Pranav Majgaonkar, Lukas Killinger, Ronny Hanich-Spahn I Brussels, Belgium I 08.02.2024

Chemical Recycling of PET at Fraunhofer ICT

Fraunhofer Institute for Chemical Technology (FhG-ICT)

Picture: Peter Eich, Karlsruhe

Fraunhofer Institute for Chemical Technology (ICT)

Research For A Better Tomorrow

Chemical Processes

- Non-Fossil Chemistry
- Electrochemistry
- Chemistry with Hazard Potential
- Continuous and Micro-Process Engineering
- On-Line Process Analytics
- Process and Operational Safety of Chemical Plants

Polymer Engineering

- Polymer Synthesis
- Material and Formulation Development
- Processing Technologies
- Component Development and Service Life Analyses
- Lightweight Construction and Composites
- Recycling and Sustainability

Energy and Drive Systems

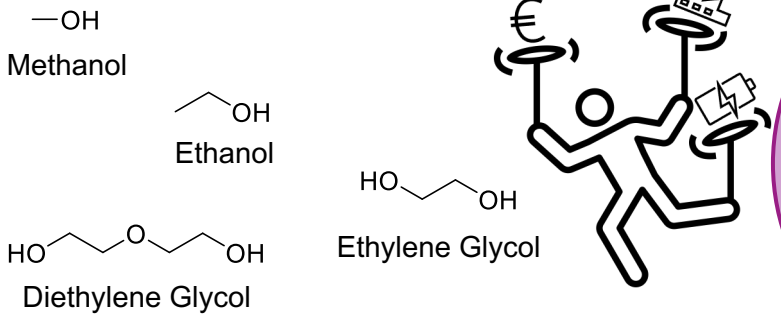
- Drive Systems for Mobility
- Batteries
- Fuel Cells and Electrolysis Systems
- Thermal Storage Devices
- Battery and Hydrogen Safety

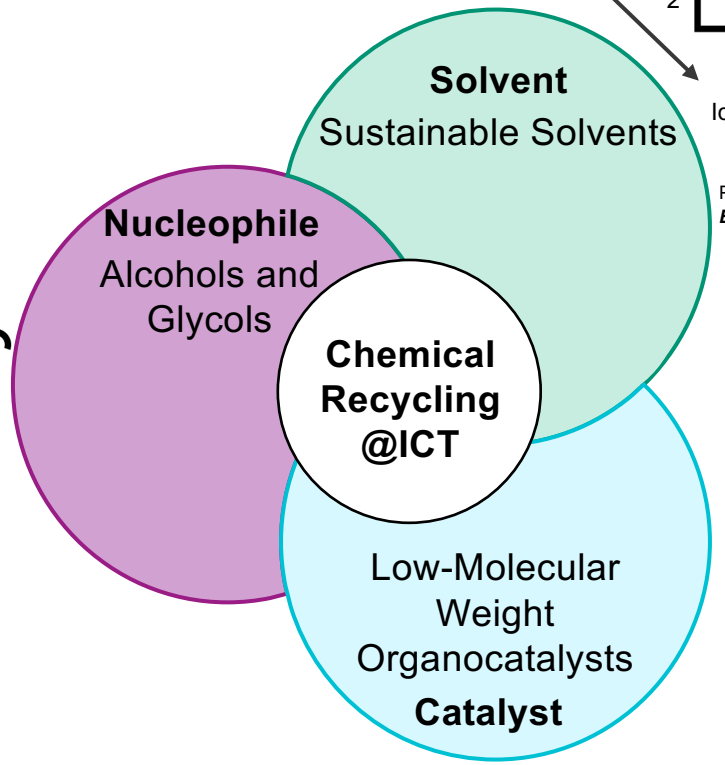
Explosives Technology, Safety and Security

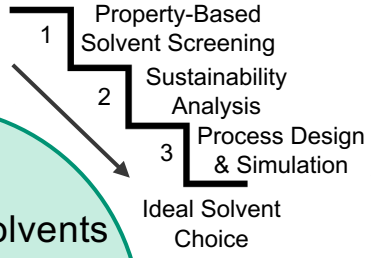
- Development of Propellants and Explosives
- Synthesis, Processing and Manufacturing Methods
- Performance Measurement and Characterization
- Modeling and Simulation
- Stability and Aging Behavior
- Detection of Explosives

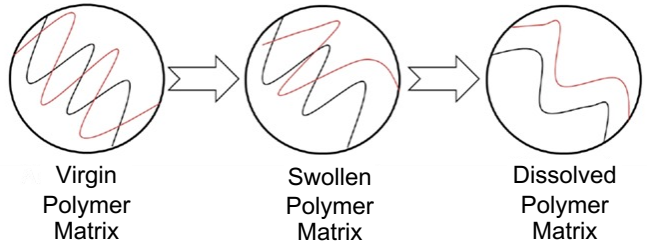
Chemical Recycling at Fraunhofer ICT

Strategy for Sustainable Process Development

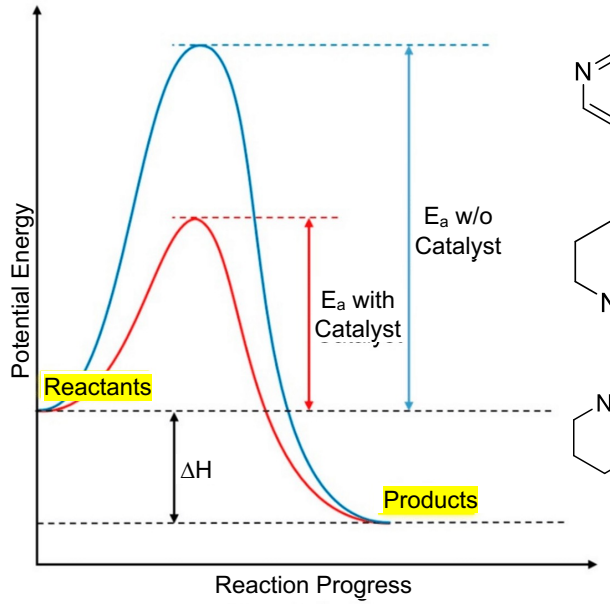


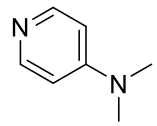


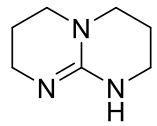


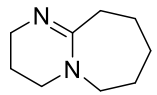


P. Majgaonkar, K. Kruber, V. Aryan, R. Hanich, D. Pico, M. Skiborowski, ***Computer Aided Chemical Engineering***, *Elsevier 2022*, pp. 829–834.




