A CRITICAL EXAMINATION OF THE ROLE OF GREEN CHEMISTRY IN ORGANIC SYNTHESIS

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Abstract

Global warming and pollution create major issues. As human everyday appliances need had expanded over years, organic chemical-based companies boosted their manufacturing method. It worsens environmental contamination. Hence, green chemistry encouraged chemical companies to be more environmentally friendly. Green chemistry concepts have influenced organic chemistry for 20 years, particularly because many researchers have focused on it. Organic compound synthesis has explored waste avoidance, cleaner solvents, energy efficiency, and renewable feed stocks. This review summarizes green chemistry concepts and their use in organic chemical synthesis.

Keywords: *environmental sustainability, green chemistry, organic compound, synthesis process.*

Introduction

Recent environmental quality is alarming and profoundly impacts human lives. Environmental pollution occurs when natural or intentional contamination raises pollutant levels above normal. Environmental contamination disrupts any ecosystem. Industrial activities are worsening soil, water, and air pollution. Greenhouse gasses also raise Earth's temperature, degrading the ecosystem (known as global warm- Ana ing). To preserve our environment, such issues must be addressed. So, industrial operations should prioritize environmental conservation above economic gain.

In the past, chemical firms focused on reaction yield and product purity rather than environmental concerns, energy use, and process efficiency. Notwithstanding national and international chemical industry restrictions, environmental contamination remains an issue, particularly in developing nations. As the government appears unable to sustain the environment, experts are trying to build "green" chemical enterprises.

Before Anastas and Warner established green chemistry in 1998, several environmental concerns were developed and improved. Green chemistry lowers or eliminates harmful compounds in chemical product design, production, and use. Image 1 shows 12 green chemicals.

As the article is limited in length, we concentrated our study on four primary principles: waste prevention, cleaner solvents, energy-efficient design, and renewable feedstocks. Yet, those four concepts also briefly explain the others. This review also covers green chemistry and organic chemical synthesis.

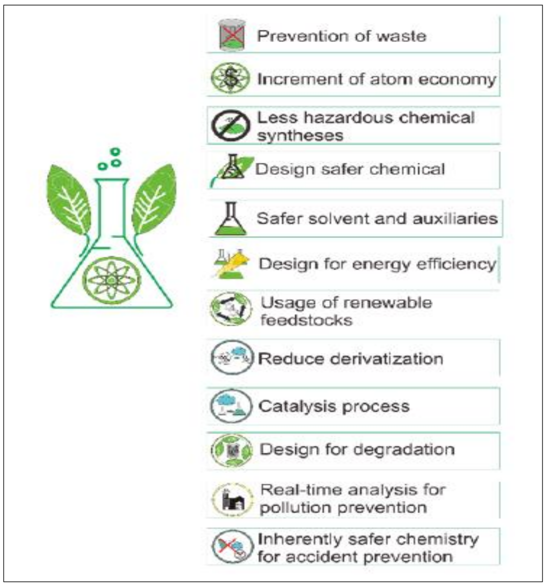


Figure - Principles of green chemistry

2. WASTE PREVENTION

Process byproducts are waste. Toxic, non-biodegradable, and radioactive chemical waste frightens humans. Chemical industry produce such wastes continually. Waste may be classed as liquid or solid. Wastes are either liquid or solid. Liquid waste typically comprises acid, base, metal ions (precious, alkali, base, and heavy metals), organic pollutants (dyes, biomolecules), and more. Solid trash includes plastics, paper, metals, ceramics, and glassware.

To create the intended output, the chemical process should combine all employed elements. Hence, waste avoidance should be achieved by rational and effective chemical process design employing green chemistry quantitative metrics including effective mass yield, product efficiency, carbon efficiency, atom economy, reaction mass efficiency, ecoscale, environmental factor, and biologictool plots. Effective mass yield is the ratio of the intended product to all non-benign ingredients (water, dilute alcohol, NaCl, etc.) employed in its chemical process. This characteristic defines "non-benign" material subjectively and does not indicate the chemical process's toxicity. Product efficiency compares the actual mass of the intended product to its theoretical total atomic mass.

