



KeSEBAE NEWS



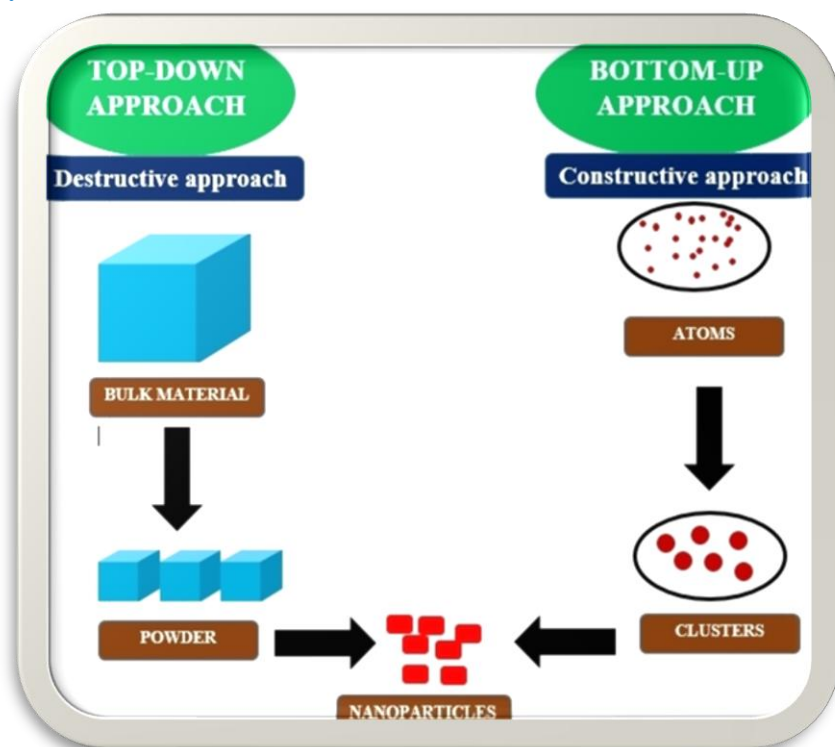
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Chemical Nanoengineering

By Korir Winnie Chemutai



Chemical engineering is often described as the discipline that transforms ideas from the laboratory into processes and products that power industries, improve lives, and sustain societies. It integrates chemistry, physics, biology, and mathematics with engineering design to develop processes that convert raw materials into valuable products fuels, fertilizers, plastics, pharmaceuticals and food. In Kenya, chemical engineers have been central to industrialization, food security and energy transformation, aligning with the nation's long-term development agenda under Vision 2030 and the Big Four Agenda. Engineering is a backbone of Kenya's progress, not only in traditional infrastructure but also in manufacturing, water, energy and environmental systems. This broad foundation is where chemical engineering naturally thrives, bridging science and industrial application. Today, the discipline is undergoing a profound evolution, extending from large-scale plants into the nanoscale realm, where atoms and molecules are engineered with precision. This emerging field, known as chemical nanoengineering, holds promise for solving some of Kenya's most pressing challenges in food, health and sustainable industrial growth. The importance of chemical engineering becomes particularly evident when examining Kenya's food systems.

DEAR READER

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A monthly Newsletter touching on topical issues affecting our environment.

KeSEBAE NEWS is a Newsletter of the Kenya Society of Environmental, Biological and Agricultural Engineers (KeSEBAE)

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Chemical engineers contribute by designing processes that enhance food shelf life, reduce contamination and ensure compliance with safety standards. Kenya faces persistent challenges of post-harvest losses, inadequate preservation infrastructure, reliance on imported processed foods, inadequate water storage, limited irrigation coverage and low mechanization restrict agricultural productivity. Chemical engineers are pivotal in addressing these gaps by designing drying systems, preservation technologies, packaging innovations and safe processing chains. For example, fortification processes enhance nutritional content, while optimized reaction engineering improves fertilizer and pesticide production for agricultural productivity.

Furthermore, the overlap between chemical engineering and food engineering is evident in value addition and agro-processing. By applying principles of heat transfer, mass transfer and thermodynamics, chemical engineers enable the conversion of raw crops into high-value products such as flours, beverages and packaged foods. This not only supports food security but also contributes to manufacturing, a pillar of Kenya's Vision 2030. These contributions in reaction engineering, catalysis, process design, and industrial scale-up are the hallmarks of chemical engineering, and they provide the foundation upon which chemical nanoengineering builds. While traditional chemical engineering operates at large scales, chemical nanoengineering brings the same design principles to the molecular and nanoscale level. It focuses on the manipulation of atoms, molecules, and nanoscale structures to design new materials, catalysts, and devices with unprecedented performance.

Chemical Nanoengineering: From Vision to Reality

Chemical nanoengineering is an interdisciplinary science subsuming chemistry, nanoscience, and engineering to design and manipulate matter at the nanoscale (1-100nm). In this scale, materials have special properties, e.g., higher reactivity, quantum behaviors, tunable optical or electrical properties, which can be exploited in transformative applications. The roots of this discipline can be traced to the lecture of Richard Feynman, given in 1959 in the form of a talk entitled *There is Plenty of Room at the Bottom*, which encouraged scientists to consider what could be done using individual atoms. The development of the scanning tunneling microscope (STM), atomic force microscope (AFM), fullerenes, carbon nanotubes and quantum dots made the vision a reality in the laboratory, making chemical nanoengineering a major contributor to modern innovation.

The article delves into the core tenets of nanoengineering, such as the effects of surface-volume ratios, quantum effects, and self-assembly, and the presentation of the application of nanoengineering in various fields. Its uses are as a targeted drug delivery system or nanosensors in medicine, nanosystem catalysts and solar cells in energy, carbon-based nanocomposites in materials science and nanoparticle solutions in environmental problems. The future of the field is taken up by emerging trends, including innovative nanomaterials, environmentally friendly synthesis (green nanoengineering), nanorobotics, and artificial intelligence (AI) integration.

