: Overall CO_2 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

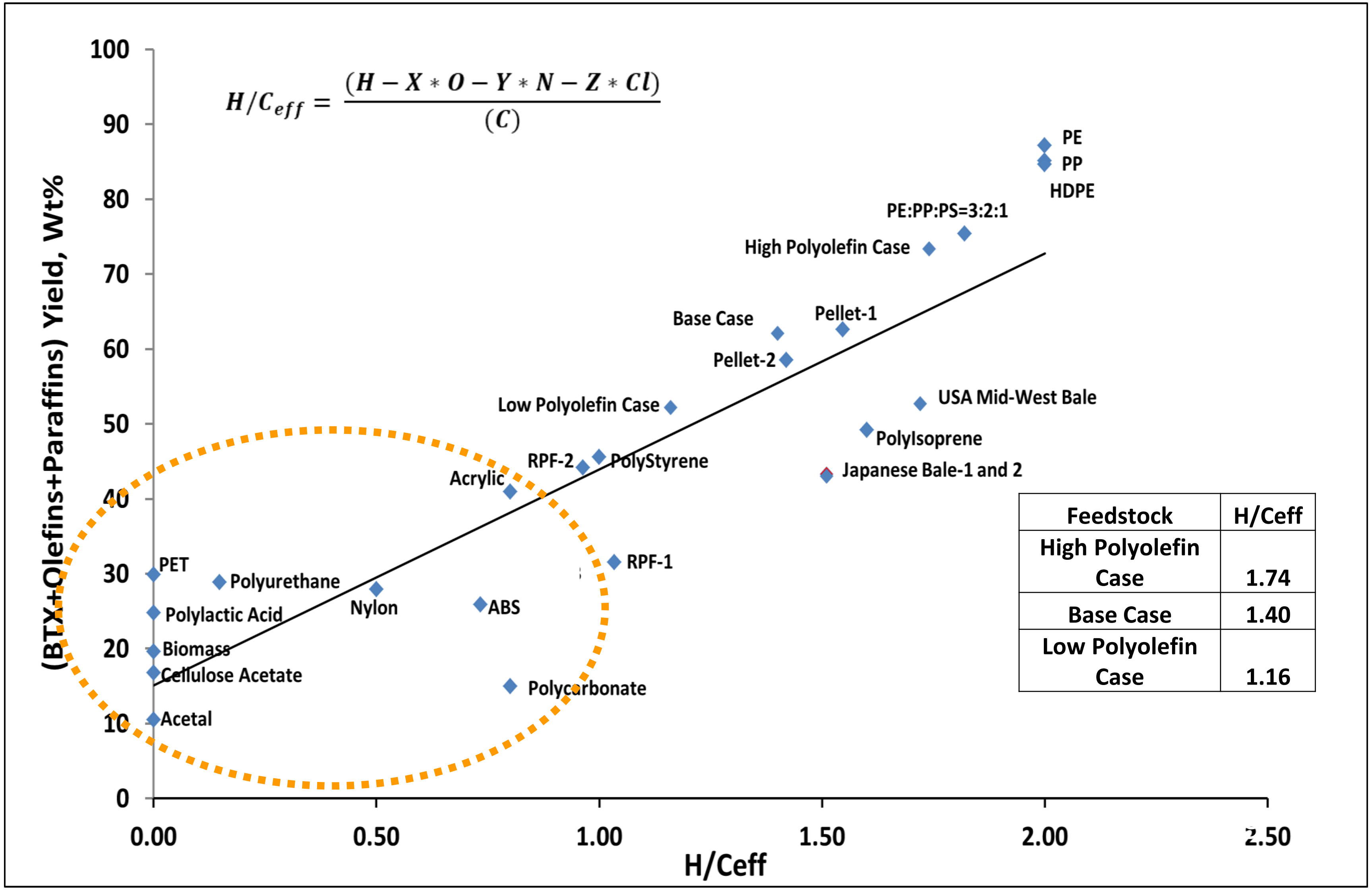
*Anellotech Lab Data

**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

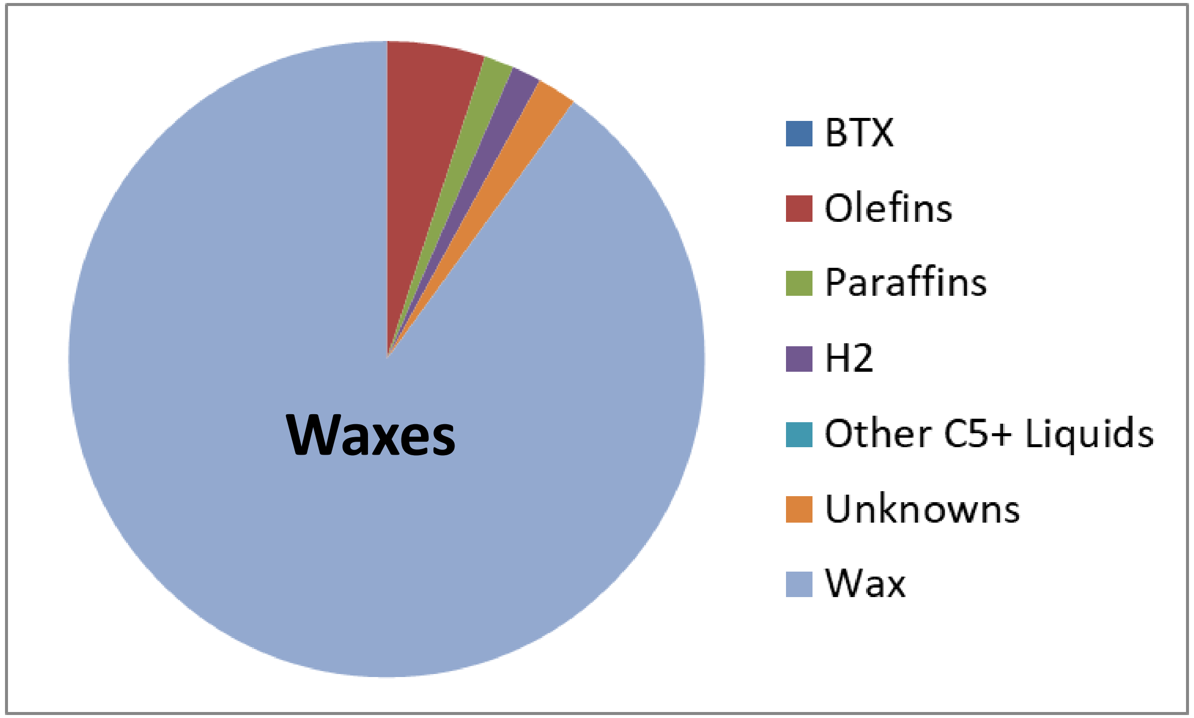
- Most No. 7 plastics contain heteroatoms such as nitrogen and oxygen in their chemical structure
- Plas-TCat converts these heteroatom containing plastics (such as PET, Acrylic, Nylon, Polyurethane, ABS, Polycarbonates, etc.) directly into BTX, olefins and paraffins.
- Due to the process wide tolerance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