DMAP


TBD


DBU

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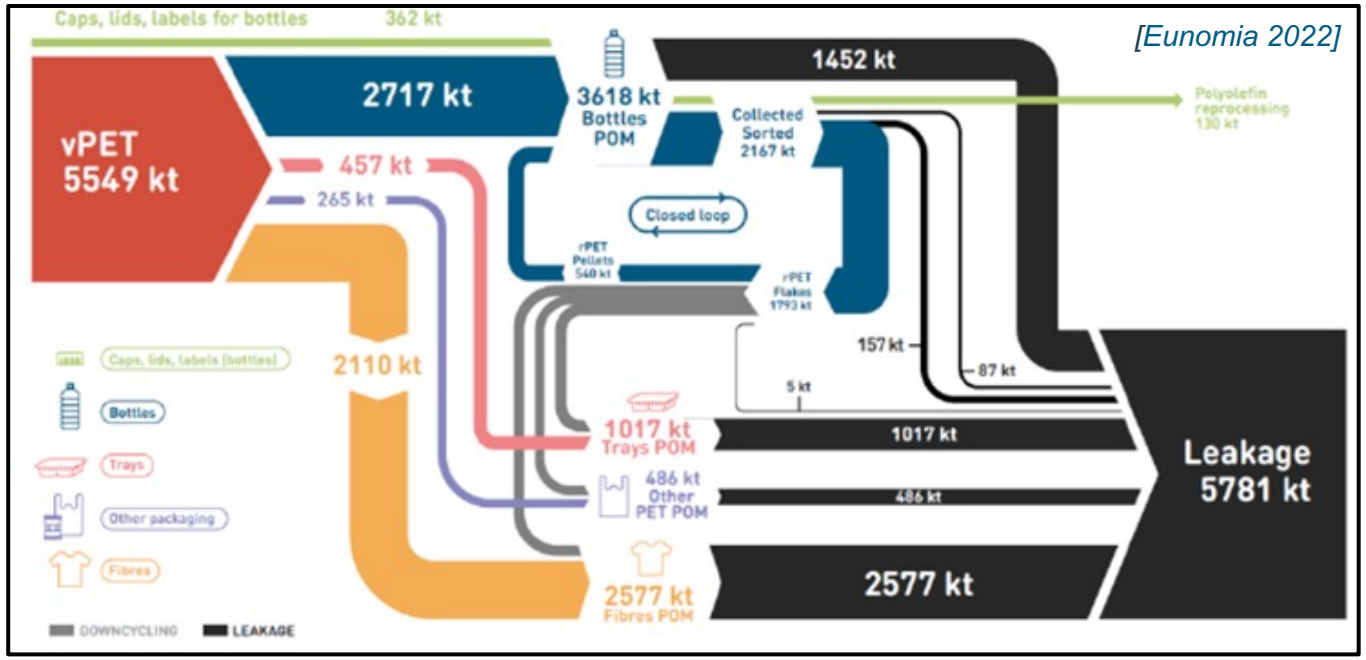
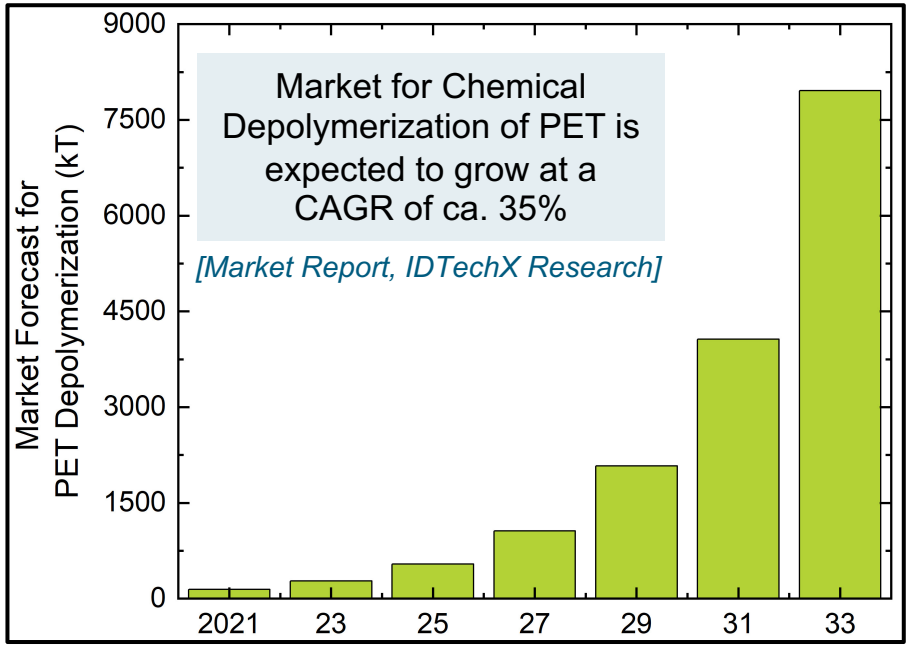
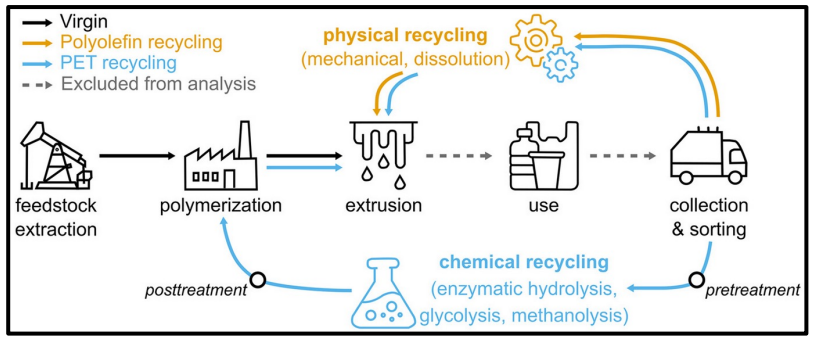
Chemical Recycling of Poly-Ethylene Terephthalate (PET)

