IJARSCT
International Journal of Advanced Research in Science, Communication and Technology
International Open-Access, Double-Blind, Peer-Reviewed, Refereed, Multidisciplinary Online Journal
ISSN: 2581-9429
Volume 6, Issue 5, September 2026
Impact Factor: 8.2

Eco-Friendly Solvents in Materials Synthesis and Environmental Remediation: A Review of Green Alternatives to Conventional Organic Solvents

Khushi Pandey[1] and Aditya Khanna[2]
[1]Department of Chemistry,
Satish Pradhan Dnyanasadhana College, Thane, Maharashtra, India
[1]khushipandey1826@gmail.com, [2]khannasaditya@gmail.com

Abstract : *Chemical synthesis and industrial processing still lean heavily on conventional organic solvents, and that dependence carries a real cost in pollution, toxicity, and resource use. Green chemistry has responded with a growing set of eco-friendly solvent systems that cut hazard without giving up much synthetic performance. Here we take stock of where that effort currently stands: deep eutectic solvents (DES), ionic liquids, aqueous and bio-derived solvents such as glycerol derivatives and Cyrene, and solvent-free mechanochemical routes, illustrated with representative reaction schemes for each. Each class is weighed on tunability, biodegradability, cost, and scalability against legacy volatile solvents such as DMF and toluene. Two case studies anchor the discussion in numbers rather than generalities: green-solvent synthesis of the zeolitic imidazolate framework ZIF-8, where BET surface area and yield are compared across DMF, methanol, water, acetic acid, glycerol carbonate, and mechanochemical routes; and green-solvent-modified biochar/biosorbents for heavy metal removal, compared by maximum adsorption capacity reported in the literature. Tables and figures throughout show how solvent choice shapes crystallinity, textural properties, and pollutant-removal performance. We close by discussing what still holds the field back — cost, viscosity, leaching, and gaps in life-cycle assessment — and where it appears to be heading, including hybrid solvent systems and computational solvent selection. The aim is a practical, quantitatively grounded reference for choosing greener solvents in synthesis and remediation work.*

Key Words: eco-friendly solvents, deep eutectic solvents, ionic liquids, green chemistry, metal-organic frameworks, environmental remediation, mechanochemistry, biosorption

1. INTRODUCTION

In a typical chemical synthesis or industrial process, solvents make up most of the mass involved, and their environmental, health, and safety footprint is now seen as one of the biggest single drags on the sustainability of the chemical industry as a whole [1]. Solvents such as N,N-dimethylformamide (DMF), N-methyl-2-pyrrolidone (NMP), dimethyl sulfoxide (DMSO), and toluene work well as synthesis media, but each comes with a well-known downside — reproductive toxicity, poor biodegradability, or regulatory restriction, as under the European Union's REACH programme [2]. Concerns like these, alongside the twelve principles of green chemistry that Anastas and Warner set out, have kept research into solvent alternatives moving — alternatives that keep the synthetic usefulness of the old solvents while cutting the hazard substantially [1,3].

Over the past twenty years or so, that search has grown from scattered proof-of-concept papers into a genuine toolbox: deep eutectic solvents (DES), ionic liquids (ILs), aqueous and bio-derived molecular solvents, and solvent-free mechanochemical strategies that do away with liquid media entirely. None of these is a universal winner — each trades

IJARSCT
International Journal of Advanced Research in Science, Communication and Technology
International Open-Access, Double-Blind, Peer-Reviewed, Refereed, Multidisciplinary Online Journal
ISSN: 2581-9429 Volume 6, Issue 5, September 2026 Impact Factor: 8.2

off tunability, cost, biodegradability, and scalability differently, so the right choice really depends on the synthetic or separation task in front of you [4].

This review pulls together recent developments across these eco-friendly solvent classes, with reaction schemes showing how each one is generated or used, and pays particular attention to two application areas central to materials and environmental chemistry: green routes to porous functional materials — metal-organic frameworks (MOFs) in particular — and the use of green solvents in extraction- and adsorption-based remediation, covering heavy metal and dye removal from wastewater. Two quantitative case studies, backed by comparative tables and figures, keep the discussion tied to measurable outcomes rather than general claims.

