Upcycling Carton Packages to Valuable Products

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Background

Municipal Solid Waste (MSW)

MSW

Novi Sad, Serbia - August 18, 2018: Municipal solid waste or communal garbage is overflowing containers in Novi sad during weekends, Illustrative Edit Stock Photo. Alamy. https://www.alamy.com/novi-sad-serbia-august-18-2018-municipal-solid-waste-or-communal-garbage-is-overflowing-containers-in-novi-sad-during-weekends-illustrative-edit-image215948883.html

Landfill

Landfill stock video footage - 4K and HD video clips. Shutterstock. https://www.shutterstock.com/video/search/landfill

Incineration

Australian Waste Export Ban Signals Green Light for dangerous waste incineration industry. IPEN. https://ipen.org/news/australian-waste-export-ban-signals-green-light-dangerous-waste-incineration-industry

Ocean pollution

The Ocean is swimming in plastic and it's getting worse – we need connected global policies now. The Conversation. https://theconversation.com/the-ocean-is-swimming-in-plastic-and-its-getting-worse-we-need-connected-global-policies-now-146380

Carton Waste

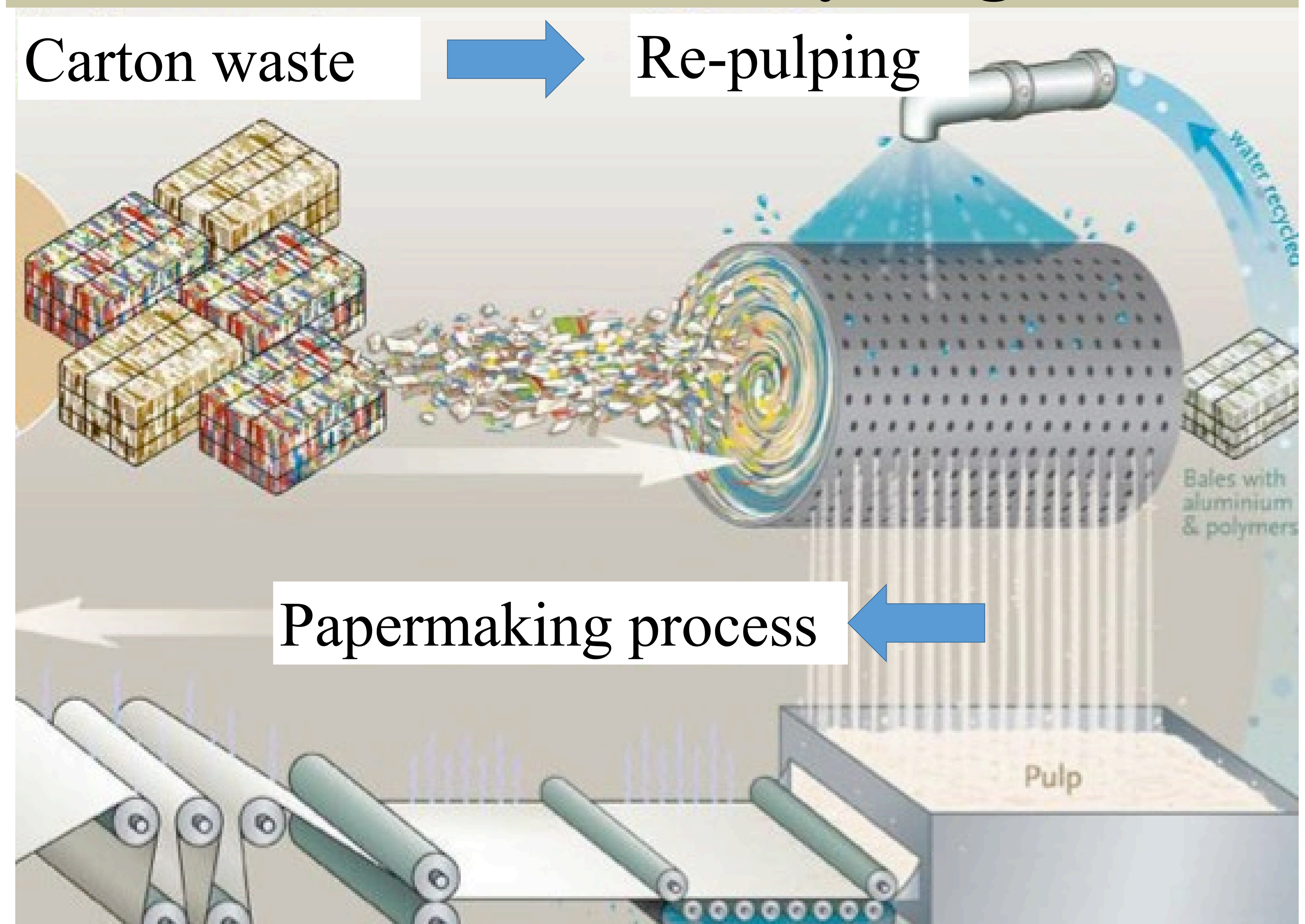
Land wastes and ocean wastes

- More than 190 billion tons of carton packages are discarded annually.
- Only 26% of post-consumer cartons are recycled.
- Recycling cartons is crucial for environmental protection and resource recovery.

Background

Current Technologies

Mechanical Recycling



Kupfer, M. (2019, April 2). *Bio-based Beverage Cartons*. Renewable Carbon News. https://renewable-carbon.eu/news/bio-based-beverage-cartons/

High energy consumption and poor product quality.

☹ **Downcycling**

Chemical Recycling
- **Pyrolysis**
- **Hydrolysis**

Low value products with high energy inputs.

- Our objective is to develop recycling approach to maximize the product value.

Research Objective

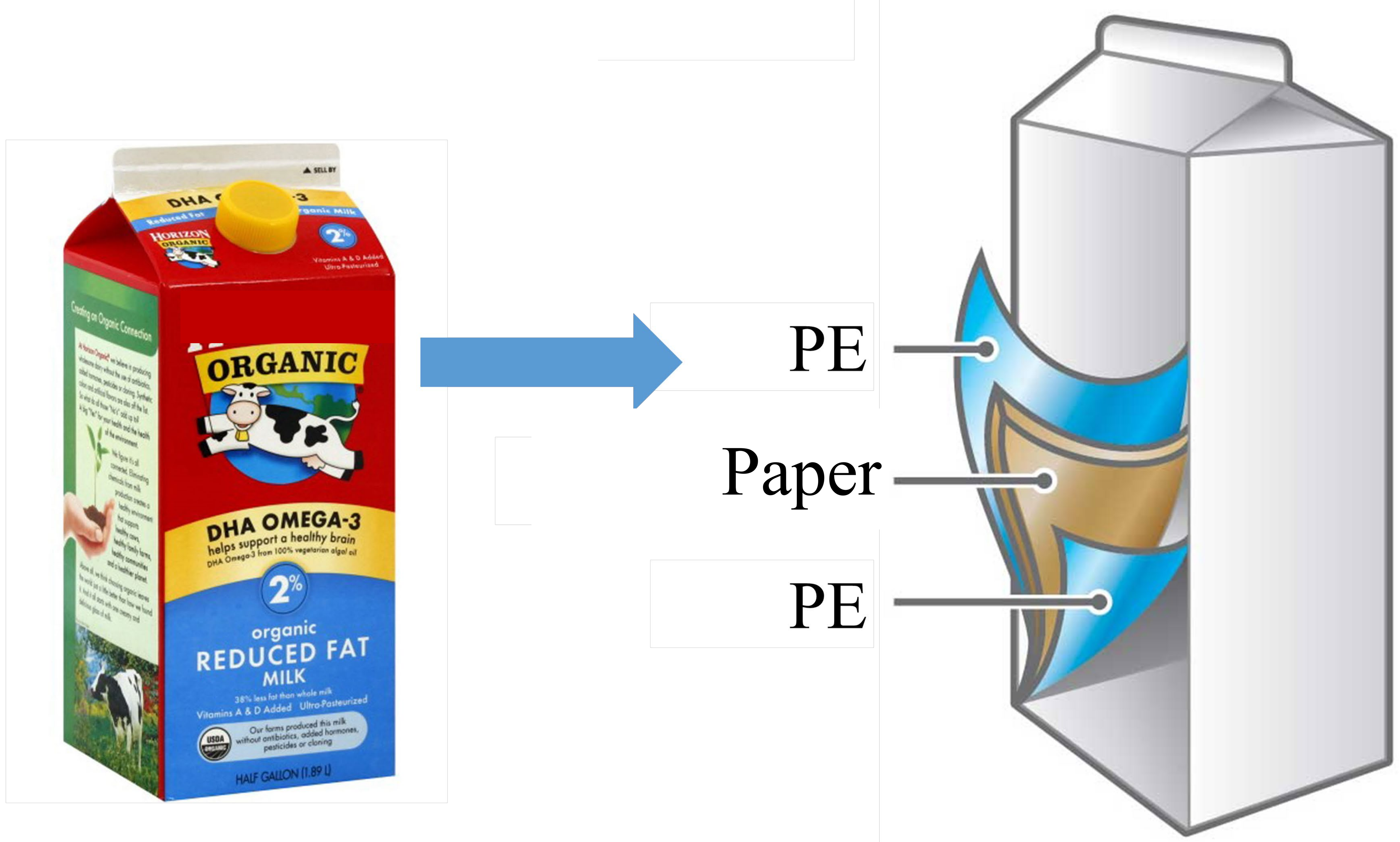
Current facts:

