An Integrated Approach towards Sustainable Design and Manufacturing In View of Attitudes and Challenges

Vasagade Vijay G[1] , Varpe Rohan S[2], Danwade Arshad S[3].,Kolekar Mahendra R[4],Patil Avdhut S[5],Banne Ashwini L[6]

[1]*(Head of Department, Mechanical Engineering, Y. D. Mane Institute of Tech., Kagal),*
[2]*(Head of Department, Science and humanities, Y. D. Mane Institute of Tech., Kagal),*
[3,4,5,6]*(Lecturer, Mechanical Engineering, Y. D. Mane Institute of Tech., Kagal),*

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Abstract: In today day, sustainability in mechanical engineering play a vital role, as all conventional sources of energy either going to vanish in upcoming centuries or provide inefficiency in energy production or consumption. Through integrated approach we can offer resilient focus on the implementation of sustainability concepts, actions and measures in design and manufacturing. Sustainable technology on urgency uses less energy and natural resources reduces emissions and material wastes and utilizing more renewable, recyclable and recycled materials. Sustainable engineering mainly consider regulatory requirements, rising energy costs and client demand, however to incorporate sustainability technology attitudes of engineers and companies must considered as well as economics, barriers in execution need to be addressed.
Keywords: Sustainability, attitudes, barriers, wastes, environment, design, manufacturing.

1. Introduction

The report framed by Brundtland commission defines the sustainable development as "the development that meets the needs of the present, without compromising the ability for the future generation to meet their own needs" [2].The Asia having rich biodiversity and natural resources and dynamic economy and more than 4 million of peoples aspiring from prosperous and secure future have seen rapid economic growth in recent decades. However rising population, growing resource scarcity, energy and food security and natural disaster made worse by climate change and are affecting peoples across the region particularly poor and marginalized peoples [5].

The message is clear for the millions having lifted out of poverty the current models are unsustainable and inequitable, a new economic model is need that boosts, development, reduces poverty, and provide high quality of life. The solution is green growth, green economy which is –resources efficient, low carbon producer, and socially inclusive. Many countries from Asia are already transforming to this new paradigm, their experience shows right policies, knowledge skills and incentives can influence behavior and catalyze investment in green business and activities. Increasingly countries are using low emission development strategies (LEDS) as the foundation for achieving green growth [5].

2. Ecological Imbalances- Causes and Consequences

The main reason for imbalance in world's ecosystem is dominance of mankind in the global ecosystem and his hostile alternation of it to satisfy his need and greed. Some specific causes for eco-imbalance are as follows [3]

Changing Hydrology

Irrigation is a major consumer of water in many countries. When river water is used for irrigation by constructing canals, the rate of water flow in the river is reduced and the quality of water down-stream may decline. Building large dams for irrigation and power generation changes the ecosystem of the area impounded for the reservoir.
In the impoundment area, a large number of trees may be felled, fertile land may be submerged under water and a large human population may be displaced. In addition, irrigation increases the water vapour contents of the surrounding air, alters the surface run-off characteristics of the land and sometimes, increases the concentration of pesticides in the underlying ground water.

Large-Scale Use of Fertilizers

Plants rarely use more than 50-60 percent of the nitrogen chemical fertilizers. The residual nitrogen in the form of nitrate is likely to pollute ground and surface waters, causing over-enrichment of nutrients and algal blooms in rivers and lakes. Some of the extra nitrates may also be converted into nitrogen oxides by the action of certain soil bacteria.
In order to reduce the adverse ecological impact of the large-scale use of fertilizers, researches are being conducted currently to determine the extent of fertilizer use and minimize environmental pollution, while maximizing food production.

Large-Scale Use of Pesticides
Pesticides are the chemicals used to eradicate pests. Pesticides are classified as insecticides, Rodenticides, fungicides, nematicides, herbicides and so on. However, none of these chemicals are so specific as to kill only the target species. As a result, they pose hazards also to other organisms including man.

Changes in Earth's Surface
The atmosphere and the ecosystem can be affected both by human activities and natural changes in the physical and biological properties of the earth's surface. Modifications (including deforestations and swamp drainage) that reduce evaporation from an area and alter the amount of energy available for evaporation, thereby changing the energy balance at the earth's surface.