In addition to opportunities, there are serious challenges. Nanotoxicology, environmental impact, equitable access, regulatory frameworks and public trust create a need for responsible innovation. The chemical nanoengineering will not fall into the traps of the previous technological revolutions by making safety, sustainability and inclusivity its core. Chemical nanoengineering has finally evolved out of the visionary dream of Feynman to become a transformative field that not only reinvents the definition of science and technology but also finds the solution to the world's pressing problems. Its narrative speaks to the ability of humankind to fantasize, create and construct responsibly at the most minute of scales- that is to say that working small can indeed make the biggest and most significant impression.

A World Within a World

Chemical nanoengineering has proven to be among the most thrilling frontiers of contemporary science; a field that combines the accuracy of chemistry, the inquisitiveness of nanoscience, and the pragmatism of engineering into one. It is a science and art of designing and manipulating matter at the nanoscale, or a tiny world between 1 and 100 nanometers. In perspective, a billionth of a meter is called a nanometer; one sheet of paper is approximately 100,000 nanometers thick. On this microscopic scale, things do not act naturally; they display new chemical reactivity, optical behavior and mechanical strength that they do not exhibit in their bulk counterparts. Chemical nanoengineering exploits these behaviors and directs them into practical applications in our daily lives.

The road to the current reality of science and technology in the world, invented by Feynman, has been characterized by significant milestones in science and technology. The first possibility for researchers to observe and even manipulate atoms on the surface was invented in the 1980s when the Scanning Tunneling Microscope (STM) and the Atomic Force Microscope

(AFM) came into being. The tools made nanoscience a possibility rather than a far-fetched thought in reality. Soon, chemists and engineers realized that they could regulate the structures at the nanoscale, enabling them to redesign materials and processes using the bottom-up approach. It was a shift, the point when nanoengineering was a feasible science and not an idealistic dream.

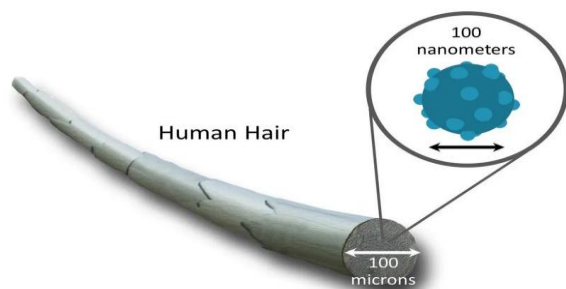


Figure 1: Illustration of nanoscale size of hair strand (Adapted from the Laboratory for Multiscale Regenerative Technologies at MIT, 2015)

Why does this matter? At the nanoscale, the laws of the game are different. Not only to act as they do, but also to exhibit large surfaces compared to their volumes, and to exhibit quantum effects that come to control material behavior. To illustrate, bulk gold is yellow and not reactive to any chemical element. In contrast, at the nanoscale, the particle of gold may be either red or purple and serve as a specific catalyst in any chemical reaction. Likewise, the common carbon we use in soft graphite or hard diamond can be redesigned over the nanoscale as carbon nanotubes or graphene sheets, stronger than steel and lighter than aluminum. Chemical nanoengineering takes these astonishing phenomena on the nano scale and offers them as building blocks of innovation.

The applicability of chemical nanoengineering is nowadays witnessed in various fields of society. Nanoscale drug delivery systems can be used in the healthcare sector, where they can be targeted to diseased cells with high precision, minimizing side effects and enhancing the quality of treatment, including cancer treatment. Nanostructured catalysts enhance the performance of fuel cells in energy, whereas nanoscale materials enhance the capacity and longevity of batteries and solar cells. In materials science, engineers develop composites that have never been as strong per their weights, making lighter vehicles and more robust infrastructure possible. Moreover, environmental science also creates nanomaterials to purify water, capture carbon emissions, and degrade pollutants more efficiently than conventional processes.

The most potent aspect of chemical nanoengineering is that it is interdisciplinary. It is not only the business of chemists, engineers, or even physicists; it is a cooperative venture that flourishes at the interface of several disciplines. Chemists provide their knowledge in the field of molecular interactions and in the field of synthesizing them; engineers build processes and systems to extend nanoscale findings into practice; physicists can give knowledge on the quantum effects that control at the nanoscale; and biologists can offer information on incorporating nanomaterials in living systems. This convergence, when combined, enables chemical nanoengineering to address problems that cannot be addressed by any single discipline and that are too complex to be addressed solely by that discipline.

The world is moving towards the 21st century, and environmental issues like climate change, renewable power, and affordable healthcare require new solutions. Nanoengineering Chemical nanoengineering is best suited to occupy a key place in solving these issues. Through the unexplored promise of nanoscale science, scientists are developing not only incremental advances but also new technologies that could revolutionize their industries and enhance the quality of life worldwide. What used to be a scientific interest has become an innovation engine and is fundamentally transforming the future.

The Principles of Nanoengineering

In order to appreciate the nature of chemical nanoengineering, we must first understand the rules that would control matter at the nanoscale level. The world of nanoscale is different from the well-known world of bulk materials, where properties such as strength, color, or conductivity can be determined in advance and are well studied. Nanoengineering is constructed on investigating, understanding, and utilizing such peculiarities in forms that can be engineered to become useful.

Nanoscale Properties: When Size is Everything

Another of the most apparent aspects of the nanoscale is that size has become a property. When materials are brought down to nanometer sizes, they act differently, and there are two reasons why:

- i. **Quantum Effects:** At the nanoscale, the electrons cease to behave as continuous bands and begin to exist in discrete energy levels. This

- ii. quantum confinement alters the absorption and emission of light and a material's electric and chemical behavior. For example, quantum dots are semiconductor nanoparticles capable of emitting light of various colors merely by changing size; a property that bulk semiconductors do not possess.
- iii. **Surface to Volume Ratio:** With a decrease in particles, a significantly greater proportion of atoms are found on the surface than the inside. This makes nanoparticles much more reactive than those of bulk. A bulk-sized portion of platinum could make a fair catalyst. However, the nanoparticles of platinum reveal many more active sites per gram and thus are considerably more effective in catalytic reactions.

Chemical nanoengineering is based on these principles. Through size, shape, and surface chemistry, scientists can control nanoscale structures and prepare materials with desired properties, be it increased reactivity in catalysis, increased conductivity in electronics, or novel optical phenomena in imaging.

Top-Down and Bottom-Up Approaches

Designing nanoscale structures is a combination of art and science. Two approaches prevail in chemical nanoengineering: the top-down approach and the bottom-up approach.

