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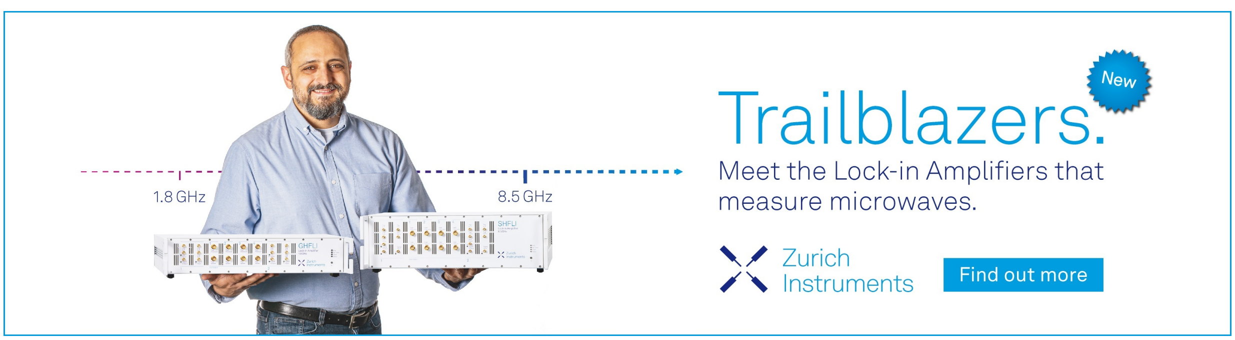
I. S. Dunmade and M. O. Daramola



A Synopsis on Designing for Multi-Lifecycle in Chemical Engineering and the Potential Impacts on the Attainment of Circular Economy in Africa

I.S. Dunmade[1,a)] and M.O. Daramola[2,]

[1]*Earth and Environmental Science Department, Mount Royal University, Calgary, Canada*
[2]*Department of Chemical Engineering, Faculty of Engineering, Built Environment and Information Technology, University of Pretoria, Hatfield, Pretoria 0028, South Africa*

[a)]Corresponding author: idunmade@mtroyal.ca, +14036817224

Abstract. Previous studies have shown that over seventy percent of product and process characteristics are determined at the design stage. Systems design goes a long way in determining not only the ecological footprint of a product but also that of the process that produces it. Over the last five decades, scholars and professionals have intensified effort at developing sustainable design approaches to minimizing resource use intensity of our industrial processes and products. Similar efforts were also targeted at waste minimization at various stages of the product life cycle. This study investigated the potential impacts that application of design for multi-lifecycle concepts in the chemical engineering field can have in the attainment of circular economy goals in Africa. This study involved a comprehensive review of various issues surrounding circular economy models and implementation, sustainable design concepts, and African socio-cultural characteristics. The study then zeroed in on design for multi-lifecycle concept, its applications, requirements, strengths and weaknesses. Taking cognizance of African sociocultural context, an investigation was then made into how and where design for multi-lifecycle (DfML) concept can be applied in key areas of chemical engineering field, and how application of DfML can foster or impair the attainment of circular economy goals in Africa. Preliminary results pointed to potentially huge success of DFML application in achieving sustainable circular economy in Africa under collaborative effort from governments, supply chain role players, and consumers. Unwavering public education and modern engineering training would also be essential before DFML would be able to deliver the desired circular economy dividend.

Keywords: Chemical engineering; Circular economy; Design for sustainability; Sustainable design

INTRODUCTION

Chemical engineering, according to Hanson [1], is defined as an applied chemistry involving the development of processes and the design and operation of plants in which materials undergo changes in their physical or chemical state. Hanson [1] further explained that chemical engineering is concerned with the design, construction, and operation of machines and plants that perform chemical reactions to solve practical problems or make useful products. Chemical engineering may also involve developing processes that contribute to improvement of our environment and human standards of living [2]. Although the creation of chemical engineering products or processes starts in the lab, it progresses through the design and implementation of a full-scale process, testing, maintenance, and improvement. A chemical engineering output may be a new process, instrument, facility or other products/devices such as polymers, paper, dyes, drugs, plastics, fertilizers, foods, or petrochemicals. According to Hanson [1], chemical engineering may involve optimizing the arrangement of “materials, facilities, and energy to yield as productive and economical an operation as possible”.