II. DEEP EUTECTIC SOLVENTS (DES)

A deep eutectic solvent is made by pairing a hydrogen bond acceptor — usually a quaternary ammonium salt such as choline chloride (ChCl) — with a hydrogen bond donor such as urea, glycerol, or a carboxylic acid; the resulting eutectic mixture melts at a much lower temperature than either component does on its own [5,6]. DES were first reported in the early 2000s and get grouped with ionic liquids because of their similarly ionic character, but in practice they tend to be cheaper, easier to make, less toxic, and biodegradable — many are built from naturally occurring metabolites, which is where the term natural deep eutectic solvent, or NADES, comes from [5,7].

Scheme 1 sketches out how a classical ChCl-based DES forms: the ammonium salt and the hydrogen bond donor come together through hydrogen bonding rather than any new covalent bond. Extensive hydrogen bonding between the chloride ion and the donor's -OH or -NH groups spreads out the anion's charge and breaks up the crystal lattice of both components — which is exactly why a liquid appears at room temperature even though you started with two solids.

$$ChCl\ (s) + 2\ HOCH2CH2OH\ (l) \rightarrow [ChCl \cdot 2(HOCH2CH2OH)]\ (l)$$

Scheme 1. A choline chloride-ethylene glycol deep eutectic solvent forming (ChCl : EG, 1:2 molar ratio) through hydrogen-bond complexation.

The range of processes DES have been put to work in is unusually wide: extraction media for bioactive compounds and metals, reaction media and catalysts in organic synthesis, biodiesel production, electrochemical energy storage, and, more recently, nanomaterial and functional-polymer synthesis [6,8,9]. Table 1 summarizes representative DES compositions and their principal application areas.

Table 1. Representative deep eutectic solvent (DES) compositions and reported applications.

HBA	HBD	Molar ratio	Principal application	Ref.
Choline chloride	Urea	1:2	Metal oxide/biopolymer dissolution, extraction media	[5]
Choline chloride	Ethylene glycol	1:2	Electropolishing, electrochemical energy storage	[6]
Choline chloride	Glycerol	1:2	Bioactive compound extraction (NADES)	[7]
p-TsOH · H2O	Choline chloride	1:1	Biochar production from lignocellulosic biomass	[52]
Choline chloride	Citric acid	1:1	Biochar surface modification for pollutant adsorption	[53]

What makes them attractive is low volatility, polarity that can be tuned just by picking a different component pair, good thermal stability, and recyclability. On the downside, they tend to be fairly viscous — which slows mass transfer — and can degrade in aqueous media after repeated use [5]. A growing set of life-cycle assessments also warns that not every DES is unambiguously green once you account for production and disposal in full, which really argues for judging each one on its own merits rather than assuming greenness as a given [10].

III. IONIC LIQUIDS

Ionic liquids are salts that melt below 100 °C, usually built from bulky organic cations — imidazolium, ammonium, phosphonium — paired with one of a range of anions. Because their vapor pressure is negligible and their polarity and thermal stability can be tuned, they have become a go-to replacement for volatile organic solvents in extraction and

IJARSCT
International Journal of Advanced Research in Science, Communication and Technology
International Open-Access, Double-Blind, Peer-Reviewed, Refereed, Multidisciplinary Online Journal
ISSN: 2581-9429 Volume 6, Issue 5, September 2026 Impact Factor: 8.2

separation work, particularly where the goal is recovering metal ions or organic pollutants from an aqueous stream [11,12].

In remediation contexts specifically, ionic liquids show up both in straightforward liquid–liquid extraction and in supported liquid membrane setups aimed at pulling heavy metals selectively out of wastewater. Table 2 pulls together extraction performance figures reported for several such systems.

Table 2. Representative ionic liquid systems applied to heavy metal extraction/removal from aqueous streams.

