



Lignin: From Structural Complexity to Versatile Applications

Lignin: From Structural Complexity to Versatile Applications

BIOMASS

DELIGNIFICATION PROCESS

LIGNIN

- LIGNIN ISOLATION
- LIGNIN STRUCTURE
- LIGNIN APPLICATIONS
- LIGNIN CHARACTERISATION

LIGNIN MODIFICATIONS

- CHEMICAL MODIFICATIONS
- MORPHOLOGICAL MODIFICATIONS

LIGNIN DEPOLYMERIZATION

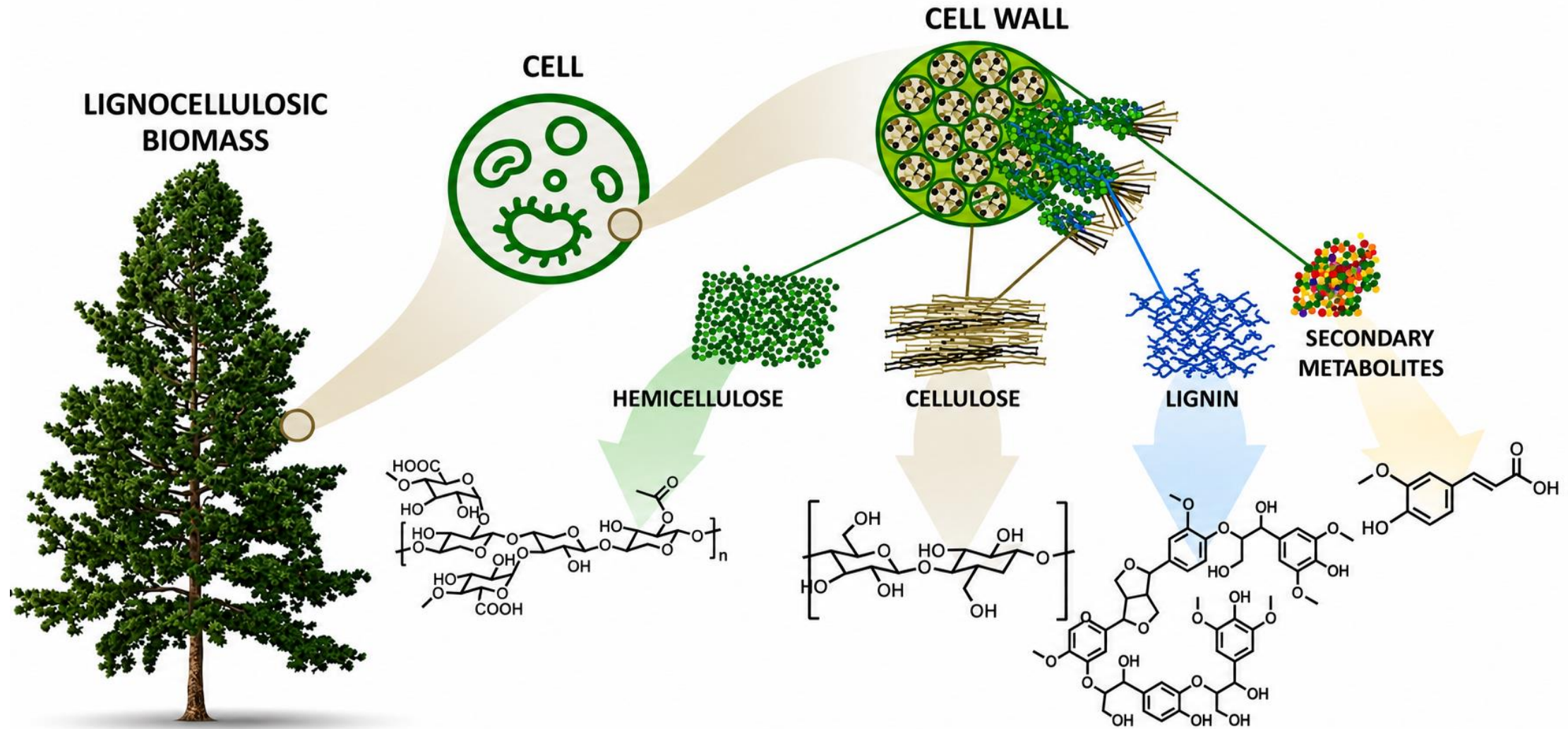
CONCLUSION



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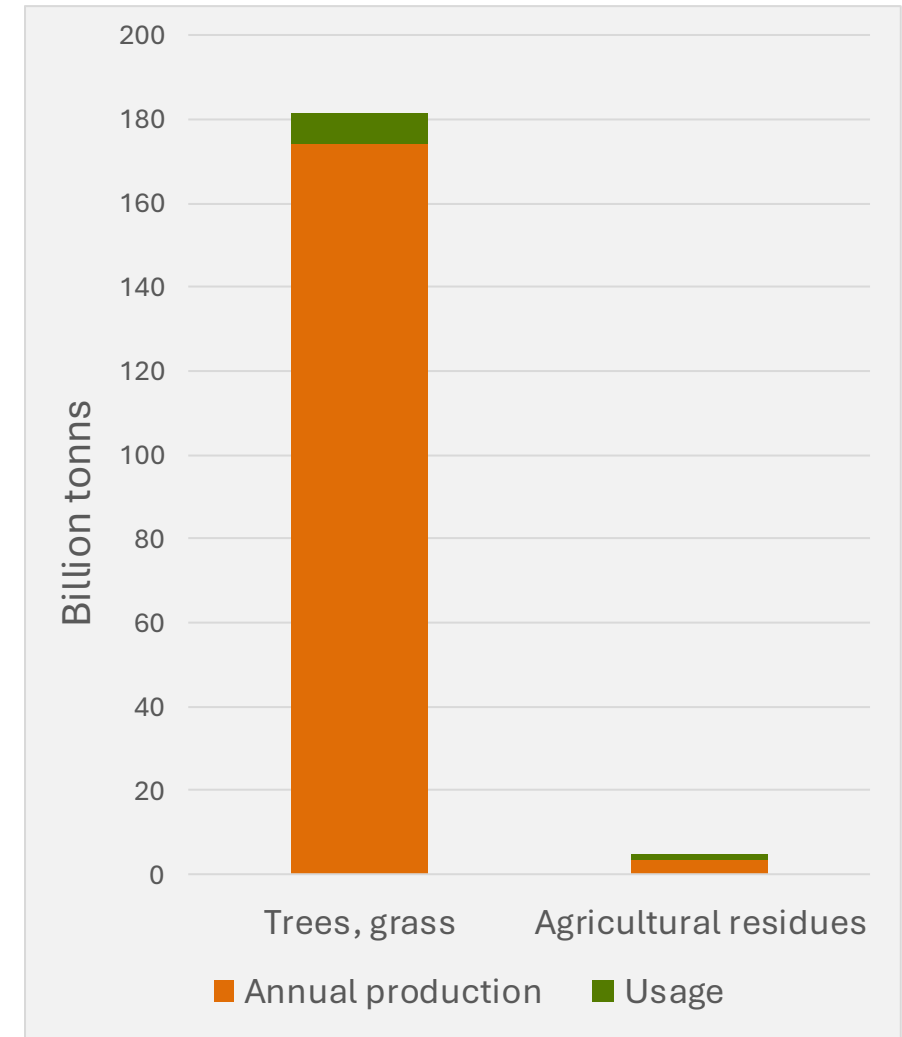
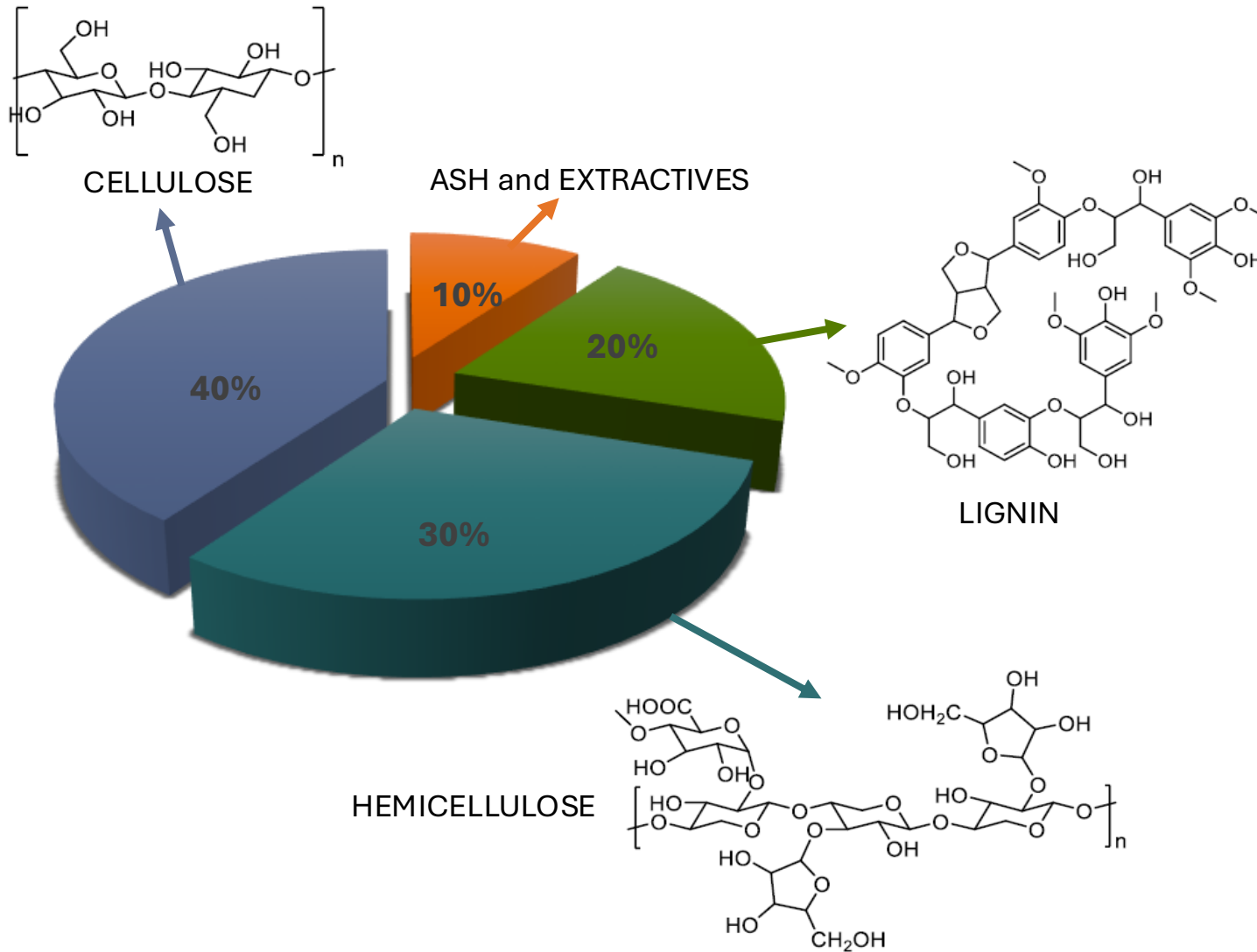
From Biomass to Molecular Building Blocks



