CHEMISTRY FOR A SUSTAINABLE FUTURE IN NIGERIA

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Abstract

Currently, Nigeria depends on finite supply of fossil fuels as the main source of energy. The present energy crisis and the attendant environmental problems associated with the use of fossil fuels call for a carbon - neutral economy that will use solar energy or alternative feed stocks or both. This paper highlights the role of chemists and chemistry as a branch of science in achieving the goals of sustainability in our national life. Research areas such as nanoscience, bioprocesses, catalysis, measurement science and cyber science are recommended for both chemists and other professionals in sciences and engineering.

Sustainability is the ability to provide a healthy satisfying and just life for all people on earth, now and for generations to come while enhancing the health of ecosystem and the ability of other species to survive in their natural environment (Grassian, 2006).

In 1987, a UN report defined sustainable development as "development that meets the needs of the present without compromising the ability of future generations to meet their own needs (World Commission on Environment and Development, WCED, 1987). This report is often recognized as the genesis of the modern sustainability movement. However, the concept of sustainability appears in historical records and ancient proverbs throughout the world and has an extensive history (Molnar Morgan and Bell 2001). As the challenge of living in harmony with the earth becomes increasingly difficult (Crutzen, 2002) more than ever, society needs education and high-quality, cutting-edge research to meet this challenge.

Our Nation currently has a non sustainable dependence on a finite supply of fossil-fuel-based hydrocarbons used in almost every synthetic material in our economy. The finite non sustainable supply of fossil fuels also serves as the main source of energy. The price of oil continues to rise while, at the same time, the countries that produce these vital fuels struggle with unstable social and political conditions. Finally, and perhaps most importantly, the growth in energy demand is projected to continue and the cumulative impact of burning fossil fuels to meet this demand raises serious concern.
Our non sustainable use of materials and energy also harm the health and well-being of the society and the ecosystem. For example, CO_2, a byproduct of combustion of fossil fuels, harms the environment by stimulating global climate change and potentially

disastrous global warming. Specifically challenges related to the chemical industry for achieving a sustainable society were identified in the National Academy of Science (NAS) workshop report (grand challenges for sustainability in the chemical industry (NAS 2005). The question now becomes, given societal needs in the 21st century and beyond what science and technology innovations do we need to achieve the goal of a sustainable future?

Chemistry, a branch of science that deals with structure, composition, energetic properties and reactive characteristics of substances at atomic, molecular and nanometer-length scales, is uniquely situated to contribute a positive and meaningful way to sustainable well being. Chemists are uniquely qualified to provide a molecular-level approach to and understanding of sustainability. Indeed, concepts that implicitly concern a sustainable philosophy such as "atom economy" and "one-pot synthesis" have goals in organic transformation, for some time (Anastas & Kirchoff, 2002). A significant future challenge is to find molecular solutions to pressing sustainability issues as well as proactive solutions that prevent future problems. Many important and stimulating chemical research activities are encompassed by sustainability. Chemists who make contributions to these areas will have a positive impact on the quality of life that will help ensure a sustainable future for our country.

During a recent workshop sponsored by the U.S National Science Foundation (NSF), a diverse group of Senior Chemistry Investigators with a wide range of expertise discussed four major areas of sustainability (NSF, 2006). These areas include energy, green chemistry and processing, the environment and education which are the present daunting issues. They are areas in which basic chemistry research and educational initiatives can play a pivoted role in driving innovations that will help achieve a sustainable future. Workshop participants considered advances in five enabling areas: nano-science, bioprocesses, catalysis, measurement science and cyber-science. This paper provides a broad overview of the issues discussed.

Research in Energy, a Grand Challenge and the Need for Change

The significant environmental consequences of the use of carbon-based fuels and the decrease in their availability demand new approaches to energy and energy conversion. Chemists have played important roles in shaping or developing new methods of energy conversion (Gratzel cells, polymer electrolyte membrane fuel cells, new electrodes for Lithium-ion batteries and the emerging use of bio-derived fuels like biodiesels). However, present energy needs require further innovation and dramatic changes. A sustainable future calls for a carbon-neutral economy that will use solar energy or alternative feedstock or both.

