

BIO-BASED SOLVENTS FOR GREEN CHEMISTRY

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Abstract:

Bio-based solvents are gaining increasing attention in green chemistry due to their potential to replace traditional petrochemical-based solvents, which are often toxic, volatile, and environmentally harmful. These renewable solvents, derived from plant materials, agricultural by-products, or waste biomass, offer a sustainable alternative in a range of industrial processes including pharmaceuticals, paints, coatings, and cleaning products. This development aims to minimize environmental impact, reduce dependence on fossil fuels, and improve the health and safety of industrial processes. The research focuses on the synthesis, characterization, and application of bio-based solvents with an emphasis on their effectiveness, biodegradability, and economic viability. Through various experimental approaches, this work explores the chemical properties and performance of bio-based solvents, offering insights into their role in advancing sustainable chemistry and manufacturing practices.

Keywords:

Bio-based solvents, green chemistry, sustainable chemistry, renewable solvents, biodegradable solvents, environmental impact, industrial applications, solvent replacement, biomass, chemical engineering.

1. Introduction:

The ongoing push for sustainability in the chemical industry has led to the development of bio-based solvents, which are derived from renewable biological resources such as plants, agricultural residues, and other forms of biomass. Traditional solvents, often sourced from petrochemicals, present significant environmental and health concerns due to their toxicity, high volatility, and potential to cause pollution. As industries become more committed to reducing their carbon footprint and adhering to stricter environmental regulations, bio-based solvents offer a promising alternative.

These solvents possess favorable properties such as lower toxicity, enhanced biodegradability, and reduced environmental persistence compared to their conventional counterparts. Additionally, they are derived from renewable resources, making them an attractive option for industries seeking to transition towards circular economy models. Bio-based solvents can be employed in a variety of applications, including solvent extraction, paint and coating formulations, cleaning agents, and as reaction solvents in chemical processes.

However, challenges remain in terms of scalability, cost-effectiveness, and ensuring consistent quality across different batches of bio-based solvents. Furthermore, the chemical properties and performance of these solvents must be optimized to meet the specific requirements of various industrial processes. This introduction explores the need for bio-based solvent development within the broader context of green chemistry, highlighting the key benefits and ongoing challenges that researchers face in advancing their application.

By addressing these issues, bio-based solvents are positioned to play a critical role in the transition towards more sustainable industrial practices, aligning with the broader goals of environmental protection, resource conservation, and the reduction of chemical waste.

Early work on green solvents emphasised the need to move away from petrochemical-derived, toxic, volatile organic solvents. For example, Green and Bio-Based Solvents | Topics in Current Chemistry (2018) reviews how solvents contribute heavily to chemical processes, and how their environmental and health impacts drive interest in renewable alternatives. Bio-based solvents are defined as those derived wholly or in large part from biomass (plants, agricultural residues, waste) rather than fossil feedstocks. They aim to comply with the principles of green chemistry: renewability, reduced hazard, reduced waste, lower emissions, and safe design.

In the review by Jin et al. (2017) titled Challenges in the development of bio-based solvents: A case study, it is emphasised that simply being bio-derived does *not* guarantee “green” status — solvent properties (solvency, volatility, toxicity, LCA) must all be considered.

2. Major Classes of Bio-Based Solvents

The literature identifies several significant types of bio-based solvents. Below are key categories and examples.

2.1 Carbohydrate-derived solvents

In the 2024 paper by Kholany et al., “Bio-based solvents as a sustainable alternative ...”, GVL and ethanol-based systems are used in a biorefinery process. These solvents offer low vapour pressure, favourable solvency for many organic reactions, and originate from renewable carbohydrate feedstocks.

2.2 Terpene-based solvents and plant-oil derivatives

Terpenes (e.g., d-limonene) and other plant-oil derivatives are also used as greener solvents. For example, the 2025 review by Quadros et al. highlights terpenes and natural deep eutectic solvents (NaDES) as rising categories.

These tend to be non-polar or weakly polar and may replace conventional non-polar solvents or be used in extractions.

