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**Applications and Risk Assessments of Ionic Liquids in
Chemical and Pharmaceutical Domains: An Updated Overview****Faisal Al-Akayleh^a, Mayyas Al-Remawi^{a*}, Ahmed S. A. Ali Agha^b, Eyad S.
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Abstract: The objective of this review is to evaluate the toxicological profiles and environmental sustainability of Ionic Liquids for chemical applications. Data from in vitro assays, Danio rerio embryo tests and computational models were herein analyzed. The development and properties of 'green' Ionic Liquids were also assessed. Safety evaluations indicate that Ionic Liquids exhibit various toxicological behaviors, challenging the assumption that they are categorically safe for environmental exposure. 'Green' Ionic Liquids show enhanced biodegradability and lower ecotoxicity but are not universally benign. Some Ionic Liquids present toxicological properties that conflict with being environmentally safe. It is, therefore, essential to conduct comprehensive assessments before deeming them environmentally safe. Lifecycle management strategies incorporating circular economy principles are promising but require further validation and detailed analysis for sustainability confirmation.

Keywords: Ionic Liquids, Toxicological Assessment, Environmental Sustainability, Green Chemistry, Danio rerio Embryo Tests, Computational Toxicity Models.

Introduction**Overview of Ionic Liquids and Their Growing Use across Industries**

Ionic liquids (ILs), formally known as room-temperature molten salts, have witnessed an exponential increase in research focus, particularly in the field of chemistry, due to their unique physicochemical attributes such as low volatility, high thermal stability and solvation capabilities for a wide range of solutes^[1]. Comprised solely of ions, typically featuring a large, asymmetric cation and a versatile selection of inorganic or organic anions^[2], ILs have proven indispensable in diverse chemical applications. These applications range from their

role as solvents in synthetic reactions^[3], electrolytes in electrochemical cells^[4], chemical demulsification^[5], and media for catalysis^[6,7] to advanced materials in energy storage systems such as supercapacitors and batteries^[8]. Moreover, ILs find utility in extraction processes for bioactive compounds^[9–11], as well as in biocatalysis and targeted drug delivery^[12]. Additionally, ILs have been explored in therapeutic deep eutectic systems for pharmaceutical applications, such as the system of capric acid and menthol^[13]. Beyond drug delivery, ILs have also shown promise in other health-related applications. Recent work has revealed the potential of deep eutectic liquids as topical vehicles for substances like Tadalafil, with preliminary findings indicating both wound

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healing and antimicrobial activities^[14]. As an adjunct to the discussion on ionic liquids, it is worth noting that deep eutectic systems have also been under investigation for their potential in transdermal delivery, particularly concerning medications like Risperidone^[15,16]. While deep eutectic systems are not ILs, they share certain pharmacokinetic challenges and opportunities, making them a relevant consideration in comprehensive safety evaluations. Despite these advantages, the employment of ILs in chemical processes requires rigorous safety evaluations. The aqueous toxicity of ILs towards aquatic organisms has been established^[17] and challenges remain in their sustainable disposal^[18].

Physicochemical Properties of ILs and Their Implications for Safety and Hazard Assessment

ILs have gained recognition as an alternative to conventional solvents due to their unique physicochemical properties^[19] as shown in Figure 1. However, the potential risks posed by ILs on human health and the environment have raised concerns about their safety and hazard assessment^[20–22]. A systematic evaluation of these properties is imperative for ensuring the safe utilization of ILs in various chemical applications.

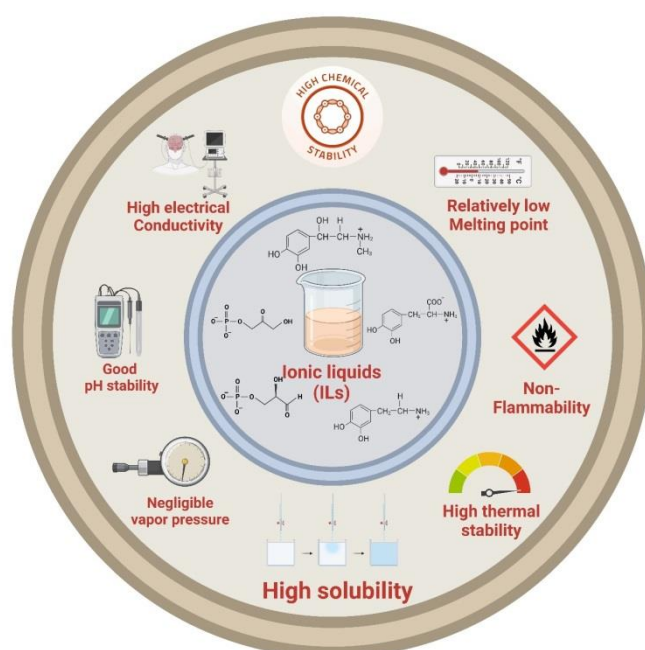


Figure 1. Physicochemical properties of Ionic Liquids and associated safety risks.

Solubility

The solubility of ILs is a key physicochemical property that must be taken into account for safety and hazard assessments. This factor has a direct effect on the distribution, toxicity and bioaccumulation potential of ILs in the body and environment^[23]. A variety of conditions, such as temperature^[24], pressure^[25] and the presence of other substances, can influence its solubility in water or other solvents like organic compounds or soils^[26,27]. Moreover, chemical structure features, including functional groups, provide further complexity to this process when designing ILs with specific properties suitable for various applications such as hydrophobic/hydrophilic solutions tailored

towards water/organic solvent needs respectively^[28]. Studies have also provided new insights into the single-phase formation of specific eutectic mixtures, enhancing our understanding of IL solubility^[29,30].

Recent studies have demonstrated correlations between high levels of ILs water soluble content resulting in elevated aquatic organism toxicity hazards^[18] and low degrees leading to reduced bioaccumulation risks^[31]. For these reasons, it is essential to thoroughly evaluate solubility along with any associated toxicological implications prior to utilization. Doing so will ensure safety during usage while simultaneously promoting sustainability through effective management practices.

Flammability and Explosivity

The non-flammability of ILs is often highlighted as a safety advantage over volatile organic compounds. However, the fact that many ILs are not flammable themselves does not mean that they are safe to use near fire and/or heat sources; a large group of ILs are combustible due to the nature of their positive heat of formation, oxygen content and decomposition products^[32].

Flammability and explosivity are key aspects to consider when performing a safety and hazard evaluation of ILs. ILs have become popular substitutes for traditional organic solvents due to their reduced flammability and explosive properties^[33]. However, certain characteristics of ILs can still lead them to be combustible or dangerous under extreme temperatures, pressures or contact with air or other reactive materials. The potential for an ILs to ignite is determined by its chemical composition^[34], functional groups such as nitro, halide and peroxide which increase the risk of oxidization/reduction reactions^[35], degree of saturation^[36], as well as the presence of hazardous impurities like water or oxygen^[34,37]. On the contrary, alkyl and aryl group based compounds tend not catch fire easily^[38]. To understand more deeply how different conditions affect an individual ILs reactivity, further research has been conducted on experiments related to ignition behavior, combustion and explosion. Through this data set, researchers were able to analyze the kinetic mechanisms behind this process better, thus enabling predictions about each compound's behaviour given specific scenarios^[39]. A comprehensive approach should be taken into account when assessing the hazards posed by ILs taking into account both their flammability and explosivity properties.

Thermal Stability and Decomposition

Thermal stability and decomposition are essential elements to consider when evaluating the safety and potential hazards of ILs. Such properties can significantly impact the risks associated with fire, explosion or toxic gas release during their handling, storage or use. Recent research has demonstrated that a range of factors may alter ILs thermal stability and decomposition behavior, such as chemical structure^[40,41], functional groups^[42] or contaminants from synthesis/handling/storage pro-

cesses^[19,32]. For instance, ILs containing halogenated/nitro-containing functional groups often exhibit lower thermal stability due to an increased risk of oxidation/reduction catalyzed decomposition. On the other side, alkyl or aryl functional groups tend to be more thermally stable with less hazardous degradation products as reported in Handa's study published in 2022^[43]. However, not only is purity key for overall performance, but also impurities can decrease this property drastically. To ensure the safe utilization of this class of compounds, experimental studies alongside modeling approaches have been developed which analyze them under various conditions, i.e., heating^[44], exposure to air^[12] and contact with other chemicals^[45]. By providing a deeper understanding of kinetic mechanisms, we can anticipate and predict behaviors. This paves the way for the development of uniform standards in quality control. These methods are essential for ensuring the sustainability of future applications.

Toxicity and Environmental Impact of Ionic Liquids: Current Understanding and Knowledge Gaps

The toxicity and biodegradability of ILs are critical factors to consider when assessing their safety and potential hazards, particularly in the realms of energy storage, drug delivery and green solvent industries. Unfortunately, some ILs can be highly toxic or resistant to biodegradation by natural microbial communities leading to detrimental effects on human health as well as environmental pollution. To counter this issue, safer alternatives were developed (Table 1), such as choline-based or amino acid derived ILs. Such classes of ILs showed improved biodegradability by hydroxyl or carboxyl functionalization^[46,47]. Incorporating both toxicity and biodegradability into our hazard assessment protocols for ILs applications across various industries, including biotechnology, pharmaceutical sciences and agriculture, enhances the promotion of these safe and sustainable solutions. Ultimately, this approach contributes to a more secure and sustainable future. Therefore it is essential that all stakeholders involved pay close attention towards these properties when evaluating the risks posed by various types of ILs, especially those containing halide/ammonium cations which show greater levels of toxicity than others^[48]. However, this

characterization is not unidimensional; some ionic liquids have exhibited antimicrobial properties, which could have both beneficial and adverse environmental implications. This dual nature complicates their risk assessment and necessitates a multi-faceted evaluation approach^[49]. With careful consideration taken towards both aspects combined with increased efforts from research teams worldwide, there is hope that cleaner and greener technologies will prevail over time.

In Vitro Assays Analyzing the Cytotoxicity of Ionic Liquids in Various Cancer Cell Lines

The investigation of the impact of ILs on biological systems has become a significant area of study in toxicology, highlighting the importance of understanding their cytotoxic properties. These investigations are relevant due to the increasing use of ILs in biomedical applications, such as their potential in cancer therapy and drug delivery systems. The assessment of ILs cytotoxicity on cancer cell lines through in vitro assays is crucial for understanding the molecular mechanisms of ILs-cell interactions and determining their suitability and safety in clinical settings. The assays cover a wide range of cellular functions and markers related to metabolic activity, membrane integrity, apoptotic induction, and genotoxic effects. Table 2 presents a summary of significant findings obtained from a range of in vitro assays with varying methodologies. The table emphasizes the varying cytotoxic effects of different ILs on multiple cancer cell lines. This data compilation offers valuable insights into the structure-activity relationships that govern the interactions between ILs and cellular systems. As a result, it informs the strategic design of ILs and facilitates the prediction of their potential systemic effects.

