Engineering Mechanics and Sustainable Engineering

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Abstract

At a time of significant global environment challenges and need for sustainable development. A new area of Sustainability in design and manufacturing is on the horizon and Engineering Mechanics Curricula need to equip the graduates with theory, knowledge, and applications of this new science. There has been global dialogue about sustainability but still it is confined to seminars and conferences. This paper endeavor to present framework of diverse discipline and its integration in engineering mechanics curriculum by redesigning and/or reformulating the existing engineering curriculum. There is urgent need for graduates to acquire the knowledge and skills to provide innovative solutions to issues being faced. Engineering profession has a vital role to play in addressing the climate change and helping the society to sustainable development. This reformulation of curricula will also assure accreditation with professional bodies and future engineering enrollment. Therefore, there is need for a lock-p approach to undertaking rapid curriculum redesign and integration of sustainability considerations and principles in mechanical engineering. Thermodynamic concepts are applied in various engineering fields in study of environmental degradation and sustainability. Thus, thermodynamic study is also utilized in ecology, economics and engineering. First and Second Laws of Thermodynamics defines Exergy is viewed as providing the basis of a tool for resources and emission accounting. Engineering education has to reformulate the curriculum so that accreditation with professional bodies is guaranteed. The lack of accreditation will adversely affect in engineering enrollments.

Introduction

The Brundtland UN Commission statement regarding sustainability states," sustainable development is the development that meets the need of the present generation without compromising the ability of future generation to meet their own needs". It is very broad statement and how far the present generation can meet this challenge of sustainability is open to discussion. However, due to depletion of resources, global warming, water, air, and soil pollution, there is need for rethink for developmental strategies of present generation. One of the most important advances in academic work in recent years has been focus on ecology as social, economic and political category. New ecological consciousness has emerged as a result of the direct assault on the ecosystem by human activity, threatening to obliterate many species, including ourselves. The unsustainable development of global economy, with its insatiable desire for energy, is at the root of ecological crisis.

Engineers are at forefront of development and the concept of sustainability must be taught in schools. Authors believe that curriculum needs to be reformulated and sustainability concept green economy included. The production of goods and services where engineers are at forefront is mainly profit driven rather than one to meet basic human needs for clean water, fresh air, and safe food. It appears as most irrational and inefficient use of earth resources. This study examines the interactions between the functioning of society, ecology, and human well-being globally. The Figures 1 and Figure 2 present the concept graphically and

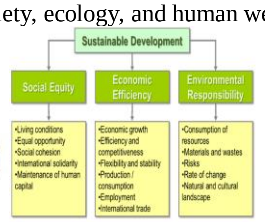


Figure 1. Environment, Economy, and Sustainability   Figure 2. Concept of Sustainable Development

Mechanical Engineering curriculum should strive to include it.

Fig.1 shows the practical framework for the use of thermodynamic ideas and analysis in second law in larger concept of environmental sustainability**.** Fig.2 shows all practical parameters for sustainability underpinned by thermodynamic principles. Engineering education need to emphasize on utilization of resources for needs of society not for making profit. The Engineering Mechanics education should incorporate green technologies or environmentally friendly technologies and energy efficiency in context of sustainability considerations in the curriculum. The concentration on energy and environment, within the mechanical engineering should prepare students to analyze technical problems in: 1) air pollution, 2) climate change, 3) energy efficiency, 4) environmental sustainability, 5) renewable energy, 6) timely issues facing the global community. The current educational systems perpetuate an unsustainable industrial/ modernist model of development. The companies wish to recruit employees who understand the principles of environmental impact on the society of their decision. Therefore, it is the university task to train and prepare those engineers to accomplish their mission which in turn should be mission of engineering schools. In this the role of Accreditation Board of Engineering and Technology (ABET) is tremendous. Green Design and Manufacturing for Sustainability are a must for engineering curricula and ABE should stress these principles in their recommendation to higher education This will help achieve the concept of sustainable development as depicted in Fig.2 above. The green engineering integrates the concepts developing green technologies, energy conservation and efficiency, waste reduction or prevention, pollution prevention or elimination, including the health and safety of consumers. We know consumers are now demanding such green products and companies have to include green technologies in their production chain to remain competitive and exist in the global market. We know that many industries are making notable effort to reduce the environmental impacts of their products and services.