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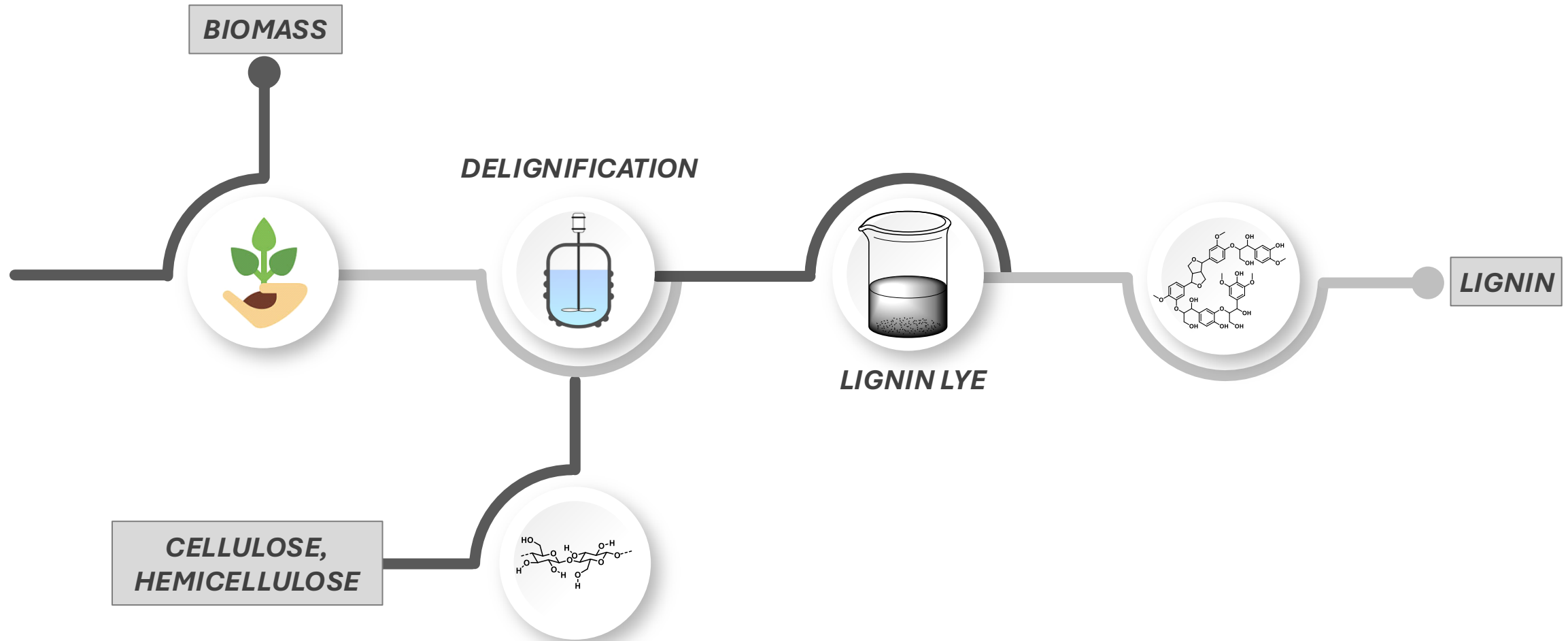


Biomass composition and its potentials



Jan Hočevár: Carbocationic polymerization of cellulose obtained from agricultural residues (bachelor thesis).
 N. Dahmen, et al.: Integrated lignocellulosic value chains in a growing bioeconomy: Status quo and perspectives.

Delignification Process



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Delignification Process



PHYSICAL / MECHANICAL

- Milling
- Steam explosion
- Liquid hot water (LHW)
- Irradiation



CHEMICAL

- Alkaline
- Acid
- Oxidative
- Organosolv



PHYSICOCHEMICAL

- AFEX
- Ionic liquids
- Deep eutectic solvents (DES)
- CO₂-based processes



BIOLOGICAL

- Fungal
- Enzymatic
- Bacterial



ELECTROCHEMICAL

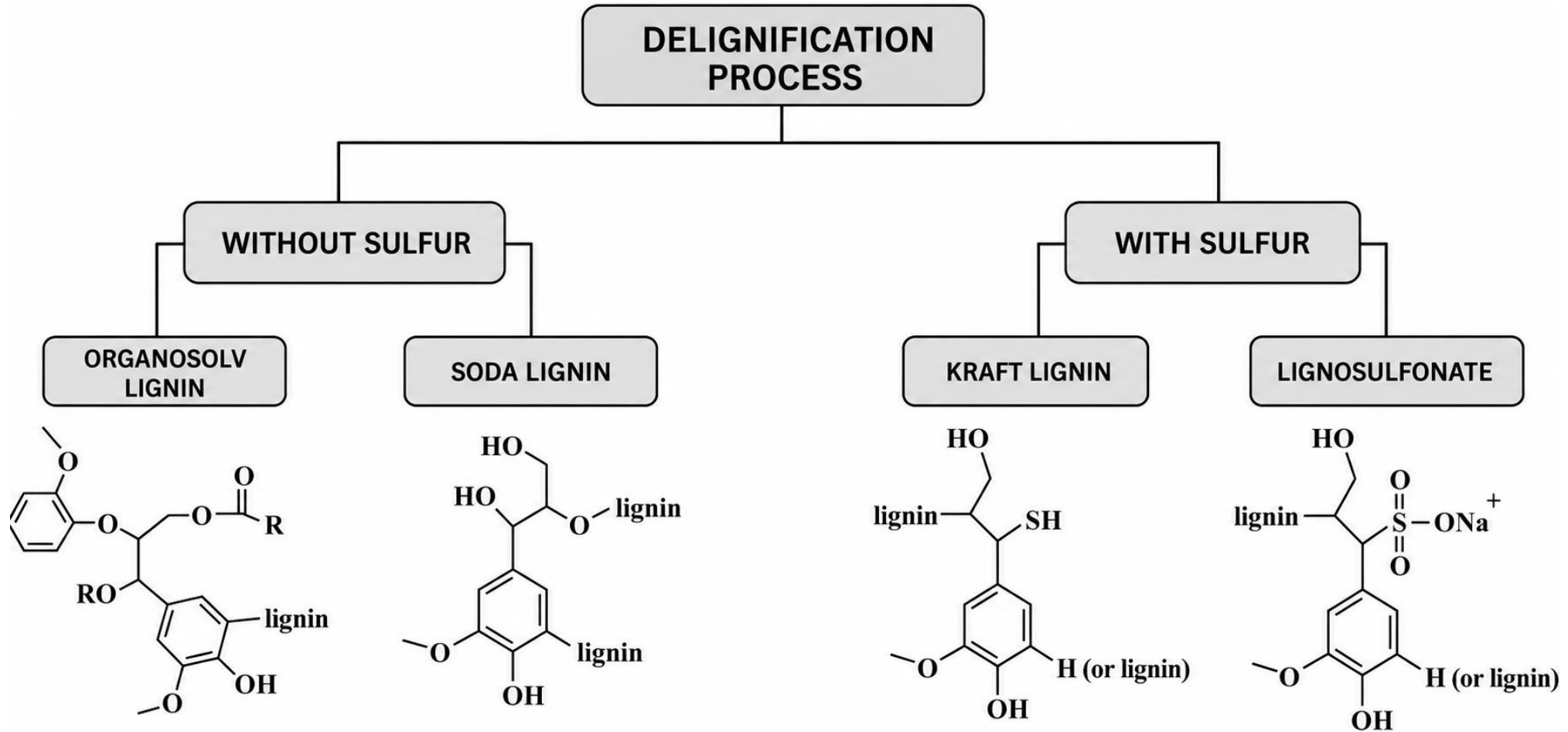
- Electro-oxidation
- Electro-Fenton



HYBRID (COMBINED)

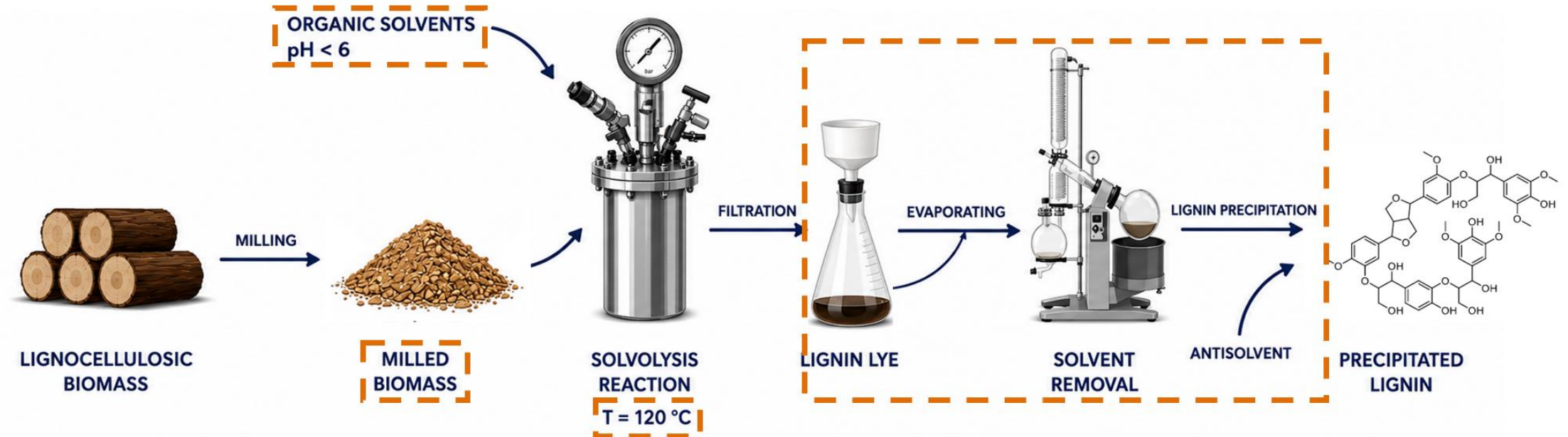
- Physical + chemical
- Biological + chemical
- Multi-stage processes

Lignin Isolation Processes (Chemical)



Lignin Isolation Processes

ORGANOSOLV LIGNIN



Raw lignocellulosic biomass is used as the starting material.

Size reduction of the biomass to increase surface area and improve solvent accessibility.

Solvolytic reaction of biomass in organic solvents under acidic conditions ($\text{pH} < 6$) at $120\text{ }^{\circ}\text{C}$.

Solid residues are separated by filtration to obtain lignin lye.

The lignin lye is concentrated by evaporation.

Addition of an antisolvent induces lignin precipitation to obtain lignin as a solid product.