Carbon efficiency measures product carbon atom use. This parameter is useful for the pharmaceutical business but worthless for inorganic industries like metal oxide, paint, polymer, and advanced materials. Barry Trost developed the atom economy formula in 1995 based on reactant concentration in the intended product. Nowadays, atom economy is a useful criterion for organic and inorganic processes, even if it overlooks the homogenous detalyst and solvents since they are not reactants. Atom economics is only examined from the handwriting reaction equation, thus it is just theoretical.

Atom economy, chemical yield, and reaction stoichiometry determine reaction mass efficiency. Reaction mass efficiency, like car-bon efficiency parameter, is an ideal calculation that shows the "greenness" of the reaction but not the actual process since it ignores solvent and energy use. Van Aken et al. developed ecoscale measure in 2006. The ecoscale, like the effective mass yield parameter, rates cost, safety, technical setup, energy, and purification from 0 to 100. It is calculated by assigning a value of 100 to an ideal reaction—"Compound A undergoes a reaction with compound B to give the desired compound C in 100% yield at room temperature with a minimal risk for the operator and a minimal impact on the environment"—and subtracting penalty points for non-ideal conditions. Real chemical processes seldom meet this ideal state.

E-factor, one of the most adaptable green chemistry quantitative measurements, remains. In 2007, Roger A. Sheldon introduced the E-factor formula as the ratio of total waste to desired output. E-factor evaluates solvent and catalyst consumption to determine whether a chemical process is environmentally friendly. Oil refining, bulk chemicals, fine chemicals, and pharmaceutical operations produce 106-108, 104-106, 102-104, and 10-103 tons annually. Oil refining, bulk chemicals, fine chemicals, and pharmaceutical operations create 105-107, 104-105, 10-104, and 102-105 tons of trash. Oil refining, bulk chemicals, fine chemicals, and pharmaceutical processes have E-factors of 0.1, 1-5, 5-50, and 25-100, respectively. The pharmaceutical business has the worst E-factor today, whereas the oil refining industry has the cleanest.

Lie et al. presented biologic tool plot, the newest green chemistry quantitative method. This parameter represents a chemical pathway using starting material, intermediates, product names, chemical formulas, and reaction step yields. Biologic tool scores are calculated by plotting heteroatom mass percentage versus molar mass. Chemical method is sensible when biologic tool score is closer to 1. Industrial chemical process design and assessment depend on this parameter. Green chemistry metrics equations are below.

We created a "greener" biodiesel manufacturing procedure by esterifying fatty acids with ethanol. Table 1 shows that process's green quantitative measures. Sulfuric acid outperformed KSF montmorillonite in reflux method yield and reaction mass efficiency. KSF montmorillonite-catalyzed reaction had 17 times lower E-factor than sulfuric acid process, proving it is a superior green approach.

Waste remediation is necessary to reduce environmental damage when waste avoidance fails. Coagulation, precipitation adsorption, bioremediation, and photocatalysis are liquid waste remediation technologies. Through chemical or physical means (centrifugation), contaminants are solidified or precipitated (precipitated as their insoluble materials). Solid solids absorb contaminants via adsorption. Enzyme and/or microorganism bioremediation degrades pollutants. Photocatalysis uses light to degrade a catalyst material. Solid garbage is generally incinerated and buried.

