VOL. 24 NO. 9
ISSN: 2878-1894
MARCH, 2022

*African Scholar Publications & Research International*

*African Scholars Journal of Science Innovation & Tech. Research (JSITR-9)*

# Emerging Applications of Deep Eutectic Solvents in Applied Sciences: a Review

**Oguche John Enemona[1]; Emeniru Daniel. C [1,2]; Sorgbara Franklin Lekara[3]; Ameh Alewo Opuada[1]; & Adubazi Momohjimoh Onimisi[4]**

*[1]Chemical Engineering, Ahmadu Bello University Zaria, Kaduna State [2]Chemical Engineering, Federal Polytechnic of Oil and Gas Ekowe, Bayelsa State [3]Mechanical Engineering, Federal Polytechnic of Oil and Gas Ekowe, Bayelsa State [4]Science Lab. Technology, Federal Polytechnic of Oil and Gas Ekowe, Bayelsa State*

## Abstract

*Recently, deep eutectic solvent (DES); being as novel and green solvent has attracted increasing interest in different areas of sciences, engineering, and medicine due to its excellent physicochemical and thermal properties. The formulation and classification of DES is dependent solely on the hydrogen bond acceptor (HBA) and hydrogen bond donor (HBD) components and their proportions. Its superiority to ionic liquids (ILs) encompasses the cheap and available starting/raw materials, and the ease of formulation and storage. DESs has gained a very wide distribution and application in various researches and industrial processes; the widest distribution being its application in synthesis. Its uses span as solvent for laboratory and industrial pretreatment, extraction, separation and purification of both inorganic metallic components and organic compounds. Though they possess core characteristics that are similar to those of ILs, DESs has been pronounced as capacity options attributive to its physicochemical properties. Notwithstanding the innumerable uses and application of DESs, their chemical, biological and physical characteristics have not been* *completely investigated. Despite the benefits the solvent has limitations of corrosion, high viscosity, mixture instability and lack of physicochemical information. This review seeks to provide a brief introduction to DES while highlighting some latent potentials and limitations of the novel solvent in the various fields of application.*

**Keywords:** *Deep eutectic solvents, Formulation, Classification, Applications, Limitations*

## Introduction

The increasing demand of new materials is on the rise due to continuous search for innovation and new technology so as to improve the previous ones. Also, interest in developing and advancing more efficient solvents has been the focus of researcher lately due to rise in applications of green chemistry (Duan et al., 2020). Solvents are central to development of new chemicals, compounds and systems; and to ensuring the use of eco-friendly industrial and domestic materials. The demand for solvents in the chemical, medical, pharmaceutical, cosmetics, food and beverage processing industries; and in biotechnology has grown exponentially. Hence, the continuous search for new solvents is on the rise. Interest in developing and advancing more efficient solvents has been the focus of researcher lately due to rise in applications of green chemistry. Numerous challenges and limitations have been identified during production and recovery of products in the above fields using the conventional solvents such as acids, bases or volatile organic solvents. Therefore, to increase yield and purity, and to achieve eco-friendliness; green solvents can be substituted for the traditional organic solvents (VOCs). Green solvents (ionic liquids) has minimal or no generation of hazardous by-products thus assure effective production of products that achieve environment friendliness (Chen et al., 2019). Recently, Deep eutectic solvent (DES) have been introduced as a novel green solvent having the typical clean, reneweable and sustainable properties (Duan et al., 2020 and Triyani and Herman, 2021). DES is a key solvent in solving the persisting challenges of toxicity, non-biodegradability, nonrecyclability and volatility of the current used organic solvents. Therefore, studies into the production of these valuable green solvent which has numerous applications in various fields calls for more attention. Therefore, chiefly, this review seeks to highlight the ideal applicability of DES in the production of lactic acid from agricultural feedstock.

DESs have attracted increasing interest thus have become the subject of intensive research in various areas of science. They are readily available green solvents resulting from the availability and cheapness of their formulation raw materials, and the ease in their synthesis and storage (Triyani and Herman, 2021). As pretreatment and/or extraction solvents, their applications have shown great promise in ensuring recyclability, biodegradability, less volatile, non-toxic, non-flammability, high tunability, high dissolution capability, ease and short time of preparation, and low costs (Emami and Shayanfar, 2020). It has shown very good applicability in the extraction of biological materials including DNA and RNA (Mondel *et al.*, 2014, Sanap and Shankarling 2014).

