International Journal of Scientific Research & Engineering Trends
Volume 7, Issue 4, Jul-Aug-2021, ISSN (Online): 2395-566X

# Minimization of Hazardous Solvent Use in Organic Synthesis: Green Chemistry Approaches

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**Abstract- Organic synthesis uses solvents in nearly every stage of a chemical process. Solvents are very important as they dissolve reactants, enhance mixing, control reaction temperature and make it easier to isolate and purify the final product. Solvents also affect the speed and result of the reaction, in many cases. Solvents are widely used in laboratory research and industrial chemical production. But many of the most commonly used solvents are dangerous. They are toxic, flammable, highly volatile and difficult to dispose of safely. Common examples include benzene, chloroform, dichloromethane, N,N-dimethylformamide (DMF) and N-methyl-2-pyrrolidone (NMP). Long-term or repeated exposure to such solvents may affect skin, lungs, liver, nervous system and in some cases even increase the risk of cancer or reproductive damage. If not managed properly, solvent waste may pollute air, water and soil. As a result of these concerns, chemists are now giving more emphasis to reducing the use of hazardous solvents in organic synthesis. This is one of the central goals of green chemistry. Green chemistry promotes the designing of safer chemical processes that use fewer harmful substances and create less waste. This paper explains why hazardous solvents are widely used in organic synthesis and how they lead to health, safety, and environmental hazards. It also discusses the main green chemistry methods used for the reduction of solvent-related hazards. And this is where we want to see if we can replace hazardous solvents with safer ones, use greener solvents, carry out solvent-free reactions, design better reaction structures and recover or recycle solvents after use when we want to. Some good things have been done so far but a lot of scientific and practical problems remain. Still, the right way forward is to reduce the use of hazardous solvents so organic synthesis is safer and cleaner.**

**Keywords- Organic synthesis, green chemistry, solvent minimization, solvent recovery, sustainable chemistry**

## I. INTRODUCTION

Solvents are very important in organic synthesis and are used in almost every stage of a chemical process. Their main task is to dissolve reactants so that the molecules can move and react in a controlled manner. They also help in mixing chemicals properly, spreading heat evenly, and achieving the required reaction temperature. In many cases, the choice of solvent will determine the rate of the reaction, the selectivity and even the final yield of the desired product. Solvents are used not only during the reaction itself but also later in the process of extraction, washing, recrystallization, chromatography, purification and final product isolation. With all those functions solvents constitute the bulk of the materials used in a reaction and thus contribute also to the total waste of chemical processes (Constable et al., 2002; Clarke et al., 2018).

For many years, chemists were dependent on organic solvents because they were effective, easily available and well understood. They were chosen because they were able to dissolve a wide range of organic compounds and help to achieve many types of reactions. In many laboratory and industrial processes, they made the reactions faster and produced high product yields. However now with more awareness of environmental risks and chemical safety, many of the commonly used solvents are so dangerous that they can impact the health of a human being in a very short or long term way, potentially. Some solvents are carcinogenic and others can damage the liver, kidneys, lungs or nervous system. Some are also highly flammable, making them more susceptible to fire and explosion when stored and used.

Volatile solvents can easily enter the air and contribute to pollution, and liquid waste solvents will contaminate water and soil if they are not treated and disposed of properly (Capello et al., 2007; Valavanidis and Vlachogianni, 2013). A few of the most common solvents in organic synthesis are now considered hazardous. These include benzene, toluene, chloroform, dichloromethane, tetrahydrofuran (THF), N,N-dimethylformamide (DMF), dimethylacetamide (DMAc) and N-methyl-2-pyrrolidone (NMP). All of these solvents have useful chemical properties so they have been used for so long.

For chlorinated solvents such as chloroform and dichloromethane, chloroform in particular is a highly dissolving solvent and is easy to remove after reaction with the solvent. Polar aprotic solvents such as DMF, DMAc and NMP are also used so that they can be used for many important reactions including coupling and substitution reactions.