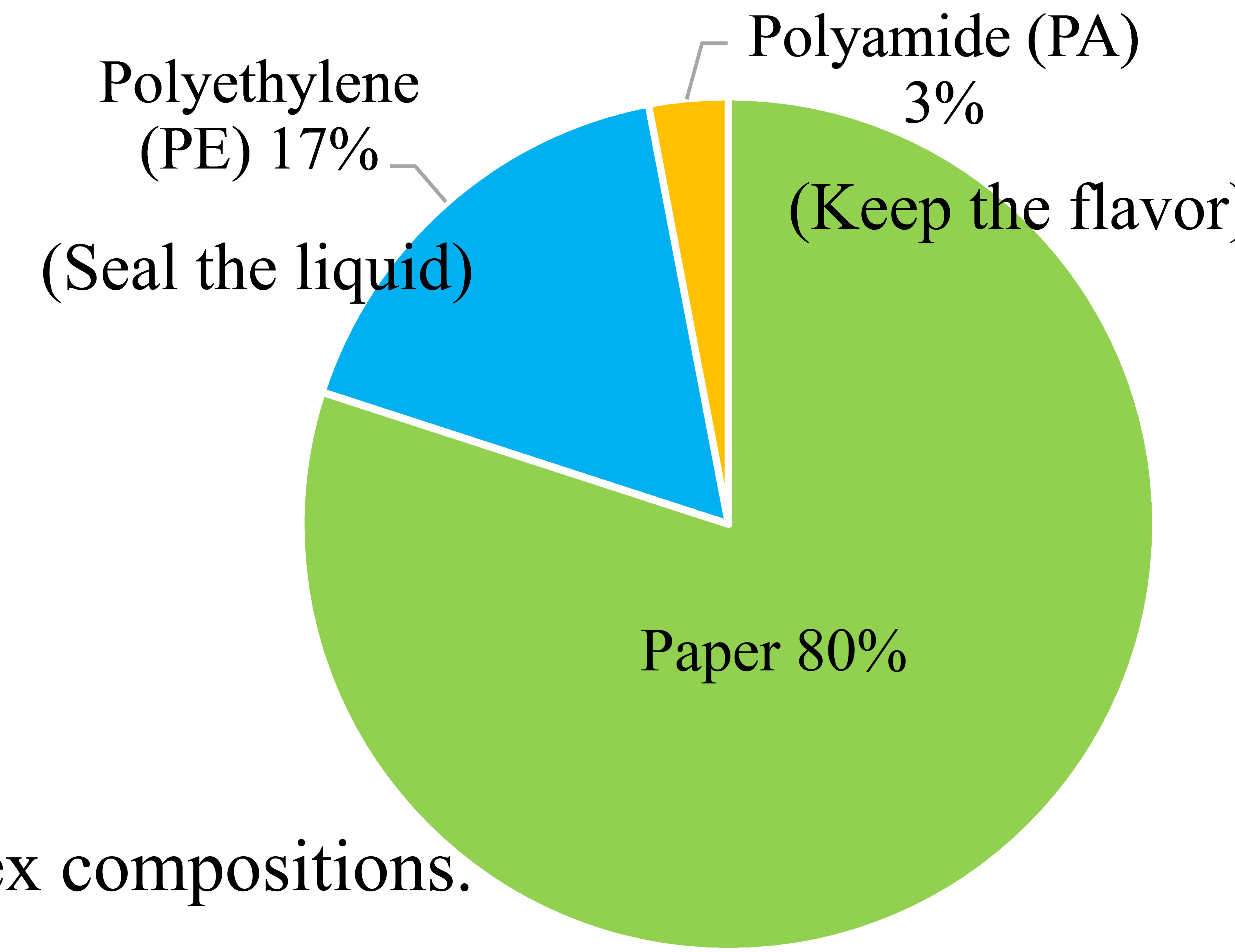
- Increasingly produced carton waste.
- Carton waste mostly ends up in landfills.
- Environmental problems and energy losses.
- Lack of efficient and economic recycling technologies.

How to recycle carton waste efficiently and economically?

Take advantage of feedstock + **Maximize product values** + **Reduce secondary pollutions**

Carton Composition





- Carton recycling is challenging due to complex compositions.

Develop recycling approach based on the properties of components

Paper → Cellulose 260 ºC — Good source of bio-based chemicals

PE, PA (**Solubility**) → Polymers 400 ºC

Cellulose and Polymers: **Thermal stability**

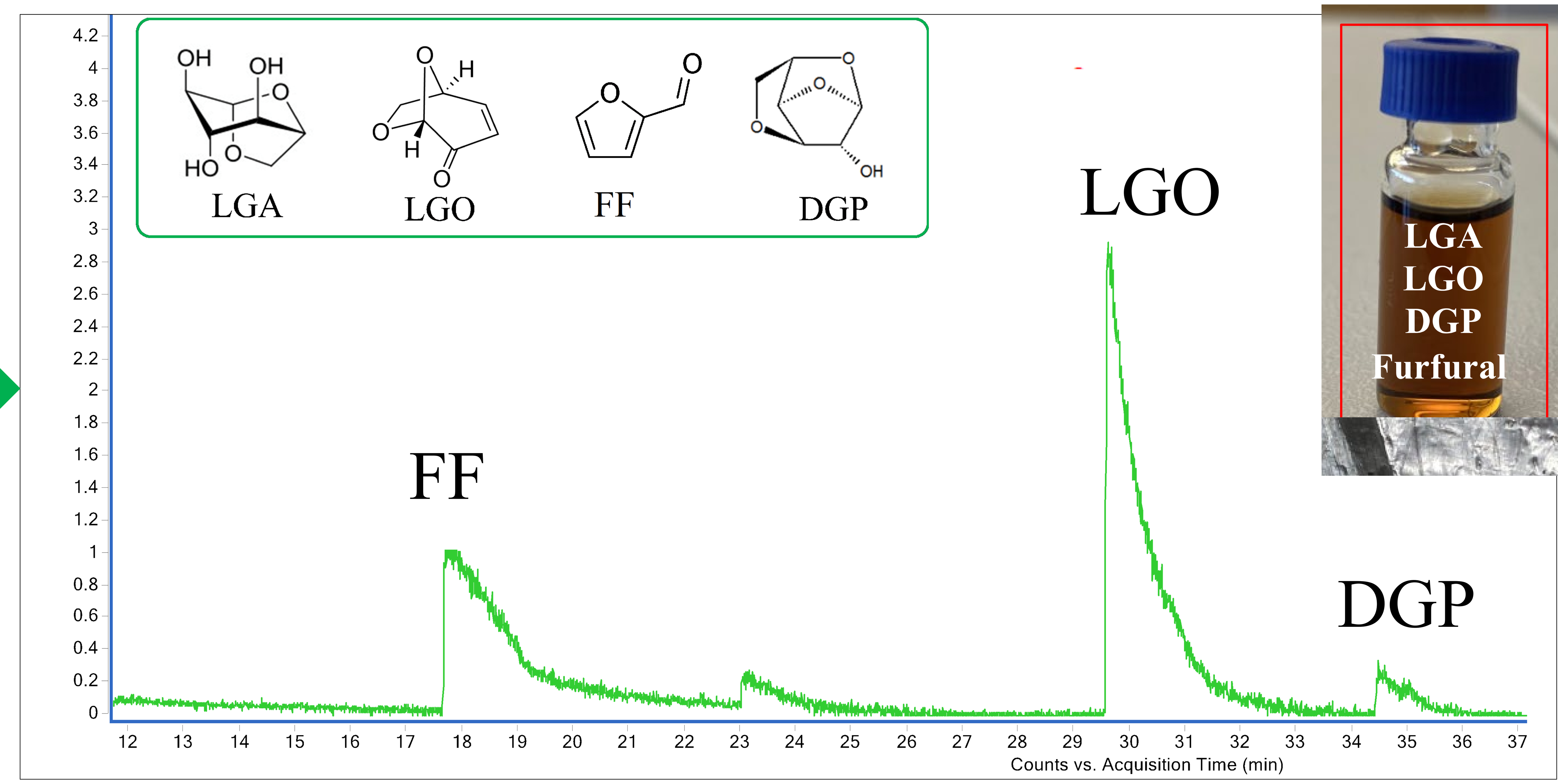
Proposed Multi-step Strategy

- **Step 1: Paper conversion** → **Liquefaction** →
  - Valuable bio-based chemicals
- **Step 2: PE recovery** → **Dissolution** →
  - Reusable PE
- **Step 3: PA recycling** → **Pyrolysis** →
  - Applicable monomer
  - High-quality solid fuel

Step 1: Selective Paper Conversion

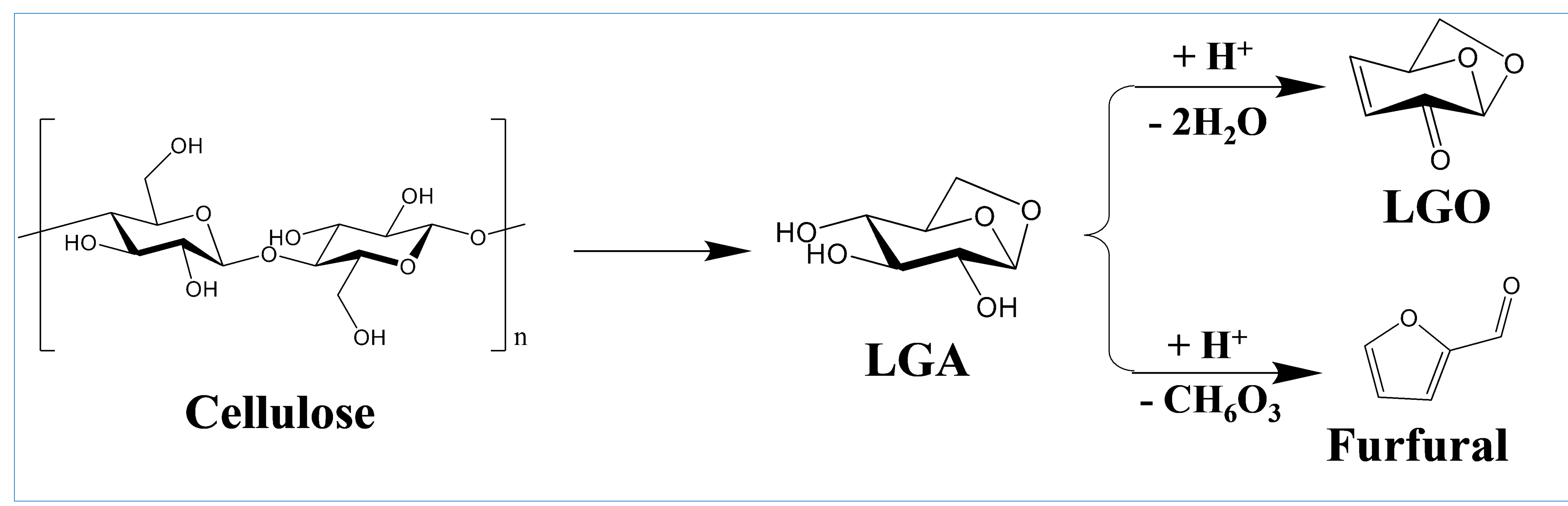
Carton Waste

THF, H_2SO_4 (10-20 mM)