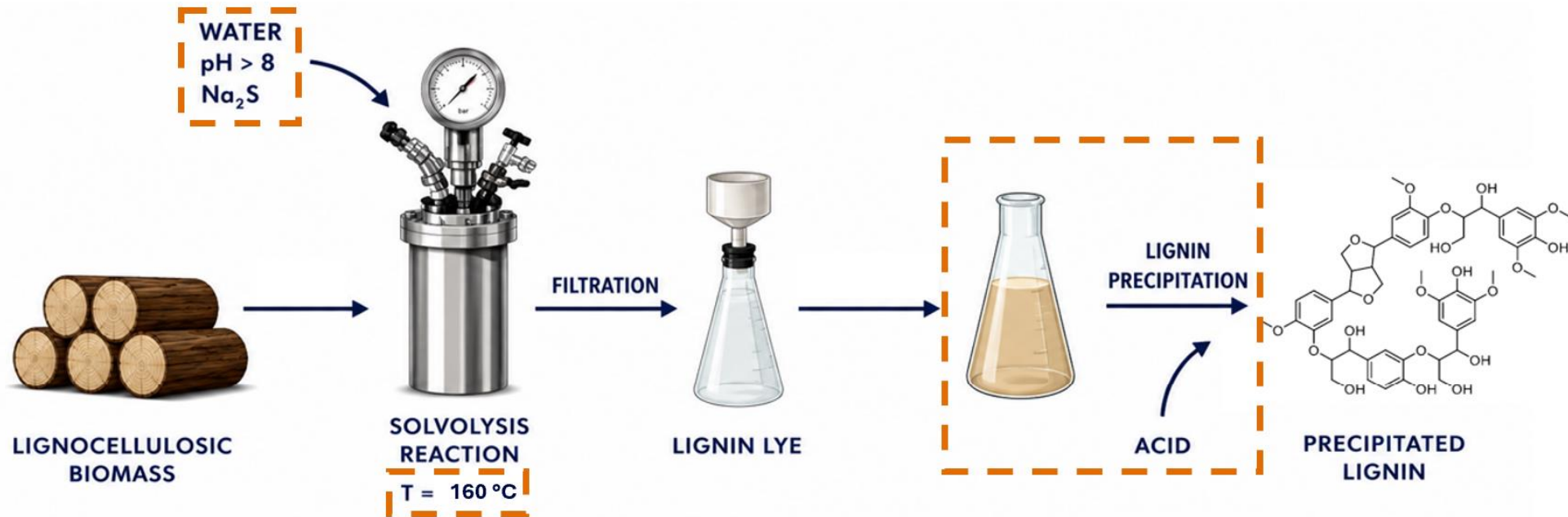


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Lignin Isolation Processes

KRAFT LIGNIN



Raw lignocellulosic biomass is used as the starting material.

Alkaline extraction with sodium sulfide (Na₂S) in water (pH > 8) in a pressurized reactor at 160 °C.

Solid residues are separated by filtration to obtain lignin lye.

The lignin lye is concentrated by evaporation.

Addition of acid induces lignin precipitation.

Lignin is obtained as a solid product after precipitation.



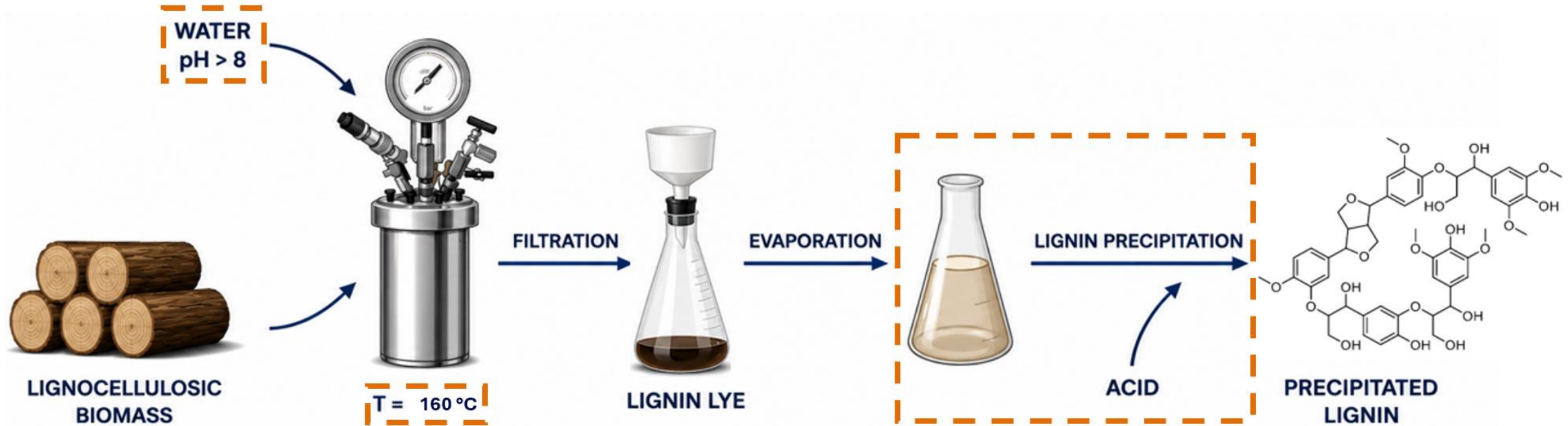
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Lignin Isolation Processes

SODA LIGNIN



Raw lignocellulosic biomass is used as the starting material.

Extraction with alkaline water (pH > 8) in a pressurized reactor at 160 °C.

Solid residues are separated by filtration to obtain lignin lye.

The lignin lye is concentrated by evaporation.

Addition of acid induces lignin precipitation to obtain lignin as a solid product.