THF is commonly used in organometallic chemistry because of its excellent coordination ability. Despite their use, these solvents are serious health, safety and environmental problems. Benzene is highly carcinogenic and of course DMF, DMAc and NMP have been under research because they may damage reproductive organs. THF is highly flammable and can give rise to dangerous peroxides in storage. Because of these risks, they should be used in laboratories and industries with strict control measures (Henderson et al., 2011; Prat et al., 2015). The production of hazardous solvents also increases the overall cost of chemical production. The costs of the solvent system are not only for buying the solvent. There is also money to keep it safe in storage, ventilation systems, protective equipment, waste disposal, fire prevention and legal compliance.

As well as solvent recovery, worker safety training and environmental monitoring are more money-intensive to do, the industries must invest in these. Hazardous solvents are therefore direct and indirect burdens. This is one of the reasons why solvent selection is now considered an important part of sustainable chemical process design (Clark and Tavener, 2007; Henderson et al., 2011). Green chemistry has been proven to be a more responsible way to make chemical synthesis. One of its main aims is to reduce or completely eliminate the use of harmful substances (e.g., choosing safer solvents, using smaller amounts of solvent or avoiding solvents entirely if possible). Green chemistry is about more than just the final product but how that product is made as well.

A process may produce a good yield, but if it uses a lot of toxic solvent, it is not sustainable. Because of this, chemists have started to pay much more attention to solvent choice as an important part of reaction planning and process development (Clark and Tavener, 2007; Clarke et al., 2018). In recent years, a lot of new approaches have been developed in organic synthesis to reduce hazardous solvent use. One of the most common approaches is solvent substitution, where a toxic solvent is substituted by a safer solvent with similar chemical behavior. More generally, greener solvents like water, ethanol, ethyl lactate, and bio-based solvents are also used. Some reactions are now designed to take place in solvent-free conditions and this greatly reduces waste and exposure to harmful chemicals. Process improvement methods such as high concentration reactions, one-pot synthesis, and flow chemistry also make solvent use more cost-effective. There still is a growing demand for solvent recovery and recycling in laboratories and industries in order to avoid waste generation and hence to reduce the need for new solvent.

These changes have made chemical synthesis safer, cleaner, more effective and are now widely seen as significant steps to sustainability (Prat et al., 2015; Smith et al., 2014; Tan and García, 2019). This paper examines the use of hazardous solvents in organic synthesis and why they have a serious impact on human health, environmental safety, and sustainable chemical practice. It also discusses the main green chemistry strategies for reducing their use in organic synthesis such as solvent substitution, greener reaction media, solvent-free synthesis, process optimization and solvent recovery. By analyzing these approaches, this paper aims to demonstrate how organic synthesis can move toward safer and more sustainable methods without losing its practical effectiveness.

## II. THE ROLE OF SOLVENTS IN ORGANIC SYNTHESIS

Solvents have a lot to do with organic synthesis and are often needed for the completion of a reaction. Reactants dissolve so that the reacting molecules come into contact with one another. Reactions are more manageable when reagents are dissolved and as a result the reaction is more consistent and controlled. A chemical reaction can be heated or cooled. The energy that is transferred in the reaction mixture is transferred to the solvent and is sent back to its original location and then dispersed throughout the reaction mixture and this heat is controlled by the solvent. The solvent is the medium in which all the chemical changes are taking place. This is particularly important in reactions that are sensitive to temperature changes. A good solvent makes stirring easier, mass transfer much better and makes the lab or industry safe. Solvents can have a direct effect on the speed of the reaction, the reaction pathway, and the type of product that is produced.

