

WEBINAR SERIES Sustainable Lignin Valorisation

Process design, techno-economic evaluation and environmental impact of
lignin conversion into value-added products

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Main research interests

- Biorefinery development using agri-industrial waste and by-product streams
- Separation of value-added co-products
- Bioprocess development using entirely renewable resources for the production of platform chemicals, biopolymers and microbial lipids
- Biorefinery and bioprocess design including techno-economic evaluation and life cycle assessment

Chem Soc Rev 2014, **43**, 2587-2627

REVIEW ARTICLE



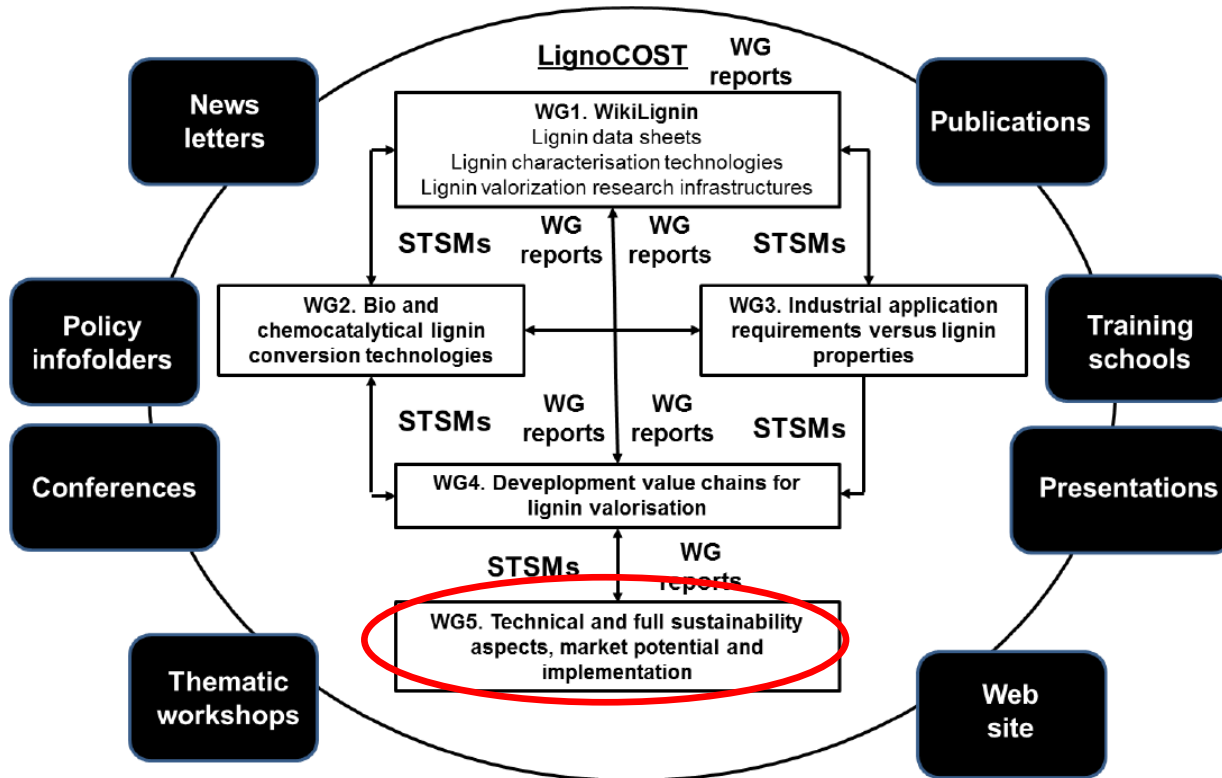
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Valorization of industrial waste and by-product streams via fermentation for the production of chemicals and biopolymers

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Objectives



- To support the most promising lignin valorization chains with multi-criteria evaluation of sustainability aspects with emphasis on process profitability to make maximal use of lignin’s market potential and support its market deployment.
- Identification of non-technical deployment barriers and of strategies to overcome them

Description of work

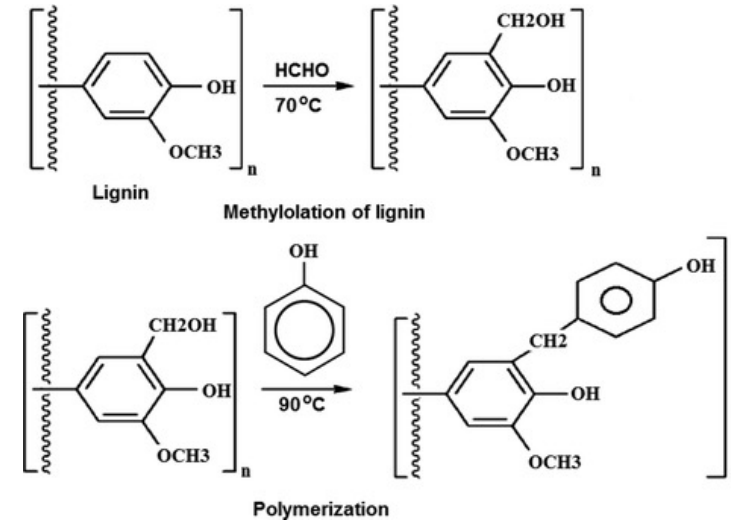
- **Techno-economic, environmental and social aspects** should be evaluated to justify the utilisation of renewable resources for the sustainable production of bio-based products under a the biorefinery development approach.
- The **estimation of sustainability indicators** (e.g. Minimum Selling Price, Net Present Value) will help convincing relevant stakeholders to focus on lignin valorization schemes.
- The **availability, cost and quality** characteristics of lignin provided by different sources should be considered. The potential development of **large-scale production** units, the evaluation of the time required to achieve **technological maturity, market stability and expansion** will be also considered.
- Assessment of **policy and legislation amendments** will facilitate industrial implementation of novel lignin valorization technologies.



