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Techno-economic analysis and life cycle assessment for the production of lignin-based adhesives from softwood kraft lignin via base-catalysed depolymerization

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Phenol-Formaldehyde resins

Phenol-formaldehyde (PF) resins:

- Is an important type of adhesives which widely used in wood-based applications by reason of their heat and water resistance, high mechanical strength and chemical stability
- Phenol-Formaldehyde resins represents about 1 million tons market on dry basis
- Produced from the reaction of phenol and formaldehyde under alkaline conditions

Phenol is an aromatic organic compound were used in many application in chemical industries (e.g. production bisphenol A, phenolic resins, adipic acid)

Disadvantage: Fossil based

Replacing with renewable ones

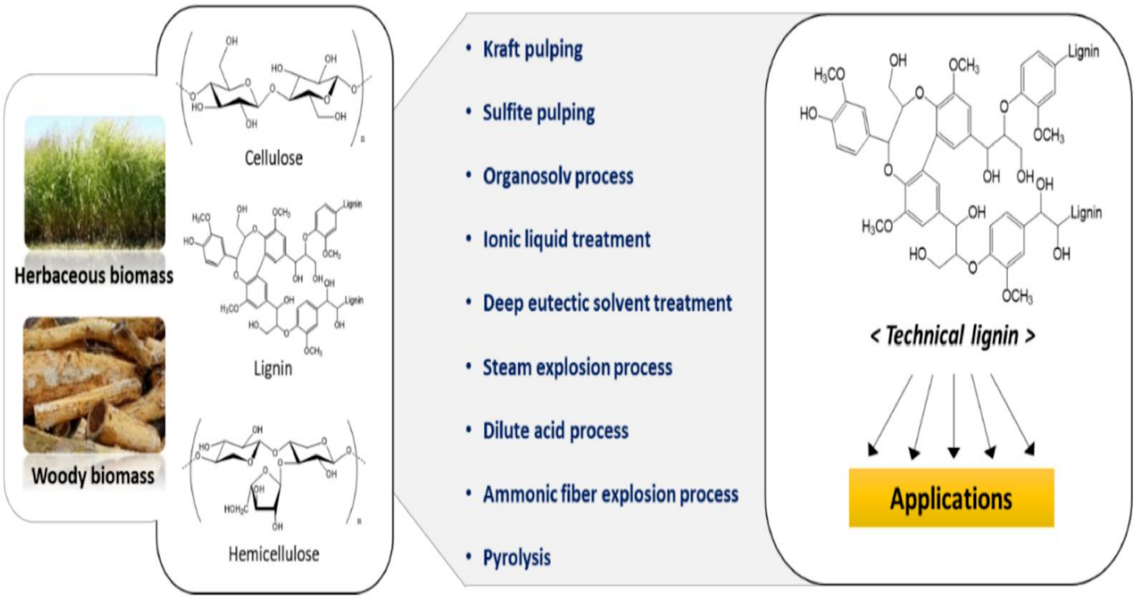
Alternatively, to PF resins is the lignin-PF resins
Phenol is replaced by lignin in different amounts

Origin of lignin

Lignin is one of the natural polymers found in wood and accounts for 33% of the weight. It is even the second most common organic substance in the world after cellulose

Globally the lignin amount accounting for approximately 300 billion tons, with a Compound Annual Growth Rate (CAGR) of 7%

Of this amount, around 100 Mt/y are technical lignin, primarily coming from the pulp and paper industry
(A technical lignin can be defined as a form of lignin isolated after a series of biomass processing stages. Types of technical lignin vary largely in terms of molecular weight and structure, which essentially determine the routes for lignin valorization and application.) Dessbesell, L. et al., 2020. *Renewable and Sustainable Energy Reviews*, *123*, p.109768.



Processes for the extraction of technical lignins.

