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SUSTAINABLE ENGINEERING:
A VITAL APPROACH TO INNOVATIVE PRODUCT DEVELOPMENT AND COMMUNITY CAPACITY BUILDING

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I. PREAMBLE

Engineering has been defined as the application of scientific and mathematical principles for practical purposes such as the design, manufacture, and operation of products and processes, while accounting for constraints invoked by economics, the environment and other sociological factors [Rosen, 2012].

A number of us have travelled to cities like Abuja and some Asian, European, or American cities. We might have possibly seen one or two beautiful or amazing things to talk about on getting back to our towns or villages. Those marvels are the works of Engineers.

Many technical advances are brought about through engineering. Engineering activities are significant contributors to economic development, standards of living and well-being of a society. Engineering activities also have significant impact on our cultural development and environment. Quoting Rosen (2012),

> "Engineering uses resources to drive the world's economic activity, in virtually all economic sectors, e.g., industry, transportation, residential, commercial, agriculture, communication, etc. Also, resources used in engineering, whether fuels, minerals or water, are obtained from the environment, and wastes from engineering processes (production, transport, storage, utilization) are typically released to the environment."

So, our environment serves as a source for resources needed by engineering for improved standards of living. It also serves as a sink for our wastes, i.e. the burial place for our emissions (Figure 1).

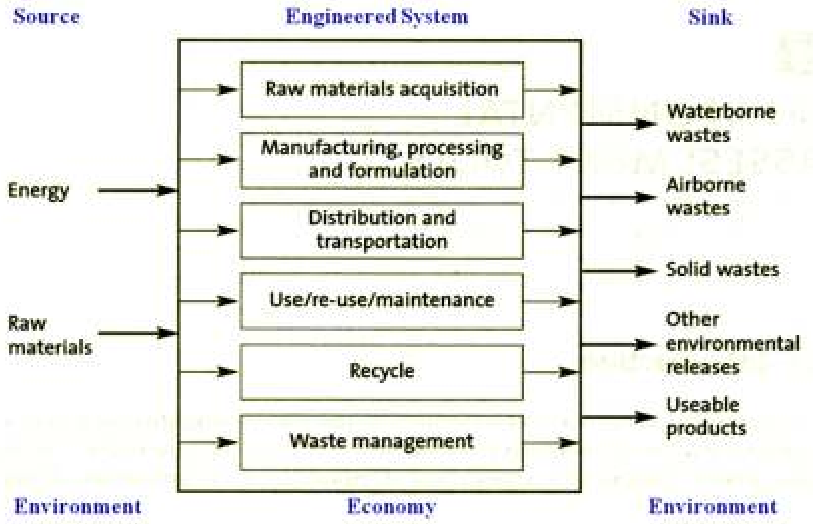

Fig. 1 Engineering and Our Environment
(Source: Adapted by the author)

However, as our population increases, more and more resources are needed from our environment for food, clothing, housing, transportation, and other necessities of life. But there is a limit to the productive capacity of the earth. Many of the resources we draw from the environment to meet the aforementioned needs are not renewable and the rate at which we harvest some of the resources is too fast to regenerate. Similarly, our engineering activities in the process of meeting the aforementioned housing, energy, transportation and other needs release enormous amount of wastes and emissions to the environment. The rate of release has been so high that it has surpassed the earth's absorptive capacity. Consequently, these voracious resource exploitation and enormous waste releases are causing resource depletion, loss of biodiversity, deforestation, desertification, global warming, ozone layer depletion, eutrophication, birth deformities, and various types of diseases (Figure 2). Definitely, something has to be done to arrest the negative trend.

2. DEFINITION AND BIBLICAL PRINCIPLES OF SUSTAINABLE ENGINEERING

2.1 Sustainable Engineering

One of the things that could be done to arrest the negative trend is a change from the current engineering way of doing things to the sustainable engineering approach. What is sustainable engineering? Two main definitions have emerged. Thorn et al (2011) referred to it as "the integration of social, environmental, and economic considerations into product, process, and energy system design methods" while a Florida company called Sustainable Engineering & Design LLC (2016) defined it as "the creative process of utilizing science and technology, making use of energy and resources at a rate which does not compromise the integrity of the natural environment, or the ability of future generations to meet their own needs. While each of the two definitions seemed to have captured most aspects of what is done in sustainable engineering, they appeared incomplete to me because their definitions placed the entire responsibility on the manufacturers.

Figure 2 Products of engineering processes and the consequences
(Source: Prepared by the Author)

Therefore, I would like to redefine sustainable engineering as "an interdisciplinary/multifaceted approach to adaptive integration of supply side and consumer side of an engineered system over its lifecycle stages by utilizing various methods in a technically sound, socio-economically sensible and environmentally friendly manner." A good look at our world, which some call "nature" provides us with the amazing craftsmanship of the Utmost Engineer of the world. It also gives us a clue as to how the Creator wants us humans to manage the created world and the basic principles of sustainable engineering.

2.2 Biblical Principles of Sustainable Engineering

Genesis Chapter 1 gives a vivid account of the Godhead as the Master Designer and the Supreme Manufacturing Engineer. A look at our world right from its natural state shows the indescribable ingenuity of our Maker. Anywhere one goes in the world, whether to a grassland, a forest, or to ice-covered lands, breathtaking mountains or the edge of a fearful canyon, one would see amazing wonders of the Master of the Universe and the Foremost Engineer that can ever be. There are some things we will observe if we do the analysis critically:

1. The work of creation was collaborative God the Father had the leading role throughout the chapter; we also see the activity of the Holy Spirit in verse 2 and we can see the work of the Master Workman (the Word, the Lord Jesus) from verse 3. The collaboration of the Trinity in the work of creation is clearly seen in Genesis 1 verse 26. Collaboration is one of the requirements of a sustainable engineered project. Though everyone has his own responsibility in the project, He is partnering with others for the success of the project. It has to be participatory in nature.