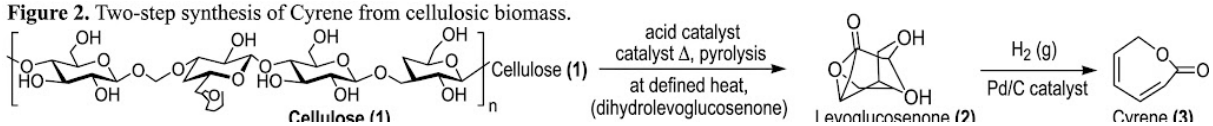
Ionic liquid system	Target metal(s)	Reported efficiency	Ref.
[OMIM][PF6]-based emulsion liquid membrane	Heavy metals (mixed)	70.4% removal in 5 min	[13]
Trioctylammonium carboxylate IL	Multiple heavy metal ions	Effective multi-metal removal	[27]
IL-based aqueous biphasic system	Zn(II), Cd(II)	>99.5% extraction, fast kinetics	[14]
3-hydroxy-2-naphthoate task-specific ILs	Cu, Zn, Cr, rare earths	High selectivity; leaching remains a limitation	[15]

Task-specific ionic liquids, designed with functional groups selective for particular metal ions, have improved extraction efficiency and selectivity, although leaching of the IL phase into the aqueous phase during extraction remains a recognized drawback that can offset their green credentials if not controlled [14,15]. Ionic liquids combined with natural deep eutectic solvents have also been reviewed as a joint strategy for organic pollutant and heavy metal removal, reflecting a broader trend toward hybridizing green solvent classes for improved performance [16]. Cost remains a significant barrier to industrial-scale adoption relative to conventional solvents, and IL "greenness" must therefore be assessed on a structure-by-structure basis rather than assumed as a class property [11,15].

IV. AQUEOUS AND BIO-BASED SOLVENTS

Water is about as non-toxic and abundant a solvent as exists, and a fair amount of research effort has gone into reworking syntheses that were historically run in DMF, DMA, or toluene so that they work in aqueous or hydro-alcoholic media instead [17]. Beyond water, a class of bio-derived molecular solvents has emerged as direct, drop-in replacements for the most problematic dipolar aprotic solvents. Cyrene (dihydrolevoglucosenone) is the most prominent example, produced from cellulose-containing biomass in two steps (Scheme 2): acid-catalyzed pyrolysis of cellulose to levoglucosenone, followed by selective catalytic hydrogenation of the enone double bond [18,19].

Figure 2. Two-step synthesis of Cyrene from cellulosic biomass.



Scheme 2. Two-step manufacture of the bio-based solvent Cyrene from non-food cellulosic biomass.

Cyrene closely reproduces the polarity of DMF and NMP without their associated reproductive toxicity, and has been demonstrated in cross-coupling reactions, graphene exfoliation, polymer synthesis, and battery-material recovery [18,19,20]. Cyrene, notably, has been used directly as a green stand-in for DMF in MOF synthesis specifically — which is exactly the kind of materials chemistry taken up in Section 6 [21]. Other bio-based solvents under active investigation include 2-methyltetrahydrofuran (2-MeTHF) as a renewable substitute for THF, glycerol and its derivatives (including glycerol carbonate) as low-toxicity reaction media, and terpene-derived solvents such as limonene [20,9,48].

IJARSCT
International Journal of Advanced Research in Science, Communication and Technology
International Open-Access, Double-Blind, Peer-Reviewed, Refereed, Multidisciplinary Online Journal
ISSN: 2581-9429
Volume 6, Issue 5, September 2026
Impact Factor: 8.2

V. SOLVENT-FREE MECHANOCHEMICAL APPROACHES

The most radical approach to solvent greening is to eliminate solvent altogether. Mechanochemistry, most commonly implemented through ball milling, drives chemical transformations using mechanical energy rather than a liquid reaction medium, and has been demonstrated across organic synthesis, heterocyclic chemistry, pharmaceutical intermediate preparation, nanoparticle synthesis, and coordination chemistry [22,23]. A representative solvent-free coordination reaction is the mechanochemical assembly of a zeolitic imidazolate framework directly from its solid metal salt and ligand (Scheme 3), in which milling energy substitutes for the solvation and diffusion step that a liquid medium would otherwise provide.