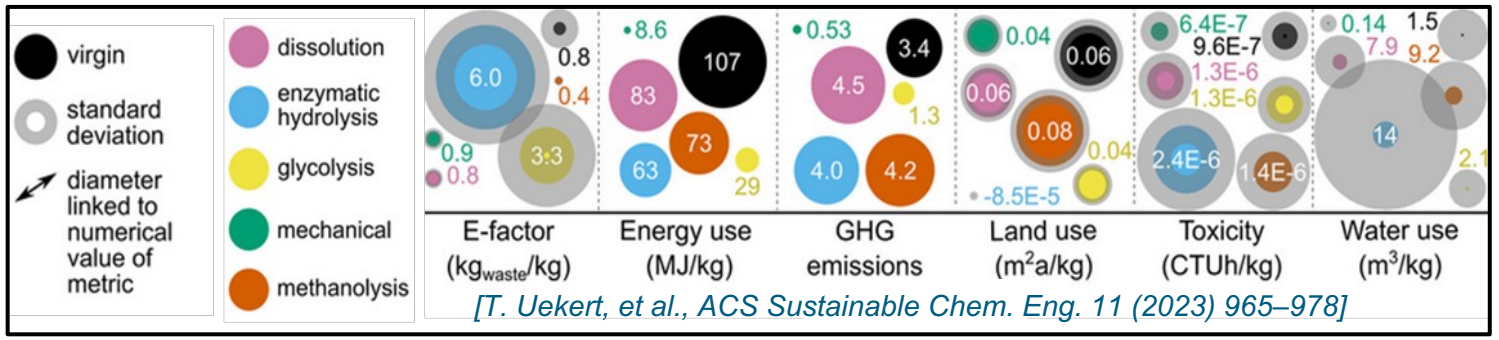
Poly-Ethylene Terephthalate (PET)

Why Recycle PET?









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Chemical Recycling of PET

Fraunhofer Cluster for Excellence Circular Plastics Economy (CCPE)

Post-Consumer PET Flakes

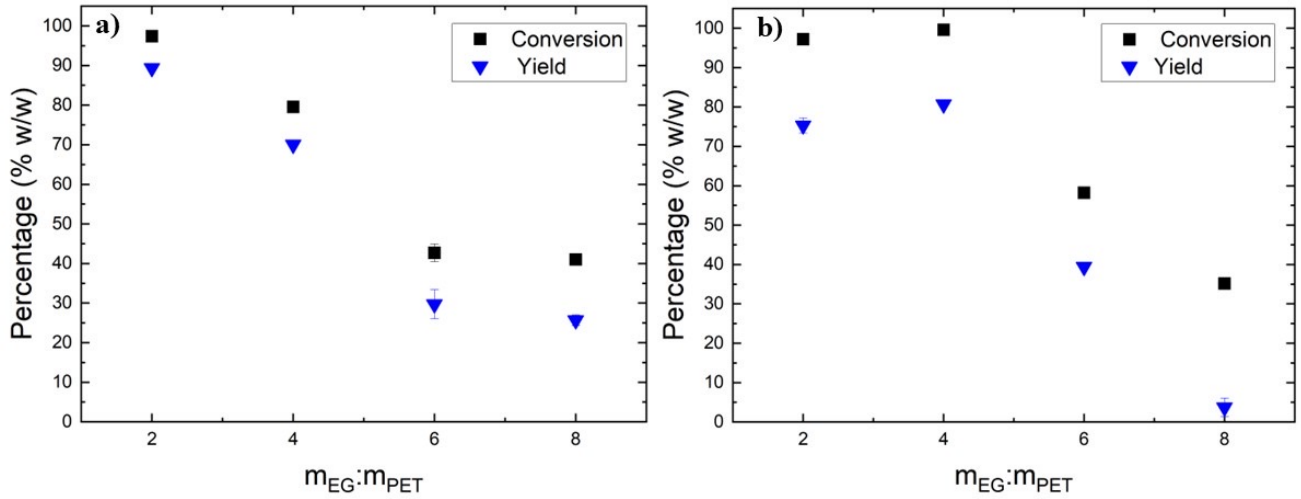
$m_{Solvent}:m_{PET}$ = 10
$m_{EG}:m_{PET}$ = 2
$m_{TBD}:m_{PET}$ = 0.05
T = 130°C