2. The whole system and subsystems are somehow linked together in a cyclic manner. God first created what would be needed by man before creating him. For example, the sun,

water, plants and animals were first created before the creation of man. All those were and continue to be needed for the survival of man. Furthermore, we have the interrelationship between heat, wind, precipitation, vegetation and climate patterns. We have the hydrological cycle, carbon cycle, nitrogen cycle, and many other cycles. While each of them has its own cycle, it affects and is affected by others. The implication is that a sustainable engineered system would have various components, modules, subassemblies and whole assembly system that are working individually and integrated together.

3. Nothing is useless or little is wasted (John 6:12). When we examine the natural ecosystem, we see that little or nothing is wasted and nothing is useless except we are yet to discover the usefulness. One could see an uninterrupted food web in a complete closed loop material cycle, that is, one is dependent on the other or useful for the survival/well-being of the other. They serve as control on one another. Similarly, a sustainable engineering system would need to close the material cycle in which waste is eliminated or minimized. This is illustrated with Figure 3 in which herbivores depend on plants while carnivores need herbivores for survival and when the flesh eater dies it itself becomes/releases nutrients required for plant growth.

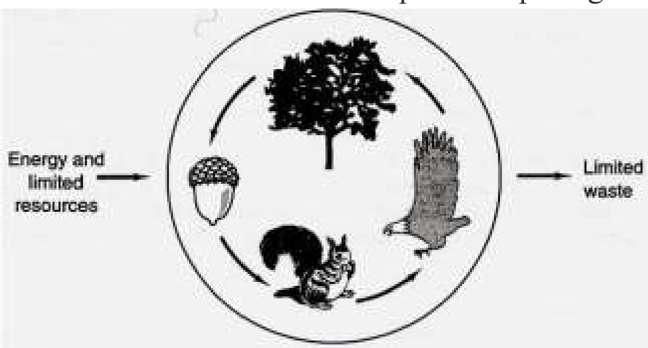

Fig. 3 A Typical Natural System
(Source: Graedel and Allenby, 1998)

These principles of the work of creation served as the historical background from which today's sustainable engineering principles were derived.

The great wonders of the world today are indications of the goodness of God to us human beings, in that God shared a bit of His ingenious DNA with us. Because of His grace we have received grace (John 1:16). At the outset of civilization, the human instinct (put there by God) taught us to comply with the natural system that our Maker had put in place. Unfortunately, as our engineering skills increased, we departed from the sustainable naturally balanced biological system model. This departure significantly upset the earth's system balance. The consequences of that departure are still haunting us today. It is the attempt to return to the old pathway that gave birth to the trending sustainable engineering principles and methods.

Sustainable engineering is adaptive in that it is a "visioneering" concept that gives every stakeholder the opportunity to share ideas and think outside the box in arriving at an appropriate solution to an engineering problem that satisfies the majority's interests in the project. It encourages the consideration of the complete product and process lifecycle during the design effort. The intent is to minimize environmental impacts across the entire lifecycle while simultaneously maximizing the benefits to social and economic stakeholders. This is illustrated in Figure 4.

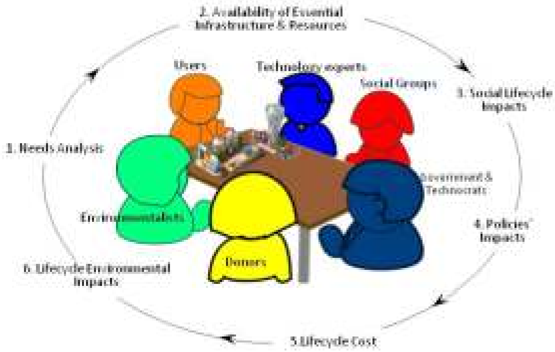

Fig. 4 An Illustration of the collaborative nature of sustainable engineering
(Source: Dunmade, 2015)

2.2 Lifecycle Concept

The lifecycle concept has to do with the consideration of each step from the point of ideation of the system through to the point of (and including) managing the end-of life of the system (Figure 5). The supply side of an engineered system places the responsibility/control on the manufacturer or producer while the demand side of the bargain places the responsibility for the system on the consumers' lifestyle. These are two sides of the same coin that have to be integrated for optimality. Such integration would vary from place to place (geographical factor), from time to time (temporal factor) and from people to people (culture and social standing). Consequently, the system's design has to be like a living organism that can be adapted to changes in time, location and/or situation. Thus, sustainable engineering consists of practices that serve today's needs and those of future generations.

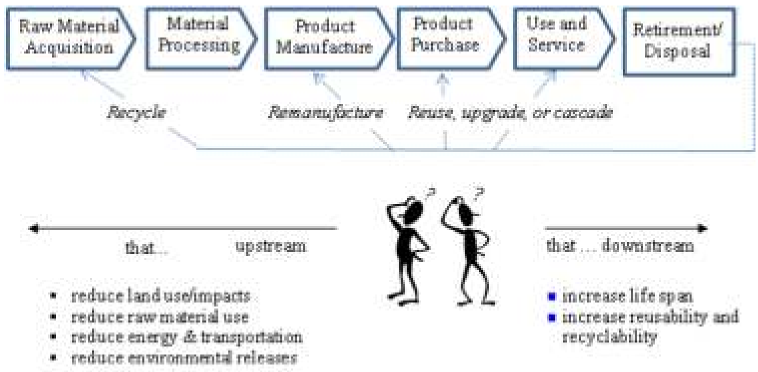

Fig. 5 Lifecycle Thinking
(Source: Dunmade, 2013a)

3. SUSTAINABLE ENGINEERING AND INNOVATION IN PRODUCT DEVELOPMENT

Human wants are unlimited but resources to meet them are limited. Regardless of the level of improvement in our technology, the desire for more comfort would still be craved. This insatiable desire for more, which we equate with standard of living is the driving force behind consumer demand. Such demand would increase and will continue to propel unhealthy resource extraction and enormous wastes generation unless we think smartly and adopt approaches that would enable us to meet those demands without increasing the pressure on our environment.