Tetrahydrofuran (THF):

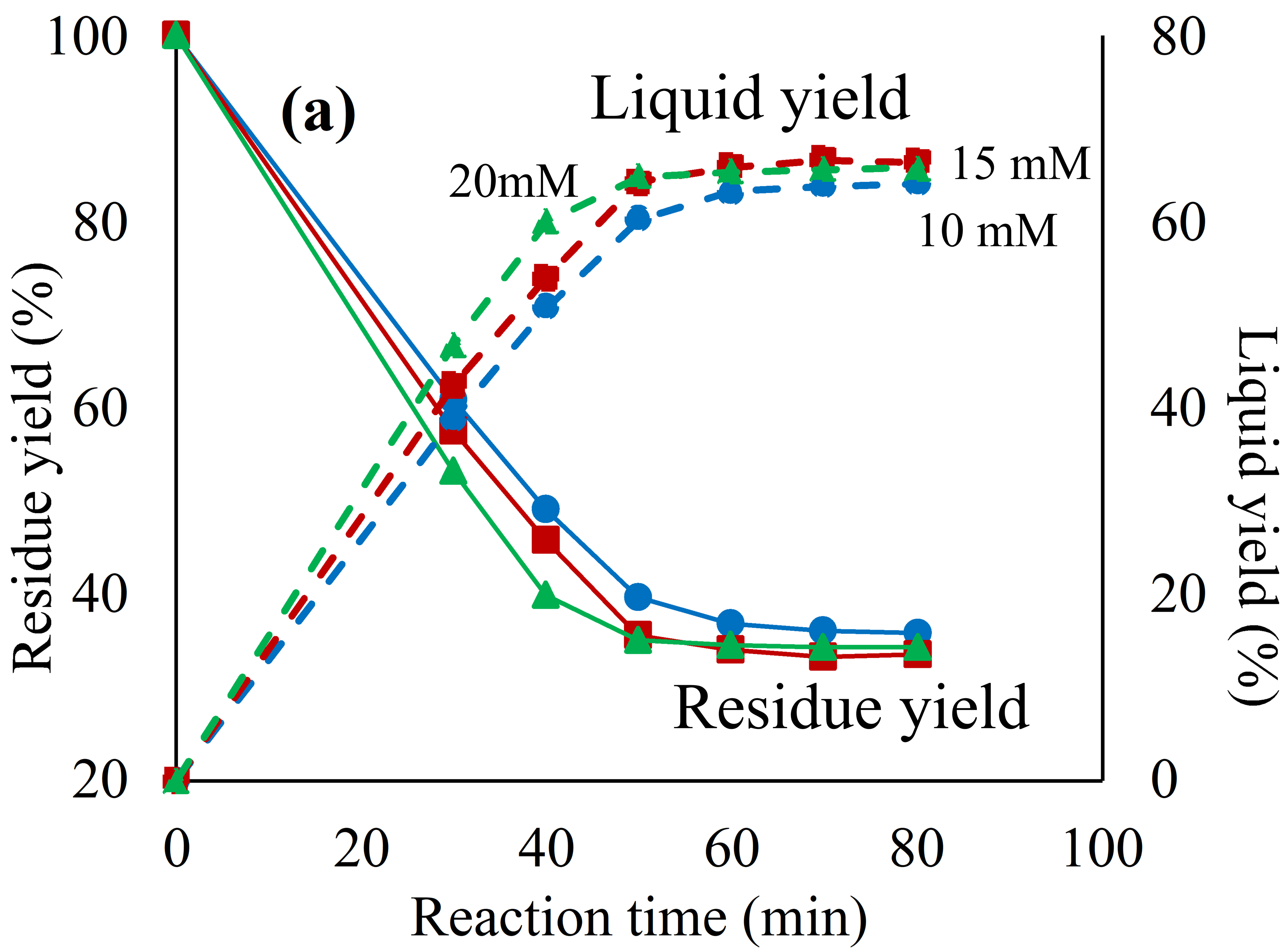
- Biomass-derivable green solvent.
- Magnify acid catalytic effect.
- Low boiling point allows easy recovery.



- Paper fraction was **selectively** decomposed to valuable chemicals.
- No PE- or PA-derived products were observed in the liquid.