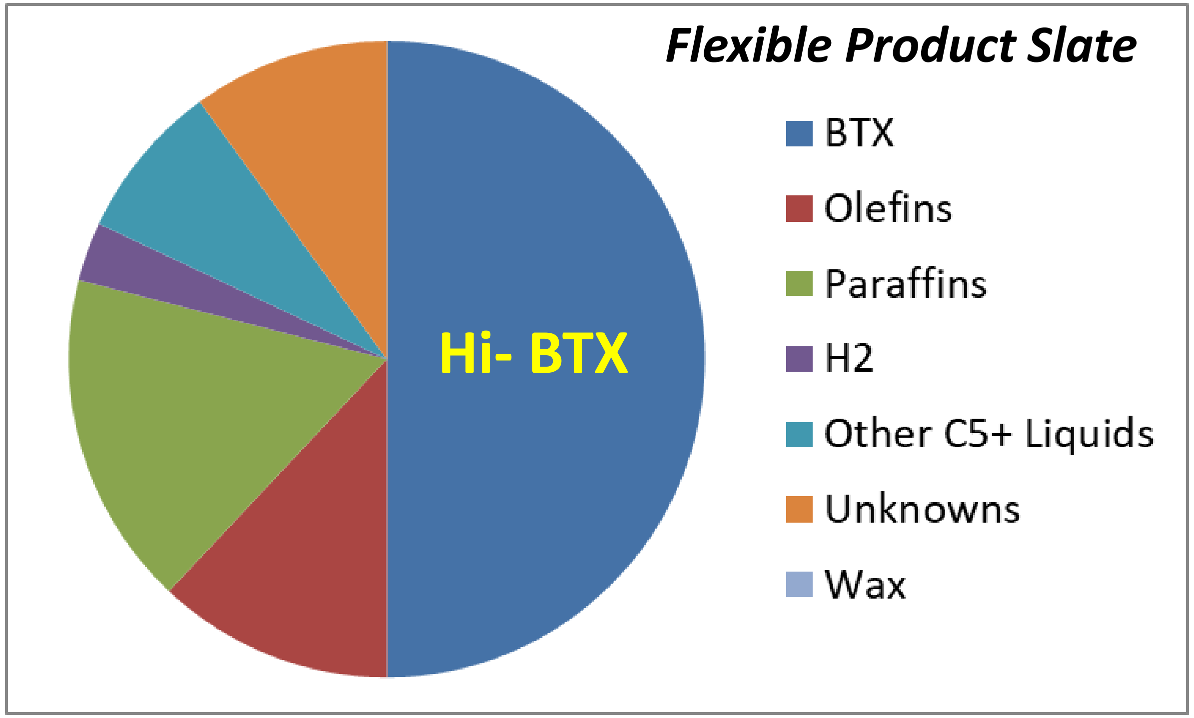
Feedstock	H/Ceff
High Polyolefin Case	1.74
Base Case	1.40
Low Polyolefin Case	1.16

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

Non-Catalytic Pyrolysis



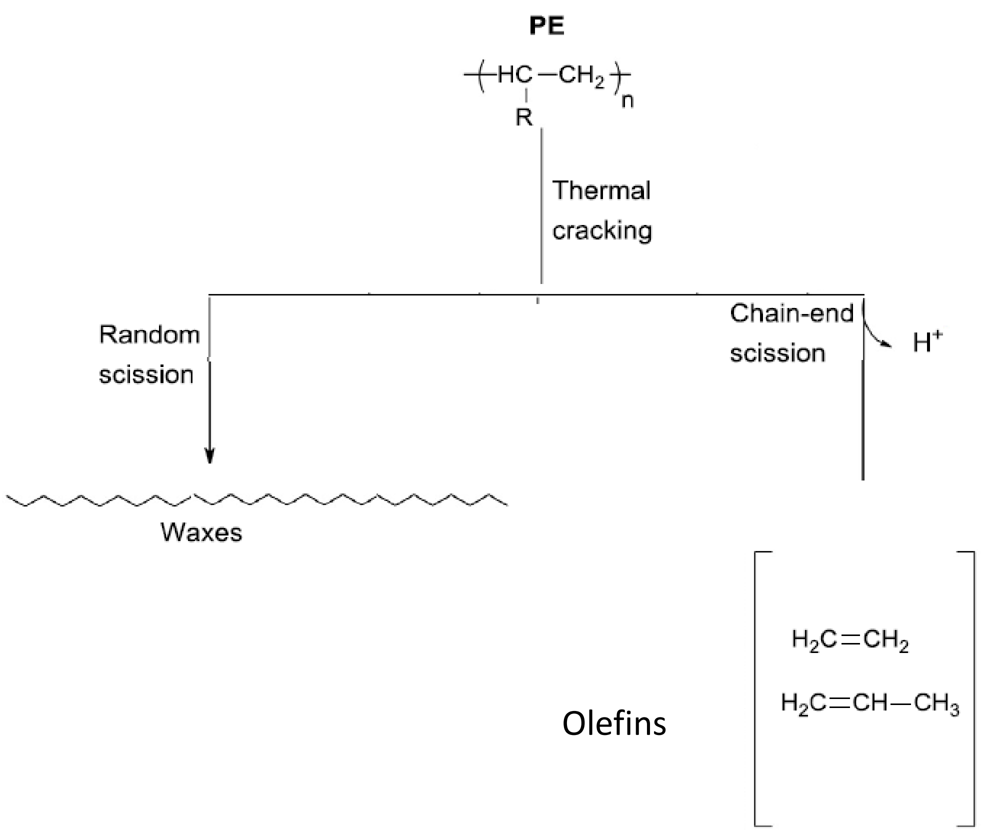
Plas-TCat Catalytic Process (Hi-BTX)