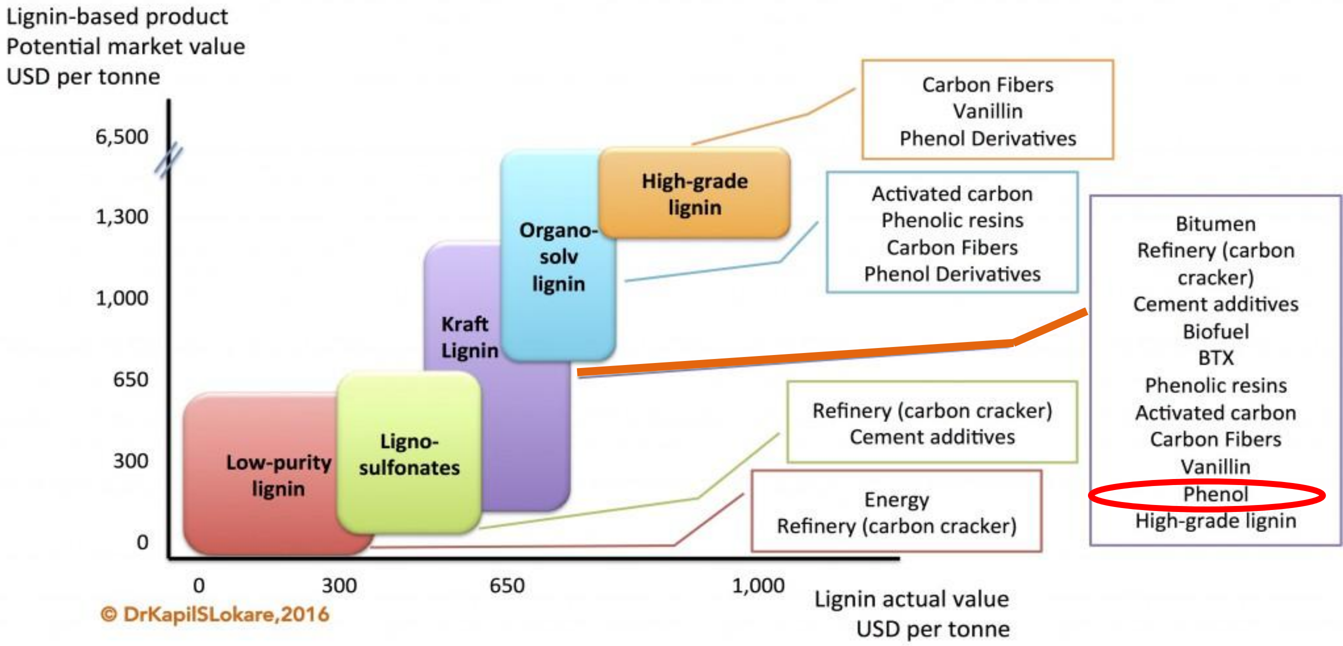


Exhibit 3. Mapping of lignin value *versus* lignin-based product value, by lignin type

Lignin-based adhesives from softwood kraft lignin via base-catalysed depolymerization

Production of Lignin-Phenol-Formaldehyde (LPF) resins

→ Lignin has les reactivity in compared to phenols

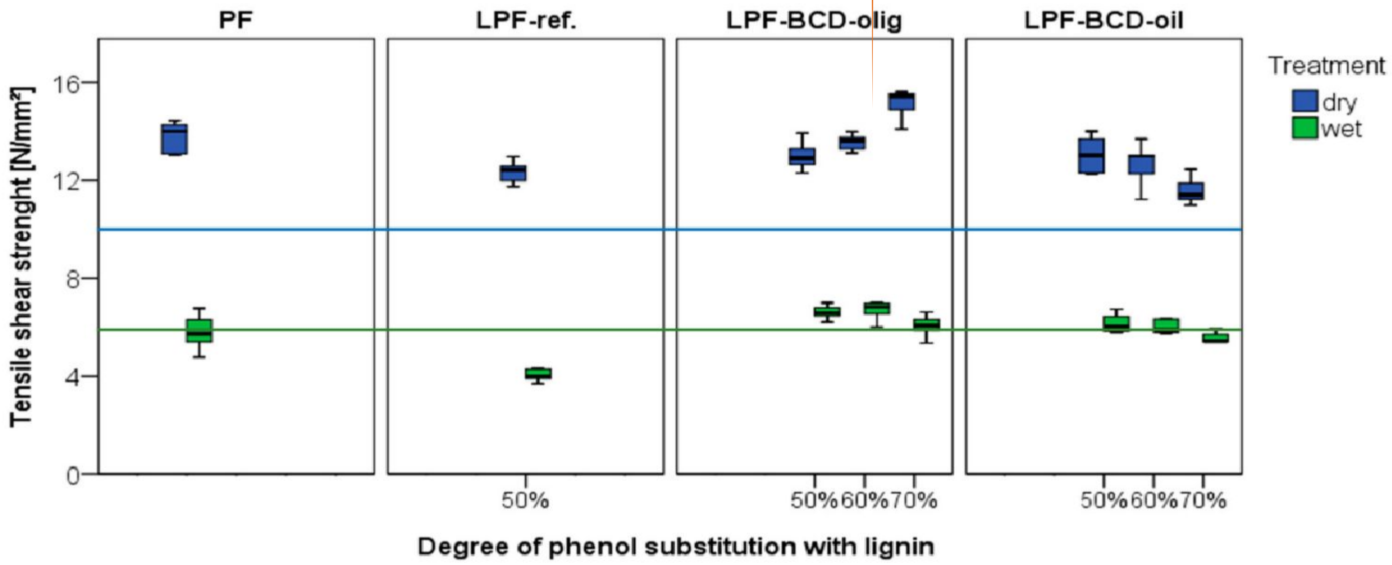
Solutions

Modification methods:
- Methylolation
- Phenolation
- Demethoxylation

Lignin homogeneity
Using solvent fractionation

Substitution level < 50% due to lower strength values compared to commercial PF resins

Depolymerisation (cracking)
Promising process convert the complex lignin compound into small molecules and, moreover, increase the chemical reactivity of the degradation products



The goal of this study is to evaluate the base-catalysed depolymerized kraft lignin (BCD) method on the resin production of lignin-based phenolic resins

Adhesives, with up to 70% phenol substituent

Performing a preliminary techno-economic evaluation

1st STEP: Development of the Process Flow Diagram (process design-Unisim, material and energy balance)

↓

2nd STEP: Sizing of all process equipment using standard chemical engineering techniques and widely acceptable rules of thumb

↓

3rd STEP: Estimation of purchased equipment cost (C_p) using relevant textbooks and reports