Phenol (C,H,OH) is used to make herbicides, detergents, polycarbonate, bakelite, and nylon polymers. The Agency for Environmental Protection lists phenol as one of 129 hazardous contaminants, even though its indispensable function drives demand. Hence, numerous phenolic wastewater treatments are created and refined. To maximize phenol adsorption (mg phenol/g adsorbed), heterogeneous materials were used. Phenol desorption is difficult, leaving a hazardous solid. Bioremediation of phenol by bacterial enzymatic metabolism is an alternate technique to degrade phenol, however the bacteria need stable environmental conditions such pH 7.4 at 310 K. It renders the chemical process too difficult for large-scale commercialization.

$$\text{Effective mass yield (\%)} = \frac{\text{mass of products x } 100\%}{\text{mass of non-benign reagents}} \quad (1)$$

$$\text{Product efficiency} = \frac{\text{real mass of the desired product x } 100\%}{\text{theoretical total atomic mass of the desired product}} \quad (2)$$

$$\text{Carbon efficiency (\%)} = \frac{\text{amount of carbon in product x } 100\%}{\text{total carbon present in reactants}} \quad (3)$$

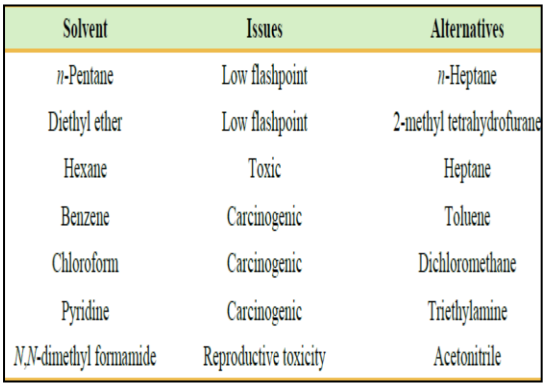
$$\text{Atom economy} = \frac{\text{m.w. of desired product x } 100\%}{\Sigma\ \text{(m.w. of used reactant)}} \quad (4)$$

$$\text{Reaction mass efficiency} = \frac{\text{molecular weight of the product x yield}}{\text{m.w. reactant A} + \text{(m.w. reactant B x molar ratio reactant B/A)}} \quad (5)$$

$$\text{E-factor} = \frac{\text{total waste}}{\text{product}} \quad (6)$$

In contrast, it is feasible to execute phenol degradation to carbon dioxide and water when metal oxide catalyst material is present. Given that it only requires lightweight, reusable catalyst materials, this approach is both straightforward and effective. In our earlier research, we used natural red amaranth pigments to make the P25 TiO nanoparticles sensitive to phenol degradation under visible light. In visible light, pure P25 TiO2 had negligible photodegradation activity, whereas sensitized P25 TiO2 had a remarkable 22% photodegradation activity for phenol. Our study suggests that an optimal smart material for the photodegradation of phenol to water and carbon dioxide might be created by mixing organic molecules with inorganic elements.

Table 1- List of the alternative solvents for a safer chemical process



Solvent	Issues	Alternatives
n-Pentane	Low flashpoint	*n*-Heptane
Diethyl ether	Low flashpoint	2-methyl tetrahydrofurane
Hexane	Toxic	Heptane
Benzene	Carcinogenic	Toluene
Chloroform	Carcinogenic	Dichloromethane
Pyridine	Carcinogenic	Triethylamine
N,N-dimethyl formamide	Reproductive toxicity	Acetonitrile

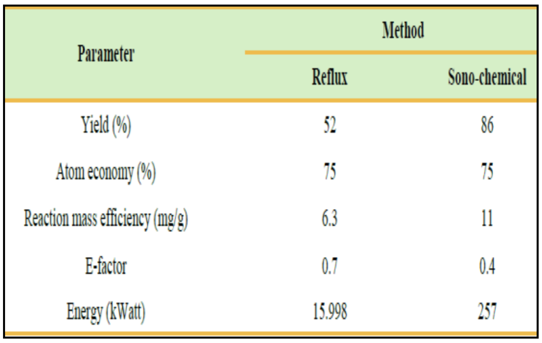
3. SAFER SOLVENTS

The solvent dissolves the components to produce a solution. A simple chemical process may need a lot of solvent for reaction media and filtration. As the solvent just dilutes the chemicals in the chemical reaction, it is possible to avoid using flammable, poisonous, and environmentally destructive solvents like benzene, carbon tetrachloride, formaldehyde, etc. Carbon tetrachloride evaporates readily, causing air pollution and human exposure. High-polarity solvents like formaldehyde may accumulate in aquatic environments and harm humans. To improve environmental sustainability, solvent replacement activities are underway. Solvent-free chemical procedures like grinding and sol-gel are ideal.