Being recipients or witnesses to the grave consequences of environmental pollution highlighted earlier on (and illustrated with Figure 2), a number of people have taken "the bull by the horn" by mounting pressure on policy-makers in order to make us (engineers) accountable for our actions or inaction. The pressure mounted by these environmental groups resulted in regulatory control of such environmental contamination which, in turn, necessitated the development of pollution prevention and waste reduction approaches to systems design. In other words, it led to the development of new ways of doing things in order to prevent the unwanted side effects of our efforts that are aimed at making life comfortable for the generality of people. That new way of doing things is an innovation. Because product innovation, according to Webster's dictionary, is "the creation and subsequent introduction of a good or service that is either new, or an improved version of previous goods or services"

So, the need to address environmental issues in product, process and energy development has led to the green design, design for environment, green energy, environmental conscious manufacturing, and many other environmental-labelled engineering strategies. However, green engineering technologies or processes are often inefficient economically and environmentally. There is therefore a need for the comprehensive, systematic lifecycle engineering approach that satisfies economical, social and environmental requirements. Sustainable engineering is that aspect of engineering disciplines that employs numerous methods to improve processes and products in an innovative manner so as to make them more efficient concurrently from the environmental, socio-cultural and economic standpoints. These have been resulting in great innovations and inventions in our days. The innovation trend is expected to increase geometrically in the years to come. Innovations with your own name tag will be part of it if you dare subscribe to sustainable engineering practice in your engineering discipline and keep at it until your breakthrough comes.

4. SUSTAINABLE ENGINEERING AND COMMUNITY CAPACITY BUILDING

Community capacity building was described in Sustaining Community (2014) as "the continuous process required to foster the pride and appropriate local leadership that allows communities, through their members, to take responsibility for their own development." It was also defined in Wikipedia as the "process of developing and strengthening the skills, instincts, abilities, processes and resources that organizations and communities need to survive, adapt, and thrive in the fast-changing world." According to Sustaining Community (2014), "community capacity building focuses on:

- Building the skills and confidence of individuals and groups
- Enhancing community decision making and problem solving processes
- Creating a common vision for the future
- Implementing practical strategies for creating change
- Promoting inclusion and social justice"

Sustainable engineering facilitates the achievement of these goals by involving all stakeholders throughout the lifecycle of the project. The participatory nature of sustainable engineering stemmed from the fact that addressing various engineering problems in a sustainable manner requires looking at issues from various angles. Stakeholders consisting of professionals from various disciplines, community groups, policy makers, donors as well as the consumers of the product have to be involved in the evolution of a solution or solutions to the problem. An illustration of how it works is shown in Figure 11 below. Detailed explanation is also given in the "Evolution of Suitable Solution from Collaborative Sustainable Engineering Process" section. The summary is that individuals and groups acquire new skills and develop their abilities in the process of their interaction with others and as they implement specific assignments given to them.

Propagation of sustainable engineering principles would also require formal training of engineers and other professionals regarding how to incorporate such principles along with the various tools of their profession in addressing a given problem.

5. SUSTAINABLE ENGINEERING AND OUR CORE VALUES

One of the questions that may come to someone's mind is whether sustainable engineering aligns with our Core Values or not. It is gratifying to say that Sustainable Engineering perfectly aligns with a number of our Core Values.

a. **Our Spirituality Core Value** hinges on the fear of God. And the fear of God is to depart from evil. It is evil to disobey the mandate given by God. It is immoral to be selfish by meeting our own current needs and denying the future generations the opportunity to meet their own needs. It is unjust to rob them of the opportunity to enjoy the same standard of living as we do because of our action or inaction. Therefore, in aligning with our Spirituality Core Value, we have to fulfill the mandate of our Maker, the Creator of the universe that directed us in Genesis 1 to take care of our world. The effective way of taking good care of our world is by sustainable application of engineering principles in systems development and utilization. And according to Rosen (2012), "such systems include processes and technologies for harvesting resources, converting them to useful forms, transportation and storage, and the utilization of engineering products and processes to provide useful services such as operating computers, providing healthcare or sheltering people. Thus, engineering sustainability goes beyond the search for sustainable resources, and implies sustainable engineering systems, i.e., systems that use sustainable resources, and that process, store, transport and utilize those resources sustainably."[Rosen, 2012]

b. Possibility Mentality

Sustainable engineering provides a platform for the transformation of a man's mentality through the participatory approach promoted by the concept. I am perfectly in agreement with this Core Value. It is "the mental picture of a man that defines his actual future." In my little interaction with people here in our country, I observe that a lot of mental reorientation work needs to be done. It is our inferiority mentality that makes us want to depend on outsiders to help us develop. It is the same mentality that makes us esteem and prefer other coloured people as being better even though they are actually not. It is that same mentality that makes us believe whatever they tell us is the correct/best one even when one of our own with better knowledge and expertise gives a "sounder" recommendation that is contrary. It is this grasshopper mentality that prevented majority of the Israelites from reaching the promised land. It is only the two people that had the "I can do all things through Christ that strengthens me" mentality that entered the land. It is that inferiority mentality that has kept our nation and many other developing countries at the level of technological development that we are today. Let us examine various countries of the world, how many countries have achieved technological development on the platform of other countries' help? How much waste have resulted from our quest for development help from outside our shores since the past 50 years? An adage says that it is a fool that keeps doing the same thing and expects a change. Our attainment of technological development can only be realized largely on our self-help and faith in God. We can do all things through Christ that strengthens us. Adaptive sustainable engineering can help us to get there.