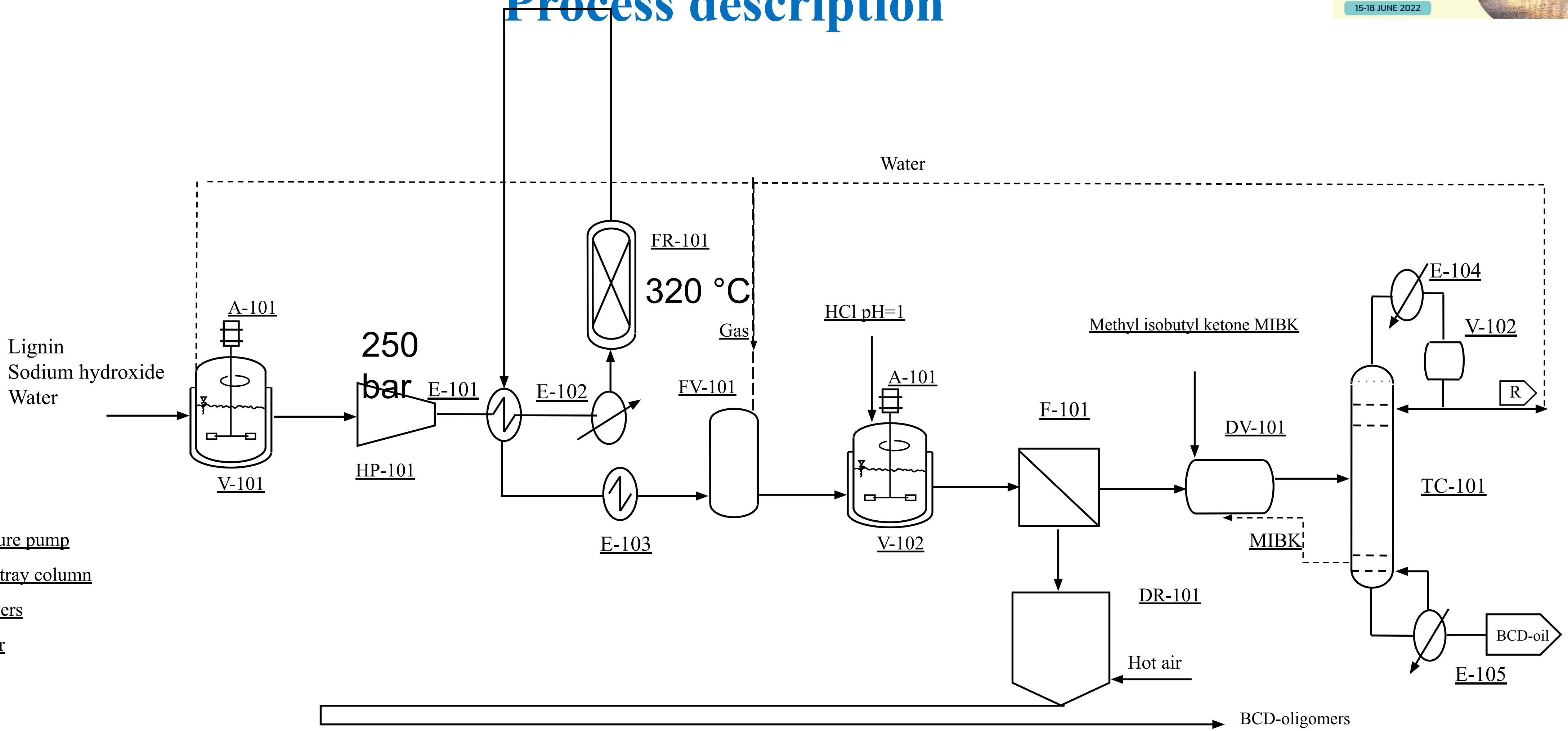
↓

4th STEP: Conversion to todays prices by using the CEPCI (CHEMICAL ENGINEERING PLANT COST INDEX)

↓

5th STEP: Economic evaluation by estimation of Fixed Capital Investment ($FCI = 5 \times C_p$), Cost of manufacturing COM , Minimum selling price (MSP)

