HANS SHODH SUDHA , Vol. 1, Issue. 1, (2020) pp. 229-240

Revisiting the Sustainable Development Goals in connect with COVID-19 and how can Green Chemistry make a difference

Sriparna Dutta and R. K. Sharma*

Introduction

Ever since the seventeen goals for sustainable development were recognized and outlined by the various member countries of U.N., the world seemed to come on a common consensus of working towards a cleaner, waste-free and healthier planet.[1] Just a few years down the line and it has been striking to note the significant advancements made in this direction. Today, we have a ready access to a broad spectrum of products that are safe, sustainable and most importantly environmentally sound. We have managed to increase agricultural production that can almost suffice the requirements of the growing population, reduce escalating levels of CO_2 in the atmosphere and other greenhouse gases, provide safe drinking water and prevent critical diseases and ailments. Also, we have started making efficient use of our resources that have enabled us to combat many of the grave environmental challenges on the horizonand these achievements can be largely credited to chemistry. In fact, chemical industrieshave shown tremendous potential towards making the SDG's a reality and transforming the world for the better by powering the manufacture of almost 95% of essential goods *via* energy generation.[2] As per the American Chemistry Council, "the business of chemistry is worth 450 billion dollar enterprise which is about 26% of the global chemical product and the key of the nation's economy." However, it is important to mention here that when we talk about chemistry and chemical manufacturing, what we mean is green chemistry which is the only way how chemistry should be practiced and the only key that can help in achieving complete sustainability. Economic growth cannot be synonymous with sustainable development, if the chemistsdo not consider the environmental impact of the manufacturing routes and adopt a waste-free route. Thankfully, Green Chemistry has transformed the landscape of syntheses and given the much needed key to achieve the SDGs.[3]

In this minireview, we have attempted to summarize the ways in which GC has impacted sustainable development and the indispensable role it has been playing in meeting the 2030 agenda of SDGsby contributing towards good health, quality education, gender equality, safe drinking water, clean energy and decent work for all and tackling climate change. We intend to enlighten the readers about the latest innovative greener tools and techniques that can be utilized for swiftlyprogressing towards a sustainable tomorrow. Even though incredible progress has been witnessed in this regard till now, yet a number of obstructions lie in the road which need to be overcome especially related to their universal, integrated, interconnected and inclusive implementation. The SDGs are ambitious and hence far reaching will require a pragmatic shift in how we think chemistry, how we conduct education and research and how we produce chemicals in a more sustainable manner. It is important to trace the obstructions for complete success. It is envisioned that this review will serve as a guiding tool to inspire the scientific community to explore, design and employ green chemistry tools and transform all our strict commitments into action for reaching these goals.

2. Glancing through the SDGsand impact of COVID-19 pandemic

The year 2015 was crucial as this was the year when the entire world got unified by common goals of protecting the planet and ensuring that by 2030,

*Corresponding Author, Green Chemistry Network Centre, Department of Chemistry, University of Delhi, Delhi-110007
Email Address: sriparna.duttagcncnew@gmail.com, rksharmagreenchem@hotmail.com

there is peace and prosperity all over.[4]The aspirational goals were paving the framework for sustainability and these were called as the "sustainable development goals"-SDGs.[5]Thesewere developed after prolongeddiscussions and consultations from relevant stakeholdersincluding those from Non-Governmental Organisations (NGOs),policy-makers, the civil society and businessmen holding international experience. Adopted by all the United Nations Member States, the SDGs provide a blueprint for all countries, industries and organisations to adopt in line withtheir own priorities in especially improving health and education, reducing inequality and spurring economic growth.Underpinning the 17 goals is a set of 169 specifictargets which describe, in detail, the ways in which the goals may be measuredand achieved.

The 17 SDGs have been highlighted below:

2.1 No Poverty: SDG-1 aims at ending poverty in all its forms everywhere and for accomplishment of this goal, ensuring social protection for all children and other vulnerable groups would be important.[6]The world, especially developing nations have been critically afflicted with poverty issues since long which have been inevitable in face of ever growing population and rapidly exacerbated by natural disasters. By the end of 2020, it has been expected that +71 million people will be pushed towards extreme poverty. However, the current COVID-19 pandemic crisis hasmade the situation worse by leading to the first increase in global poverty in decades. The loss in terms of a social as well as economic crisis is devastating and discouraging. Coping up with the severe crisis will take indeed not just months but years.In response to the socio-economic COVID-19 crisis, the UN divulged a framework of action for extending maximum help to the poorest and most vulnerable, whichcalls for a massive scale-up of international efforts and commitment for assuring that people all across the globe have a basic access to all essential services and are given social protection.

2.2 Zero Hunger: SDG-2preaches to end hunger, achieve food security and improvednutrition and promote sustainable agriculture.[7]It is highly disheartening to note that today, nearly 820 million people go to bed hungry. Out this huge number, almost 135 million are affected with problems arising due to acute hunger aggravated by man-made conflicts, climate change and economic downturns. Adding to the complexity of the situation, the COVID-19 has worked as a poison by almost doubling this figure and hence swift action needs to be taken in this regard. Increase in agricultural and food production food production can prevent this stressful situation by alleviating the perils of hunger.

