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# New era of sustainable design for molecular motors

Native lignocellulose can be used to create light-driven molecular motors via a "green" synthetic approach. In the May issue of *Green Chemistry*, Barta and Feringa provided new insights into the sustainable design of molecular motors through reductive catalytic fractionation using a lignocellulose platform.

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## Main text

Can we sustainably derive tiny machinery from biomass sources? The jury is still out, but such fundamental curiosity regarding this topic has now become a reality because of the researchers at the University of Groningen. The quest for conquering random thermal motion has triggered the design of synthetic molecular machines for decades. A molecular motor is an example of miniature machinery that can produce mechanical work by feeding on various chemical and energy inputs.[1] They can control the movement of their submolecular parts, with the mechanical work ultimately being amplified into a macroscopic effect. Such motors are present in nature—in particular, within biological systems.

Myosins, kinesins, and dyneins are some commonly investigated natural molecular motors, which induce cellular functions such as muscle movement and vesicle transport and are all powered via adenosine triphosphate. Another notable example of a molecular motor is the process of ribonucleic acid polymerase and ribosome working with genetic information.

Scientists have been mimicking biological motors for decades now,[2] since Richard Feynman first proposed the idea.[3] The motion generated by molecular motors can be harnessed through their grating onto surfaces or by incorporating them into complex structures such as network polymers, liquid crystals, and supramolecular systems, covering different length scales. Gaining control over the aligned motion induced via molecular motors enables various applications, including drug delivery, smart coatings and films, responsive materials, self-healing surfaces, power actuators and engines, cargo trafficking, sensors, computer devices, and artificial muscles for soft robotics.

Molecular motors were inspired by nature, and their synthetic analogs have typically been prepared using conventional fossil-based raw materials. However, a new and exciting class of molecular motors has emerged recently. Barta and Feringa employed a lignocellulose-based sustainable raw material to obtain a light-driven unidirectional molecular motor using a reductive catalytic fractionation methodology (**Figure 1**).[4] Lignocellulose is the largest renewable source of aromatic building blocks on Earth, and consequently has great potential to be efficiently converted into biobased products.[5] Lignocellulose is considered as a by-product in the biofuel and pulping industries, which primarily convert cellulose from plants.

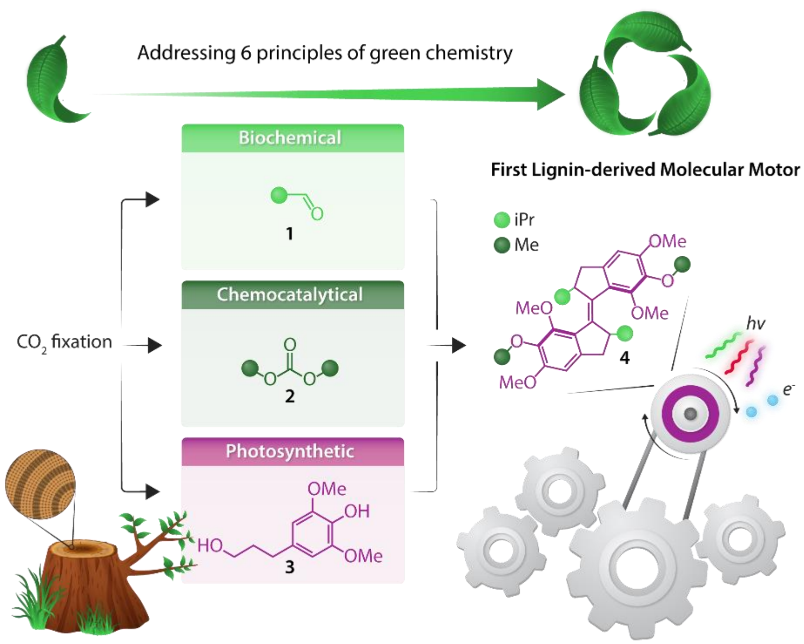


**Figure 1**. Sustainable design for molecular motors.

Researchers have thus designed a green synthetic chemistry strategy for molecular motors using the native lignin component of wood sawdust. It is a leap forward from 1999 when the first of its kind light-driven molecular motor (capable of unidirectional 360° rotation) was reported.[6] The challenges of converting biomass material to valuable building blocks are multifaceted, not to mention the additional inherent difficulties associated with successfully designing and constructing functional molecular motors. It is commendable that the synthesis process not only uses renewable raw materials but also addresses another 6 of the 12 principles of green chemistry,[7] namely prevention of waste, atom economy, reduced reliance on hazardous chemical synthesis, use of benign solvents and auxiliaries, reduction of derivatives, and catalysis.

The article describes the six-step total synthesis of the *E* (*R*,*R*) isomer (conglomerate) of the molecular motor **4**, which comprised lignin-derived dihydrosinapyl alcohol/4-(3-hydroxypropyl)-2,6-dimethoxyphenol **3**, dimethyl carbonate **2**, and isobutyraldehyde **1**. A moderate overall yield of 15% was ultimately achieved, which requires further optimization. The three starting materials can be sustainably derived via native lignin and carbon dioxide using chemical and biochemical catalyses, respectively. In a particularly elaborate experiment, **1** can be obtained with 30% yield from a reductive catalytic fractionation of various wood sources.[8] The methoxy substituents in **4** were directly accessible from the lignin framework, causing a bathochromic shift of the material's absorption spectrum due to high electron density. Owing to the low thermal helix inversion barriers, the molecular motor successfully underwent 360° rotation at room temperature, induced via a single light stimulus. Increasing the efficiency of the photochemical properties of molecular motors is considered difficult because such processes are not as clearly understood as the analog thermal processes.

No degradation of **4** was observed over its considerably long storage period of 2.5 years, which was confirmed by its stable photoresponsive behavior. The authors highlighted that the observed unidirectional, continuous motion at room temperature is crucial for certain applications in complex molecular machinery systems. The photoisomerization and fast thermal helix inversion results supported the overall hypothesis and were consistent with the first-generation molecular motor behavior of continuous unidirectional rotation at ambient temperatures.

The authors pave the way toward a green chemistry platform to obtain molecular motors. The reported procedures were designed to be green and featured green solvents, and likewise involved methylation with dimethyl carbonate, catalytic oxidation with molecular oxygen, metal-free Friedel–Crafts acylation, aldol condensation, and hydrogenation. Undesired purification processes such as high-solvent-consuming chromatography were omitted during five of the steps.

The results demonstrate that the late-stage alkylation of α carbon has future prospects in preparing various molecular motors via the principles of green chemistry on a biomass platform. The design of molecular motors via the principles of green chemistry has the potential to yield commercially viable devices in the long run, but it also elevates our understanding of the design problems posed when using biomass as raw materials. The work by Barta and Feringa is the most fully developed synthetic effort to date for synthesizing molecular motors on a sustainable platform. The methodology, of course, still has unresolved problems, as the authors point out. In addition, green metrics analyses and the quantitative comparisons of synthetic routes for obtaining molecular motors are yet to be performed. Nonetheless, the presented synthetic platform is a fascinating and intellectual frontier of nature-inspired nanoscience research.

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**Declaration of interests**

The authors declare no competing interests.

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