- i. **Bottom-Up Approach:** This approach creates nanoscale structures based on atoms and molecules. It depends on chemical synthesis and self-assembly, whereby molecules form into orderly structures in the appropriate conditions. Indicatively, nanoparticles may be prepared in solution by modulating pH, temperature, and precursor concentration. On the same note, thin films may be formed via chemical vapor deposition (CVD), where gases are reacted and a material layer is formed atom by atom. The power of the bottom-up methods is their capability to generate homogeneous structures and take advantage of the natural molecular interactions. A chemist will play on it, with an ability of precision and control at the atomic level to produce nanomaterials of considerable specialization.
- ii. **Top-Down Approach:** Conversely, top-down nanoengineering involves using large materials and etching or carving them to the nanoscale. In semiconductor production, techniques like lithography are the best examples. Engineers can mold nanoscale circuits and devices by illuminating or irradiating materials with beams of electrons. Etching, ion milling, and nonprinting are other methods of top-down. Top-down methods are less chemically beautiful than bottom-up methods, but are more precise, scalable, and can be incorporated with the existing processing in the industry.

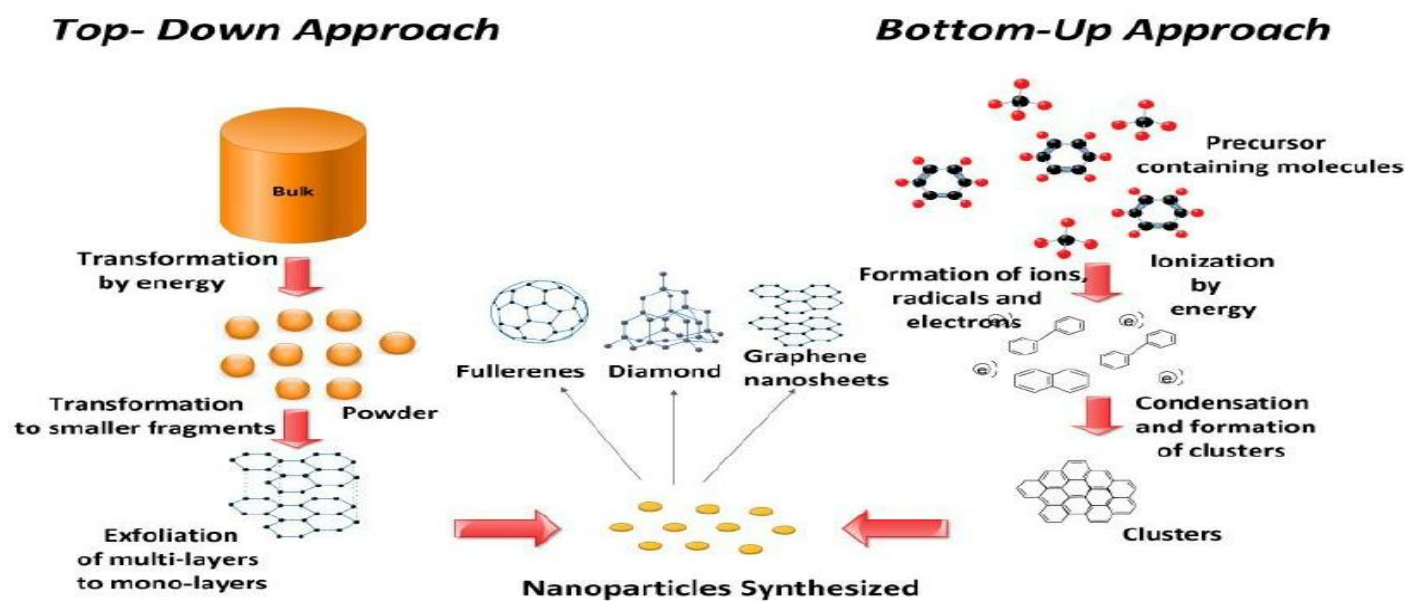


Figure 2: Bottom-Up and the Top-Down Approaches on Synthesis of Carbon-Based Nanomaterials

Practically, the current nanoengineering frequently incorporates both methods. As an example, nanomaterials having desired properties may be

synthesized in a bottom-up process, followed by incorporation into devices by top-down fabrication.

The Role of Molecular Design

Molecular design, a conceptualized arrangement of molecules to bestow preferred functions on the Nano-level, is at the center of the chemical nanoengineering field. This is the synthesis of new molecules and the design of their interactions, assembly pathways, and reactivity. For example, surface functionalization procedures enable nanoparticles to be wrapped in specific molecules that guide particles to cancerous cells in the human body. Similarly, the ligand systems that stabilize nanoparticles make them non-clumped nanoparticles that do not clump in bulk, maintaining their individual nanoscale characteristics.

This focus on their molecular-level interaction points to the significance of chemistry in nanoengineering. Whereas physics can determine the physical reasons underlying nanoscale behavior, and establishment can give the ability to take advantage of such behavior, chemistry can be important to allow one to fine-tune matter on the scale of atoms and molecules. To a great extent, chemical nanoengineering could be regarded as engineering poly the chemistry, with synthetic strategies and the ability to be creative with molecules being the instruments of innovation.

Tools and Techniques: Seeing and Shaping the Nanoscale

One of the principles of nanoengineering is that it is possible to imagine, visualize and manipulate the nanoscale world. This was achieved in the 1980s when instruments, such as the Scanning Tunneling Microscope (STM) or the Atomic Force Microscope (AFM), were developed. Now, the scientists could observe single atoms visually and manipulate them. It was an experiment carried out in 1989 at IBM that produced a name composed of the company name of IBM with 35 xenon atoms and consisted of 35 particles that spelled the company name, which caught the attention of the world and enabled researchers to understand that nanoscale manipulation was possible.