Acid Rain
In common language, "acid rain" means the presence of good amount of acids in rain water. Acid rain is one of the major effects of air pollution. Large amounts of sulphur dioxide and oxides of nitrogen are released into the atmosphere through the burning of fossil fuels (oil and coal) and fuel wood. These oxides (SOx and NOx) react with the atmospheric water vapour to produce sulphuric acid (H2SO4) and nitric acid (HNO3), which then return to the earth's surface with rain water. Acid rain poses a major threat to ecological balance with potential for both macro and microbiological effects on plants and animals. Acid rain not only affects crops, forests and aquatic ecosystems adversely, but it also leches exposed rocks, there by damaging ancient monuments such as the Taj Mahal. Since many famous structures have been constructed from soft rocks, acid rain has already damaged many ancient monuments of great historical value

Green-House Effect
The atmosphere of the earth is said to act like a "green-house" and carbon dioxide is one of the major components of the atmosphere which stimulates the "green-house effect". The green-house becomes warm because glass is transparent to visible light but practically opaque to infrared radiation. As a result, the sunlight can pass through the glass walls of the green-house and can get absorbed by the soil inside it. It is then reemitted as heat rays (infrared radiation), which cannot pass through the glass walls. As a result, the temperature inside the green-house rises above the ambient temperature. The rising proportion of carbon dioxide is causing great concern because the green-house effect will result in higher average temperature on the surface of the earth (the so-called "global warming”). If this happens, there will be wide-spread climatic change with possibly disastrous consequences. The rising temperature could melt the polar ice caps, submerging much of low-lying land mass and many coastal cities (like London, New York, Mumbai, Kolkata and Chennai) under sea water. Similarly, fertile land may be turned into desert and agricultural production may fall drastically due to global warming.

Forest Fires
Fire is still employed to help man hunt wild animals, clear forests and obtain charcoal for fuel. Repeated forest fires, combined with overgrazing, can seriously degrade the environment and harm the ecosystem.

Overgrazing
Environmental degradation and ecological damage arising from overgrazing are wide-spread in aridand semi-arid regions of the Near-Eastern countries, Central Asia and the Mediterranean basin for many years.
One important consequence of overgrazing is desertification (i.e., a process of reduction or elimination of the productive capacity of land that leads ultimately to desert-like formation). About 95% of the land in the arid and semi-arid regions of the world is in the processes of desertification

Clearance of Forests
Reduced the world's original forest area by at least 33%. Man has converted forests to grasslands and crop lands. In addition to the clearance of forests for agriculture and animal husbandry, the forests are being destroyed for timber and fuel-wood.

Integrated approaches to Sustainability
To achieve sustainability it is favorable to integrate engineering design, manufacturing, environment concerns and attitude. To understand these parameters, it is feasible to design manufacture the product or processes keeping in mind environment, we have discussed it in detail as follows.

Fig a. Integrated approach to Sustainability

3. Sustainable Design and Manufacturing

Sustainability is the intersection of these three concepts; this is “people, planet, and profit”

Sustainable Manufacturing
The Green Suppliers Network (DOC/EPA) defines clean manufacturing as “a systematic approach to eliminating waste by optimizing use and selection of resources and technologies, thereby lessening the impact on the environment.”Sustainable manufacturing focuses on both how the product is made as well as the product’s

attributes. This includes the inputs, the manufacturing processes, and the product's design.

Sustainable manufacturing includes things such as making products using less energy and materials, producing less waste, and using fewer hazardous materials as well as products that have greener attributes such as recyclability or lower energy use.Sustainable manufacturing practices can range from very simple process improvements to large investments in new technologies and product redesign [2].

Clean Technologies

Clean or Environmental Technologies are technologies associated with things like environmental protection, assessment, compliance with environmental regulations, pollution control and prevention, waste management, remediation of contaminated property, design and operation of environmental infrastructure, and the provision and delivery of environmental resources. Renewable energy technologies are also considered to be clean technologies.

Examples of clean technologies include technologies for wastewater treatment, recycling, solid waste management, solar panels and wind turbines. Many clean technologies can be used to green the manufacturing process and are therefore important to sustainable manufacturing [2].

Green Products

Making "green products" can be seen as part of sustainable manufacturing, and we will discuss it in more detail later. A green product can be any product that is designed to reduce its environmental impact. A key concept is that environmental concerns and impacts are taken into account from the beginning of the product design process. This is important because most of a product's environmental impact is determined in the design phase. The product may be made of recycled materials, designed so that it can be easily recycled, made without hazardous materials, or produced with less packaging. There are no accepted standards for what constitutes a "green product," although there are rules from the Federal Trade Commission about making environmental marketing claims. There are also many eco-labeling programs that are used to identify and market green products [2].