Value chains under study

a) Production of Lignin-Phenol-Formaldehyde (LPF) resins

- Phenol-Formaldehyde resins represents about 1 million tons market on dry basis
- Lignin can substitute up to 50% of the expensive petroleum-derived phenol
- Emission reduction of the carcinogenic formaldehyde by using an already crosslinked resin component
- The LPF resin is synthesized through the methylation of lignin and the subsequent polymerization
- However, lignin needs to be **pretreated** to enhance its reactivity to an acceptable level

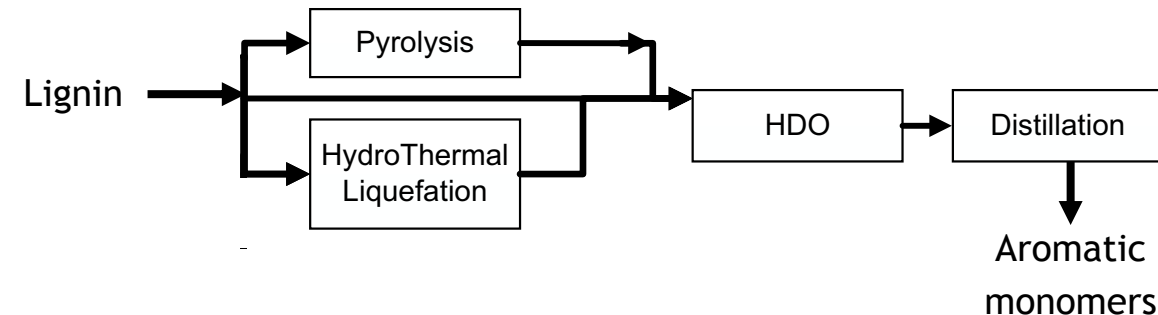


b) Production of aromatic monomers

Extraction of primarily phenolics of:

- Benzene
- Toluene
- Ethylbenzene
- Xylenes

BTEX compounds



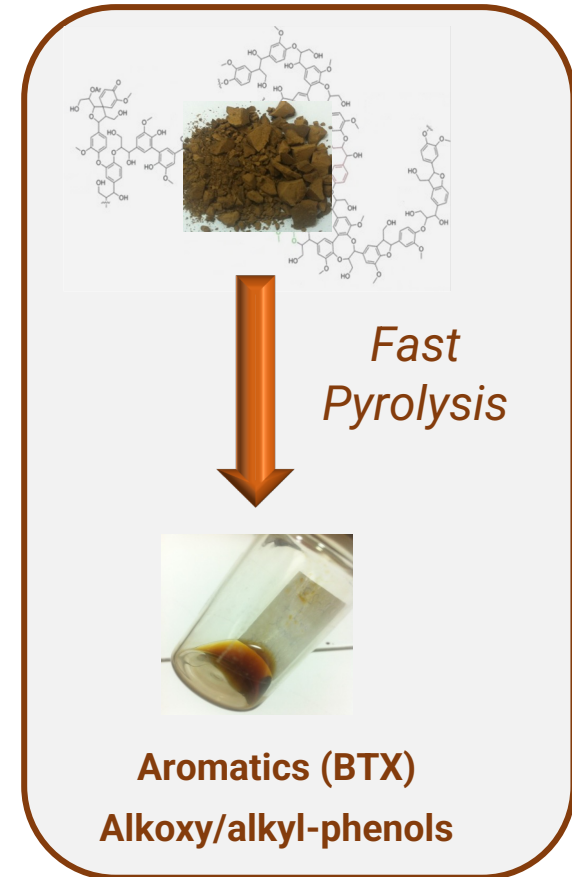
Techno-economic analysis and Life cycle assessment of Lignin (Catalytic) Fast Pyrolysis towards phenolics and aromatics (HVAC)