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[(1)(2)]

Requires upgrading in a steam cracker to yield upgraded valued product

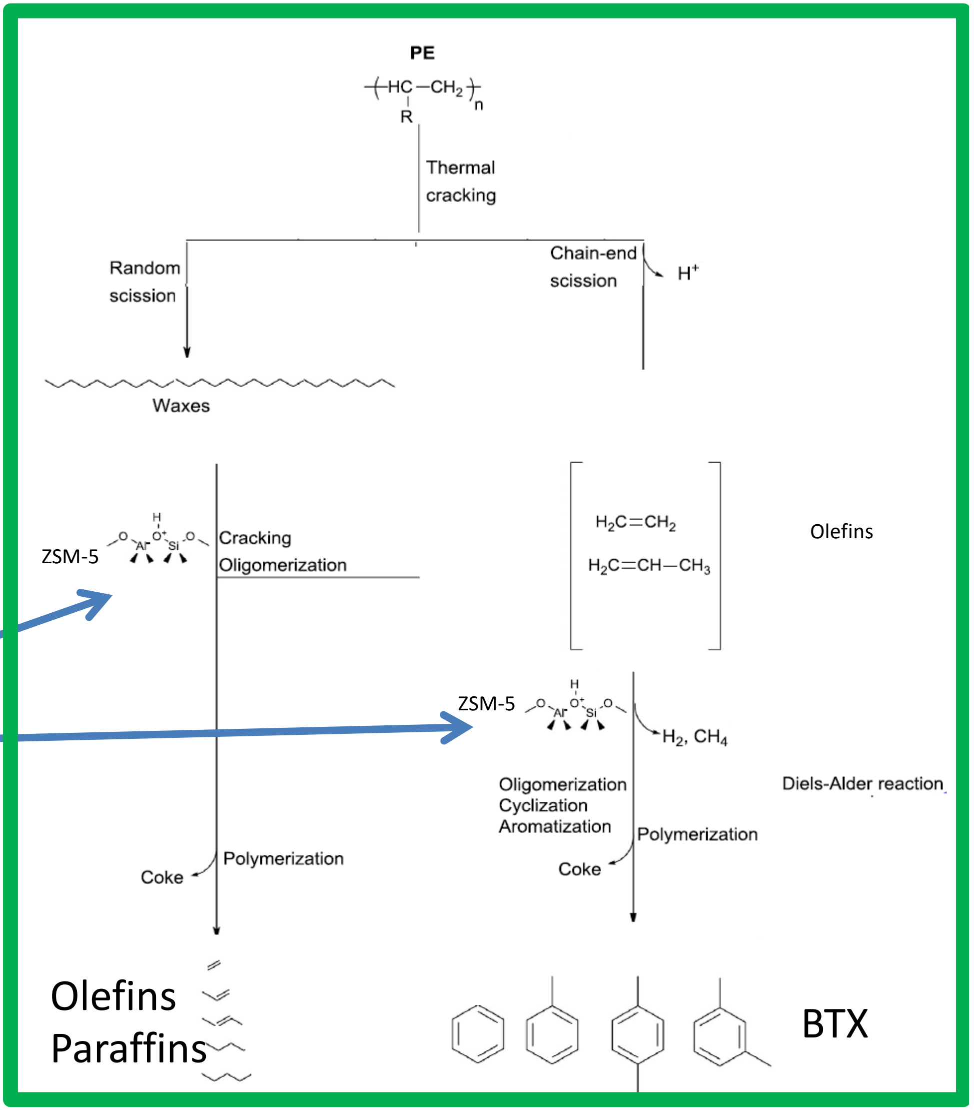


[1.] Dongting Zhao, Xianhua Wang, James B Miller, George W Huber, "The chemistry and kinetics of polyethylene pyrolysis: A feedstock to produce fuels and chemicals.

[2] 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

ZSM-5 Catalyst



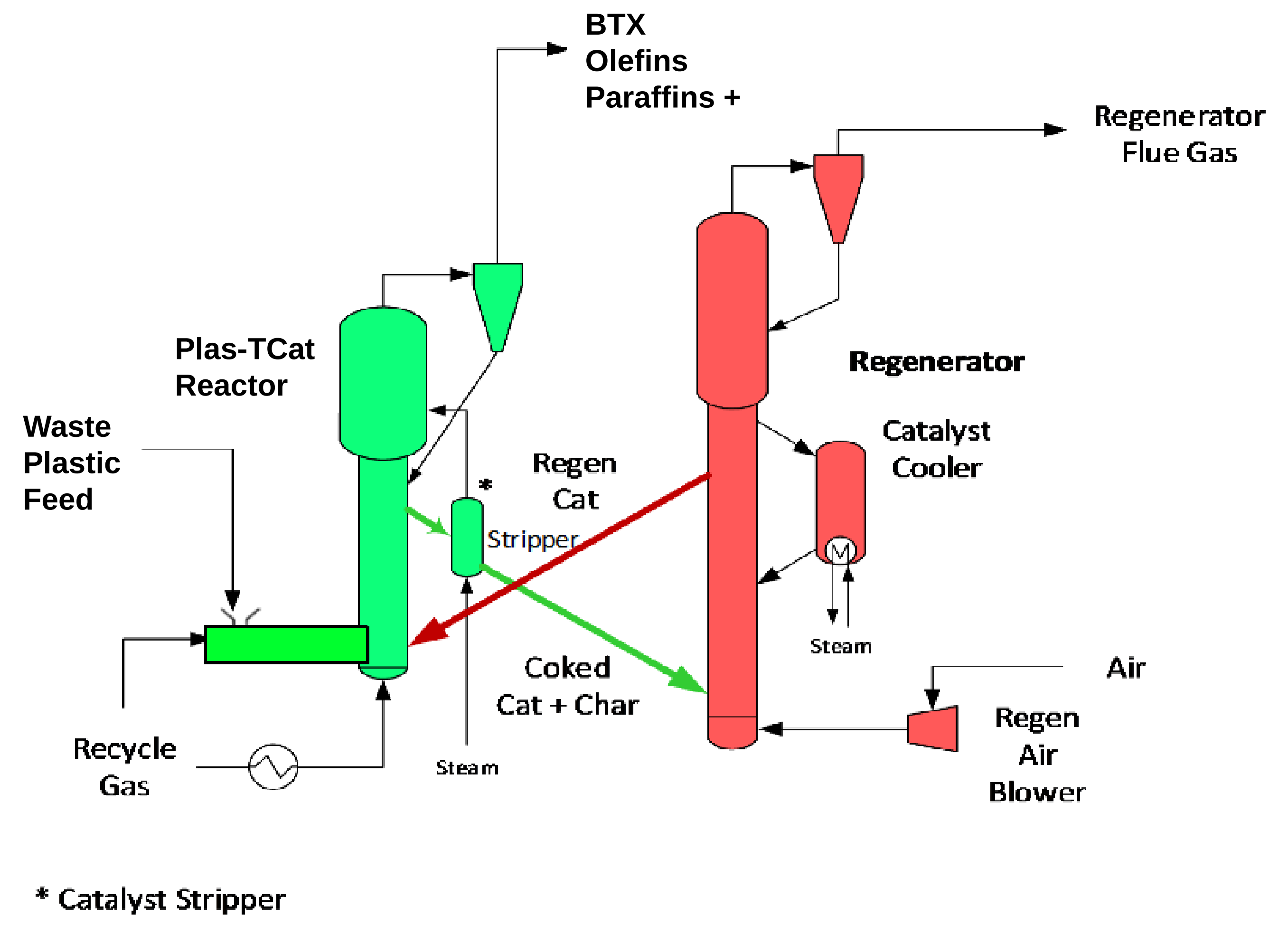
Products ready for purification and use to make virgin plastics