BHET
Yield = 89.05%

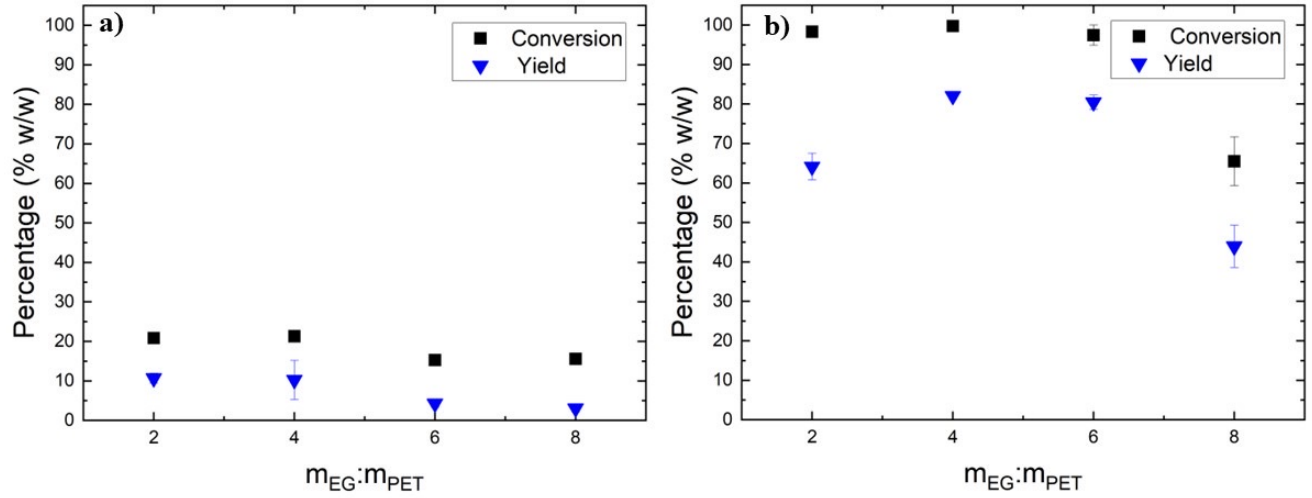
$m_{Solvent}:m_{PET}$ = 10
$m_{EG}:m_{PET}$ = 4
$m_{TBD}:m_{PET}$ = 0.025
T = 150°C

BHET
Yield = 82.85%

% Conversion & Yield for 5% Catalyst Loading at a) 130°C b) 150°C



Conversion & Yield for 2.5% Catalyst Loading at a) 130°C b) 150°C



Chemical Recycling of PET

Fraunhofer Cluster for Excellence Circular Plastics Economy (CCPE)

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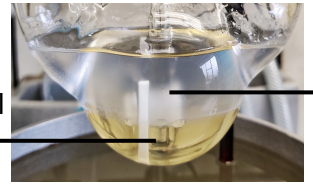
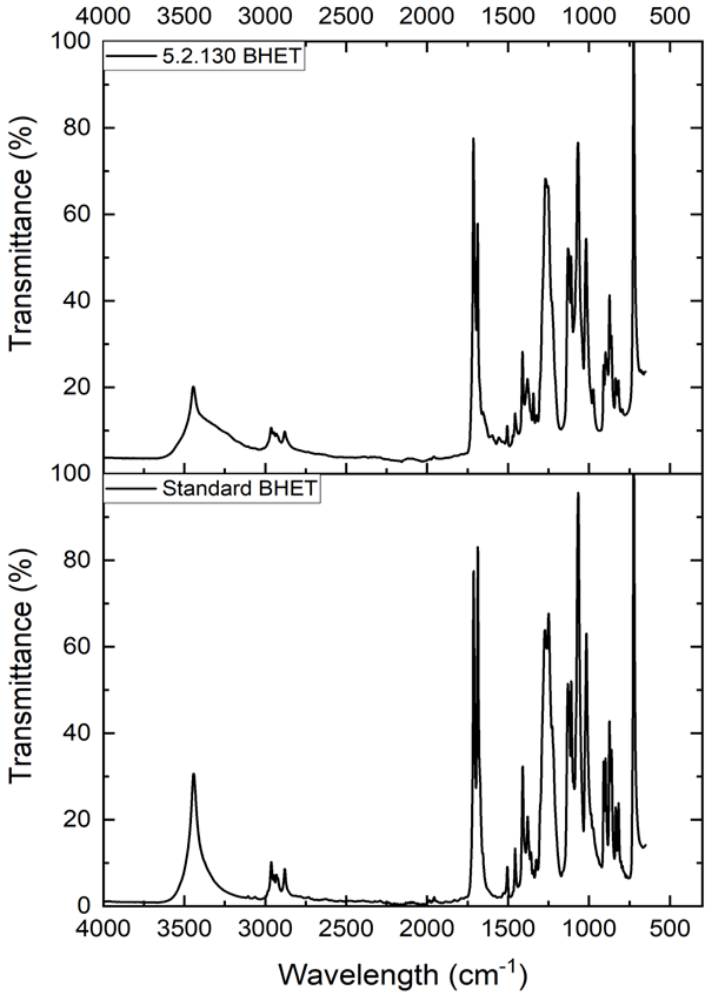
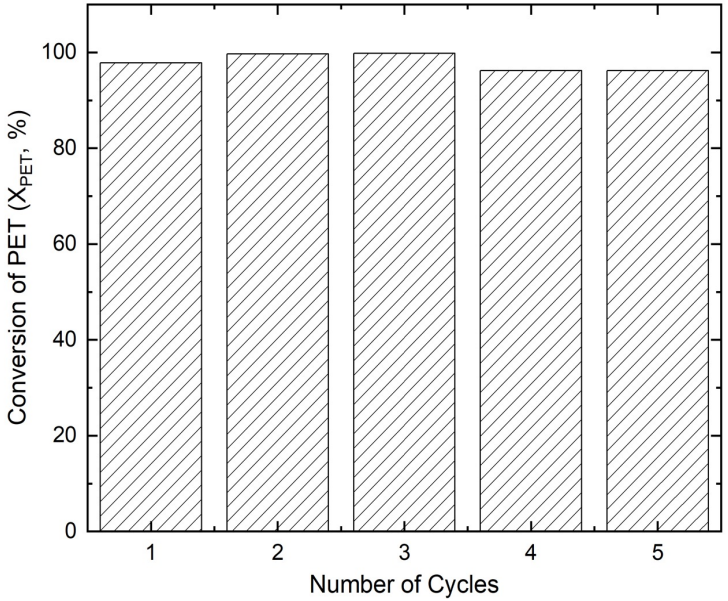