Process description



HP=hight pressure pump

TC=distillation tray column

E=heat exchangers

FR=flow reactor

DV=decanter

F=filter

DR=dryer

V=vessel

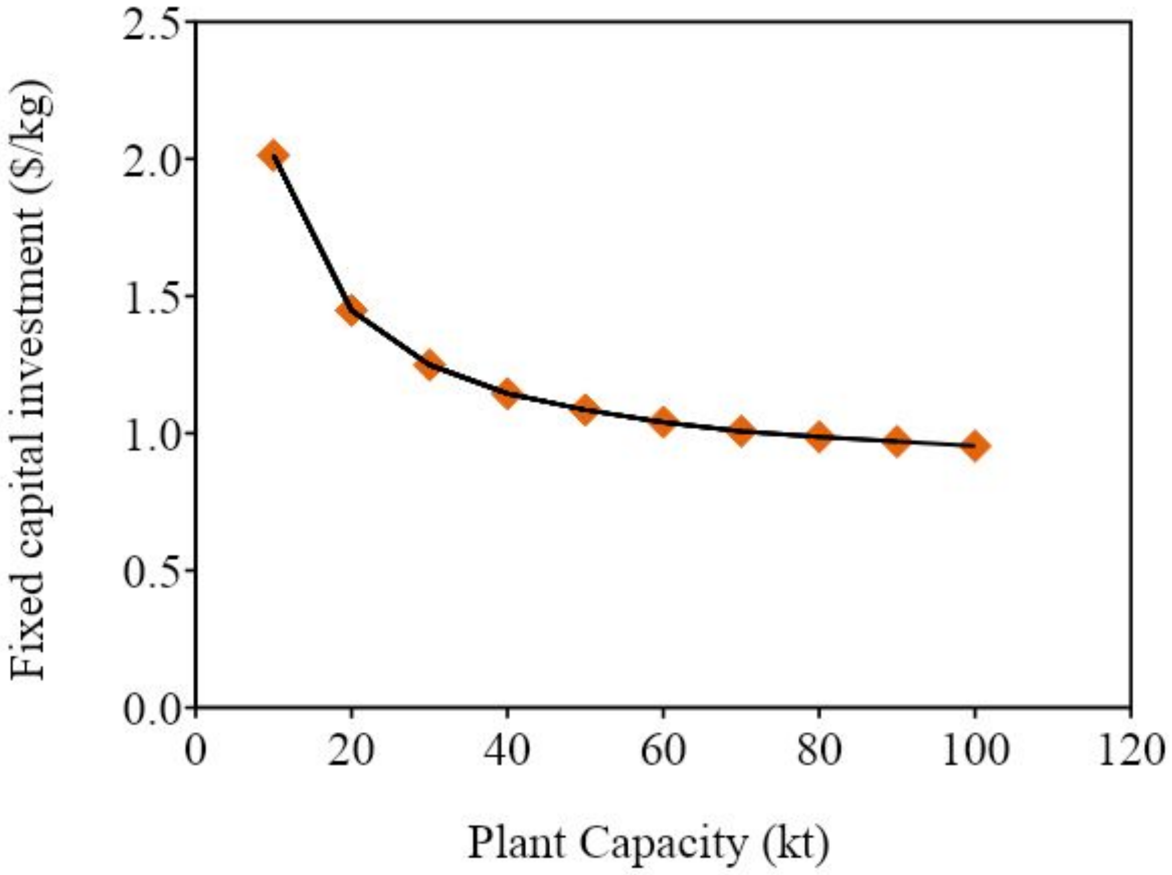
A=agitator

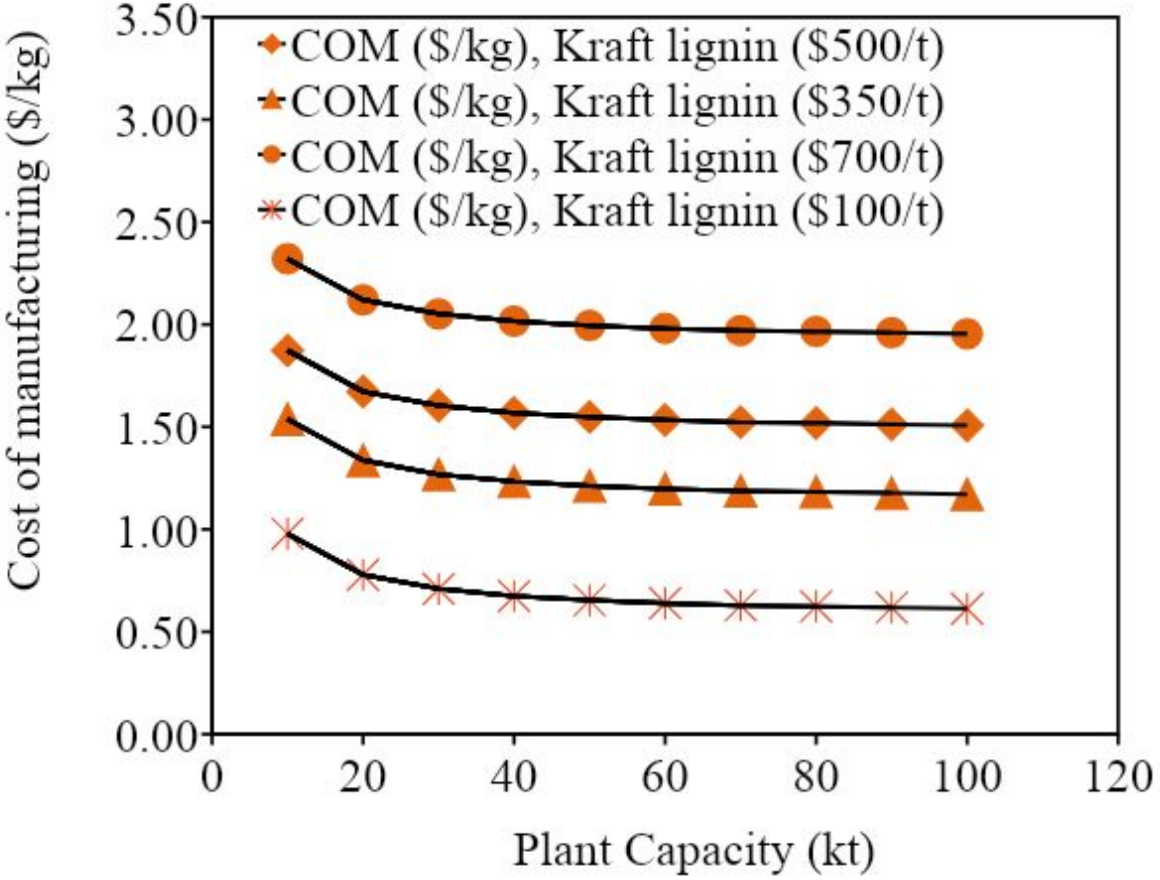
FV=flash vessel

Solt et al.,2018. Polymers, 10(10), 1162.