Industrial ecology

"The study of the physical, chemical, and biological interactions and interrelationships both within and between industrial and ecological systems" Fig.01

It is based on systems thinking – industry is an interdependent part of the overall ecosystem. It studies the material and energy flows through the system to find inefficiency and waste. One of the goals of industrial ecology is to move industry from a linear to a cyclical or closed system where waste is used as an input rather than disposed of.

An advanced version of this would be an Eco-Industrial Park where companies design their products and processes to use fewer virgin materials and use each other's byproducts, co products, or wastes as inputs [2].

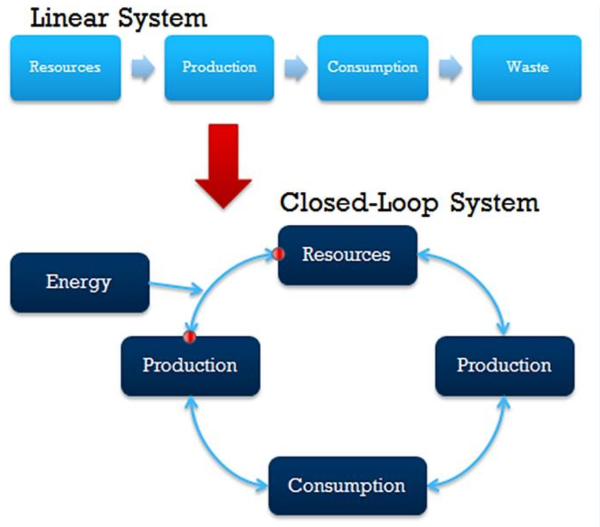

Figure 01-Industrial ecology [2]

Housekeeping

Housekeeping is the simplest method of implementing sustainable manufacturing practices. Housekeeping can be as simple as better inventory management, better monitoring and scheduling of the production process, reducing loss from leaks, spillage, and drag-out, and making sure equipment is maintained properly. It can also involve training your employees about sustainable manufacturing [2].

Process Optimization

Process optimization involves changing your manufacturing process to minimize waste, conserve raw materials, and capture and reuse waste materials. There may be simple things you can do to change your production process to become more sustainable.

Maybe you can collect metal shavings for recycling, change the steps in a painting process to use less paint, or rearrange your machines to minimize movement [2].

Raw Material Substitution

Although it is challenging, you may be able to find ways to substitute greener materials for hazardous materials, chemicals with high environmental or health impacts, materials that are non-renewable, or those that are scarce. You may also be able to find ways to eliminate materials that are used during your production process but don't remain in the final product. Example: use water-based solvents rather than chemical solvents. If the materials you are eliminating are considered hazardous, this can help you avoid regulatory costs associated with storage and disposal of materials [2].

New Technologies

Utilizing new technologies involves incorporating more environmentally responsible technologies and equipment into your production process.

This can involve capital investments to purchase equipment that uses less energy or materials or alternative energy production. For example, you might invest in more energy-efficient production equipment, systems that reuse heat and energy, or more advanced water treatment systems.

New Product Design

Design your product to be greener from the ground up. This concept touches on all of the previous sustainable manufacturing concepts. It can even include redesign involving rethinking how your product is used, and may involve:

i. Using recycled materials instead of new ones
ii. Using renewable materials
iii. Designing for easy disassembly, for recycling, or for remanufacturing
iv. Using less packaging and more recycled or recyclable packaging
v. Green product design can have the same benefits as other aspects of sustainable manufacturing, including improved resource efficiency.

Environmental Waste

EPA's Lean and Environment Toolkit describe environmental waste as "any unnecessary use of resources or a substance released into the air, water, or land that could harm human health or the environment." Environmental Waste includes:

1. Any energy, water, or other materials used that are more than what is really needed to meet the customer's needs
2. Hazardous materials and substances
3. Pollutants, residuals, and other material wastes released into the environment (air emissions, wastewater discharges, hazardous wastes, solid wastes)

As mentioned previously, adding "clean" to lean can result in significantly greater returns for your company. The following chart outlines how lean wastes have an environmental impact.

Table No.01. Lean wastes and its Environmental Impact [2].