Ethylene Glycol

Solvent



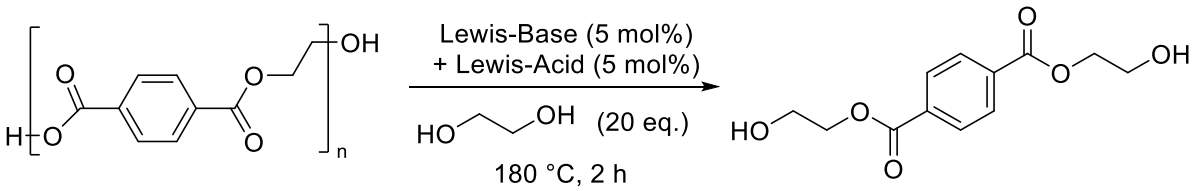


Component	Molecular Formula
BHET	$C_{12}H_{14}O_6$
Ethylene Glycol	$C_2H_6O_2$
Polyethylene Terepthalate	$(-C_{10}O_4H_8-)_n$
Triazabicyclodecene	$C_7H_{13}N_3$
Solvent	C_nH_{2n+2}

Chemical Recycling of Poly-Ethylene Terephthalate (PET)

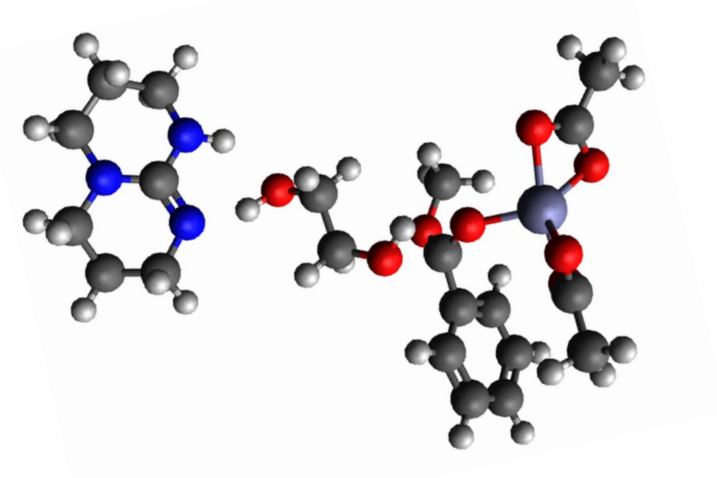
Expertise in Catalyst Design and Synthesis

Catalyst Design for Glycolysis of PET



Lewis-Acid \ Lewis-Base	-	NEt_3	Imidazole	DBU	TBD
-	0 %	0 %	0 %	88.0 %	86.0 %
$Zn(OAc)_2$	67.0 %	65.7 %	91.5 %	89.5 %	95.7 %
$ZnCl_2$	55.2 %	98.4 %	61.6 %	79.2 %	93.1 %
BEt_3	2,5 %	11,5 %	8,8 %	99,6 %	94,1 %
Zinc Neodecanoate	99,6 %	-	-	-	-

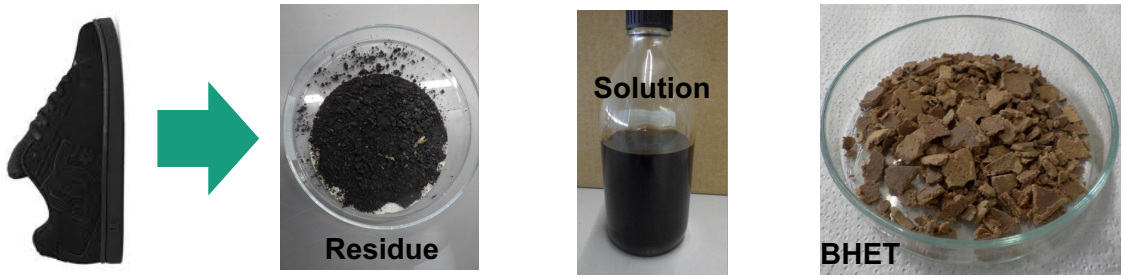
Computational Chemistry for Catalyst Design



Calculated Activation Energies for the Transesterification of Methyl Benzoate with Ethylene glycol using Different Catalysts

Catalyst	Activation Energy [kJ/mol]
no catalyst	171
TBD	152
$Zn(OAc)_2$	140
TBD / $Zn(OAc)_2$	141
$ZnCl_2$	161
TBD / $ZnCl_2$	110

Chemical Recycling of Shoes

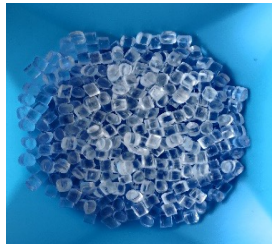


Fraunhofer ICT

Chemical Recycling of Poly-(Bisphenol-A) Carbonate (PC)

Chemical Recycling of Polycarbonate

Recycling Packaging Waste by Selective Solvolysis (reSOLve)



PC Makrolon® 2858
M_w = 45.25 kDa

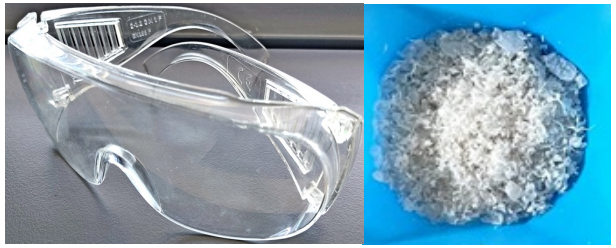
$m_{MethylAcetate}:m_{PC}$ = 7
$m_{Methanol}:m_{PC}$ = 1
$m_{TBD}:m_{PC}$ = 0.011