From the foregoing, one could easily see that chemical engineering contributes to various aspects of our lives

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ranging from food, clothes, footwears, shelter, and energy to healthcare. However, unintended by products of chemical engineering have caused significant damages to human lives and the ecosystems. In the last few years, efforts are directed at eliminating or minimizing the negative ecological footprints of chemical engineering activities by closing the material cycles and creating value added commodities from wastes created by chemical engineering processes. These efforts are component parts of the circular economy concepts.

Circular economy is a resource use optimization concept consisting of activities that facilitate the use of materials and other resources for as long as it is rationally feasible. According to Dunmade and Rosentrater [3], facilitates conservation of material, energy and other resources by reducing, reusing and recycling them in various ways. However, maximum results from these activities can only be achieved if planned and incorporated into the design of the products and processes. This necessity was recognized by Whicher et al [4] who advocated development of design-driven circular economy action plans among European Union member States.

METHODOLOGY

The study is based on intensive literature survey and more than 20 years' experience in the sustainable design and analysis of systems. A survey of current trends in chemical engineering systems and associated wastes was implemented. An examination was then conducted on the areas of possible incorporation of design for multi-lifecycle concepts in a typical chemical engineering system. This was followed by an analysis of potential impacts of designing a chemical engineering system for multi-lifecycle on the attainment of circular economy.

RESULTS AND DISCUSSION

The following are the outcomes of our research:

Key Areas of Chemical Engineering

Chemical engineering covers several areas of our lives and economic activities (Fig. 1). Main areas include fluid separations, energy, food and drink manufacturing, and mining and minerals processing. Some other areas of chemical engineering are nuclear technology, oil and gas, particle technology, pharmaceutical, biotechnology, and water. All these areas involve design, development, operation and control of chemical processes as well as equipment used in implementing the processes involved. All the equipment utilized for the implementation of these processes can benefit from the concept of design for multi-lifecycle (DfML).

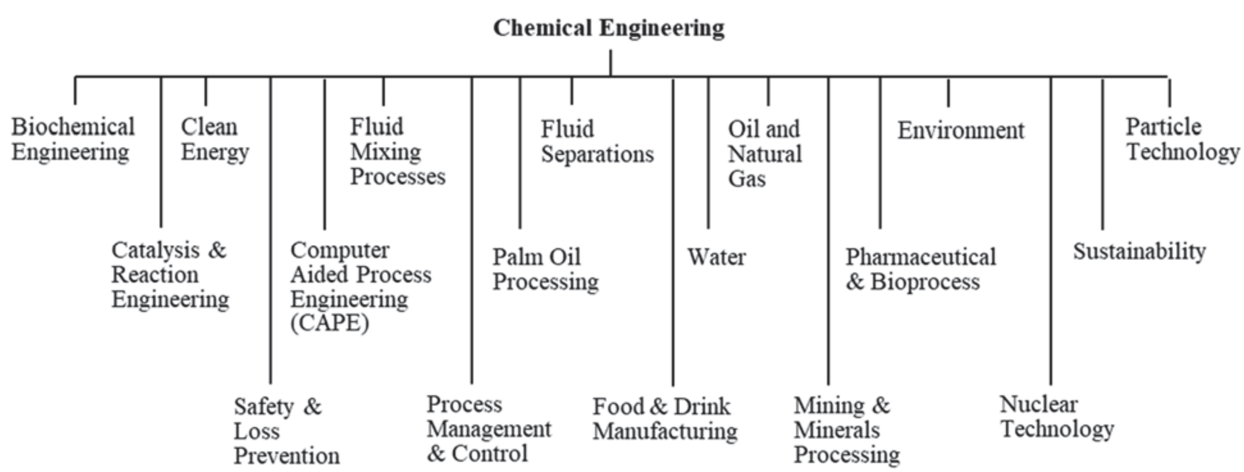

FIGURE 1. Major areas of Chemical Engineering

Circular Economy Models

Circular economy (CE) can be implemented in various ways. The focus of a CE project could be on an aspect of a product/process, the entire product lifecycle or a waste stream resulting from a number of products/processes. For example, the focus could be to optimize water use in a water intensive process by recycling through finding maximum use for greywater, avoiding wasteful use, or prioritizing what water is being used for at different times of the year. It could also focus on eliminating certain material from the waste stream through recycling of such material. Metals such as copper, silver and aluminum are few examples of materials that have benefited from CE projects that focused on closing the material cycle [5].