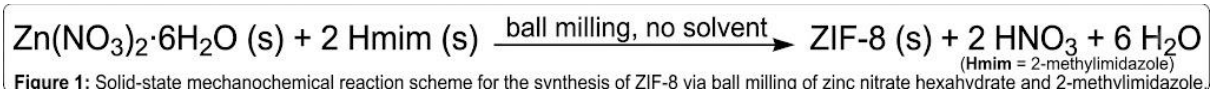


Figure 1: Solid-state mechanochemical reaction scheme for the synthesis of ZIF-8 via ball milling of zinc nitrate hexahydrate and 2-methylimidazole.

Scheme 3. Solvent-free mechanochemical synthesis of ZIF-8 (Hmim = 2-methylimidazole) by ball milling.

Ball milling offers several practical advantages: it eliminates solvent waste and associated disposal costs, can access reaction pathways not readily available in solution, often shortens reaction times, and in several documented cases produces materials with comparable or superior crystallinity and surface area to solution-based synthesis [22,24]. Remaining challenges for mechanochemical routes include reaction monitoring during milling, equipment wear, and scale-up from laboratory batch quantities to industrially relevant volumes [23].

VI. CASE STUDIES: GREEN SOLVENTS IN MATERIALS SYNTHESIS AND REMEDIATION

6.1 Case Study I — Green-Solvent Synthesis of ZIF-8

ZIF-8, a zeolitic imidazolate framework built from Zn2+ nodes and 2-methylimidazolate linkers, is among the most extensively benchmarked MOFs for comparing solvent effects because it has been synthesized via essentially every green and conventional route reported to date [24,45,46,49,50]. Table 3 collates BET surface area and yield data reported for ZIF-8 prepared under conventional DMF-based solvothermal conditions versus several greener alternatives, and Figure 1 visualizes the surface area comparison.

Table 3. Comparison of textural properties of ZIF-8 synthesized via conventional and green solvent routes.

Solvent / method	Conditions	BET surface area (m^2/g)	Yield	Ref.
DMF (solvothermal)	140 °C, 24 h	~1300	~30%	[43]
Methanol (solvothermal)	Room temp.–65 °C	~1000	Moderate	[46]
Water (aqueous, surfactant-free)	Room temp., 2 L batch	~780 (high uniformity)	High, scalable	[45]
Acetic acid (aqueous, polar)	Room temp.	~500 (mesoporous)	Uniform 65 nm particles	[46]
Glycerol carbonate (bio-based)	Mild heating	660	Comparable to DMF/water	[48]
Dry-gel / mechanochemical (solvent-free)	Ball milling / vapor-assisted	1306–1450	~84%	[44,49]

IJARSCT
International Journal of Advanced Research in Science, Communication and Technology
International Open-Access, Double-Blind, Peer-Reviewed, Refereed, Multidisciplinary Online Journal
ISSN: 2581-9429
Volume 6, Issue 5, September 2026
Impact Factor: 8.2

Figure 1. BET Surface Area of ZIF-8 Synthesized Using Conventional vs. Green Solvents / Solvent-Free Routes

