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Review

# Advancement of lignin into bioactive compounds through selective organic synthesis methods

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ABSTRACT

The conversion of lignin into bioactive compounds through selective organic synthesis methods represents a promising frontier in the pursuit of sustainable raw materials and green chemistry. This review explores the versatility of lignin-derived bioactive compounds, ranging from their application in drug discovery to their role in the development of biodegradable materials. Despite notable advancements, the synthesis routes and yields of highly bioactive molecules from lignin still require further exploration and improvement. This review provides an in-depth examination of the progress made in understanding the complex structure of lignin and developing innovative approaches to exploit its potential. Specifically, the types of lignins covered include softwood Kraft lignin, hardwood organosolv lignin, and soda lignin. This work is divided into three parts: first, the transformation of lignin into bioactive molecules with chemically active centres and functionalised hydroxyl groups through depolymerisation; second, kinetic modelling techniques essential for understanding the chemical kinetics of lignin and enabling significant scaling up in the conversion of organic molecules; third, efficient catalytic pathways for synthesising molecules with anticancer and antibacterial properties. In conclusion, this comprehensive review spurs further investigations into lignin-derived bioactive compounds, their applications, and the advancement of sustainable processes.

## 1. Introduction

Lignin is a polymer that binds hemicellulose and cellulose fibres, providing essential strength to plant building blocks. Globally, ~31,011 t of lignin are available, making it the second most abundant polymer after cellulose. Lignin from different biomass sources, such as softwood and hardwood, and extraction processes like Kraft, soda, and organosolv, have diverse applications (see Fig. 1) in manufacturing, serving as a nucleating agent, copolymer or filler to enhance its mechanical and thermal properties [1,2]. Notably, lignin comprises aromatic rings with ether compounds, making it a valuable raw material for the sustainable production of aromatic hydrocarbons, speciality chemicals and fuels. Research interest in using lignin for the production of high-value chemicals, fuels, materials and catalysts has increased significantly [3].

Furthermore, lignin generates diverse oxygen-containing products such as phenols, ethers, alcohols, ketones and aldehyde-based chemicals [4]. Another crucial and sustainable technique for converting lignin into chemicals involves the synthesis of organic solvents such as benzene and toluene, along with their derivatives. Phenols, alcohols and ethers derived from lignin exhibit significant versatility as primary compounds for synthesising valuable chemicals. As a result, there has been a significant increase in research efforts dedicated to the aromatic fractionation of depolymerised lignin, driven by the increasing importance of biorefineries [5].

In contrast, amines are vital substances commonly employed as bulk materials in fine chemical production and serve as crucial precursors and core ingredients in the manufacturing of sophisticated chemicals, medicines, agrochemicals and materials [6]. Lewis acid–based catalysts such as $SiO_2$–$Al_2O_3$, $TiO_2$–$Al_2O_3$, $H_3PO_4$, $ZrO_2$–$Al_2O_3$ or $WO_3$ are used in ammonolysis for commercial amination processes, converting phenol

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