On the other hand, the implementation of a CE could be at micro level, meso level or macro level. The micro level implementation would necessarily involve a company or a group of companies attempting to optimize their use of resources in a synergistic manner. The meso level implementation of CE would be an implementation of CE at municipal level involving a look at varieties of waste streams with the aim of closing the resource cycle to reduce waste and minimize their overall ecological footprint. The consideration could be a selection of some products, materials or processes. CE implementation at the macro level would usually be a project involving a number of municipalities, region or country-wide.

Similarly implementation of CE could be sectorial in nature. For example it could be an agricultural/biobased circular economy alternatively called bioeconomy or bio-circular economy. It could also be focused on a manufacturing sector or a mining sector. Furthermore, it could be a combination of the aforementioned concepts. The possible CE pathways are limitless, it only requires availability of enabling conditions [6], [7].

Factors Affecting Circular Economy Implementation in Africa

Successful implementation of circular economy projects anywhere requires prevalence of certain conditions. The necessary conditions would vary from one jurisdiction to another depending on the focus of the CE project and on the scale of its implementation. Factors for successful implementation of CE in Africa can be divided into four categories, namely: technical, institutional, economic and sociocultural factors [4], [8].

The technical factors include availability of infrastructure that are necessary for the development and smooth operation of the CE system. This includes accessibility of reliable and affordable supply of energy, water and transportation systems required for gathering and taking back unwanted products/materials and for processing them to value-added commodities. Availability of requisite technical know-how at the location will also be necessary for the development of a sustainable CE system and for its smooth running. The skills can be acquired through proper training of the charge hands and provision of suitable conditions for their effective operations.

Institution factors include development of new supportive legislations and policies that would encourage private sector and municipal participation. It also includes re-calibrating existing policies to remove the "bottlenecks" that could impair a successful implementation of the CE system. The economic factors include availability of input resources such as junks and wastes needed for continuous operation of the CE system in the required quantity, utilizable qualities, and at a low cost. Government has a crucial role to play in providing necessary incentives for the take-off of the projects. Among the CE supportive government incentives include spearheading and funding pilot CE projects, and providing willing participants some take-off grants, subsidies, tax rebates, marketing infrastructure/ channels for their CE products [9].

The socio-cultural category includes creation of CE awareness and consistent public education regarding various benefits of CE and of being involved. Consistent education is particularly needed for re-orientation of public perception regarding CE products and those that are engaged in its value-chain such as garbage pickers, junk sellers and buying reused products. There is also a need for formal education, training and re-training for skilled manpower required to design products that are amenable for the creation of a sustainable CE system [10], [11].

Sustainable Design Concepts

There are quite a number of design paradigms aimed at promoting improving the sustainability of our resource use. The focus of such design concepts vary from focusing on a specific aspect of a product, a lifecycle stage of a product or more than one stage of a product lifecycle. At times, the focus is on the processes used to create the product in question. Some of the sustainable design concepts, according to Dunmade [12], include design for materials (DfM); design for Modularity (DfMD); design for simplicity (DfSP); design for assembly (DfA); design for manufacturing (DfMF); design for maintenance (DfME); design for remanufacturing (DfRM); design for minimum residue (DfMR); design for multi-purpose use (DfMU); design for disassembly (DfD); design for Reassembly (DfRA); design for Use and Reuse (DfUR); design for recycling (DfR), and design for multi-lifecycle (DfML). A number of these design concepts depend on implementation of other requisite design paradigms or are composites of other design paradigms. For example, design for remanufacturing necessarily designing the product for X where X stands for materials, modularity, assembly, reusability, disassembly and reassembly. The reason is because remanufacturing would not be possible if the component parts are not designed for reuse, and component parts' reusability would not be possible if the product cannot be disassembled to various parts. Disassembling may be time consuming and costly if the product is not designed for modularity which is necessary to reduce the amount of disassembly that would be needed to free parts into functional units/components.

Design for Multi-Lifecycle (DfML)

This is a sustainable design approach that fosters optimal resource use by prescribing the use of processes and materials that facilitate easy and fast disassembly as well as reuse of disassembled components over a long time period at the design stage [13]. It also promotes the use of less materials and energy at all stages in the lifecycle of an engineered system. In addition, according to Dunmade [12], DfML is aimed at facilitating adoption of a higher hierarchy route of products' end-of-life management involving direct reuse of the product or its sub-assembly rather than material recycling and incineration (Fig. 2).