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

[2] 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 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

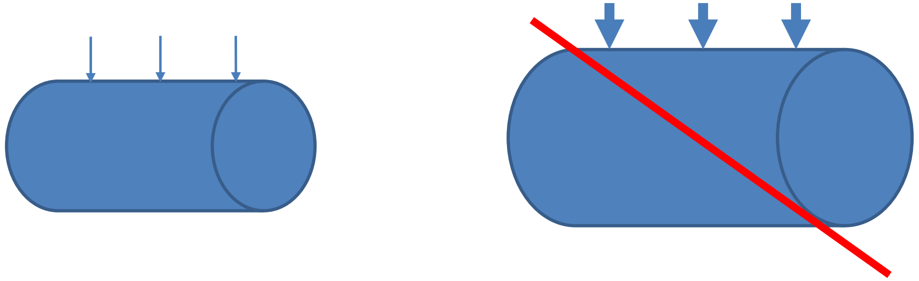
Thermal Pyrolysis

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

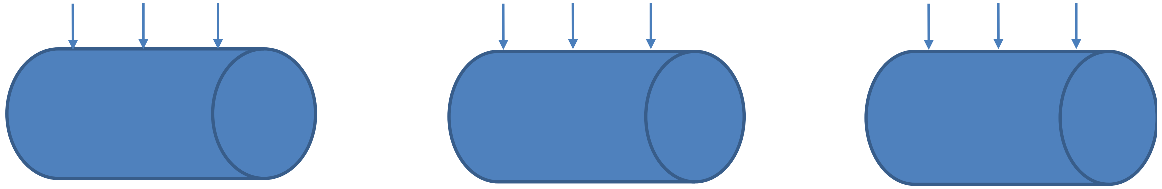
Thermal Pyrolysis Heat Transfer Scale up Dilemma

Thermal Pyrolysis (numbering –up)

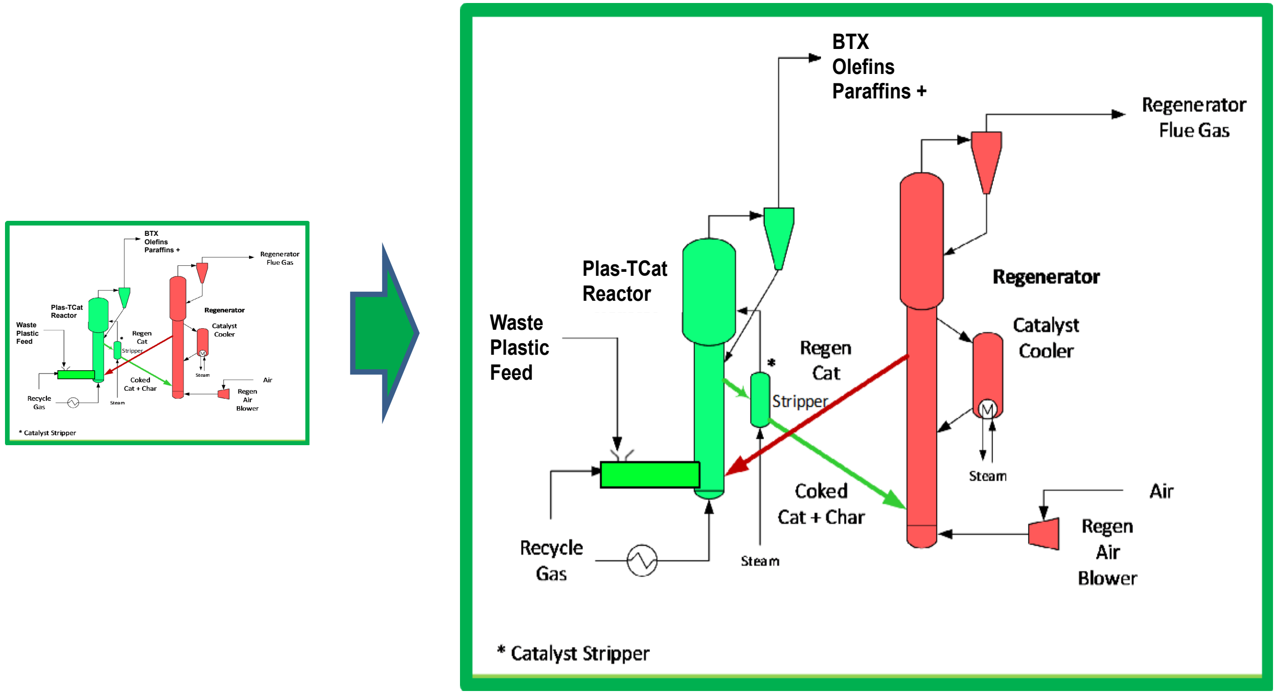
Scale-up potential has inherent limitations