T = 50°C

Bisphenol-A
Yield = 98.2%

PC used in Motor Headlights
M_w = 41.59 kDa

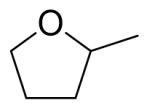
Bisphenol-A
Yield = 91.95%



PC used in Laboratory Goggles
M_w = 45.96 kDa

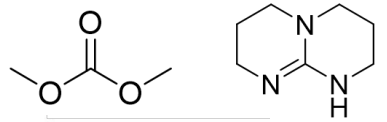
Bisphenol-A
Yield = 87.30%

University of Bath, UK
(Y_{BPA} = 88%)

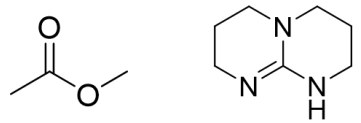


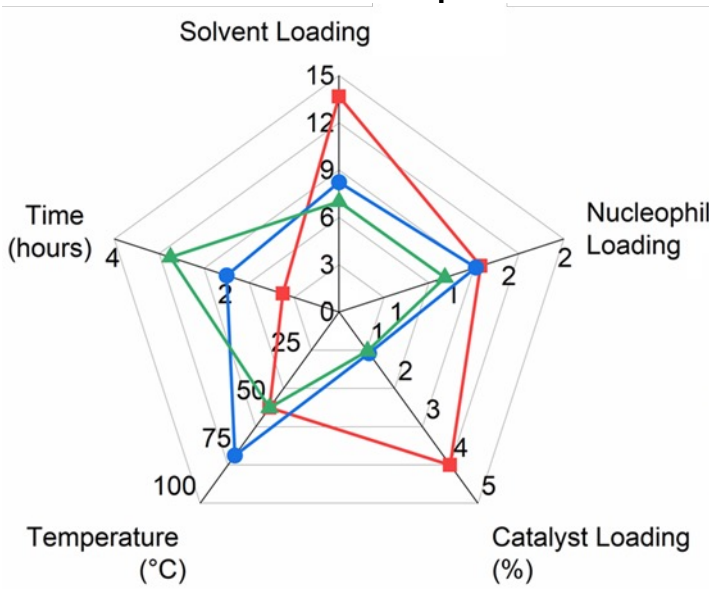
Heterolepticic
Zn^{II}-Complex

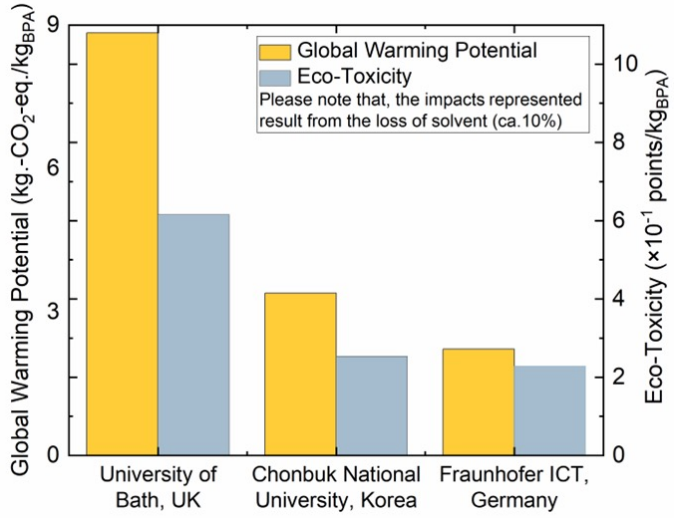
Chonbuk University, Korea
(Y_{BPA} > 98%)



Fraunhofer ICT, Germany
(Y_{BPA} = 91%)

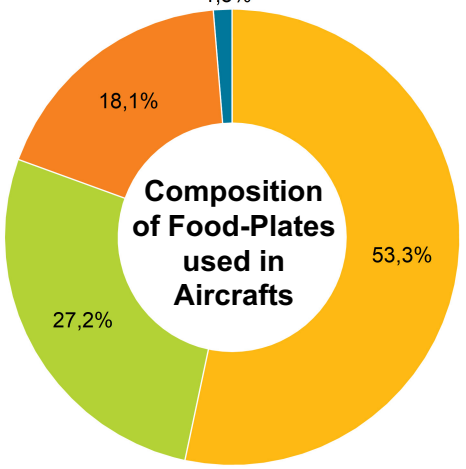






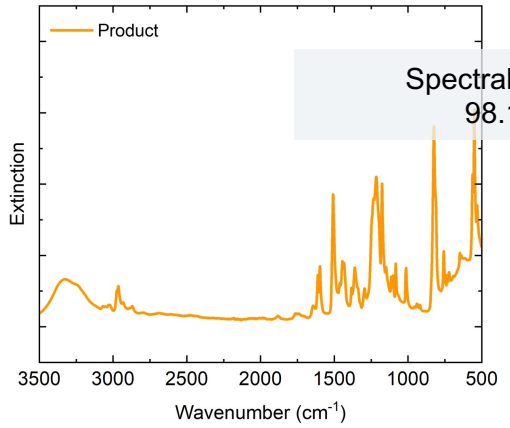
Cascade Process for Chemical Recycling by Selective Solvolysis