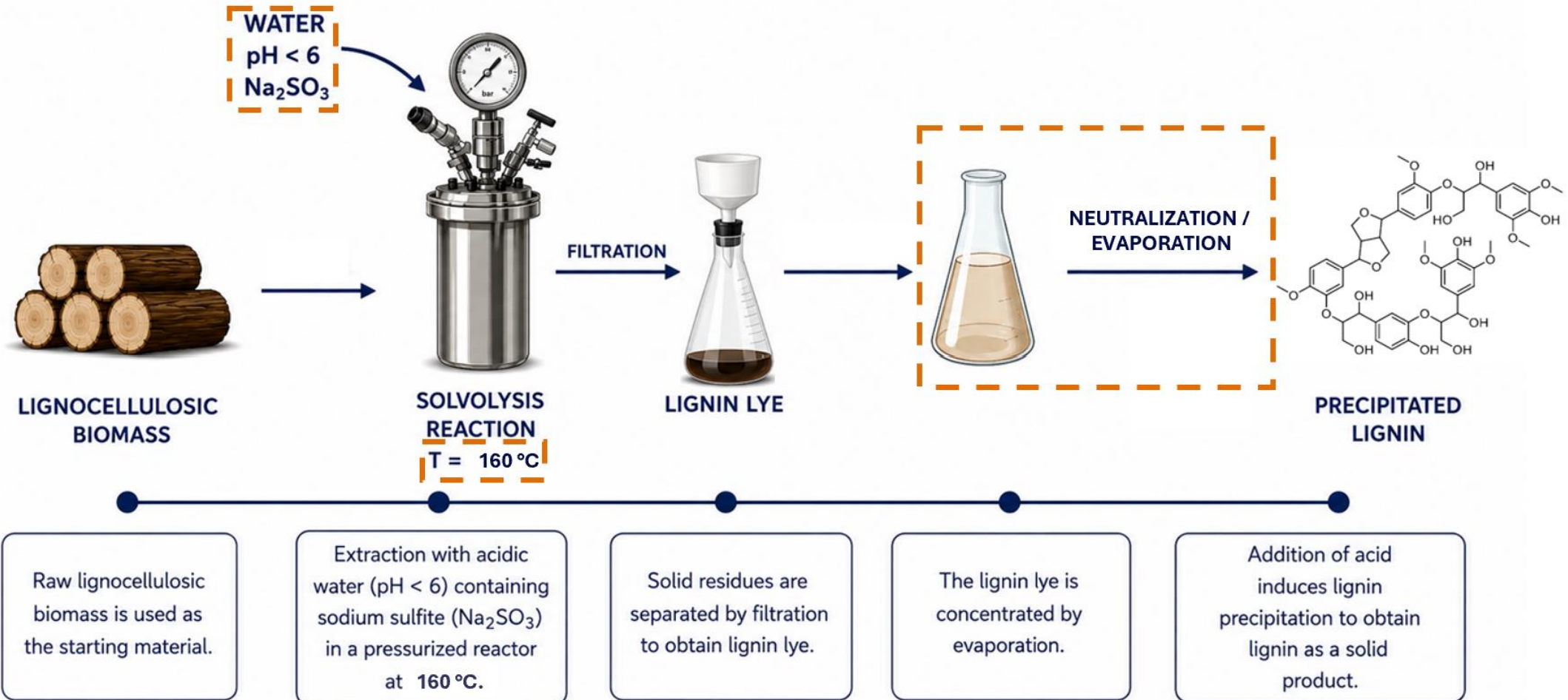


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Lignin Isolation Processes

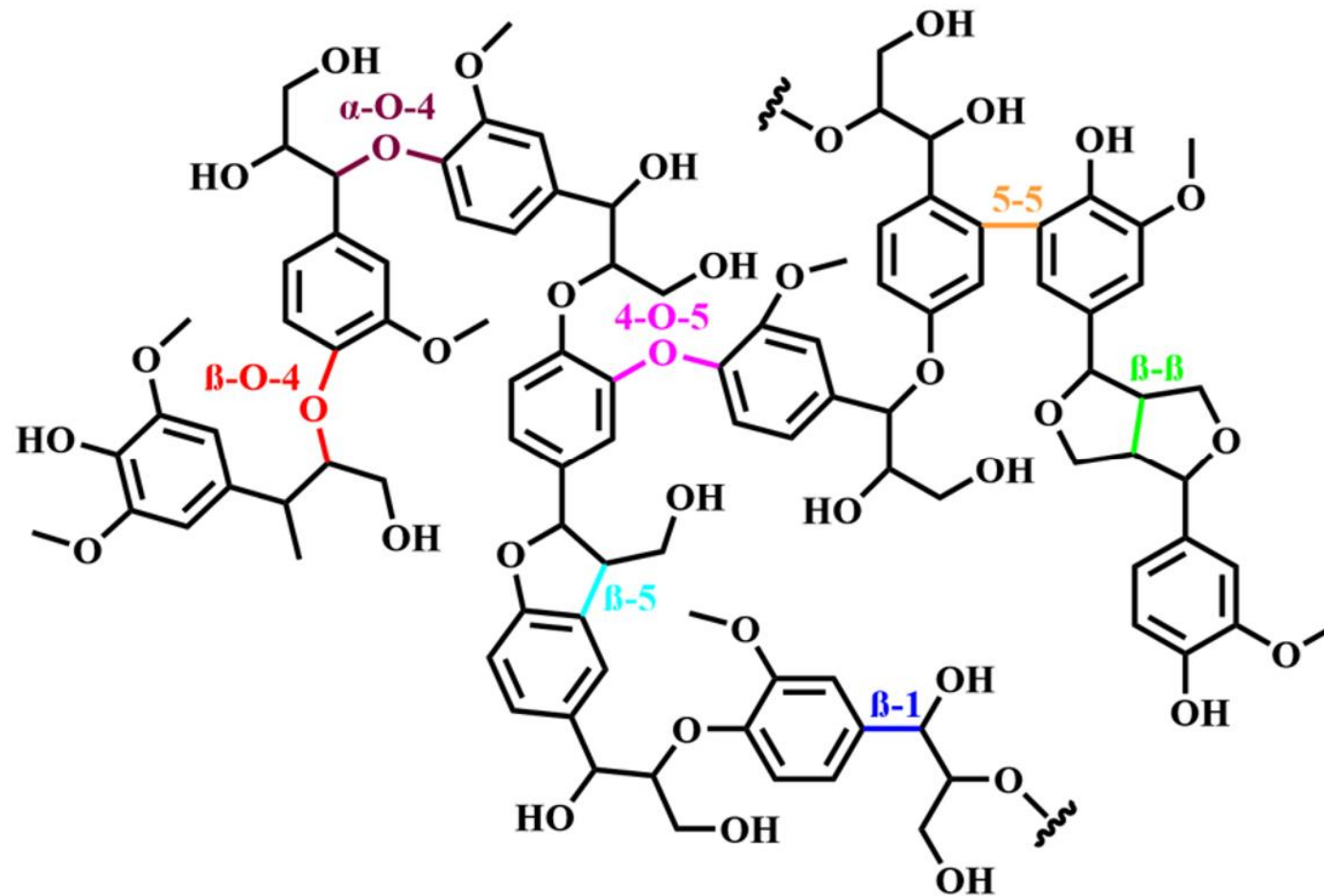
LIGNOSULFONATE



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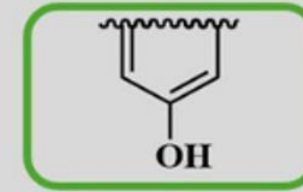


Lignin structure



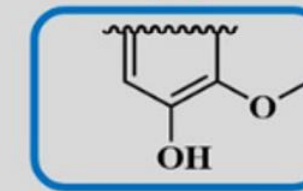
p-hydroxyphenyl

(H)



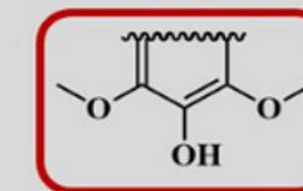
guaiacyl

(G)



syringyl

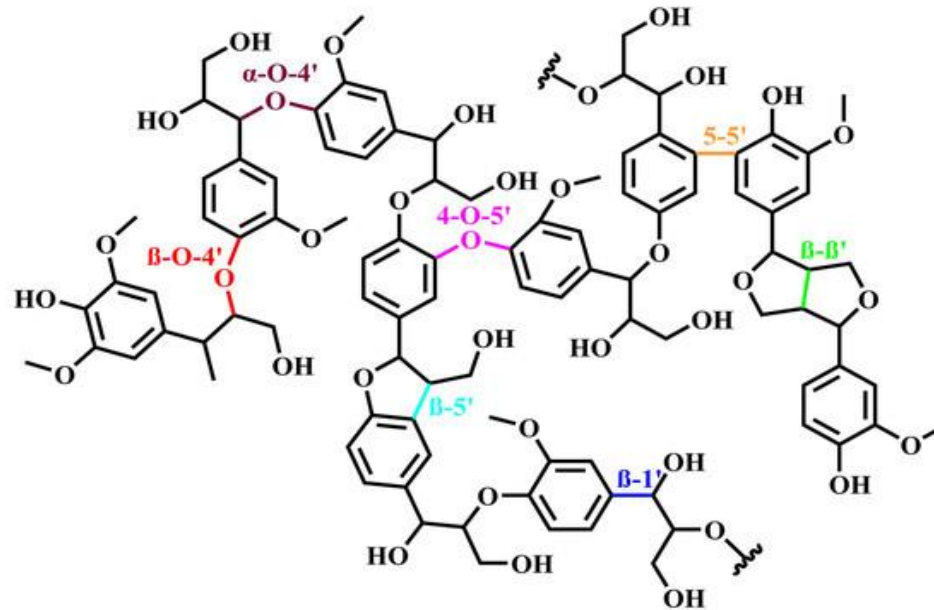
(S)



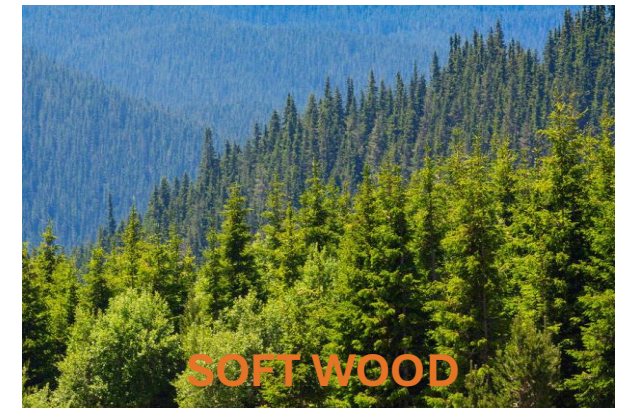
Lignin structure

Aromatic subunit	Softwood	Hardwood	Grasses
Syringyl (S)	0–1%	50–75%	25–50%
Guaiacyl (G)	90–95%	25–50%	25–50%
<i>p</i> -Hydroxyphenyl (H)	0.5–3.4%	In traces	10–25%

Bonds	Soft wood	Hard wood
β -O-4	49-51%	65%
α -O-4	6-8%	-
4-O-5	3.5%	1.5%
β -5	9-15%	6%
β -1	2%	15%
5-5	9.5%	2.3%
β - β	2%	5.5%



GRASSES



SOFT WOOD



HARD WOOD

J. P. Djaniš, et al.: Breaking Down Lignin: A Macromolecule's Path to the Nanoscale.

<https://www.energyfarmers.com.au/wheat-straw-for-bioenergy/>.

<https://agrobiznis.finance.si/gozdarstvo-kako-smo-porabili-sredstva-evropskega-kmetijskega-skлада-za-razvoj-pod-ezeja/a/8979788>.

<https://galerija.foto-narava.com/displayimage.php?pos=-97779>.



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Applications of Lignin



<https://www.bioplasticmagazine.com/en/news/meldungen/201903-26Lignin-based-carbon-fibres-are-cost-effective-and-made-from-plants.php>.

<https://www.dbsa.org/article/how-road-infrastructure-improvement-can-benefit-south-africas-healthcare>.

Bierach, C., et al.: Wood-based 3D printing: potential and limitation to 3D print building elements with cellulose & lignin.

<https://www.lignin.se/news/2024/08/19/lignin-industries-featured-in-packaging-europe>.

<https://carboncredits.com/batteries-from-wood-renewable-energy-storage-solution/>.

https://startupcity.hamburg/startups-ecosystem/lignopure_de.

<https://gbc-slovenia.si/dobro-je-vedeti/ursa-lignin-izolacija-za-boljsi-jutri>.

<https://www.indiamart.com/proddetail/gray-self-compacting-ready-mix-concrete-2853530927288.html>.

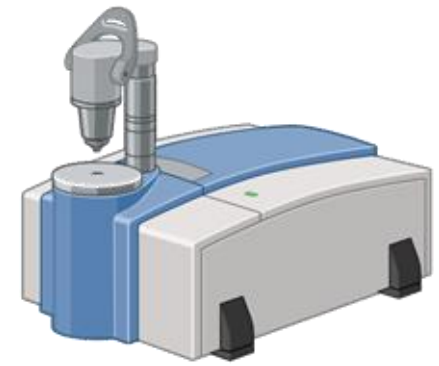
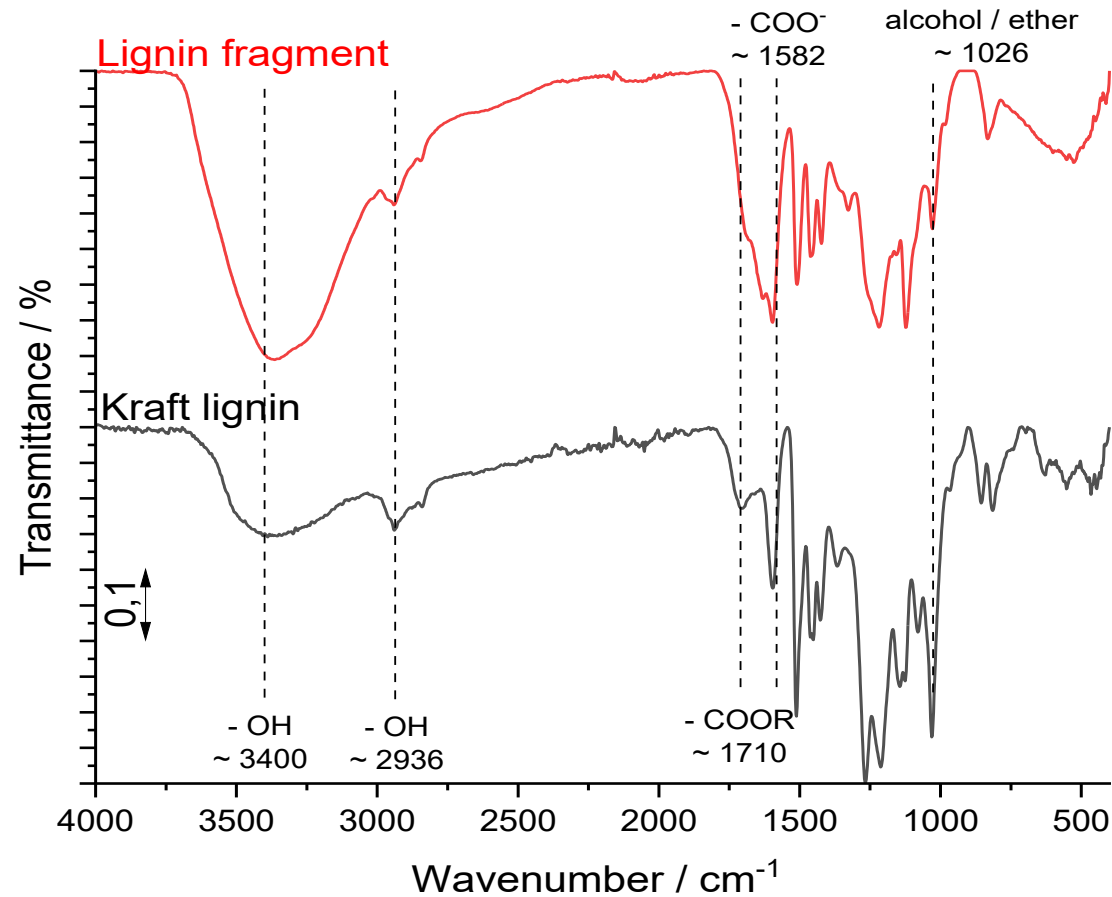