In Silico Methodologies for Elucidating the Toxicological Profile of Ionic Liquids

Advancements in computational toxicology have enhanced our understanding of the toxicological profiles of ILs. This section focuses on the advanced computational techniques that significantly contribute to the predictive toxicology of ionic liquids, as outlined in Table 3. The methodologies mentioned in this research involve advanced QSAR models that incorporate new molecular descriptors, machine learning algorithms for intricate pattern recogni-

tion, and molecular docking studies to understand the interaction dynamics between ILs and biological targets. These approaches, including high-throughput screening, adverse outcome pathway mapping, toxicogenomic profiling and metabolomics analyses, create a comprehensive computational arsenal. The table summarizes the innovative contributions and specific applicability of the stated contributions to ILs toxicity prediction.

Exposure Pathways and Risk Assessment for Ionic Liquids in the Occupational Exposure and Beyond

The use of ILs in the occupational exposure (toxicity) can be hazardous to workers, particularly those employed in industries that involve potential aerosol exposure or skin contact^[50]. To protect employees and reduce risk, it is essential to evaluate the risks posed by these substances and create effective risk management plans. It is necessary to thoroughly assess all associated dangers and develop appropriate strategies for minimizing or eliminating any potential health hazards. To ensure the safety of workers and minimize risk in industries with potential aerosol exposure or skin contact, it is essential to evaluate the dangers posed by ILs and implement rigorous risk management plans. Employers should conduct thorough assessments of all associated hazards, create effective strategies for minimizing them, provide staff with comprehensive training on how to safely handle such materials, as well as regularly monitor relevant areas. Taking these precautions when working with ILs can help businesses significantly reduce risks while promoting a secure environment for their workforce^[50]. This could include establishing exposure limits and standards, implementing engineering controls such as ventilation systems, and supplying adequate personal protective equipment. Also, periodic health surveillance is crucial in conjunction with these strategies. Routine physical exams, which include liver and renal function tests, as well as pulmonary function assessments, are integral to occupational health monitoring. Screenings aid in early detection of ILs exposure's adverse effects, enhancing safety protocols and ensuring continuous workforce protection. Despite these challenges, there have been some assessments conducted for specific ILs used industrially; for example, 1-butyl-3-methylimidazolium chloride (BMIM Cl) was

Table 1. A comparison of the toxicity profiles of ILs, outlining their constituent elements and toxicological effects.

Ionic Liquid	Cation	Anion	Toxicity Description	References
1-ethyl-3-methylpyrrolidinium bromide	Pyrrolidinium	Bromide	Moderate toxicity due to the lipophilic nature of the cation and the potential for bioaccumulation.	[51]
N, N-dimethyl-N-propyl-N-propylammonium tetrafluoroborate	Ammonium	Tetrafluoroborate	Low to moderate toxicity; persistence of the fluorinated anion can lead to bioaccumulation.	[52]
Cholinium acetate	Cholinium	Acetate	Low toxicity due to the natural occurrence of the cation and biodegradable anion.	[53]
N-butyl-N-methylmorpholinium	Morpholinium	Bromide	Moderate toxicity due to the lipophilic nature of the cation and the potential for bioaccumulation	[54]
1-butyl-1-methylpyrrolidinium bis(trifluoromethylsulfonyl)imide	Pyrrolidinium	Bis(trifluoromethylsulfonyl)imide	Moderate to high toxicity due to the lipophilic cation and persistence of the fluorinated anion.	[55]
1-hexyl-3-methylimidazolium hexafluorophosphate	Imidazolium	Hexafluorophosphate	Moderate toxicity due to the lipophilic nature of the cation; persistence of the fluorinated anion can lead to bioaccumulation.	[56]
1-butyl-3-methylimidazolium dicyanamide	Imidazolium	Dicyanamide	Moderate toxicity due to the lipophilic nature of the cation and the potential for bioaccumulation.	[57]
L-alanine methyl ester sulfate	Amino acid-based	Methyl ester sulfate	Low toxicity due to the biodegradable nature of the amino acid-based cation and the sulfate anion.	[58]
1-butyl-3-methylimidazolium thiocyanate	Imidazolium	Thiocyanate	Moderate toxicity due to the lipophilic nature of the cation and the potential for bioaccumulation.	[59]
1-butyl-3-methylimidazolium chloride	Imidazolium	Chloride	Moderate toxicity due to the lipophilic nature of the cation and the potential for bioaccumulation.	[60]

Table 2. Summary of in vitro assays analyzing the cytotoxicity of Ionic Liquids in various cancer cell lines.

Assay Type	Description	Cancer Cell Line	Endpoint Measured	IL Example	Key Findings	Ref
MTT Assay	Assesses cell metabolic activity as an indicator of cell viability.	MCF-7 (Breast)	Viability (Cell Metabolism)	1-butyl-3-methylimidazolium chloride	Reduced cell viability with increasing IL concentration.	[61]
Caspase Activity Assay	Quantifies apoptosis by measuring the activity of caspases, enzymes that play a role in programmed cell death.	HeLa (Cervical)	Apoptosis (Enzyme Activity)	N-butyl-N-methylpyrrolidinium bis(trifluoromethylsulfonyl)imide	Activation of caspase-3 and -7, suggesting apoptotic pathways.	[62]
Annexin V/PI Staining	Differentiates between live, early apoptotic, and late apoptotic or necrotic cells via flow cytometry.	A549 (Lung)	Apoptosis and Necrosis (Membrane Phospholipid Binding)	Cholinium acetate	High proportion of early apoptotic cells at lower IL concentration.	[63]
Comet Assay	Detects DNA damage via single-cell gel electrophoresis.	PC-3 (Prostate)	Genotoxicity (DNA Damage)	1-decyl-3-methylimidazolium chloride	DNA strand breaks indicative of genotoxicity.	[60]
JC-1 Assay	Assesses mitochondrial membrane potential, indicative of apoptosis.	SGC-7901 (Gastric)	Mitochondrial Dysfunction (Membrane Potential)	1-octyl-3-methylimidazolium tetrafluoroborate	Mitochondrial membrane depolarization suggesting early apoptosis.	[64]
Trypan Blue Exclusion	Viable cells exclude the dye, whereas dead cells do not.	MIA PaCa-2 (Pancreatic)	Viability (Membrane Integrity)	1-hexyl-3-methylimidazolium chloride	Elevated levels of dead cells reveal high cytotoxic potential.	[65]
ROS Generation Assay	Measures reactive oxygen species as stress markers.	U87MG (Glioblastoma)	Oxidative Stress (ROS Levels)	1-butyl-3-methylimidazolium tetrafluoroborate	Increased intracellular ROS, signifying oxidative stress.	[66]
BrdU Assay	Incorporates BrdU into DNA during replication; a measure of proliferation.	K562 (Leukemia)	Proliferation (DNA Synthesis)	1-butyl-3-methylimidazolium bromide	Inhibited DNA synthesis, suggesting anti-proliferative activity.	[67]

Table 3. Overview of contemporary In Silico strategies for Ionic Liquid toxicity prediction: Novel contributions and applications with key bibliographic references.

In Silico Approach	Novel Contribution	Application to Ionic Liquids	Ref
Enhanced QSAR Models	Incorporation of novel molecular descriptors and hybrid algorithms to improve prediction accuracy.	Application to predict specific toxicity endpoints of ionic liquids, such as mutagenicity and aquatic toxicity.	[68]
Machine Learning Algorithms	Use of deep learning techniques to understand complex biological interactions.	Deep neural networks applied to predict the pharmacokinetics and toxicodynamics of ionic liquids.	[69]
Molecular Docking Studies	Advanced simulation techniques to model ionic liquid interactions with biomolecular targets.	Use in assessing the potential enzyme inhibition caused by ionic liquids.	[70]
High-throughput Screening (HTS)	Automation and miniaturization of assays combined with computational analysis.	High-throughput virtual screening of ionic liquids to rapidly identify potential toxicological properties.	[71]
Adverse Outcome Pathways (AOPs)	Development of detailed mechanistic pathways from molecular interactions to adverse outcomes.	Construction of AOPs for ionic liquids to systematically predict their effects on health and environment.	[72]
Toxicogenomics	Integrating genomic data to understand the effects of chemicals on gene expression.	Application to ionic liquids for predicting their impact on cellular pathways and potential carcinogenicity.	[73]
Metabolomics Approaches	Analysis of small-molecule metabolites to understand the metabolic changes induced by chemicals.	Studying the metabolomic profile changes induced by ionic liquids to predict their toxicity.	[74]

found not likely to cause any health problems when concentrations remained below 1 mg/m³^[75]. Nonetheless, more detailed toxicological studies are needed on different types of ILs along with ways how best we can manage their risks. The use of such compounds continues increasing across industries but understanding their effects is critical if we want them utilized safely everywhere, from occupational exposure (toxicity) onwards. Considering this compelling need for action we must conduct further research into hazardous properties related to these materials plus establish exposure thresholds & directions alongside deploying successful hazard mitigation plans, all ensuring the safe utilization of such chemicals in a wide range of settings.

Regulatory Frameworks and Safety Standards for Ionic Liquids

As the utilization of ILs in multiple industries continues to expand, it becomes increasingly essential to develop regulatory frameworks and safety standards for their secure management and application. Currently, regulations such as the Toxic Substances Control Act (TSCA) in America and Registration, Evaluation, Authorization and Restriction of Chemicals (REACH) within Europe govern ILs. Additionally, organizations like the American Chemical Society and International Organization for Standardization provide guidelines and safety protocols concerning this matter. To ensure standards are upheld, these rules have been established to protect people from hazardous conditions associated with ILs. Even though there are no specific laws regarding ILs yet implemented at the present time, we must continue establishing policies while augmenting them with advanced techniques so that they can be applied safely.