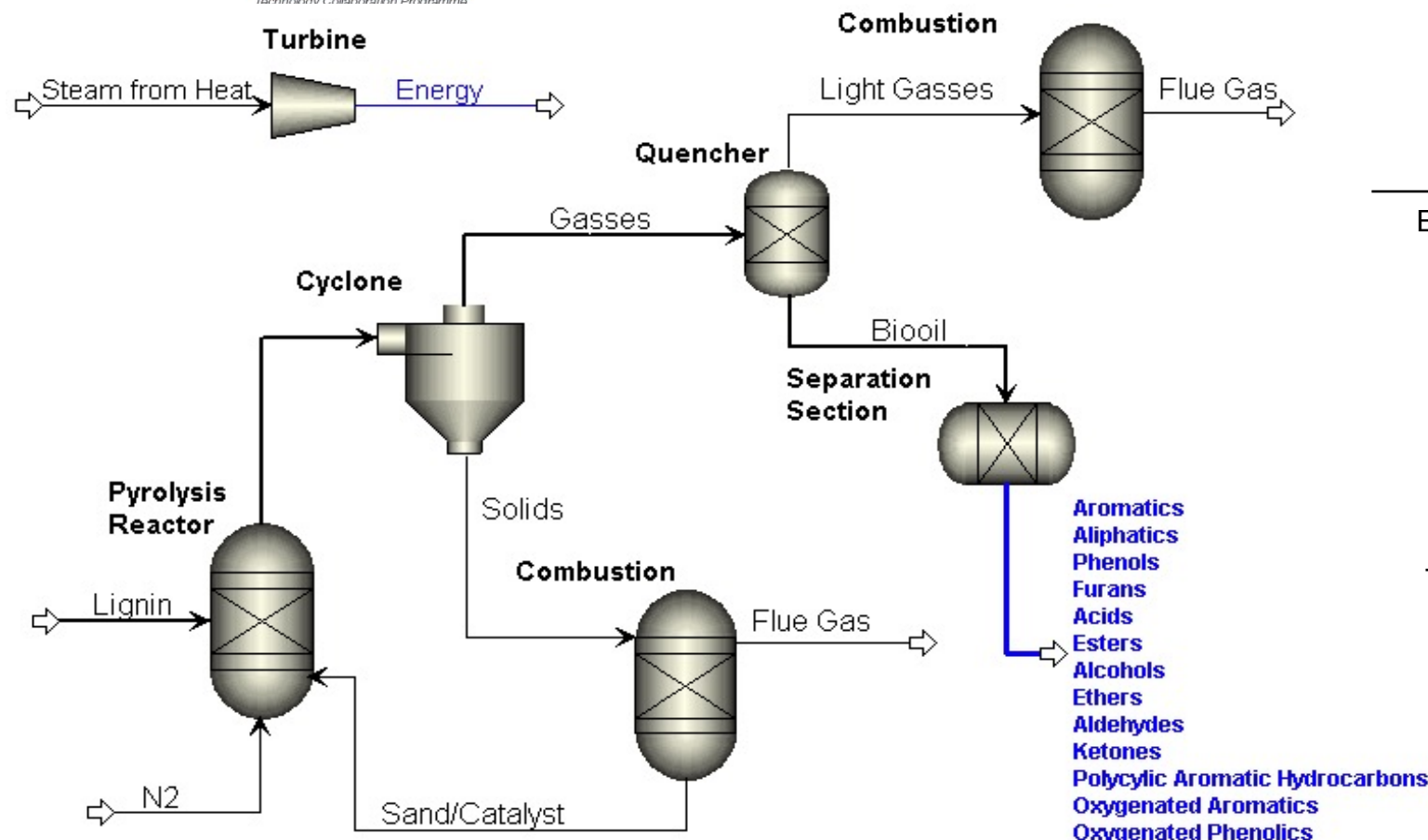
Eight (8) Scenarios investigated

Scenario	Lignin	Process type	Main Product
1	Kraft	Fast Pyrolysis, Thermal	Electric energy production
2	Kraft	Fast Pyrolysis, Catalytic	Electric energy production
3	Organosolv	Fast Pyrolysis, Thermal	Electric energy production
4	Organosolv	Fast Pyrolysis, Catalytic	Electric energy production
5	Kraft	Fast Pyrolysis, Thermal	HVACs (SMB)
6	Kraft	Fast Pyrolysis, Thermal	HVACs (Distillation)
7	Kraft	Fast Pyrolysis, Thermal	HVACs (Liquid-liquid extraction)
8	Kraft	Fast Pyrolysis, Catalytic	HVACs (SMB)