The same reactants can give different products depending on the solvent used. This is because solvents can also affect the stability of ions, free radicals, intermediates, transition states, and transition states. For example, a polar solvent can have a better effect on ionic reactions and a non-polar solvent can have neutral ones. Protic solvents and aprotic solvents can also be very different and as a result affect the mechanism of a reaction in a very different way. Hence, solvent choice is very much a decisive factor in reaction design and optimization (Clarke et al., 2018). The solvent can also affect catalyst performance. Some solvents improve catalyst solubility and activity, while others may decrease catalyst efficiency or even deactivate it. For catalytic reactions, the right solvent is the key to conversion, selectivity, and yield. Solvents can also influence the solubility of gases such as oxygen, hydrogen, or carbon dioxide in reaction systems and thus change reaction behavior.

For this reason, chemists tend to spend so much time choosing or testing a solution for a reaction when they are developing a synthetic process. Solvents have a role to play in a reaction even when the reaction is complete. Solvents are also highly used in post-reaction processes such as extraction, washing, filtration, recrystallization, distillation, and chromatography. These steps are key in order to isolate the desired product from by-products, unreacted starting materials, catalysts, and impurities. In fact, in most synthetic processes, particularly pharmaceutical and fine chemical production, solvent is used more in purification than in the actual reaction itself. Hence, even though a reaction produces a high yield and works well, the entire process can still consume a lot of solvent and create a lot of waste (Constable et al., 2002). This is even more acute in multistep synthesis. In such processes, solvent is necessary not only for each reaction step but also for isolation and purification after all phases. So the amount of solvent used is far greater than the final product.

This is a huge environmental and economic burden. Large quantities of solvent waste need to be treated, recycled, or disposed of in a safe manner. If the solvents used are toxic, volatile, or flammable, the risks and costs are even larger. In this way, solvent use is now considered one of the main contributors to waste generation in chemical industries (Capello et al., 2007). Because of all these reasons, solvent use has become an important concern for green chemistry. Green chemistry is not so much about getting that desired product as to being safe and efficient and environmentally responsible. A reaction may appear good in terms of yield, but if it is based on large quantities of hazardous solvent, it cannot be considered green. This has led chemists to pay more attention to solvents, solvent reduction, and solvent replacement. Today, the role of solvents in chemical synthesis is being re-emphasized from a health, safety, environmental, and economic perspective (Clark and Tavener, 2007; Clarke et al., 2018). So to reduce solvent use is very important in modern organic synthesis.

Today, scientists try to design reactions where we use less solvent, are not using solvents at all, or don't use solvents at all if possible. This change is in line with a larger movement to clean and sustainable chemistry in which every element of the process is considered to be the environmental one. Since solvents are used so widely and in such large amounts, improvements in solvent use can help to keep chemical synthesis safer and more sustainable.

## 3. Hazardous Solvents Commonly Used in Organic Synthesis

Many of the solvents used in organic chemistry are now hazardous. They are still useful by virtue of their practical applications. Many of them dissolve organic compounds in a very favorable way and can be used in a variety of reactions and are easy to remove after the reaction is finished. Some have good boiling points, low chemical reactivity, or good compatibility with catalysts and reagents. The same solvents that are so effective in chemical reactions can lead to serious health problems, workplace safety, and the environment.

The most well-known chemical solvent is benzene. Since benzene is chemically stable and can dissolve many organic compounds, it was commonly used in organic reactions. It was slowly discovered that benzene is very toxic and now is associated with cancer and blood diseases such as leukemia. Due to these serious health threats, benzene has been practically banned and in many cases replaced by other solvents. While benzene is much less common nowadays, this is a case of how a useful solvent is rejected from a safety point of view, and it is a great example of it. Chloroform and dichloromethane are also dangerous solvents. These chlorinated solvents are well known and dissolve many organic substances and are also a great solvent to remove due to volatility.

They are commonly used in extraction, purification, and synthesis. Dichloromethane, for instance, is widely used for separation in laboratories because it is soluble and evaporates quickly. Chloroform has also been used in extraction as well as in some synthetic procedures. But both are toxic and can be harmful if inhaled or if exposure occurs in succession over time. They may affect the central nervous system and other organs, and they have environmental effects as they can enter air and water (Capello et al., 2007). Toluene and xylene are generally substituted for benzene because they are less associated with cancer. But they aren’t harmless. If used in poorly ventilated spaces or handled casually, they are flammable and very hazardous. Long-term exposure to vapors can have adverse effects on health and the nervous system after long exposure. In this sense, they are safer than benzene by far in terms of safety, but they need more careful handling and control.