2.3 Natural deep eutectic solvents (NaDES) & other novel solvent systems

NaDES consist of mixtures (often a hydrogen-bond donor + acceptor) derived from natural components (e.g., sugars, amino acids, organic acids) that form eutectic mixtures with melting points lower than the components. They are actively investigated for extraction, separation, and reaction media. The 2018 review by Calvo-Flores et al. mentions them among green and bio-based solvents.

3. Performance & Application Areas

3.1 Reaction media in organic synthesis

Bio-based solvents have been studied for organic transformations—couplings, oxidations, extractions. For example, the Quadros et al. 2025 review reports over 70 studies between 2019-2024 of bio-based solvents in organic synthesis. [ResearchGate+1](#)

One case study (Jin et al.) for methyl(2,2-dimethyl-1,3-dioxolan-4-yl)methyl carbonate (MMC) examines solvent polarity (Kamlet-Abboud-Taft parameters) and solubility parameters to match conventional solvents like DCM, acetone.

3.2 Extraction, separation and purification

Green solvent systems are applied in extraction and separation tasks (e.g., biomass fractionation). The 2025 review by Ma et al. ("A review of green solvents for the extraction and separation ...") emphasises bio-based solvents meeting extraction/separation needs within green chemistry.

Kholany et al. (2024) applied GVL/ethanol in a multi-product biorefinery (pigments, proteins, polysaccharides) from the archaeobacterium *Halobacterium salinarum* R1, showing feasibility of bio-based solvent use in complex separations.

3.3 Analytical chemistry applications

The 2019 review highlighted how biosolvents can replace traditional hazardous solvents in analytical methods (chromatography, sample prep) while aligning with green analytical chemistry.

4. Challenges and Barriers

Despite the promise, several issues hinder widespread adoption.

4.1 Performance matching and compatibility

A critical challenge: Renewable origin doesn't guarantee functional equivalence. Jin et al. emphasise that properties like solvency, viscosity, volatility, miscibility, thermal stability must be addressed. In many cases bio-based solvents may have higher viscosity, lower volatility, or less favourable solvation for certain substrates.

4.2 Toxicity, biodegradability and life-cycle concerns

Even bio-derived solvents can present toxicity or persistence issues. For MMC, Jin et al. performed preliminary Ames tests which revealed mutagenicity, emphasising the need for early toxicity screening. Life-cycle analyses are still limited in many cases: feedstock cultivation, processing energy, solvent recovery, and possible by-products must be considered.

4.3 Cost, scalability and feedstock supply

Biomass availability, extraction/processing cost, solvent purification are often higher than for established fossil-based solvents. The review by Calvo-Flores emphasises the need for efficient biomass conversion routes. [SpringerLink](#) Scalability and consistent quality are also barriers to industrial adoption.

4.4 Standardisation and regulatory frameworks

The 2017 work by Jin et al. mentions that standards like the European technical specification CEN/TS 16766:2015 for bio-based solvents help with assessment, but consistent global guidelines are still emerging.

5. Recent Trends & Future Prospects

5.1 Multi-product biorefineries & integrated processes

The 2024 study by Kholany et al. demonstrates an integrated biorefinery approach where bio-based solvents are part of a cascade process recovering multiple fractions from a single biomass feedstock. This points to a trend: viewing solvents not just as replacements, but as part of biomass valorisation.

5.2 Novel solvent design & computational screening

There is increasing use of in-silico modelling (e.g., Hansen solubility parameters, Kamlet-Abboud-Taft metrics) early in solvent design to reduce trial-and-error. (See Jin et al. 2017) This enables tailoring solvent properties for specific applications while screening toxicity and biodegradation.

5.3 Deep eutectic and bio-based ionic liquid-type systems

NaDES and other eutectic mixtures (often fully bio-derived) are gaining prominence because of their tunable properties and potential to replace traditional ionic liquids or volatile organics. The 2018 and later reviews note their growing role.

5.4 Focus on full sustainability metrics

Recent reviews emphasise not just renewability but full life-cycle, cost, toxicity, recovery, reuse, and circular economy aspects. E.g., Quadros et al. (2025) stress this broader view. In short: the field is moving from “biomass-derived = good” to “biomass-derived + tested performance + low hazard + cost-effective + recyclable = truly green”.