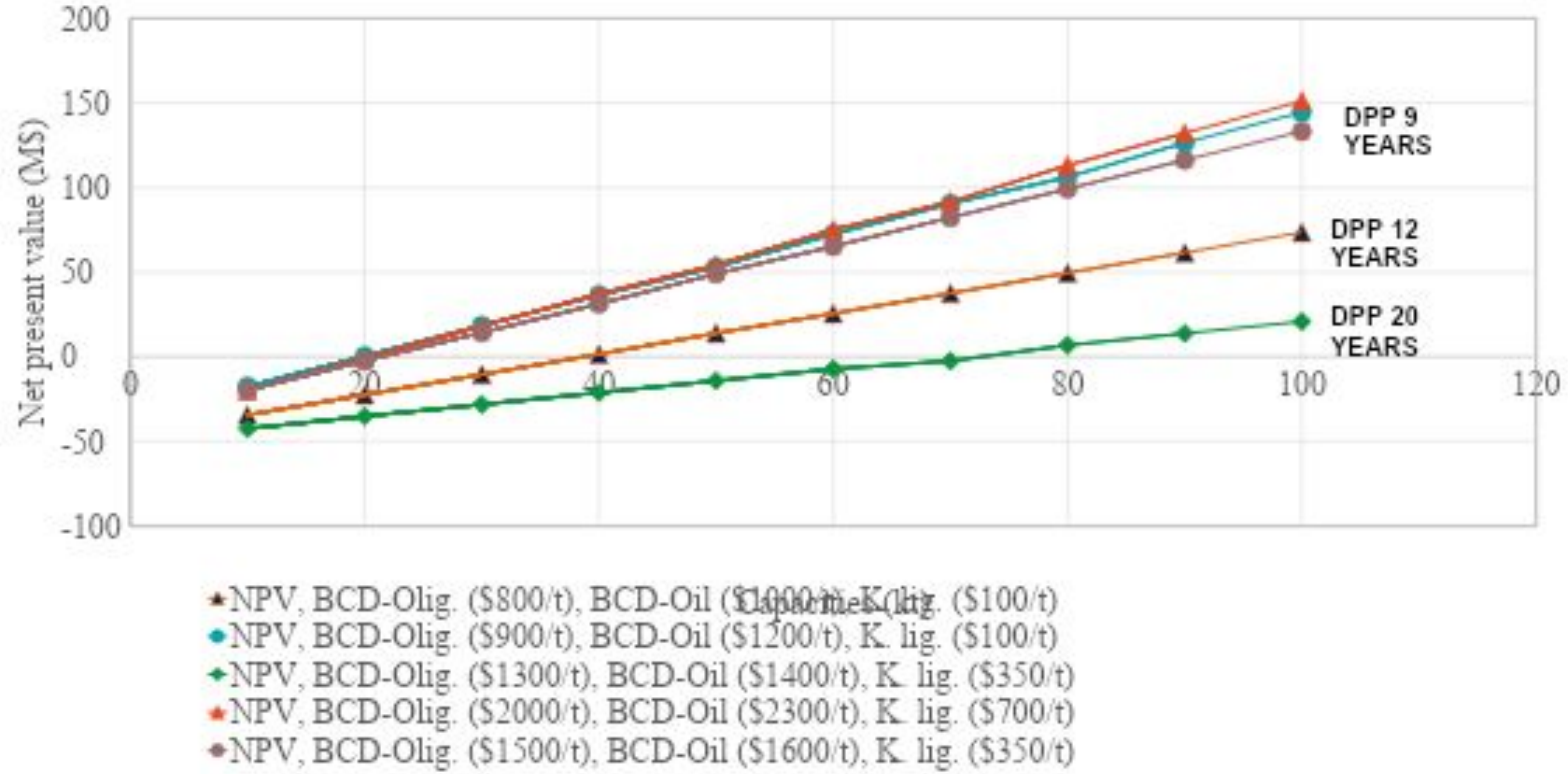
Unit operations, such as the reactor, the pumps, and the heat exchangers are modelled using Unisim software