Toluene replaced benzene owing to its carcinogenic properties, while chloroform or dichloromethane replaced carbon tetra-chloride due to its ozone-depleting properties. Byrne, et al. defined "green solvent" as an ecologically friendly solvent made from renewable sources with minimal net cumulative energy consumption. Ethanol is a "greener" solvent than N,N-dimethyl formamide because it can be easily generated from biomass waste by large-scale fermentation. Pfizer and Sanofi classified solvents by environmental impact and manufacturing energy in Table 2.

Solvent-replacement usually depends on its physicochemical features. Solvent substitution is achievable if the alternative solvents have similar physicochemical characteristics. Solubility (d), acidity (a), basicity (b), and polarity (p*) are Kam-let-Taft parameters. A solvent replacement design may be rationalized by studying those factors. Table 3 lists alternative solvents that reduce chemical process environmental harm. Many chemical processes now use supercritical fluids and ionic liquids.

Table 2- The comparison of ethyl 9,10-dihydroxyoctadecanoate synthesis using reflux and sono chemistry methods



Parameter	Method	
	Reflux	Sono-chemical
Yield (%)	52	86
Atom economy (%)	75	75
Reaction mass efficiency (mg/g)	6.3	11
E-factor	0.7	0.4
Energy (kWatt)	15.998	257

4. DESIGN FOR HIGH ENERGY EFFICIEN CY

Chemical processes may need high temperatures to pass the activation energy or make them thermodynamically feasible. Certain inorganic materials need calcination at >700 K to develop a crystal structure. Organic reactions use reflux. Sonochemistry, microwave chemistry, photocatalysis, and microfluidics are now "green" reaction conditions. The alternative reaction technique relies on quick energy transfer from heat sources to chemicals to reduce reaction time. Catalyst material may speed up chemical reactions and purification, reducing energy use. Catalysts decrease activation energy and increase reaction rate without changing chemically. Changing catalyst materials controls reaction selectivity and stereo-chemistry to produce the desired product in high yield and purity. The catalyst material's selectivity and high catalytic efficiency are superior than racemic mixtures in a slow process.

Sonochemistry uses ultrasonic radiation (20 kHz–10 MHz) to chemically react under green reaction conditions. Due to unique cavitation processes, sonochemistry may quickly generate hot spots with 5,000-25,000 K temperatures and 1,000 atm pressure (heating rate > 1011 K s-1). Table 4 shows the results of our esterification of 9,10-dihydroxyoctadecanoic acid with ethanol utilizing KSF montmorillonite as a catalyst using reflux and sonochemical methods. Sonochemical yielded greater yield and reaction mass efficiency than reflux. Sono-chemical approach produces ethyl 9,10-dihydroxyoctadecanoate more efficiently and sustainably than reflux method.

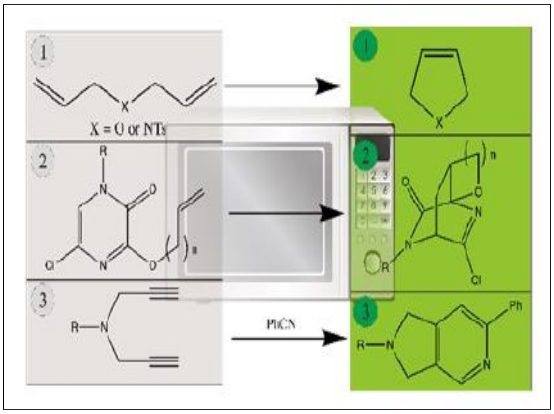


Figure- MAOS process for several organic reactions

Microwave-assisted reaction occurs when molecules collide and/or conduct electromagnetic energy. Recently, microwave-assisted organic synthesis

(MAOS) has been used for ring-closing metathesis of diallyl derivatives, intramolecular hetero-Diels-Alder cycloloaddition of alkenyl-tethered 2(1H)-pyrazolines, cyclotrimerization reaction between diyne and benzonitrile, and others. The microwave-solid support approach (300 Watt, 10 min) increased cyclotrimerization reaction yield from 9% (traditional heating) to 92%. Figure 2 shows these compounds' microwave reaction pathway.