Borrowing from our University Core Values, I believe that as a nation we need to “begin to develop a royal attitude, cultivate royal habits and form the royal character so as to” move forward with good speed to achieve the much-desired sustainable development.

c. Capacity Building

I have explained earlier on how sustainable engineering can help us to build capacity in engineering and sustainable development. I also mentioned how we can build professional capability in engineering sustainability. Sustainable engineering being participatory and collaborative in nature would facilitate shared knowledge among participants in a project.

6. SUSTAINABLE ENGINEERING PATHWAYS

A number of strategies have been developed in the field of design for sustainability to address the issue of resource consumption and waste generation by manufacturers and consumers [Kuijer and de Jong, 2009]. These strategies focus on Design/Planning, Manufacturing/Production, Transportation, Utilization and End-of-Life Management. They include paradigms that are targeted at reducing resource use, achieving near-zero waste, minimizing effluent and emission, and creating self-supporting infrastructures.

The Sustainable Engineering approach to solving engineering problems can be divided into four pathways (illustrated in Table 1), namely: Design, Process, Management and Assessment pathways. Each of the pathways is either targeted at all the lifecycle stages or one of the lifecycle stages. In addition, there are a number of approaches/paradigms that have been developed to address specific issues or aspects of the system's lifecycle within each of the pathways. Here are short descriptions of some of the approaches and paradigms under each pathway.

6.1 Design pathway

This seems to be the most important pathway in sustainable engineering. It has received the greatest attention by scholars/researchers because of the understanding that more than seventy percent of a system's lifecycle's characteristics and operational behaviour are determined at the design stage. Another reason is that every engineering discipline is engaged in one form of design or another, employing numerous principles and mechanisms. Historically, the recent innovative design trend started with a focus on the environment. According to Dunmade (2005),

> Designing products with minimum impact on the environment became increasingly important because of the upsurge in environmental consciousness. Other reasons include increasing competition for resources, high energy cost, decreasing easily exploitable material resource pool, and high ecological rucksack associated with resource exploitation. All these have environmental and socio-cultural consequences. The success of the agricultural sector depends on the ecosystem welfare. It is therefore reasonable for the agricultural machinery designer to incorporate principles that promote resource conservation, pollution prevention and environmental wellness in their designs. Doing this is not only good for the environment but also makes good techno-economic sense.

This environmental focused design is also known as Green Design (especially in Australia), Ecodesign (in Europe), Environmental Conscious Design or Environmental Friendly Design (in USA), Design for Environment (in Canada), and Lifecycle Design in various places. When social and economic factors are simultaneously considered, it is called Sustainable Design [Dunmade, 2005; Dunmade and Rosentrater, 2006, and Dunmade, 2010].

Design for Environment is defined as "systematic consideration of design performance with respect to environmental, health, and safety objectives over the full product and process life-cycle" [Fiksel, 1996]. It is also defined as the process of incorporating various values (such as manufacturability, serviceability, recyclability, etc.) of a product in the early stages of design [Sun et al, 2003]. This implies that at the product and process conception stage, the designer considers the potential impacts of materials selected and manufacturing methods to be used in developing the product on the environment. He/she also considers their potential impacts on the health and safety of the product users, factory workers as well as on the populace. The environmental, health and safety (EHS) effects of using the product is also considered at this stage. Furthermore, the EHS impact of the product's end-of-life management options is also evaluated when designing for the environment. The reason for taking these steps at the design stage is that most of the environmental performances of a product are determined at the design stage and because the end-of-life management of a product depends to a large extent on whether the product can be disassembled or not.

Moreover, the objective of taking the aforementioned steps is to arrive at a choice of the best mix of options that will lead to the manufacture of a product that is technically sound, environmentally friendly, economically sensible and socio-culturally acceptable. Attainment of these objectives necessitated the development and utilization of a number of complementary design paradigms (DfX) such as design for modularity; design for assembly/disassembly; design for manufacturing/ remanufacturing; design for use/reuse; design for recycling; design for energy efficiency, design for multi-purpose use,

Table 1 Sustainable Engineering Pathways

Pathways	Lifecycle stage(s)	Approaches/Paradigms
Design	All	Design for Modularity Design for Materials Design for Assembly Design for Disassembly Design for Manufacturing Design for Remanufacturing Design for Use Design for Reuse Design for Maintenance/Service Design for Safety Design for Simplicity Design to Cost Design for Packaging Design for Recycling Design for Minimum Residue Design for Multilifecycle Design for Sustainable Behaviour
Process(es)	Manufacturing	Cleaner Production Green Manufacturing Sustainable Manufacturing
Management	End-of-Life/ Retirement	Disassembly Reuse Eco-Industrial Development Refurbishing Remanufacturing Reverse Logistics Recycling Pyrolysis Product Stwardship Hydrolysis Lifecycle Extension Certifications e.g. Ecolabel
Assessment	All	LCA sLCA LCC LCSA RA CBA MFA Enabling Resources and Infrastructural Analysis

and other DfXs (Figure 6).

6.1.1 Design for Assembly (DFA) is a process for improving product design for easy and low-cost assembly by focusing on functionality and assemblablity concurrently. This is achieved by simplifying the product configuration and minimizing part count. DFA involves analyzing both the part design and the whole product for any assembly problems early in the design process. In addition to reducing the cost of assembly, design for assembly also improves the product quality and reliability [Chan and Salustri, 2012; Dewhurst, 2005 and Boothroyd and Alting, 1992].