Defective Products or Components	Energy and materials are consumed to make defective products, and defective products need to be disposed of.
Overproduction of Components or Final Products	Materials and energy are consumed to make unnecessary products. Products may spoil or become obsolete. Products may require hazardous materials
Waiting	Materials may spoil or become damage. Downtime wastes energy for heating, cooling, and lighting.
Unnecessary Transport or Motion	Energy is used for transport and produces emissions. Transport can cause damage or spills. More space is needed for additional motion, requiring heating and cooling.
Excess Inventory	More packaging and space is needed for excess inventory. Storage could cause deterioration of products and waste. Requires energy to heat, cool, and light inventory space.
Extra Processing	If processing is unnecessary, increases waste and energy use. Consumes more parts and raw materials

4. Integrated Solid Waste Management

1. Source Reduction or "Reduce" [2].
- Preferred method: Prevents the generation of waste in the first place
- Manufacturer: Decrease materials/energy used during manufacturing/distribution
- Consumer: Purchase items with minimal packages
- Includes backyard composting

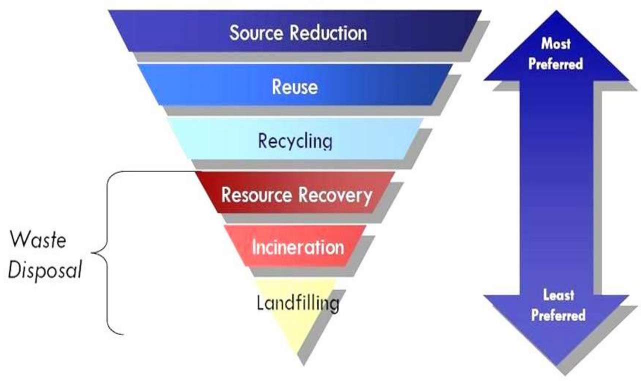

Figure 02. Integrated Solid Waste Management Approach [2].

2. Reuse
- Prolonging a product's usable life
- Repairing items, selling them or donating them to charity
- Using durable rather than disposable items (i.e. reusable shopping bags, metal spoons)
- Preferable to recycling because item does not need to be collected/reprocessed [2].

3. Recycling
- Recycling is the "process of collecting and processing materials that would otherwise be thrown away as trash and turning them into new products" (US EPA, 2015).
- The benefits of recycling are many; they include the reduction of waste sent to landfills, the conservation of natural resources, the reduction in pollution due to a lower need of virgin raw materials, and the possibility of creating new jobs within the recycling industry [6].

4. Waste Disposal resource recovery
- Resource Recovery (AKA Waste-to-Energy): Waste is burned to produce energy
- Preferred to landfilling – reduces bulk of municipal waste to ash and provides energy
- Downsides:
- Some items may be difficult to burn or cause potentially harmful emissions
- Strict regulatory restrictions and high environmental and economic costs[2].

5. Incineration & Landfilling

A waste treatment technology, which includes the combustion of waste for recovering energy, is called as "incineration". Incineration coupled with high temperature waste treatments are recognized as thermal treatments. Strict regulatory restrictions and high environmental and economic costs. Items barely decompose in a modern landfill Landfills face capacity restrictions [2].

05. Sustainability and Product Life Cycle

The industrial sector has been responsible for emissions of 1235 x 10^6 metric tons of carbon dioxide in the United States as of 2007. This number is expected to increase to 1667x10^6 metric tons by 2030. It is therefore imperative to design products and processes that are environmentally sustainable. It is well known that although only 5–7% of the entire product cost is attributable to early design, the decisions made during this stage lock in 70–80% of the total product cost correspondingly; one can hypothesize the same to be the case for environmental impacts. That is, whether or not a product is relatively sustainable is largely determined during the early design stage. Due to high levels of uncertainty regarding design embodiments at the early design phase, novel methods and tools are essential to providing designers a basis for ascertaining the degree of sustainability of a given product or process Fig.03.

Design for environment (DFE) is a practice by which environmental considerations are integrated into product and process engineering design procedures. DFE practices are meant to develop environmentally compatible products and processes while maintaining product, price, performance, and quality standards. Sherwin and Bhamra suggested that the real focus for innovation should be around stages 3 and 4 redesign and rethink. Indeed, sustainability is inextricably linked with economic and social considerations that differ across cultures and technology, and combined with improved design; they can greatly aid this quest [4].