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

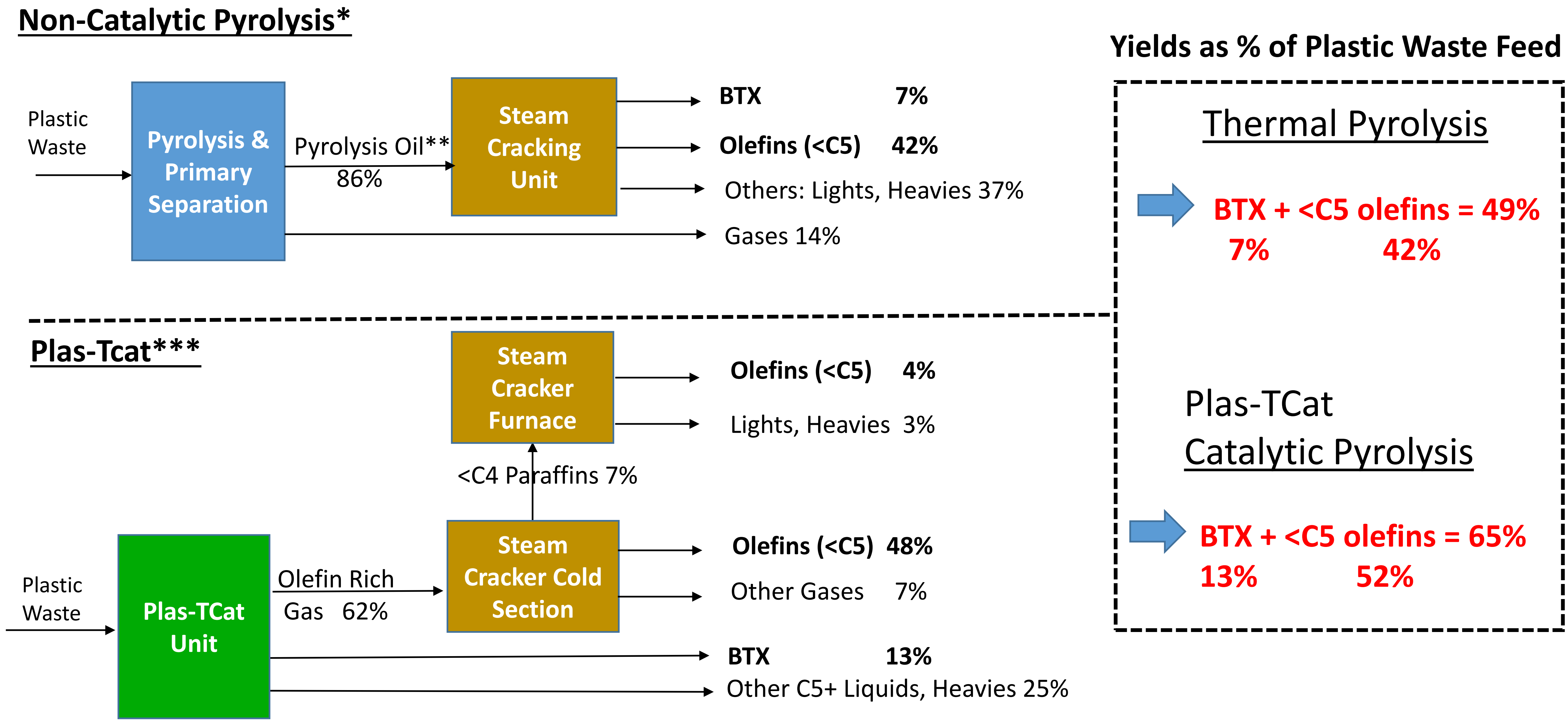


Plas-TCat (single system scale-up)



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

Plas-TCat Hi-Olefin Case vs Thermal Pyrolysis – PE:PP:PS = 3:2:1

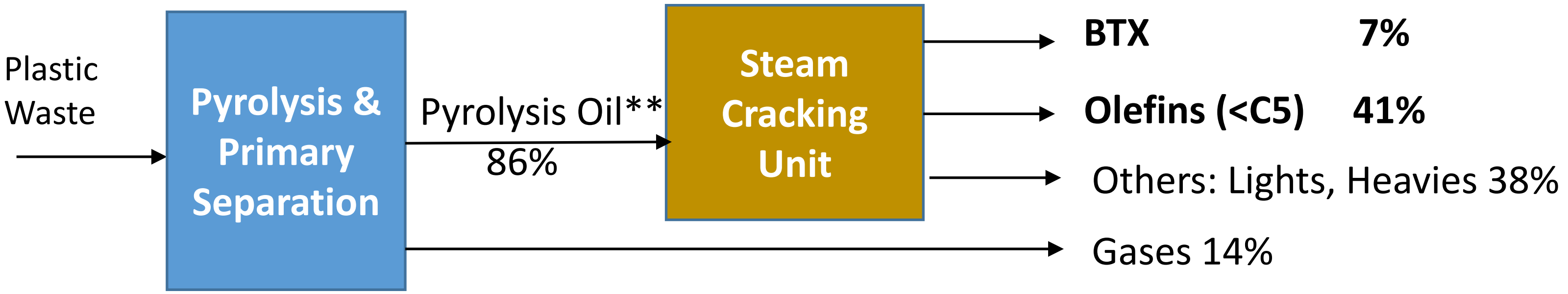


* Source: Elizabeth A. Williams & Paul T. Williams, “The Pyrolysis of Individual Plastics and a Plastic Mixture in a Fixed Bed Reactor”, *J. Chem. Tech. Biotechnol.* 70, 9-20 (1997)
** Assume pyrolysis oil has same avg steam cracker yields as naphtha
***Anellotech Lab data