Catalyzed photochemical processes include Claisen rearrangement, Diels Alder reaction, and other pericyclic reactions depend on orbital molecules and charge transfer under UV (400-750 nm) or infrared (750-2,500 nm) illumination. Trommsdorff reported the first photochemical reaction in 1834 by reacting a-santonin under visible light. Visible light irradiation reorganized, dimerized, and reacted a-santonin to create a crystal. The photooxidation of (Z)-1,2-diphenylethene to phenanthrene and the benzene-fulvene-benzvalene reaction are also beneficial. The easy degradation of benzene to fulvene is notable since it solves an insurmountable problem. Figure 3 shows these compounds' photochemistry reaction pathway.

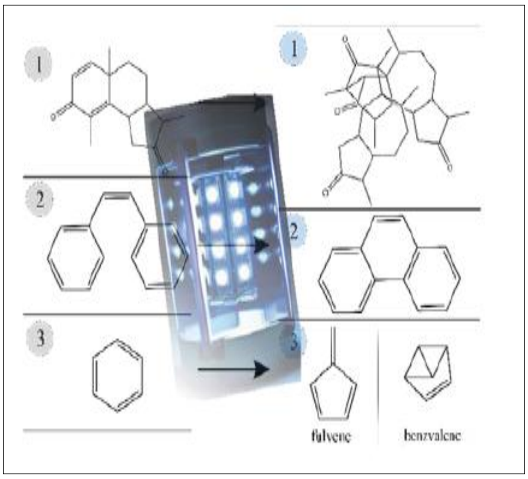


Figure - Photochemistry reaction for the production of organic compounds

The microfluidics response on the micro-vessel device is last. Microfluidics has high mass transfer, huge surface contact area, and low diffusion distance. Micro-fluidics expertise has been used for chemical production and other applications. Yoshida and colleagues used the microfluidic technology to synthesize chemical molecules in submilliseconds. Due to highly quick response mixing, traditional reactors cannot reach short reaction times. Good kinetic control in microfluidics increased response selectivity and reduced waste. Rapid mixing velocity allows moderate organic reactions at ambient temperature without cryogenic conditions or protective groups. The tiny gadget makes this technology portable and reduces chemical distribution energy. Due to its atom- and step-economical simple synthesis, microfluidics was a suitable reaction platform.

Organolithium compounds with unstable carbon-lithium bonds are reactive and pyrophoric. Yet, microfluidics can handle organolithium reagents for an anionic Fries rearrangement in a second, a catalyst-free amination of aromatic compounds in a minute, a functionalization of 2,5-norbornadiene in 3 minutes, a Suzuki-Miyaura cross-coupling reaction in 5 minutes, and more. Microfluidic technique allowed large-scale complete synthesis of Pristane and Pauciflorol F compounds in 5 minutes.