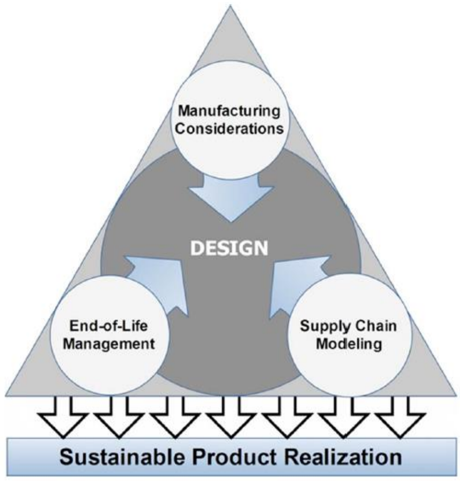

Figure 03- Design decisions affect every stage of a product's life [4].

Design for the environment enables consideration of environmental issues as business opportunities. These opportunities may exist for new products, processes, or manufacturing technologies. The extent of the product's environmental friendliness depends on the level of DFE implemented by the company. Therefore, most of the levels of DFE have to be set up before companies start to implement their own DFE. In general, because of the complexity of today's products and the departmental organization of most companies, DFE is essentially a cross-functional activity fig.04. [4]

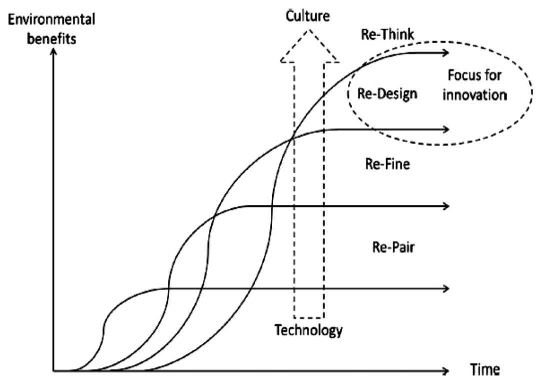

Figure 04- Approach to DFS [4].

06. Attitudes of Engineers towards Sustainability

Personal attitudes of practicing engineers are very positive towards sustainability, with well over 80% indicating that they are personally involved in sustainable information and causes outside of work. More specifically, the responses show that 29% of practicing respondents are extremely involved personally, 55% are somewhat involved, 11% are neutral, and 5% are not interested. The professional views and attitudes of practicing engineers are generally, but not exclusively, positive. That is, the majority of practicing engineer respondents feels that the use of sustainable and/or green design principles in the design, production, and operation of manufactured products is of increasing interest to colleagues (60% of respondents) and results in more product innovation (66%).69% of practicing engineer respondents believe that sustainable and/or green design principles typically have higher design costs, and 18% feel that incorporating sustainable and/or green design practices is too complex for her/his company [1].

07. Attitudes of Engineering Students

The personal attitudes of engineering students are very positive towards sustainability, even more so than those of practicing engineers. Outside of engineering studies, 89% are personally involved in green and sustainable information and causes, while only 2% are not interested and 9% are neutral [1].

08. Attitudes and Actions of Engineering Corporations towards Sustainability

The most common sustainable technologies with which organizations are currently involved are shown in Table 2. They include designs that use less energy and reduce emissions (71% of respondents' organizations), and designs that comply with environmental standards and regulations (also 71%) [1].

09. Factors Influencing Sustainable Design

Numerous factors influence the use of sustainable design and practices, according to practicing engineers. Many of these are listed in Table. Regulatory requirements are most likely to influence organizations' use of green design practices and procedures (indicated by 42% of respondents as the greatest factor and by 69% as one of the top three factors). Client demand was cited as the second most likely factor (by 19% of respondents as the greatest factor and by 51% as one of the top three factors).Rising energy costs was also indicated to be significant factor (with 16% of respondents considering it the greatest factor and by 53% as one of the top three factors).Factors that influence the use of sustainable design and practices must be balanced by organizations against other priorities, especially economics and production. In general, most organizations consider sustainable technologies for new products only if they yield some form of economic benefit. More specifically, the balance between sustainable methods and other priorities is achieved by working respondents' organizations as follows Table No 03.