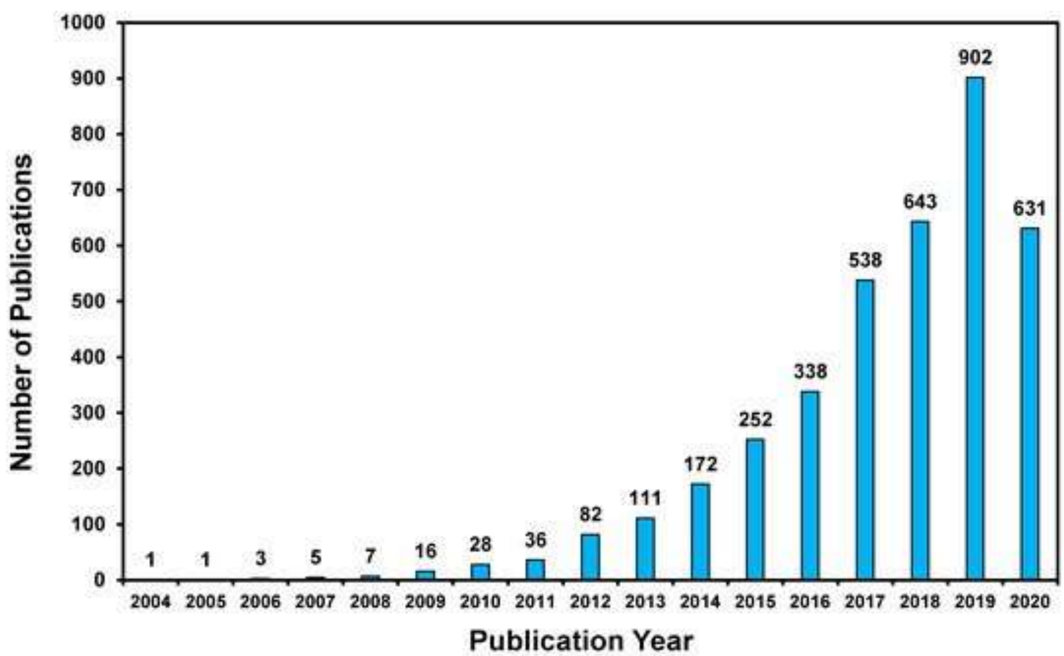


**Figure 1**: Total publications for DESs by 2020 (Emami and Shayanfar, 2020).

DESs has numerous applications in various industries. It can be used as solvent for extraction and separation of both inorganic metallic components and organic compounds consisting of phenolic compounds, flavonoids, sugars, and aromatic amines from food samples (Chen et al. 2019 and Duan *et al.*, 2020). Its application extents to enhance crude oil recovery, $CO_2$ captured, pretreatment of biomass, metal processing, extraction/separation, solvent electro-catalysis, development/reaction medium, electro-polishing, and as catalyst or catalyst carrier, etc. (Degam, 2017). Figure 1 shows the total publication of DESs from 2004 to 2020 indicating the rapid acceptability and versatility of this green and novel solvent. In the pharmaceutical industries, DES serve as reaction media in the designing and preparation of drug delivery systems (DDSs) *(*Emami and Shayanfar, 2020). That is, they have exclusive application in nanotechnology, biotechnology, Catalysis, oil exploration, hydrometallurgy, electrochemistry, Extraction and Seperation processes, medicine (uniquely as vehicles for delivery of problematic drugs), etc. The suitability of DES has been revealed in metal electro-deposition (Ayşe and Serpil 2020), enzyme-catalyzed reactions (Lynam *et al*., 2017; Sheldon, 2016 and Wu *et al*., 2014), liquid separation and nanoparticle functionalization (Chen *et al*., 2018), extraction in biological materials (Mondel *et al.*, 2014, Sanap and Shankarling 2014). There are very numerous areas remaining to authenticate the wide applicability of the DES; specifically, in food processing, the use of DES has not been examined for the production of lactic acid.

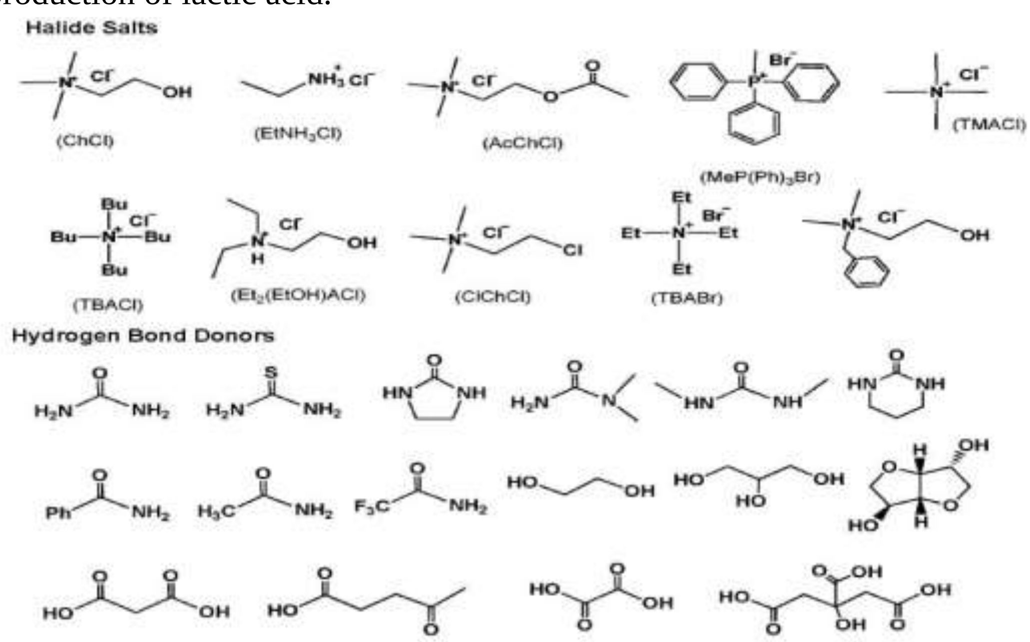


Figure 2: Structures for a number of hydrogen bond acceptors (HBAs) and hydrogen bond donors (HBDs) used for deep eutectic solvent (DES) synthesis (Payam and Ghandi, 2019).