Case Studies: Examples of Safety Challenges and Successful Risk Mitigation Strategies in Ionic Liquids Applications

This section shows several case studies to illustrate the potential safety issues related to ILs use and the methods that have been developed for risk mitigation. An example of such a case study is the utilization of ILs as electrolytes in lithium-ion batteries, which has demonstrated superior performance compared with traditional ones^[41,76,77]. However, certain types can react dangerously with lithium metal^[78], so researchers are utilizing ceramic membranes and optimizing

electrolyte composition to ensure safety. Another example involves using these liquids for natural product extraction. While they excel in this area, environmental toxicity and impact concerns exist. To address these worries, scientists created biodegradable variants and adjusted extraction parameters to reduce environmental footprint while maintaining sustainability standards. Additionally, pharmaceutical industry professionals' apprehension about human health impacts when using them as solvents in drug synthesis has resulted in safer options being developed along with optimized reaction conditions plus stringent laboratory protocols establishment for safe usage assurance. These cases highlight why it is essential to identify possible risks associated with employing ILs then establishing efficient countermeasures accordingly as shown in (Table 4). By following best practices learned from these examples and applying sufficient effort into their implementation, experts continue unlocking advantages from such materials without compromising on security aspects at all costs.

Assessing the Safety Profile of Ionic Liquids: A Comprehensive Overview

Standard protocols must also be established for the safe handling and disposal of these compounds, including guidelines concerning personal protective equipment (PPE), ventilation systems, storage methods, spill response plans etc. Moreover, emerging trends include incorporating these liquids into novel hybrid materials such as ILs-polymer composites which can enhance mechanical properties/stability^[79-81]. Similarly, they are being explored for nano-material synthesis^[82], electrochemistry^[83] and energy storage systems^[84,85]. Finally, there has been a shift towards integrating them into circular economy models through green chemistry approaches aimed at eliminating waste and the continual use of resources. Circular methods facilitate recycling, reuse, and remanufacturing, thus extending the lifecycle of products. In the context of ILs, circular economy strategies involve the design, application, and recycling of ILs in a manner that maximizes their efficiency while minimizing environmental impact. This may involve the creation of recyclable ILs or the implementation of closed-loop systems for ILs recovery and reuse. The integration of ILs in circular economy models can enhance industrial practices to align with

Table 4. A list of case studies that highlight the nature of risk associated with different ILs used in various industrial or academic settings, along with the corresponding mitigation strategies employed to minimize these risks.

Nature of Risk	ILs Used	Industry/Academic Setting	Mitigation Strategies	Ref.
Material incompatibility	[AMIM][OAc]	Chemical processing	Material compatibility testing, equipment selection	[86]
Resource depletion	[BMIM][Ac]	Cellulose processing	Resource management, recycling, process optimization	[87]
Inhalation toxicity	[HMIM][Tf2N]	Carbon capture	PPE, closed systems, engineering controls	[88]
Combustion hazard	[HMIM][Tf2N]	Fuel cell electrolyte	Inert atmosphere, fire suppression system	[89]
Gas emissions	[Pyr14][Br]	Absorption refrigeration	Leak detection, closed systems, proper ventilation	[90]
Eye irritation	[BMIM][TFA]	Analytical chemistry	PPE (safety goggles), training, emergency eyewash stations	[91]
Corrosion	[EMIM][Cl]	Metal surface coating	Equipment selection, PPE, ventilation	[92]
Thermal stability	[EMIM][Tf2N]	Solar energy storage	Temperature control, closed systems	[93]
Toxicity	[BMIM][Cl]	Nanoparticle synthesis	PPE, closed systems, waste treatment	[40]
Accidental ingestion	[EMIM][Lactate]	Food packaging	Employee training, proper labeling, and storage	[94]
Terrestrial ecotoxicity	[TEA][Tf2N]	Soil remediation	Ecotoxicity testing, risk assessment, mitigation measures	[95]
Explosive hazards	[EMIM][Ntf2]	Chemical synthesis	Ventilation, explosion-proof equipment	[96]
Health hazards	[DMIM][DMP]	Biomedical research	PPE, engineering controls, ventilation	[97]
Skin irritation	[BMIM][BF4]	Chemical manufacturing	Personal protective equipment (PPE), ventilation, training	[98]
Fire hazard	[OMIM][BF4]	Lithium-ion battery electrolyte	Inert atmosphere, fire suppression system	[99]
Environmental impact	[TEA][Lactate]	Chemical industry	Waste treatment, closed systems	[100]
Toxicity	[Proline][NO3]	Biotechnology	PPE, closed systems, engineering controls	[52]
Fire hazard	[EMIM][Ac]	Energy industry	Inert atmosphere, fire suppression system	[101]
Health hazards	[Choline][OAc]	Pharmaceutical industry	PPE, ventilation, training	[102]
Thermal stability	[DBU][Pro]	Environmental engineering	Temperature control, closed systems	[96]
Corrosion	[Choline][Lev]	Polymer industry	Equipment selection, PPE, ventilation	[52]
Occupational exposure	[DEME][Gly]	Textile industry	PPE, training, engineering controls, ventilation	[103]
Reactive hazards	[Pyr14][DCA]	Chemical synthesis	Inert atmosphere, reaction monitoring, temperature control	[104]
Waste generation	[EMIM][BF4]	Metal extraction	Waste minimization, closed systems, proper waste disposal	[105]
Environmental impact	[BMIM][PF6]	Pharmaceutical synthesis	Closed systems, waste treatment	[106]
Combustion hazard	[EMIM][EtSO4]	Bioenergy	Inert atmosphere, fire suppression system	[107]
Inhalation toxicity	[AMIM][Br]	Chemical industry	PPE, closed systems, engineering controls	[108]
Explosive hazards	[Pyr14][TFSI]	Energy industry	Ventilation, explosion-proof equipment	[109]
Groundwater contamination	[Choline][NO3]	Agrochemicals	Waste treatment, closed systems, spill containment	[110]
Skin irritation	[Choline][Gly]	Textile industry	PPE, training, ventilation	[111]

global sustainability goals^[112,113]. Overall, it is clear that further research needs to be done in order to ensure safer use of ILs while taking advantage of all their beneficial qualities. ILs have been the focus of much research in recent years due to their unique features and potential applications across numerous sectors^[114]. Nevertheless, like any other chemical substance, ILs can possibly cause harm to humans and the

environment when not used correctly^[18,115]; thus making it essential for a safety profile evaluation prior to widespread utilization. To evaluate this safety profile, various methods can be utilized including acute toxicity studies^[37], chronic toxicity studies^[116], genotoxicity tests^[117] and ecotoxicity assessments^[118], as shown in Figure 2, as well as biodegradation testing^[119].

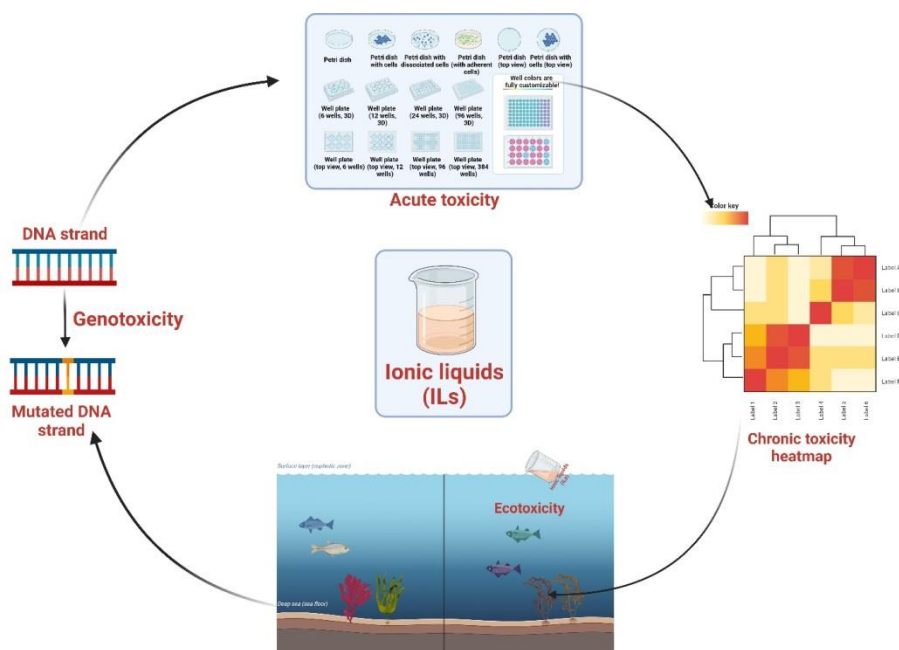


Figure 2. Classification of Ionic Liquid Toxicity Types for Safety Assessment.

Acute Toxicity Testing

One of the most commonly employed techniques for assessing potential risks associated with ILs is acute toxicity testing, which entails exposing test organisms to varying concentrations of these compounds over a limited time frame and observing their response^[37]. It is defined as the adverse effects that occur within a short period of time following oral or dermal administration of a single dose of a substance or multiple doses given within 24 hours^[120], or an inhalation exposure of 4 hours^[121]. Such tests can furnish useful information on the hazards that ILs may pose to people and nature^[122] while helping in devising appropriate safety protocols for proper handling of such substances. Nevertheless, the outcomes of acute toxicity studies are subject to

several factors including species and age of test subjects^[123], mode/route of exposure^[124], as well as physicochemical properties related to the tested ILs^[125]. It is thus essential that one takes an exhaustive yet prudent approach when evaluating the risk profile presented by these chemicals. Various other methods must also be used like chronic toxicity studies, genotoxicity analyses, or ecotoxicity evaluations alongside acute toxicology examinations. Although valuable in gauging short-term effects due to exposure, certain drawbacks exist within this framework; it does not take into consideration the chances of bioaccumulation or long-term repercussions caused by extended contact. To address such limitations researchers have taken up initiatives in developing novel tactics like 3D cell culture models^[126], zebrafish embryo toxicological assessments^[127] along with

computer modeling simulations based on In Silico methodologies^[126]. In contrast, Chronic Toxicology Studies probe deeper into possible consequences arising out of extensive durations spent under exposed conditions whereas Genotoxic evaluations assess the possibility of genetic mutations brought about via chemical agents, whilst ecotoxicological scans delve deep into likely environmental side effects posed by said exposures. Biodegradation experiments measure the capacity possessed to breakdown into simpler components.

