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Bio-Based Polymers

PEP Report 265C

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Glossary

¢	Cents
$	Dollars
Å	Angstrom
Ac_2O	Acetic anhydride
AFEX	Ammonia fiber explosion
AMF	Alkoxymethylfurfural
ASTM	American Society for Testing and Materials
atm	Atmospheres
BDO	1,4-Butanediol
BFW	Boiler feedwater
bhp	Brake horsepower
BLI	Battery limits investment
BMF	5-(bromomethyl)furfural
BTL	Biomass-to-liquids
Btu	British thermal units
2BuOH	Butan-2-ol
capex	Capital expenditure
CAS	Chemical Abstracts Service
4-CBA	4-Carboxybenzaldehyde
ChCl	Choline chloride
CMDMF	2-(Chloromethyl)-5-(dibutoxymethyl)furan
CMF	5-Chloromethylfurfural
CP	Continuous polymerization
CSTR	Continuous stirred tank reactor
CTA	Crude terephthalic acid
DCE	1,2-Dichloroethane
DEE	Diethyl ether
DES	Deep eutectic solvent
dia	Diameter
DMF	Dimethylfuran
DFT	Density functional theory
EADC	Ethyl aluminum dichloride
EC	Ethylene carbonate
EG	Ethylene glycol
EL	Ethyl levulinate
EO	Ethylene oxide
EPC	Engineering, procurement, and construction
ETBE	Ethyl tert-butyl ether
ETO	Ethanol-to-olefins
FA	Formic acid
FAME	Fatty acid methyl ester
FCC	Fluid catalytic cracking
FDCA	2,5-Furandicarboxylic acid
FOB	Free/freight on board
ft	Feet
ft^3	Cubic feet
ft dia	Feet diameter
g	Grams
G&A	General and administrative
gal	Gallons
g/g	Grams per gram
g/L	Grams per liter
g/mol	Grams per mole
g/mL	Grams per milliliter
gpm	Gallons per minute
h	Hours

HDPE	High-density polyethylene
HMF	5-Hydroxymethylfurfural
HOMO-LUMO	Highest occupied molecular orbital and lowest unoccupied molecular orbital
HP	Homopolymer
HTC	Hydrothermal carbon
HVAC	Heating, ventilation, and air conditioning
HVO	Hydrotreated vegetable oil
ICP	Impact copolymer polypropylene
IH^2	Integrated hydropyrolysis and hydroconversion
IPA	Isophthalic acid
kcal	Kilocalories
kg	Kilograms
kg/m^3	Kilograms per cubic meter
kJ	Kilojoules
kPa	Kilopascals
KTPA	Kilo tons per annum
kW	Kilowatts
kWh	Kilowatt-hours
LA	Levulinic acid
lb	Pounds
LCA	Life cycle assessment
M	Molar
MCL	Medium chain length
MDEA	Methyldiethanolamine
MF	5-Methylfurfural
MFA	Multi Fibre Agreement
µS/m	Microsiemens per meter
m^2/g	Meter square per gram
Mgal	Thousand gallons
Mlb	Thousand pounds
mg/kg	Milligrams per kilogram
min	minute
MIBK	Methyl isobutyl ketone
MJ/L	Megajoules per liter
Mlb/h	Thousand pounds per hour
MMBtu/h	Million British thermal units per hour
MMlb/y	Million pounds per year
MMt	Million metric tons
MMt/y	Million metric tons per year
mol%	Molar percent
mPa	Megapascals
Mscf/h	Thousand standard cubic feet per hour
MSW	Municipal solid waste
MTBE	Methyl tert-butyl ether
MW	Molecular weight
Nft^3/lb	Normal cubic feet per pound
NHC	N-heterocyclic carbene
nm	Nanometer
NMR	Nuclear magnetic resonance
NREL	National Renewable Energy Laboratory
OA	Oxalic acid
OCT	Olefins conversion technology
opex	Operating expenditure
P	Pressure
PA	Polyamide
PBAT	Polybutylene adipate terephthalate
PBS	Polybutylene succinate

