Biomass valorization

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A sustainable alternative to bisphenol A

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Bisphenol A (BPA) is an industrial chemical produced in large quantities for use primarily in the manufacturing of plastics. However, its adverse effects on human health are driving the development of safer and more sustainable alternatives. Now, a synthetic route enables such an alternative, starting from renewable lignin biomass.

Bisphenols, including the well-known bisphenol A (BPA), are used in the production of various plastics, such as polycarbonates. However, BPA is coming under increased scrutiny as it may leach from food storage containers and drink bottles, especially during heating, thereby entering our food chain[1,2]. Particularly, BPA is known to be a xeno-oestrogen and has been related to health issues, including infertility[3–5]. Furthermore, the current production routes for BPA are entirely based on fossil resources. Finding more sustainable alternatives, ideally produced from non-fossil resources, such as biomass, would be an important step towards a more circular and safer society. Now, writing in *Nature Sustainability*, Trullemans and colleagues have developed a route towards the production of bisguaiacols, an alternative to BPA, utilizing arenes, such as guaiacol, and alkenes, such as para-propenylguaiacol, both of which are derived from lignin, a widely available biopolymer[6].

Figure 1a illustrates the molecular structure of lignin, which together with hemicellulose and cellulose are the main constituents of plants[7]. Lignin has an aromatic backbone, rendering it an ideal starting material to synthesize BPA alternatives with a biomass origin. Recent lignin valorization routes have demonstrated the possibility to fractionate and depolymerize lignin into, for example, monomeric