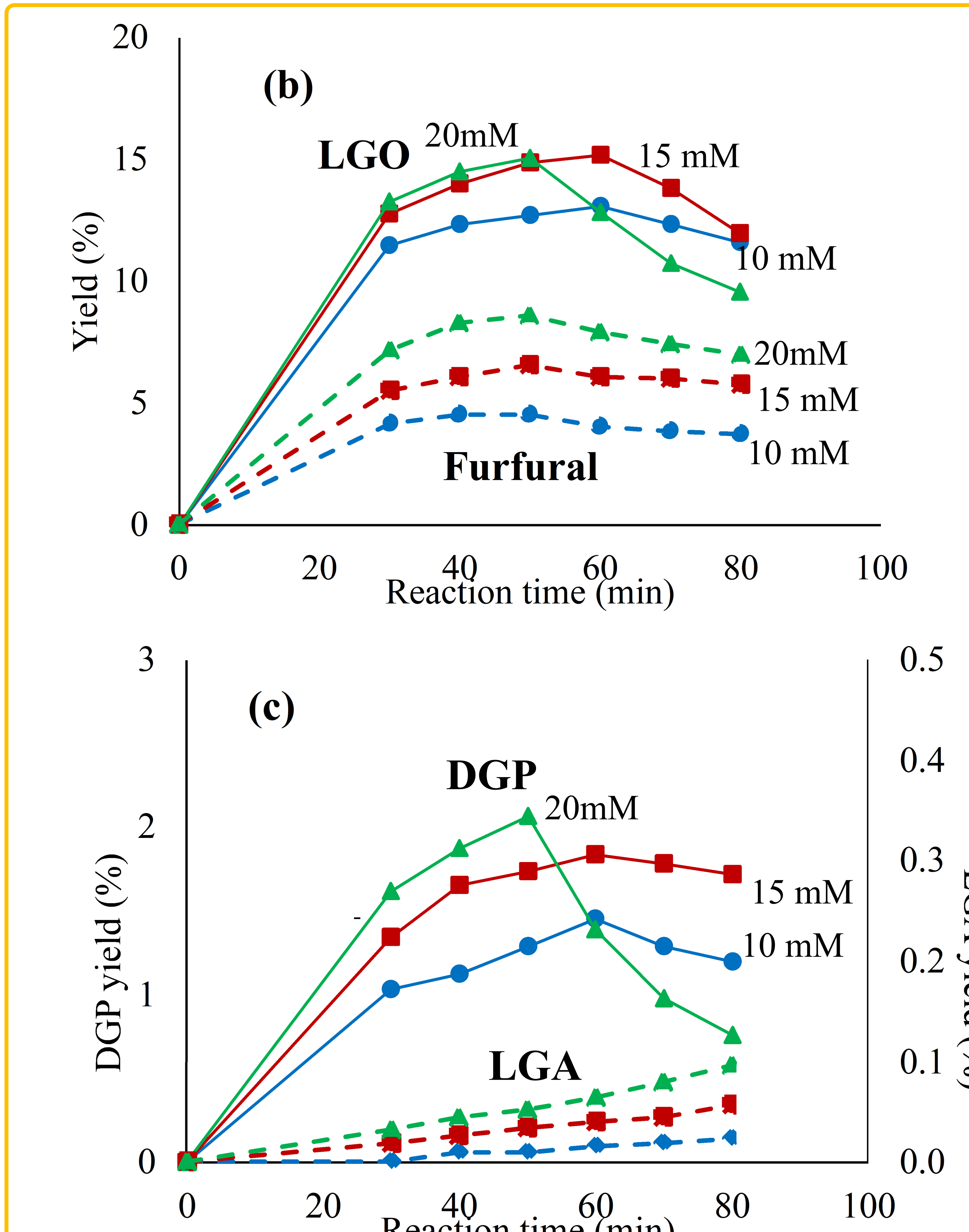
Effect of Acid Concentration

Mass Balance



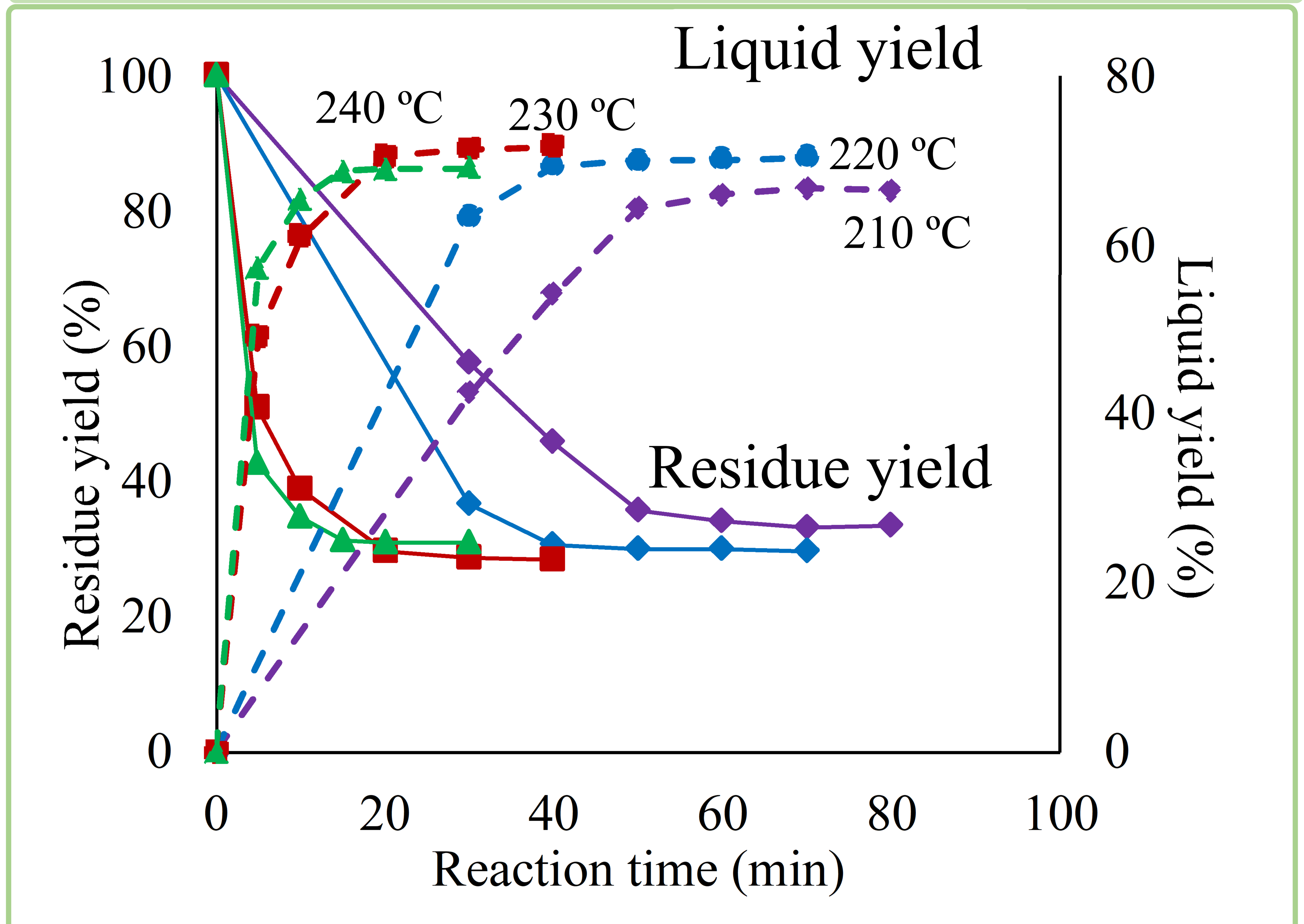
- Conversion rate increased with higher acid concentrations.
- LGO was increasingly unstable at longer reaction times with higher acid concentrations.
- Up to 15.2% of LGO was produced with 15 mM sulfuric acid.