6.1.2 Design for Disassembly (DFD) is closely related to DFA. However a product designed for assembly may not be easily disassembled. DFD considers the ease with which a product can be economically taken apart at the end of the service life or for maintenance. It enables the product and its parts to be easily reused, re-manufactured or recycled at end of life. DFD is one of the three core design paradigms on which majority of other design concepts depend. The disassemblability of a system affects the maintenance cost as repair technician charge is dependent on the number of minutes or hours used in repairing the system. A consumer would rather buy a brand new product rather than pay the same amount to repair the faulty system. Some of the design for disassembly guidelines are:

- Minimize part count ;
- Utilize "push and pull" mating parts except it is not functionally possible to do so;
- Use fasteners that does not require the use of tools or setup wherever possible;
- Design joints that makes mis-matching parts almost impossible; and
- Employ fasteners that facilitate component reuse or material

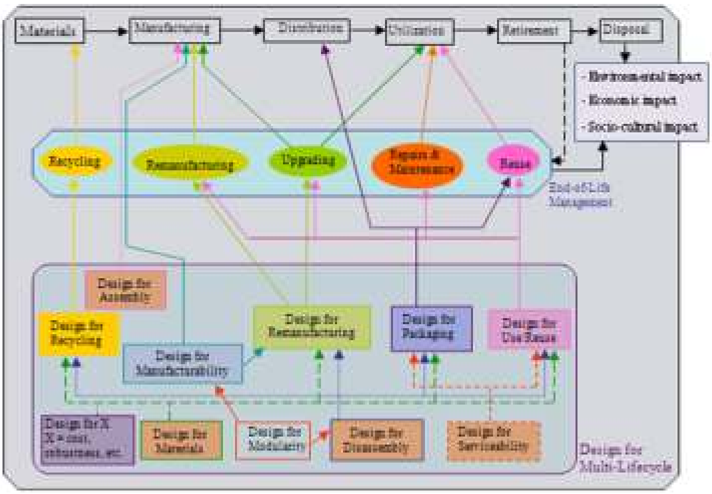

Fig 6 Various Design Paradigms, their interrelationships and stage of lifecycle focused
(Source: Prepared by the Author)

Figure 7 below shows a tea kettle as an example of a product designed for disassembly.

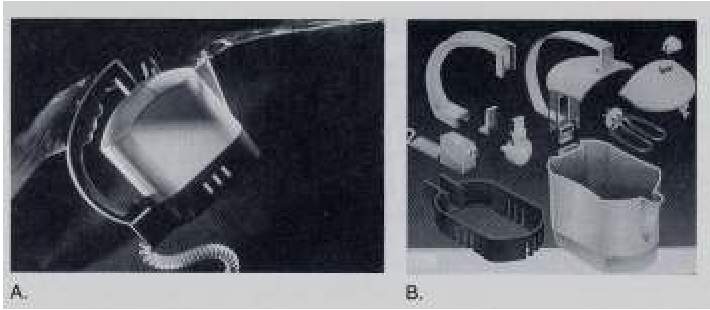

Figure 7 A tea kettle designed for disassembly
(Source: Lecture Notes by the Author)

recycling at the end of life.

6.1.3 Design for material

This involves evaluating the suitability of a set of candidate materials for a given engineering system development and selecting the "best" option at the design stage. Some of the evaluation criteria are availability, toxicity, durability, recyclability, and biodegradability. According to Dunmade (2013a), design for material guidelines says:

- utilize renewable materials except it is not possible;
- use minimum possible amount of material;
- utilize locally available materials except it is not possible;
- incorporate highest possible recycled content;
- use recyclable materials;
- employ lowest possible varieties of materials;
- use of homogenous materials rather than composite materials;
- utilize biodegradable materials wherever possible;
- choose non-hazardous materials; and
- consider using materials that require least amount of energy to process.

6.1.4 Design for Modularity

This is a design principle in which an attempt is made to ensure that each function that a product performs is made independent of all other functions that the product performs [Gershenson et al, 1999 and Ishii, 2012]. It is a means to incorporate life cycle considerations into product architecture design [Chung et al, 2011; He and Kusiak, 1997; Huang and Kusiak, 1998; Kusiak, 2002; Baldwin and Clark, 2006]. To achieve this goal, there would have to be similarity in the physical and functional architecture of product subassemblies' design. Consideration would also have to be given to the coupling of subassemblies in a way that the effectiveness of the whole product system will not be hampered. This design principle would make it easy to locate the faulty parts of a product, and thereby eliminate unnecessary disassembly of unessential parts. That would result in shorter labour time and consequent reduction in the cost of recycling the product. It would also make it possible to upgrade the product by simply replacing outdated modules with new technology-based modules instead of having to buy a whole new product [Kusiak, 2002]. This anticipation of the future need to upgrade functional units is very essential for a product that will be used for multi-lifecycle. Incorporation of this design principle will facilitate product disassembly, component reuse and remanufacturing, and material recycling. Outcomes of such design features and the facilitated operations are reduction in resource exploitation and waste generation, as well as lower cost of ownership when compared with production and utilization of replacement products. Consequently, products designed for multi-lifecycle would be more environmentally and economically sustainable compared to single lifecycle products.

6.1.5 Design for Simplicity

Simplicity as a design consideration is very essential if the system would have to be used, repaired and maintained by the rural populace where the level of conventional education is low. The simplicity would need to be in terms of product configuration as well as in relation to the language of instruction for assembling component parts. Simplicity of product configuration would make it easy to train intending users and local technicians on the use of the product and on the repair and maintenance of the product respectively. This design principle is enshrined in the concept of design for serviceability. A number of scholars such as Smith and Duffy, Watson, and Karvonen have articulated the need for simplicity of design [Smith and Duffy, 2001; Karvonen, 2000 and Watson,1990]. Easy use facilitated by design for simplicity will make the product more socially sustainable than its more complicated peers. Long-time use of the same product encouraged by its simplicity would reduce the number of demands for new products. That would lead to resource conservation, reduction in waste, and reduction in expenses on consumer products or on machinery. That would consequently make such products that are designed for multi-lifecycle to be environmentally, economically and socially more sustainable than similar products that are not designed for multi-lifecycle.