2.3 Good Health and Well Being: SDG 3 aims at ensuring healthy lives and promoting well-being for all.[8]This is the most essential tool towards achieving sustainable development. We all are very well aware of the prevailing global health crisis the world is facing due to COVID-19 which has also destabilized the global economy. Just before the virus had taken the entire world under its clutch, remarkable progress was being witnessed in the health sector, measured by the increasing life expectancy, improved sanitation and hygiene, augmented access to physicians etc. However, now the current situation is demandingmore investment in this regard and calling urgent attention from government and society.

2.4 Quality Education: The fourth SDG signifies the need to ensure inclusive and quality education for all and promote lifelong learning. Education is the only strategic tool to uplift socioeconomic status of the society along with ending poverty.[9]The past decade has witnessed an overall hike in access to education at all levels. However, the pandemic has caused a major setback by leading to temporary closure of schools and colleges, jeopardizing 91% of children worldwide. In an attempt to ensure that the students have access to continued learning, UNESCO launched the COVID-19 Global Education Coalition. Thisprime aim of this coalition is to foster multisector collaboration between IT partners, UN family, civil organization and media so that they can collectively and intellectuallydesign as well as deploy novel solutions that can enable different countries to tackle the connectivity gaps, expedite comprehensive learning opportunities during this difficult period.

2.5 Gender Equality: This SDG discourses the concept of gender equality and empowering all girls and women.[10]This goal is self-explanatory. It is clear that if the world is to progress, then women need to be given priority as they represent half of the population and henceforth half of its potential.[11] Gender inequality has remained a problem of serious global concern which has retarded complete social evolution. Women continue to remain under represented and suffer from serious discrimination

issues. As per reports, during this COVID-19 pandemic, domestic violence has increased manifold in many of the countries. Thus, initiatives have been directed in this regard. For instance: The Spotlight Initative was a global intiatives by EN/UN partnership has focused on ending all forms of violence against women and girls.

2.6 Clean Water and Sanitation: This is one of the most important SDGs; as we know that no form of life could have ever existed had it not been "water" the key resource for quenching our thirst and sustaining all forms of life on earth. SDG-6 sheds light on ensuring rapid and facile access to water and sanitationfor all.[12]Although great strides have been achieved so far in fulfilling this goal, however, still billions of people especially those residing in the rural areas still do not have access to clean water. Water is extravagantly polluted by a myriad of contaminants including heavy metals, dyes, pesticides, drugs etc. Thus, the Water Action Decade was launched by the UN General Assembly launched on 22 March 2018 for mobilizing action towards transforming the current water management techniques in a sustainable manner.[13]

2.7 Affordable and Clean Energy-SDG 7 advocates the need to generate and use energy sources judiciously and ensure access to affordable, reliable and sustainable energy for all.[14]Efforts have been directed in this regard and the outcomes are appreciable. We have been able to utilize biomass for conversion into fuels for powering various chemical processes. Not just chemicals, but we have also been able to utilize bioenergy for the purpose of sufficing basic needs like cooking. Also, we have managed to derive renewable sources of energy from natural resources such as sun, wind etc. Photochemical and visible light driven reactions have gained increasing momentum for accelerating industrial transformations as well as combating environmental challenges. The energy progress report has provided a snapshot of how far we are still from triumphing the targets of SDGs.

2.8 Decent Work and Economic Growth: SDG-8 aims to promote inclusive and sustainable economic growth, employment and decent work for all.This goal propagates the concept of sustained economic growth which can drive progress in true sense and drastically improve the current living standards. COVID-19 has disrupted billions and trillions of life by hampering the economic growth. Unfortunately, there has been a historic recession, marking unemployment, hunger, deprivation and this crisis is unfortunately hitting the economically weaker section. Therefore, an agenda for the prompt socio-economic response to this pandemic was outlined which will serve as a roadmap to extend social and economic support to all the countries.

2.9 Industry, Innovation and Infrastructure: This goal primarily expounds building of resilient infrastructure that aim atpromoting sustainable industrialization and fostering innovation.[15] Development ofinnovative technologies, expediting international trade and empowering the effective utilization of resources can play an essential role in meeting this goal.The pandemic situation created due to the rapid spread of corona virus has called the need for extensive investment in infrastructure. Thus, it is not surprising that digitalization of many businesses and services have been accelerated to cope up with the crisis. The teleworking and video conferencing systems have particularly assisted largely in connecting people all over the globe.

2.10 Reduced Inequalities: SDG-10 sheds light on reducing inequality within and among countries which is integral to attaining sustainability.[16] Unfortunately, COVID-19 has worsened the existing inequalities, and hit the economically weaker section the most. It has also risked the progress made in gender equality.

2.11 Sustainable cities and communities: This SDG propagates the need to make cities and human settlements more inclusive, safe, resilient, and sustainable.[17] The prime target for this goal is to ensure safe and affordable housing for all. Although cities have been the contributors towards economic growth and prosperity, yet, unfortunately they have been responsible for also causing 70% of global carbon emissions. The accelerated urbanization rates have also overburdened existing infrastructure and worsened the problems related to atmospheric pollution. The impulsive, life threatening corona virus has further threatened the cities and communities, endangering the public health tremendously. The overcrowding issues have also made it difficult to follow the measures of social distancing in this pandemic COVID-19 situation.