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Lignin Characterisation

FTIR SPECTROSCOPY



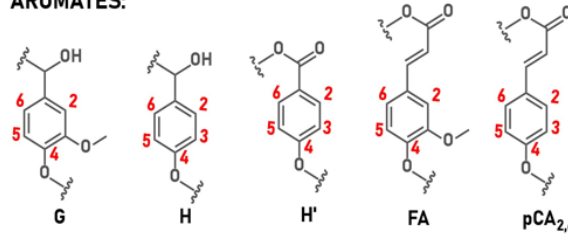
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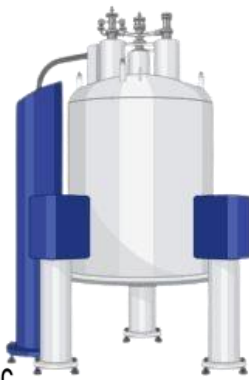
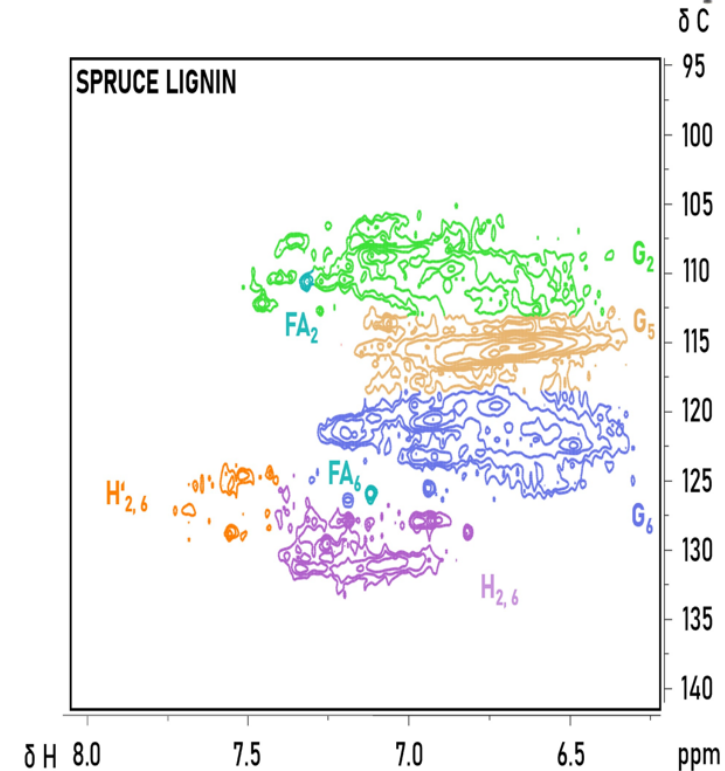
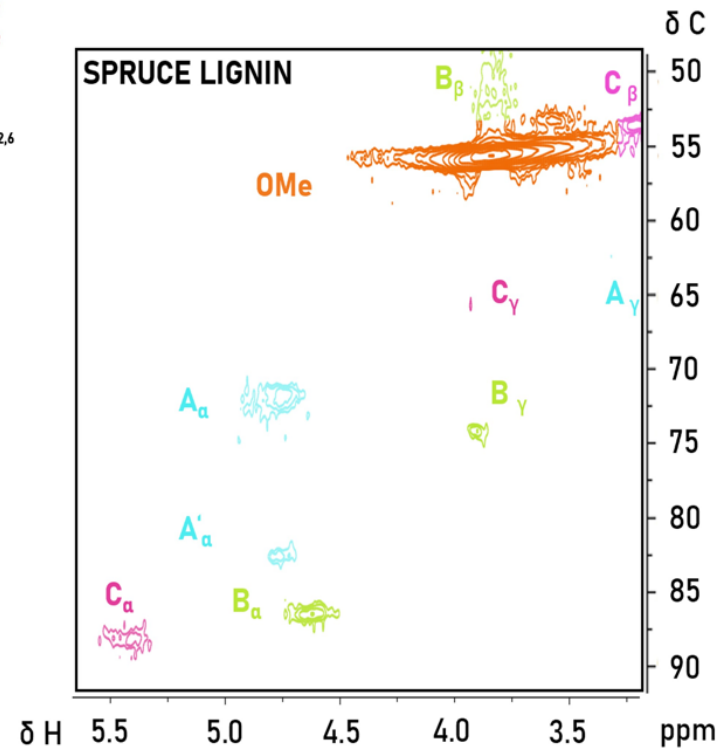
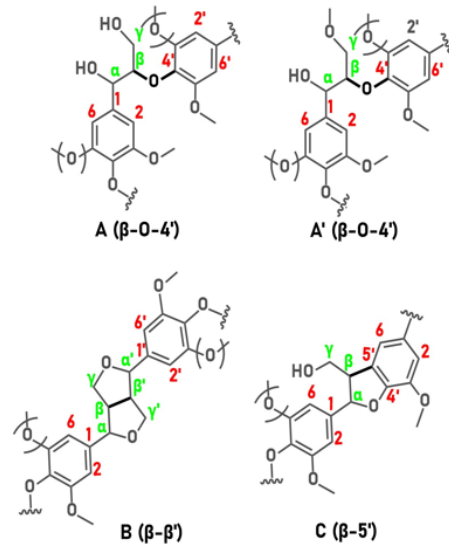
Lignin Characterisation

NMR SPECTROSCOPY

AROMATES:



BONDS:



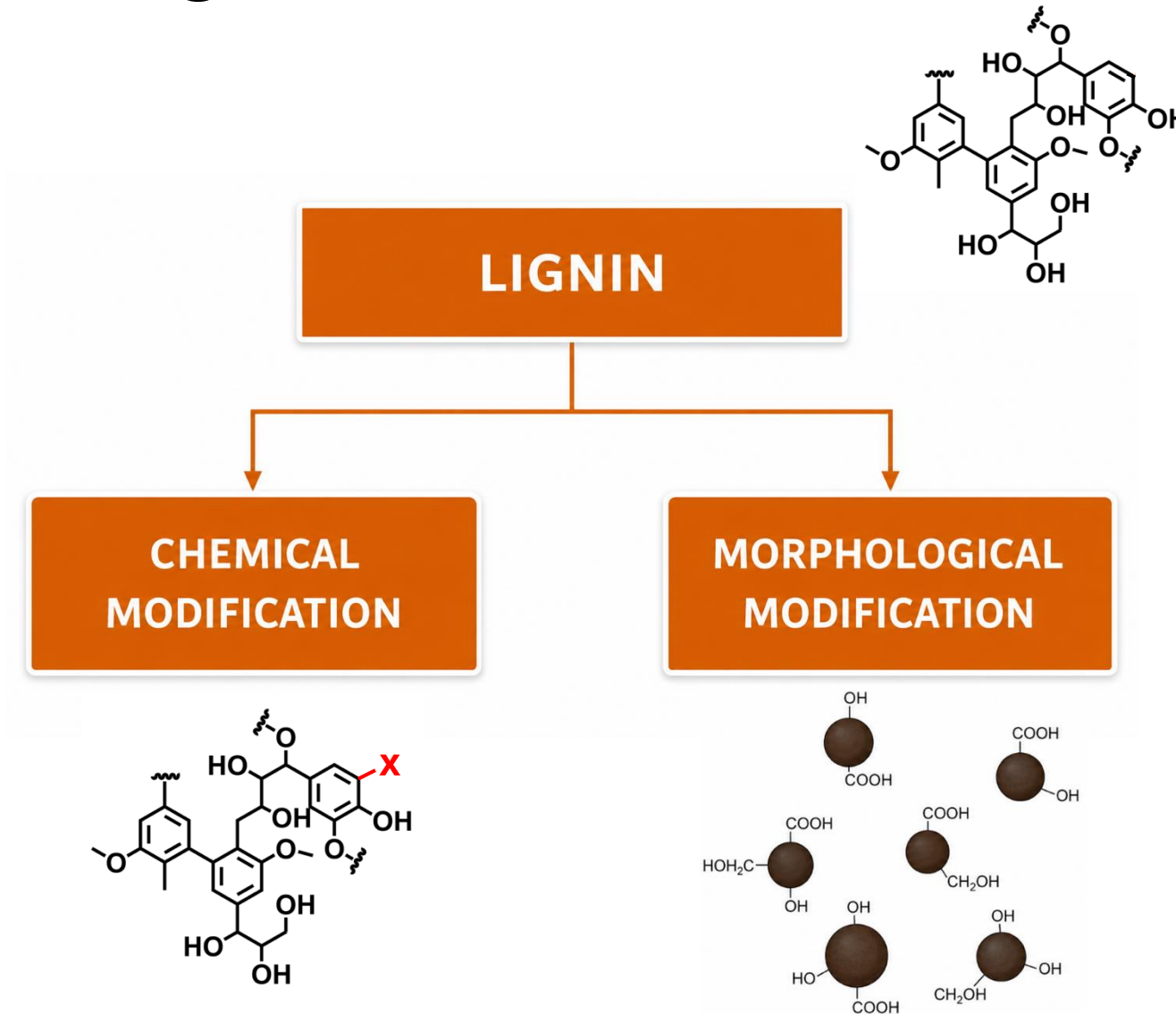
J. P. Djaniš, et al.: Exploring the interplay between formation mechanisms and luminescence of lignin carbon quantum dots from spruce biomass.



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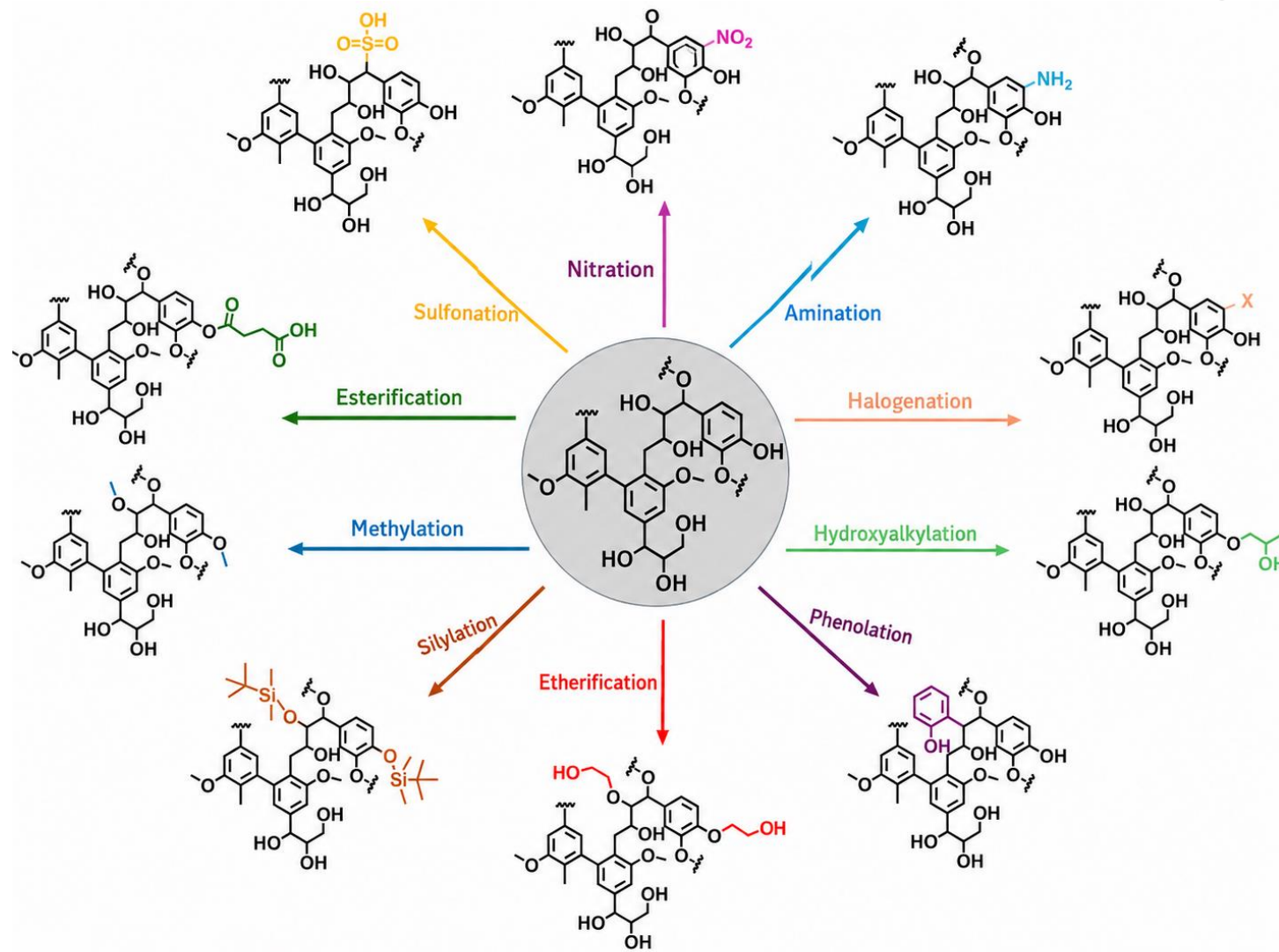
Lignin Modifications