Chronic Toxicity Testing

Ionic Liquids have been widely heralded as a promising source of compounds for industrial and consumer purposes, however it is critical to examine the potential risks posed by these substances before they enter widespread use. Chronic toxicity refers to the adverse health effects resulting from long-term exposure to a substance, where the duration can extend across a significant portion of the organism's lifetime^[128], which may result in gradual, cumulative damage to specific organ systems. Chronic toxicity testing provides invaluable data on the effects of long-term exposure to ILs and recent studies have yielded remarkable progress in this area^[116]. It has been found that chronic contact with certain ILs can cause considerable damage to organs such as the liver and kidneys^[118], changes in blood chemistry^[129] and modifications to behaviour or reproduction rates^[130]. This underscores the importance of further research into identifying effective methods for assessing chronic toxicity. Advanced techniques like in vitro models or computer simulations are being actively explored, due their ability to assess impact upon various biological systems with greater precision. Additionally, evaluations must be made concerning any environmental implications associated with using ILs, since traditional solvents may be more hazardous than expected, particularly when considering aquatic lifeforms which could suffer from significant harm caused by these chemicals^[17,131]. Thus, ongoing investigation is needed if safe application of ILs is ever going to become commonplace.

Genotoxicity Studies

Genotoxicity studies are a vital part of determining the safety of ILs. The tests provide key information about the potential for ILs to cause genetic damage, which can lead to cancer and other health issues^[117]. Recent research has indicated that certain ILs containing halogenated anions may induce DNA damage and mutations in bacterial and mammalian cells^[132], leading to concerns regarding their safety. Moreover, some ILs have been linked with chromosomal aberrations and other genetic harm in fish species^[133,134], suggesting possible environmental risks. The degree of genotoxicity differs among ILs compounds because it depends on factors such as chemical structure^[134], concentration^[134], exposure duration^[135] or route of exposure^[136]. Scientists use several types of assessments including in vitro assays using cells, in vivo studies employing animal models or molecular biology techniques for evaluating genotoxicity caused by these substances^[37]. Advances in high-throughput screening have also enhanced both accuracy and efficiency when conducting such experiments^[34]. These findings emphasize the need for ongoing investigations into this matter and developing effective systems for testing and managing risk related to utilizing them. To ensure safe utilization thereof across various applications, future research should focus on creating better strategies based upon current data gathered from reliable sources.

Ecotoxicity Studies

The potential ecological risks posed by ILs have raised serious concerns in recent years, prompting the need for an improved understanding of their ecotoxicity. To this end, researchers have developed innovative testing methods such as omics-based approaches to better assess ILs toxicity and its effects on organisms^[137]. The results suggest that several factors influence ILs ecotoxicity, including chemical structure^[138], concentration levels and duration of exposure^[139]. In particular, halogenated anions are more toxic than non-halogenated ones. Furthermore, bioaccumulation has been observed with certain types of ILs which can lead to detrimental environmental

outcomes. In addition to traditional laboratory tests for assessing ecotoxicity risk profiles associated with these materials, predictive models based on physicochemical properties and toxicity data have recently been developed in order to identify potentially hazardous substances from a larger collection of samples quickly and efficiently without the need for additional experimentation or analysis. These powerful tools enable scientists not only to screen numerous compounds but also provide vital information regarding their fate as well as possible impacts they might cause if released into the environment^[34,140]. It is essential that we continue our efforts towards developing novel strategies based on combining modern technologies with advanced mathematical techniques so that we can effectively manage risks related to the use of ILs while simultaneously advancing sustainable development initiatives^[140].

Biodegradation Testing

The use of ILs as alternatives to volatile organic solvents in industrial applications requires a thorough assessment of their biodegradability to address potential health and environmental concerns. Biodegradation is the natural microbial process of breaking down complex compounds into simpler, non-toxic substances. This property is a crucial determinant of an intelligent system's environmental compatibility^[119]. Studies have shown that there is variability in the biodegradation profiles of ILs. Some ILs decompose quickly, while others are resistant to microbial breakdown^[119]. Recent research has shed light on how certain factors may influence biodegradation rates: shorter chain-length alkanes and smaller cations tend to enhance breakdown due to increased water solubility and microbial accessibility^[141], while anions such as bis(trifluoromethanesulfonyl)imide can inhibit degradation completely^[142]. Despite advances made in this field, there still exist several issues when attempting to accurately predict how a given ILs will behave within natural environmental settings^[126]. Additionally, more studies need be done to assess long-term effects of non-biodegradable ILs on ecosystems or human health. Table 5 presents the assays used in biodegradation studies, as well as upcoming

techniques that have the potential to improve the ability to predict outcomes in real-world situations.

Advancing Sustainable Practices with Green and Eco-friendly Ionic Liquids

Green and eco-friendly ILs can offer a viable solution, providing the same advantageous properties as conventional ILs with reduced hazards. Design strategies that prioritize these solutions focus on low toxicity, high biodegradability and minimized environmental impact, while maintaining the desired physicochemical characteristics. Such green alternatives are developed through choline-based or amino acid-derived synthesis processes which further incorporation of functional groups/molecular structures to enhance biodegradation or reduce toxicity levels. Sustainability and hazard mitigation remain key goals when developing green ILs for use in industry applications. The potential of green and eco-friendly ILs is highlighted in Table 6, highlighting their diverse uses across a range of industries. By using these alternatives instead of conventional ILs, safety risks and environmental hazards can be minimized while promoting greener technologies^[143]. Despite the promising future for green ILs, challenges remain to develop them further and integrate them into regulatory frameworks and safety standards^[144]. To maximize their benefits, more research should be conducted on improving the performance of eco-friendly ILs and to extend beyond their safety profiles to encompass their overall functionality in industrial applications. Enhancing the performance of ILs is vital to ensure they not only meet safety standards but also offer competitive efficacy, cost-effectiveness, and stability. Research aims to optimize ILs for higher catalytic activity, improved physical stability under diverse operational conditions, and cost reduction in synthesis and recycling processes. Additionally, customization of ILs for specific industrial uses is essential. Progress in these areas will support the adoption of ILs as economically and environmentally sustainable alternatives within various sectors, aligning safety with superior performance.

Table 5. Biodegradability of ionic liquids (ILs), providing information on constituent components, test durations and standard methods.

Ionic Liquid	Cation	Anion	Timeframe	Conditions/Method	Ref.
1-hexyl-3-methylimidazolium acetate	Imidazolium	Acetate	28 days	OECD 301C (MITI Test - I)	[119]
1-butyl-3-methylimidazolium lactate	Imidazolium	Lactate	28 days	Zahn-Wellens/EMPA Test (OECD 302B)	[145]
1-butyl-3-methylimidazolium glycolate	Imidazolium	Glycolate	28 days	Modified Sturm Test (OECD 301A)	[146]
N-butyl-N-methyl piperidinium bromide	Piperidinium	Bromide	28 days	Aerobic and Anaerobic Transformation in Soil (OECD 307)	[147]
1-butyl-1-methyl pyrrolidinium acetate	Pyrrolidinium	Acetate	28 days	Modified OECD Screening Test (OECD 301E)	[119]
Cholinium butyrate	Cholinium	Butyrate	14 days	Anaerobic Biodegradability of Organic Compounds (ISO 11734)	[119]
Cholinium propionate	Cholinium	Propionate	14 days	Ultimate Aerobic Biodegradability Test (ISO 9888)	[148]
1-butylpyridinium chloride	Pyridinium	Chloride	28 days	Manometric Respirometry Test (ISO 9408)	[140]
N, N-dimethyl-N-ethyl-N-propyl ammonium acetate	Ammonium	Acetate	21 days	Activated Sludge Respiration Inhibition Test (OECD 209)	[149]
1-butyl-3-methylimidazolium formate	Imidazolium	Formate	28 days	OECD 301B (CO ₂ Evolution Test)	[107]

Table 6. Comprehensive overview of ILs, including their constituent components and applications in various sectors.

Ionic Liquid	Cation	Anion	Application	Description / Benefits	Ref.
1-butyl-1-methylpyrrolidinium	Pyrrolidinium	Glutarate	Biopolymer processing	Facilitates the processing of biodegradable polymers, development of sustainable materials	[150]
1-butyl-3-methylimidazolium	Imidazolium	Oxalate	Nanomaterial synthesis	Provides a green and low-toxicity medium for the synthesis of nanomaterials with various applications	[151]
Cholinium lysinate	Cholinium	Lysinate (amino acid)	Pharmaceutical industry	Green solvent used for the synthesis of pharmaceuticals with reduced environmental impact	[152]
Tetrabutylphosphonium glycinate	Phosphonium	Glycinate (amino acid)	Carbon capture and gas separation	Demonstrates high CO ₂ absorption capacity and low viscosity, contributing to energy-efficient systems	[153]
Cholinium acetate	Cholinium	Acetate	Biodegradable solvents	Eco-friendly solvent with low toxicity, used in extraction processes, catalysis and drug delivery	[154]
1-butyl-3-methylimidazolium levulinate	Imidazolium	Levulinate	Catalysts for organic reactions	Offers high catalytic activity, selectivity and recyclability, reducing waste in chemical processes	[101]
Triethyl sulfonium methane sulfonate	Sulfonium	Methane sulfonate	Electroplating	Provides a less toxic and environmentally friendly alternative to traditional electroplating baths	[155]
Betainium bis(trifluoromethyl sulfonyl)imide	Betainium	trifluoromethyl sulfonyl imide	Energy storage	Exhibits high ionic conductivity and non-flammability, used in safer and more efficient batteries	[156]
1-ethyl-3-methylimidazolium thiocyanate	Imidazolium	Thiocyanate	Solar cells	Enhances the performance of dye-sensitized solar cells due to its high ionic conductivity	[157]
Cholinium malonate	Cholinium	Malonate	Organic synthesis	Green and biodegradable solvent with low toxicity, suitable for a variety of organic reactions	[158]
N-methyl pyrrolidinium	Pyrrolidinium	Dicyanamide	Corrosion protection	Provides an environmentally friendly and non-toxic alternative for corrosion protection applications	[159]
Tetrabutylammonium saccharinate	Ammonium	Saccharinate	Metal processing	Low-toxicity ionic liquid suitable for metal processing applications, such as dissolution and recovery	[160]
1-butyl-3-methylimidazolium	Imidazolium	Taurinate (amino acid)	Protein extraction	Provides efficient protein extraction with low environmental impact, promoting sustainable bioprocessing	[161]
N, N-dimethyl-N-ethyl-N-propyl lactate	Ammonium	Lactate	Cleaning and degreasing	Biodegradable and low-toxicity IL, suitable for cleaning and degreasing applications in various industries	[162]
1-ethyl-3-methylimidazolium	Imidazolium	Benzoate	Polymer processing	Promotes efficient dissolution of cellulose, enabling the production of eco-friendly polymer materials	[163]