DESs were pronounced lately as capacity options to ionic liquids (ILs). Although they possess core characteristics that are similar to those of ILs such as low volatility, non-flammability, low melting points, low vapor pressure and dipolar nature; DESs have better properties spanning higher chemical and thermal stability, good biocompatibility, high solubility, low toxicity, biodegradable and higher tuneability. Moreover, DES has been reported to be better in all the characteristics it shares with the Ionic Liquids (Tang *et al*., 2014; Juneidi *et al*., 2017).
DES is a liquid that is usually made up of two or more compounds that can self-associate, often by hydrogen bond interactions, to form a eutectic mixture with a temperature lower than the temperature of each individual component (Abbott et al., 2004). DESs constitute majorly of non-flammable organic salts which are suggested substitute for volatile conventional organic solvents; usually hydrogen bond acceptors (HBAs) and hydrogen bond donors (HBDs) with negligible vapor pressure (Juneidi *et al*., 2017). They usually consist of large nonsymmetrical ions, most commonly a quaternary ammonium cation coupled with a halide anion, which is complexed with a metal salt or a hydrogen bond donor (HBD). **Figure 2** shows a number of common salts as HBAs and HBDs used to make DESs.

**DES Formulation and Classification**

DESs samples can be formulated in different molar ratios of hydrogen bond acceptor (HBA) such as Choline Chloride (ChCl), betaine and L-proline, and hydrogen bond donor (HBD) such as Urea, polyols, sugar, carboxylic acid (Triyani and Herman, 2021), glucose, sorbitol, oxalic acid, glycerol, ethylene glycol, etc. in an incubator shaker at an appropriate molar ratio. The preparation is simple; no solvent or final product purification is required because no side products are formed (Li and Row, 2019). DES is formed by cation, anion and complex agents while Ionic liquids are formed by cation and anion only. DESs are prepared either by vacuum evaporation or heating. In the **Vacuum Evaporating method** (VEM), various components are dissolved in water and evaporated at 50$^{o}$C with a rotatory evaporator. The liquid obtained is cooled to a constant weight in a desiccator. Using the **Heating method** DESs of known water content is formulated. In a bottle with a stirring bar and cap, the two-component mixture with calculated amounts of water is heated for 30 - 90 min in a water bath below 50$^{o}$C with agitation till a clear homogeneous liquid is formed (Chen and Tiancheng , 2019). Typical combination of two component in the formation of a DES can be represented as shown in figure 3 bellow. It is worthy of note that altering the components (different quaternary ammonium, phosphonium or sulfonium salts) and their ratios can yield a broad array of DESs with variation in the following physiochemical and thermal properties:

pH, density, refractive index (RI), viscosity, solvatochromic parameters, surface tension, octanol-water partition coefficient ($K_{ow}$), conductivity, freezing temperature ($T_f$), glass transition temperature ($T_g$), melting temperature ($T_m$), decomposition temperature ($T_d$), flammability, miscibility, miscibility and polarity (Degam, 2017; Payam and Ghandi, 2019). This component alteration brings about the formulation of different types of DESs that can be classified as types I to IV.

*Type (I)* - a quaternary salt + a metal chloride (e.g. $C_2mimCl + AlCl_3$),
*Type (II)* - a quaternary salt + a hydrated metal chloride (e.g. $ChCl + MgCl_2 \cdot 6H_2O$),
*Type (III)* - a quaternary salt (HBA) + a hydrogen bond donor (HBD) (e.g. ChCl + Urea),

*Type (IV)* - a metal chloride + HBD (e.g. $ZnCl_2$ + Urea) (Abbott et al., 2004)
DES can also be classified as Natural and Hydrophobic DESs. **Natural DESs** (NADESs) which meet the green chemistry objectives are bio-based primary metabolites (plant cellular metabolites) (Payam and Ghandi, 2019) consisting of organic acids, sugars, alcohols, amines and amino acids. The **Hydrophobic DESs** are typical of exhibiting low or even negligible water miscibility, low vapor pressure, wide liquid range, low flammability, and high solvation capability. They can be simply prepared by mixing low-cost constituents in the right molar ratio.