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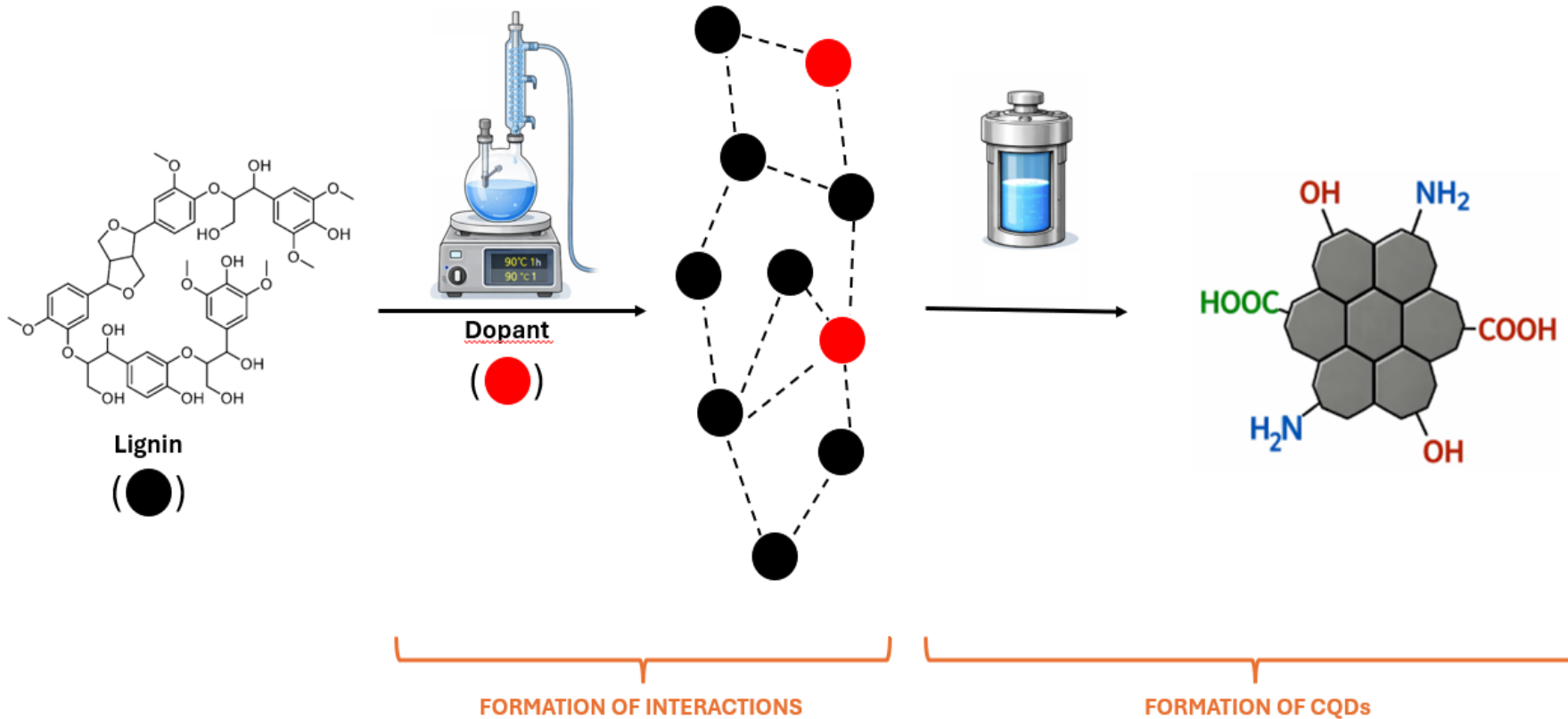
Chemical Modifications of Lignin



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Chemical Modifications of Lignin to CQDs



J. Periša, J. Hočevár, et al.: Tomato-derived carbon quantum dots: composition-driven structure and copper sensing potential.

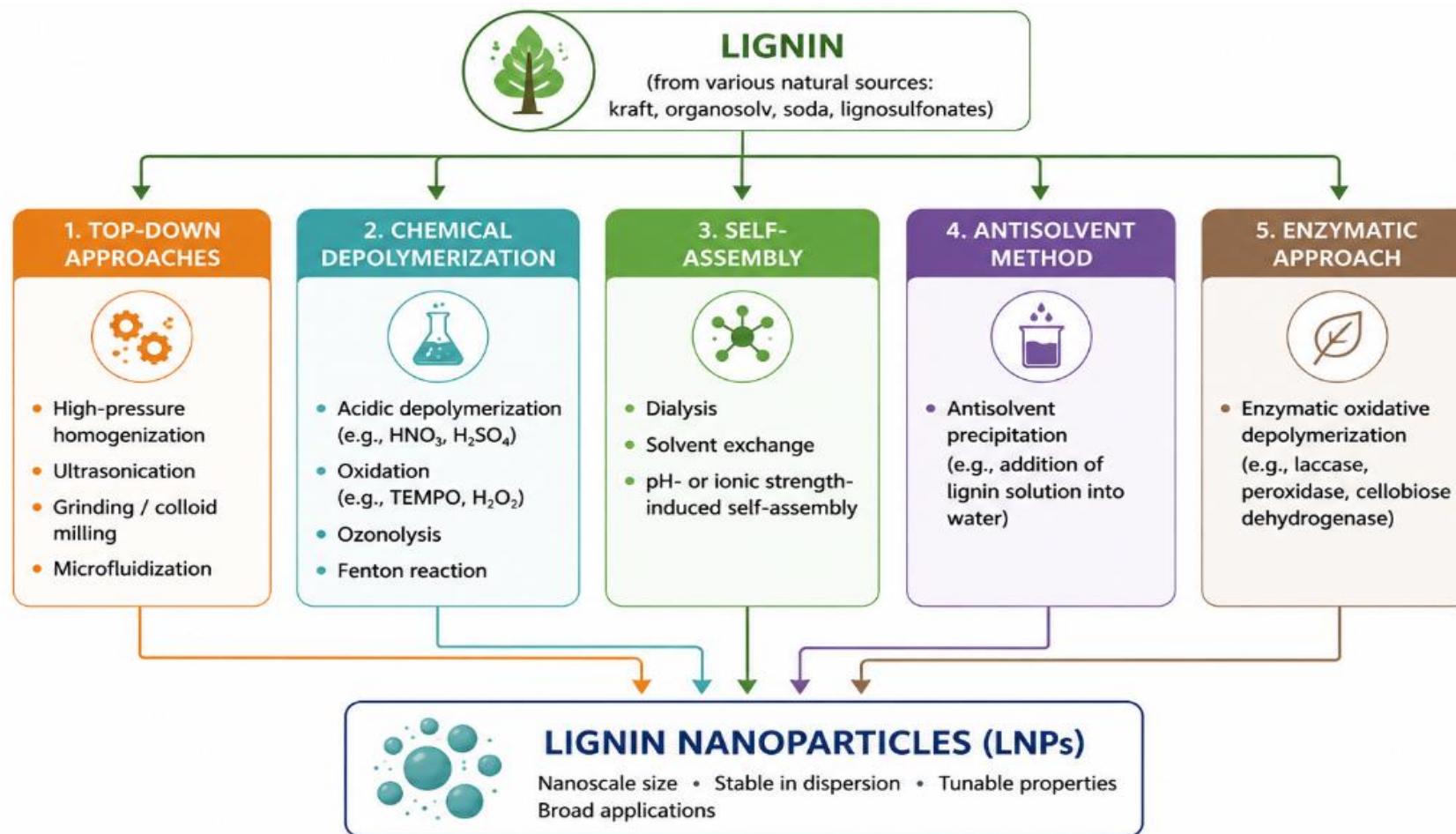


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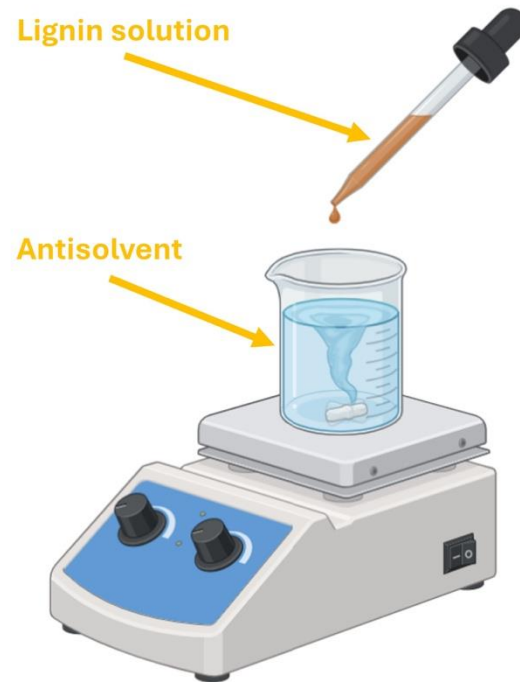
Morphological Modifications of Lignin