Ionic Liquid	Cation	Anion	Application	Description / Benefits	Ref.
N-butyl-N-methyl pyrrolidinium	Pyrrolidinium	Dicyanamide	Heat transfer fluids	Offers high thermal stability and low viscosity, suitable for use in thermal management systems	[164]
Tetrabutylammonium	Ammonium	Citrate	Bio-based plasticizers	Environmentally friendly alternative to traditional plasticizers, with high biodegradability and low toxicity	[165]
1-ethyl-3-methyl-imidazolium	Imidazolium	Tartrate	Chiral catalysis	Facilitates asymmetric synthesis in organic reactions, promoting sustainable chemical processes	[166]
1-butyl-1-methyl-pyrrolidinium	Pyrrolidinium	Adipate	Textile dyeing	Eco-friendly solvent for textile dyeing processes, contributing to reduced water and energy consumption	[167]
Tri-hexyl-tetra-decyl-phosphonium	Phosphonium	Ascorbate	Antioxidants	Exhibits antioxidant properties with low toxicity, suitable for use in food, cosmetics and pharmaceuticals	[54]
1-butyl-3-methyl-imidazolium	Imidazolium	Methane sulfonate	Electrodeposition	Offers a less toxic and more environmentally friendly alternative for metal electrodeposition processes	[168]
N, N-dimethyl-N-ethyl-N-propyl gluconate	Ammonium	Gluconate	Enzyme stabilization	Provides a biodegradable and low-toxicity medium for stabilizing enzymes in biocatalysis applications	[169]
1-butyl-3-methyl-imidazolium	Imidazolium	Salicylate	Green catalysis	Sustainable and efficient catalyst for various organic reactions, including esterification and condensation	[170]
Cholinium phenylacetate	Cholinium	Phenylacetate	Antimicrobial agents	Demonstrates antimicrobial activity with low toxicity, suitable for use in healthcare and food industries	[171]
Trihexyltetradecyl-phosphonium bis(oxalate)borate	Phosphonium	Bis(oxalato)-borate	Lubrication	Exhibits excellent lubrication properties, low toxicity and high thermal stability for use in lubrication applications	[172]
1-ethyl-3-methylimidazolium	Imidazolium	Perchlorate	Electrolytes for supercapacitors	Offers high ionic conductivity and wide electrochemical stability, enhancing supercapacitor performance	[173]
1-ethyl-3-methylimidazolium	Imidazolium	Alaninate (amino acid)	Pharmaceutical formulations	Demonstrates low toxicity and high biocompatibility, used as a drug carrier in pharmaceutical formulations	[174]
N, N-dimethyl-N-ethyl-N-propyl Ammonium Formate	Ammonium	Formate	CO ₂ capture and utilization	Exhibits high CO ₂ solubility and low viscosity, enabling efficient and environmentally friendly CO ₂ utilization	[175]
1-ethyl-3-methylimidazolium dihydrogen phosphate	Imidazolium	Dihydrogen phosphate	Electrochemistry	Exhibits high ionic conductivity and thermal stability, used in electrochemical devices	[171]
1-ethyl-3-methylimidazolium lactate	Imidazolium	Lactate	Biomass pretreatment	Provides efficient biomass dissolution and low toxicity, promoting sustainable biofuel production	[176]

Conclusion

In conclusion, the assessment of ILs through toxicity testing, genotoxicity studies, ecotoxicity assessments and biodegradation tests is essential to guarantee their safe utilization in a variety of applications. The increasing interest in ILs due to their unique properties highlights the need for assessing their safety beforehand. Recent advancements, such as 3D cell culture models, zebrafish embryo toxicological assessments and in silico approaches, have enabled us to gain insight into potential hazards associated with ILs. In addition, establishing green alternatives has become an encouraging prospect when it comes to managing environmental and health concerns usually linked with traditional ILs; these 'green' versions focus on low toxicity levels that are also highly biodegradable while preserving required physicochemical characteris-

tics without compromising performance or security. In addition, incorporating hybrid materials containing ILs for nanomaterial synthesis applications like electrochemistry and energy storage systems further underlines the importance of continuing research on its safety profile. Finally, integrating these substances into circular economy models via sustainable means, including recovery/recycling processes, illustrates great potential towards an eco-friendlier future ahead. To sum up, conducting thorough evaluations about ionic liquid's risks alongside developing environment friendly variants is imperative for leveraging its benefits whilst minimizing any possible dangers. By emphasizing responsible use along with making green substitutes available, we can create pathways towards an improved tomorrow across many industries through sustainability initiatives.

References

- [1] Padua, A. A.; Costa Gomes, M. F.; Canongia Lopes, J. N., *Acc. Chem. Res.* **2007**, *40*, 1087–1096.
- [2] Varona, M.; Eor, P.; Neto, L. C. F.; Merib, J.; Anderson, J. L., *Trends Analyt. Chem.* **2021**, *140*, 116275 (14 pages).
- [3] Antony, F. M.; Wasewar, K. L., *Chem. Eng. Commun.* **2023**, *210*, 2138–2145.
- [4] Forsyth, M.; Porcarelli, L.; Wang, X.; Goujon, N.; Mecerreyes, D., *Acc. Chem. Res.* **2019**, *52*, 686–694.
- [5] Hassanshahi, N.; Hu, G.; Li, J., *Molecules*, **2020**, *25*, 4915 (24 pages).
- [6] Seitkalieva, M. M.; Samoylenko, D. E.; Lotsman, K. A.; Rodygin, K. S.; Ananikov, V. P., *Coord. Chem. Rev.* **2021**, *445*, 213982 (73 pages)
- [7] Greer, A. J.; Jacquemin, J.; Hardacre, C., *Molecules*, **2020**, *25*, 5207 (31 pages).
- [8] Ray, A.; Saruhan, B., *Materials*, **2021**, *14*, 2942 (21 pages).
- [9] Choi, Y. H.; Verpoorte, R., *Curr. Opin. Food Sci.* **2019**, *26*, 87–93.
- [10] Murador, D. C.; de Souza Mesquita, L. M.; Vannuchi, N.; Braga, A. R. C.; de Rosso, V. V., *Curr. Opin. Food Sci.* **2019**, *26*, 25–34.
- [11] Turrone, F.; Milani, C.; Ventura, M.; van Sinderen, D., *Curr. Opin. Biotechnol.* **2022**, *73*, 81–87.
- [12] Huang, Y.; Chen, Z.; Crosthwaite, J. M.; Aki, S. N.; Brennecke, J. F., *J. Chem. Thermodyn.* **2021**, *161*, 106560 (18 pages)
- [13] Al-Akayleh, F.; Mohammed Ali, H. H.; Ghareeb, M. M.; Al-Remawi, M., *J. Drug Deliv. Sci. Technol.* **2019**, *53*, 101159 (10 pages)
- [14] Alkhawaja, B.; Al-Akayleh, F.; Al-Khateeb, A.; Nasereddin, J.; Ghanim, B. Y.; Bolhuis, A.; Jaber, N.; Al-Remawi, M.; Qinna, N. A., *Molecules*, **2023**, *28*, 2402–2418.
- [15] Al-Akayleh, F.; Adwan, S.; Khanfar, M.; Idkaidek, N.; Al-Remawi, M., *AAPS PharmSciTech*, **2020**, *22*, 4 (11 pages).

- [16] Daadoué, S.; Al-Remawi, M. D.; Al-Mawla, L.; Idkaidek, N. M.; Khalid, R. M.; Al-Akayleh, F., *J. Mol. Liq.* **2022**, *345*, 117347 (10 pages).
- [17] Sanches, M. V.; Freitas, R.; Oliva, M.; Cuccaro, A.; Monni, G.; Mezzetta, A.; Guazzelli, L.; Pretti, C., *Environ. Sci. Pollut. Res.* **2023**, *30*, 1–31.
- [18] Wei, P.; Pan, X.; Chen, C.-Y.; Li, H.-Y.; Yan, X.; Li, C.; Chu, Y.-H.; Yan, B., *Chem. Soc. Rev.* **2021**, *50*, 13609–13627.
- [19] Padilla, M. S.; Bertz, C.; Berdusco, N.; Mecozzi, S., *Green Chem.* **2021**, *23*, 4375–4385.
- [20] Flieger, J.; Flieger, M., *Int. J. Mol. Sci.* **2020**, *21*, 6267 (41 pages).
- [21] Maculewicz, J.; Świacka, K.; Stepnowski, P.; Dołżonek, J.; Białk-Bielińska, A., *J. Hazard. Mater.* **2022**, *437*, 129353 (11 pages).
- [22] Kulacki, K. J.; Chaloner, D. T.; Larson, J. H.; Costello, D. M.; Evans-White, M. A.; Docherty, K. M.; Bernot, R. J.; Brueseke, M. A.; Kulpa Jr., C. F.; Lamberti, G. A., *Curr. Org. Chem.* **2011**, *15*, 1918–1927.
- [23] Bambam, A. K.; Dhanola, A.; Gajrani, K. K., *J. Mol. Liq.* **2023**, *380*, 121727 (10 pages).
- [24] Abdi, J.; Hadipoor, M.; Esmaeili-Faraj, S. H.; Vaferi, B., *Sci. Rep.* **2022**, *12*, 1–18.
- [25] Nakhaei-Kohani, R.; Atashrouz, S.; Hadavimoghaddam, F.; Bostani, A.; Hemmati-Sarapardeh, A.; Mohaddespour, A., *Sci. Rep.* **2022**, *12*, 14276 (25 pages).
- [26] Yalcin, D.; Welsh, I. D.; Matthewman, E. L.; Jun, S. P.; Mckeever-Willis, M.; Gritcan, I.; Greaves, T. L.; Weber, C. C., *Phys. Chem. Chem. Phys.* **2020**, *22*, 11593–11608.
- [27] Zhang, M.; Zhang, X.; Liu, Y.; Wu, K.; Zhu, Y.; Lu, H.; Liang, B., *Environ. Sci. Pollut. Res.* **2021**, *28*, 35537–35563.
- [28] Liu, Q.; Zhao, X.; Yu, D.; Yu, H.; Zhang, Y.; Xue, Z.; Mu, T., *Green Chem.* **2019**, *21*, 5291–5297.
- [29] Ali, H. H. M.; Ghareeb, M. M., AL-Rremawi, M. M.; Al-Akayleh, F., *Trop. J. Pharm. Res.* **2020**, *19*, 361–369.
- [30] Al-Mawla, L.; Al-Akayleh, F.; Daadoué, S.; Mahyoob, W.; Al-Tameemi, B.; Al-Remawi, M.; Adwan, S.; Ali Agha, A. S. A., *J. Pharm. Innov.*, <https://doi.org/10.1007/s12247-023-09784-9>, **2023**, 1–14.
- [31] Niemczak, M.; Rzemieniecki, T.; Sobiech, Ł.; Skrzypczak, G.; Praczyk, T.; Pernak, J., *J. Mol. Liq.* **2019**, *276*, 431–440.
- [32] Wang, W.-T.; Liu, S.-H.; Wang, Y.; Yu, C.-F.; Cheng, Y.-F.; Shu, C.-M., *J. Mol. Liq.* **2021**, *343*, 117691 (10 pages).
- [33] Wu, H.-B.; Zhang, B.; Liu, S.-H.; Chen, C.-C., *J. Loss Prev. Process Indust.* **2020**, *66*, 104196 (4 pages).
- [34] Chen, Y.; Yu, D.; Liu, Z.; Xue, Z.; Mu, T., *New J. Chem.* **2022**, *46*, 17640–17668.
- [35] Khan, A. S.; Ibrahim, T. H.; Jabbar, N. A.; Khamis, M. I.; Nancarrow, P.; Mjalli, F. S., *RSC Adv.* **2021**, *11*, 12398–12422.
- [36] Zhang, J.; Zhou, H.; Liu, D.; Zhao, X., *Pretreatment of Lignocellulosic Biomass for Efficient Enzymatic Saccharification of Cellulose*, In *Lignocellulosic Biomass to Liquid Biofuels*, Abu Yousuf, Pirozzi, D.; Sannino, F., Eds., Elsevier, **2020**, 17–65.