2.12 Responsible Consumption and Production: This goal highlights the need toensure

sustainable consumption and production patterns.[18] Unfortunately, over the last century we have threatened our environment through increased industrialization and other activities, that is endangering our very own survival on this planet. The environmental degradation scenario has made us realize that we did not follow sustainable consumption and production practices in near past. We all need to understand that if we wish to alleviate poverty and transition towards a sustainable economy, then we need to incorporate sustainable practices in our production as well as consumption processes. The advent of COVID-19 has delineated the significance of relationship between nature and human beings. It has made us understand and appreciate the limits to which the humans can actually push nature, before the impact turns out to be hazardous. This means that although we have unlimited desires and needs, but nature has limited capacity to suffice these needs. Hence, we must not try to overburden our resources.

2.13 Climate Action: According to the SDG-13-"UrgentAction is mandatory to combat climate change and its impacts by regulating emissions and promoting developments in renewable energy." The sudden climatic changes as a consequence of global warming have been devastating for our economy as well as lives.[19] Our own activities have caused the levels of $CO_2$and other greenhouse gases to rise in the atmosphereand the year 2019 was recorded to be the warmest year. However, since the COVID-19 pandemic made its way into this universe, nature has been able to rejuvenate and the greenhouse gas emissions have been projected to drop by 6 % due to all the imposed travel bans.

2.14 Life below Water: This goal aims at conserving and sustainably using the oceans, seas and marine resources for sustainable development. In view of deterioration in the quality of coastal waters due to pollution and ocean acidification, life below water has been impacted negatively. As we know, marine biodiversity is important to the health and functioning of this planet, therefore we need to save these resources.[20]Thankfully, the pandemic has again had a positive impact on this goal as it has provided an opportunity to revive the oceans advance the goal of building a stable and sustainable ocean economy.

2.15 Life on Land: SDG-15 intends to protect, restore and promote sustainable use of terrestrial ecosystems, sustainably manage forests, combat desertification, and halt and reverse land degradation and halt biodiversity loss.COVID-19 has emphasized the necessityof addressingvarious threats to ecosystem as well as wildlife.

2.16 Peace, Justice and Strong Institutions: As per this goal, we need to promote peaceful and inclusive societies for sustainable development, provide access to justice for all and build effective, accountable and inclusive institutions at all levels. In response to the COVID-19 pandemic crisis, we must respect human rights and build holistic solutions for today's emergency and tomorrow's recovery.

2.17 Partnerships for the Goals: According to this goal, we need to strengthen the means of implementation and revitalize the global partnership for sustainable development. If we wish to have a win-win situation over the SDGs, then we need to have strong partnerships/collaborations.[21] The current pandemic has also made us realize the same. We are experiencing the worst recession and to recover from this crisis we need to ensure a strong international co-operation.

3. Green Chemistry: A catalyst for accomplishing SDGs

Although it has taken almost a decade, but nevertheless, chemical entrepreneurs, researchers and other relevant stakeholders have started realizing their responsibility to provide society withsafer products and goods that are manufactured using environmentally benign pathways. The growing consciousness was fueled by a number of severe incidences and grave circumstances caused by lack of knowledge pertaining to usage and disposal of chemicals.[22]For instance, the Minimatadisaster-a dangerous case of mercury poisoning had led to the death of more than 100 people. This incident had occurred due tothe continuous disposal of waste residues containing Hg catalystby a polyvinyl manufacturing company located at Chissco, Japan near Minamata Bay. Likewise, the Bhopal Gas Tradegy, Love Canal Disaster, Times Beach, DDT poisoning case had raised an alarming situation forcing the chemists to rethink of their existing processes and practices. It was evident that the chemical industries were continuing to make technological advancements at the verge of harming the environment, without considering the repercussions of the use of chemical-products and pathways. Green Chemistry was the much neededkey to combat the environmental

challenges and move towards a sustainable tomorrow.[23]The twelve principles of green chemistry which also serve as the twelve basic tenets were incredibly designed by the fathers of this field-Prof. Paul Anastas and Dr. John C. Warner (**Figure 1**).[24]