Another important solvent is tetrahydrofuran (THF). THF is very widely used in organic synthesis, especially organometallic and reduction reactions. It is well-known for its ability to dissolve a wide range of compounds and to be well integrated with reactive compounds. This makes it very useful in a number of laboratory activities. But THF poses serious safety concerns. It is extremely flammable and is prone to fire during use and storage. THF can also form peroxides when it is exposed to air over time. If the solvent is concentrated or distilled as per this process, the peroxides can become explosive. Therefore, old THF samples must be tested and handled very carefully. Polar aprotic solvents are among the most commonly used solvents in modern synthesis, especially DMF (N,N-dimethylformamide), DMAc (dimethylacetamide), and NMP (N-methyl-2-pyrrolidone).

These solvents are highly valued in organic chemistry as there is an effective interaction between organic and inorganic substances and many important reactions can be performed with them. They have been used in substitution reactions, coupling reactions, polymer synthesis, and in other processes where a polar but non-protic medium is required for chemical reactions. These solvents are subject to more regulatory scrutiny, and now most organizations recommend curbing their use and replacing them when possible (Henderson et al., 2011; Prat et al., 2015). The dangers associated with these solvents are not limited to health effects. All of them are volatile, which means they can quickly dissipate into the air.

This could lead to more worker exposure and contribute to air pollution. Some are difficult to dispose of safely and may lead to toxic waste streams. Some solvents can enter the soil and water if they are not properly washed or treated. In industrial settings, these problems are more pronounced as solvents are used at a much larger scale. This necessitates ventilation systems, fire control measures, protective equipment, waste treatment, and compliance with standards. So hazardous solvents have a negative effect on not just safety and health but also on the economic cost of chemical production. On the one hand, they are excellent chemical agents of chemistry and are well established in existing synthetic methods. But on the other hand, these are associated with toxicity, flammability, environmental damage, and high management costs. So today chemistry is moving towards safer products.

That is why scientists are now trying to replace hazardous solvents with better alternatives, reduce the amount of solvent used, or redesign reactions such that solvents do not even matter anymore. The increase in the search for safer and more sustainable solvents is emblematic of a seismic change in organic synthesis, where not only performance is important, but also environmental performance will be a big factor. Safety, sustainability, and environmental impact are also now as important as safety, sustainability, and environmental impact.

## IV. HEALTH AND ENVIRONMENTAL EFFECTS OF HAZARDOUS SOLVENTS

Hazardous solvents can be harmful to humans and the environment. These impacts can occur when the solvent is used, after disposal, and when it is made to be transported or delivered. People can come into contact with solvents in laboratories and industries. Most commonly, they breathe in solvent vapors, get the solvent on their skin, or, in some cases, swallow it. Short-term exposure to hazardous solvents may sound like a little thing, but it can cause serious health problems.

You may feel headaches or dizziness, nausea, eye irritation, skin irritation, or difficulty breathing. Some solvents can also cause tiredness, loss of concentration, or irritation of the nose and throat. These effects are common in solvent vapors for a few hours or for someone who is not well-protected from them. Students and workers in research laboratories may not always realize these effects quite as quickly if solvents are handled carelessly. Long-term exposure is usually worse. Contact with some solvents once in a lifetime can damage internal organs, like the liver and kidneys. Some of the solvents might have a significant effect on the brain and nervous system, causing memory issues, poor coordination, and long-term weakness. Other solvents can be damaging to the reproductive system and increase the risk of cancer after long exposure.