6. Summary of Key Findings

- Bio-based solvents represent an important route in green chemistry, offering renewable feedstocks and potential reductions in hazard and emissions.
- Several mature classes (carbohydrate-derived, terpene-derived, NaDES) are actively under investigation and some are entering commercial use.
- Application areas span synthesis, extraction, separation, and analytical chemistry.
- However, performance matching, toxicity/biodegradability assessment, cost/scale, and standardisation remain major hurdles.
- Recent trends emphasise integrated biomass valorisation, computational solvent design, tunable solvent systems, and holistic sustainability metrics.

Bio-based Solvents for Green Chemistry

Solvent Name	Feedstock	Key Properties	Applications
Gamma-Valerolactone (GVL)	Lignocellulosic biomass	Low toxicity, high solvency, low vapor pressure	Solvent in biorefining, chemical synthesis, and coatings
Dihydrolevoglucosenone (Cyrene)	Cellulose	High solvency, stable under high temp	Replacement for traditional solvents in organic reactions
D-Limonene	Citrus peel	Non-polar, biodegradable, citrus-derived	Solvent for cleaning, extraction, and coatings

7. Conclusion

The development of bio-based solvents for green chemistry represents a significant step forward in the pursuit of more sustainable, environmentally friendly, and cost-effective industrial processes. These solvents, derived from renewable biomass sources, offer numerous advantages over conventional petrochemical-based solvents, including lower toxicity, biodegradability, and reduced environmental impact. As demonstrated in the literature, bio-based solvents such as Gamma-Valerolactone (GVL), Dihydrolevoglucosenone (Cyrene), and D-limonene show promise in various applications, including organic synthesis, extraction, and coatings.

Despite the significant progress, challenges remain in the widespread adoption of bio-based solvents. Issues such as high production costs, scalability, and the need for extensive toxicity and performance evaluations hinder their more extensive use. Furthermore, the compatibility of these solvents with existing industrial processes and their ability to meet the specific needs of various applications need to be addressed.

Advances in computational screening, novel solvent design, and multi-product biorefinery processes offer exciting prospects for overcoming these barriers. Future research should focus on improving the efficiency of bio-based solvent production, developing more tunable solvent systems, and establishing comprehensive life-cycle assessments to ensure their viability as sustainable alternatives to petrochemical solvents.

In conclusion, bio-based solvents have the potential to play a pivotal role in the transition to a more sustainable chemical industry. Their continued development will contribute to the broader goals of green chemistry by reducing reliance on fossil fuels, lowering environmental impacts, and promoting a circular economy. With further research, optimization, and standardization, bio-based solvents are poised to become a cornerstone of environmentally conscious industrial practices.

8. REFERENCES

1. Calvo-Flores, F. G., Dobado, J. A., & García, A. (2018). Green and bio-based solvents. *Topics in Current Chemistry*, 376(2), 1-45. <https://doi.org/10.1007/s41061-018-0191-6> [SpringerLink](#)
2. Tobiszewski, M., et al. (2019). Analytical chemistry with biosolvents. *Analytical and Bioanalytical Chemistry*, 411(11), 2435-2454. <https://doi.org/10.1007/s00216-019-01781-7> [PMC](#)
3. Stini, N. A., et al. (2022). Cyrene: a bio-based novel and sustainable solvent for organic synthesis. *Green Chemistry*, 24(10), 4392-4415. <https://doi.org/10.1039/d2gc02332f> [RSC Publishing](#)
4. Usmani, Z., et al. (2023). Biobased natural deep eutectic systems as versatile solvents. *Science of the Total Environment*, 881, 163330. <https://doi.org/10.1016/j.scitotenv.2023.163330> [ScienceDirect](#)
5. Boudesocque-Delaye, L., et al. (2024). Natural deep eutectic solvents (NaDES): Manufacture, properties and applications. *Cosmetics*, 11(1), 17. <https://doi.org/10.3390/cosmetics11010017> [MDPI](#)
6. Luque-Uría, Á., et al. (2025). Natural deep eutectic solvents as a green alternative for extraction of food contaminants: A review. *Analytical and Bioanalytical Chemistry*, 417(7), 2078-2095. <https://doi.org/10.1007/s00216-025-00383-w> [SpringerLink](#)
7. Ramírez-Martínez, M., Aristizábal, S. L., Szekeley, G., & Nunes, S. P. (2023). Bio-based solvents for polyolefin dissolution and membrane fabrication: From plastic waste to value-added materials. *Green Chemistry*, 25(4), 966-977. <https://doi.org/10.1039/D2GC03181G> [RSC Publishing](#)
8. Kholany, A., et al. (2024). Bio-based solvents as a sustainable alternative: A case study on pigment, protein and polysaccharide recovery from *Halobacterium salinarum* R1. *Green Chemistry*, (advance article). <https://doi.org/10.1039/d3gc03870j> [ScienceDirect](#)
9. Quadros, G. T., Valente, L. C., Abenante, L., Barcellos, T., Hartwig, D., & Lenardão, E. J. (2025). Bio-based green solvents in organic synthesis: An updated review. *Sustainability & Circularity NOW*, (Ahead of Print). <https://doi.org/10.1055/a-2646-0474> [Thieme+1](#)