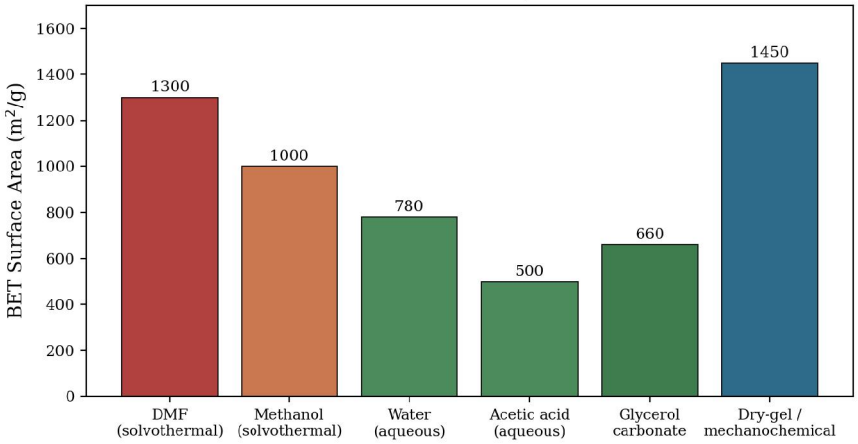


Figure 1. BET surface area of ZIF-8 synthesized using conventional DMF-based solvothermal synthesis compared with greener alternatives (data compiled from refs. [43–46,48,49]).

These data indicate that solvent-free and dry-gel mechanochemical routes are the only green alternatives that match or exceed the surface area obtained in DMF, while also improving yield roughly threefold [44,49]. Purely aqueous and bio-based routes trade some surface area and porosity for a substantially reduced environmental and toxicological footprint, which may be an acceptable compromise depending on the intended application of the framework [45,46,48].

6.2 Case Study II — Green-Solvent-Modified Biosorbents for Heavy Metal Removal

Green solvents also play a direct role in environmental remediation processes, both as extractants for pollutant recovery (Section 3) and as processing media in the preparation of biosorbent materials such as biochar. DES-assisted production and modification of biochar from lignocellulosic biomass has been reported to substantially enhance adsorption capacity relative to unmodified biochar, and Table 4 compares maximum adsorption capacities (Qm) reported for several green-solvent-processed biosorbents against heavy metal ions, visualized in Figure 2.

Table 4. Maximum adsorption capacity (Qm) of green-solvent-processed biosorbents for heavy metal ions, fitted to the Langmuir isotherm model in the cited sources.

Biosorbent	Modification / solvent	Target ion	Qm (mg/g)	Ref.
Lignocellulosic biochar	Acidic DES (p-TsOH:ChCl), 140 °C	Cr(VI)	270.3	[52]
Rice husk biochar	DES + Fe3O4/ZnO nanocomposite	Pb(II)	113.6	[54,55]
Humulus scandens biochar	Molten-salt method	Pb2+	748	[59]
Cassava root husk biochar	ZnO nanoparticle loading	Pb(II)	44.3	[60]
Sewage sludge biochar	Solvent-free synthesis, 45 °C	Pb2+	151.5	[58]

IJARSCT
International Journal of Advanced Research in Science, Communication and Technology
International Open-Access, Double-Blind, Peer-Reviewed, Refereed, Multidisciplinary Online Journal
ISSN: 2581-9429
Volume 6, Issue 5, September 2026
Impact Factor: 8.2

Figure 2. Maximum Adsorption Capacities of Green-Solvent-Modified Biosorbents Reported for Heavy Metal Removal

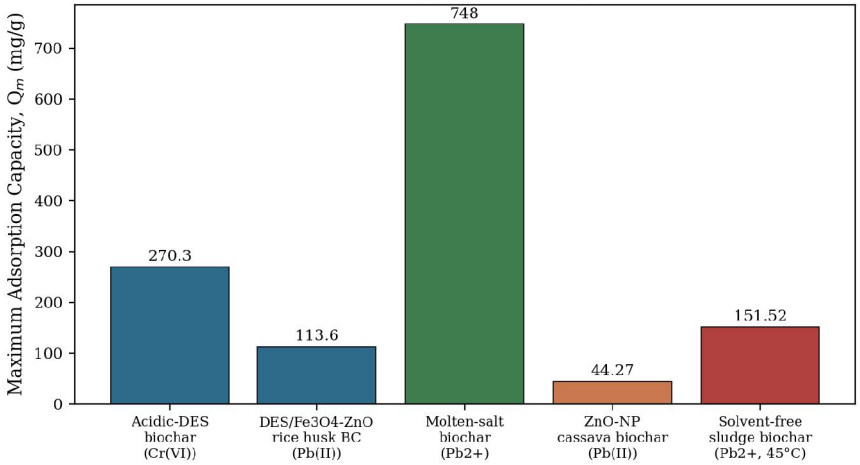


Figure 2. Maximum adsorption capacities (Qm) reported for green-solvent-modified biosorbents against target heavy metal ions (data compiled from refs. [52,54,55,58,59,60]).