The effect of each solvent depends on the type of solvent, the amount and frequency of exposure, and how often it happens. This is why many of the so-called traditional solvents that were once used in laboratories are now being carefully evaluated (Valavanidis and Vlachogianni, 2013). The risks are not limited to chemicals as they are also a problem for cleaning personnel, maintenance workers, transport workers, and the surrounding community. The risk of solvents is even higher in industries where they are used in huge volumes. One simple wrong move in storage, transfer, or disposal can cause a huge risk to health and safety. Hazardous solvents are therefore most often used for more expensive reasons: fume hoods, protective clothing, ventilation systems, fire control systems, and waste treatment. They adversely affect the environment as well.

The most commonly used solvents are volatile organic compounds (VOCs) and evaporate quickly. Once they are released, they can create pollution and take part in the chemical reactions in the atmosphere that produce smog. Such emissions can reduce air quality and lead to broader environmental problems when solvent use is high in places where solvents are used daily and in high volumes (Capello et al., 2007). Water and soil pollution are also significant. If solvents are spilled, leaked, or discarded carelessly, they can go into drains, rivers, groundwater, or agricultural land. Some solvents break down gradually, so they can remain in the environment for a very long time. Cleanup is challenging and expensive. Solvents can harm plants, animals, and aquatic creatures in some cases even at low concentrations.

Chlorinated solvents and other persistent compounds are especially dangerous because they can drift into the environment and remain there for years. A solvent also needs to be manufactured, packed, transported, stored, and finally treated or disposed of after use. All of these steps use energy and can result in pollution. Solvents are produced from raw materials, industrial processes, and fuel consumption. Transport requires more energy and increases the risk of leaks or accidents. Waste treatment and disposal also require resources, and in some cases, harmful emissions may still be produced.

This means that the true impact of a solvent should be understood through its whole life cycle and not only because of its direct use in synthesis (Clarke et al., 2018). Hazardous solvents lead to a chain of problems. They can pose a hazard to workers, increase operational risk, add to chemical waste, and damage the environment at different stages. They also raise the cost of chemical work, as industries and laboratories need to pay for protective equipment, waste management, monitoring, and legal compliance. In this way, hazardous solvents impact health, safety, sustainability, and economics all at once. Such issues are why solvent minimization is so important in green chemistry. Reducing the use of hazardous solvents can protect laboratory workers and industrial employees from harmful exposure. It can also reduce emissions and waste generation and lower the risk of contamination of air, water, and soil. Also, using less hazardous solvent may reduce disposal and treatment costs and make chemical processes easier to manage in a safe way. So by minimizing hazardous solvent use as an environmental decision, it is also an approach that makes sense and is ultimately a responsible practice in chemical synthesis.

## V. GREEN CHEMISTRY AND SOLVENT MINIMIZATION

Green chemistry is based on a very realistic concept. And chemical processes should be effective but also safe for people and better for the environment. Many chemical reactions in the past were based on the idea of achieving the desired product in good yield. Today, that view is no longer the case with chemical engineers who realize that the process in which a chemical is made is as important as the final product. A process that produces the right product but creates a lot of hazardous waste is not sustainable. Hence, green chemistry is about reducing risk, reducing waste and making use of the resources in more strategic ways. One of its key principles is that safer solvents and auxiliaries should be used if they are not really required. If a solvent is needed then it should be chosen (Anastas and Warner, 1998).

Solvent minimization is part of that idea. It does not just mean replacing one harmful solvent with another that is slightly better. It's a much broader approach that involves using less solvent, selecting safer reaction conditions, designing reactions that work more effectively in more concentrated form and recycling solvent after it's been used. In some cases, changing the whole synthetic method so that little or no solvent is needed. This kind of thinking is making chemists think about solvent use in the early stages of process design and not just as a technical detail later on. The field of this area has developed significantly in the last two decades. Solvent selection guides are one of the major reasons that has been developed.