Results of Techno-economic evaluation



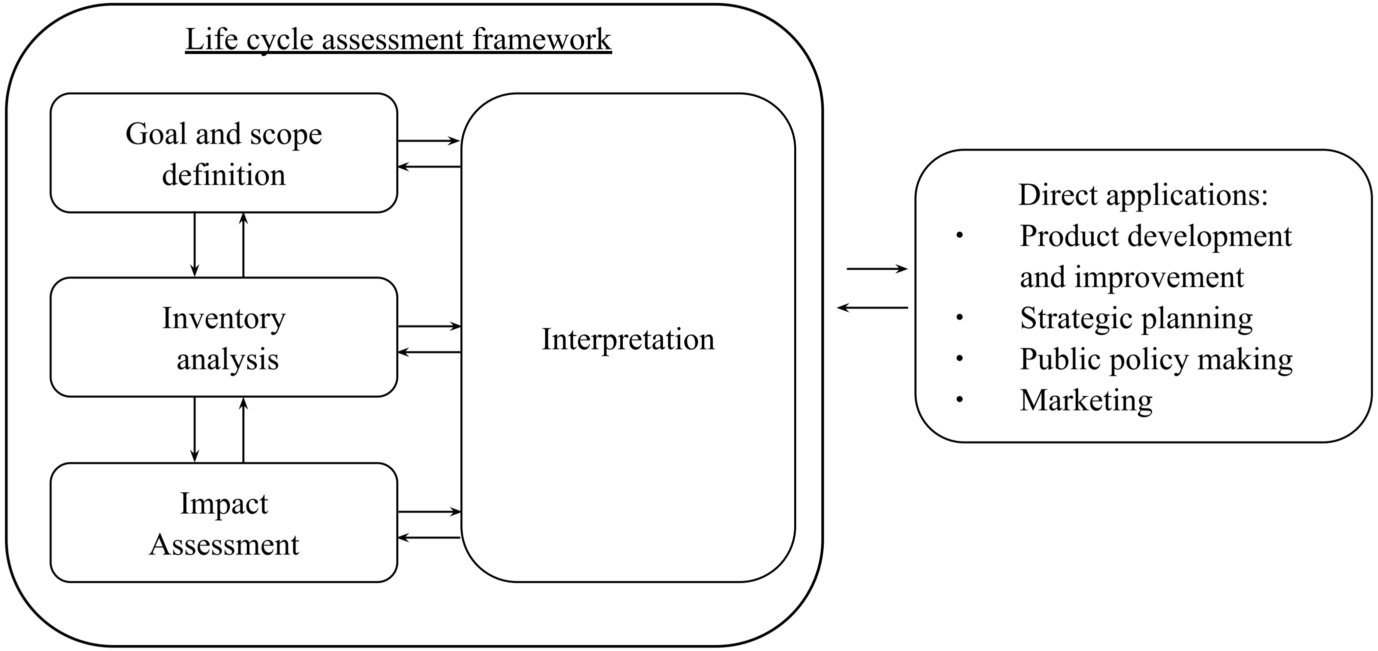


Results of Techno-economic evaluation

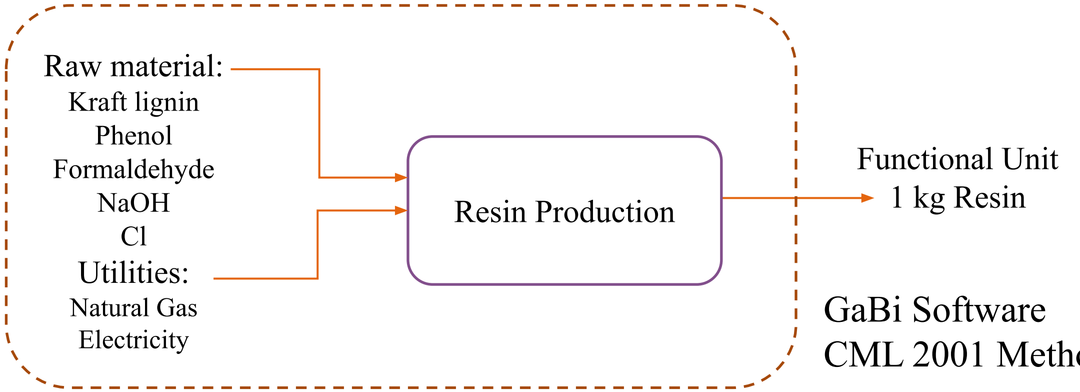


0.8-1.2 $/kg

Performing a life cycle assessment



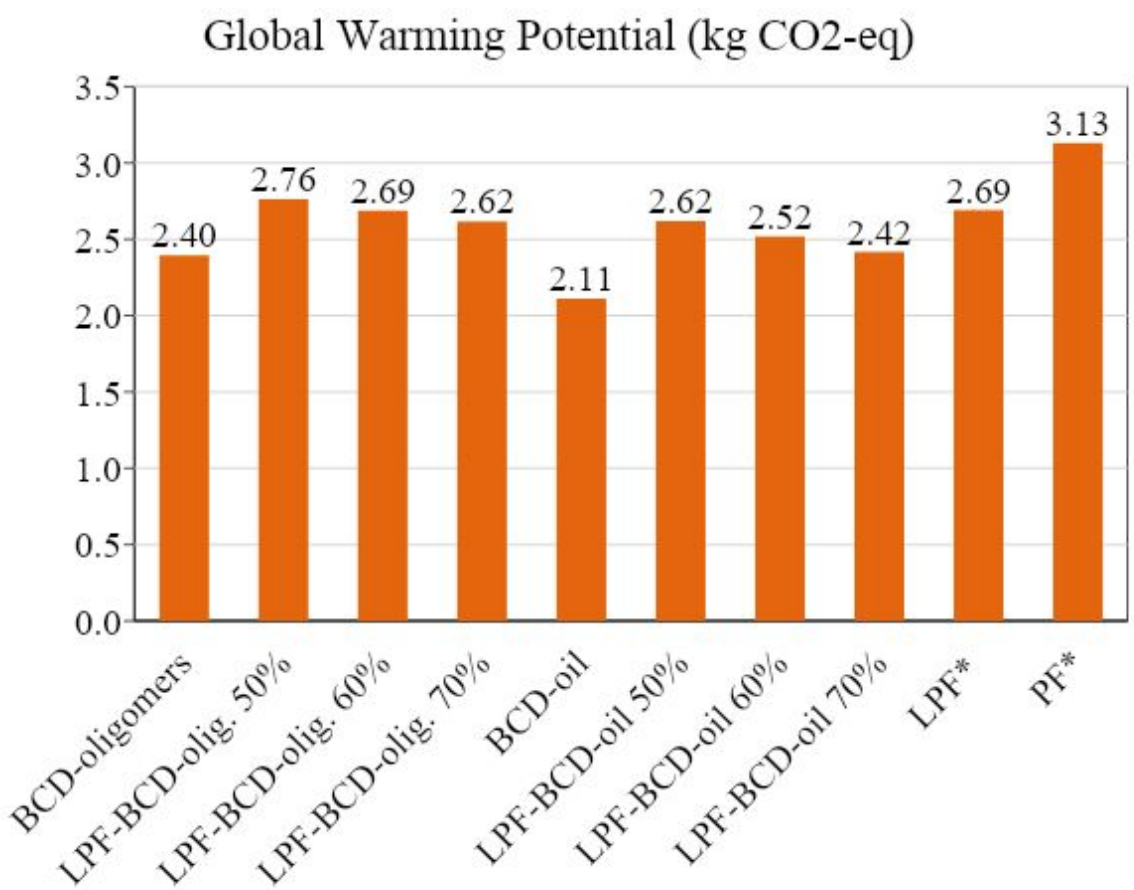
Cradle-to-Gate system boundary

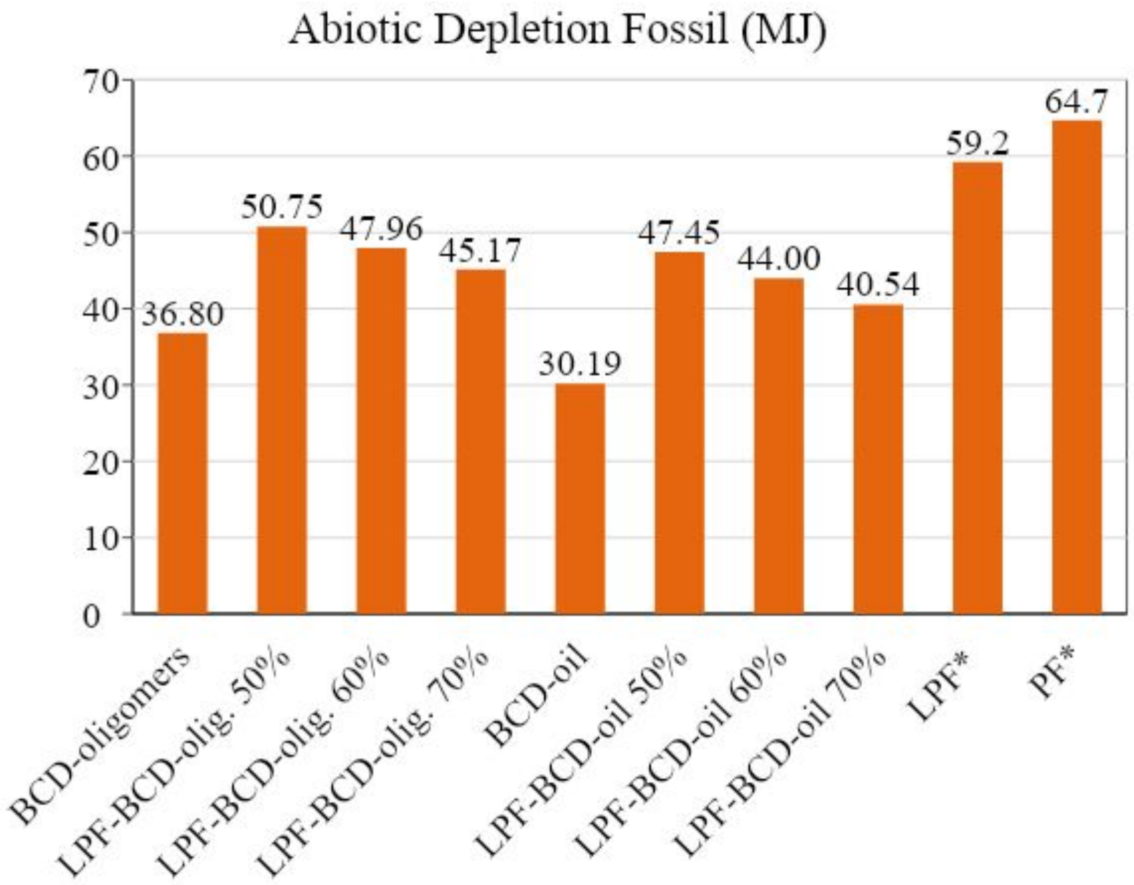


GaBi Software
CML 2001 Method

Indicator	Unit	Description
Global Warming Potential	kg $CO_{2\text{-eq}}$	Potential global warming due to emissions of greenhouse gases to air
Acidification	kg $SO_{2\text{-eq}}$	Potential acidification of soils and water due to the release of gases such as nitrogen oxides and sulphur oxides
Eutrophication	kg $PO_{4\text{-eq}}$	Indicator of the enrichment of the aquatic ecosystem with nutritional elements
Abiotic depletion	MJ	Indicator of the depletion of natural fossil fuel resources
Human toxicity	1,4-$DCB_{\text{-eq}}$	Impact on humans of toxic substances emitted to the environment