6.1.6 Design for Remanufacturing

Remanufacturing is a process of restoring an old product to “like-new” conditions. Design for remanufacturing therefore is the incorporation of features that would facilitate easy remanufacturing of a product at the end of its life into the product's design. For example, a product that would be remanufactured must have a durable core. Design for remanufacturing is a combination of some other design paradigms, namely, design for simplicity, design for durability, design for cleaning, design for disassembly and others. Some of the design for remanufacturing guidelines are:

- manufacture without producing hazardous waste ;
- use cleaner technologies;
- reduce product chemical emissions;
- simplification of product geometry; and
- design and utilize processes that generate durable core and sturdy frame.

6.1.7 Design for Multilifecycle

This is an integrated design approach that maximizes the utility of resources used in developing a technology by incorporating, at the design stage, features that enable the elongation of the techno-economic service life of that technology [Dunmade, 2013a]. The incorporated product features are to enable a product go beyond single lifecycle. This design concept includes design for assembly, design for disassembly, design for simplicity, design for modularity, design to cost, design for materials and design for use and reuse [Boothroyd and Alting, 1992;Brennan et al, 1996; Desai and Mital, 2003; Harjula et al, 1996; Kroll et al, 1996; Sodhi and Knight,1998].

The goal of design for multi-lifecycle is 'indefinite' use of the resources invested/ embodied in a product without compromising its economic value, technological soundness and socio-cultural acceptability. Theoretically, one should be able to use and re-use a product or system designed for multi-lifecycle indefinitely. However, the system may become socially, ecologically or economically obsolete even if it is technically functional. One example that could be used to buttress this point is that of asking someone to be using floppy disk or Pentium II computer at the present stage of computer and information development.

6.2 Process Pathway

Process pathway is aimed at the choice of production processes that:

- do not pollute the environment;
- do not negatively affect the health of workers, those in the surrounding area of manufacturing and people that are far away; and
- use less material, energy and water resources.

Processes that satisfy these conditions are classified as cleaner production processes. Sustainable manufacturing refers to processes that satisfy these conditions and certain socio-economic considerations. It should be noted that production processes are usually specified at the design stage.

6.3 Management pathway

The focus of this strategy is usually the End-of-Life stage of the system's lifecycle. It seeks to close the material loop of the system in a way that minimizes waste. Among the paradigms under this category is Eco-Industrial Development (EID). EID is a concept that seeks to close the material loop through synergetic collaboration of organizations where the waste/residue from an organization serves as input for another organization in the group. EID is divided into three sub-categories, namely: Eco-Industrial Park, Eco-Industrial Network, and Converted Industrial Park or Converted Brownfield. The Eco-Industrial Park (EIP) consists of companies that are co-located on a piece of land and share some resources like in conventional Industrial Estates. In addition, the waste from one serves as input for the other. Development of an Eco-Industrial Park involves relatively large investment and good management skills. Eco-Industrial Network (EIN) is similar to EIP except that the companies involved may not be in the same location. EIN is the easiest of the three sub-categories to form and manage. It is usually a loose association of companies that agrees to take each other's waste as input to their production process. The third sub-category is either an Industrial Park or a Brownfield that is converted to an Eco-Industrial Park. It is the most complicated because some remediation may be required. As remediation is expensive and takes time, it may significantly add to the cost of renovation and conversion of some facilities that can accommodate a network of companies that would be using the Infrastructure. Figure 8 is an illustration of an EIP while Figure 9 is an illustration of EIN. The other paradigms under management pathway are Product life extension consisting of processes like remanufacturing, repair, cascading, refurbishing, and others [Dunmade, 2001 and 2002;

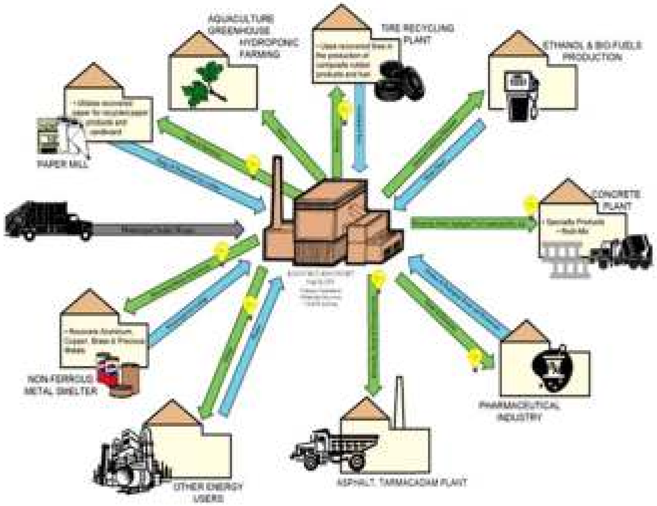

Fig. 8 An Illustration of Eco-Industrial Park (EIP)
(Source: Lecture Notes by the Author)