The wide spread in Qm values across Table 4 reflects the strong dependence of adsorption performance on feedstock, pyrolysis conditions, and the specific surface chemistry introduced by the green-solvent modification step, rather than on the choice of green solvent alone. Nonetheless, in every case reported here the DES- or solvent-free-processed biosorbent achieved adsorption capacities comparable to, or exceeding, values typically reported for biochars modified using conventional acid or organic-solvent treatments, supporting the case that solvent greening need not come at the cost of remediation performance [52,54,58,59]. This reinforces the broader point made in Section 6.1: aligning solvent choice across both the synthesis of a functional material and the extraction or activation step used to prepare or regenerate it is an important, and currently under-exploited, strategy for designing genuinely green remediation systems.

VII. CHALLENGES AND FUTURE OUTLOOK

Table 5. Summary of principal advantages and limitations of the eco-friendly solvent classes discussed in this review.

Solvent class	Key advantage	Key limitation
Deep eutectic solvents	Low cost, biodegradable, tunable via component pairing	High viscosity; aqueous-phase degradation
Ionic liquids	Negligible vapor pressure; high selectivity via task-specific design	High cost; leaching during extraction
Aqueous / bio-based (e.g., Cyrene)	Low toxicity; renewable feedstock; drop-in DMF/NMP replacement	Somewhat lower surface area/porosity in some MOF syntheses
Solvent-free mechanochemical	No solvent waste; comparable or superior yield/surface area	Scale-up, monitoring, and equipment wear challenges

Beyond the class-specific limitations summarized in Table 5, three cross-cutting challenges stand out. First, life-cycle uncertainty: green solvent status is frequently asserted without full cradle-to-grave life-cycle assessment, and some DES and IL systems show meaningfully different sustainability profiles once synthesis and disposal are included [10]. Second, standardization: comparative, standardized benchmarking of green solvent performance against conventional solvents — across yield, selectivity, and E-factor — remains limited, making solvent selection guidance inconsistent

IJARSCT
International Journal of Advanced Research in Science, Communication and Technology
International Open-Access, Double-Blind, Peer-Reviewed, Refereed, Multidisciplinary Online Journal
ISSN: 2581-9429 Volume 6, Issue 5, September 2026 Impact Factor: 8.2

across research groups. Third, economics: production costs for ionic liquids and many DES formulations remain above those of legacy solvents at current manufacturing scale, which continues to slow industrial adoption despite favourable laboratory-scale performance.

Looking ahead, some of the more promising directions are hybrid solvent systems that pair two or more green solvent classes to cancel out each other's weaknesses (IL–NADES mixtures, for instance), computational solvent selection using predictive tools such as COSMO-RS, and further expansion of bio-based dipolar aprotic solvents such as Cyrene into new reaction classes [9,16,20]. Wider adoption will likely depend as much on economic and regulatory drivers, such as REACH restrictions on legacy solvents, as on further technical optimization [2].

VIII. CONCLUSION

Eco-friendly solvents and processes have progressed from a niche green chemistry concern to a practically viable toolbox spanning deep eutectic solvents, ionic liquids, bio-based molecular solvents, and solvent-free mechanochemical routes. The quantitative case studies presented here — green-solvent synthesis of ZIF-8 and DES-modified biosorbents for heavy metal removal — demonstrate that green solvent chemistry can deliver textural and remediation performance comparable to, and in several documented cases exceeding, conventional approaches, while substantially reducing environmental and toxicological burden. Continued progress will depend on closing life-cycle assessment gaps, reducing production costs, and standardizing performance benchmarks, but the trajectory of the field points firmly toward eco-friendly solvents becoming the default rather than the alternative choice in synthetic and remediation chemistry.