Monomer Yield

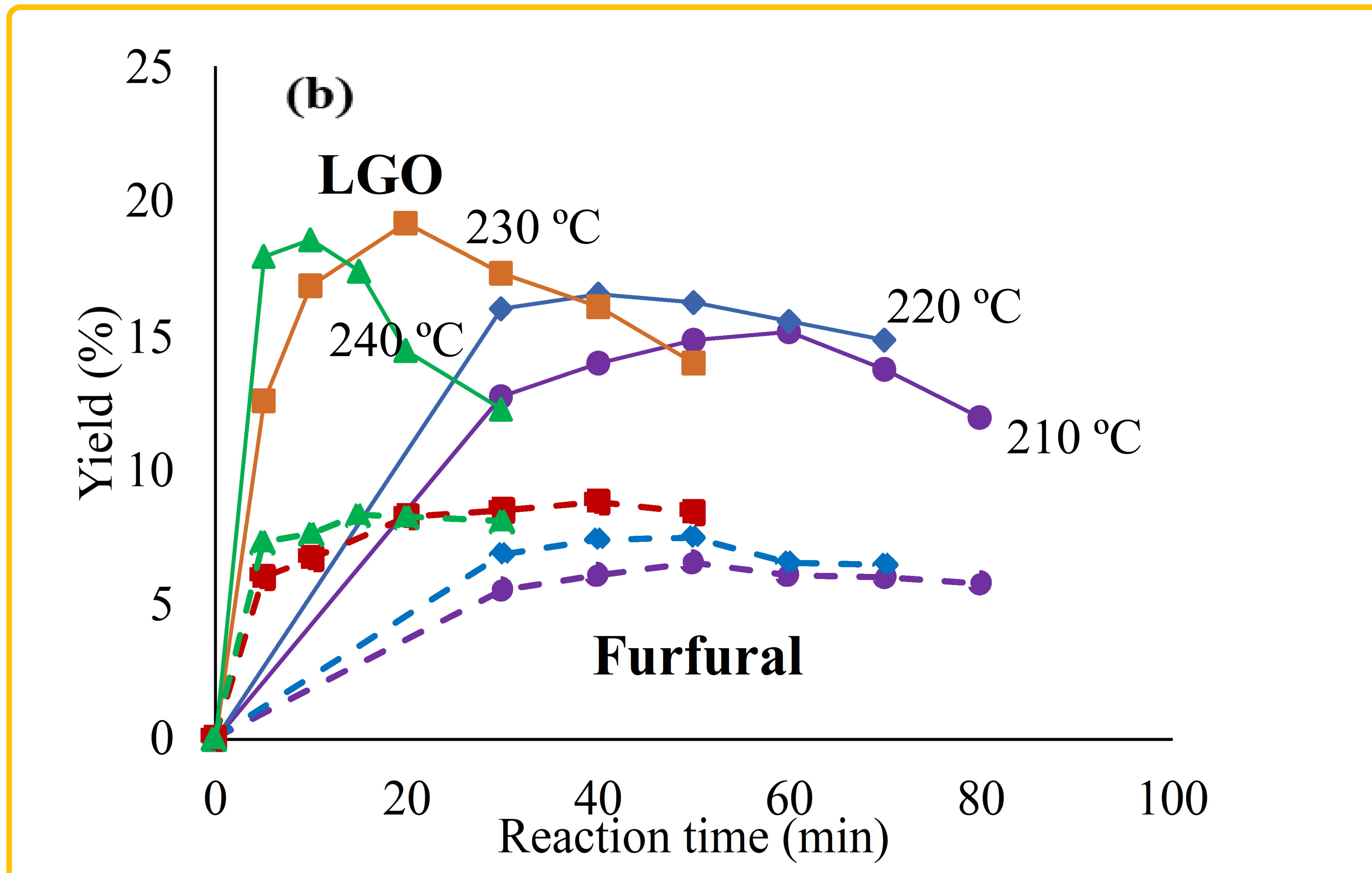


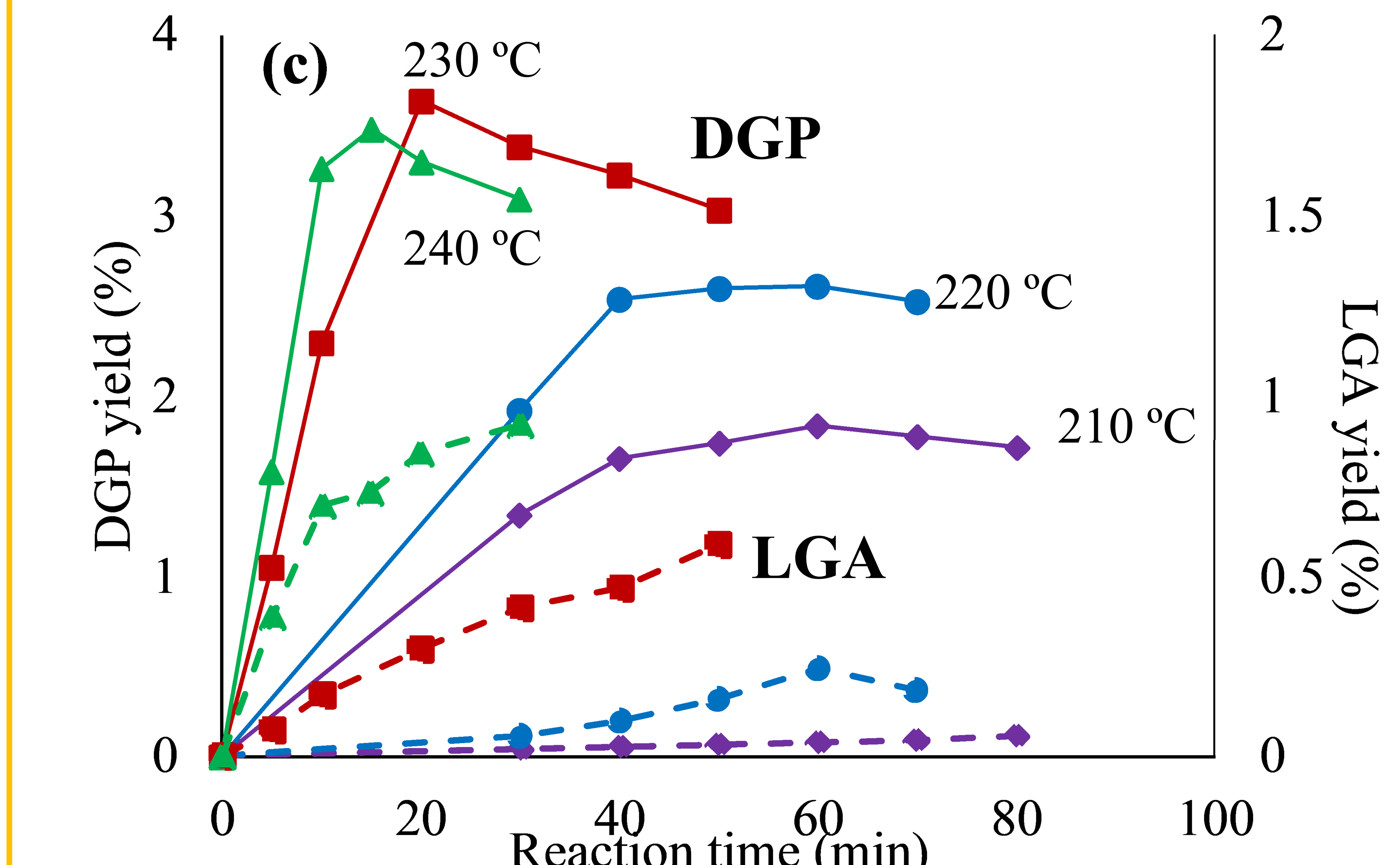
Effect of Solvent Temperature

Mass Balance



Monomer Yield

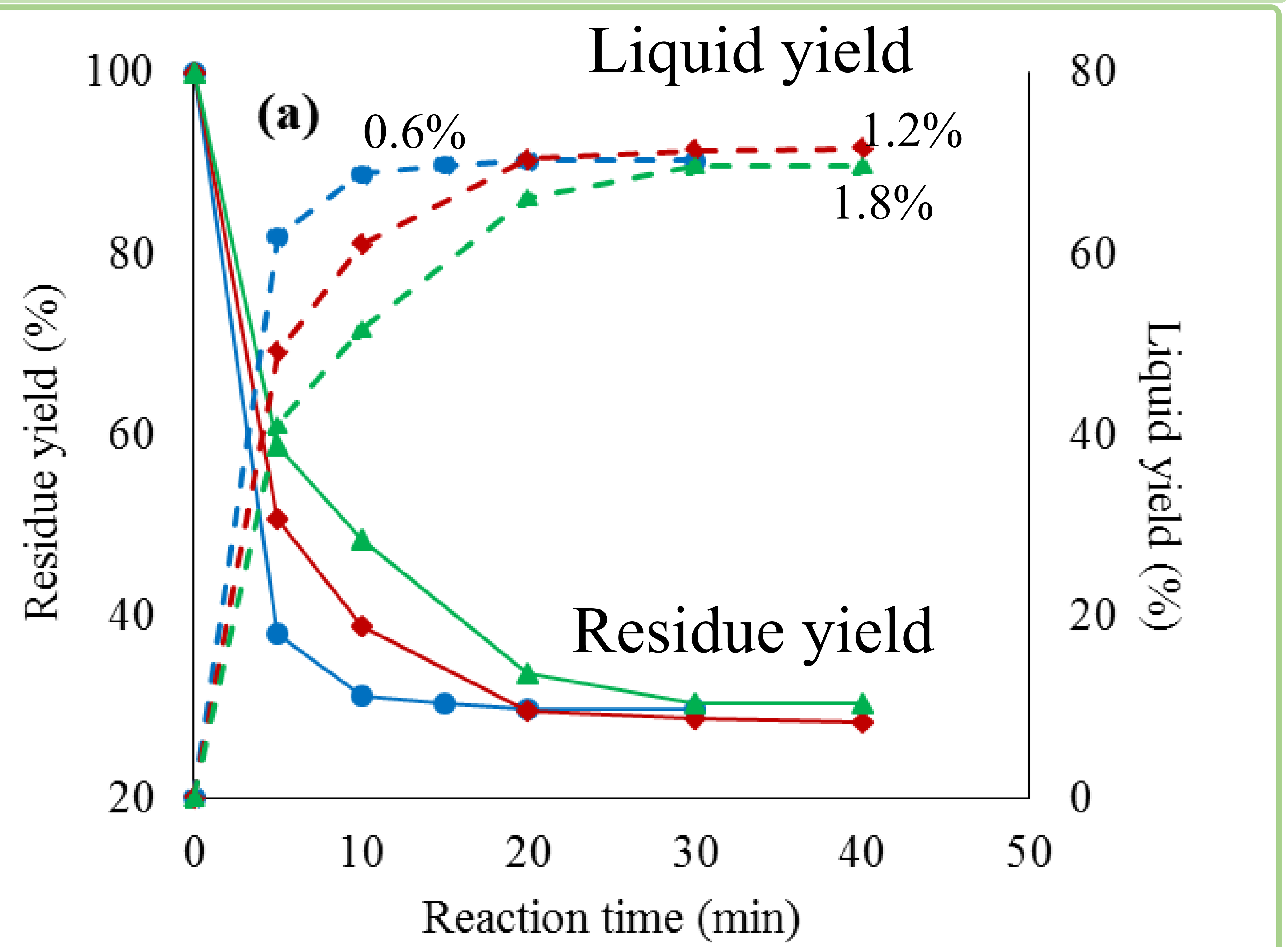




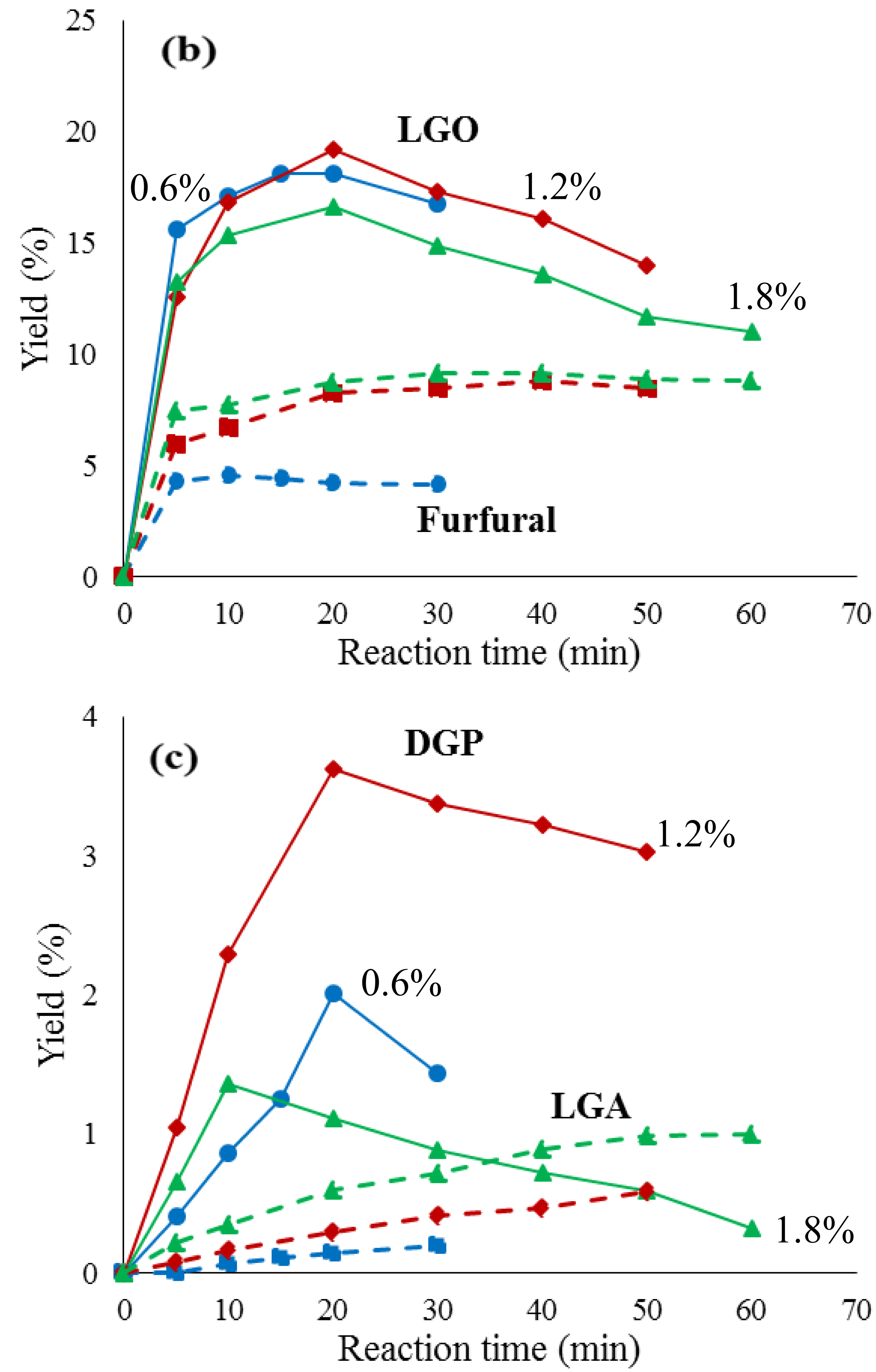
- Conversion rate increased at higher solvent temperatures.
- Up to 19.2% of LGO was obtained at 230 °C.