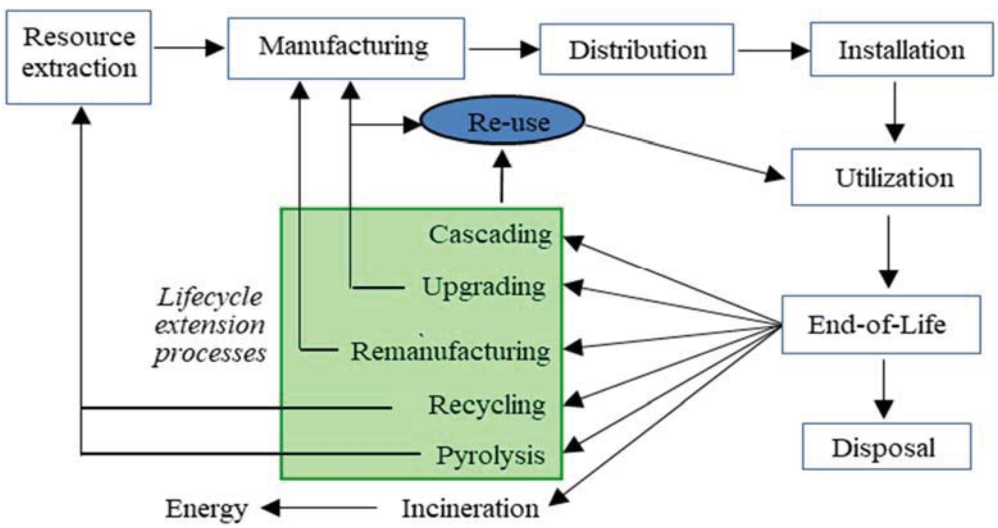

FIGURE 2. A typical closed-resource cycle system

Key Areas of Chemical Engineering and Potential Applications of DfML

All aspects of chemical engineering involving creation of tangible products are amenable to design for multi-lifecycle. It starts with conception of the product in a way that durable materials that can be recycled several times are selected, subject to its functional suitability for the intended product. This is followed by the consideration of how the materials are processed in arriving at the final product. The materials treatment has to be such that the durability and reuse of the materials are positively impacted. In addition, multi-lifecycle use is enhanced by an entire product/device being produced from one type of material, functional components being assembled together, and designing product structure for simplicity. Moreover, application of design for multi-lifecycle paradigm highly suited for areas of chemical engineering involving manufacturing hardware products and creation of tools, machinery and facilities such as heat exchangers, reaction vessels, flash dryers and other similar devices. Such products would have to be designed for X where X stands for materials, modularity, simplicity, assembly, disassembly, reuse, recycling, and remanufacturing to facilitate their multi-lifecycle use. This design for multi-lifecycle component paradigms can be applied to the development of more efficient and economic separation processes and equipment that are used for purifying raw materials and products, recovering intermediates, and for removing by-products and impurities from various types of feeds [14].

How Application of DfML Concept Can Affect Circular Economy Practices in Chemical Engineering

Design for multi-lifecycle and circular economy have the same target. Design for Multi-lifecycle is aimed at enhancing the possibility of using the resources embedded in a product for as long as it is technically, ecologically, economically and socially feasible while circular economy is the actual process/practice of using a product for as long as it is rationally possible. Fig. 3 illustrates how and where design for multi-lifecycle can be applied in chemical engineering to promote circular economy. Designing chemical engineering products for multi-lifecycle provides owners and allied stakeholders with greater flexibility in choosing circular economy pathways that maximizes the utility embedded in the product or products under consideration [15].