REFERENCES

[1] Anastas, P. T.; Warner, J. C. Green Chemistry: Theory and Practice; Oxford University Press: Oxford, 1998.
[2] MilliporeSigma. Cyrene™: A New Bio-based Dipolar Aprotic Solvent, Sigma-Aldrich Green Chemistry Nexus; REACH Substances of Very High Concern listing for DMF and NMP.
[3] Demir, D.; Antos, J.; Švec, F.; Sklenářová, H. Recent Developments in Deep Eutectic Solvents Applications in Liquid Chromatography: 2019–2025. J. Sep. Sci. 2025, DOI: 10.1002/jssc.70160.
[4] Chen, Z.; Mu, T. Green solvents design principles applied to solvent selection. Curr. Opin. Green Sustain. Chem. 2021.
[5] Abbott, A. P. Deep eutectic solvents and their application in electrochemistry. Curr. Opin. Green Sustain. Chem. 2022, 36, 100649.
[6] dela-Huerta-Sainz, S. et al. Deep Eutectic Solvents: A Review of Fundamentals and Applications. Chem. Rev. (ACS).
[7] Mota, F. G.; Rebelatto, E. A.; Benvenutti, L.; Ibáñez, E.; Ferreira, S. R. S.; Lanza, M. Monoterpenoid-Based DES/NADES: A Review. ACS Omega 2026, DOI: 10.1021/acsomega.5c10885.
[8] Design Strategy and Application of Deep Eutectic Solvents for Green Synthesis of Nanomaterials. Molecules/MDPI, 2023.
[9] Weerasinghe, U. A.; Wu, T.; Chee, P. L.; Yew, P. Y. M.; Lee, H. K.; Loh, X. J.; Dan, K. Deep eutectic solvents towards green polymeric materials. Green Chem. 2024, 26 (15), 8497–8527.
[10] Are deep eutectic solvents really green?: A life-cycle perspective. J. Energy Chem. 2023.
[11] Zhao, H.; Xia, S.; Ma, P. Use of ionic liquids as 'green' solvents for extractions. J. Chem. Technol. Biotechnol. 2005, 80, 1089–1096.
[12] White analytical chemistry (WAC): sample preparation with ionic liquids, deep eutectics and MOFs. Talanta 2024.
[13] A review on determination of heavy metal ions in wastewater using ionic liquids. J. Environ. Chem. Eng. 2020.
[14] Efficiently Removing Heavy Metals from High-Salinity Wastewater via Ionic Liquid-Based Aqueous Biphasic Systems. ACS Omega 2023, DOI: 10.1021/acsomega.3c01423.

IJARSCT
International Journal of Advanced Research in Science, Communication and Technology
International Open-Access, Double-Blind, Peer-Reviewed, Refereed, Multidisciplinary Online Journal
ISSN: 2581-9429 Volume 6, Issue 5, September 2026 Impact Factor: 8.2