Chemical Recycling of PC

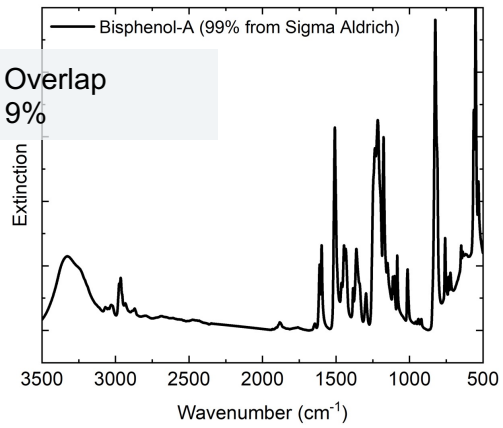


Poly(Bisphenol-A) Carbonate
Polyurethane and Adhesives
Polyamide and Stainless Steel
Polyvinyl Chloride

Food Tablets used in Aircrafts



Spectral Overlap
98.19%



Case A
$m_{MethylAcetate}:m_{Waste}$ = 6.992
$m_{Methanol}:m_{Waste}$ = 0.942
$m_{TBD}:m_{Waste}$ = 0.022
T = 50°C
t = 3 hours

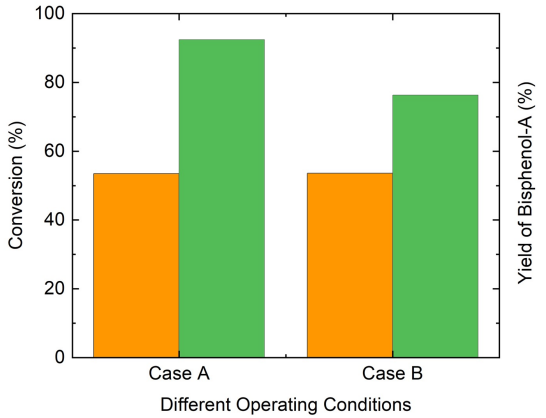
Bisphenol-A

Residue

Case B
$m_{MethylAcetate}:m_{Waste}$ = 3,734
$m_{Methanol}:m_{Waste}$ = 0.538
$m_{TBD}:m_{Waste}$ = 0.012
T = 50°C
t = 3 hours

Bisphenol-A

Residue



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Fraunhofer ICT

Chemical Recycling of Poly-Lactic Acid (PLA)

Chemical Recycling of PLA

Fraunhofer Cluster for Excellence Circular Plastics Economy (CCPE)

Post-Consumer PLA Cups obtained from DAS FEST, Karlsruhe

Post-Consumer Yoghurt Containers

Filaments for 3-D Printing

PLA Sandwich Panel for Light-Weight Construction

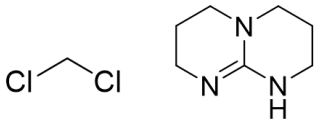
$m_{Acetone}:m_{PLA} = 5$
$m_{Ethanol}:m_{PLA} = 2$
$m_{TBD}:m_{PLA} = 0.02$
T = 50°C

Ethyl Lactate (A Bio-Based Solvent)

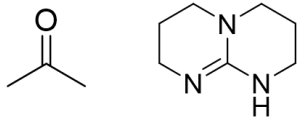
University of Birmingham
(Y_{EL} = 71%)

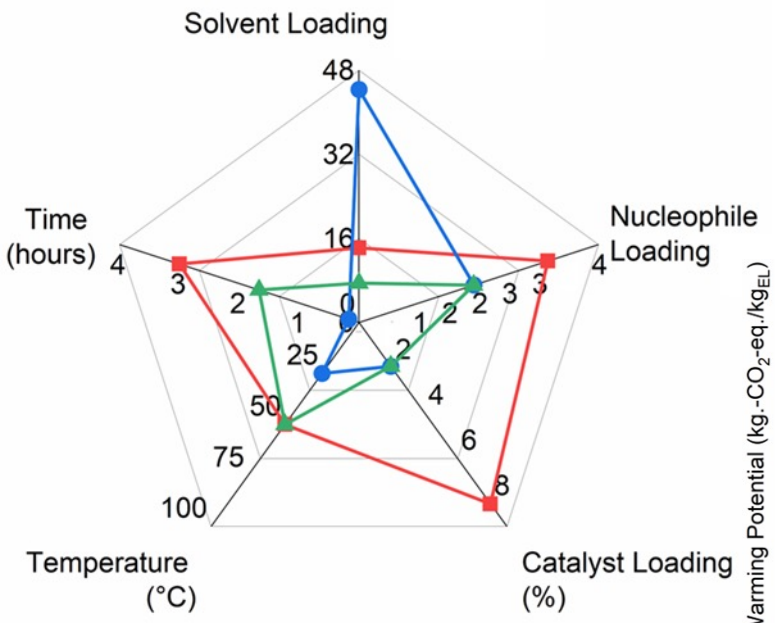
Propylendiamine
Zn^{II}-Complex

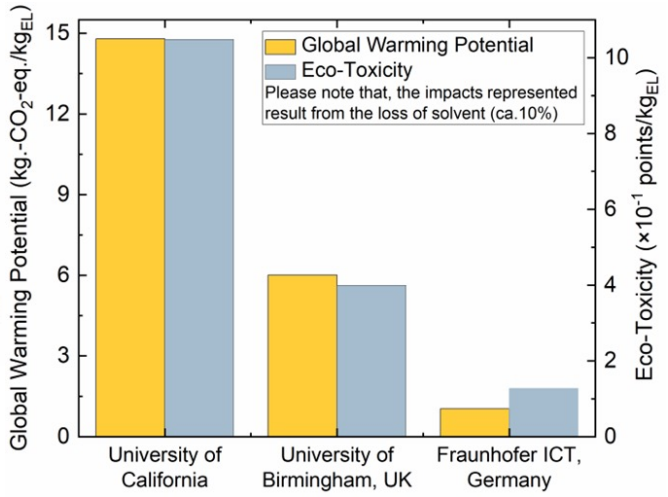
University of California
(Y_{EL} = 80%)



Fraunhofer ICT, Germany
(Y_{EL} = 83%)