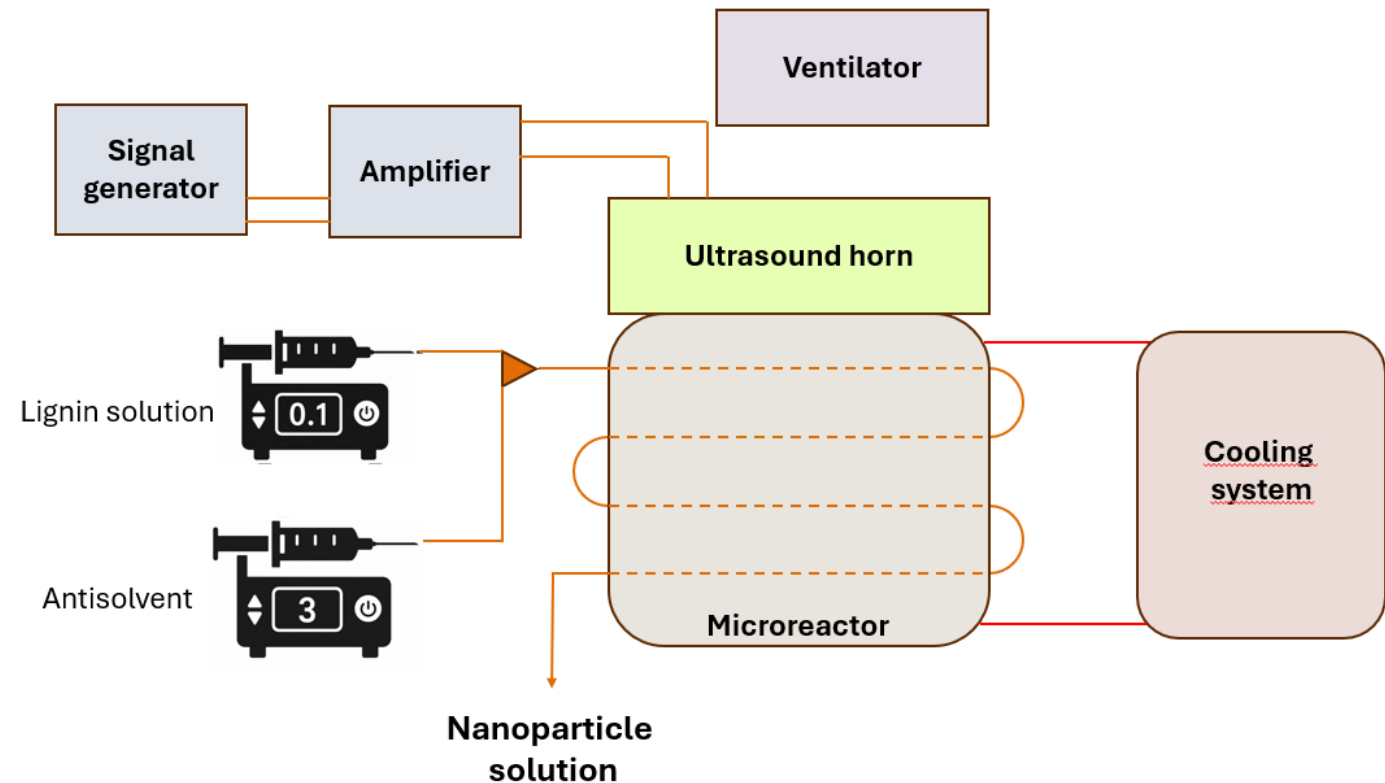
Morphological Modifications of Lignin

ANTISOLVENT METHOD

Batch system



Flow US assisted system

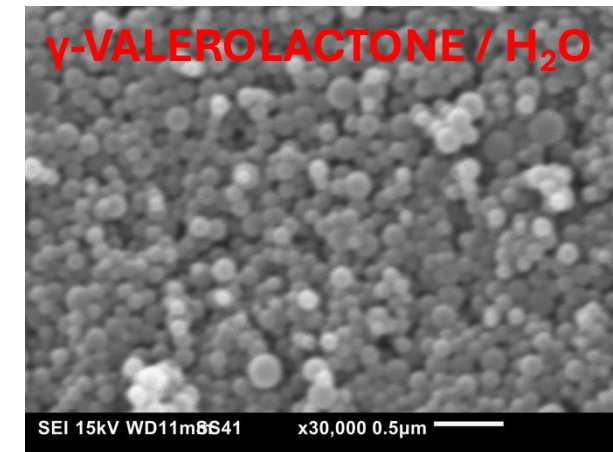
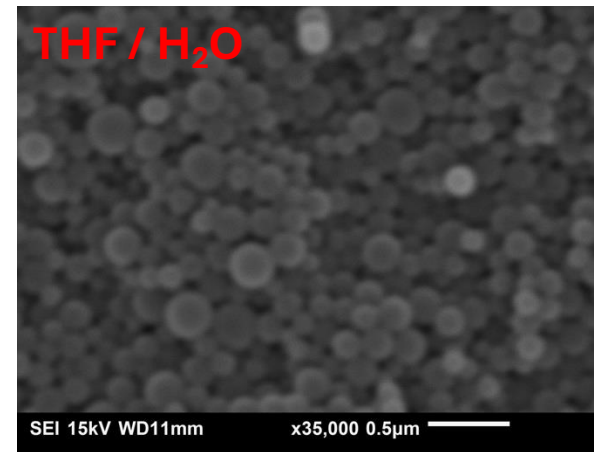
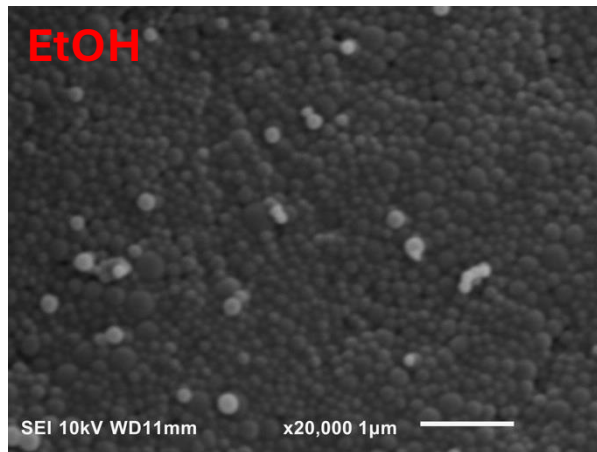
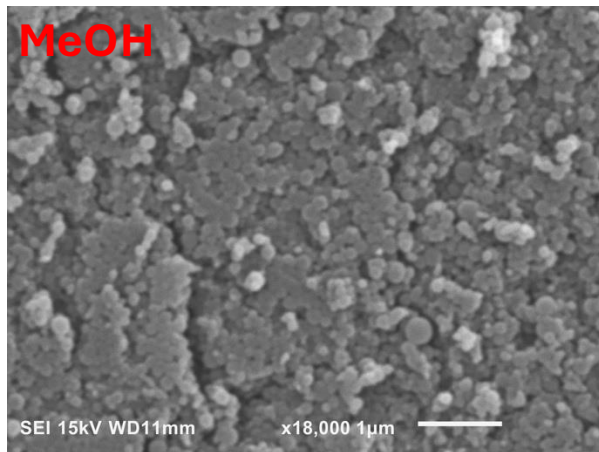
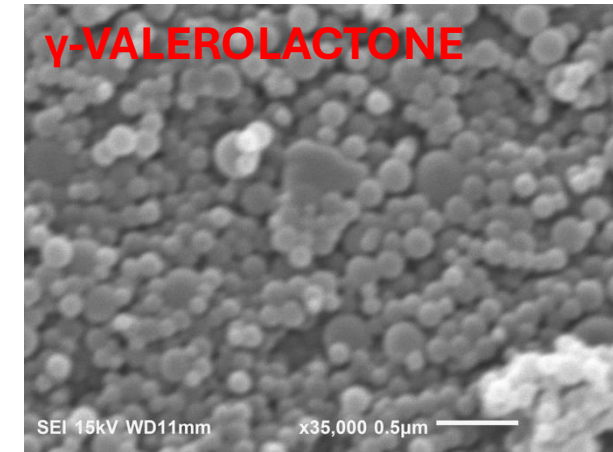
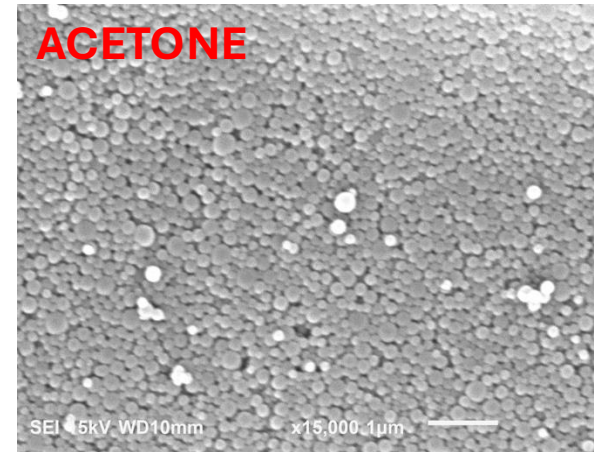
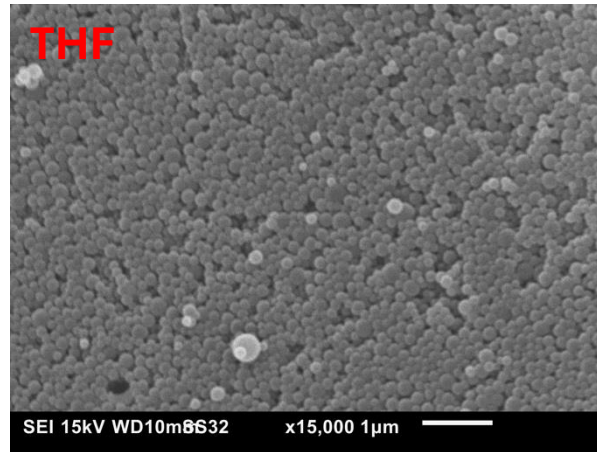
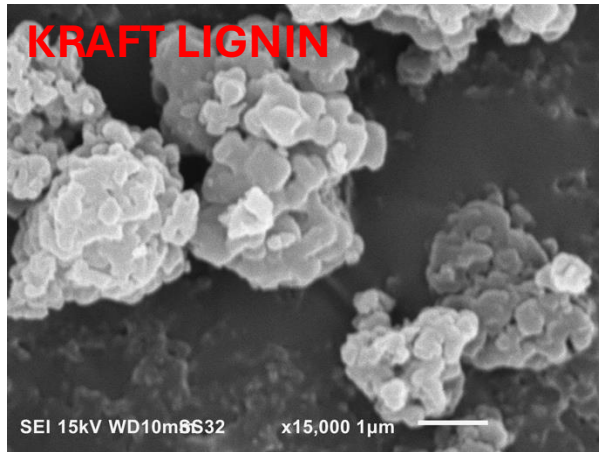


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Morphological Modifications of Lignin