HVACs: High Value-Added Chemicals

SMB: Simulated moving bed chromatography





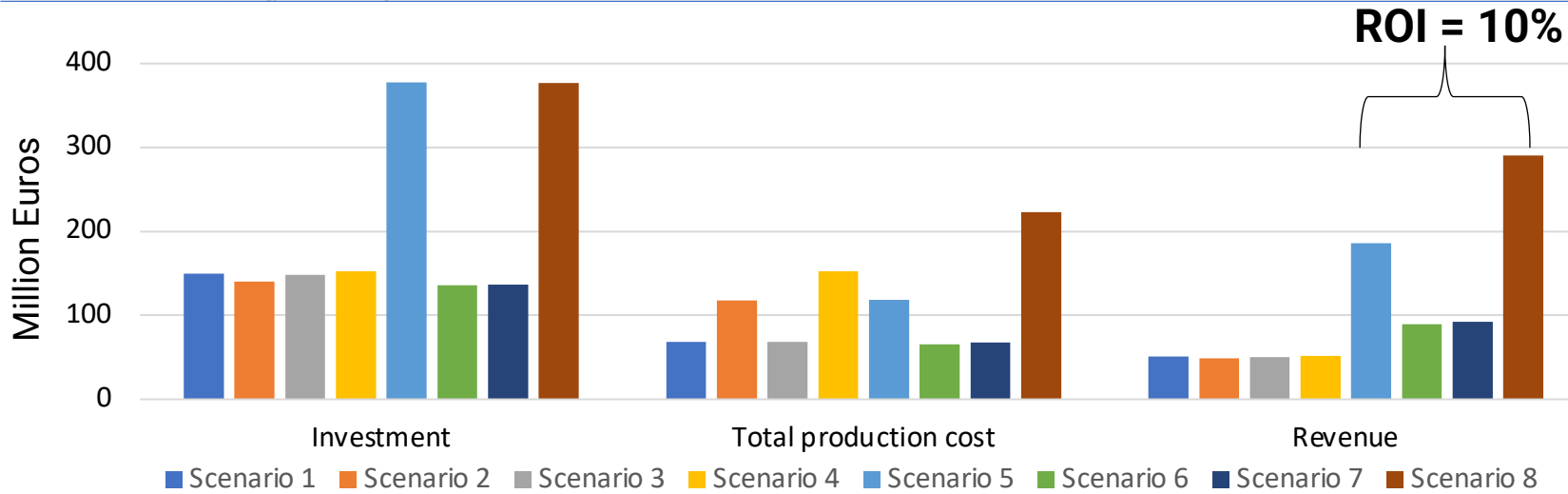
Simplified Process Flow

Products of scenarios 1-4

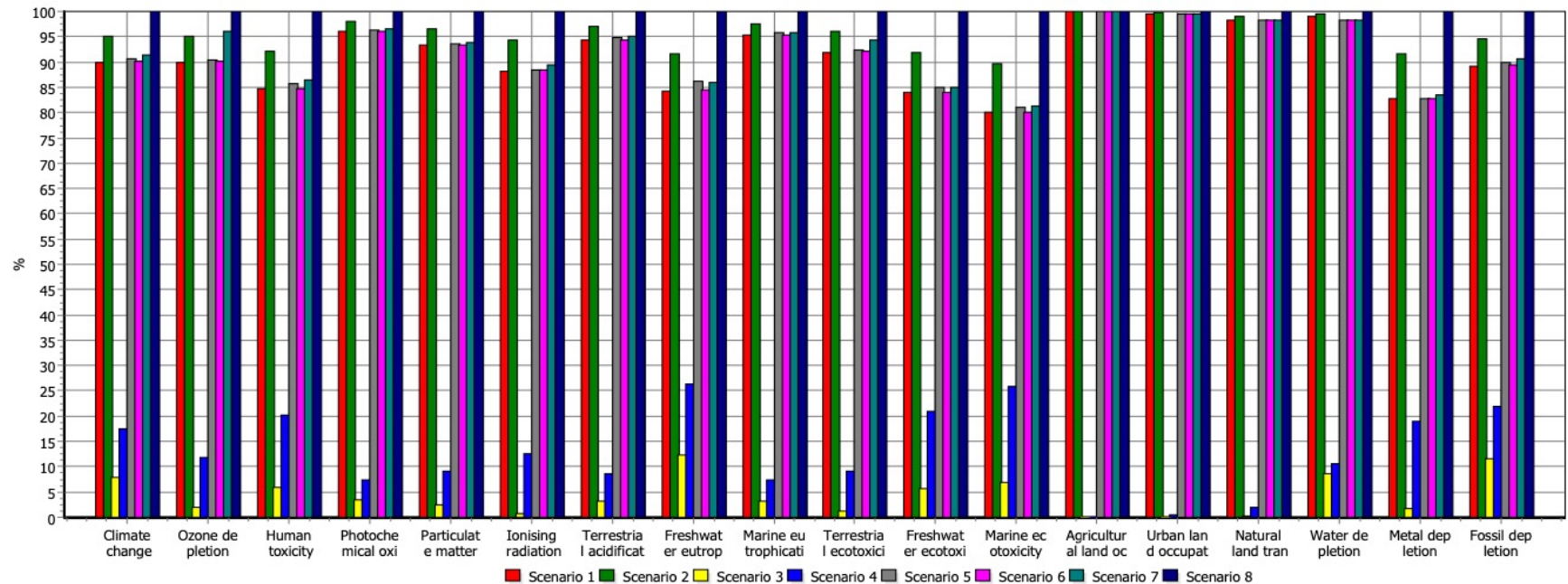
Products	1	2	3	4
Energy (kWh/h)	44946,57	43080,80	44488,69	46132,18
Ash (kg/h)	107,93	118,06	113,96	116,13
O ₂ (kg/h)	87,21	87,21	87,21	87,21

Products of scenarios 5-8

Products	5	6	7	8
Energy (kWh/h)	40382,0	40382,0	40689,1	40167,1
Ash (kg/h)	107,93	107,93	107,93	118,06
O ₂ (kg/h)	87,21	87,21	87,21	87,21
HVACs (kg/h)	632,90	592,90	642,11	342,49
NaCl (kg/h)	-	-	382,29	-



Representative
TEA and LCA results



Parameters comparison and effects on TEA

FEEDSTOCK

Kraft Lignin: It is not a “waste” – it has a certain production cost by treating black liquor
Organosolv Lignin: Slightly more expensive than kraft when both are purchased (as pyrolysis feedstock)

PROCESS

Thermal Pyrolysis: Slightly Cheaper – Better environmental performance
Catalytic Pyrolysis: Higher production Cost – Higher Value products

SEPARATION

Chromatography: Distinct HVACs – High income potential - High investment cost
Distillation: Low investment cost – Low production cost - Bio-oil fractions
Liquid-liquid extraction: Low investment cost – Bio-oil fractions