These guides were developed by chemical and pharmaceutical companies to help researchers make educated decisions. Instead of choosing a solvent because it can be used in a reaction, chemists can now compare solvents on health reasons, flammability, environmental factors and ease of disposal. These guides generally classify solvents into preferred, usable, problematic, or hazardous categories. Two of the best known are the GSK solvent selection guide and CHEM21 solvent guide. Both have had a significant impact on research and industry for solvents (Henderson et al., 2011; Prat et al., 2015). These guides have made a huge difference in the practice of chemistry today. Solvent choice is no longer based on reaction speed, yield or solubility only. It is now also judged by safety, waste generation, and long-term environmental impact. This has led chemists to a more responsible and informed decision-making. As a result, solvent selection has become an important element of sustainable synthesis and a major step toward greener chemical practice.

## VI. MAIN GREEN CHEMISTRY APPROACHES

### Solvent Substitution

One of the most sustainable ways to minimize the use of hazardous solvents is to substitute them for a better solvent. This is to replace a harmful solvent with a solvent that does that job as well but is less hazardous to human health and the environment. This is the first step chemists take when trying to make a reaction green, as it does not often have to change the whole synthetic route. Sometimes the same reaction will still happen, but in a safer reaction medium. For instance, chlorinated solvents can be substituted for ethyl acetate, ethanol, acetone or some other less hazardous solvents in the chemistry in question (depending on the type of reaction and the compounds involved). This can reduce toxicity, reduce environmental impact and provide an increased safety in a laboratory or industrial environment.

Replacing a toxic solvent can also reduce storage, handling and disposal expenses. Solvent selection guides have been helpful in this area. These guides categorize solvents according to their health, safety and environmental characteristics. They usually describe solvents as "preferred, usable, problematic or hazardous." The GSK solvent selection guide and CHEM21 guide have been used to get chemists to opt out of solvents like benzene, NMP and other substances that are dangerous (Henderson et al., 2011; Prat et al., 2015). But solvent substitution is not always easy. A safer solvent may not behave exactly the same way as the original solvent. It may change the reaction rate, affect selectivity, lower the yield or make isolation of the final product more difficult. Sometimes it will even affect catalyst performance or solubility of the reactants. For this reason every solvent replacement needs to be carefully studied before it is adopted on a larger scale. A solvent might be safer, but it needs to be able to support chemistry well.

### Use of Greener Solvents

But another important green chemistry strategy is to use greener solvents. Instead of using hazardous solvents, chemists are now trying to use solvents that are safer, less toxic and in some cases made of renewable resources. It has attracted a lot of attention because solvents are used in large quantities and often contribute heavily to waste. Water is one of the most attractive green solvents. It is inexpensive, non-flammable, widely available, and far less hazardous than most common organic solvents. For many years, water was not considered suitable for a large number of organic reactions since many organic compounds do not dissolve well in water. But it has been recently shown that a lot of reactions can still be carried out in water or water-based systems, and with catalysts, surfactants, or mixed solvent systems.

Ethanol is the other common solvent which is also greener but less toxic than many traditional organic solvents and can be extracted from renewable biological sources. It serves in many reactions and purification processes. Other solvents that are considered to be greener are ethyl lactate, glycerol-derived solvents and 2-methyltetrahydrofuran (2-MeTHF) which is currently in vogue as an alternative to some petroleum ethers (Clarke et al., 2018). Recently, solvent systems like ionic liquids and deep eutectic solvents have been developed as well. Ionic liquids have very low vapor pressure, so they don't evaporate out into the air easily. This can reduce solvent loss and air pollution. But ionic liquids are not all safe or sustainable. Some are expensive, hard to prepare and not biodegradable so they need to be assessed before we'll call them green (Plechkova and Seddon, 2008). Deep eutectic solvents are often cheaper and easier to prepare. Good results have been obtained with extraction, catalysis and synthesis of them.

But more detailed research is needed in order to understand their long-term safety and impact on the environment (Smith et al., 2014). So the promise of greener solvents is to be welcomed, even though every solvent must be considered carefully. A solvent should not be green just because it's new or different. It must also be safe, effective, practical and environmentally acceptable at all times with the full life cycle.