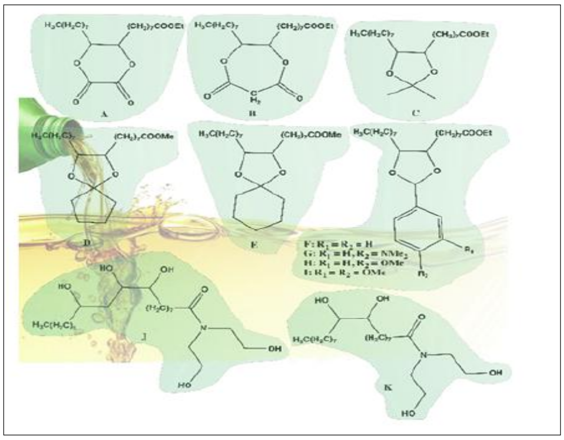


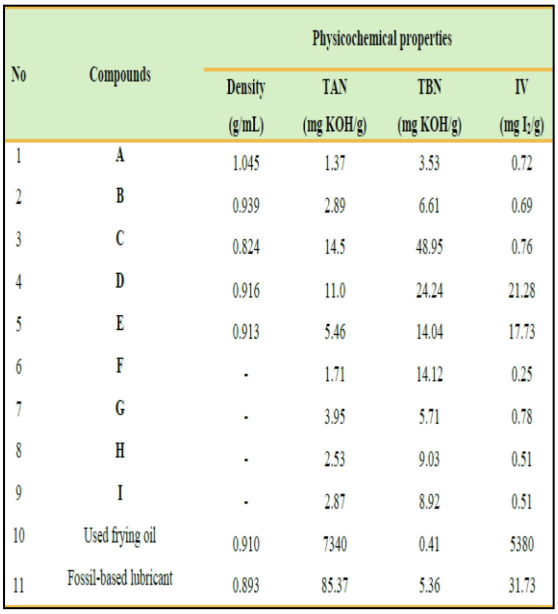
Figure- Structure of Biolubricant compound A-K

5. USAGE OF RENEWABLE FEEDSTOCKS

Renewable sources and bio-sources are being used as fossil material sources deplete. The petroleum feedstock plastics sector is in trouble because demand exceeds output. Because of it, many businesses switch from petroleum-based polymer to biomass-derived polymer. Since it was mild, atom transfer radical (ATRP) polymerization of biopolymers was considered ecologically acceptable. Moreover, a good catalyst material controls polymerization pace, degree, and selectivity. The catalyst material is impregnated on silica, making it inexpensive and easy for large-scale production. Polylactide (polylactic acid) may replace polystyrene and polyethene. Since polylactide degrades quickly under aerobic conditions or under UV irradiation, unlike polystyrene and polyethene (> 1,000 years). Commercial production of biomass-derived polymers like polyglyconic acid and bio-polyethene from sugar beet and biomass fermentation is excellent news for the environment.

Researchers are creating biomaterials from waste oils as fossil-based resources deplete. Biolubricants, biogreases, and bio-surfactants have been created and tested for commercial use. We previously prepared cyclic ketal of 9,10-dihydroxyoctadecanoates and other heterocyclic compounds from spent frying oil. Transesterifying, hydrolyzing, and oxidizing old frying oil yielded 9,10-dihydroxyoctadecanoic acid. Esterifying the fatty acid and reacting with carbonyl chemicals produced the desired result. Such method yielded dioxane-dione (A), dioxepame (B), dioxolane (C, F-I), and diox-aspiro (D and E). Figure 4 shows their chemical structures and Table 4 their physical attributes.

Table 4 Physicochemical properties of several biolubricants, biogreases, and biosurfactants synthesized from used frying oil waste



No	Compounds	Physicochemical properties			
		Density (g/mL)	TAN (mg KOH/g)	TBN (mg KOH/g)	IV (mg I_2/g)
1	A	1.045	1.37	3.53	0.72
2	B	0.939	2.89	6.61	0.69
3	C	0.824	14.5	48.95	0.76
4	D	0.916	11.0	24.24	21.28
5	E	0.913	5.46	14.04	17.73
6	F	-	1.71	14.12	0.25
7	G	-	3.95	5.71	0.78
8	H	-	2.53	9.03	0.51
9	I	-	2.87	8.92	0.51
10	Used frying oil	0.910	7340	0.41	5380
11	Fossil-based lubricant	0.893	85.37	5.36	31.73

Based on physicochemical properties, biolubricants A-E had better density values and lower total acid numbers (TAN) and iodine values (IV) than frying oil or fossil-based lubricants. Total base number (TBN) varies from low to medium due to eterocyclic moiety substituents. Bi-ogreases F-I, however, showed reduced TAN and IV but greater TBN, making them suitable biomaterials for machine-based chemical processes [20]. Plant oils also make nonionic biosurfactants J and K. According to a physicochemical study, their critical micelle concentrations are 1.5 and 1.5 g/L, their surface tensions are 16.1 and 14.2 mN/m, their foam stability values for 100 minutes are 3.0 and 42 mL, and their emulsification indices for 4 days are 10.0 and 68.0%. These physicochemical results suggest that nonionic biosurfactants are good industrial prospects.