Investment Potential– High profitability ratios
Need for pilot testing
Investment cost depends greatly on products separation

Research on bio-oil separation technology

Needed Future Work:

Market needs

Techno-economic analysis and life cycle assessment of kraft lignin fast (catalytic) pyrolysis for the production of high value-added chemicals (HVACs)

Conclusions and prospects

- **Lignin Fast Pyrolysis towards HVACs** (phenolics) shows high potential as a large-scale industrial process
- The **use of catalyst** for bio-oil upgrading towards BTX aromatics and alkyl-phenols has **higher investment and production costs but offers substantially higher revenues**
- Column chromatography (SMB) is the only separation method in an up-scaled process able to produce **distinct high purity compounds** whereas distillation and liquid-liquid extraction can only separate **bio-oil fractions with specific compounds**
- Additional **environmental impact** of catalyst use is not significant and in between the error margin

Techno-economic evaluation of the process for valorising kraft lignin into three monomeric products: vanillin, vanillic acid and acetovanillone

- Process design, simulation and economics, including a process for kraft lignin conversion to aromatic chemicals.
- Process integration with existing pulp mills.
- Providing know-how and data input for further study of the superstructure optimization of the lignin-to-vanillin route.



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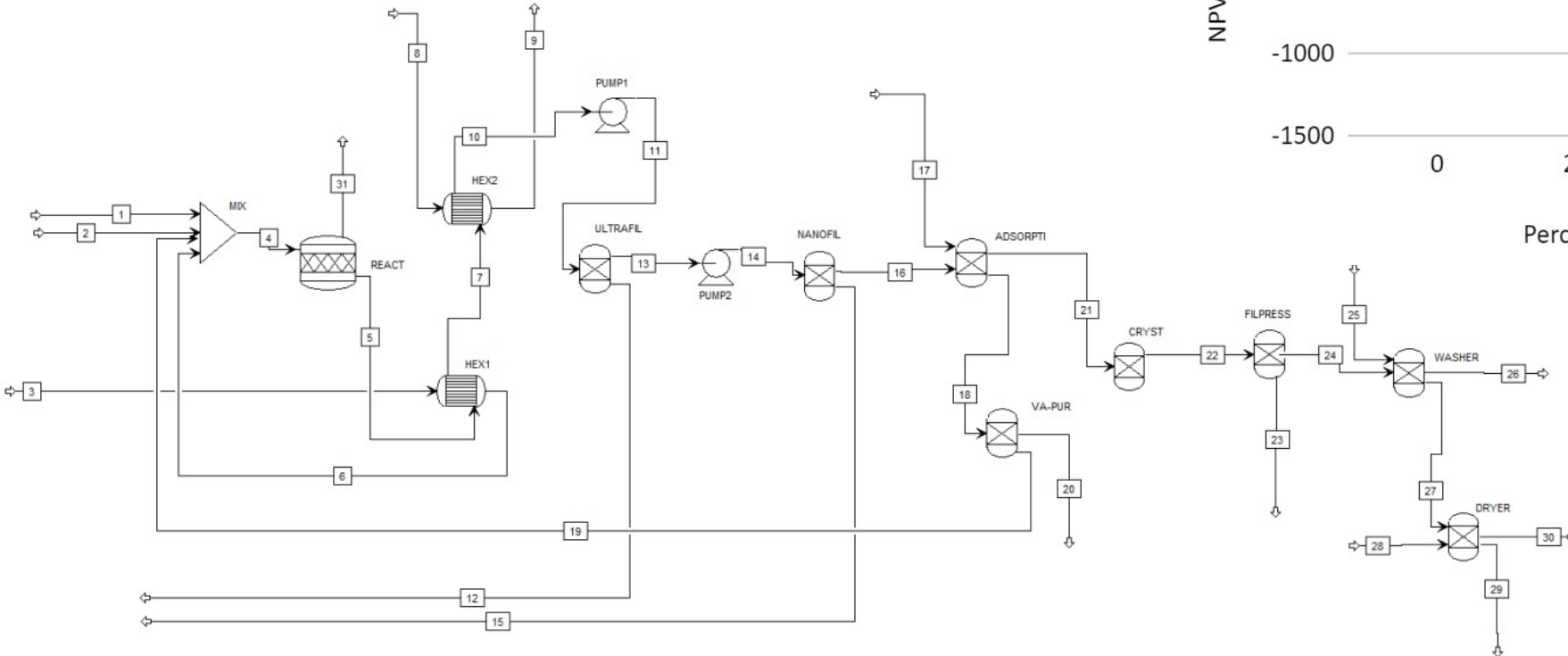
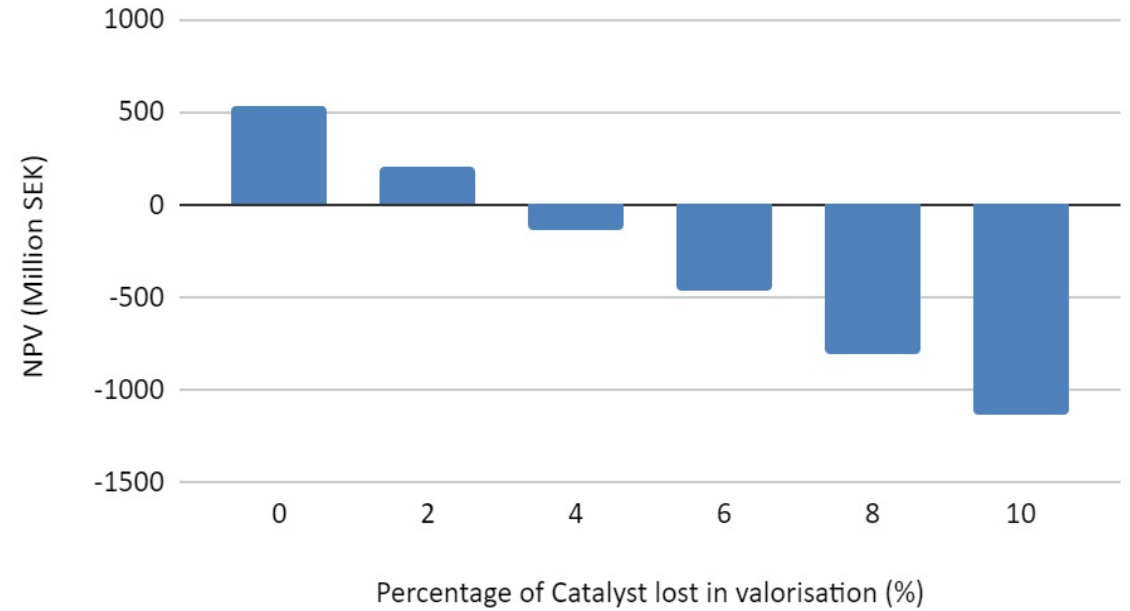
ΓΕΩΠΟΝΙΚΟ ΠΑΝΕΠΙΣΤΗΜΙΟ ΑΘΗΝΩΝ
AGRICULTURAL UNIVERSITY OF ATHENS