- [37] Magina, S.; Barros-Timmons, A.; Ventura, S. P.; Evtuguin, D. V., *J. Hazard. Mater.* **2021**, *412*, 125215 (26 pages).
- [38] Mishra, R.; Mishra, J. S.; Chaubey, S. A., *Curr. Org. Chem.* **2019**, *23*, 1239–1255.
- [39] Yang, N.; Tang, Y.; Wu, H.; Shu, C.-M.; Xing, Z.-X.; Jiang, J.-C.; Huang, A.-C., *J. Loss Prev. Process Indust.* **2023**, *82*, 104977 (9 pages).
- [40] Chen, H.; Wan, K.; Zhang, Y.; Wang, Y., *ChemSusChem*, **2021**, *14*, 4123–4136.
- [41] Tang, X.; Lv, S.; Jiang, K.; Zhou, G.; Liu, X., *J. Power Sources*, **2022**, *542*, 231792 (15 pages).
- [42] Clarke, C. J.; Bui-Le, L.; Hallett, J. P.; Licence, P., *ACS Sustain. Chem. Eng.* **2020**, *8*, 8762–8772.
- [43] Handa, M.; Almalki, W. H.; Shukla, R.; Afzal, O.; Altamimi, A. M. S. A.; Beg, S.; Rahman, M., *Drug Discov. Today*, **2022**, *27*, 2415–2424
- [44] Yu, C.-F.; Liu, S.-H.; Xia, R.; Wu, K.-F., *J. Mol. Liq.* **2022**, *360*, 119422 (5 pages).
- [45] Dörr, N.; Merstallinger, A.; Holzbauer, R.; Pejaković, V.; Brenner, J.; Pisarova, L.; Stelzl, J.; Frauscher, M., *Tribol Lett.* **2019**, *67*, 1–18.
- [46] Billeci, F.; D’Anna, F.; Feroci, M.; Cancemi, P.; Feo, S.; Forlino, A.; Tonnelli, F.; Seddon, K. R.; Gunaratne, H. N.; Plechkova, N. V., *AACS Sustain. Chem. Eng.* **2019**, *8*, 926–938.
- [47] Li, Z. J.; Sun, J. F.; Xu, Q. Q.; Yin, J. Z., *ChemCatChem*, **2021**, *13*, 1848–1866.
- [48] Musiał, M.; Zorębski, E.; Malarz, K.; Kuczak, M.; Mrozek-Wilczkiewicz, A.; Jacquemin, J.; Dzida, M., *ACS Sustain. Chem. Eng.* **2021**, *9*, 7649–7657.
- [49] Al-Akayleh, F.; Khalid, R. M.; Hawash, D.; Al-Kaissi, E.; Al-Adham, I. S. I.; Al-Muhtaseb, N.; Jaber, N.; Al-Remawi, M.; Collier, P. J., *Lett. Appl. Microbiol.* **2022**, *75*, 607–615.
- [50] Fanti, G.; Spinazzè, A.; Borghi, F.; Rovelli, S.; Campagnolo, D.; Keller, M.; Borghi, A.; Cattaneo, A.; Cauda, E.; Cavallo, D. M., *Sensors*, **2022**, *22*, 4841 (16 pages)
- [51] Kabane, B.; Redhi, G. G., *J. Chem. Thermodyn.* **2022**, *173*, 106849 (5 pages).
- [52] Zunita, M.; Kevin, Y. J., *Results Eng.* **2022**, 100562 (28 pages).
- [53] Piedade, P. J.; Kochańska, E.; Lukasik, R. M., *Curr. Opin. Green Sustain. Chem.* **2022**, *35*, 100609 (7 pages).
- [54] Sharmhal, A.; Kumar, A.; Kumar, A., *J. Mol. Liq.* **2022**, *368*, 120580 (21 pages).
- [55] Forero-Martinez, N. C.; Cortes-Huerto, R.; Benedetto, A.; Ballone, P., *Molecules*, **2022**, *27*, 1647 (46 pages).
- [56] Egorova, K. S.; Ananikov, V. P., *J. Mol. Liq.* **2018**, *272*, 271–300.
- [57] Raman, A. P. S.; Singh, M. B.; Jain, P.; Chaudhary, P.; Bahadur, I.; Lal, K.; Kumar, V.; Singh, P., *J. Mol. Liq.* **2022**, *364*, 119989 (25 pages).
- [58] Li, E.; Li, Y.; Liu, S.; Yao, P., *Colloids Surf. Physicochem. Eng. Aspects*, **2023**, *657*, 13054 (9 pages).
- [59] Samorì, C.; Pirini, D., *Abiotic Degradation of Ionic Liquids (ILs)*, In *Encyclopedia of Ionic Liquids*, Zhang, S., Eds.; Springer, Singapore, **2023**, 1–8.
- [60] Joarder, S.; Bansal, D.; Meena, H.; Kaushik, N.; Tomar, J.; Kumari, K.; Bahadur, I.; Choi, E. H.; Kaushik, N. K.; Singh, P., *J. Mol. Liq.* **2023**, *367*, 121355 (12 pages).

- [61] Daddiouaissa, D.; Amid, A.; Kabbashi, N. A.; Fuad, F. A.; Elnour, A. M.; Epandy, M. A., *J. Ethnopharmacol.* **2019**, *236*, 466–473.
- [62] Kuczak, M.; Musiał, M.; Malarz, K.; Rurka, P.; Zorębski, E.; Musioł, R.; Dzida, M.; Mrozek-Wilczkiewicz, A., *J. Hazard. Mater.* **2022**, *427*, 128160 (9 pages).
- [63] Nguyen, C.-H.; Augis, L.; Fourmentin, S.; Barratt, G.; Legrand, F.-X., *Deep Eutectic Solvents for Medicine, Gas Solubilization and Extraction of Natural Substances*, Springer, **2021**, *56*, 41–102.
- [64] Zielonka, J.; Joseph, J.; Sikora, A.; Hardy, M.; Ouari, O.; Vasquez-Vivar, J.; Cheng, G.; Lopez, M.; Kalyanaraman, B., *Chem. Rev.* **2017**, *117*, 10043–10120.
- [65] Mohamed, H. A.; Shepherd, S.; William, N.; Blundell, H. A.; Das, M.; Pask, C. M.; Lake, B. R.; Phillips, R. M.; Nelson, A.; Willans, C. E., *Organometallics*, **2020**, *39*, 1318–1331.
- [66] Ghalkhani, M.; Kaya, S. I.; Bakirhan, N. K.; Ozkan, Y.; Ozkan, S. A., *Crit. Rev. Anal. Chem.* **2022**, *52*, 481–503.
- [67] Tuzimski, T.; Petruczynik, A.; Plech, T.; Kaproń, B.; Makuch-Kocka, A.; Szultka-Młyńska, M.; Misiurek, J.; Buszewski, B., *Molecules*, **2021**, *26*, 1738 (14 pages).
- [68] Kumar, A.; Kumar, P., *J. Mol. Liq.* **2020**, *318*, 114055 (6 pages).
- [69] Maertens, A., *Green Toxicology: Making Chemicals Benign by Design*, RSC, **2022**, *68*, 25–30.
- [70] Celik, S.; Albayrak, A. T.; Akyuz, S.; Ozel, A. E., *J. Biomol. Struct.* **2020**, *38*, 1354–1364.
- [71] Ayon, N. J., *Metabolites*, **2023**, *13*, 625 (61 pages).
- [72] Badioli, S.; Champion, T.; Roumiguier, L.; Dargaud, M.; Léonard, A., *Prospective LCA on the Design of New Refractories for a Greener Steelmaking Process*, SETAC Europe 33rd Annual Meeting, **2023**.
- [73] Gruber, E. S.; Stadlbauer, V.; Pichler, V.; Resch-Fauster, K.; Todorovic, A.; Meisel, T. C.; Trawoeger, S.; Hollóczki, O.; Turner, S. D.; Wadsak, W., *Expo. Health*, **2023**, *15*, 33–51.
- [74] Sanwald, C. T., *Analysing Toxicity of Ionic Liquids Based on Combined Targeted Amino Acid Analysis and Untargeted Metabolic Profiling as well as Lipidomic Profiling of Stressed Mammalian Cell Extracts*, Universität Tübingen, PhD Thesis, **2023**.
- [75] Belda, M. C., *Silk Bio Nanocomposites: Design, Characterization and Potential Applications*, PhD Thesis, Compiègne; **2020**.
- [76] Niu, H.; Wang, L.; Guan, P.; Zhang, N.; Yan, C.; Ding, M.; Guo, X.; Huang, T.; Hu, X., *J. Energy Storage* **2021**, *40*, 102659 (30 pages).
- [77] Stettner, T.; Walter, F. C.; Balducci, A., *Batteries Supercaps.* **2019**, *2*, 55–59.
- [78] Wang, X.; Cheng, Z., *Chest.* **2020**, *158*, S65–S71.
- [79] Correia, D.; Fernandes, L.; Pereira, N.; Barbosa, J.; Serra, J.; Pinto, R.; Costa, C.; Lanceros-Méndez, S., *Appl. Mater. Today*, **2021**, *22*, 100928 (7 pages).
- [80] Correia, D. M.; Fernandes, L. C.; Martins, P. M.; García-Astrain, C.; Costa, C. M.; Reguera, J.; Lanceros-Méndez, S., *Adv. Funct. Mater.* **2020**, *30*, 1909736 (43 pages).
- [81] Suen, J. W.; Elumalai, N. K.; Debnath, S.; Mubarak, N. M.; Lim, C. I.; Reddy, M. M., *Adv. Mater. Interfaces.* **2022**, *9*, 2201405 (35 pages).