[15] Novel 3-Hydroxy-2-Naphthoate-Based Task-Specific Ionic Liquids for an Efficient Extraction of Heavy Metals. Front. Chem. 2018, 6, 172.
[16] Ionic liquids and NADES for removal of organic pollutants and heavy metals in wastewater: A comprehensive review. J. Mol. Liq. 2023.
[17] Seed-aided green synthesis of metal-organic frameworks in water. Green Energy Environ. 2022.
[18] Camp, J. E. Cyrene: a bio-based novel and sustainable solvent for organic synthesis. Green Chem. 2022, 24, 6435–6457.
[19] Wang, Y.; Dai, M.; Luo, G. et al. Preparation and Application of Green Sustainable Solvent Cyrene. Chemistry (Switzerland) 2023, 5 (4), 2322–2346.
[20] Controlled Polymer Synthesis Toward Green Chemistry: ATRP in Biobased Substitutes for Polar Aprotic Solvents. ACS/PMC 2024.
[21] Zhang, J.; White, G. B.; Ryan, M. D.; Hunt, A. J.; Katz, M. J. Dihydrolevoglucosenone (Cyrene) as a Green Alternative to DMF in MOF Synthesis. ACS Sustain. Chem. Eng. 2016, 4 (12), 7186–7192.
[22] Sustainable and solvent-free synthesis of molecules of pharmaceutical importance by ball milling. Bioorg. Med. Chem. 2024.
[23] Ball-mill-assisted mechanochemical approaches for heterocyclic compound synthesis (2015–2024). Mol. Divers. 2025.
[24] Green synthesis of metal–organic frameworks: A state-of-the-art review of potential environmental and medical applications. Coord. Chem. Rev. 2020.
[25] Green and sustainable metal-organic frameworks (MOFs) in wastewater treatment: A review. Chem. Eng. J. 2025.
[26] Green Synthesis of Zeolitic Imidazolate Frameworks: A Review of Their Characterization and Industrial and Medical Applications. PMC, 2022.
[27] Effective elimination of multiple heavy metal ions from wastewater using circular liquid-liquid extraction based on trioctylammonium carboxylate ionic liquids. Sep. Purif. Technol. 2024.
[43] ZIF-8: A comparison of synthesis methods. Microporous Mesoporous Mater., ResearchGate.
[44] ZIF-8: A comparison of synthesis methods (dry-gel and mechanochemical synthesis data). ScienceDirect.
[45] Kim, D. et al. Surfactant-Free, Size-Controllable, and Scalable Green Synthesis of ZIF-8 Particles in Water. Small Methods 2024, DOI: 10.1002/smtd.202400236.
[46] A comparative study on ZIF-8 synthesis in aqueous and methanolic solutions: Effect of temperature and ligand content. J. Porous Mater., ScienceDirect 2019.
[48] Synthesis of Zeolitic Imidazolate Framework-8 Using Glycerol Carbonate. ACS Sustain. Chem. Eng., PMC 2023.
[49] ZIF-8 solvothermal, dry-gel, and mechanochemical synthesis textural property comparison. J. Colloid Interface Sci., ScienceDirect 2015.
[50] Different view of solvent effect on the synthesis methods of ZIF-8 to tuning the crystal structure and properties. RSC Adv., PMC 2021.
[52] Production of biochar from lignocellulosic biomass with acidic deep eutectic solvent and its application as efficient adsorbent for Cr(VI). Bioresour. Technol. 2021.
[53] Mechanism of Antibiotic Removal from Wastewater by Choline-Based Deep Eutectic Solvents Modified Biochar. Water Air Soil Pollut. 2026.
[54] Rice husk biochar doped with deep eutectic solvent and Fe3O4/ZnO nanoparticles for heavy metal and diclofenac removal from water. Sep. Purif. Technol. 2024.
[55] Hinsene, H.; Bhawawet, N.; Imyim, A. Rice husk biochar doped with DES and Fe3O4/ZnO nanoparticles for heavy metal and diclofenac removal. Sep. Purif. Technol. 2024.
[58] Solvent-Free Synthesis of Magnetic Sewage Sludge-Derived Biochar for Heavy Metal Removal from Wastewater. PMC 2023.

IJARSCT
International Journal of Advanced Research in Science, Communication and Technology
International Open-Access, Double-Blind, Peer-Reviewed, Refereed, Multidisciplinary Online Journal
ISSN: 2581-9429
Volume 6, Issue 5, September 2026
Impact Factor: 8.2

[59] Humulus scandens-Derived Biochars for the Effective Removal of Heavy Metal Ions: Isotherm/Kinetic Study, Column Adsorption and Mechanism Investigation. PMC 2021.
[60] Enhanced simultaneous adsorption of As(III), Cd(II), Pb(II) and Cr(VI) ions using cassava root husk-derived biochar loaded with ZnO nanoparticles. RSC Adv., PMC.