An International Collaboration
in Bioenergy

Preliminary results by Lund University

Catalyst Loss Rates vs NPV

Walch et al., 2021. *Catal. Sci. Technol.* 11, 1843–1853

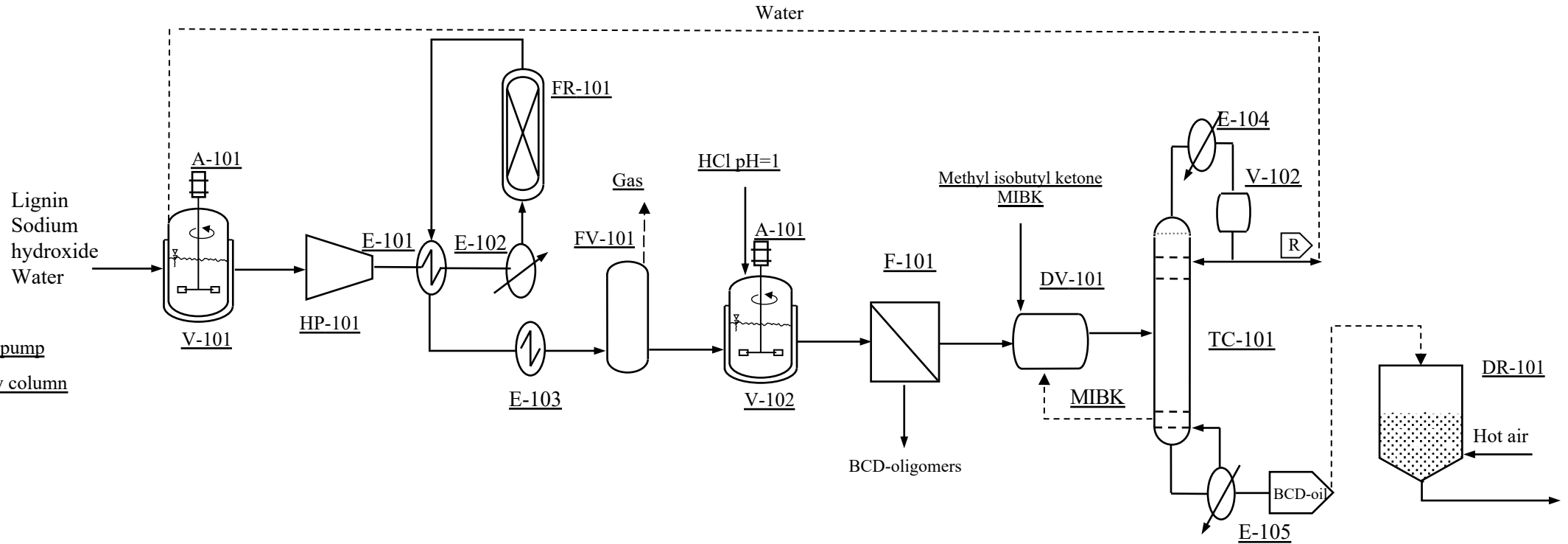


Techno-economic analysis and life cycle assessment for the production of monomeric-rich(BCD-oil) and oligomeric (BCD-oligomers) bio-based phenolic compounds from softwood kraft lignin via base-catalysed depolymerization.