### Solvent-Free Synthesis

One of the most straightforward ways to avoid solvent-related hazards is to avoid solvents. This idea was the basis for solvent-free synthesis, where reactions are carried out with no solvent or very little solvent. Solvent-free synthesis is probably the strongest green chemistry approach because it directly reduces waste and limits exposure to harmful chemicals. In some solvent-free reactions, the reactants are just mixed together and heated until the reaction takes place. In others, grinding or mechanical mixing is done to bring the reactants close together. These methods can often speed up the reaction and minimize the need for later purification. They may also reduce the cost of the process by minimizing solvent purchase and waste treatment. One example of this is mechanochemistry.

In mechanochemical methods, reactants are ground together in a ball mill to promote the reaction and have become increasingly important in green organic synthesis and have been applied to many chemical transformations. It is particularly useful because it can reduce waste of solvent, reduce reaction time, and sometimes enhance product selectivity (Tan and García, 2019). But solvent-free synthesis is not for all reactions. Some reactions need a solvent for heat control, proper mixing, or stabilization of reactive species. Other reactions need dilution to avoid side reactions. So solvent-free methods are very useful, but they are not a universal solution. But when applied in a way that can be done effectively, they are a potent strategy for reducing the environmental impact of chemical synthesis.

### Process Improvement

A good way to decrease solvent use in some cases is not only to change the solvent, but to make the whole process more efficient. One way is to run the reaction in a more concentrated way. If the same number of reactants can react in a smaller volume of solvent then solvent use will significantly decrease. Another method is to use one-pot reactions. In a one-pot process, several reaction steps take place in the same vessel without isolating the intermediate after each step. This saves time and also reduces solvent in extraction, washing, and purification between stages. One-pot synthesis can therefore enhance both efficiency and sustainability. Flow chemistry is also a modern approach to minimize the solvent.

In flow systems, chemicals move continuously through a reactor and do not react in a large batch. As part of this process, heat transfer, mixing, and safety can be improved. It can also lower solvent volume and make it easier to control hazardous reactions. In some cases, flow chemistry allows reactions to be carried out more concentrated and the solvent use can be reduced (Clark and Tavener, 2007; Clarke et al., 2018). Process improvement is important because it demonstrates that greener chemistry is not always about changing one chemical. Sometimes the biggest gains come from redesigning the process itself so there are fewer materials and less waste produced.

### Solvent Recovery and Recycling

There are cases where hazardous solvent is not necessarily the best way to avoid it at all. Recovering and recycling solvent is the next best thing and reuse it as much as possible. So solvent recovery and recycling are essential in green chemical practice in industry because solvents are used so much. The most common method of solvent recovery is distillation. The solvent is separated from impurities and purified and reused. Other techniques such as membrane separation, adsorption and phase separation techniques can also be used depending on the solvent type and process conditions. Recycling solvents has many benefits. It reduces the amount of waste sent for disposal, less need to go for fresh solvent, and over time it can reduce operating costs.

It also reduces the environmental cost of creating or transporting new solvent in addition to the cost. But recycling is not always green in every case. The recovery process itself may require energy, equipment and additional resources to accomplish this. If the energy demand is too high, the environmental benefit may be smaller. It is because of this that the whole process should be evaluated carefully before we know if recycling strategy is the best option (Capello et al., 2007). However, solvent recovery remains a good strategy when solvents cannot be eliminated or replaced.

## VII. FUTURE OUTLOOK AND CONCLUSION

The future of green solvent use in organic synthesis is bright. Over the past two decades chemists have become more aware of the health and environmental problems associated with hazardous solvents. For the same reason, it is now that research is moving into safer and more sustainable solutions. Bio-based solvents, safer polar solvents, and biodegradable solvents are being developed as a solution to chemical reactions for which the risk is low and can be used to produce less toxic and hazardous solvents in the environment. At the same time, we are also seeing the acceleration of technology in this domain. Digital tools, solvent databases, and solvent selection guides are getting more sophisticated and easier to use. These tools enable chemists to compare solvents at a much higher speed and choose safer solvents at the initial stage of a reaction.