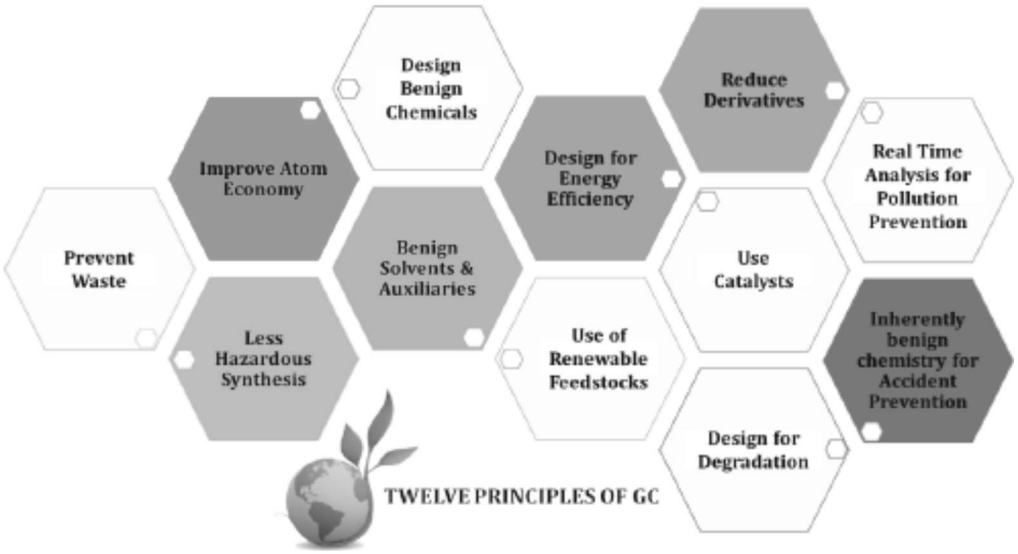


Figure 1 Glance into the 12 principles of Green Chemistry.

These serve as potential guiding tool for practitioners to revisit the age old methodologies, identify the loopholes, improvise and redesign them in a way that they are beneficial for the environment as well as human health. The word "green" embraces the color of environment and goodness of health and prosperity. Green Chemistry, since inception, has been playing a superlative role inreducing the environmental footprint. Today, we have greener catalysts for boosting industrially significant chemical reactions, greener solvents that provide eco-friendly medium for dissolution of reactants and greener energy sources for driving a host of processes without the need to worry about the availability in future.With the aid of green chemistry, we are also being able to recycle back the resourceswhich our mother earth had once gifted us, by utilizing the circular economic models. Different waste materials are being converted into valuables. We have slowly but steadily started our journey towards achieving the key goals of sustainability. American Chemical Society has identifiesseven SDGs that have utmost relevance to the chemistry community (**Figure 2**).[25]

Figure 2. Contribution of Green Chemistry to SDGs.

We shall take up each of these SDGs and show how GC can prove to be useful in this regard:

3.1 GC and SDG-2

Accomplishing the zero hunger goal can indeed be highly challenging.GC has played a significant role

in contributing towards this goal by protecting plants/ crops from pest infestations, bringing major reformation in the food production and distribution practices and prolonging the shelf life of food viaremarkable advancements in packaging and enhancing food quality and safety.The following examples clearly illustrate the role of GC in meeting SDG-2:

3.1.1 Drought protection for plants

To help plants retain water and impart protection to them during struggling drought periods, Sean R. Cutlerfrom University of California, Riverside managed to identify a compound named "quinabactin" that could mimic the natural plant hormone abscisic acid (ABA).[26]Although successful for a number of key crops, yet it did not work well for tomatoes and wheat which led the researchers to gain an insight into the cause. After careful introspection, they managed to unlock the cause and developed a new compound it calls opabactin which was more successful.

3.1.2 Development of Greener Pesticides

Cortiva Agriscience™, the Agriculture Division of DowDuPontwon the Greener Chemicals Award in 2018 for designing and developing a herbicide named "Rinskor™" that provided a sustainable solution for farmers to control grass, broadleaf and sedge weeds, thereby improving rice production.[27]The advantages of low toxicity to various organisms including, birds and insects, low persistence in soil renders, low use ratesit a true example of "sustainable innovation for agriculture."

3.2 GC and SDG-3

Chemistry has played an instrumental role in improving health and is critical for well-being as it enables the production of numerous life-saving drugs and medicines.Due to efforts directed by the research community, today we have high quality vaccines, tables and syrups for almost any critical disease, which hashelped in increasing life expectancy. Albeit the remarkable achievements, the dwindling COVID-19 pandemic situation has made us realize that intensive investment is required in the healthcare sector, as there willalways be a need to keep developing drugs that will be effective against a broad range of viruses. All countries have deeply realized that the nation and its economy cannot progress, if the health of the citizens is endangered/riskedthe significance of developing effective treatment for this disease. Millions of people across the globe have already lost their lives and millions still fighting this difficult situation. Attempts are being directed towards exploring promising vaccine for the corona virus and hopefully people will be able to take a sigh of relief soon.

Nevertheless, why GC is critical in reaching this goal (SDG-3)can be readily understood as it is offers diverse tools for meeting the challenges of green manufacturing. The drug manufacturing processes should ensure environmental benignity. The following tools may be useful in this regard:

3.2.1 Green Solvents

GC Principle 5 states "The use of auxiliary substances (eg: solvents, separating agents etc) should be made unnecessary wherever possible and innocuous when used." The pharmaceutical industries employ enormous amounts of solvents in formulating life-saving drugs for dissolution of a broad range of substrates and separation of desired product from unreacted starting materials as well as by-products. Unfortunately, many of the solvents are toxic, volatile, flammable, carcinogenic expensive and synthesized from depleting fossil fuels. Organic solvents are associated with hazardous health effects including eye irritation, headache, allergy etc. The problems associated with the traditional solvents have made it necessary for us to carefully select solvents and preferably substitute it with a safer one. Thus, greener solvents, characterized by low toxicity, ready availability, enhanced efficiency and reusability have attracted significant interest of the academic and industrial researchers.[28]Examples of green solvent include water, ionic liquids, bio-based solvents, supercritical fluids (SCFs) etc.Industries view solvent selection as a crucial component in the complete sustainability profile of any manufacturing process. Thus solvent selection guides have been developed to help the user select a solvent based on health, safety and environmental criteria.[29]

3.2.2 Green Catalysts

According to GC Principle 9 "*Catalytic reagents (as selective as possible) are superior to stoichiometric reagents."*Catalysts are substances employed for accelerating rates of reaction and also enhancing yield as well as selectivity. They are accredited for shaping the modern world and have played a significant role in the generation of blockbuster drugs as well as other pharmaceuticals.