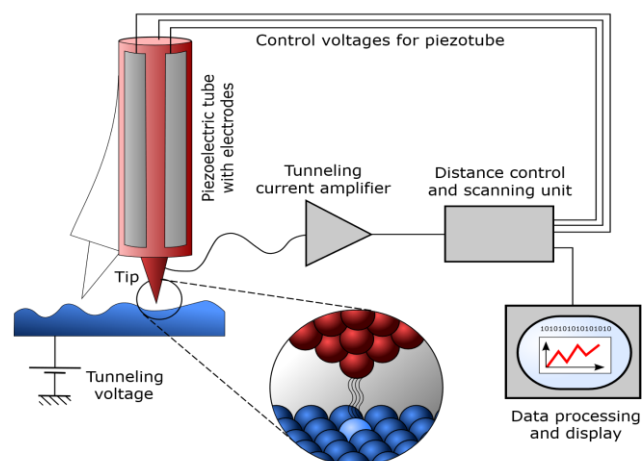


Figure 3: Schematic Diagram of a Scanning Tunneling Microscope (Adapted from Wikipedia Contributors)

This has since given rise to a giant toolbox. Using transmission electron microscopy (TEM), it is possible to see the nanostructure on an atomic scale. Spectroscopies are used to describe their electronic and chemical characteristics. At the same time, nanoimprint lithography and focused ion beam machining exemplify more sophisticated fabrication methods with unprecedented abilities in the shape of the nanoscale buildings. These machineries represent the concepts of nanoengineering: precision, control, and the use of creativity at scales that it has never had a chance to imagine.

Principles in Practice

The nanoengineering principles are not mere concepts; they are emerging to transform industries. Nanoparticles are utilized in catalysts by taking advantage of the large surface-to-volume ratio. Using quantum effects, quantum dots are currently used on high-definition display screens. Small, faster microchips are possible through nanolithography, the result of which is the rapid exponentiation of the computing power envisaged in the Moore law. These developments are all based on the principles we have covered: unique nanoscale properties, new fabrication strategies, and molecular design. Nanoengineering is essentially concerned with taking advantage of the strange properties of the very small and applying them in technologies that have large effects.

Through learning the roles of nanoscale properties, integrating bottom-up growth mechanisms with top-down methods, and weakening the dominion limits of molecular design, chemical nanoengineering has proven to be disruptive to the science community in contemporary times. It is on this basis that innovative applications have flourished -the subject of discussion in the following section.

Key Applications – From Theory to Practice

The aspect that determines any scientific discipline to a significant extent does not just come in the way of its theoretical beauty but in every aspect of innovation in a new field that has been put into action in medicine, energy, materials science, and even in the sustainability of the environment. The most impressive aspects of this transformation, however, have been the fact that many of these breakthroughs have been made through the concepts of nanoscale, such as quantum effects and improved surface reactivity, which have been fine-tuned by chemistry. This part will discuss the application of chemical nanoengineering in the various fields and why its impact will continue to expand even more.

Medicine and Biotechnology: Healing with Precision

Among the most thrilling uses of chemical nanoengineering is in the field of medicine, where the idea is not only to cure illnesses but also to cure them with a specific accuracy in a measure unprecedented. There is usually an overloading of the whole body with the use of traditional drugs, which leads to harmful side effects and decreases the effectiveness. Nanoengineered drug delivery systems can, however, be engineered in such a way that they specifically target diseased cells and deliver therapeutic agents to them.

As an example, nanoparticles that have an appropriate ligand surface coating may identify and bind to receptors of cancerous cells in order to release their drug cargo at the point of need. A direct product of this technology is lipid-based nanocarriers, which efficaciously transport delicate genetic material into cells (as is the case with some COVID-19 mRNA vaccines). Nanosensors are also being designed to terminate drug delivery up to detecting disease biomarkers at exceedingly low levels, so that companies find a way of diagnosing the disease earlier and more precisely. Glucose or pathogen geosimpedance Biosensors that use gold nanoparticles or carbon nanotubes, such as biosensors, can detect glucose

concentration or pathogens with a high degree of sensitivity. Nanoengineered scaffolds have been utilized in regenerative medicine to determine the growth of cells and the regeneration of tissues. By producing nanostructured surfaces in the formulation of the extracellular matrix, scientists have the opportunity to induce stem cells to differentiate into the required tissue types, which promise potential applications in organ repair or replacement. Together, these advances stem out as a paradigm shift: medicine is no longer a one-size-fits-all model, but a model that is targeted and focused on the individual, driven by the engineering science of nanoscale.

Energy: Powering the Future at the Nanoscale

The modern society is running on energy, and chemical nanoengineering is availing the means to make it cleaner, more efficient, and sustainable. The best use of nanomaterials is that they have enormous surface areas that ensure that they excel as catalysts. Nanocatalysts are already making changes to fuel cells through enhancing fuel cell reactions and minimizing complex metals such as platinum, which are costly. Likewise, nanoscale engineering is improving battery technology. Scientists have enhanced charge capacity and cycle stability by creating nanostructured surface electrodes, thereby setting the stage for the lithium-ion batteries that have long-lasting operation and the upcoming application of the energy storage method.

The chemical nanoengineering has also impacted solar energy in a similar way. Solar cells made of perovskite nanostructures have been enabled by quantum dots together with nanostructured materials, making them not only more effective, flexible, and lightweight, but also usable on wearable electronics and other portable electronics, keeping up with their energy infrastructure in buildings. The long-standing clean energy challenge of hydrogen storage is being achieved using nanostructured materials that are capable of storing hydrogen at increased densities in a safe and reversible way. These innovations are bringing us nearer to an efficient, accessible, and sustainable renewable energy economy.

Materials: Stronger, Lighter, Smarter

Nanoscale design capability has transformed materials science. Traditional materials can always entail trade-offs; heavier materials can be tougher, whereas lighter materials can be shorter-lived. Strength without weight has, however, been attained in chemical

nanoengineering. As an example, graphene and carbon nanotubes, which are versions of carbon, exist at the nanoscale and are stronger than steel but lighter than aluminum. The material is now being incorporated into composites in the aerospace, automotive, and building sectors, producing more fuel-efficient and, more importantly, longer-lasting vehicles and heavier constructions.

Another application that is used to explain the versatility of nanoengineering is nanocoating's. Creating new properties through using thin layers on surfaces with some behavioral traits that can be conferred onto surfaces, either by using nanomaterials as scratch-resistant substrates, self-cleaning, or even anti-bacterial defenses. As an illustration, the titanium dioxide nanoparticles employed in things like coatings can decompose organic contents using sunlight, producing self-cleaning windows or surfaces that are unsuitable to microbial development. There has also been the development of smart clothing with nanoscale fibers, which provide fabrics with features such as water resistance, UV protection, and even health parameter monitoring.