CONCLUSION

In conclusion, significant attention is needed to build an efficient and effective organic synthesis process and ensure environmental sustainability. Using green chemistry principles—preventing waste by employing green chemistry quantitative measures, using safer and biofriendly solvents, using an appropriate synthesis process with high energy efficiency, and using renewable feedstocks such unused wastes—could attain this condition. So, there is no reason to ignore green chemistry in chemical industry management to improve our planet.

REFERENCES

[1] *B. A. de Marco, B. S. Rechelo, E. G. Tótoli, A. C. Kogawa, and H. R. N. Salgado. (2019). "Evolution of green chemistry and its multi- dimensional impacts: A review". Saudi Phar- maceutical Journal.* ***27*** *(1): 1–8. 10.1016/ j.jsps.2018.07.011.*

[2] *S. K. Singh, D. N. Rao, M. Agrawal, J. Pan- dey, and D. Naryan. (1991). "Air pollution tolerance index of plants". Journal of Envi- ronmental Management.* ***32*** *(1): 45–55, 1991, doi: 10.1016/S0301-4797(05)80080-5.*

[3] *C. J. Li and B. M. Trost. (2008). "Green chemistry for chemical synthesis". Proceed- ings of the National Academy of Sciences of the United*

States of America. ***105*** *(36): 13197–13202. 10.1073/pnas.0804348105.*

[4] *J. B. Manley, P. T. Anastas, and B. W. Cue. (2008). "Frontiers in Green Chemistry: meeting the grand challenges for sustainability in R&D and manufacturing". Journal of Clean- er Production.* ***16*** *(6): 743–750. 10.1016/ j.jclepro.2007.02.025.*

[5] *M. Poliakoff, J. M. Fitzpatrick, T. R. Farren, and P. T. Anastas. (2002). "Green chemistry: Science and politics of change". Science.* ***297*** *(5582): 807–810. 10.1126/ science.297.5582.807.*

[6] *M. J. Mulvihill, E. S. Beach, J. B. Zimmer- man, and P. T. Anastas. (2011). "Green chemistry and green engineering: A frame- work for sustainable technology develop- ment". Annual Review of Environment and Resources.* ***36****: 271–293. 10.1146/annurev-environ-032009-095500.*

[7] *J. A. Linthorst. (2010). "An overview: Ori- gins and development of green chemistry". Foundations of Chemistry.* ***12*** *(1): 55–68.10.1007/s10698-009-9079-4.*

[8] *P. Anastas and N. Eghbali. (2020). "Green Chemistry: Principles and Practise". Chemi- cal Society Reviews.* ***29****: 301–12. 10.1039/ b918763b.*

[9] *L. Giusti. (2009). "A review of waste man- agement practices and their impact on human health". Waste Management.* ***29*** *(8): 2227– 2239. 10.1016/j.wasman.2009.03.028.*

[10] *C. Brown, M. Milke, and E. Seville. (2011). "Disaster waste management: A review arti- cle". Waste Management.* ***31*** *(6): 1085–1098. 10.1016/j.wasman.2011.01.027.*

M. Tobiszewski, M. Marć, A. Gałuszka, and J. Multidiscip. Appl. Nat. Sci. J. Namieś nik. (2015). "Green chemistry metrics with special reference to green analytical chemistry". Molecules. ***20*** *(6): 10928–10946.10.3390/molecules200610928.*

[11] *T. Hudlicky, D. A. Frey, L. Koroniak, C. D. Claeboe, and L. E. Brammer Jr. (1999). "Toward a 'reagent-free' synthesis". Green Chemistry.* ***1*** *(2): 57–59. 10.1039/a901397k.*