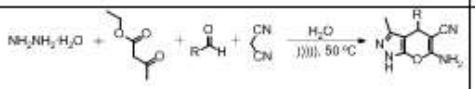
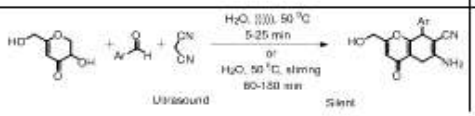
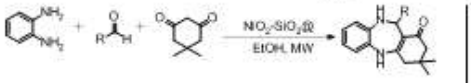
[30]The success stories of drugs such as Letermovir is a perfect example of State-of-the-Art Approaches to Sustainable Commercial Manufacturing Processes in the Pharmaceutical Industry that underwent rapid boost up in terms of yield by more than 60%, reduction in raw material cost by almost 93% by employing a better catalyst.[31]It is well known that the utilization of Pd based catalysts for C-C and C-heteroatom bond formation had completely changed the landscape of organic synthesis and the discoverers of these important coupling reactions had been conferred noble prizes. However, the separation as well as problems associated with metal contamination was a limiting factor for the large scale industrial applicability of these catalysts. Apparently, to overcome the drawbacks, heterogeneous catalysts were developed but these were not active and selective like the homogeneous ones. Thus, it was realized that there is a need to develop a catalyst that can integrate activity, selectivity and recyclability in one platform and such a catalyst would be called a "green catalyst."Now, the biggest question was "*how to design a green catalyst*?" Delightfully a solution was developed that could integrate the key benefits of homo and hetero catalysts, accomplished using heterogenization approach.[32] As per this approach, homogeneous metal complexes are immobilized onto the surface of an appropriate support matrix. Carbon, silica, graphene oxide, titania, zirconia etc have been commonly employed as support materials for the fabrication of heterogenized catalytic systems. With the advent of nanotechnology and nanoscience, nowadays attempts are being directed towards utilizing nanosized support, as they can tremendously boost the catalytic activity owing to larger surface area to volume ratio and also offer prospects of tuning their morphology for controlling catalysis. Consequently, iron oxide nanoparticles[33] and nanosilica[34]have emerged as support matrices of choice.The former one also facilitates ease of catalytic recovery by magnetic attraction.Biocatalysis also presents an interesting example of green catalysis.[35]

3.3.3 Green Energy

As per principle 6, Energy requirements should be recognized for their environmental and economic impacts and should be minimized." This principle simply states that for all processes, we must make efficient use of energy which means the focus should be on designing for energy efficiency. Green Chemistry has contributed towards promoting ways and technologies that can help in minimizing energy consumption required for powering various reactions.[36]**Figure 3** highlights all the green energy sources and their advantages.

Figure 3 Advantages of various green energy sources.

Table 1 projects examples of bioactive molecules possessing potent drug like activity that have been synthesized using safer eco-friendly energy.

Sl.No	Drug containing moeity	Bioactivity exhibited	Energy Source	Schematic Illustration	Ref
1.	Dihydropyrano [2,3c]pyrazoles	Autotaxin inhibition	Ultrasound		37
2.	4-Aryl-4H-chromenes	Potent apoptosis-inducing agents possessing vascular-disrupting activity	Ultrasound		38
3.	Tricyclic benzodiazepine derivatives	The benzodiazepine structure is present in some vital medicines such as diazepam, alprazolam, lorazepam, oxazepametc which have been utilized for treatment of anxiety disorders, alcohol withdrawal symptoms or muscle spasms.	Microwave		39

3.3 GC and SDG-6

The significance of water in sustenance all forms of life on earth is known to everyone.Unfortunately, but by virtue of our own activities we have ended up threatening the quality as well as quantity of water. By 2030, we aim to achieve universal and equitable access to safe and affordable drinking water for all. The contribution of GC in achieving this goal has remained unparalleled.Principles of minimizing waste, using safer solvents and catalysts, increasing energy efficiency, designing for degradation and real time analysis have been applied towards solving water pollution problems.By effective implementation of these principles, we have been able to develop new methods of water purification and lower cost desalination processes. Also, efforts shed in this regard have led to the development of efficient nanomaterials (nanosorbents and nanocatalysts) that have shown promising capability to eradicate/degrade diverse water contaminants such as heavy metals, dyes, drugs, pesticides from wastewater streams.[1]Photocatalytic technologies that rely on the rays of sunlight to drive the degradation of various toxic contaminants have proven to be highly useful in cleaning up of water. Nanosensors have particularly proven their utility in water quality monitoring.

Although considerable work has been carried out in improving water quality via exploration and deployment of greener technologies,[2] yet more research would be required in finding outinnovative methodologies for removal of micropollutants such as microplastics which is a challenging task.