Environment: Cleaning and Protecting Our Planet

Chemical nanoengineering is used in many ways, with one of the most pressing needs being environmental concerns. Water shortage and pollution are challenges that occur worldwide, and nanomaterials are providing new solutions. Indicatively, heavy metals, bacteria, and other contaminants can be filtered through a nanostructured membrane at a rate that is never reached by conventional purification technology. Nanoparticles like zero-valent iron are under development to bring down toxic pollutants in groundwater as a cheap technology to clean up contaminated water.

Catalytic nanoparticles are also applied to create automotive converters and industrial processes to control air pollution by reducing harmful emissions. In the meantime, walls, nanoparticles of photocatalysts such as titanium dioxide, can use sunlight to dismantle pollutants or to separate water into pure hydrogen fuel. Such applications clean our environment, and they introduce sustainability in industrial processes as they lower the ecological footprint.

From Vision to Everyday Impact

The use of chemical nanoengineering is evidence of a deeper fact: what seemed like a dream in the past to

manipulate atoms has now been utilized as the foundation of contemporary innovation. Nanoscale engineering in hospitals, energy, materials, and the environment is no longer a phenomenon constrained to academic laboratory groups- nanoscale engineering is finding its way to the technologies that move millions of lives every day. These applications can only extend into more corners as the field itself is coming to maturity, closing that gap between theory and practice that continues to raise the question of what is possible.

Emerging Trends – The Next Chapter

Chemical nanoengineering is dynamic and not a fixed area; we should be aware that emerging scientific information, instruments, and 21st-century demands will all collide. As early as we have seen its transformative usages in medicine, energy, materials, and the environment, the next generation of nanoengineering says it goes further. These new trends have not only shown scientific ingenuity but also the dire human need to find solutions to world challenges. Due to the ability to adapt to the environment of smart materials, the proposed ways of eco-friendly synthesis and artificial intelligence incorporation, chemical nanoengineering is set to continue being as transformative in the future as it was in the past.

Smart Nanomaterials: Matter That Responds

The construction of smart nanomaterials- engineered systems are capable of sensing, responding, and adapting to changes in their environment- this is one of the most exciting frontiers. It is a contrast to passive materials, which react fixedly to circumstances; however, smart nanomaterials are to be dynamic. As an example, it is possible to develop nanoparticles that react to certain biological triggers, such as a decrease in pH or the availability of certain enzymes. This has great potential in cancer treatment, with smart nanocarriers being able to deliver chemotherapeutics only in the acidic microenvironment of a tumor, compromising the architecture of healthy tissues minimally.

Another outstanding development in regions other than medicine is self-healing materials. The cracks or damages may be controlled by means of implanting in the coatings or composite, the nanocapsules containing repair agents, so that when the cracks or damages appear, the invasion causes a chemical reaction that closes and mends the medium automatically. Think of airplanes, bridges, or even smartphones, which can fix themselves after a minor breakage, this is no more a

fiction than its possible reality. In the same spirit, shape-memory nanomaterials in which form is reconfigured by heat, light, or magnetic beams are also being developed for use, extending to robotics and adaptive building materials.

Green Nanoengineering: Sustainability at the Core

Despite such a strong potential for chemical nanoengineering, its fast growth attracted some apprehensions regarding toxicity, waste, and environmental issues. The development of green nanoengineering has been the result of such an effort, and it focuses on sustainability on a ground-level basis.

Green nanoengineering deals with greener synthesis techniques, bioproducts, biodegradable nontechniques, and safe-by-design engineering approaches that pose minimum risks and maximum benefits.

Indicatively, there is the possible biological technique of nanoparticle creation through plants, bacteria, or fungi. Nanoparticles can be developed in these so-called green factories without the use of chemicals or processes requiring a lot of energy. Plant extracts, e.g., have been effectively demonstrated in reducing metal ions into nanoparticles in water-based solutions, in place of more expensive syntheses, and are greener, lower cost, and have a lower environmental impact.