- Process design and simulation of the process for bio-based phenolic compounds based on the experimental results from literature [Solt et al.,2018. Polymers, 10(10), 1162.(pilot plant results)]
- Techno-economic analysis and life cycle assessment.
- Design parameters:
 - Continuous process
 - Conversion yields of lignin to products 55% (BCD-oligomers 40%, BCD-oil 15%)
 - Total Capacities 10, 20, 30,100 Kt



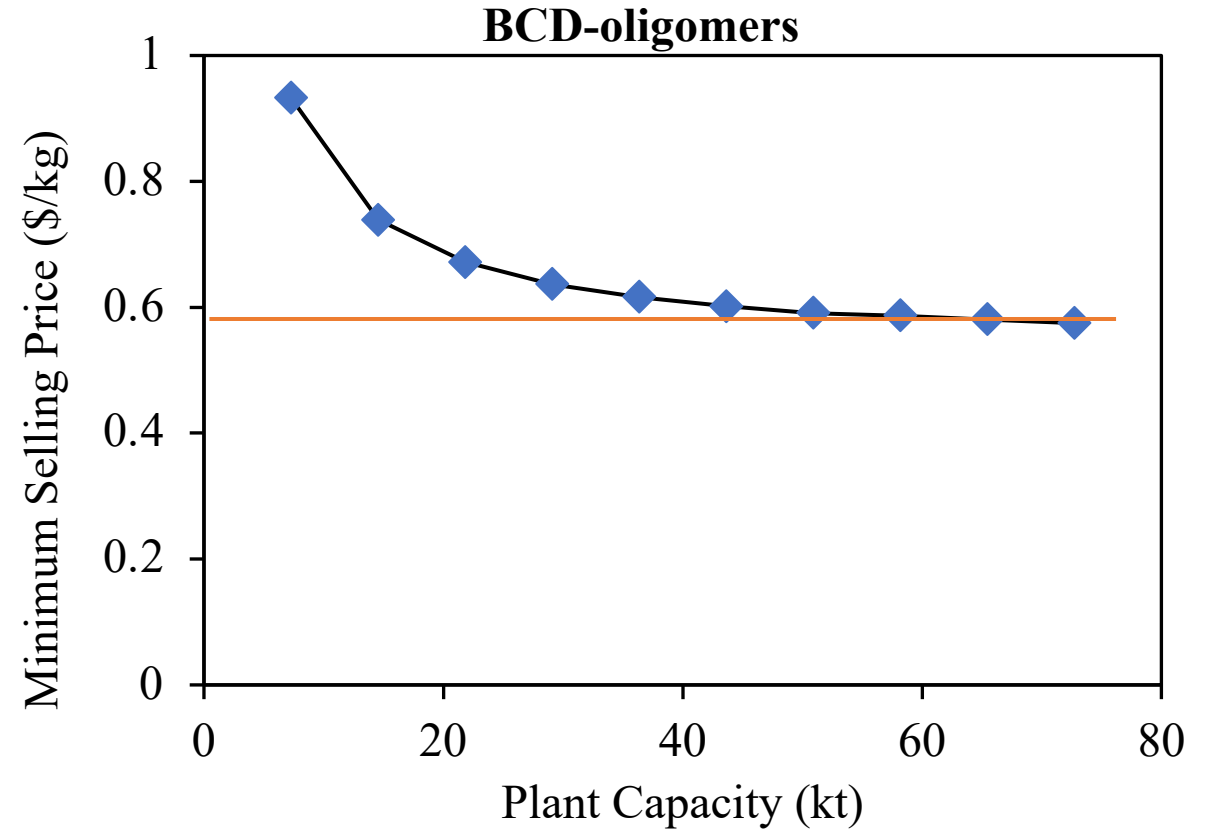
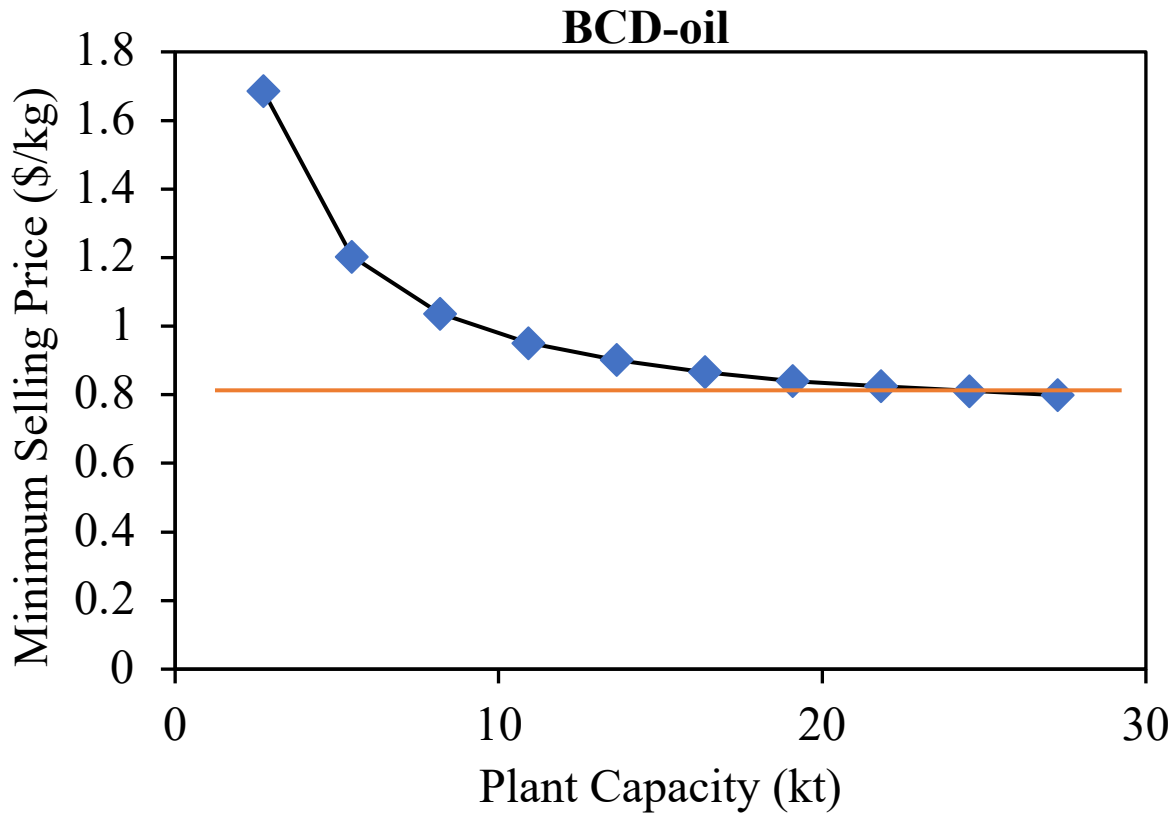
Process description