- [82] Hammond, O. S.; Mudring, A.-V., *Chem Commun.* **2022**, 58, 3865–3892.
- [83] Wu, J.; Liang, Q.; Yu, X.; Lü, Q. F.; Ma, L.; Qin, X.; Chen, G.; Li, B., *Adv. Funct. Mater.* **2021**, 31, 2011102 (25 pages).
- [84] Marfavi, Y., AliAkbari, R., Kowsari, E., Sadeghi, B., Ramakrishna, S. *Application of Ionic Liquids in Green Energy-storage Materials*, In *Ionic Liquid-Based Technologies for Environmental Sustainability*, Elsevier, **2022**, 155–166.
- [85] Yusuf, A.; Li, Z.; Yuan, X.; Wang, D. Y., *Small Methods*, **2022**, 6, 2101428.
- [86] Schindl, A.; Hagen, M. L.; Muzammal, S.; Gunasekera, H. A.; Croft, A. K., *Front. Chem.* **2019**, 7, 347 (31 pages).
- [87] Rauber, D.; Philippi, F.; Seibert, J.; Huwer, J.; Natter, H.; Hempelmann, R., *WJCE* **2019**, 7, 153–165.
- [88] Kailasa, S. K.; Koduru, J. R.; Vikrant, K.; Tsang, Y. F.; Singhal, R. K.; Hussain, C. M.; Kim, K.-H., *J. Mol. Liq.* **2020**, 29, 111886 (17 pages).
- [89] Dos Santos, L. M.; Bernard, F. L.; Polesso, B. B.; Pinto, I. S.; Frankenberg, C. C.; Corvo, M. C.; Almeida, P. L.; Cabrita, E.; Einloft, S., *J. Environ. Manage.* **2020**, 268, 110340 (10 pages).
- [90] Nasirpour, N.; Mohammadpourfard, M.; Heris, S. Z., *Chem. Eng. Res. Des.* **2020**, 160, 264–300.
- [91] de Jesus, S. S.; Maciel Filho, R., *Renew. Sust. Energ. Rev.* **2020**, 133, 110289 (35 pages).
- [92] Gurjar, S.; Sharma, S. K.; Sharma, A.; Ratnani, S., *Appl. Surf. Sci. Adv.* **2021**, 6, 100170 (25 pages).
- [93] Jin, S.; Hao, Z.; Zhang, K.; Yan, Z.; Chen, J., *Angew Chem.* **2021**, 133, 20795–20816.
- [94] Jadhav, N. R.; Bhosale, S. P.; Bhosale, S. S.; Mali, S. D.; Toraskar, P. B.; Kadam, T. S., *J. Drug Deliv. Sci. Technol.* **2021**, 65, 102694 (14 pages).
- [95] Carpentieri, S.; Soltanipour, F.; Ferrari, G.; Pataro, G.; Donsì, F., *Antioxidants*, **2021**, 10, 1417 (42 pages).
- [96] Chen, Y.; Han, X.; Liu, Z.; Li, Y.; Sun, H.; Wang, H.; Wang, J., *J. Mol. Liq.* **2022**, 366, 120336 (11 pages).
- [97] Wu, W.; Zhai, C.; Huang, S.-M.; Sui, Y.; Sui, Z.; Ding, Z., *Energy*, **2022**, 239, 122180 (9 pages).
- [98] Escobedo, P.; Fernández-Ramos, M.; López-Ruiz, N.; Moyano-Rodríguez, O.; Martínez-Olmos, A.; Pérez de Vargas-Sansalvador, I.; Carvajal, M.; Capitán-Vallvey, L.; Palma, A., *Nat. Commun.* **2022**, 13, 72 (12 pages).
- [99] Ashoshan, H. M., Extractive Desulfurization of Fuel Oils Using Ionic Liquids, PhD Thesis, Memorial University of Newfoundland, **2022**.
- [100] Kosamia, N. M.; Samavi, M.; Piok, K.; Rakshit, S. K., *Fuel*, **2022**, 324, 124532 (10 pages).
- [101] Ali, S. A.; Mulk, W. U.; Ullah, Z.; Khan, H.; Zahid, A.; Shah, M. U. H.; Shah, S. N., *Energies*, **2022**, 15, 9098 (31 pages).
- [102] Mehrabani, S. A. N.; Vatanpour, V.; Koyuncu, I., *Sep. Purif. Technol.*, **2022**, 298, 121691 (32 pages).
- [103] Singh Raman, A. P.; Muhammad, A. A.; Singh, H.; Singh, T.; Mkhize, Z.; Jain, P.; Singh, S. K.; Bahadur, I.; Singh, P., *ACS Omega*, **2022**, 7, 47471–47489.
- [104] Karimi, N.; Zarrabeitia, M.; Hosseini, M.; Ates, T.; Iliev, B.; Schubert, T. J.; Varzi, A.; Passerini, S., *ACS Appl. Mater. Interfaces*, **2022**, 14, 20888–20895.

- [105] Tiwari, V. K.; Kumar, A.; Rajkhowa, S.; Tripathi, G.; Singh, A. K., *Green Chemistry: Introduction, Application and Scope*, Springer, **2022**, pp. 113–176.
- [106] Li, Y.; Li, F.; Laaksonen, A.; Wang, C.; Cobden, P.; Boden, P.; Liu, Y.; Zhang, X.; Ji, X., *Ind. Chem.* **2023**, *1*, 410–430.
- [107] Elmobarak, W. F.; Almomani, F.; Tawalbeh, M.; Al-Othman, A.; Martis, R.; Rasool, K., *Fuel*, **2023**, *344*, 128102 (21 pages).
- [108] Jacobs, B.; Yao, Y.; Van Nieuwenhove, I.; Sharma, D.; Graulus, G.-J.; Bernaerts, K.; Verberckmoes, A., *Green Chem.* **2023**, *25*, 2042–2086.
- [109] Park, J.; Jin, H.; Yeon, S.; Kim, H. W.; Ko, M., *Energy Technology*, **2023**, *11*, 2201153 (10 pages).
- [110] Kapitanov, I. V.; Raba, G.; Špulák, M.; Vilu, R.; Karpichev, Y.; Gathergood, N., *J. Mol. Liq.* **2023**, *374*, 121285 (13 pages).
- [111] Md Moshikur, R., Goto, M., *Chem. Rec.* **2023**, e202300026 (15 pages).
- [112] Hakeem, I. G.; Halder, P.; Aktar, S.; Marzbali, M. H.; Sharma, A.; Surapaneni, A.; Short, G.; Paz-Ferreiro, J.; Shah, K., *Hydrometallurgy*, **2023**, *218*, 106044 (9 pages).
- [113] Yin, X.; Liu, R.; Cheng, M.; Sun, Q.; Yang, Y., *Sep. Purif. Technol.* **2023**, *313*, 123456.
- [114] Singh, S. K.; Savoy, A. W., *J. Mol. Liq.* **2020**, *297*, 112038 (32 pages).
- [115] Kowalska, D.; Maculewicz, J.; Stepnowski, P.; Dołżonek, J., *J. Hazard. Mater.* **2021**, *403*, 123896 (6 pages).
- [116] Shen, T.; Teng, L.; Hu, Y.; Shen, W., *Front. Chem. Eng.* **2023**, *17*, 34–45.
- [117] Spandana, K. A.; Bhaskaran, M.; Karri, V. R.; Natarajan, J., *J. Drug Deliv. Sci. Technol.* **2020**, *57*, 101628 (16 pages).
- [118] Mezzetta, A.; Becherini, S.; Pretti, C.; Monni, G.; Casu, V.; Chiappe, C.; Guazzelli, L., *New J. Chem.* **2019**, *43*, 13010–13019.
- [119] Amsel, A.-K.; Olsson, O.; Kümmerer, K., *Chemosphere*, **2022**, *299*, 134385 (6 pages).
- [120] Shanmugam, P. S. T.; Sampath, T.; Jagadeeswaran, I., *Biocompatibility Protocols for Medical Devices and Materials*, Elsevier, **2023**, pp. 67–76.
- [121] Lyons-Darden, T.; Blum, J. L.; Schooley, M. W.; Ellis, M.; Durando, J.; Merrill, D.; Oller, A. R., *Nanomaterials*, **2023**, *13*, 261 (8 pages).
- [122] Khan, M. I.; Mubashir, M.; Zaini, D.; Mahnashi, M. H.; Alyami, B. A.; Alqarni, A. O.; Show, P. L., *J. Hazard. Mater.* **2021**, *415*, 125364 (10 pages).
- [123] Bauer, A. E.; Hewitt, L.; Parrott, J.; Bartlett, A.; Gillis, P.; Deeth, L.; Rudy, M.; Vanderveen, R.; Brown, L.; Campbell, S., *Sci. Total Environ.* **2019**, *669*, 702–710.
- [124] Rhazouani, A.; Gamrani, H.; El Achaby, M.; Aziz, K.; Gebrati, L.; Uddin, M. S.; Aziz, F., *Biomed. Res. Int.* **2021**, 5518999 (19 pages).
- [125] Adewale, O. B.; Davids, H.; Cairncross, L.; Roux, S., *Int. J. Toxicol.* **2019**, *38*, 357–384.
- [126] Abramenko, N.; Kustov, L.; Metelytsia, L.; Kovalishyn, V.; Tetko, I.; Peijnenburg, W., *J. Hazard. Mater.* **2020**, *384*, 121429 (14 pages).
- [127] Esson, M. M.; Mecozzi, S., *Mol. Pharm.* **2020**, *17*, 2221–2226.