3.4 GC and SDG-7

Green Chemistry has helped enormously in meeting SDG-7 byenabling the development of new renewable energy sources and also made energy efficient in chemical industries. We have discussed briefly in the previous section about the green energy sources. Amongst the various significant contributions of GC, advancement in the design of cleaner fuel technologies has been remarkable. Biomass comprising of plant and animal waste material is being utilized largely for the production of biofuels like biodiesels that provide the much energy fuel source to vehicles for running.[3] As compared to conventional diesels that are derived from fossil fuels which have a limited stock left and are also highly polluting, biodiesels are cleaner fuels and also derived from renewable sources such as vegetable oil producing crops. The transportation sector of many the countries across the world have benefitted from the use of biodiesels, though there are challenges related to cost factor and implementation regulations in countries that undergo drastic climatic changes. Apart from this, energy from sun and wind are also being used for powering a host of processes. These are called as the photochemical and wind energy.

3.5 GC and SDG-9

The chemistry community as a whole can play a powerful role in these three aspects:Industries, Innovation and Infrastructure.[4] The industries can

innovate and tune the existing infrastructure to become more sustainable. In fact, GC has been helpful in accomplishing this goal as theprinciples of green and sustainable chemistry provide the researchers new tools for creation of products and processes that are cleaner, greener, safer and sustainable.

3.6 GC and SDG-12

This goal of responsible production and consumption again has a strong link with GC. There are a few examples of ways which illustrate this fact. GC has fundamentally given birth to the concept of circular economy that enables the practice of reconverting back the waste into precious resource, which has given the industries the much needed outlook and pathway in reducing life cycle impacts of consumption.[5]Materials that can be recycled, biobasedfeedstocks and second generation biofuels are examples of key technologies that have contributed towards SDG-12. However, the task of achieving a stable economy that promotes life cycle is challenging and will require novel business models, products as well as solutions that will that are based on the notion of multiple usage.

3.7GC and SDG-13

GC has also been instrumental towards meeting the goal of climate action. Global warming arising due to increase in level of CO_2 in the atmosphere has raised an alarming situation.To tackle this problem, catalytic CO_2 fixation/capture has emerged as a viable solution.[6] GC has enabled the design of novel catalysts that have shown the phenomenal capability to fix CO_2 and convert it into valuable chemical feedstocks.Apart from this, the development of advanced materials for renewable energy, improvement indisease treatment and production of high-yield seeds and fertilizers for increased food production have proven to be successful in combatting thecritical climate changes.The chemical industrieshavealso started making a paradigm shift towards low-carbon economy by designing products that are helping other sectors in reducing their carbon footprints.

Conclusionand Future Outlook

The framework for the 2030 Agenda of UN Sustainable Development goals was providedto direct the world collectively towards a prosperous, inclusive and environmentally sustainable future. However, with only a very few years left to accomplish the SDGs, the ever increasing perplexities of climatic changes as well as other challenges posed by the current COVID-19 crisis, we have been compelled to revisit the goals with a renewed focus. During these trying times, it is green chemistry that possesses the magic of transformingthese goals into reality. Green Chemistry is the chemistry that is sustainable, the chemistry that respects the boundaries of the planet, a chemistry that is beneficial for all. The modern world which is under the dearth of potent tools to meet the current grievous challenges needs this form of chemistry. In fact, the effective implementation of the fundamental principles of GC have already contributed immensely towards many of the SDGs. Right from water clean-up to improved health care to mitigating the impacts of climate changes to providing solutions for zero hunger to ending poverty to contributing towards better infrastructure, industries, innovation, GC has wondrously made all these possible. The Presidential Green Chemistry Challenge Awards have been conferred to many of the GC innovations also highlight the significance of GC in SDGs.

Although the accomplishments have been promising and worth applauding, yeta lot of efforts need to be directed not just towards innovating through GC,but also changing things at the ends of the supply chain. In particularly, we need to raise awareness amongst the general publicabout the usage of developed goods judiciously. Every consumer must considerit as their responsibility to make best use of the product and subject it to proper disposal methods once the use is over.This way the waste management hierarchy will be followed and we can slowly step towards a sustainable tomorrow that comprises of a healthier and safer planet. Nevertheless, this is just one aspect. There are so many other linked "to do's and not to do's" which must be identified and followed.It is the right time to accept our share of responsibility for reaching the 2030 vision.For this, we need to accept that GC is synonymous to sustainability and hence instead of questioning its capabilities and wasting time, we need towisely adopt it in our practices. Biomimetics, miniaturization, continuous flow techniques and photochemistry are some of the hot areas of GC which can play a significant role in near future in attainment of the SDGs. Fruitful collaborations may also foster the realization of the activities in this direction and have a relevant international impact.