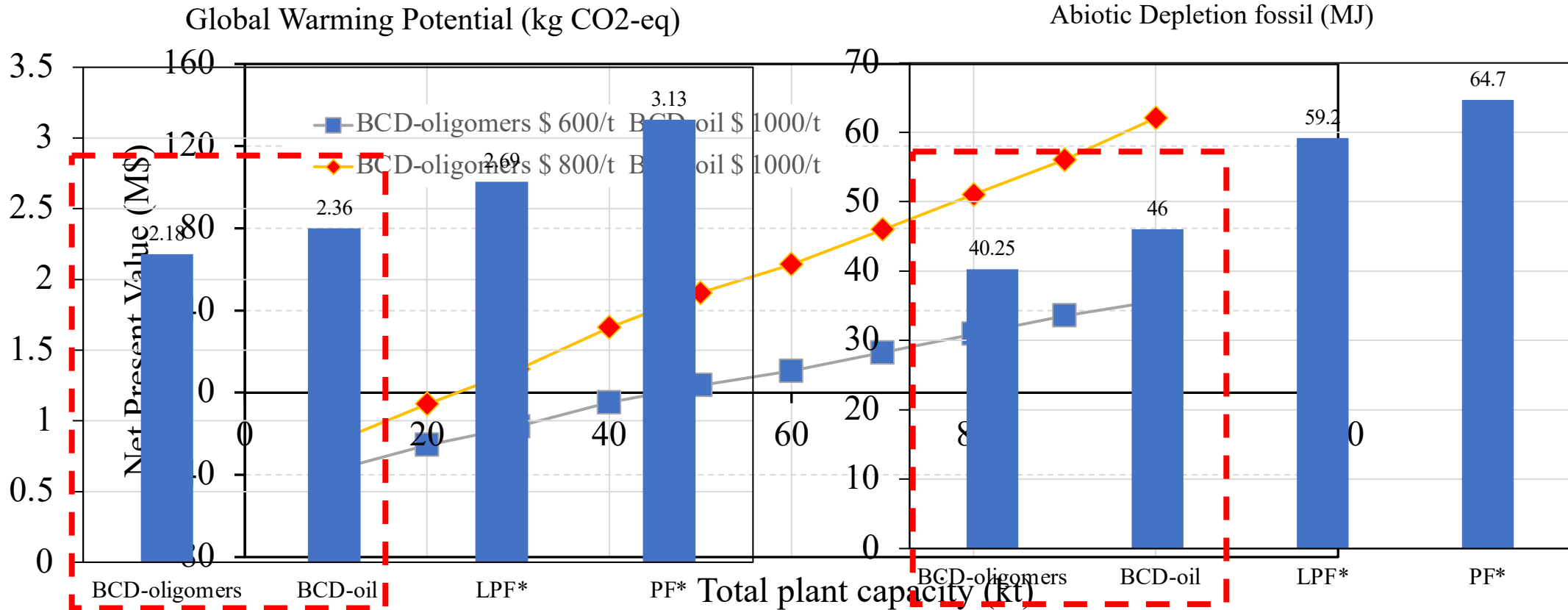
- HP=high pressure pump
- TC=distillation tray column
- E=heat exchangers
- FR=flow reactor
- DV=decanter
- F=filter
- DR=dryer
- V=vessel
- A=agitator
- FV=flash vessel

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

Minimum selling price



Economic and Environmental performance



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

Conclusions

- The production of monomeric-rich (BCD-oil) and oligomeric (BCD-oligomers) bio-based phenolic compounds from softwood kraft lignin via base-catalysed depolymerization process shows high potential as a large-scale industrial process
- The MSP of BCD-oil and BCD-oligomers estimated lower than the petroleum derived counterparts - high opportunity for substitution up to 50% of the expensive petroleum-derived phenol
- The environmental impact of BCD-oil and BCD-oligomers estimated lower than the petroleum derived counterparts

Thank you for your attention