The role of chemistry and advances needed. Chemistry is a central science in energy conversion, storage and utilization. Most of our widely used forms of energy come from combustion of fossil fuels that are clearly not sustainable. Our Nation requires new energy sources that can be sustainably created, stored, interconverted and used. Chemistry plays a crucial role in enabling many if not all of these transformations. Solar light can be used to create chemical feedstocks or to create electricity in a solar cell. Fuel cells convert chemical feedstocks into electricity and batteries can be used to store the electrical energy produced. Chemical reactions convert commodity materials into more readily utilized fuels. Combustion reactions convert chemical energy into mechanical energy, whereas electrochemical reactions convert chemicals directly into electrical energy. All of these reactions also produce heat and thermo electrical materials can be used to convert heat to electricity. Advances are highly needed at least on three key areas. First, the harvesting of sunlight and the conversion of this energy need to be further developed. Solar energy is by far the largest exploitable energy source of the future. However, to be valuable to our society, it must be harvested and conversion to electrical power can be accomplished by photovoltaic. New, low-cost materials that efficiently harvest-sunlight and separate charge for photo electrochemical and photovoltaic applications are critically needed. Storage can for example, be accomplished in batteries or in chemical bonds. The rate at which consumers can deliver gasoline to their automobiles underscores the utility of storing energy from the sun in chemical bonds. Chemical feedstocks represent a desirable means for storing energy derived from the sun because of their high volumetric and gravimetric energy densities, ease of storage and transport and ease of rapid continuous or transient energy extraction. However, conversion of solar energy into useful feedstocks, such as the splitting of water into O_2 and $H_{2:}$. represents a formidable challenge that has not been met after decades of research. Achieving this and related transformation is difficult and will require new or more efficient methods to activate inert molecules (N_2, CO_2, H_2O) and convert them photo chemically into fuel stocks. In addition, chemists need a much deeper fundamental understanding of coupled, multi-electron processes, including the kinetics of these reactions and the ability to control or direct the flow of electrons and energy in the system or device.

Secondly, improvements in the conversion of chemical into electrical energy are needed. Advances in this conversion require significant improvements in fuel cells and batteries. The development of fuel cells must be coupled with parallel efforts to produce and store the fuels needed to power these devices. New sustainable electrode materials, membranes and electrolytes are critically needed (Grassian, 2006).

Thirdly, more energy-efficient chemical transformations are needed. Advances also require new catalytic processes that allow efficient conversion of inert molecules such as N_2 into enabling fuel stocks, such as NH_3 and that allow more ready commercialization of the chemistry of complicated chemical transformation with thermodynamics that are close to equilibrium. In some cases, the catalysis should be coupled with solar harvesting. Advances require improvements in materials and control that allow extraction of chemical energy by the operation of chemical reactors and combustors near equilibrium (Grassian, 2006).

Research in green chemistry and processing, a grand challenge and the need to change: A sustainable future will require materials processing practices that use alternative and renewable feedstocks more efficiently with fewer unwanted byproducts. Materials synthesized from non renewable feedstocks, such as petroleum-derived molecules that will begin to grow scarce in this century. A further problem comes from the products and byproducts of materials processing. Covalent bonds used to assemble products must be degraded before reuse. Conversion also requires quantities of reagents and accessory compounds (chiral auxiliaries, protecting groups etc), manufacturers must retrieve and dispose of such byproducts or risk polluting the environment with them (Grassian, 2006).

Thermodynamic rather than kinetics, process control most carbon- carbon bond transformation reaction that leads to undesirable by products and nonselective chemistry. To discover and optimize these reactions become a time-consuming process. Chemists must prepare and screen numerous candidate materials and use specialized macro reactors for each synthetic step. Each unit operation advances the synthesis by a single step. Chemists must also tailor organic solvents for each reaction type. Finally, product separation and purification frequently remain difficult and energy-intensive.