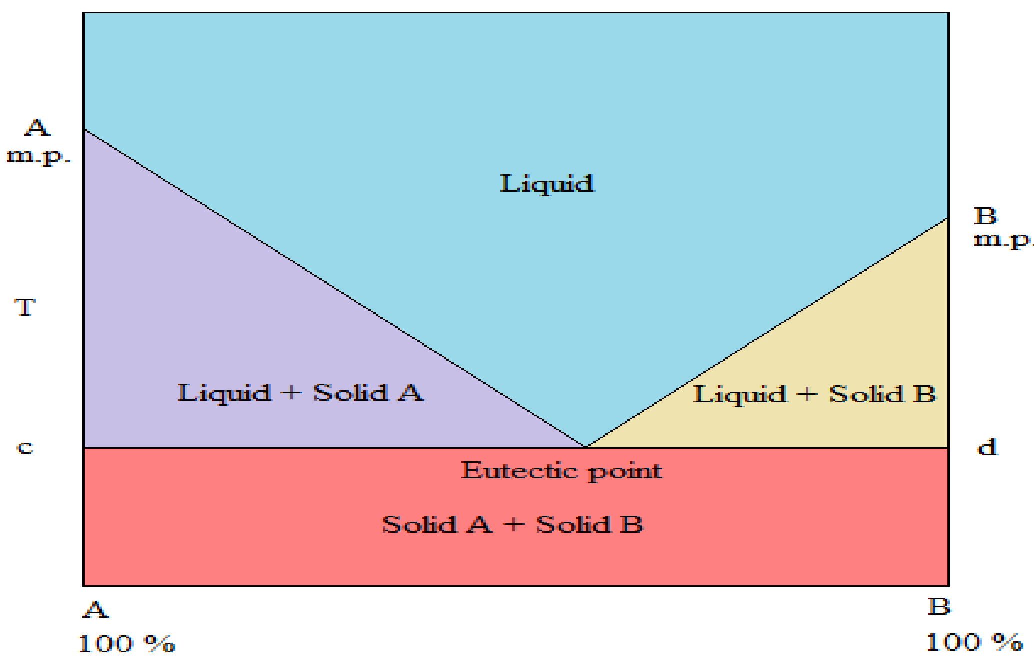

**Figure 3:** Schematic representation of a eutectic point on a two component phase that formed DESs. (Degam, 2017).

## Distribution in the Research Field

The Summary of the distribution of the DESs in research and industry, as seen in Fig. 4, gives an idea of the general direction of this new concept. The result shows that synthesis, the output of virtually every industrial process has the highest proportion of all fields, making approximately one-third of the chart. These proportions show advancement in the wide application of DESs with highest applicability (more than half of the references chart) in synthesis and electrochemistry.

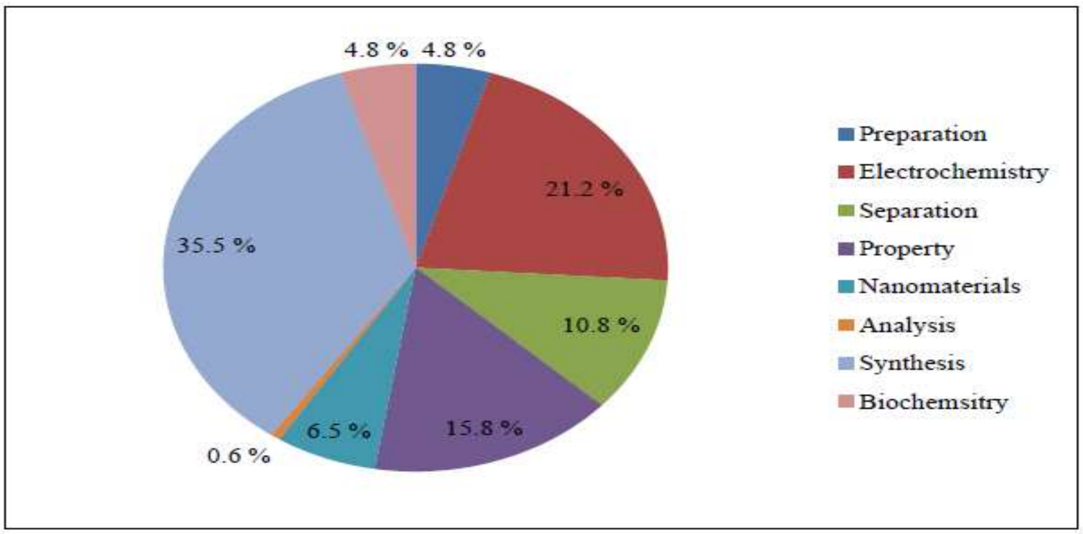


**Figure 4:** Percentage breakdown of references related to the DES research field (Degam, 2017)

## Uses and Application

The uses of DES for biotransformation are gaining a lot of interest owing to its enhancement in the stability and action on enzymes like cellulose, lipase and protease, etc. Thus, there is need to evaluate biological interactions of DES and their utilization in biotransformation. The important features of DES has increased its potentials for utilization in various biochemical applications when compared to ionic liquids or conventional organic solvents (Domínguez *et al*., 2011). Usually, although biotransformations have been performed using conventional organic solvents such as methanol, hexane and acetone; they are typical to cause enzymes denaturation (Juneidi *et al*., 2017). Consequently, with the use of DES; enhance substrates dissolution and enzyme activation have been observed (Juneidi *et al*., 2017).

DESs can be easily synthesized in high purity at low cost due to the low cost and high purity of the starting materials. Their synthesis procedure is very simple and straightforward, only requires the mixing of the quaternary ammonium, phosphonium or sulfonium salts and HBDs mechanically in an appropriate mole ratio and no waste products are formed during this reaction. Therefore, according to the twelve principles of green chemistry, synthesis of DESs is green and environmentally benign because their reaction has zero emissions, zero E-factor value, and 100 % mass efficiency (Deetlefs and Seddon, 2010). In terms of an economic perspective, DESs are inexpensive and approximately tenfold less expensive than the components of ILs (Degam, 2017).

The main advantage of DESs are their potential as more designable solvents attributive to their tunable physical, chemical and thermal properties (Smith et al., 2014). Considering that no chemical reactions occur during their formation, disrupting the complex structures in their matrix can be easy making the starting materials of DESs more easily recoverable. Considering the significant edge of the DES over other ILs in teams of applicability, DES is typically desirable as green alternatives for large-scale industrial applications. Some DESs (ChCl-U- and ChCl-G based) are already available on commercial scale and are industrially applied in biodiesel synthesis (Zhao et al., 2013), purification (Abbott et al., 2007) and electrodeposition of metals (Abbott and McKenzie, 2006).