Effect of Mass Loading

Mass Balance

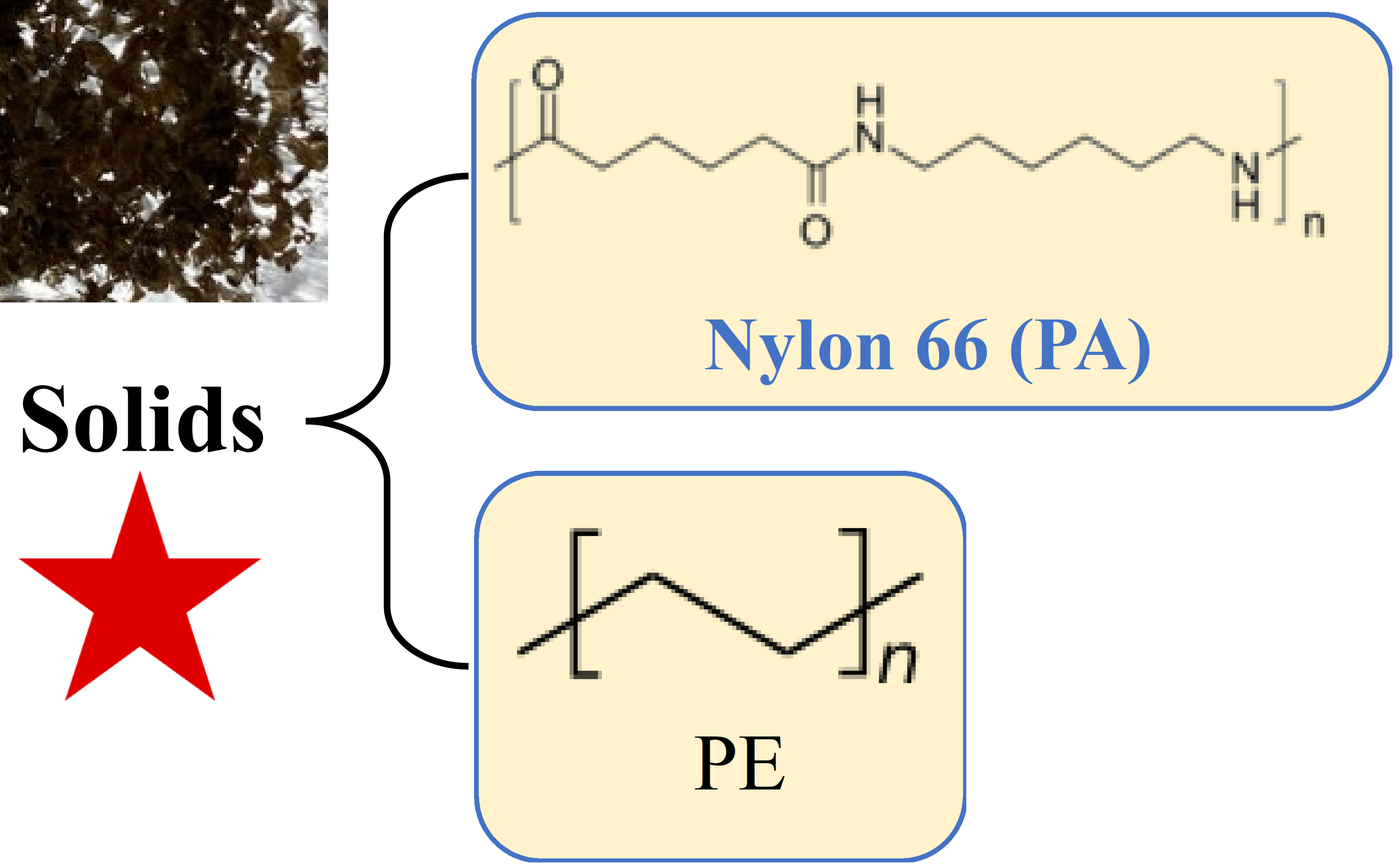


Monomer Yield

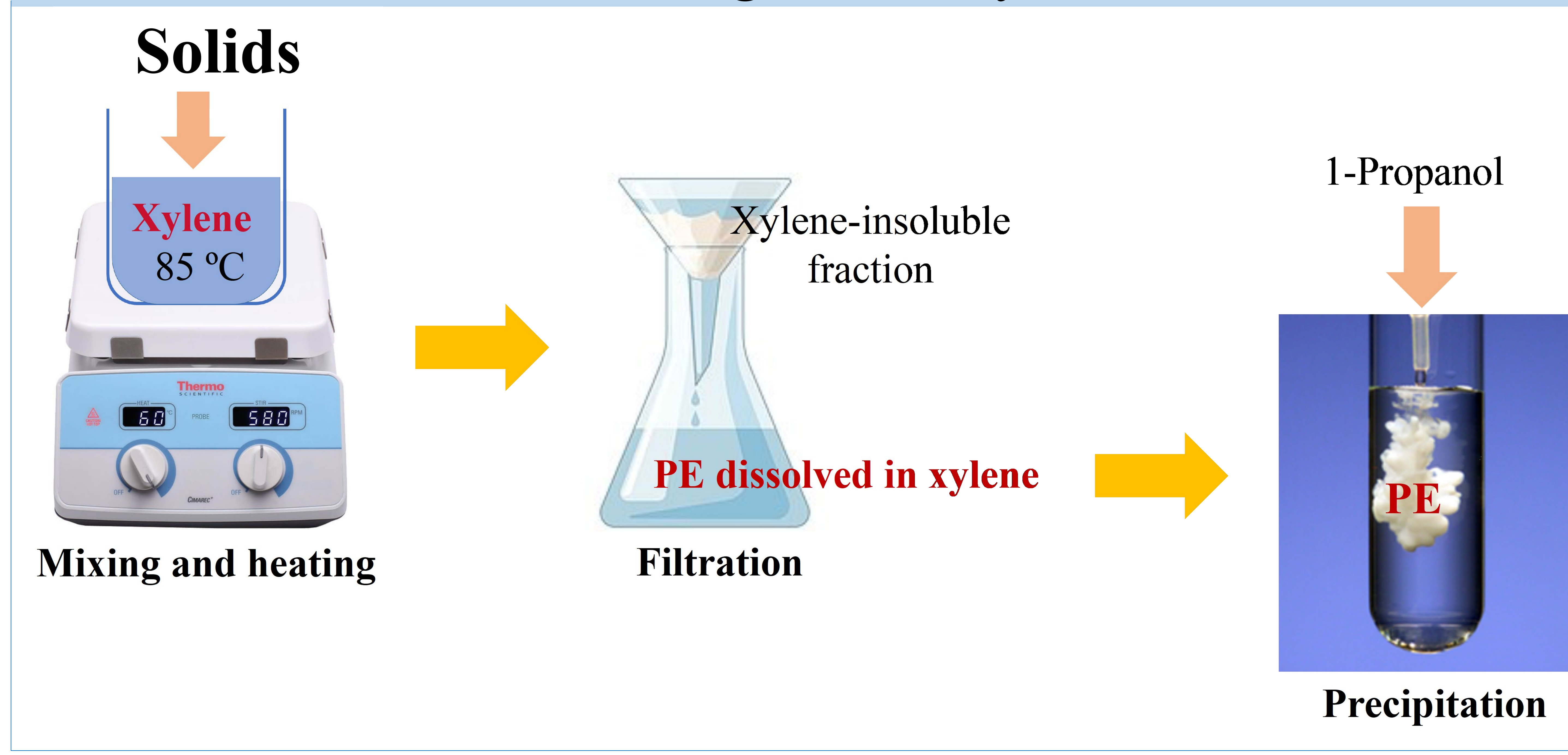


- Conversion rate of carton decreased with higher mass loadings.
- 1.2% carton loading was the optimum for chemical production.