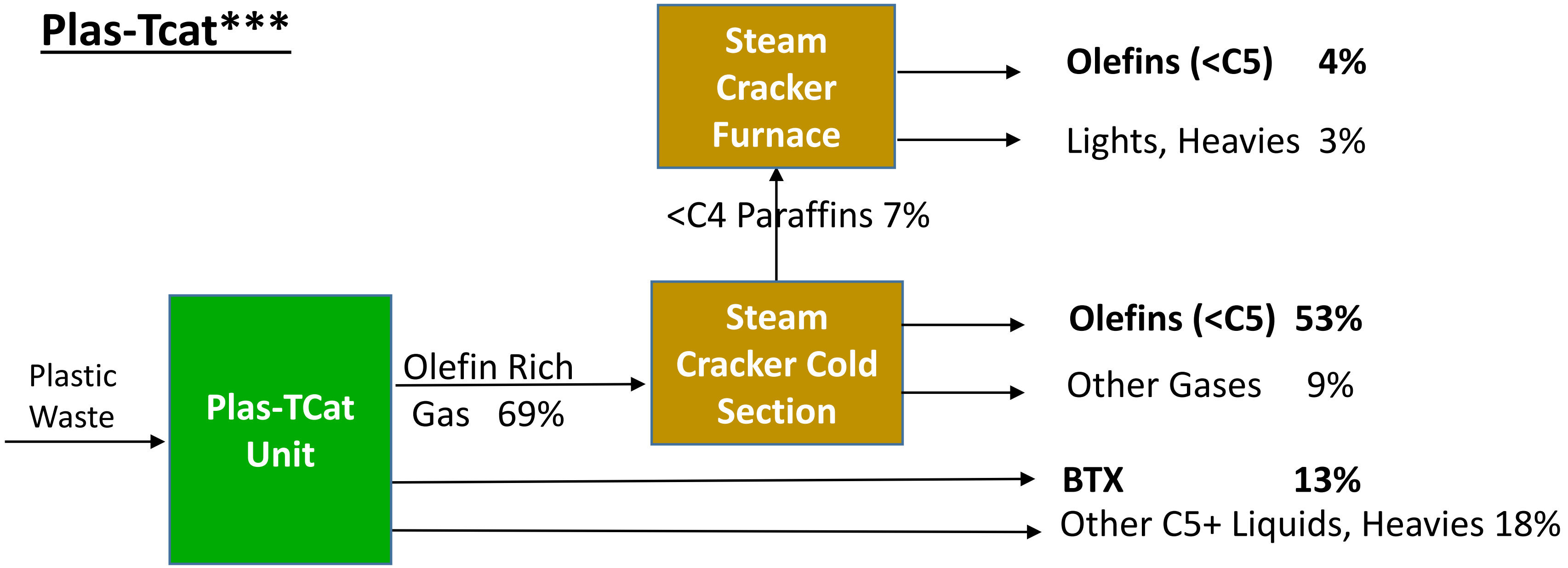
Plas-TCat Hi-Olefin Case vs Thermal Pyrolysis – 100% Polyethylene Feedstock

Anellotech

Non-Catalytic Pyrolysis*



Plas-Tcat***



Yields as % of Plastic Waste Feed

Thermal Pyrolysis

BTX + <C5 olefins = 48%
7% 41%

Plas-TCat Catalytic Pyrolysis

BTX + <C5 olefins = 70%
13% 57%

* 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

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

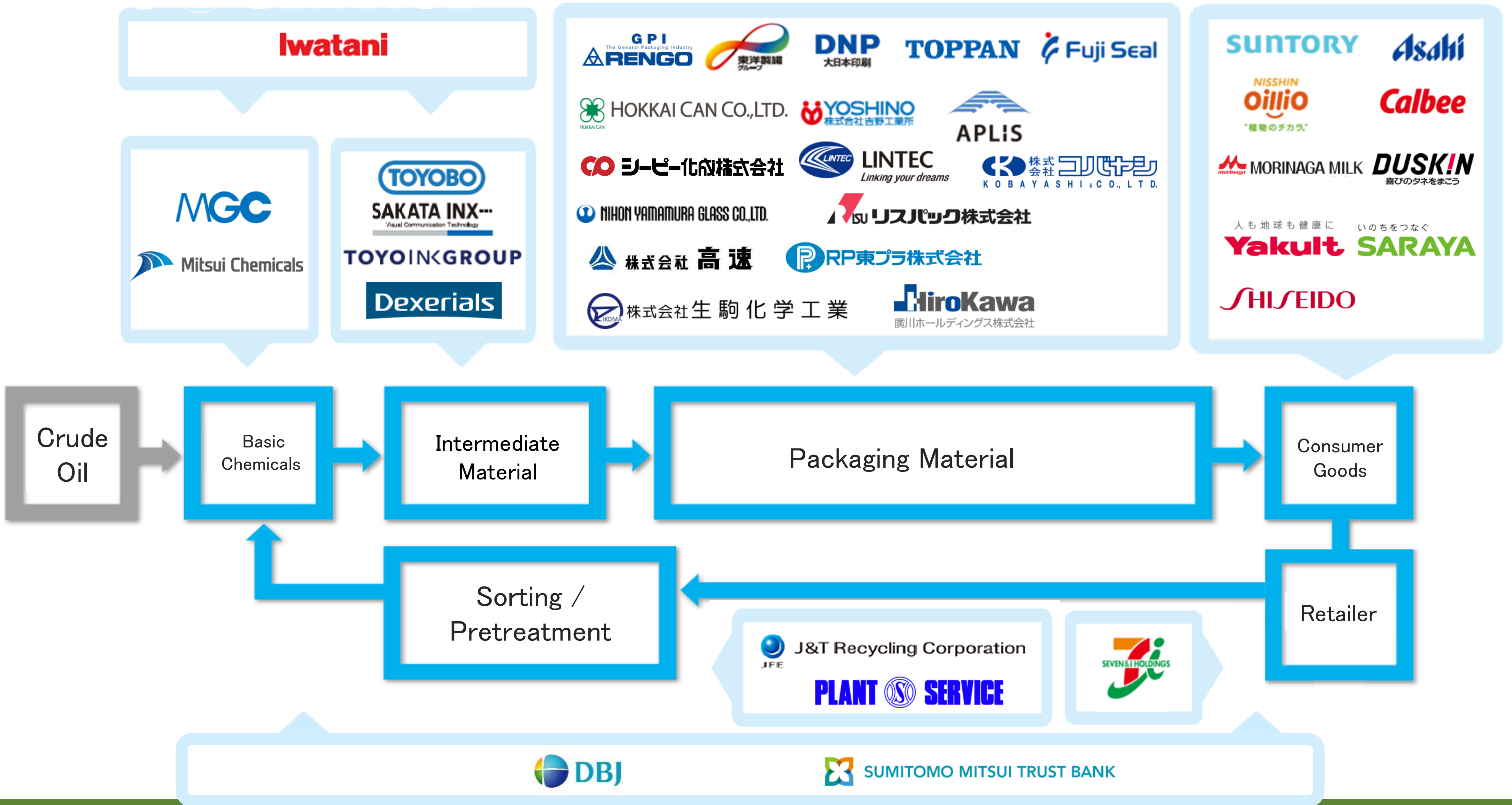
HOKKAI CAN
Container Business
HOKKAI CAN CO.,LTD