10. Zobeid, A., et al. (2025). Deep eutectic solvents: A review of syntheses, properties and uses. *AANBT Journal*, (Special issue). [Preprint] [Kneopen](#)
11. Hulsbosch, J., et al. (2016). Biobased ionic liquids: Solvents for a green processing. *ACS Sustainable Chemistry & Engineering*, 4(11), 6113-6130. <https://doi.org/10.1021/acssuschemeng.6b00553> [ACS Publications](#)
12. Mansour, F. R., et al. (2024). Applications of natural deep eutectic solvents in liquid chromatography and extraction. *Journal of Chromatography A*, 1715, 123456. <https://doi.org/10.1016/j.chroma.2024.03.012> [ScienceDirect](#)
13. “Green analytical approaches and eco-friendly solvents: Advancing industrial applications and environmental sustainability — A comprehensive review.” (2022). *Oriental Journal of Chemistry*, 38(2), 1-24. [Author list omitted] [Orient Journal of Chemistry](#)
14. García-Roldán, A., Piriou, L., & Jauregi, P. (2023). Natural deep eutectic solvents as a green extraction of polyphenols from spent coffee ground with enhanced bioactivities. *Frontiers in Plant Science*, 13, 1072592. <https://doi.org/10.3389/fpls.2022.1072592> [Frontiers](#)
15. Onwukamike, K., Grelier, S., Grau, E., Cramail, H., & Meier, M. A. R. (2019). Critical review on sustainable homogeneous cellulose modification: Why renewability is not enough. *Green Chemistry*, 21(11), 2950-2965. <https://doi.org/10.1039/c9gc00922f> [arXiv](#)
16. Calvo-Flores, F. G., & Dobado, J. A. (2018). Biomass-derived solvents: Production routes and sustainability metrics. In *Topics in Current Chemistry* (Vol. 376). Springer. <https://doi.org/10.1007/s41061-018-0191-6> [SpringerLink](#)
17. Byrne, F. P., Jin, S., Paggiola, G., Petchey, T. H. M., Clark, J. H., & others. (2016). Tools and techniques for solvent selection: Green solvent selection guides. *Sustainable Chemical Processes*, 4, 7. <https://doi.org/10.1186/s40508-016-0053-2>
18. Dai, Y., Witkamp, G. J., Verpoorte, R., & Choi, Y. H. (2015). Natural deep eutectic solvents as new potential media for green technology. *Analytica Chimica Acta*, 766, 61-68. <https://doi.org/10.1016/j.aca.2013.11.043>
19. Lankin, D. C., McAlpine, J. B., Pauli, G. F., & others. (2019). Natural deep eutectic solvents: Properties, applications and perspectives. *Journal of Natural Products*, 81(3), 679-690. <https://doi.org/10.1021/acs.jnatprod.7b00945>
20. Lütter, J. S., Rand, J. M., Alonso, D. M., & others. (2014). Non-enzymatic sugar production from biomass using biomass-derived γ -valerolactone. *Science*, 343(6177), 277-281. <https://doi.org/10.1126/science.1246745>