The DES has been reported applicability in the bulk processing of metals in the Fabrication of novel metal surfaces and Coatings (Ali et al., 2014, De Vreese et al., 2014 and Yanai et al., 2014) polymer synthesis (Liao et al., 2005), carbon-carbon nanotube composite preparation (Gutiérrez et al., 2010) , biodiesel purification (Abbott et al., 2007), Pharmaceutical: drug solubilization (Morrison et al., 2009), biological transformations in Biotechnology and nanotechnology (Gutierrez et al., 2010) and $CO_2$ absorption (Li et al., 2008, Ali et al., 2014 and Lu et al., 2015), extraction and separation of organic compounds in biomass pretreatment and conversion, Enhanced oil recovery, and Medicine. DESs were also found to be viable solvents for the fabrication of novel metal surfaces and coatings and thermos-chromic polyvinylidene fluoride composite film (Gu et al., 2011). DESs have been attracting significant attention as a greener media for organic synthesis (Serrano et al., 2012 and Dai et al., 2014), materials synthesis and processing (Carriazo, et al., 2012) and biotransformations (Krystof et al., 2013, Pöhnlein et al., 2015). They have been the choice for a number of enzyme-based biotransformation, because of their excellent properties for a wide variety of solutes, including enzymes and substrates (Krystof et al., 2013, Pöhnlein et al., 2015). DESs have taken the place of ILs in the industrial synthesis of zeolite analogs (Cooper et al., 2004), nanoparticles (Liao et al., 2008), gold nanostars (Degam, 2017); extraction of aromatics from naphtha (Kareem et al., 2012), removal of excess glycerol from biodiesel fuel (Stassi et al., 2012), and electrochemical applications (Degam, 2017). Recently DES is reported applicable as high-performance size exclusion chromatography packing materials (Tang and Row, 2015), sorbent for solid-phase extraction (Karimi, et al., 2016), in pretreatment for nanofibrillation of wood cellulose (Sirviö et al., 2015), dissolution of biological samples (Helalat-Nezhad et al., 2015), biomass valorization (Vigier et al., 2015), processing of leather (Abbott et al., 2015), pulp fiber, and killing bacteria (Tenhunen et al., 2016). These copious application of DES caught the interest of many researchers in green chemistry. Table 1 shows the summary of applications of DESs in various fields.

Most common in the aforementioned are the applications in biomasses pretreatment, and the subsequent extraction, separation and purification processes of the essential organic compounds and chemicals. In pretreatment of biomasses: carbohydrates, various conventional solvents like ILs have been reported toxic, high cost and environmentally unfriendly. Ren *et al*., (2016) produced a DES allyltriethylammonium chloride: oxalic acid at ratio of 1:1 for pretreatment of cellulose and they enhanced solubility of 64.8%. Sirvio *et al.*, (2015) utilized 1:2 molar ratio of ChCl:Urea as DES for pretreatment of cellulose into individual nanofilbrils: a novel success in nanofibrils without chemical or mechanical modification of cellulose. In synthetic pretreatment, the intra-molecular hydrogen bonds in DES is particular in aiding the cleavage of hydrogen bonds in lignocellulosics materials, making the materials soluble for conversion, extraction and separation enhancement (Juneidi *et al*., 2017 and Chen and Tiancheng, 2019). It aids in overcoming the challenges of separation and purification of sugar based chemicals from lignocellulosics materials; that is, it guarantee only the solubility of sugar molecules in biomass rather further conversion to undesirable products (Chen and Tiancheng, 2019). Also, DESs are reported to serve as both solvent and catalyst for the synthesis of bioactive compounds. Wan *et al*. (2018) reported their good interactions with enzymes and microorganism. Despite existed applications in biomass pretreatment and conversion, there are many contingencies for designing more efficient DESs to broaden applicability and to suit the complexity of some biomass. The above applications in lactic acid production have not been reported. However, DESs have been applied to examine the isomeric distribution of fructose, N-acetyl-D-glucosamine, glucose and xylose in $D_2O$; thus revealing its tendency in lactic acid synthesis from glucose.

**Limitations in DES Applications**

Regardless of the numerous possible applications of DESs and the advantages of their use, reports of the fundamental properties of these solvents are still rather scarce in the current literature. Few research works have dealt with measuring the properties of DESs (Degam, 2017). More studies is encouraged to reveal the full properties of this versatile solvent. Investigating the properties of novel solvents will increase the possibility of many future applications. For instance, having a knowledge of viscosity may help in the proper selection of a solvent and temperature that is suitable for a particular application which consequently saves material and energy (Degam, 2017). Therefore, the physicochemical and thermal properties of every applicable DES: industrial or laboratory scale, needs to be reported.

**Conclusion**

A variety of deep eutectic solvents can be prepared with properties superior to those reported for conventional solvents and ILs since DESs is less toxic, more biodegradable, and quicker and easier to prepare. Their unfavorable physicochemical properties can be surmounted by tailoring them: that is, altering the nature of the component salts, cosolvents and other physicochemical properties. Examining the properties and application of this novel solvent will increase the possibility of many future applications.