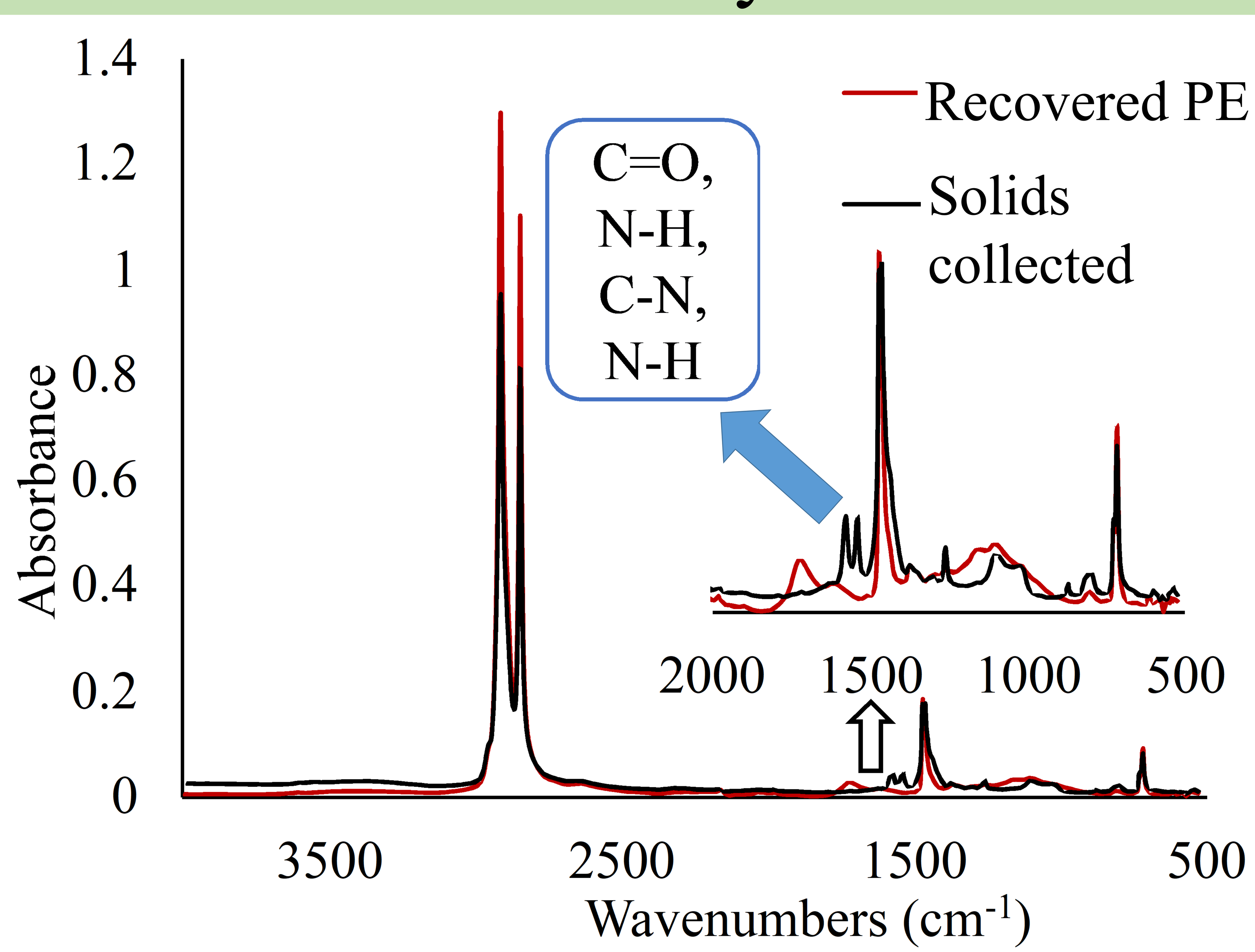
Step 2: PE recovery



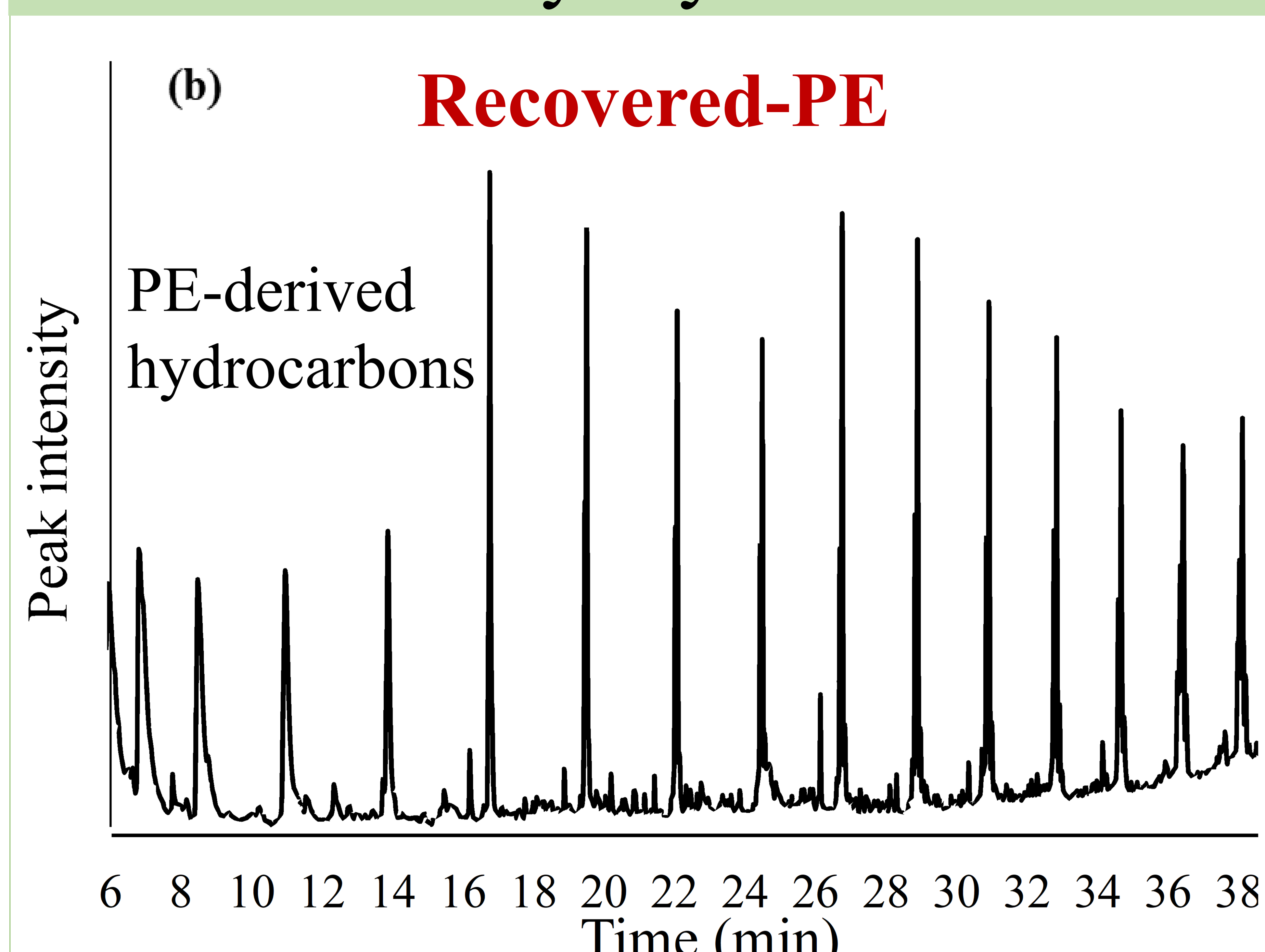
Dissolving PE in xylene

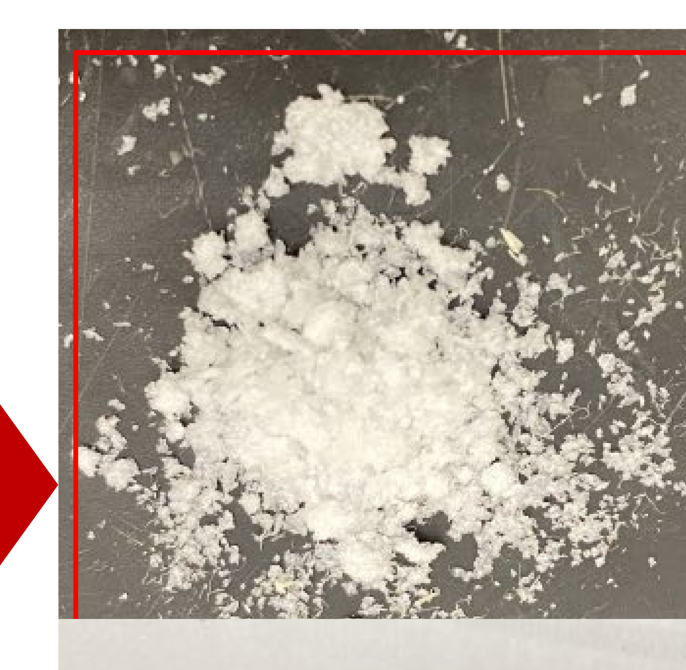


FTIR analysis



Pyrolysis

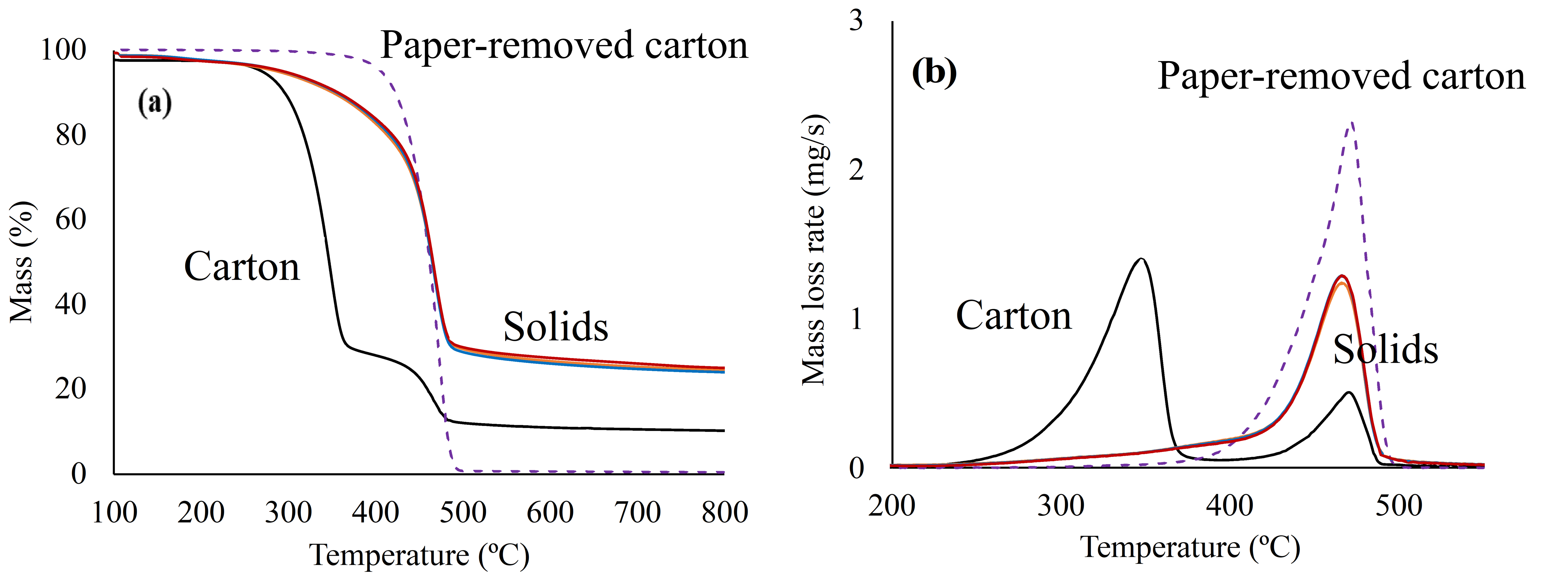




Recycled PE.