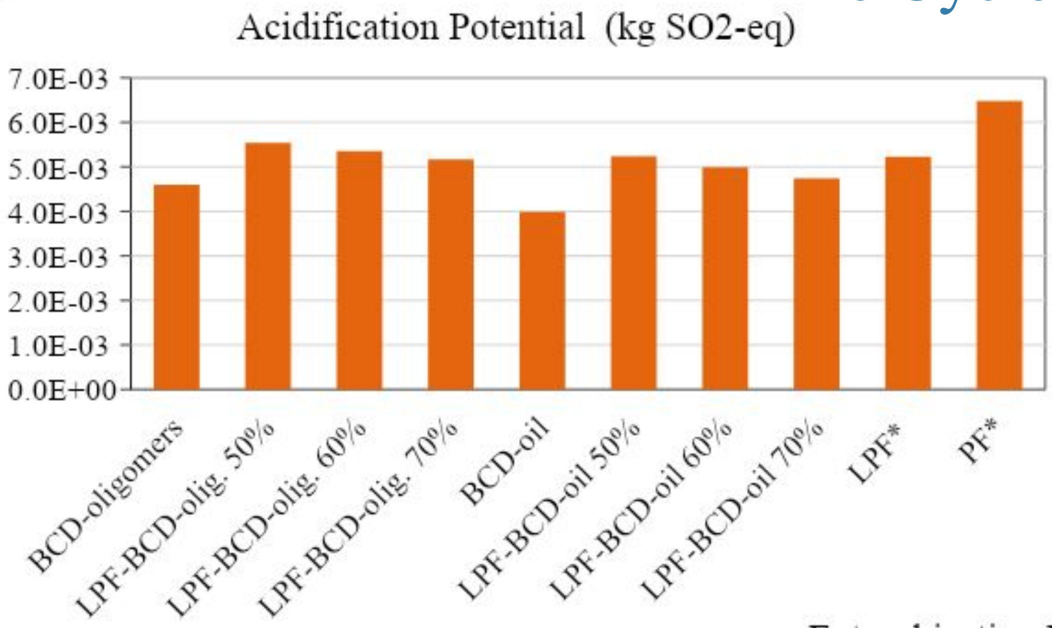
Life Cycle Assessment Results

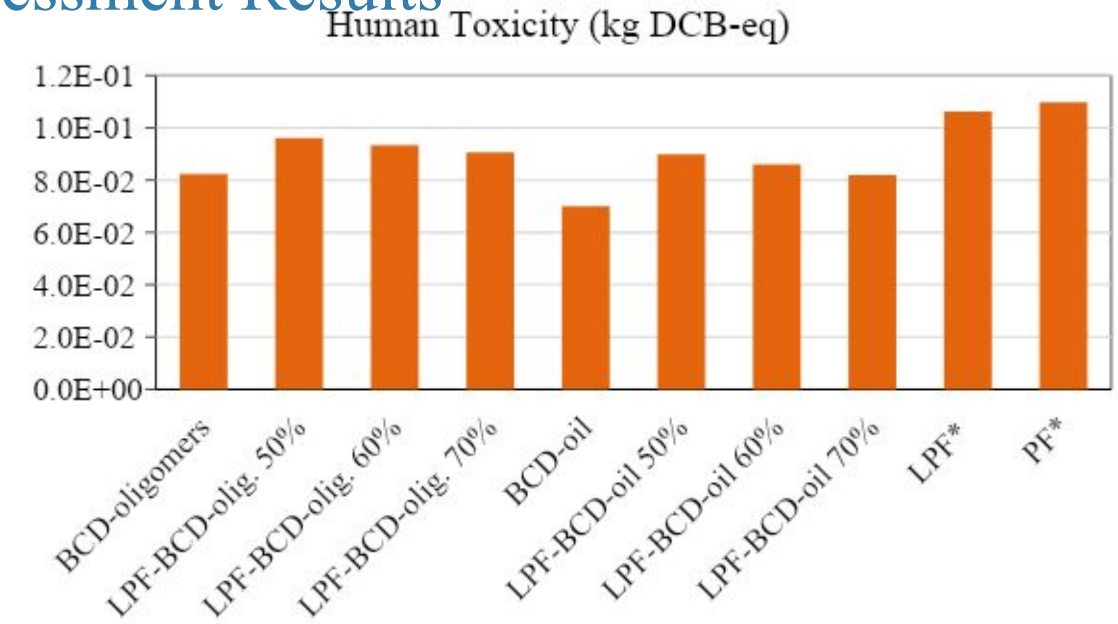


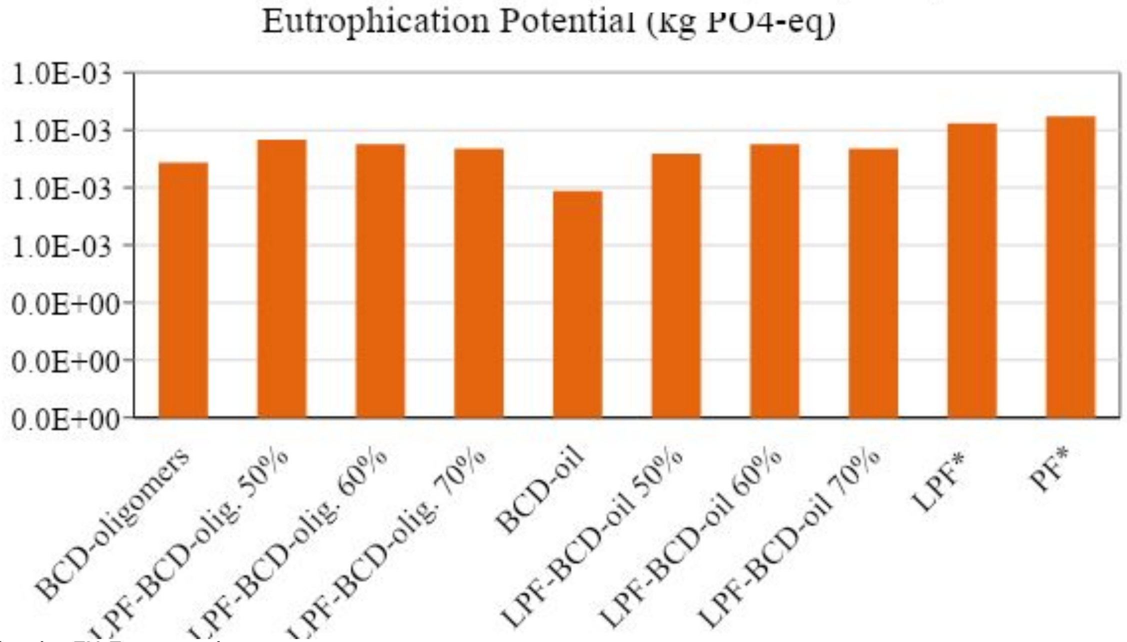


*Perederic et al.,2020. In Computer Aided Chemical Engineering (Vol. 48, pp. 607-612).

Life Cycle Assessment Results







Conclusions

- The economic performance of the process is strictly depended on the raw material (specially kraft lignin price)
- The process is profitable for the cases which the kraft lignin utilized in integrated facilities and at the cases were the BCD-oil, BCD-olig. selling prices are higher to $1.4/kg
- The environmental impact of the products (BCD-oil, BCD-olig.) is lower from the petroleum derived counter part products

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