The Role of Chemistry and Advances Needed

Change will come about when chemists have the tools to use renewable resources with few byproducts produced by simpler, less energy intensive and more efficient processes to power our society. A sustainable future will come about when chemists can control and monitor chemical reactions more effectively (Grassian, 2006).

An ideological shift is required in the chemistry community as a whole from current chemical practices to new paradigms in sustainability chemistry. The basic concepts of this paradigm shift, the conversion of old practices to new ones are being advocated. These new practices include the use of renewable feedstocks, green solvents, module micro reactors and multiple reactions in a single vessel as well as finding highly selective reaction pathways.

Research in Environmental Molecular Science, a Grand Challenge and the Need to Charge

Research in energy production and strategies for minimizing waste in chemical processing all revolve around the environmental impact of these processes. The environment is a complex system. One of the greatest challenges in fully understanding the environment and environmental consequences of human activity comes from the molecular complexity of the natural and human impacted environment (NAS/NRC, 2003). Chemists must ask: given the level of complexity can we identify the main contributors to a complex system? Knowledge of the contributors v/ill at least help chemists begin to better understand the system and also just as importantly, help chemists form useful questions about what they do not understand. Secondly, chemists must find strategies for cleaning the environment. A sustainable society needs technologies to recycle and safely degrade pollutants, safely entrain radioactive waste, and provide clean water globally as well as strategies for advancing our understanding of chemical processes in natural and engineered waters.

The Role of Chemistry and Advances Needed

Recent advances in chemistry allow a more detailed molecular and elemental understanding of the component of air, water and soil. For example, molecular level understanding of dissolved organic matter in aqueous system is beginning to emerge and recent analytical techniques allow chemists to measure the size and chemical composition of individual atmospheric particles that are known to play a role in health and climate. Scientists now have a molecular-level understanding of the important chemical reactions that take place on polar stratospheric clouds during ozone depletion. These advances have increased our understanding of the earth's system (Grassian, 2006).

An integral part of sustainable chemistry is the prediction of how chemical components interact with and affect the biospheres and ecospheres. A proactive approach to this goal requires fundamental advances in understanding the structure and reactivity of the complex chemical matrices responsible for transformation and phases-change reactions occurring in the natural environment and consideration of the coupled effects of atmospheric, aqueous, soil and biochemical processes. However, despite recent advances, our understanding of the impact of humans on the environment is clearly still limited (Grassian, 2006).

Some of the most pressing new environmental challenges come from increasing CO_2 levels in the atmosphere. Chemists need a better understanding of ways to sequester CO_2 convert it to a useful chemical building blocks and minimize its unwanted production in chemical processes. In general, chemists will need to predict the potential for dangerous accumulation such as CO_2 in a proactive way.

Education, Grand Challenge and the Need for Change

Many chemists are working in the areas of energy, green chemistry and processing, environment and most chemists would recognize the concept of sustainability in chemistry as something important. However, most chemistry educators do not include these concepts in the classroom. To create a citizenry that is competent to make technical judgments, our society needs to teach sustainability issues throughout the education system. Universities, Polytechnics and Colleges of Education need to incorporate concepts of green chemistry and sustainability in chemistry in their curriculum.

The Role of Chemistry and Advances Needed

Chemists working in sustainable chemistry need to educate the industrial and academic communities and convince them of the importance of addressing sustainability. Chemists working in sustainable chemistry must help chemistry students understand sustainability concepts so that the future workforce will see sustainability as a necessary issue in process development. The public must see the importance and urgency of sustainability in the chemically related areas (the biggest of which is the energy consumption). To accomplish these aims, the chemistry community should take several steps in the teaching of sustainability issues. Advances needed to create a sustainable Nation and the world at large will involve workforce training, public education and global involvement (Grassian, 2006).