34% consider sustainable technologies for new products only if they are cost-saving;
27% invest in sustainable technologies only if they increase throughput and cut costs of existing products/processes;
24% invest in sustainable technologies if they do not affect throughput or cost of existing products;
19% will spend extra to incorporate sustainable technologies in most new products;
15% do not invest in sustainable technologies;
9% invest in sustainable technologies to make a statement with some flagship products but not others [1]

Table 02. Usage and Views on Selected Sustainable Technologies and Measures [1]

Sustainable technology/measure	Organization currently Involved with	Worked on in past year
Designs that reduce energy use or emissions	71	64
Designs complying with environmental standards and regulations	71	54
Designs using renewable/recyclable/recycled materials	43	27
Designs that reduce material waste in manufacturing	40	22
Designs with non-toxic materials	37	20
Designs with low carbon footprints	36	21
Manufacturing with less energy and natural resources	33	21
Manufacturing processes that pollute less	31	15
Products that can be disposed of safely	29	15
Products that require less packaging	16	9

Table 03. Factors Influencing an Organization's Use of Green Design Practices and Procedures [1].

Factors	Most likely (%)	One of top three Most likely (%)
Regulatory requirements	42	69
Client demand	19	51
Rising energy costs	16	53
Ability to gain a market advantage	6	30
Long-term return on investment	5	25
Personal sense of environmental responsibility	5	19
Government/industry incentives	3	32
None of the above	3	5

10. Barriers and Challenges

Based on comments made by respondents to the survey, there exist many barriers and challenges to enhancing the way sustainability is utilized by engineers and the extent to which it is incorporated in engineering work [1].

Economics and cost. Respondents indicated that cost is a major consideration when deciding to factor sustainability into a new product or process. The concerns include high start-up and retooling costs and the long-term nature of the return on an investment in sustainability.

Competitiveness. Many feel that adopting sustainable practices in engineering will make the work non-competitive relative to those, within a country or abroad, that do not enhance sustainability.

Market forces and customer demand. Many believe that expanded sustainable engineering is hindered by inadequate customer demand for more sustainable engineering and a lack of corresponding market forces that drive sustainable engineering practices.

Corporate culture and commitment. There is normally not an ingrained corporate culture that supports and fosters sustainable engineering in companies, and other corporate priorities usually receive much greater attention. Further a firm commitment from corporate leaders is commonly not present.

Incentives. Corporations often list inadequate incentives from governments as a barrier to improved engineering sustainability, while practicing engineers often cite a lack of employee Incentives.

Inertia and change. With many corporations and engineers, there is often a reluctance to change, combined with an inertia, that renders it difficult to introduce sustainable engineering practices. This is partly due to the transitional nature of a shift to more sustainable engineering practices and the uncertainty regarding the ultimate destination.

Practices. Commonly accepted and consistent practices for performing sustainable engineering and for developing sustainable products are often indicated to be lacking. In particular, it is often indicated that an improved understanding of best practices would be very useful.

Assessment. Corresponding to the previous point, it is often noted that there is a significant lack of commonly accepted and consistent measures for assessing sustainable engineering and, more broadly, sustainability.

Codes and standards. Often engineers cite the lack of codes and standards for sustainable practices and products as a hindrance to the enhancement and extension of sustainable engineering practices.

Regulations and laws. There are few regulations and laws that call for sustainable engineering, or set sustainability thresholds that need to be met.

Success stories, failures and best *practices.* Many indicate that they feel that more reports of successful applications of sustainable engineering are needed to foster further uses, and that unsuccessful attempts to incorporate sustainable engineering into processes and products need to be explained to help others learn.

Confidentiality. The need for confidentiality to protect competitive advantages often is cited as hindering the sharing of knowledge and lessons learned from applying sustainable engineering.

Short-term focus. The common focus on short-term benefits, rather than a life-cycle approach to benefits, usually hinders the long-term decision making needed to support sustainable engineering practices [01].

11. Summary and Conclusion

To become more sustainable and environment friendly it's mandatory to focus strongly on implementation of sustainability concepts, actions and measures by engineers. The governing points sustainable engineering are regulatory requirements, rising energy costs and client demand. An integrated approach includes use less energy, emission reduction, manufacturing processes that use less energy and natural resources, utilizing renewable, recyclable and recycled materials, and reducing material wastes. Integrating downstream life cycle data into eco-design tools is essential to achieving true sustainable product development. Numerous challenges remain to expansion of sustainable engineering, especially economics, and these need to be addressed to simplify increased shifts towards sustainability in engineering. If we failed to become sustainable and environment friendly the consequences could be catastrophic to us and our next generations.

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