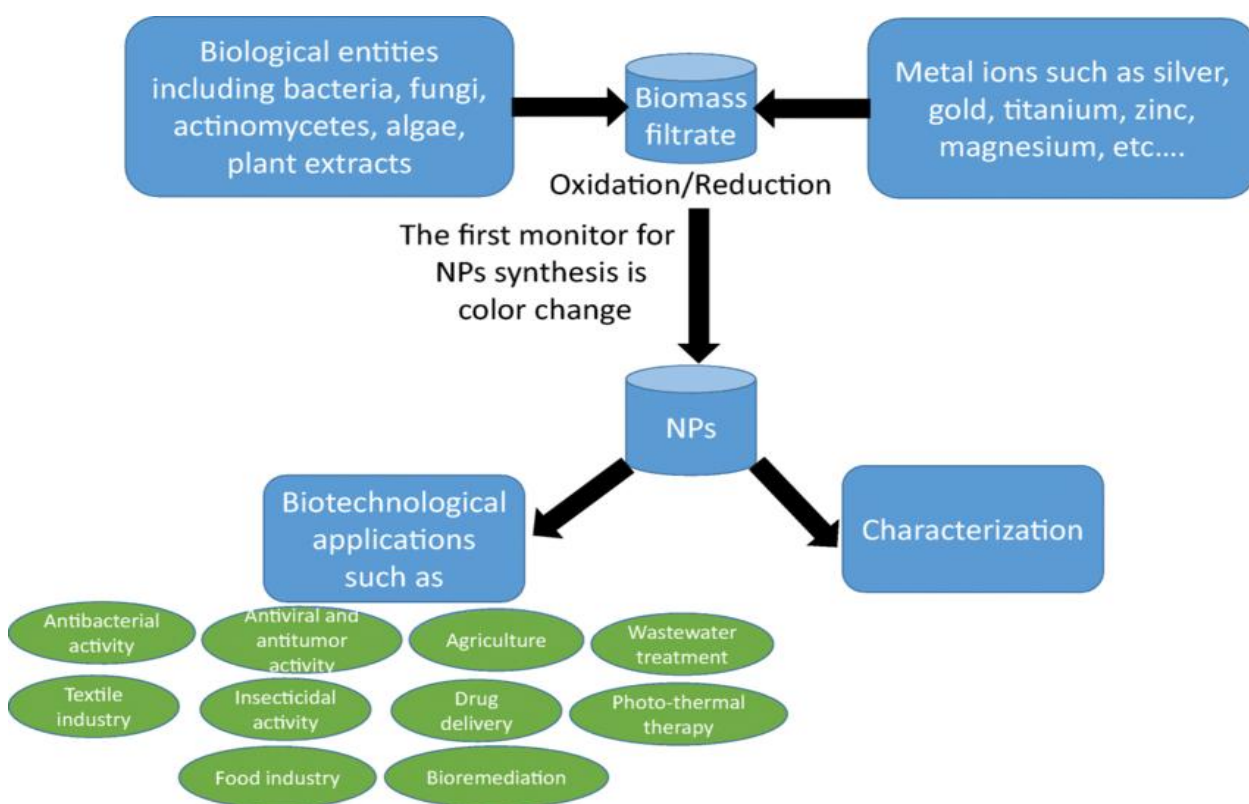


Figure 3: Green Nanoengineering (Bio-Inspired Nanoparticle Synthesis Flowchart)

A second avenue worthy of exploration is the design of nanomaterials that peter out innocently upon use. This becomes of special importance to biomedical applications, where nanoparticles taken to the body will have to be clearable in due course, before long-term build-up will occur. In the same manner, nanomaterials, which have been applied in the environment, like water purification, are to be designed to prevent the occurrence of secondary contamination. Researchers have struck by making sustainability a core part of the DNA of nanoengineering, and in this way, the nanoengineering will not end up costing future generations.

Nanorobotics: Engineering at the Smallest Scale

Considering that the dream of chemical nanoengineering started with the control of atoms, it would be said that nanorobotics is the implementation of this dream. Nanorobots, also known as nanobots, are nanoscale systems that can be used to carry out work in living organisms, or in more complicated systems, such as nanorobots. Though this area has been emerging, developments in this sector have been fast. One application of nanorobots in medicine is that someday, a precision administration of drugs into diseased tissue could be delivered using nanorobots surgically, or

damaged tissue could be repaired and damaged via repair nanorobots, or real-time findings of pathogens could be destroyed using repair nanorobots. The DNA-controlled nanomachines, which open and close, resembling the folds of molecular origami, have already been demonstrated by the researchers and can deliver therapeutic molecules upon their interaction with certain disease markers. Elsewhere, nanorobots could be utilized to clean up toxic spills, monitor infrastructure maintenance, or perform nanoscale tasks in the industrial field.

As futuristic as these ideas might sound, the principles are already being tested in laboratories all over the planet. Nanorobotics is one of the most promising trends to keep an eye on in the next few decades due to a synthesis of chemical nanoengineering, robotics, and synthetic biology.

AI and Machine Learning: Accelerating Discovery

The other strength is the incorporation of artificial intelligence (AI) and machine learning (ML) in the future of chemical nanoengineering. Historically, the process by which new nanomaterials were discovered has been both resource-intensive and time-consuming, as it required trial and error experiments and time-intensive computational modeling. However, AI is able to process large volumes of data, identify trends, and forecast material characteristics at a speed never seen before.

As an example, machine learning algorithms are being applied to develop new catalysts, predicting their reaction rate in the new nanoscale structures. In the field of materials science, AI-based models are assisting in ensuring that good candidates for batteries, solar cells, and superconductors with high performance are identified. Currently, AI combined with automated synthesis and characterization methods is pushing scientists into a new era where an entire new nanomaterial can be discovered, prototyped and optimized in weeks instead of years.

AI seeks to allow not only faster discovery but also intelligent designing. In the case of nanoparticles designed with AI-control optimization, the researcher can design non-toxic particles that will end up producing good results in addition to being safe, with risks to toxicity being reduced before their adverse effects are seen in the lab. Combining the creative potential of humanity with nanoscale chemistry and the

field of artificial intelligence can transform the nature of innovation in the industry.

The Next Chapter

The trends in chemical nanoengineering that are coming up depict the scenario where it is not decelerating but rather accelerating rapidly. Smart nanomaterials offer flexibility and intelligence; green, nanoengineering will make it sustainable; nanorobotics makes nanoscale machines, with capabilities never before seen; AI just increases the rate at which discoveries are achieved. These changes, combined with more, suggest that nanoengineering will cease to be a supporting technology, but it will become an engine of evolution all around the world.

Chemical nanoengineering, in a lot of ways, lies at a crossroad. The principal building blocks have been laid, and the initial implementations are already revolutionizing sectors of industry. This time, the next generation of innovations will redefine entire sectors of society. This is the sequel to the story of nanoengineering on the chemical platform, which will make a great mark in the 21st century and beyond.

Challenges and Ethical Considerations

Each technology is a dominant power and therefore carries a two-sided situation, which, on the one hand, allows progress and, on the other hand, can cause harm. Elements of the art of nanoengineering, Chemicals are not an exception. Although it promises to revolutionize medicine, energy, materials, and the environment, it poses serious questions of safety, sustainability, and ethics. Contrary to what has been experienced in other eras of technological advancement, when the future associated with risks can be realized only when the damage is created, nanoengineering gives us the opportunity to make informed choices and to take professional responsibility in the first place. In order to experience all the positive aspects of this genre, we should pay close attention to the scientific, environmental, and ethical consequences of the fast-changing sphere.

Toxicity and Human Health Concerns

Toxicology is one of the most pressing problems of chemical nanoengineering. Nanomaterials do not, in most cases, behave like their bulk in terms of chemical properties, but they vary in their interaction with biological systems. Their minute size gives them the ability to enter deep into tissues, cross cell membranes,

and even bypass biological barriers such as the blood-brain barrier. Although this property makes nanoparticles the ideal choice in drug delivery, it is a cause of concern when the nanoparticles find their way into the drug delivery system without the user intending the action, such as during inhalation, ingestion, or direct skin contact.