JFE
J&T Recycling Corporation

Anellotech

As of Feb. 2022

R PLUS JAPAN



R Plus Japan Plas-TCat Vision – June 30 2020 Press Release

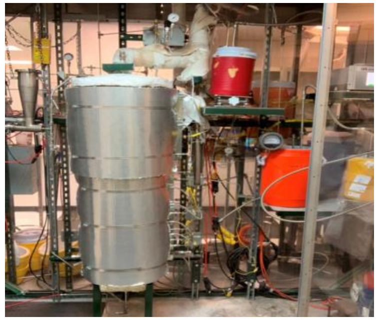
With the engagement of various industries throughout the supply chain,

- from raw materials manufacturers, and packaging suppliers to brand owners,
  - the newly established R Plus Japan,
    - together with Anellotech,
      - will advance the development & **commercialization of this eco-efficient plastic recycling technology by 2027.**

Plas-TCat Development Program

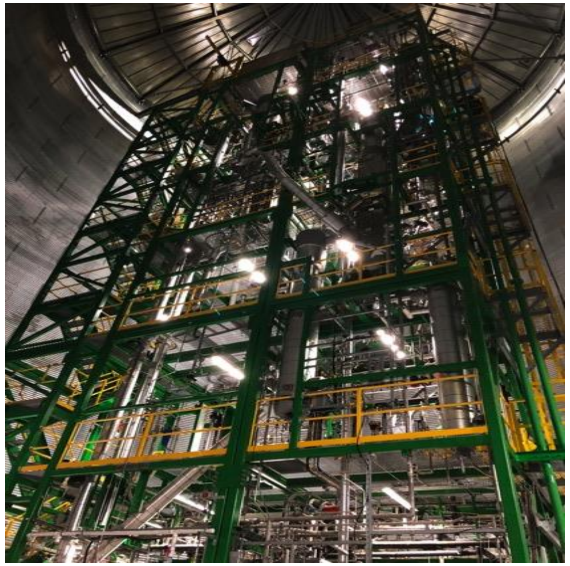
Future Commercial Plant

Laboratory Fluid Bed Reactors



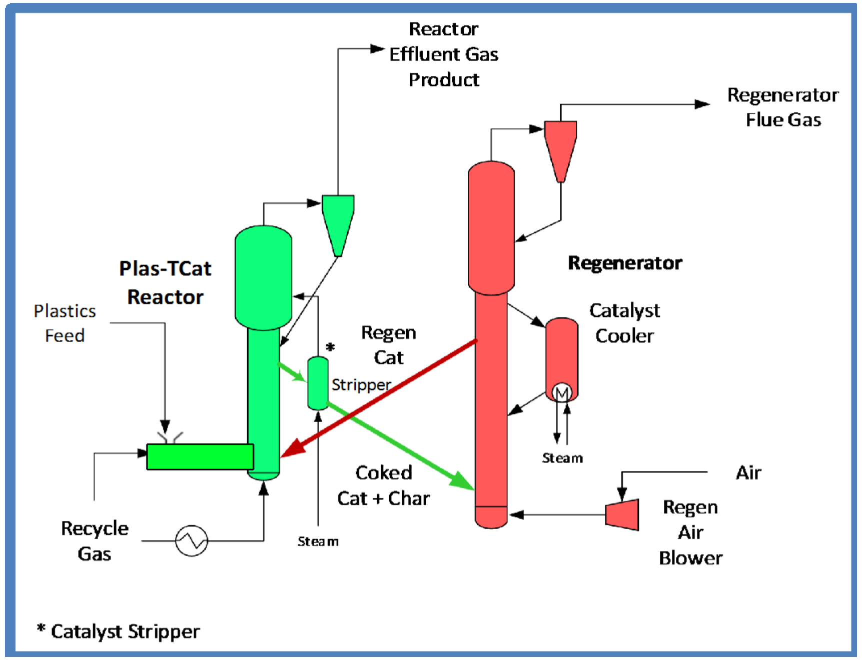
Completed

TCat-8 Pilot Plant
(VIDEO LINK)



2022-2023

Plas-TCat™



2027

6 Reasons that Plas-TCat is a Game Changer

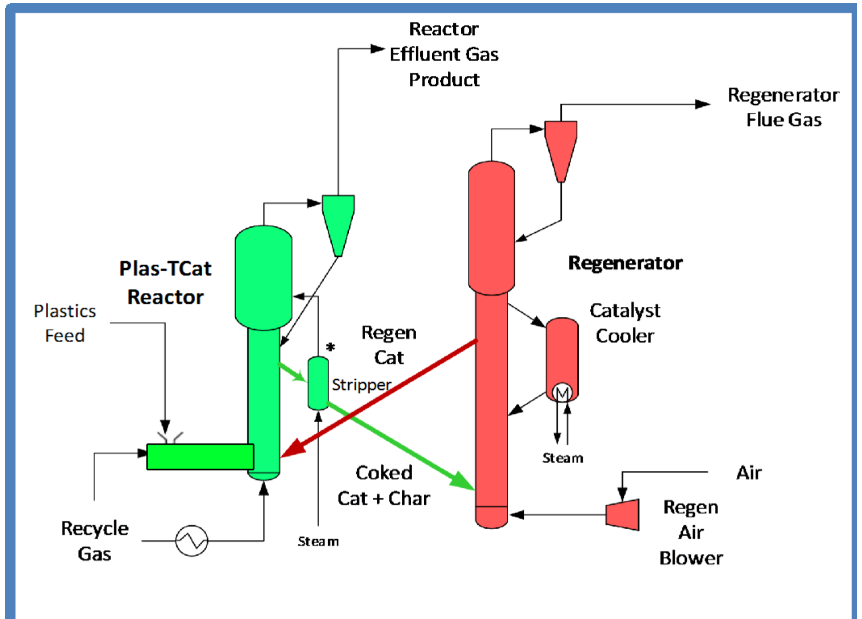
Anellotech

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) <u>**or**</u> 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, CO2, H2S, N2 to nitriles, Cl removed in pretreatment