**References**

Ab Rani, M. A.; Brant, A.; Crowhurst, L.; Dolan, A.; Lui, M.; Hassan, N. H.; Hallett, J. P.; Hunt, P. A.; Niedermeyer, H.; Perez-Arlandis, J. M.; Schrems, M.; Welton, T.; Wilding, R.,(2011) Understanding the polarity of ionic liquids. *Phys Chem Chem Phys* **2011,** *13* (37), 16831-40.

Abbott, A. P.; Alaysuy, O.; Antunes, A. P. M.; Douglas, A. C.; Guthrie-Strachan, J.; Wise, W. R., Processing of Leather Using Deep Eutectic Solvents. *ACS Sustainable Chemistry & Engineering* **2015**, 150427145725007.

Abbott, A. P.; Cullis, P. M.; Gibson, M. J.; Harris, R. C.; Raven, E.(2007). Extraction of glycerol from biodiesel into a eutectic based ionic liquid. *Green Chemistry* **2007,** *9* (8), 868-872.

Abbott, A. P.; McKenzie, K. J.(2006). Application of ionic liquids to the electrodeposition of metals. *Phys Chem Chem Phys* **2006,** *8* (37), 4265-79.

Abbott, A.P.; Boothby, D.; Capper, G.; Davies, D.L.; Rasheed, R.K.( 2004). Deep eutectic solvents formed between choline chloride and carboxylic acids: Versatile alternatives to ionic liquids. *J. Am. Chem. Soc., 126, 9142–9147*

Abbott, G. Capper, D.L. Davies, R.K. Rasheed, V. Tambyrajah, (2003). Novel solvent properties of choline chloride/urea mixtures, *Chem. Commun. (1) 70-71.*

Ali, E.; Hadj-Kali, M. K.; Mulyono, S.; Alnashef, I.; Fakeeha, A.; Mjalli, F.; Hayyan, A.(2014). Solubility of CO2 in deep eutectic solvents: Experiments and modelling using the Peng–Robinson equation of state. *Chemical Engineering Research and Design* **2014,** *92* (10), 1898-1906

Ali, M. R.; Rahman, M. Z.; Saha, S. S.(2014). Electroless and electrolytic deposition of nickel from deep eutectic solvents based on choline chloride. *Indian J. Chem. Technol.* **2014,** *21* (2), 127-133.

Aparicio, S.; Atilhan, M.; Karadas, F.(2010)., Thermophysical properties of pure ionic liquids: review of present situation. *Industrial & Engineering Chemistry Research* **2010,** *49* (20), 9580-9595.

Ayşe Ezgi Ünlü and Serpil Takaç (2020): Use of Deep Eutectic Solvents in the Treatment of Agro-Industrial Lignocellulosic Wastes *DOI:* http://dx.doi.org/10.5772/intechopen.92747

Carriazo.D, M.C. Serrano, M.C. Gutierrez, M.L. Ferrer, F. del Monte, (2012). Deep-eutectic chemical synthesis with biocatalysts in ionic liquids, Molecules 20(9) 16788-16816.contaminants detected in great lakes fish, Environ. Toxicol. Chem. 6(11) (1987) 901-907.

Chen Jingnan 1, Yun Li 2, Xiaoping Wang 1 and Wei Liu (2019): Application of Deep Eutectic Solvents in Food Analysis: A Review *Molecules **2019**, 24, 4594*

Chen, Z.; Bai, X.; Lusi, A.; Wan, C.( 2018). High-solid lignocellulose processing enabled by natural deep eutectic solvent for lignin extraction and industrially relevant production of renewable chemicals. ACS Sustain. Chem. Eng. 6, 12205–12216

Chen, Z.; Zhu, W.; Zheng, Z.; Zou, X. (2010). One-pot α-nucleophilic fluorination of acetophenones in a deep eutectic solvent. *Journal of Fluorine Chemistry* **2010,** *131* (3), 340-344.

Cooper, E. R.; Andrews, C. D.; Wheatley, P. S.; Webb, P. B.(2004). Wormald, P.; Morris, R. E.(2004). Ionic liquids and eutectic mixtures as solvent and template in synthesis of zeolite analogues. *Nature* **2004,** *430* (7003), 1012-1016.

Dai, D.-y.; Wang, L.; Chen, Q.; He, M.-Y.(2014).Selective oxidation of sulfides to sulfoxides catalysed by deep eutectic solvent with H2O2. *Journal of Chemical Research* **2014,** *38* (3), 183-185.

De Vreese, P.; Skoczylas, A.; Matthijs, E.; Fransaer, J.; Binnemans, K.(2013). Electrodeposition of copper–zinc alloys from an ionic liquid-like choline acetate electrolyte. *Electrochimica Acta* **2013,** *108*, 788-794.