- [128] Macko, P.; Palosaari, T.; Whelan, M., *Toxicol. In Vitro.* **2021**, *76*, 105206 (10 pages).
- [129] Sumanu, V.; Naidoo, V.; Oosthuizen, M.; Chamunorwa, J., *Int. J. Biometeorol.* **2022**, *66*, 2379–2393.
- [130] Shi, Y.; Meng, X.; Zhang, J., *Sci Total Environ.* **2021**, *778*, 146371 (8 pages).
- [131] Płotka-Wasyłka, J.; De la Guardia, M.; Andruch, V.; Vilková, M., *Microchem. J.* **2020**, *159*, 105539 (12 pages).
- [132] Gijjapu, D. R.; Nazal, M. K., *Ionic Liquids for Phenolic Compounds Removal and Extraction, In Green Sustainable Process for Chemical and Environmental Engineering and Science*, Dr. Inamuddin, Altalhi, T., Eds., Elsevier, **2023**, pp. 217–238.
- [133] Suchana, S. A.; Ahmed, M. S.; Islam, S. M.; Rahman, M. L.; Rohani, M. F.; Ferdusi, T.; Ahmmad, A. S.; Fatema, M. K.; Badruzzaman, M.; Shahjahan, M., *Biol. Trace Elem. Res.* **2021**, *199*, 3869–3885.
- [134] Thamke, V.; Singh, P.; Pal, S.; Chaudhary, M.; Kumari, K.; Bahadur, I.; Varma, R. S., *J. Environ. Chem. Eng.* **2022**, 107303 (8 pages).
- [135] Shao, Y.; Wang, J.; Wang, J.; Du, Z.; Li, B.; Zhu, L.; Juhasz, A.; Liu, X.; Xu, Y.; Li, W., *Chemosphere*, **2019**, *227*, 570–579.
- [136] Abdelghany, T. M.; Hedyia, S. A.; de Santis, C.; Abd El-Rahman, S. S.; Gill, J. H.; Abdelkader, N. F.; Wright, M. C., *Ecotoxicol. Environ. Saf.* **2023**, *249*, 114439 (15 pages).
- [137] Bhatia, S. K.; Jagtap, S. S.; Bedekar, A. A.; Bhatia, R. K.; Patel, A. K.; Pant, D.; Banu, J. R.; Rao, C. V.; Kim, Y.-G.; Yang, Y.-H., *Bioresour. Technol.* **2020**, *300*, 122724 (35 pages).
- [138] Magina, S.; Barros-Timmons, A.; Ventura, S. P.; Evtuguin, D. V., *J. Hazar. Mater.* **2021**, *412*, 125215 (30 pages).
- [139] Kusumahastuti, D. K.; Sihtmäe, M.; Kapitanov, I. V.; Karpichev, Y.; Gathergood, N.; Kahru, A., *Ecotoxicol. Environ. Saf.* **2019**, *172*, 556–565.
- [140] Klein, J.; Łuczak, J.; Brillowska-Dąbrowska, A., *Molecules*, **2023**, *28*, 1268 (10 pages).
- [141] Mustahil, N. A.; Baharuddin, S. H.; Abdullah, A. A.; Reddy, A. V. B.; Mutalib, M. I. A.; Moniruzzaman, M., *Chemosphere*, **2019**, *229*, 349–357.
- [142] Mena, I.; Diaz, E.; Palomar, J.; Rodriguez, J.; Mohedano, A., *Chemosphere*, **2020**, *240*, 124947 (9 pages).
- [143] Hoang, M. T.; Ünlü, F.; Martens, W.; Bell, J.; Mathur, S.; Wang, H., *Green Chem.* **2021**, *23*, 5302–5336.
- [144] Arabi, M.; Ostovan, A.; Li, J.; Wang, X.; Zhang, Z.; Choo, J.; Chen, L., *Adv. Mater.* **2021**, *33*, 2100543 (9 pages).
- [145] Bouchouareb, K.; Combès, A.; Pichon, V., *Talanta*, **2022**, *249*, 123704 (26 pages).
- [146] Nigam, S.; Das, A. K.; Matkawala, F.; Patidar, M. K., *Environ. Sustain.* **2022**, *5*, 423–441.
- [147] Verma, S.; Verma, A.; Mondal, M.; Prasad, N. E.; Srivastava, J.; Singh, S.; Verma, J. P.; Saha, S., *J. Mol. Struct.* **2022**, *1250*, 131679 (8 pages).
- [148] Elhami, V.; Antunes, E. C.; Temmink, H.; Schuur, B., *Molecules*, **2022**, *27*, 1389 (41 pages).
- [149] Zunita, M.; Batara, B., *Case Stud. Chem. Environ. Eng.* **2023**, *7*, 100341 (13 pages).

- [150] Rynkowska, E., *Innovative Polymer-Based Membrane Materials Containing Reactive (RILs) and Polymerizable (PIL) Ionic Liquids*. Thesis, Normandie Université, Uniwersytet Mikołaja Kopernika (Toruń, Pologne), **2019**.
- [151] Kumar, H.; Das, R.; Choithramani, A.; Gupta, A.; Khude, D.; Bothra, G.; Shard, A., *ChemistrySelect*, **2021**, *6*, 5807–5837.
- [152] Miao, S.; Atkin, R.; Warr, G., *Green Chem.* **2022**, *24*, 7281–7304.
- [153] Patil, T.; Dharaskar, S.; Sinha, M.; Jampa, S. S., *Environ. Sci. Pollut. Res.* **2022**, *29*, 35723–35745.
- [154] de Jesus, S. S.; Maciel Filho, R., *Renew. Sust. Energ. Rev.* **2022**, *157*, 112039 (37 pages).
- [155] Ali, S. M.; Arif, N. A.; Hashmi, M. M.; Khan, M. B.; Khan, Z. H., *Recent Developments in Electrolyte Materials for Rechargeable Batteries*, In *Nanomaterials for Innovative Energy Systems and Devices*, Khan, Z. H., Ed., Springer, **2022**, pp. 369–415.
- [156] Xue, B.; Wu, X.; Guo, Y.; Zhang, C.; Qian, W.; Zhang, L., *J. Electrochem. Soc.* **2022**, *169*, 080501 (17 pages).
- [157] Zolghadr, A. R.; Azari, N.; Dokoohaki, M. H., *J. Mol. Liq.* **2022**, *364*, 119982 (8 pages).
- [158] Mecerreyes, D.; Porcarelli, L., *Green Electrolyte Based Organic Electronic Devices*, In *Sustainable Strategies in Organic Electronics.*, Marrocchi, A., Ed., Elsevier, **2022**, pp. 281–295.
- [159] Berdimurodov, E., Kholikov, A., Akbarov, K., Guo, L., Umirov, N., Verma, D. K., Rbaa, M., Dagdag, O., Haldhar, R., Kaya, S. Ionic liquids as green and sustainable corrosion inhibitors, In *Eco-Friendly Corrosion Inhibitors*, Guo, L.; Verma, Ch.; Zhang, D., Eds., Elsevier, **2022**, pp. 331–390.
- [160] Tzani, A.; Karadendrou, M.-A.; Kalafateli, S.; Kakokefalou, V.; Detsi, A., *Crystals*, **2022**, *12*, 1776 (37 pages).
- [161] Bernardo, S. C.; Carapito, R.; Neves, M. C.; Freire, M. G.; Sousa, F., *Molecules*, **2022**, *27*, 1618 (24 pages).
- [162] Buarque, F. S.; Gautério, G. V.; Coelho, M. A. Z.; Lemes, A. C.; Ribeiro, B. D., *Processes*, **2022**, *11*, 31 (33 pages).
- [163] Tiwari, V. K.; Kumar, A.; Rajkhowa, S.; Tripathi, G.; Singh, A. K., *Growing Impact of Ionic Liquids in Carbohydrate Chemistry*, In *Green Chemistry: Introduction, Application and Scope*, Springer, **2022**, pp. 177–205.
- [164] Bhat, M.; Edwards, A.; Tucker, T.; Davidowski, S.; Amin, S.; Thoms, E.; Yarger, J.; Richert, R.; Angell, C., *J. Electrochem. Soc.* **2022**, *169*, 086502 (28 pages).
- [165] Chong, W. J.; Shen, S.; Li, Y.; Trinchì, A.; Pejak, D.; Kyratzis, I. L.; Sola, A.; Wen, C., *J. Mater. Sci. Technol.* **2022**, *111*, 120–151.
- [166] Lim, J. R.; Chua, L. S.; Mustaffa, A. A., *Process Biochem.* **2022**, *122*, 292–306.
- [167] Zunita, M.; Hastuti, R.; Alamsyah, A.; Kadja, G. T.; Khoiruddin, K.; Kurnia, K. A.; Yulianto, B.; Wenten, I., *J. Ind Eng. Chem.* **2022**, *113*, 96–123.
- [168] Villemejeanne, B.; Legeai, S.; Meux, E.; Dourdain, S.; Mendil-Jakani, H.; Billy, E., *J. Environ. Chem. Eng.* **2022**, *10*, 107063.
- [169] Racovita, S.; Popa, M.; Atanase, L. I.; Vasiliu, S., *Int. J. Biol. Macromol.* **2022**, 305–335.

- [170] Neofotistos, S. P.; Tzani, A.; Detsi, A., *Catalysts*, **2023**, *13*, 474 (41 pages).
- [171] Kanjilal, B.; Zhu, Y.; Krishnadoss, V.; Unagolla, J. M.; Saemian, P.; Caci, A.; Cheraghali, D.; Dehzangi, I.; Khademhosseini, A.; Noshadi, I., *Adv. Intell. Syst.* **2023**, *5*, 2200306 (22 pages).
- [172] Rohlmann, P.; Black, J. J.; Watanabe, S.; Leckner, J.; Shimpi, M. R.; Rutland, M. W.; Harper, J. B.; Glavatskih, S., *Tribol. Int.* **2023**, *185*, 108263 (11 pages).
- [173] Hashmi, S., *J. Power Sources*, **2023**, *557*, 232548 (9 pages).
- [174] Sagitha, P.; Dhandapani, H.; Tayalia, P., *Int. J. Biol. Macromol.* **2023**, *238*, 124059 (8 pages).
- [175] Pandey, A.; Jadhao, P. R.; Mishra, S.; Pant, K., Ionic Liquids: Designer Sorbents for CO₂ capture, In *CO₂-philic Polymers, Nanocomposites and Chemical Solvents*, Nadda, A. K.; Sharma, S.; Kalia, S., Eds.; Elsevier, **2023**, pp. 163–191.
- [176] Haykir, N. I.; Zahari, S. M. S. N. S.; Harirchi, S.; Sar, T.; Awasthi, M. K.; Taherzadeh, M. J., *Biochem. Eng. J.* **2023**, *193*, 108850 (18 pages).