[12] *B. M. Trost. (1995). "Atom Economy—A Challenge for Organic Synthesis: Homogene- ous Catalysis Leads the Way". Angewandte Chemie International Edition in English.* ***34*** *(3): 259–281. 10.1002/anie.199502591.*

[13] *K. van Aken, L. Strekowski, and L. Patiny. (2006). "EcoScale, a semi-quantitative tool to select an organic preparation based on economical and ecological parameters". Beilstein Journal of Organic Chemistry.* ***2****.10.1186/1860-5397-2-3.*

[14] *R. A. Sheldon. (2007). "The E Factor: Fif- teen years on". Green Chemistry.* ***9*** *(12): 1273–1283. 10.1039/b713736m.*

[15] *Y. Lie, P. Ortiz, R. Vendamme, K. Vanbroekhoven, and T. J. Farmer. (2019). "BioLogicTool: A Simple Visual Tool for Assisting in the Logical Selection of Path- ways from Biomass to Products". Industrial and Engineering Chemistry Research.* ***58*** *(35): 15945–15957. 10.1021/acs.iecr.9b00575.*

[16] *Y. S. Kurniawan, M. Anwar, and T. D. Wahyuningsih. (2017). "New lubricant from used cooking oil: Cyclic ketal of ethyl 9,10-dihydroxyoctadecanoate". Materials Science Forum.* ***901****: 135–141. 10.4028/ www.scientific.net/MSF.901.135.*

[17] *J. Jumina, Y. Priastomo, H. R. Setiawan, Mutmainah, Y. S. Kurniawan and K. Ohto. (2020). "Simultaneous removal of lead(II), chromium(III) and copper(II) heavy metal ions through an adsorption process using C- phenylcalix[4] pyrogallolarene material". Journal of Environmental Chemical Engi- neering.* ***8****: 103971. 10.1016/j.jece.2020.103971.*

[18] *L. G. C. Villegas, N. Mashhadi, M. Chen, D. Mukherjee, K. E. Taylor and N. Biswas. (2016). "A Short Review of Techniques for Phenol Removal from Wastewater". Current Pollution Reports.* ***2*** *(3): 157–167. 10.1007/ s40726-016-0035-3.*

[19] *Y. S. Kurniawan, K. Anggraeni, R. Indrawa- ti, and L. Yuliati. (2020). "Functionalization of titanium dioxide through dye sensitizing method utilizing red amaranth extract for phenol photodegradation". IOP Conference Series: Materials Science and Engineering.*

[20] *D. Ariyanti, D. Iswantini, P. Sugita, N. Nur- hidayat, and Y. S. Kurniawan. (2020). "Highly Sensitive Phenol Biosensor Utilizing Selected Bacillus Biofilm Through an Electrochemical Method". Makara Journal of Science.* ***24*** *(1). 10.7454/mss.v24i1.11726.*

[21] *M. M. Khan, S. F. Adil, and A. Al-Mayouf. (2015). "Metal oxides as photocatalysts". Journal of Saudi Chemical Society.* ***19*** *(5): 462–464. 10.1016/j.jscs.2015.04.003.*

[22] *A. Loupy. (2017). "Solvent-Free Microwave Organic Synthesis as an Efficient Procedure for Green Chemistry". ChemInform.* ***36*** *(10).*
10.1002/chin.200510294.

[23] *M. Vian, C. Breil, L. Vernes, E. Chaabani, and F. Chemat. (2017). "Green solvents for sample preparation in analytical chemistry". Current Opinion in Green and Sustainable Chemistry.* ***5****: 44–48. 10.1016/j.cogsc.2017.03.010.*

[24] *P. J. Walsh, H. Li, and C. Anaya de Parrodi. (2007). "A Green Chemistry Approach to Asymmetric Catalysis: Solvent-Free and Highly Concentrated Reactions". ChemInform.* ***38*** *(36). 10.1002/ chin.200736264.*