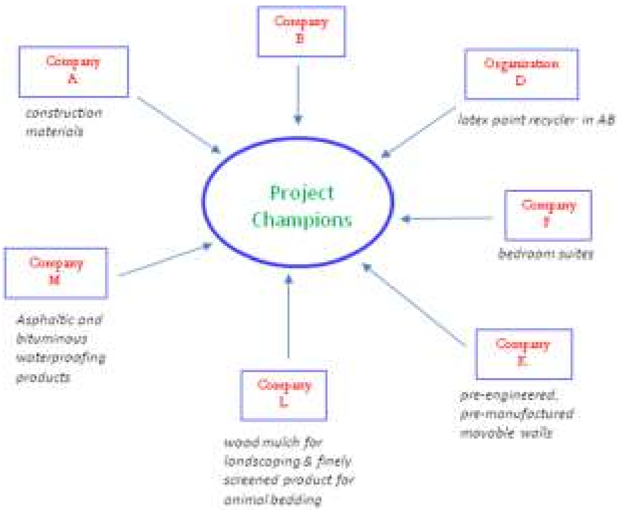

Fig. 9 An Illustration of Eco-Industrial Network (EIN)
(Source: Lecture Notes by the Author)

Dunmade and Rosentrater, 2006]

6.4 Assessment pathway

6.4.1 Lifecycle Assessment (LCA) is a comprehensive and proven analytical tool for evaluating potential environmental burdens resulting from resource consumption and emissions by a product or process. It also enables us to assess product/process environmental impacts and to evaluate improvement opportunities that could be implemented to address areas of concern. The method consists of four iterative steps (Figure 10): goal and scope definition, inventory

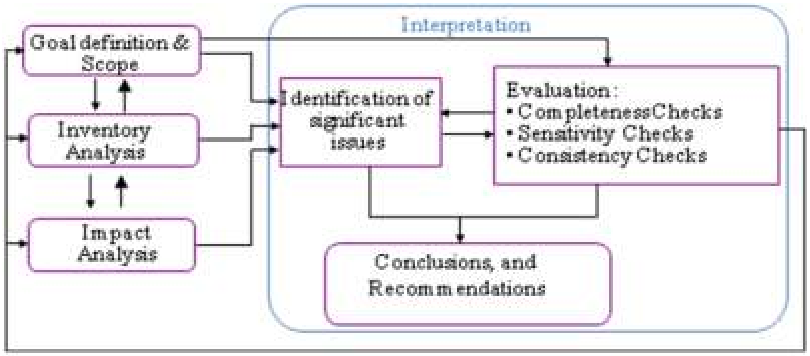

Fig. 10 Lifecycle Assessment Process Steps
(Source: Dunmade, 2012)

analysis, impact assessment, and interpretation.

6.4.2 Lifecycle Costing (LCC) is similar to the environmental lifecycle assessment except that it is used to analyze the technology cost at each stage of its lifecycle. This helps us to account for the true and total cost of the technology.

6.4.3 Social Lifecycle Assessment (sLCA) is also a lifecycle analysis approach. It is used to determine the socio-cultural impacts of the technology at each stage of its lifecycle. Here we account for how it will affect the way of life of people that develop, use and live/work in the neighbourhood where the technology is deployed.

6.4.4 Risk Assessment (RA): This is the determination of the potential impact of an individual risk associated with each stage of the lifecycle (especially the development and utilization) of the technology by measuring or otherwise assessing both the likelihood that it will occur and the impact if it occurs (a definition by Wikipedia).

6.4.5 Cost Benefit Analysis (CBA). This is an analysis that compares present values of all benefits derivable from the technology, less all costs, related to the technology when benefits can be valued in dollars the same way as costs. This is performed in order to select the (technology) alternative that maximizes the benefits of a technology or programme.

6.5 Evolution of Suitable Solution from Collaborative Sustainable Engineering Process

Figure 11 is an illustration on the sustainable engineering decision process for arriving at a solution for an engineering problem. It begins with the assembly of stakeholders and providing process guidelines that would be followed. It is then followed by needs assessment. The next step is articulation of the performance/assessment criteria before the decision to buy or to develop is taken. If the decision is to buy, then there is going to be a search for locally available options before any consideration for foreign-made ones. Let's assume the decision is to develop a system. Relevant members of the group are assigned the responsibility of coming up with conceptual designs which would later be assessed by the group in relation to how well sustainable engineering paradigms are utilized. The best option that satisfies the paradigms is then subjected to lifecycle evaluation. If the required minimum condition is satisfied, the option is taken further through detailed design, and prototype development before a final modification is made prior to on-the-field deployment. The process is repeated at any stage where any of the set requirements is not satisfied.

Continuous monitoring and collection of feedbacks from the system would be put in place to facilitate future improvements on the system's performance. The monitoring process would start from the point of installation through utilization, adaptation, maintenance and decommissioning/end-of-life management. If the evaluation results are not satisfactory at any point during the developmental stage, the previous step(s) taken would have to be re-examined to determine what needs to be done to improve the performance and to make the technology appropriate for the location in question. The lessons learned from each step taken in this technology development process can be used to modify the original or version of the design. Such lessons learned would also be useful in updating relevant policies [Dunmade, 2010].

7. SUSTAINABLE ENGINEERING OPPORTUNITIES IN NIGERIA

The concept of sustainable engineering is still new and unfamiliar to many engineers, researchers, managers, and policymakers. Sustainable engineering principles can be applied to virtually all engineering projects. Its application is particularly recommended for the development and management of our infrastructure. Doing so would result in the development of appropriate and long-lasting infrastructure. It will also help the community to take ownership of the facility in their domain because they are involved in the process. On the long run, when many practitioners and policy makers imbibe the doctrine of sustainable engineering, there would be drastic reduction in our infrastructure project cost and project abandonment. It would also result in preservation of our all-important ecosystems from destruction [Dunmade, 2001, 2002 and 2010].