PC	Polycarbonate
Pd/C	Palladium on carbon
PE	Polyethylene
PEF	Polyethylene furanoate
PEP	Process Economics Program
PET	Polyethylene terephthalate
PFD	Process flow diagram
PHA	Polyhydroxyalkanoate
PHBV	Polyhydroxybutyrate-valerate
PLA	Polylactic acid
PP	Polypropylene
ppb	Parts per billion
ppm	Parts per million
ppmv	Parts per million by volume
psi	Pounds per square inch
psia	Pounds per square inch absolute
psig	Pounds per square inch gauge
PTA	Purified terephthalic acid
PX	p-Xylene
RCP	Random copolymer polypropylene
REACH™	Renewable Acid-hydrolysis Condensation Hydrotreating
RED II	Renewable Energy Directive II
ROI	Return on investment
ROP	Ring-opening polymerization
s	Second(s)
SAF	Sustainable aviation fuel
SAP	Super absorbent polymer
scf	Standard cubic feet
SCL	Short chain length
SMILES	Simplified molecular input line entry system
sq ft	square feet
SS	Stainless steel
SSP	Solid-state polymerization
Syngas	Synthesis gas
t	Metric ton
T	Temperature
TCE	1,1,2-Trichloroethane
TEAI	Triethylaluminum iodide
TEMA	Tubular Exchanger Manufacturer Association
TFC	Total fixed capital
THF	Tetrahydrofuran
TOR	Tons of refrigeration
TPA	Metric tons per annum
t/t	Metric tons by metric ton
t/y	Metric tons per year
UFPP	Upflow prepolymerizer
USDA	US Department of Agriculture
USGC	US Gulf Coast
UV	Ultraviolet
vol%	Volume percent
WHSV	Weight hour space velocity
wt%	Weight percent
w/w	Weight for weight
ZSM-5	Zeolite Socony Mobil-5

Abstract

As sustainability has become increasingly critical, companies within the plastic industry are under growing pressure to mitigate the adverse effects of plastic use. Key industry players, including polymer producers and brand owners, are aiming to reduce the use of fossil-derived virgin plastics by transitioning to plastics made from recycled or renewable materials. The demand for plastics from renewable sources is mainly growing for manufacturing consumer products, fueling significant interest in bio-based polymers. Among the diverse range of bio-based polymers, polypropylene (PP) and polyethylene terephthalate (PET) are prominent due to their extensive use in industries such as packaging, textiles, automotive parts, etc.

Several companies are leading the advancements in bio-based plastics and polymers. Avantium uses its YXY® technology to transform plant-based sugars into 2,5-furandicarboxylic acid (FDCA), a crucial component for producing eco-friendly polyethylene furanoate (PEF), which is a sustainable alternative to PET. Origin Materials Inc. (Origin Materials) is converting wood residues into chemical building blocks for 100% bio-based PET and polyesters.

Similarly, Braskem is leading the advancement in bio-based polypropylene (PP). It has announced a project to explore investment in producing carbon-negative bio-based PP in the US, using its proprietary technology. Gevo Inc. is also advancing in bio-based PP manufacturing with its ethanol-to-olefins (ETO) technology, aiming for carbon-neutral or carbon-negative alternatives to traditional petroleum-based olefins, including bio-propylene for renewable chemicals and fuels like sustainable aviation fuel (SAF). LyondellBasell, in partnership with Neste, is producing bio-based PP from renewable feedstocks such as vegetable and residual oils. Lummus Technology offers Verdene™ PP suite, which converts bioethanol to PP using its industrially proven technologies.

This report presents the techno-economic analysis of three processes to produce bio-based polymers from an integrated plant. These processes are:

- Bio-based PET using bio-based purified terephthalic acid (PTA) (from 5-chloromethylfurfural [CMF]) and bio-based ethylene glycol (EG)
- Polypropylene (PP) from bio-naphtha
- Polypropylene (PP) from bio-based ethanol

In addition to covering the above three processes, the report will provide an overview of the recent technological advancements and performance, emphasizing technology readiness.

This assessment includes a process flow diagram, a material balance, a list of major equipment with specifications, details of capital expenditure (capex), operating expenditure (opex), and overall production costs. The production economics assessment in this report is based on a US Gulf Coast (USGC) location. However, an iPEP Navigator module (an Excel-based computer costing model developed by S&P Global Commodity Insights) is attached to this report to allow a quick calculation of the process economics for three other major regions — Germany, Japan, and mainland China. The module also provides the production economics for every process, in English or metric units, for each region.

The technological and economic assessment of the processes is the Process Economics Program (PEP)'s independent interpretation of the companies' commercial processes based on information presented in the open literature such as patents or technical articles. It may not reflect the actual plant configuration in whole or in part. We believe they are sufficiently representative of the processes and process economics within the range of accuracy necessary for economic evaluations of the conceptual process design.

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