Endnotes

1. McGuinness, N. B., Garvey, M., Whelan, A., John, H., Zhao, C., Zhang, G., ... & Pillai, S. C. (2015). Nanotechnology solutions for global water challenges. In *Water challenges and solutions on a global scale* (pp. 375-411). American Chemical Society.
2. Ghernaout, D., Ghernaout, B., &Naceur, M. W. (2011). Embodying the chemical water treatment in the green chemistry—A review. *Desalination*, *271* (1-3), 1-10.
3. Bulushev, D. A., & Ross, J. R. (2011). Catalysis for conversion of biomass to fuels via pyrolysis and gasification: a review. *Catalysis today*, *171* (1), 1-13.
4. Schwager, P., Decker, N., &Kaltenegger, I. (2016). Exploring green chemistry, sustainable chemistry and innovative business models such as chemical leasing in the context of international policy discussions. *Current Opinion in Green and Sustainable Chemistry*, *1*, 18-21.
5. Sheldon, R. A. (2016). Green chemistry and resource efficiency: towards a green economy. *Green Chemistry*, *18* (11), 3180-3183.
6 Appel, A. M., Bercaw, J. E., Bocarsly, A. B., Dobbek, H., DuBois, D. L., Dupuis, M., ... &Kerfeld, C. A. (2013). Frontiers, opportunities, and challenges in biochemical and chemical catalysis of CO2 fixation. *Chemical reviews*, *113* (8), 6621-6658.

References

1. https://sdgs.un.org/goals
2. Messerli, P., Murniningtyas, E., Eloundou-Enyegue, P., Foli, E. G., Furman, E., Glassman, A., ... &Moatti, J. P. (2019). The Future is Now–Science for Achieving Sustainable Development. *Irrigated and integrated agro production systems help Mozambique adapt to climate change, Republic of Indonesia*.
3. Poliakoff, M., Licence, P., & George, M. W. (2018). UN sustainable development goals: How can sustainable/green chemistry contribute? By doing things differently. *Current Opinion in Green and Sustainable Chemistry*, *13*, 146-149.
4. Griggs, D., Stafford-Smith, M., Gaffney, O., Rockström, J., Öhman, M. C., Shyamsundar, P., ... & Noble, I. (2013). Sustainable development goals for people and planet. *Nature*, *495*(7441), 305-307.
5. Biermann, F., Kanie, N., & Kim, R. E. (2017). Global governance by goal-setting: the novel approach of the UN Sustainable Development Goals. *Current Opinion in Environmental Sustainability*, *26*, 26-31.
6. Dornan, P. (2017). Children, poverty and the sustainable development goals. *Children & Society*, *31*(2), 157-165.
7. Bellina, L. (2016). 16. Feeding cities sustainably: the contribution of a 'zero-foodwaste-city'to sustainable development goal 2,'zero hunger'. In *Food futures: ethics, science and culture* (pp. 315-341). Wageningen Academic Publishers.
8. Costanza, R., Daly, L., Fioramonti, L., Giovannini, E., Kubiszewski, I., Mortensen, L. F., ... & Wilkinson, R. (2016). Modelling and measuring sustainable wellbeing in connection with the UN Sustainable Development Goals. *Ecological Economics*, *130*, 350-355.
9. Nazar, R., Chaudhry, I. S., Ali, S., & Faheem, M. (2018). Role of quality education for sustainable development goals (SDGS). *PEOPLE: International Journal of Social Sciences*, *4*(2).
10. Koehler, G. (2016). Tapping the Sustainable Development Goals for progressive gender equity and equality policy?. *Gender & Development*, *24*(1), 53-68.
11. Leach, M. (Ed.). (2015). *Gender equality and sustainable development*. Routledge.
12. Milan, B. F. (2017). Clean water and sanitation for all: interactions with other sustainable development goals. *Sustainable Water Resources Management*, *3*(4), 479-489.
13. https://www.un.org/sustainabledevelopment/water-action-decade/
14. Hillerbrand, R. (2018). Why affordable clean energy is not enough. A capability perspective on the sustainable development goals. *Sustainability*, *10*(7), 2485.
15. Bebbington, J., &Unerman, J. (2018). Achieving the United Nations sustainable development goals. *Accounting, Auditing & Accountability Journal*.
16. Doyle, M. W., & Stiglitz, J. E. (2014). Eliminating extreme inequality: A sustainable development