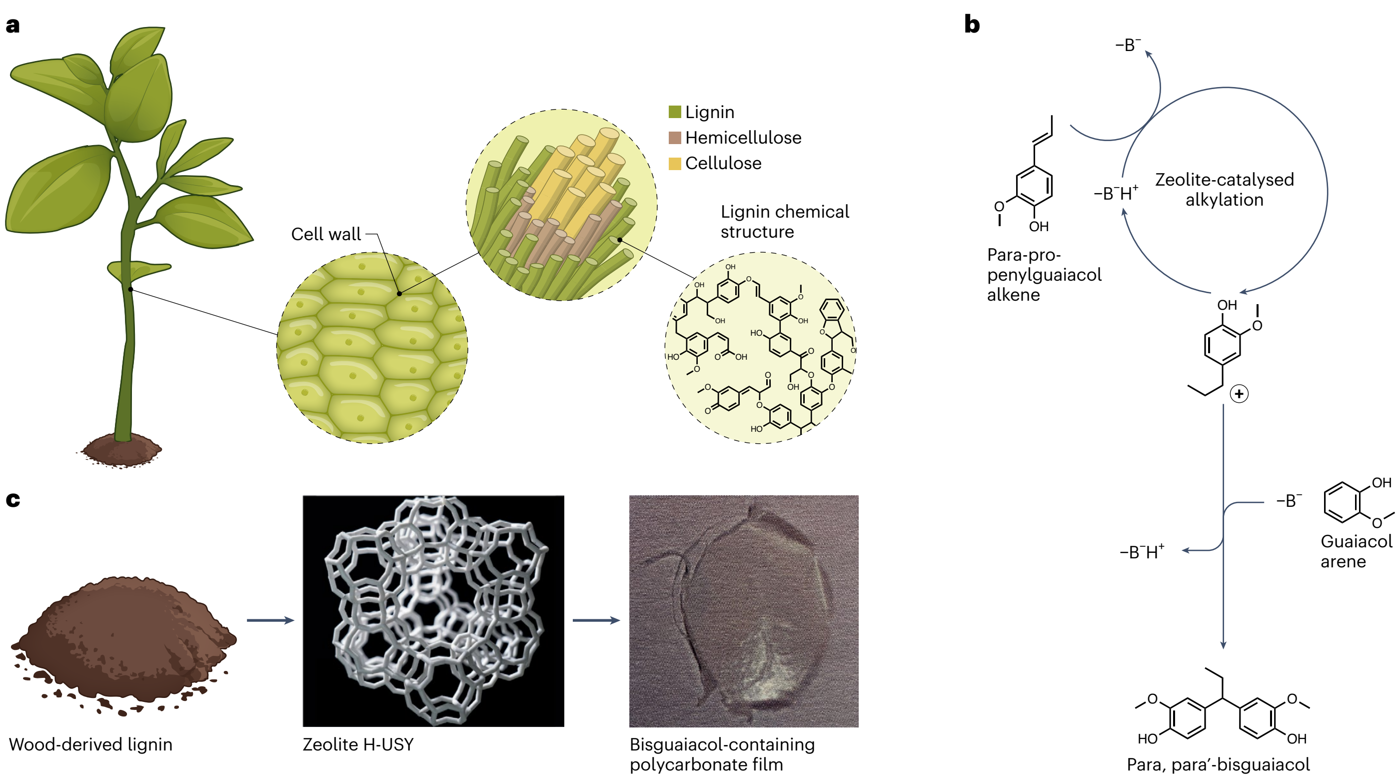

Fig. 1 | Zeolite-based catalytic conversion of arenes and alkenes, derived from lignin, into bisguaiacol-based compounds, as less toxic and renewably produced alternatives to bisphenol A. a, Molecular structure of lignin, an aromatic-rich biopolymer, which can be derived from plants. **b**, Alternative synthesis route, as designed by Trullemans and colleagues, to make para, para′-bisguaiacol from para-propenylguaiacol (that is, the alkene reactant) and guaiacol (that is, the arene reactant). B^-H^+ represents the Brönsted acid, belonging to the zeolite material. The developed zeolite-based catalytic chemistry has several advantages over the current production route, which is not only based on petrochemical resources but also involves more complex hydroxyalkylation–alkylation condensation chemistry. **c**, Overall and simplified synthesis process, in which a wood-derived lignin (left) is transformed via zeolite H-USY (middle; represents a FAU zeolite framework structure) as a catalyst into a polycarbonate film, containing lignin-derived bisguaiacol (right).

methoxyphenols, which could be entry points for the synthesis of bisguaiacols. Figure 1b shows that the synthetic approach, developed by Trullemans and colleagues, possesses several advantages over the classic petroleum-based synthesis route. Fortunately, following this extraction process, it is possible to obtain phenolic compounds with methoxy groups in the ortho position, which are known to substantially lower the xeno-oestrogenic activity, thereby providing a viable production route for sustainable and safer alternatives to BPA.

The authors found that using zeolite-based catalyst materials would allow bisguaiacols to be synthesized in sufficiently high yields. After testing 25 solid catalysts, they identified zeolite H-USY, which outperforms sulfuric acid, a soluble acid also suitable for the proposed synthesis but more problematic from an environmental standpoint. In addition, Trullemans and colleagues have examined in vitro xeno-oestrogenic activity of the obtained bisguaiacols to ensure that they have indeed synthesized safer alternatives to BPA.

Another interesting aspect of the study has been the integration of the zeolite-based alkylation chemistry with potential biorefinery schemes for lignin[6]. By modifying the reductive catalytic fractionation process of wood, thanks to the lignin-first biorefinery scheme[8], they extract a lignin oil, rich in para-propenylguaiacol, next to a solid carbohydrate pulp, which can be upgraded via other valorization routes. Using this extract, together with guaiacol as the substrate and zeolite H-USY as the catalyst, very similar results were obtained to with pure para-propenylguaiacol. These findings highlight the robustness of the proposed synthesis route. Furthermore, Trullemans and colleagues assessed the bisguaiacols synthesized for their practical use. They successfully combined them with two thermoplastics (that is, poly-terephthalates and polycarbonates) and one thermosetting resin (that is, poly-epoxides) and found that these three BPA-alternative polymers possessed similar or even better properties. Figure 1c shows, as an example, the physical appearance of a bisguaiacol-based polycarbonate film made from wood-derived lignin.

One of the intriguing aspects of the described synthesis is the high product selectivity. The zeolite framework structure of the catalyst enables shape-selective active site confinement leading to entropic control over the transition state, thereby enhancing both chemo- and regioselectivity. This suggests that it should be possible to find better zeolite-based catalysts, as well as improved reaction conditions (for example, alternative relative concentrations of alkene and aryl concentrations in the reaction mixture) that could maximize the product yield. Clearly, more advanced characterization methods, preferably applied under in situ or in operando conditions, have to be performed to uncover the reaction and deactivation routes of this alternative synthesis process[9].

Trullemans and colleagues showcase how different new aspects are coming together. More specifically, they have not only designed a greener synthesis route for an alternative BPA compound, based on a readily available and renewable resource with a recyclable solid catalyst, but have also evaluated the potential toxicity of this alternative chemical compound. Hence, apart from searching for suitable and scalable alternative manufacturing routes for currently widely used chemicals, the assessment of the potential health and environmental impacts of newly synthesized chemicals should be a priority of future chemistry research, even when the new chemicals originate from more renewable resources. Only then can we make our chemical manufacturing processes more sustainable, circular and environmentally safe.

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Competing interests

The author declares no competing interests.