As an illustration, some studies have indicated that some forms of carbon nanotubes have a shape that is similar to asbestos fibers, and can result in lung inflammation in case of inhalation. Likewise, antimicrobial nanoparticles (silver nanoparticles used

widely) have the capability of accumulating in the tissues, which is the point of concern due to the consequences accruing in the long term. Due to the enormous number of nanomaterials and their capacity to act in different ways, it is impossible to have a universal perception of their safety yet.

This has been further complicated by the fact that conventional toxicology is not always applicable to nanoscale issues. The bulk chemical standard testing methods do not necessarily detect nanoparticles' reaction with cells, proteins, or DNA. This has spawned a new area of study: nanotoxicology, which is focused on the health hazards of manufactured nanomaterials.

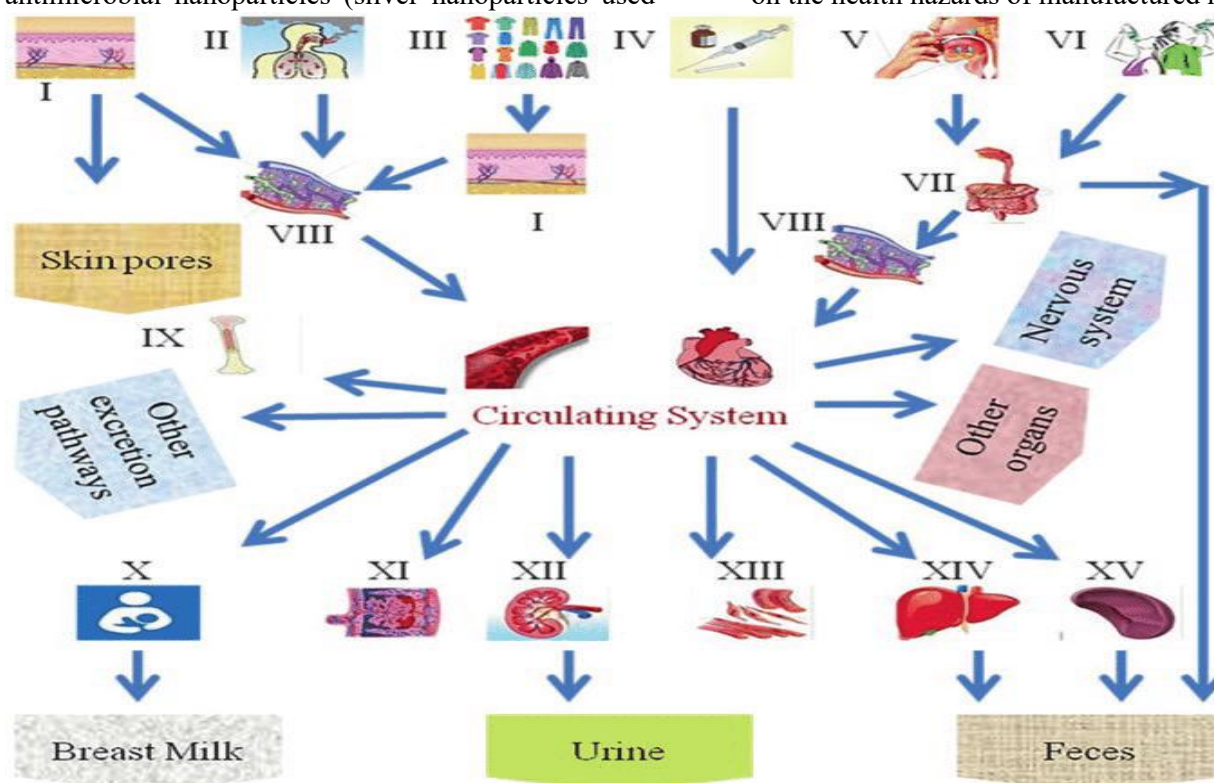


Figure 4:Diagram of nanoparticle pathways in the human body (respiratory, circulatory (Adapted from from Brohi et al. 2017)

Environmental Impact

In addition to the health of human beings, nanomaterials also pose the threat of harming the environment. When set free, nanoparticles may be deposited in soil, waters, air, and, excessively, they may concentrate on plants, animals, and microorganisms in ways that cannot be predicted. To illustrate the example, nanoparticles needed by cosmetics and sunscreens, such as titanium dioxide or Zinc oxide, may be washed into rivers and oceans, where they may cause havoc to aquatic ecosystems. Some studies have suggested that nanoparticles can cause beneficial microorganisms to grow poorly or that they can be singled out in the food chain, but the effect is not well known on a long-term basis.

The sheer diversity of nanomaterials makes the investigation of the environmental challenge difficult. Both possess distinct characteristics that have a bearing on their movements, conversion, or decadence within the environment. This is because some of them can disappear harmlessly, whilst others might persist or even transform themselves in manners that are more dangerous. To avoid unintentional consequences, designing materials with life-cycle consideration, in relation to how they will be used after production to disposal, is necessary.

Regulatory Frameworks: Catching Up with Innovation

Regulation has typically been behind technological innovation, and nanoengineering is no exception. The

bulk chemistry regulatory schemes that are primarily available around the world were created to consider bulk behaviors and have not taken into consideration the specific behavior that happens at the nanoscale. As just one example, a chemical that is safe on a large scale can have completely novel properties and even have risks that people have no idea about before, beyond the nanoscale.

Nation-states and global agencies are starting to change. Such regulations as the European Union, these circumscision regulations in the form of REACH originated, and nanotopographic safety data can be requested. In the same light, the U.S. Food and Drug Administration (FDA) has provided guidelines on the potential assessment of nanotechnology, as applied in drug and food developments. Nevertheless, there is minimal convergence of regulations across borders, and the rate of innovation usually keeps up with innovation.

One of the most important ethical dilemmas that emerges in this case is how to create the ideal balance between initiatives and safety. An absence of adequate regulation can place humans and the biosphere at unwarranted risks, whereas excess regulation would inhibit innovation and retard the good that could be delivered by nanoengineering. To reach this balance, there should be clear communication between countries, collaboration on the international level, and dynamic policies that will keep changing with the science.

Equity and Access

The other ethical aspect that tends to be ignored is the issue of equity. Who is going to gain out of the chemical nanoengineering, and who are they likely to abandon? New medical methods in nanotechnology, such as those, should not only appear first to the rich groups of people or nations; they also increase global health inequity. There are also other chances that inventions in renewable energy or water cleaning may not get to those people who require them the most, unless specific measures are undertaken to achieve fair allocation.