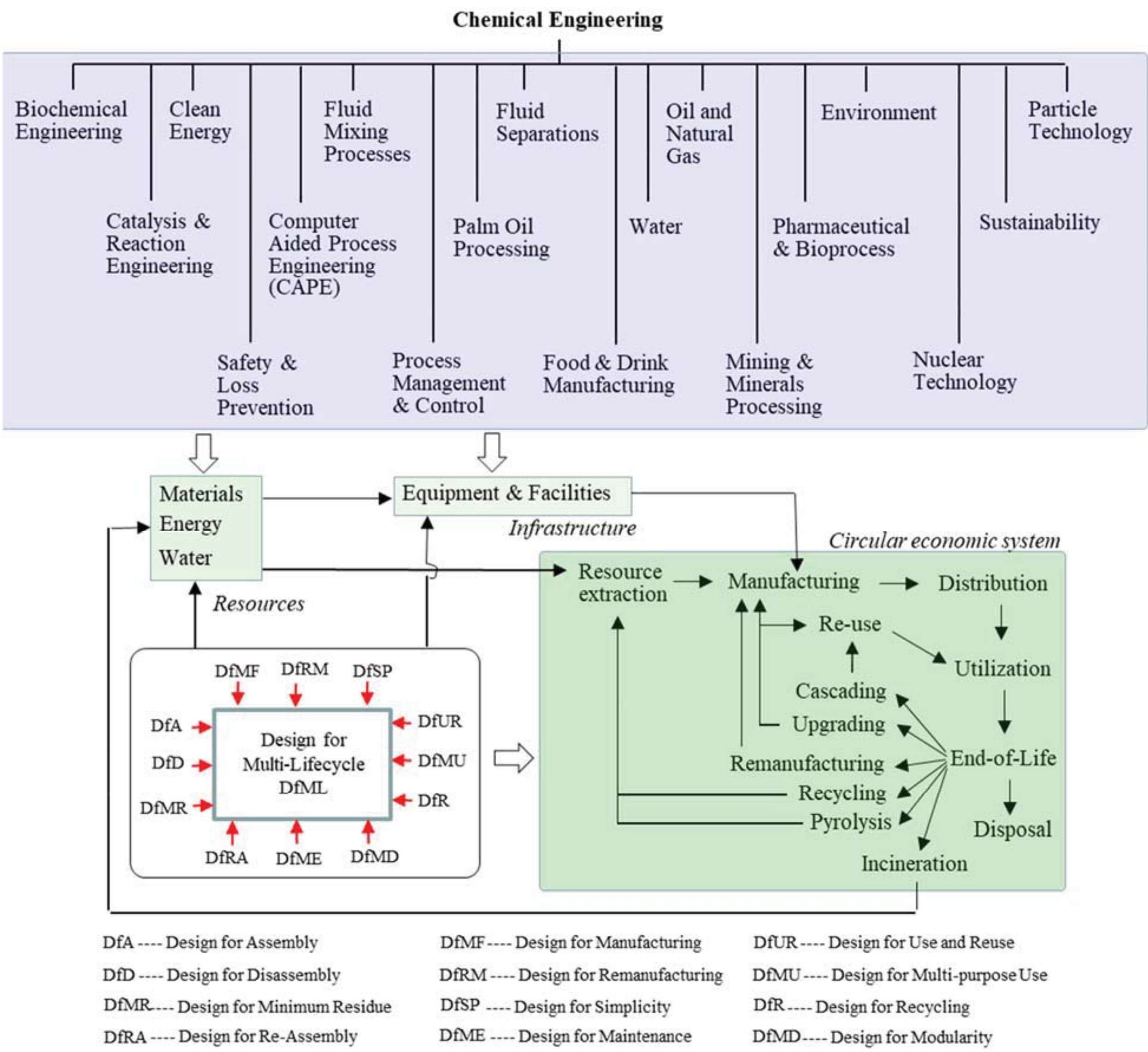

FIGURE 3. An illustration of DfML application for Circular Chemical Engineering

CONCLUSION

Chemical engineering has brought significant transformation to several areas of our lives, our society and our environment. Utilization of chemical engineering technologies have also resulted in a lot of undesirable negative consequences. These necessitated changes in the linear approach to circular chemical technologies development and management. Attainment of circularity in chemical processes and the related activities and technologies will be greatly enhanced by considering various aspects of the system's lifecycle at the design stage. Design for multi-lifecycle (DfML) is the sustainable design approach that facilitates and aligns well with circular economy goals. This study provided a synopsis of how the goals of circular economy in chemical engineering can be enhanced through the use of design for multi-lifecycle when designing the hardware for implementing the processes. Outcomes of this study would provide insight to Chemical engineers and other engineers involved in developing facilities for energy generation, food processing, pharmaceuticals manufacturing, oil and gas production and other areas regarding how they can design the system for circularity.

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