Deetlefs, M.; Seddon, K. R.,(2010). Assessing the greenness of some typical laboratory ionic liquid preparations. *Green Chemistry* **2010,** *12* (1), 17-30.
Degam Ganesh (2017) Deep Eutectic Solvents Synthesis, Characterization and Applications in Pretreatment of Lignocellulosic Biomass http://openprairie.sdstate.edu/etd
Domínguez de María, Z. Maugeri, (2011). Ionic liquids in biotransformations: from proof-of concept to emerging deep-eutectic-solvents, *Curr. Opin. Chem. Biol. 15(2) 220-225.*
Duan Ming, Mengjuan Luo, Ziyi Yang, Yan Xiong, Peng Shi, Shenwen Fang Shan Qin (2020): Application of Choline-Based Deep Eutectic Solvent for Extraction of Crude Oil Contaminated Soils, Environmental Technology, DOI: 10.1080/09593330.2020.1717643
Emami Shahram and Ali Shayanfar (2020): Deep Eutectic Solvents for Pharmaceutical Formulation and Drug Delivery Applications, *Pharmaceutical Development and Technology, DOI: 10.1080/10837450.2020.1735414 ISSN: 1083-7450 (Print) 1097-9867 (Online) Journal homepage:* https://www.tandfonline.com/loi/iphd20
Giernoth, R., (2011). Solvents and Solvent Effects in Organic Chemistry 4th Ed by Christian Reichardt and Thomas Welton. *Angew. Chem., Int. Ed.* **2011,** *50* (48), 11289.
Gu, C.-D.; Tu, J.-P.(2011). Thermochromic behavior of chloro-nickel(II) in deep eutectic solvents and their application in thermochromic composite films. *RSC Advances* **2011,** *1* (7), 1220.
Gutiérrez, M. a. C.; Rubio, F.; del Monte, F. (2010). Resorcinol-Formaldehyde Polycondensation in Deep Eutectic Solvents for the Preparation of Carbons and Carbon−Carbon Nanotube Composites. *Chemistry of Materials* **2010,** *22* (9), 2711-2719.
Gutierrez, M. C.; Ferrer, M. L.; Yuste, L.; Rojo, F.; del Monte, F., Bacteria incorporation in deep-eutectic solvents through freeze-drying. *Angew Chem Int Ed Engl* **2010,** *49* (12), 2158-62.
Hayyan, M.; Hashim, M. A.; Hayyan, A.; Al-Saadi, M. A.; AlNashef, I. M.; Mirghani, M. E.; Saheed, O. K.,(2013). Are deep eutectic solvents benign or toxic? *Chemosphere* **2013,** *90* (7), 2193-5.
Helalat-Nezhad, Z.; Ghanemi, K.; Fallah-Mehrjardi, M. (2015). Dissolution of biological samples in deep eutectic solvents: An approach for extraction of polycyclic aromatic hydrocarbons followed by liquid chromatographyfluorescence detection. *J Chromatogr A* **2015,** *1394*, 46-53.
https://www.osha.gov/dte/library/flammable_liquids/flammable_liquids.html, Accessed January 15, 2022.
Juneidi Ibrahim, Hayyan Maan, Hashim Mohd Ali.(2017). Intensification of biotransformations using deep eutectic solvents: Overview and outlook. *Process Biochemistry* https://doi.org/10.1016/j.procbio.2017.12.003
Kareem, M. A.; Mjalli, F. S.; Hashim, M. A.; AlNashef, I. M.(2012). Liquid–liquid equilibria for the ternary system (phosphonium based deep eutectic solvent– benzene–hexane) at different temperatures: A new solvent introduced. *Fluid Phase Equilibria* **2012,** *314*, 52-59.
Karimi, M.; Dadfarnia, S.; Shabani, A. M. H. (2016). Application of Deep Eutectic Solvent Modified Cotton as a Sorbent for Online Solid-Phase Extraction and Determination of Trace Amounts of Copper and Nickel in Water and Biological Samples. *Biological Trace Element Research* **2016**, 1-9.
Kosan, B.; Michels, C.; Meister, F.(2008). Dissolution and forming of cellulose with ionic liquids. *Cellulose* **2008,** *15* (1), 59-66.

Krystof, M.; Perez-Sanchez, M.; Dominguez de Maria, P., Lipase-catalyzed (trans) esterification of 5-hydroxy- methylfurfural and separation from HMF esters using deep-eutectic solvents. *ChemSusChem* **2013,** *6* (4), 630-4.

Li, X.; Hou, M.; Han, B.; Wang, X.; Zou, L.(2008). Solubility of CO2 in a choline chloride+ urea eutectic mixture. *Journal of Chemical & Engineering Data* **2008,** *53* (2), 548-550.

Liao, H. G.; Jiang, Y. X.; Zhou, Z. Y.; Chen, S. P.; Sun, S. G.(2008) Shape-Controlled Synthesis of Gold Nanoparticles in Deep Eutectic Solvents for Studies of Structure–Functionality Relationships in Electrocatalysis. *Angewandte Chemie* **2008,** *120* (47), 9240-9243.

Liao, J.-H.; Wu, P.-C.; Bai, Y.-H.(2005). Eutectic mixture of choline chloride/urea as a green solvent in synthesis of a coordination polymer: [Zn(O3PCH2CO2)]·NH4. *Inorganic Chemistry Communications* **2005,** *8* (4), 390-392.

Lu, M.; Han, G.; Jiang, Y.; Zhang, X.; Deng, D.; Ai, N.(2015). Solubilities of carbon dioxide in the eutectic mixture of levulinic acid (or furfuryl alcohol) and choline chloride. *The Journal of Chemical Thermodynamics* **2015,** *88*, 72-77.