Plas-TCat™



* Catalyst Stripper

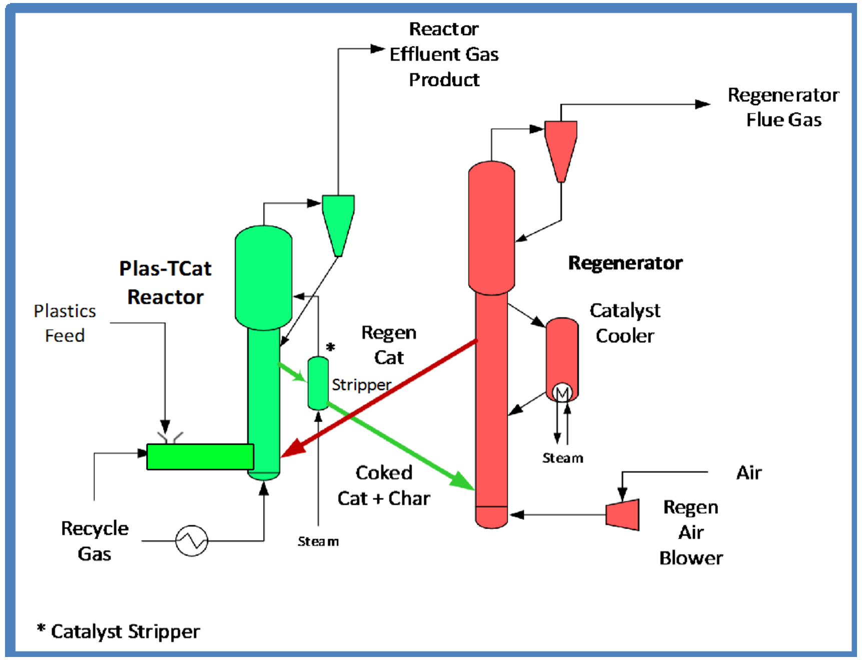
6 Reasons that Plas-TCat is a Game Changer (continued)

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.

Plas-TCat™



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Anellotech

Plas-TCat Catalytic Pyrolysis vs. Thermal Pyrolysis

Catalytic pyrolysis directly yields high value products

- BTX
- Olefins (mainly ethylene, propylene, butylene)
- Paraffins (mainly methane, butane, propane)

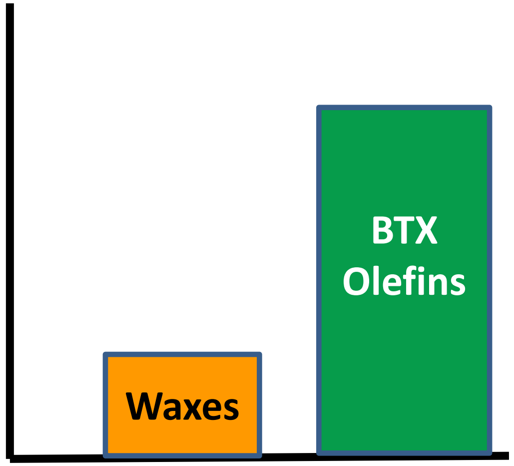
Thermal pyrolysis products have oligomeric structure (waxes) and need to be upgraded to make commercial products (Olefins, BTX)

- in steam crackers furnace to produce olefins (and some BTX)
- in FCC unit to make BTX
- Furthermore, heteroatoms contained in the pyrolysis oil might be critical for steam cracker processing (since can promote coking), and must be removed prior to feeding.
- And..... steam cracker (or FCC) upgrading of pyrolysis oil generates a significant yield loss
- Naphtha cracking yields as proxy for pyrolysis oil:
  - Ethylene 25– 35 %
  - Propylene 14 – 18%
  - Butadiene 4– 6 %
  - Methane 14%
  - BTX 5 – 10%

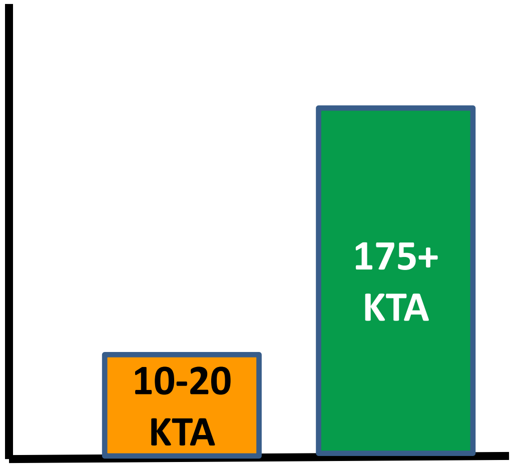
Naphtha conversion in Steam Cracker: 44% to 63% wt. Olefin+BTX Yield (on feed)

Plas-TCat Vs Non-Catalytic Pyrolysis - Graphic

Product Value



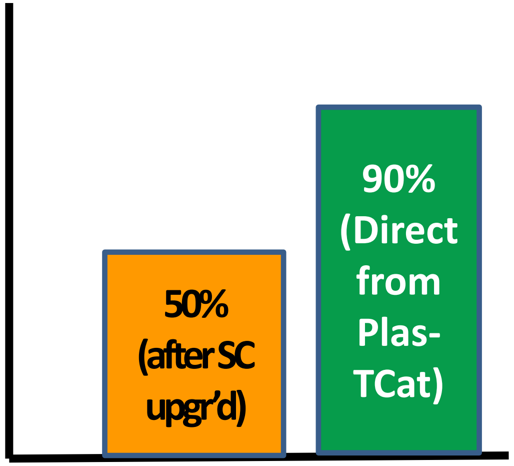
Scale



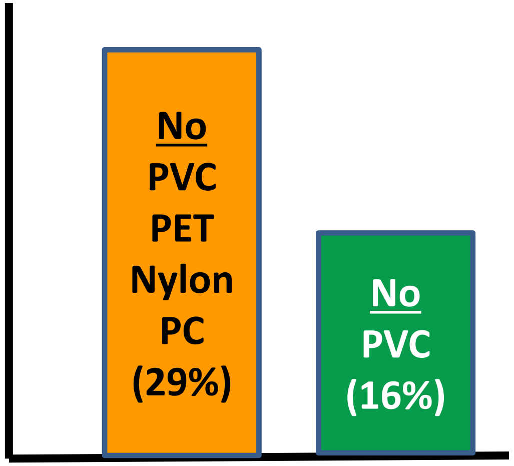
Plas-TCat Overall Winner

FEATURES	PLAS-TCAT	PYROLYSIS
Value of Products	✓	
Additional Processing	✓	
Highest Carbon Yields (after SC upgrade for pyrolysis)	✓	
Practical Scalability	✓	
Limited Feedstock Restrictions	✓	

Carbon Yield to Olefin BTX, etc.



Feedstock Restrictions



Additional Processing Required