goal, 2015–2030. *Ethics & International Affairs*, *28*(1), 5-13.
17. Al-Zu'bi, M., VeselaRadovic, M. A. Z. B., &Radovic, V. (2018). *SDG11 and the Associated Challenges to Implementation', SDG11–Sustainable Cities and Communities: Towards Inclusive, Safe, and Resilient Settlements (Concise Guides to the United Nations Sustainable Development Goals)* (pp. 21-76). Emerald Publishing Limited.
18. Bengtsson, M., Alfredsson, E., Cohen, M., Lorek, S., & Schroeder, P. (2018). Transforming systems of consumption and production for achieving the sustainable development goals: moving beyond efficiency. *Sustainability science*, *13*(6), 1533-1547.
19. Yohe, G., Lasco, R., Ahmad, Q. K., Cohen, S., Janetos, T., Perez, R., ... &Menne, B. (2006). Perspectives on Climate Change and Sustainability 3. *change*, *25*(48), 49.
20. Wood, S. L., Jones, S. K., Johnson, J. A., Brauman, K. A., Chaplin-Kramer, R., Fremier, A., ... & Mulligan, M. (2018). Distilling the role of ecosystem services in the Sustainable Development Goals. *Ecosystem services*, *29*, 70-82.
21. Biermann, F., Kanie, N., & Kim, R. E. (2017). Global governance by goal-setting: the novel approach of the UN Sustainable Development Goals. *Current Opinion in Environmental Sustainability*, *26*, 26-31.
22. Paul, A., Warner, T., & John, C. (1998). Green chemistry: theory and practice. *Oxford [England], New York: Oxford University Press*, *11*, 1394013941.
23. Clark, J. H. (2006). Green chemistry: today (and tomorrow). *Green Chemistry*, *8*(1), 17-21.
24. Jessop, P. G., Trakhtenberg, S., & Warner, J. (2009). The twelve principles of green chemistry.
25. https://www.acs.org/content/acs/en/sustainability/chemistry-sustainable-development-goals.html
26. *Proc. Natl. Acad. Sci. U.S.A.* 2013, DOI: 10.1073/pnas.1305919110.
27. https://www.acs.org/content/acs/en/funding-and-awards/awards/gci/green-chemistry-challenge-awards.html
28. 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.
29. Prat, D., Hayler, J., & Wells, A. (2014). A survey of solvent selection guides. *Green Chemistry*, *16*(10), 4546-4551.
30. Sheldon, R. A., Arends, I., &Hanefeld, U. (2007). *Green chemistry and catalysis*. John Wiley & Sons.
31. Xu, Y., & Humphrey, G. (2016, August). Development highlights towards a green manufacturing route for Letermovir exploiting novel asymmetric reactions. In *ABSTRACTS OF PAPERS OF THE AMERICAN CHEMICAL SOCIETY* (Vol. 252). 1155 16TH ST, NW, WASHINGTON, DC 20036 USA: AMER CHEMICAL SOC.
32. Sharma, S., Dutta, S., & Sharma, R. K. (2017). Recyclability of Reagents. In *Hazardous Reagent Substitution* (pp. 18-52).
33. Sharma, R. K., Dutta, S., Sharma, S., Zboril, R., Varma, R. S., & Gawande, M. B. (2016). Fe 3 O 4 (iron oxide)-supported nanocatalysts: synthesis, characterization and applications in coupling reactions. *Green Chemistry*, *18*(11), 3184-3209.
34. Dutta, S., Gaur, R., Sharma, S., & Sharma, R. K. (2019). Silica Nanoparticles: A Smart and Promising Support Material for the Design of Heterogeneous Catalytic Systems. *Silica-based Organic-inorganic Hybrid Nanomaterials: Synthesis, Functionalization And Applications In The Field Of Catalysis*, *4*, 33.
35. Arora, G., Dutta, S., Gupta, R., & Sharma, R. K. (2019). Other Potential Catalytic Applications and Future Perspectives. *Silica-based Organic-inorganic Hybrid Nanomaterials: Synthesis, Functionalization And Applications In The Field Of Catalysis*, *4*, 221.
36. Midilli, A., Dincer, I., & Ay, M. (2006). Green energy strategies for sustainable development. *Energy policy*, *34*(18), 3623-3633.
37. Zou, Y., Wu, H., Hu, Y., Liu, H., Zhao, X., Ji, H., & Shi, D. (2011). A novel and environment-friendly method for preparing dihydropyrano [2, 3-c] pyrazoles in water under ultrasound irradiation. *Ultrasonicssonochemistry*, *18*(3),

708-712.

38. Banitaba, S. H., Safari, J., &Khalili, S. D. (2013). Ultrasound promoted one-pot synthesis of 2-amino-4, 8-dihydropyrano [3, 2-b] pyran-3-carbonitrile scaffolds in aqueous media: a complementary 'green chemistry'tool to organic synthesis. *Ultrasonicssonochemistry*, *20*(1), 401-407.
39. Nasir, Z., Ali, A., Shakir, M., &Wahab, R. (2017). Silica-supported NiO nanocomposites prepared via a sol–gel technique and their excellent catalytic performance for one-pot multicomponent synthesis of benzodiazepine derivatives under microwave irradiation.*New Journal of Chemistry*, *41*(13), 5893-5903.
40. McGuinness, N. B., Garvey, M., Whelan, A., John, H., Zhao, C., Zhang, G., ... & Pillai, S. C. (2015). Nanotechnology solutions for global water challenges. In *Water challenges and solutions on a global scale* (pp. 375-411). American Chemical Society.
41. Ghernaout, D., Ghernaout, B., &Naceur, M. W. (2011). Embodying the chemical water treatment in the green chemistry—A review. *Desalination*, *271*(1-3), 1-10.
42. Bulushev, D. A., & Ross, J. R. (2011). Catalysis for conversion of biomass to fuels via pyrolysis and gasification: a review. *Catalysis today*, *171*(1), 1-13.
43. Schwager, P., Decker, N., &Kaltenegger, I. (2016). Exploring green chemistry, sustainable chemistry and innovative business models such as chemical leasing in the context of international policy discussions. *Current Opinion in Green and Sustainable Chemistry*, *1*, 18-21.
44. Sheldon, R. A. (2016). Green chemistry and resource efficiency: towards a green economy. *Green Chemistry*, *18*(11), 3180-3183.
45. Appel, A. M., Bercaw, J. E., Bocarsly, A. B., Dobbek, H., DuBois, D. L., Dupuis, M., ... &Kerfeld, C. A. (2013). Frontiers, opportunities, and challenges in biochemical and chemical catalysis of CO2 fixation. *Chemical reviews*, *113*(8), 6621-6658.