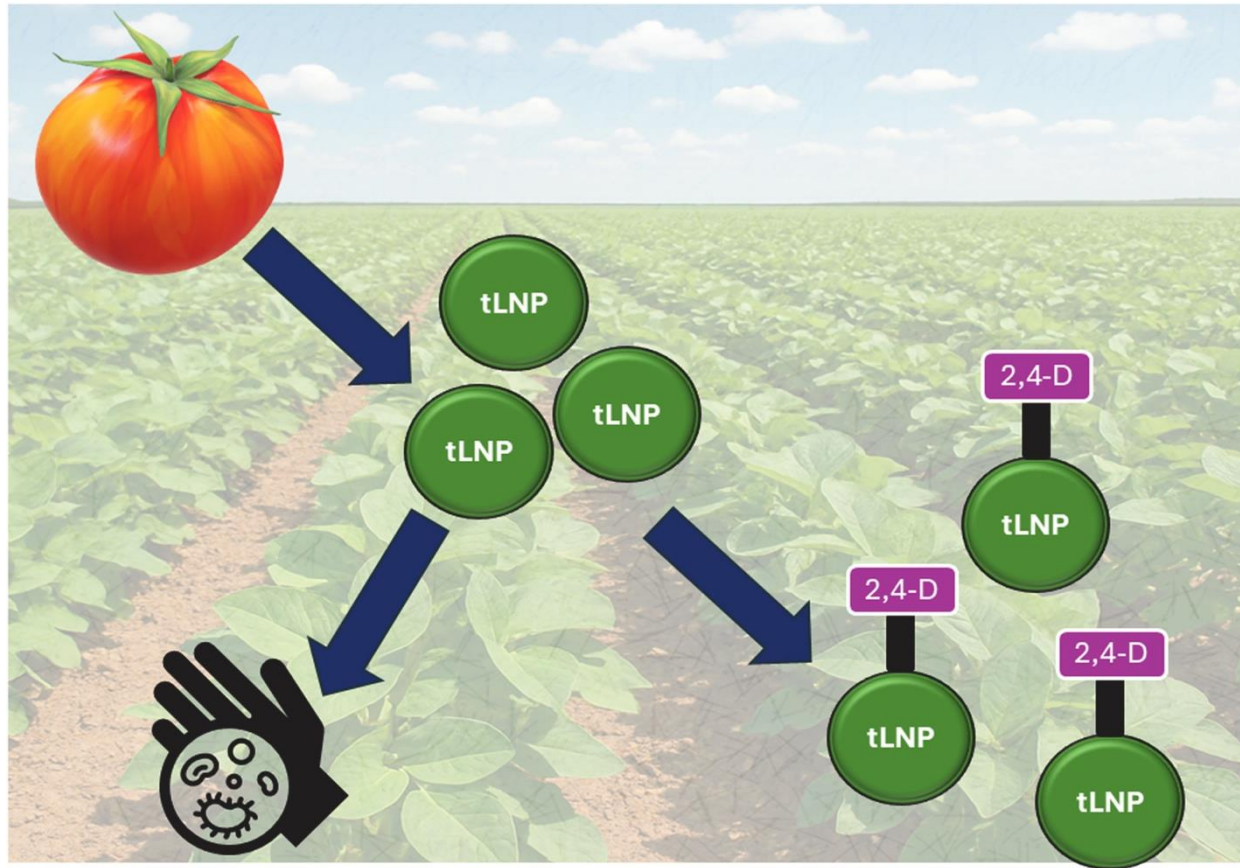
ANTISOLVENT METHOD



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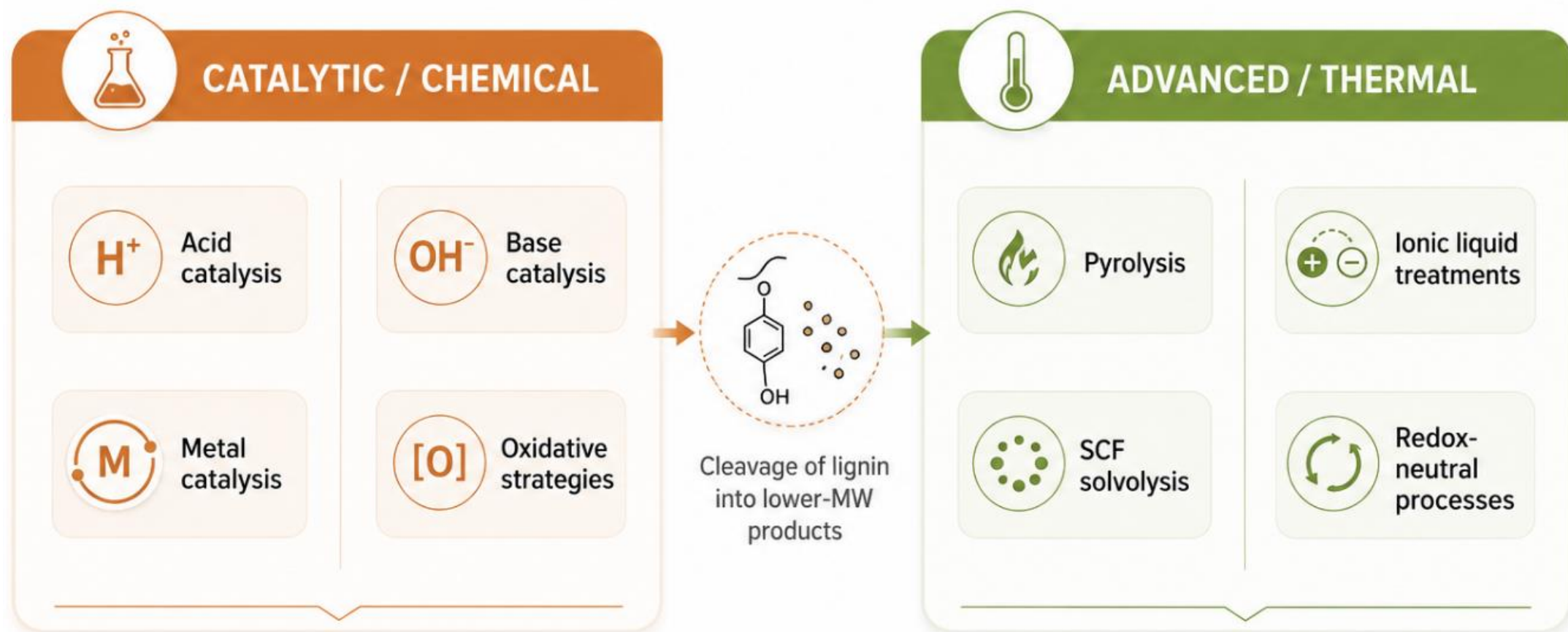


Morphological Modifications of Lignin USAGE



N. Kněžević, J. Hočevár, et al.: Valorization of tomato stem waste: Lignin nanoparticles as eco-friendly platforms for 2,4-D and antimicrobial applications.

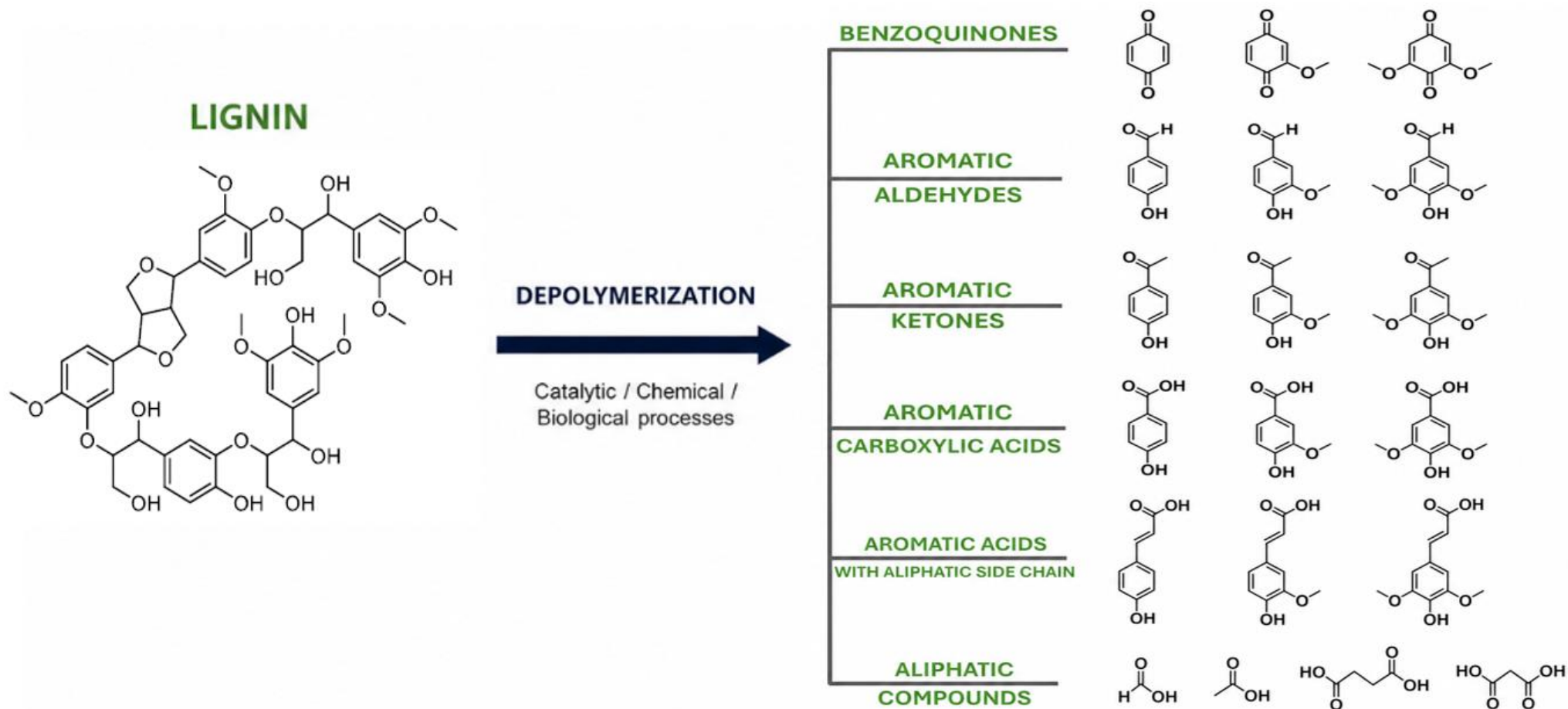
Lignin Depolymerization



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Lignin Depolymerization



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Conclusion

- BIOMASS CONSISTS OF CELLULOSE, LIGNIN, HEMICELLULOSE, EXTRACTIVES, AND INORGANIC COMPONENTS
- THE KEY PROCESSES FOR LIGNIN ISOLATION ARE THE KRAFT, ORGANOSOLV, AND LIGNOSULFONATE PROCESSES
- LIGNIN CAN BE USED IN MANY APPLICATIONS, EVEN THOUGH WE OFTEN CONSIDER IT A WASTE PRODUCT
- CHEMICAL MODIFICATIONS ENABLE CHANGES IN THE CHEMICAL STRUCTURE OF LIGNIN
- MORPHOLOGICAL MODIFICATIONS ENABLE CHANGES IN LIGNIN MORPHOLOGY
- THE MAIN TECHNIQUES FOR CHARACTERIZING LIGNIN OR MODIFIED LIGNIN ARE FTIR AND NMR SPECTROSCOPY, AND SEM MICROSCOPY



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THANK YOU VERY MUCH FOR
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Lignin: complex by nature,
full of possibilities.

Questions & Discussion



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