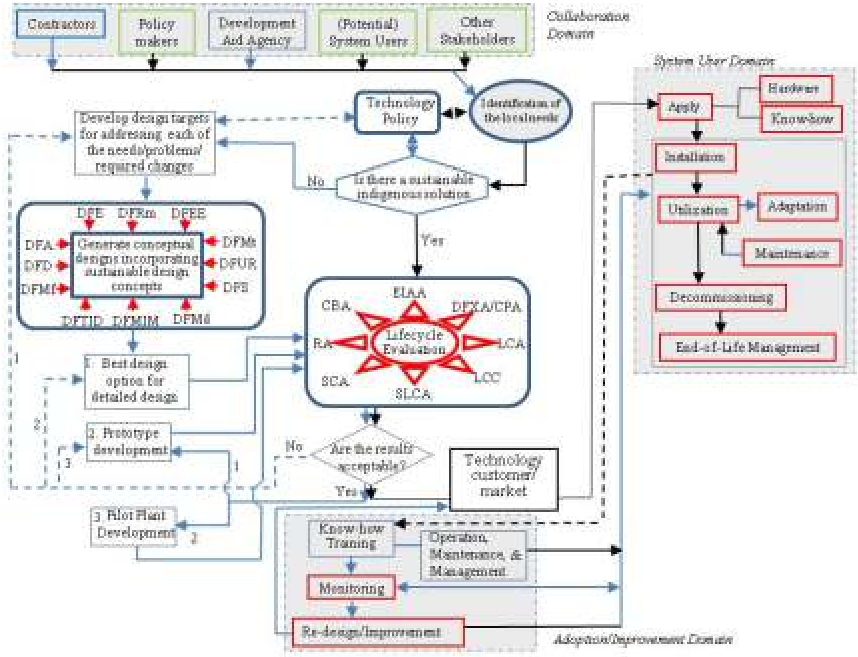

Fig 11. Sustainable Engineered System Development and Management Decision Model (Source: Dunmade, 2010)

There are many areas of research that are yet to be explored in sustainable engineering. The following are some of the identified areas where more efforts are needed with regard to sustainable engineering propagation and on the role of sustainable engineering in our economic activities, some of which are also listed on Wikipedia:

- Creation of more awareness about sustainable engineering
- Adaptation of existing engineering principles and development of new sustainable engineering techniques to suit our local situation
- Evaluation of sustainability profile of current and emerging sustainable engineering technologies
- Development of sustainable engineering policies and their

incorporation into engineering practices

- Implementation of infrastructural projects on the basis of sustainable engineering technologies in various sectors of our economy, and
- Development of metrics for assessing progressive changes in sustainable engineering practices and the consequences on the three pillars of sustainability

Engaging in these areas of research will lead to a better understanding of sustainable engineering. It will also result in the technological advancement of our great country in a sustainable manner.

7.1 Sustainable Engineering Opportunities and Covenant University

Covenant University, being a proactive University, can play a pioneering role in sustainable engineering in Nigeria by supporting researches in some of the earlier mentioned research areas. It can also provide leadership through educating the practising engineers through certificate courses in relevant areas. Furthermore, it can develop and run research degree programmes while working with the National University Commission on Bachelor degree programmes in Sustainable Engineering and related areas. In this way, Covenant University would be among the few universities all over the world that are promoting engineering sustainability and thereby helping to achieve the global sustainable development goals.

8 CLOSING THOUGHTS

Friends, it is important to approach development in a sustainable manner because doing otherwise puts our nation at great risk. I have seen and also heard about enormous waste resulting from foreign technology imported into our country. While I am not saying imported technology should be totally banned, I believe that our future lies in our own hands. It should be noted that approaching development in a sustainable manner requires patience, as there are some learning curves that may take some time. Since effective sustainable engineering require working in collaboration with various stakeholders, a number of requirements would need to be satisfied for successful partnership. These requirements include: 1) operational guidelines that stipulate the partnership governing structure and project implementation procedure; 2) transparency; 3) trust; 4) a sense of common destiny; 5) effective management of involvement cost and time demand; 6) sharing of responsibilities; 7) establishment of a framework for identifying priorities and for reaching agreement on action to be taken; and 8) supportive government policies and incentives that encourage adoption of sustainable engineering principles [Dunmade, 2013a, 2013b and 2014]

8.1 Recommendations

My recommendations are centred on capacity building from the grassroots up because the strength of a chain is determined by the strength of its weakest link. Similarly, it is the foundation of a house that determines how many stories can be built on it. I would like to support Compston's (2010) idea regarding how the capacity of engineers can be built in sustainable engineering. According to him, engineers from any discipline can effectively integrate the concept of sustainability into solutions for complex engineering problems by taking a number of steps, namely:

1. Mapping whole system optimization and innovation tracking onto the traditional systems engineering approach. The best way to achieve this is by integrating elements that provide a pathway for sustainability thinking into engineering design, particularly at the all-important conceptual and preliminary design stages. Details on the “how to” had been discussed under sustainable engineering pathways.

2. Incorporating sustainability education into engineering design courses in the undergraduate Engineering programmes. According to Compston (2010), "exposing students in a very technical, multidisciplinary engineering programme to sustainability thinking would have a number of effects. It would make students realize that sustainability principles should be at the core of their future engineering practice. This realization would also motivate them to always consider sustainability." This may be in the form of college-wide course or courses that involve teaching basic pillars of sustainable engineering. The three of them are: Design for Disassembly, Design for Modularity, and Design for Materials. Some details had been discussed under sustainable engineering pathways.

3. Another way to build engineering sustainability capacity is by setting the direction for all stakeholders in the engineering profession; educators, students, practitioners and policy-makers, for years to come. Such direction may have to be varied from one economic sector to another and/or from one people/ culture to another. It may also require seasonal adaptation. However, the template should essentially be the same.

I believe that if we take these steps, our nation will achieve the much desired technological development that is sustainable in long run. There will also be an overall improvement in our people's standard of living. We will live happy and we will live in technologically safe communities without denying the coming generations of their capability to enjoy the same level of affluence.

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