Research in Enabling Areas and Technologies

Several areas will be key in advancing the sustainability research themes of energy, green chemistry and processing and environment. Enabling research areas and technologies include nanoscience, bioprocesses, catalysis, measurement science and cyber science. How these enabling areas provide the science and technology innovations required for the different sustainability research areas are discussed below.

Nanoscience: - Nanoscience is a means of discovering new materials for sustainability research that offers some of the most exciting possibilities. Nano materials often yield new properties (e.g. efficient multiple - excitation generation) that can be exploited for applications in sustainability. Tunability is an important property of Nano materials. Optical, electrical, toxicological and magnetic properties of Nano materials can now be tuned by controlling their size, phase, shapes and surface properties. Other important attributes of Nano materials include large surface areas that can be functionalized at the molecular level, new combinations of photon penetration dept with modified carrier diffusion lengths, improved light harvesting and band-gap manipulation suspensions or thin films of the Nano materials can be made transparent to visible light, inhibiting light scattering and allowing more efficient photo transformations. This research could improve photochemistry useful for sustainability research for example, can solids dispersed as Nano particles, be used for more efficient photochemistry? Opportunities exist for researchers to further explore the interface of biology with Nano materials and thereby develop rules for compatibility or structure - property relationship or both. (Grassian, 2006).

The use of porous Nano materials as "Solid-solvent" cages in chemical synthesis could reduce the massive amounts of solvent that are currently consumed and may help identify "green" scalable synthetic methods. Chemists could design materials on the Nano scale for rapid disassembly. Can we fabricate semi conductor devices that disintegrate? Can we harness self assembly, and use those devices to enable disassembly? Can methods be found for element recovery and recycling through assembly and disassembly? All of these questions represent interesting and exciting opportunities raised by the potential of nanoscience (Grassian, 2006).

Bioprocesses: Recent key advances in bio processes have contributed to chemistry advances in sustainability. Bio processes try to mimic or even use environmental materials to increase efficiency and decrease hazardous waste in the chemical process. The genome sequence explosion has increased knowledge about bioprocesses. That knowledge is helping in the application of nanoscience. Plants are known to synthesize Nano particles and the process can be controlled by genetic manipulations.

Bioprocesses offer the chance to change from a petroleum feedstock source to a renewable stream (Ragauskas, 2006). The challenge is to identify bioprocess routes to new chemical building blocks on a much shorter timescale. A fast screening approach would facilitate progress in exploring a broad range of new methods for identifying chemical building blocks.

New bioprocess discoveries are now being exploited by industry. The establishment of commercial plants that produce 1,3- propanediol and polylacetic acid has shown that bio renewable materials can be manufactured on an economically competitive basis. Recent research has shown that certain bacteria grow conductive wires that can be connected to external conductors for use as fuel cells and has demonstrated the feasibility of an integrated bio refinery (Grassian, 2006).

Catalysis: Today, challenges exist in creating alternative fuels, reducing harmful byproducts in manufacturing, cleaning up the environment and preventing future pollution dealing with the causes of global warming, protecting citizens from the release of toxic substances and infectious agents and creating safe Pharmaceuticals (Grassian, 2006). Catalysts increase the rate of a desirable chemical reaction and are needed to meet these challenges, but their complexity and diversity demand a revolution in the way catalysts are designed and used. Challenges to catalysis research include discovering materials that harvest, store and use energy and can effectively be used to clean water, air and soil.

Measurement Science

Chemistry relevant to sustainability issues often takes place in very complex environments. A necessary and promising area of enabling research involves process - measurement science. In particular, process measurement may help improve the efficiency of chemical reactions and avoid the production of waste by- products by carefully monitoring reaction products. Advances in measurement science have driven many recent advances in the energy field. For example, improvements in our ability to characterize a material structurally, both in the laboratory and under conditions relevant to its use, whether in catalysis, in a lithium battery, or in fuel cell, have arisen from advances in measurement science. The chemical and molecular nature of the natural and human-impacted environment also needs to be accounted for. This entails detailed measurement of soil, water and air.