That's an important development in many ways because safer solvent choice works best when it's done early, not after the process is in place. Other areas (mechanochemistry, flow chemistry, and high-concentration reaction methodologies) are also opening up new avenues. These methods reduce the need for large amounts of solvent and, in some cases, avoid solvent entirely. These techniques are only going to improve and in the future, they will be a much bigger part of both academic and industrial chemistry (Clarke et al., 2018; Tan and García, 2019). The most important aspect of progress, though, will be achieved by using a variety of green strategies as opposed to only one solution. And in many cases, the best solutions will be based on safer solvents, better reaction design, smaller quantities of solvent, and solvent recovery or recycling.

This kind of combined approach can make chemical processes much more efficient and reduce hazards for workers and the environment. Solutions to this problem are several practical methods. Hazardous solvents can be replaced with safer ones. Solvents are frequently used in chemical processes and because solvents are a major part of the chemical process, reducing or replacing them with safer ones is an extremely important step. Some reactions can be performed in water, alcohols, and bio-based solvents. Others can be done in solvent-free conditions. Process improvement and solvent recycling can also help reduce waste and be more sustainable. From 2002 to 2019 research shows that solvent minimization is possible which is very important in the future of chemistry. Obviously, there are still scientific and technical challenges that exist but the progress made so far is very good. The clear direction is there. Reducing hazardous solvent use is one of the most important steps toward making organic synthesis safer, cleaner, and more sustainable.

## REFERENCES

1. Anastas, P. T., & Warner, J. C. (1998). Green chemistry: Theory and practice. Oxford University Press.
2. Capello, C., Fischer, U., & Hungerbühler, K. (2007). What is a green solvent? A comprehensive framework for the environmental assessment of solvents. Green Chemistry, 9(9), 927–934.
3. Clark, J. H., & Tavener, S. J. (2007). Alternative solvents: Shades of green. Organic Process Research & Development, 11(1), 149–155.
4. Constable, D. J. C., Curzons, A. D., & Cunningham, V. L. (2002). Metrics to 'green' chemistry—Which are the best? Green Chemistry, 4(6), 521–527.
5. Henderson, R. K., Jiménez-González, C., Constable, D. J. C., Alston, S. R., Inglis, G. G. A., Fisher, G., Sherwood, J., Binks, S. P., & Curzons, A. D. (2011). Expanding GSK's solvent selection guide—Embedding sustainability into solvent selection starting at medicinal chemistry. Green Chemistry, 13(4), 854–862.
6. Plechkova, N. V., & Seddon, K. R. (2008). Applications of ionic liquids in the chemical industry. Chemical Society Reviews, 37(1), 123–150.
7. Prat, D., Wells, A., Hayler, J., Sneddon, H., McElroy, C. R., Abou-Shehada, S., & Dunn, P. J. (2015). CHEM21 selection guide of classical- and less classical-solvents. Green Chemistry, 18(1), 288–296.
8. Sherwood, J., Clark, J. H., Fairlamb, I. J. S., & Slattery, J. M. (2019). Solvent effects in palladium catalysed cross-coupling reactions. Green Chemistry, 21(9), 2164–2213.

9. Smith, E. L., Abbott, A. P., & Ryder, K. S. (2014). Deep eutectic solvents (DESs) and their applications. Chemical Reviews, 114(21), 11060–11082.
10. Tan, D., & García, F. (2019). Main group mechanochemistry: From curiosity to established protocols. Chemical Society Reviews, 48(8), 2274–2292.
11. Valavanidis, A., & Vlachogianni, T. (2013). Laboratory experiments of organic synthesis and decomposition of hazardous environmental chemicals following green chemistry principles. Central European Journal of Chemistry, 11(2), 190–215.