Main Topic

Conceptual Design of a Bio-Circular Polypropylene Production Plant

This project presents a conceptual chemical process design for the production of bio-circular polypropylene (PP) from ISCC-certified waste-based bio-feedstocks, developed as part of an undergraduate Chemical Engineering plant design course.

The proposed design processes 100,000 tonnes per year of renewable oils, converting them through a sequence of hydrotreating, catalytic cracking, and polymerization steps into about 4,600 tonnes per year of bio-circular polypropylene resin. The project places particular emphasis on process selection and yield justification, rather than commercial optimization.

The project will help demonstrate how chemical engineering principles applied to the design of a modern bio-based polymer production route.

Background

Polypropylene, PP, is one of the most widely used thermoplastics due to its low cost, mechanical strength, and versatility. Conventional PP production relies entirely on fossil-derived propylene, contributing significantly to greenhouse gas emissions.

In response to sustainability and circular-economy objectives, bio-circular polypropylene has emerged as an alternative in which

- Fossil feedstocks are replaced by certified renewable waste oils
- The final polymer is chemically identical to fossil PP
- Existing polymer processing infrastructure can be retained

This makes bio-circular PP an ideal case study for chemical engineering students, as it combines reaction engineering, separation processes, catalysis, and sustainability considerations in a single design problem.

Objective

1. Design a complete process route for the production of bio-circular polypropylene from renewable feedstocks
2. Justify technological choices, particularly the selection of Deep Catalytic Cracking for propylene production
3. Develop and close a full material and energy balance for all process stages

4. Apply chemical engineering fundamentals (reaction stoichiometry, yield analysis, separations, catalysis, and process economics)
5. Evaluate process limitations and scale effects, highlighting realistic industrial constraints

Input -Feedstock Basis

- Total feed rate 100,000 t/y
- Feedstock type ISCC-certified waste and residue oils
- Representative blend of
  - Used Cooking Oil (UCO) 55% **(see specification in Appendix A.1)**
  - Palm Fatty Acid Distillate (PFAD) 30% **(see specification in Appendix A.2)**
  - Other certified bio-oils 15% **(see specification in Appendix A.3)**

The blend composition is assumed flexible within ISCC mass-balance rules, which simplifies procurement considerations for the design study.

Assumptions Used in the Design

Operating Assumptions

- Plant capacity 100,000 t/y
- Operating hours 8,000 h/y
- Steady-state operation

Design Scope Assumptions

- Feedstock logistics excluded
- Hydrogen supply assumed available
- Equipment is sized at conceptual level only

These assumptions are typical for undergraduate design projects and ensure the problem remains tractable.

Output (For 100,000 tonnes/year of feed with expected yields)

- Bio-circular PP 4.5% (about 4,600 tonnes)
- Renewable diesel 52%
- Ethylene + C4 fraction 40.5%

- Off-gas fuel (all stages) 12%
- Process water + heavy residue + waste 20%

(see specification in Appendix A.5-A.7)

Deliverable

The report contents should be presented in the following order. Forms and some examples of deliverables are provided in the attachments.

1. Letter of Transmittal
2. Cover Page
3. Table of Contents
4. Abbreviations
5. Introduction
6. Literature Reviews
7. Design Basis
8. Conceptual Design, including block diagrams
9. Process Selection
10. Process Flow Diagram / Plant Layout
11. Process Description
12. Material/Energy Balances and Utility Requirements
13. Equipment lists and Equipment Datasheet
14. Equipment Cost Summary
15. Cost and Economic Analysis (such as NPV, payback period, IRR)
16. Safety, Health, and Environment (such as Carbon footprint)
17. Conclusions and Recommendations
18. References
19. Appendix: Sample calculations

Appendix

A. Feedstock Specifications

A.1 Used Cooking Oil (UCO)