Lynam Joan G , Narendra Kumar -, Mark J Wong (2017) :Deep eutectic solvents' ability to solubilize lignin, cellulose, and hemicellulose; thermal stability; and density Bioresour. Technol. 238 (2017) 684–689PMID: **28494411** DOI: 10.1016/j.biortech.2017.04.079

Mamajanov, I.; Engelhart, A. E.; Bean, H. D.; Hud, N. V.(2010). DNA and RNA in anhydrous media: duplex, triplex, and G-quadruplex secondary structures in a deep eutectic solvent. *Angew Chem Int Ed Engl* **2010,** *49* (36), 6310-4.

Morrison, H. G.; Sun, C. C.; Neervannan, S. (2009). Characterization of thermal behavior of deep eutectic solvents and their potential as drug solubilization vehicles. *Int. J. Pharm.* **2009,** *378* (1-2), 136-139.

Payam, K and Ghandi, K (2019). Deep Eutectic Solvents for Pretreatment, Extraction, and Catalysis of Biomass and Food Waste *A Review doi: 10.3390/molecules24224012 http//www.mpdci.com.*

Pöhnlein, M.; Ulrich, J.; Kirschhöfer, F.; Nusser, M.; Muhle-Goll, C.; Kannengiesser, B.; Brenner-Weiß, G.; Luy, B.; Liese, A.; Syldatk, C.; Hausmann, R., Lipase-catalyzed synthesis of glucose-6-O-hexanoate in deep eutectic solvents. *European Journal of Lipid Science and Technology* **2015,** *117* (2), 161-166.

Pontolillo, J.; Eganhouse, R. P.(2001), *The search for reliable aqueous solubility (Sw) and octanol-water partition coefficient (Kow) data for hydrophobic organic compounds: DDT and DDE as a case study*. US Department of the Interior, US Geological Survey Reston, Virginia: 2001.

Serrano, M. C.; Gutierrez, M. C.; Jimenez, R.; Ferrer, M. L.; del Monte, F.(2012). Synthesis of novel lidocaine-releasing poly(diol-co-citrate) elastomers by using deep eutectic solvents. *Chem Commun (Camb)* **2012,** *48* (4), 579-81.

Shamsuri, A. A.; Abdullah, D. K.(2010). Ionic liquids: Preparations and limitations. *Makara, Sains* **2010,** *14,* 101-106.

Sheldon.R.A, (2016). Biocatalysis and biomass conversion in alternative reaction media, Chem.

Sirviö, J. A.; Visanko, M.; Liimatainen, H. (2015). Deep eutectic solvent system based on choline chloride-urea as a pre-treatment for nanofibrillation of wood cellulose. *Green Chem.* **2015**.

Smith, E. L.; Abbott, A. P.; Ryder, K. S.(2014), Deep eutectic solvents (DESs) and their applications. *Chem Rev* **2014,** *114* (21), 11060-82.

Stassi, S.; Cauda, V.; Canavese, G.; Manfredi, D.; Pirri, C. F.(2012). Synthesis and Characterization of Gold Nanostars as Filler of Tunneling Conductive Polymer Composites. *European Journal of Inorganic Chemistry* **2012,** *2012* (16), 2669- 2673.

Tang, B.; Row, K. H.(2015). Exploration of deep eutectic solvent-based mesoporous silica spheres as high-performance size exclusion chromatography packing materials. *Journal of Applied Polymer Science* **2015,** *132* (27), n/a-n/a.

Tang, H.E. Park, K.H. Row, (2014). Preparation of chlorocholine chloride/urea deep eutectic solvent-modified silica and an examination of the ion exchange properties of modified silica as a Lewis adduct, Anal. BioAnal Chem. 406(17) 4309-4313.

Tenhunen, T.-M.; Hakalahti, M.; Kouko, J.; Salminen, A.; Härkäsalmi, T.; Pere, J.; Harlin, A.; Hänninen, T.(2016). Method for Forming Pulp Fibre Yarns Developed by a Design-driven Process. *BioResources* **2016,** *11* (1), 2492-2503.

Triyani Sumiati and Herman Suryadi (2021). Potency of Deep Euteutic Solvent as an Alternative Solvent on Pretreatment Process of Lignocellulosic Biomass: Review Journal of Physics: Conference Series **1764** 012014

Vigier, K. D. O.; Chatel, G.; Jérôme, F., Contribution of Deep Eutectic Solvents for Biomass Processing: Opportunities, Challenges, and Limitations. *ChemCatChem* **2015,** *7* (8), 1250-1260.

Wu. B.P, Q. Wen, H. Xu, Z. Yang, (2014). Insights into the impact of deep eutectic solvents on

www.nnfcc.co.uk Asessed on 5th April, 2020

Yanai, T.; Shiraishi, K.; Shimokawa, T.; Watanabe, Y.; Ohgai, T.; Nakano, M.; Suzuki, K.; Fukunaga, H.(2014). Electroplated Fe films prepared from a deep eutectic solvent. *Journal of Applied Physics* **2014,** *115* (17), 17A344.

Zhang, Q.; Vigier, K. D. O.; Royer, S.; Jérôme, F., (2012). Deep eutectic solvents: syntheses, properties and applications. *Chemical Society Reviews* **2012,** *41* (21), 7108-7146.

Zhao, H.; Zhang, C.; Crittle, T. D.(2013). Choline-based deep eutectic solvents for enzymatic preparation of biodiesel from soybean oil. *Journal of Molecular Catalysis B: Enzymatic* **2013,** *85-86*, 243-247.