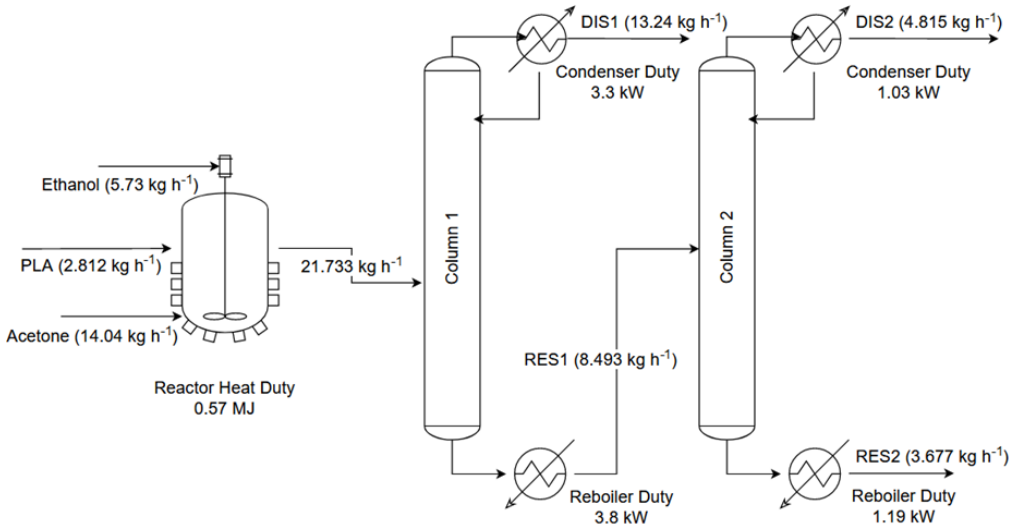






Process Modelling and Simulation

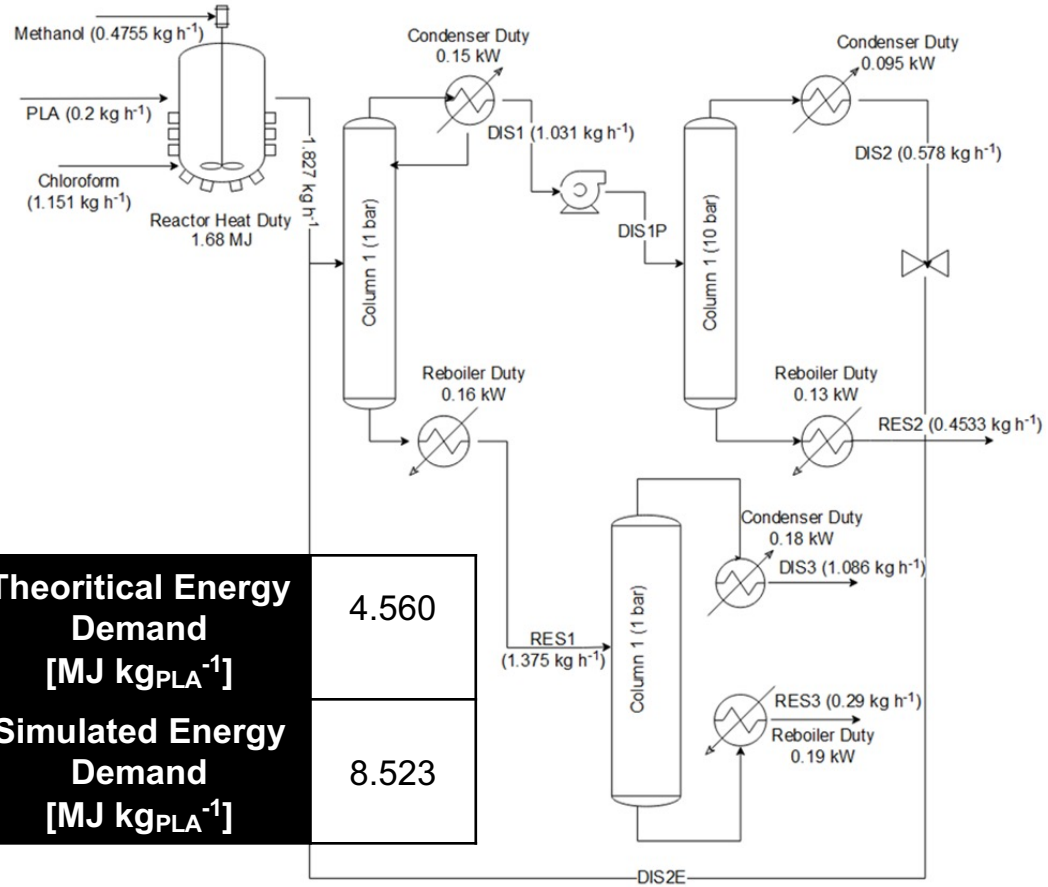
Downstreaming of Methyl/Ethyl Lactate obtained from Alcoholysis of PLA Waste



[P. Majgaonkar et al., in *Chem. Engg. Journal 2021, 423, 129952]*

Theoritical Energy Demand [MJ kg_{PLA}^{-1}]	Simulated Energy Demand [MJ kg_{PLA}^{-1}]	Experimental Energy Demand [MJ kg_{PLA}^{-1}]
4.87	5.55	35.013

[V. Aryan, P. Majgaonkar et al, in *Res. Cons. and Recycling 2021, 172, 105670]*



Theoritical Energy Demand [MJ kg_{PLA}^{-1}]	4.560
Simulated Energy Demand [MJ kg_{PLA}^{-1}]	8.523

[Anneaux, B., Campanelli, J., Foley, E., at ANTEC 2018. Or lando May 7-10, 2018]

Fraunhofer ICT

THANK YOU FOR YOUR ATTENTION

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