This imposes a crucial role upon scientists, engineers, and policymakers: not to create nanoengineering innovations solely based on their functionality, but also on their availability. The issues of global orientation, such as climate change, illness, or pollution, are not new to anyone, and their solutions must be created with a sense of inclusivity.

Public Perception and Trust

Lastly, chemistry nanoengineering lives or dies on the footprint of science as well as policy, but also on the trust of people. The very word nano is a matter of wonder, and sometimes it is even a matter of fright, as some people consider science-fiction views of a nanobot taking over or some kind of anarchist pollutant. The wrong message or not being transparent may contribute to making resistance, and this can be seen in resistance to genetically modified organisms (GMOs).

Trust needs to be built by being able to communicate clearly. This requires scientists to interact with society, and they should clarify the consequences of the nanoengineering apart from its advantages, the risks that it involves, and what steps are underway to ensure that these risks are controlled. Ethical responsibility is not just confined to the laboratory table, but also involves protecting the provision of informed dialogue and making the general population feel that they have been part of the decision-making when various technologies are introduced in society.

Responsible Innovation

The human health risks, environmental effects, lack of regulatory oversight, equity, and lack of trust produce challenges to chemical nanoengineering, which are not piercing ones. Actually, they provide a chance to develop this sphere ethically at the very beginning. Ideas such as safe-by-design and the notion of performing safety considerations during all phases of developing materials have already become more popular. Similarly, standard setting at the international level, using open dialogues, can both guarantee that the gains of nanoengineering will be achieved and that its possible evils will be minimal.

The Holocaust has taught people that neglecting potential risks is likely to create a crisis that is avoidable. Under chemical nano engineering, we can do even better: we can be ahead of things, solve consciously, and find a field that is not only innovative but also safe, sustainable, and fair.

Conclusion: From Dream to Discipline

Chemical engineering has long been at the heart of Kenya's industrial and social transformation, driving progress in manufacturing, energy, and food security. For Kenya, embracing chemical nanoengineering means building on these existing strengths while investing in research, skills and infrastructure. This progression reflects not only a scientific shift but also a national opportunity to position Kenya as a leader in sustainable, high-value innovation.

In retrospect, chemical nanoengineering as a field of study has served as a symbol of human ability to bring their vision to life. Initial innovative systems, such as the scanning tunneling microscope (STM) and atomic force microscope (AFM), became real and practical implementations of the vision of Feynman. Chemists have learned how to assemble nanoparticles, nanotubes, and quantum dots; engineers have learned how to add them into the devices, and physicists have learned about the strange quantum physics by which they interact. It is through these employments that an anthology of labor came to be coalesced into a field that would no longer look at nanoscale matter, as it is, but rather design it intentionally so that it could serve the purposes of mankind.

The fruits of this study are everywhere today. Nanoengineered drug delivery systems in medicine have become remarkable in terms of their targeted mode of action, whereby cancerous cells have been hit with great precision, whereas nanosensors give us an early diagnosis of disease. Nanostructured catalysts and electrodes are also finding their way in energy to produce fuel cells, batteries, and solar cells that are more efficient and are the most vital tools in the worldwide change to sustainability. Carbon nanotubes, graphene, and nanocoating are radically redefining strength, argumentability, and functionality, and designing smarter and lighter in the field of materials science. In environmental science, nanomaterials are purifying water, removing poisons, and providing yearning answers to a few of the most pressing environmental issues of the planet.

Nonetheless, his account of chemical nanoengineering is not entirely an account of achievement- it is also an account of responsibility. What has made nanomaterials very useful are also their very properties, which render them predictable and even dangerous. They are very small, thus able to enter biological systems and biological ecosystems where bulk materials cannot. Unless scrutinized, nanoparticles might become dangerous to the environment, health, and safety. The sector is thus faced with a two-pronged challenge of innovating as much as possible, but innovating in a responsible way. It involves the integration of sustainability principles, safety principles, and equity into each of the research and development processes.

This dual mandate is represented in the emerging trends in the field. Nanomaterials that can change with environmental conditions will lead to better utilization in a more specific and efficient way, but additional

research will require stringent trials in order to ascertain safety. The use of green nanoengineering is moving toward eco-friendly synthesis and biodegradable materials, making sure it does not compromise the ecological progress. Nanorobotics is also providing possibilities to nanoscale machines that can perform miracles in medicine or industry, yet there are new ethical concerns of control and abuse. Emerging technologies have made material discovery fast with the development of artificial intelligence, meaning that its opportunities are increasing at a higher rate than previously, and there is also a greater need to govern material discovery responsibility as an entity.

At this junction, it is obvious that even chemical nanoengineering is not merely a field of science but a phenomenon that affects society. It defines industries and policy and poses deep questions about our desired future and what sort of society we intend to make it. And will these technologies become the privilege of the rich, or will they assist in bridging health, energy, and clean water disparities around the globe? Is it the short-run profits that will be served at the cost of long-term social accountability of the environment, or shall we make sustainability central to nanomaterials design? They are not questioning pure science; they need to be answered not only by the researchers but also by the policymakers, ethical managers, and the masses.

The purpose of scientific advancement, after all, is to acquire new knowledge, and specifically, engineering advances the concept of creating tools in order to ameliorate lives. It shows how well working across the greatest number of fields enables the integration of chemical specificity of molecules, engineering problem-solving, physics fundamental knowledge, and modern biological learning into life and education. The nanoscale has not only become a secret lab secret you can unlock anymore, but it is the Swiss cheese of innovation, a Swiss cheese that human innovation is just beginning to open.

To sum up, returning to the challenge that Feynman issued, it does bypass the abounding room that exists at the bottom. This room has provided us with new drugs, cleaner power, smarter stuff, and cleaner water, but it has also given us room to grow responsibly, ethically, and inclusively. Chemical nanoengineering is only writing its story as it is still in its early days, and the future of the discipline will be determined by how we use it today.

Provided that at least the last sixty years have taught us a lesson, this is that imagination, together with

discipline and responsibility, can transform the world. That making small has the greatest impact of all is achieved by chemical nanoengineering not only in science, but in society, the planet, and posterity.

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