For each of the sustainability research themes, energy, green chemistry and processing and environment - the ability must be to develop to make measurement on a multidimensional parameter space that includes varying time scales, length scales, chemical resolution, concentration resolution and surface versus subsurface versus bulk measurements. Furthermore, these measurements need to be made under what have been termed operand conditions, as in- situ, or field measurements. These terms can be summed up as "point-of-use" measurement.

Cyber Science

Sustainability Science as well as the chemistry that will lead to a sustainable earth, is both data-intensive and data-driven. Sustainability in research now produces such massive amounts of data that a new infrastructure must manage data, promote access to data and encourage further discovery and strategies for acute and long-term problem solving related to energy, green processing and environmental chemistry. Advanced tools for cyber-enabled chemistry will lead to better and more efficient data management, mining, capture, processing and presentation.

Advanced cyber science enhances understanding of chemical kinetics from the molecular to the field scale and addresses the immense time scales of geological (and hence geochemical) processes. Advanced cyber science should also aid in the design and discovery of catalysts for alternative fuels and help reduce energy consumption in many industrial processes. All these data-intensive (and necessary) undertakings will accelerate with the proper investments in cyber science and cyber infrastructure.

In addition, advanced capabilities in high-end simulations have been key for several developments. Theory and computer simulations of processes at the molecular scale, as well as the ability to link simulations across multiple length scales and timescales, are emerging as essential partners with experiment in enabling understanding and design of materials and devices, for instance, simulations and experiment have successfully partnered in the design of lithium-battery electrode materials (Kang, 2006); and simulations has provided valuable guidance in the selection of catalysts for nitrogen activation (Honkala, 2005). Although these examples illustrate creative applications of tools available today, methodological advances are needed to address chemical and materials challenges associated with energy green chemistry and environmental problems.

Future Challenges and Needs

Issues related to sustainability are vast and complex and many individuals in a wide range of technical fields will ultimately need to work together to tackle them. Furthermore, complex economic, political and human-dimension aspects need to be addressed (Clark & Dickson, 2003). Basic research in science and engineering, in general, and in some cases, chemistry in particular, can play a pivotal role in driving the science and technology innovations needed to achieve a sustainable future. Initiatives in chemistry related sustainability issues already exist for example, the green chemistry institute of the American Chemical Society, the European Technology, platform for sustainable chemistry and the International Union of Pure and Applied Chemistry's green chemistry (I.U.P.A.C., 2001). A goal of this paper is to inspire even more chemists to take on sustainability challenges, questions and issues and to make advances that will positively impact our nation and influence fields that include pharmaceuticals, biomaterials, and agrochemicals. Because it is ultimately up to the public to support these initiatives and changes, it is important to remember that education on all levels is essential for creating a sustainable society. Many problems in sustainability are molecular in nature; therefore chemistry can play an important role in both sustainability research and education.

Conclusion

Chemists should use chemistry as a branch of science that deals with the structure, composition, energetic properties and reactive characteristics of substances at atomic molecular and nanometer-length scales to contribute positively and meaningfully to achieve the concept of sustainability for our society or as a nation.

Recommendation

Currently, the nation depends on non sustainable finite supply of fossil fuel which serves as the main source of energy. Also the use of this finite fossil fuel has serious negative impact on our environment. In view of the above the following recommendations are proffered:

1. A sustainable future that requires a carbon neutral economy that will use solar energy or alternative feedstock is recommended.
2. That chemistry educators should incorporate the concept of green chemistry and sustainability issues in the school curriculum especially at the tertiary level of our educational system.
3. That more research work be carried out by chemists in nanoscience bioprocess, catalysis, measurement science and cyber science to achieve the goals of sustainability in chemistry.
4. That collaborative research should be encouraged among chemists and other professionals to achieve the goals of sustainability.

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