Property	Typical Value	Unit
Appearance	Dark yellow to brown liquid	-
Density @ 15°C	0.90 – 0.93	g/cm³
Viscosity @ 40°C	35 – 45	cSt
Water content	< 0.5	wt%
Free Fatty Acid (FFA)	5 – 15	wt%
Sulfur	< 50	ppm
Nitrogen	< 100	ppm
Oxygen content	10 – 12	wt%
Heating value	37 – 39	MJ/kg
Conradson carbon residue	< 0.3	wt%

Representative Composition

- Triglycerides : 75–85 wt%
- Free fatty acids : 5–15 wt%
- Water + solids : <1 wt%
- Metals/ash : trace

A.2 Palm Fatty Acid Distillate (PFAD)

Property	Typical Value	Unit
Appearance	Brown semi-liquid	-
Density @ 15°C	0.88 – 0.91	g/cm³
FFA content	80 – 95	wt%
Moisture	< 0.5	wt%
Sulfur	< 30	ppm
Oxygen content	10 – 11	wt%
Iodine value	45 – 60	g I_2/100 g
Heating value	38 – 40	MJ/kg

Main Fatty Acid Distribution

- Palmitic acid (C16:0) : 40–50 wt%
- Oleic acid (C18:1) : 35–45 wt%
- Linoleic acid : 5–10 wt%

A.3 Residue Oils (Other ISCC-certified residue oils)

Property	Typical Value	Unit
Density @ 15°C	0.89 – 0.94	g/cm³
Water content	< 1.0	wt%
FFA	10 – 30	wt%
Sulfur	< 100	ppm
Oxygen content	8 – 12	wt%
Metals (Na+K+Ca+Mg)	< 20	ppm
Total chlorine	< 5	ppm

Typical Composition

- Triglycerides
- Fatty acids
- Animal fat derivatives
- Waste lipid fractions

A.4 Pretreatment Requirement

Target after pretreatment:

Parameter	Target
Water	< 0.1 wt%
Metals	< 1 ppm
Phosphorus	< 1 ppm
Solids	Nil

A.5 Renewable Diesel

Property	Typical Value
Cetane number	> 70
Sulfur	< 10 ppm
Density @ 15°C	0.77–0.79 g/cm³
Oxygen	Nil
Freezing point	-10 to -30°C

A.6 Propylene Stream to Polymerization

Property	Specification
Propylene purity	> 99.5 wt%
Ethylene	< 0.3 wt%
C4+	< 0.1 wt%
Water	< 5 ppm
Sulfur	< 1 ppm

A.7 Bio-Circular Polypropylene Resin

Property	Typical Value	
Polymer type	Isotactic polypropylene	
Melt Flow Index (230°C/2.16kg)	8–20 g/10 min	
Density	0.90–0.91 g/cm³	
Tensile strength	30–40 MPa	
Ash content	< 0.03 wt%	
Moisture	< 0.05 wt%	
Color	Natural translucent pellets	
Bio-circular certification	ISCC PLUS	

A.8 Utilities Detail (based on data Q1,2026)

Utility	Condition	Cost Range (Thailand Market)
Electricity		4–5 THB/kWh
HP Steam	40–60 bar, 450 C	450–650 THB/ton
Cooling Water	30→40°C	8–15 THB/m³
Hydrogen	99.9% purity	120–180 THB/kg
Natural Gas	20–40 bar	300–450 THB/MMBtu
Nitrogen	6–10 bar	5–12 THB/Nm³
Chilled Water	5–10°C	8-15 THB/m3
Refrigeration	-40 C	
Fuel gas		300-450 THB/MMBtu
Boiler Feed Water		25-40 THB/m3
Used Cooking Oil (UCO)		20-35 THB/Kg
Palm Fatty Acid Distillation (PFAD)		28-38 THB/Kg
Bio-Circular PP		1,600 $/ton
Renewable diesel		300 $/ton

Remark: The cost range will vary upon the season and others factors, the provided data here is used for education project purposes

A.9 Exchange Rate

Approx. 32.4 Baht : 1 US Dollar (11 May 2026 Bank of Thailand)

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