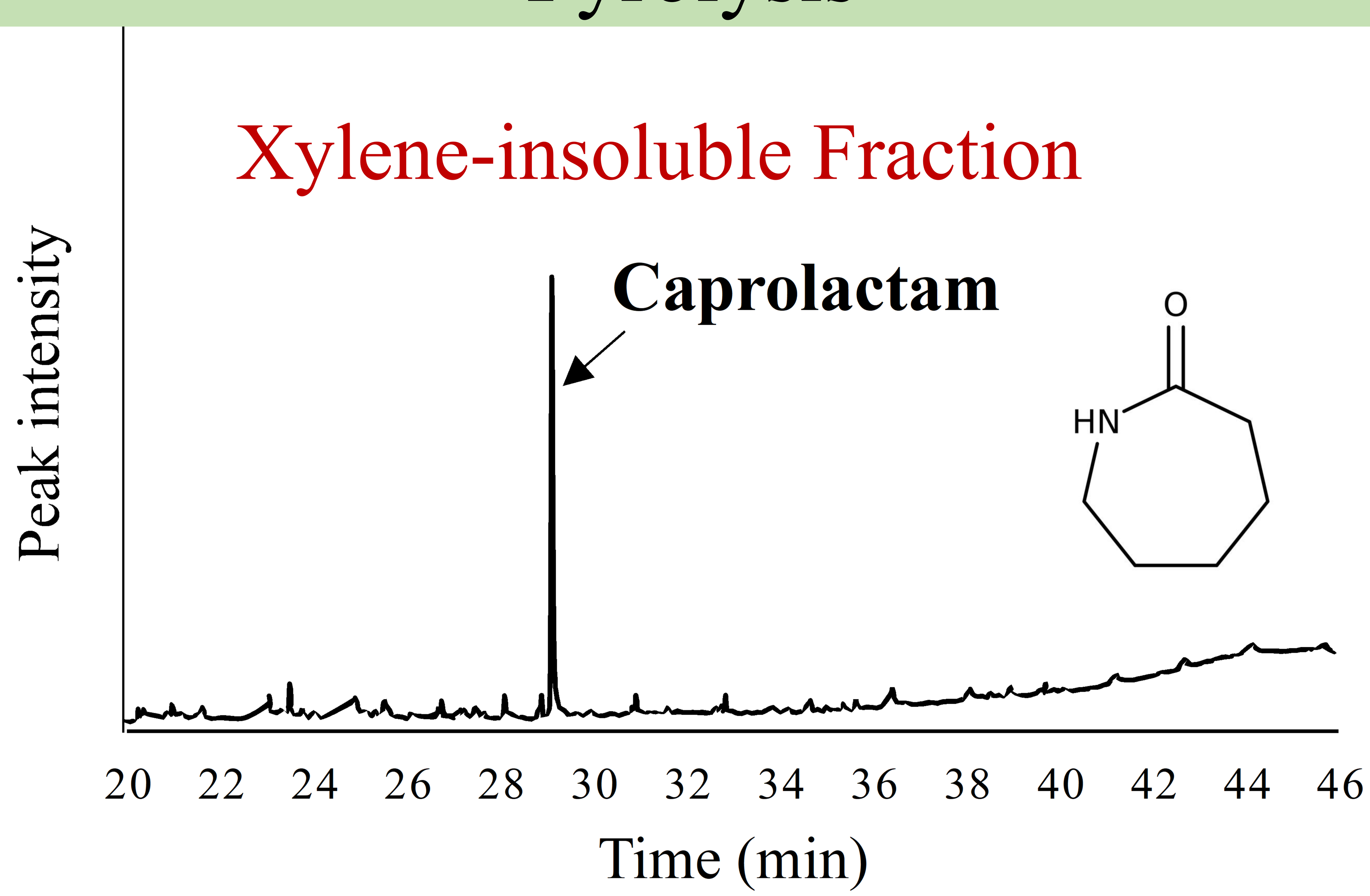
Step 3: PA recycling

TGA and DTG



✓ Xylene-insoluble fraction consists of PA and the paper-derived char.

Pyrolysis



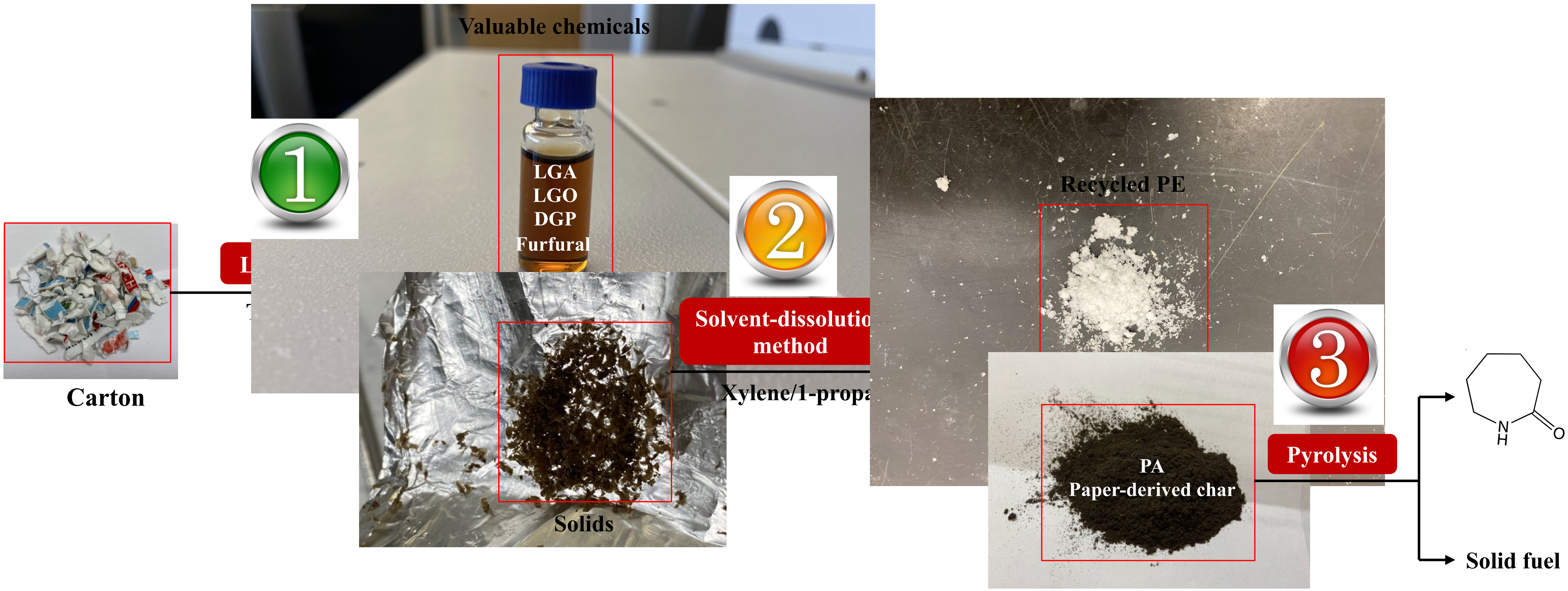
Application

caprolactam is used to produce **nylon fibers** for textile, carpet and industrial yarns, with the rest applied in engineering resins and films.

M., W., & S., C. (2021, September 2). *Nylon 6, nylon 6/6 and Nylon 6/12 – what is the best nylon rod or sheet to use*. The Plastic Mentor Blog. Retrieved April 2, 2022, from https://www.plasticmentor.com/what-is-the-best-nylon-rod-sheet-type-6-66-612/

Conclusions

Carton waste as low-cost feedstock was upcycled using a multi-step approach.



✓ Paper fraction was selectively converted into value-added chemicals.

✓ Solids consisting of PE, PA and paper-derived char were processed by a dissolution method to separate PE from the mixture.

✓ Pyrolysis of the PE-removed solids produced caprolactam with high-quality solid fuel.

✓ The value of each component was maximized through this multi-step approach.

Publication

Waste Management 131 (2021) 423–432

Contents lists available at ScienceDirect

Waste Management

journal homepage: www.elsevier.com/locate/wasman

Upcycling polyamide containing post-consumer Tetra Pak carton packaging to valuable chemicals and recyclable polymer

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ARTICLE INFO

Keywords:
Tetra Pak
Recycling
Levoglucosenone
Furfural
Caprolactam
Polyethylene

ABSTRACT

Billion tons of post-consumer Tetra Pak cartons are discarded annually as land and ocean wastes, creating significant environmental problems and resource losses. Recycling of the carton wastes is hindered by its multi-material compositions and low values of the recycled products. In this study, a novel upcycling of the cartons was investigated. A post-consumer carton consisting of paper, polyolefin, and polyamide was directly converted in 210–230 °C tetrahydrofuran containing 10–20 mM acid to produce up to 19.2% of levoglucosenone and 8.6% of furfural by selectively decomposing paper fraction. The remaining solids containing mostly intact polyethylene and polyamide but also a smaller fraction of paper-derived char were separated using a solvent-dissolution method. The xylene-soluble fraction was a recycled polymer similar to the original polyethylene, which was verified by its functional groups, the composition of the pyrolysis products, and the melt rheology results. The xylene-insoluble fraction was a mixture of polyamide and paper-derived char. Upon pyrolysis, caprolactam was produced as the only major vapor product. The remaining, thermally stable paper-derived char could be used as a high-quality solid fuel. Overall, the demonstrated recycling method could potentially maximize the values of the products recovered from carton wastes.

Chen, X., Luo, Y., Bai, X., 2021. Upcycling polyamide containing Post-consumer Tetra Pak carton packaging to Valuable chemicals and Recyclable polymer. Waste Management 131, 423–432. doi:10.1016/j.wasman.2021.06.031

Thank you very much!