1.1 Ecology and Engineering:

Industrial ecology applies the structure and processes of natural ecosystem for organizing activities across several domains of material, energy, environmental quality, and information exchange. The industrial ecology emphasizes the concept of sustainability-which means composite (integrated) development while consuming least resources and minimizing the pollution of land, water, and air. It will reduce global warming and climate change. Sustainability advocates systematic and global approach in order to minimize resources consumption, decarbonizes energy, minimize greenhouse gas (GHG) emissions, and encourage recyclability and reuse of materials. The emphasis on recycling and reuse in production process reduces the need for raw material extraction and waste disposal. It strives to encourage the use of renewable energy with low carbon emissions and GHG. Sustainable engineering integrates green technology in design and manufacturing along with environmental management. In past, we were not concerned with environmental management in engineering education but now energy sustainability emphasizes this part of industrial activity. The ecology of production follows the flow of materials from mining, to end-of-life and we should strive to minimize the negative effects to the environment. The tools for sustainable engineering include life-cycle assessment, material flow analysis, input/output economic models, and indicators for measuring or assessing sustainability. According to ISO 14040 standards, LCA shall include four phases and they are goal and scope definition, inventory analysis, impact assessment, and interpretation of result as shown in figure below.

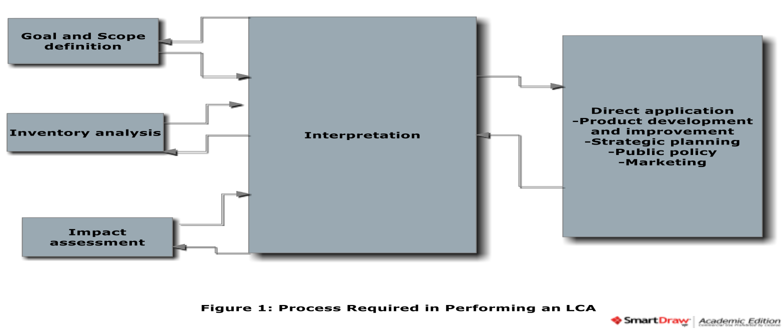


Figure 3: Life Cycle of a Product

Industry must integrate LCA for systematic evaluation of product design methods. The environmental input-output analysis increasingly plays a role in measuring the economic and environmental effects of sustainable development policies in Europe. Consequently, there is need to merge both approaches to address the calculation of unbiased and consistent carbon dioxide emission multipliers. Now a new policy-relevant application of these multipliers has been introduced for the quantification of the performance of the carbon dioxide emission reductions by industries via external trade. At the heart of industrial ecology is the knowledge of how to reuse or modify and rec This will not only save money for materials and reduce GHG emissions and energy consumption. This will reduce the depletion of resources and extraction from nature and thereby reduction of natural degradation. The goal for mechanical engineers should be to take on design tasks such as managing the recycling and reuse of the product at end of life. The target should be to make more intricately networked and efficient design to disposal activities. The basic principles of industrial ecology may be same for every major field of engineers. However, it may need a little tweaking or modification for different fields of engineering. The most important aspect for industrial ecology is material and energy balancing. Material balances are fundamental to the control of production, particularly in the control of yields of the products. Volume of materials, as they pass through production systems, can be described by the statements of conservation of mass. With every step in the production process such as design, material, rate of production, and equipment, the material balances need to be determined again and again.

The increasing cost of energy has caused the industries to examine means of reducing energy consumption in production. Energy balances are used in the examination of the various stages of a process, over the whole production process and even extending over the total production system from the raw material to the finished and to the disposal.

1.2 Method for Preparing Process Flow Chart

The identification and drawing up a unit operation/process is prerequisite for energy and material balance. The procedure for drawing up the process flow diagrams is illustrative of the production process, involving various input resources, conversion steps and outputs and recycled streams. The process flow may be constructed stepwise i.e., by identifying the inputs/outputs/wastes at each stage of the process. A graphical representation provided in Figure 1.

Process steps should be sequentially drawn from raw material to finished product. Intermediates and any other byproduct should be represented. The operating process parameters such as temperature, pressure, % concentration, etc. should be included.

- Inputs of the process should include raw materials, water, steam, energy (electricity, etc.);
- The flow rate of various streams should also be represented in appropriate units like m^3/h or kg/hr.
- Wastes / by product could include solids, water, chemicals, energy etc. For each process steps (unit operation) as well as for an entire plant, energy and mass balance diagram should be drawn.
- Output of the process is the final product produced in the plant.

Material and energy balances can be very complicated at stages, but the basic approach is straight forward. Experience in working with a single item manufacturing can be extended to more complicated production systems. The increasing use of computers facilitates the mass and energy balance models to be manipulated quite easily and therefore used for production management to maximize production and minimize costs. We should not forget that whole concept of industrial ecology is based on the principle that it must be able to reduce the greenhouse gas (GHG) emissions and reduction in use of energy and materials. Material and Energy balances are important, since they make it possible to identify and quantify previously unknown losses and emissions. These balances are also useful for monitoring the improvements made in an ongoing project, while evaluating cost benefits. Raw materials and energy in any manufacturing activity are not only major cost components but also major sources of environmental pollution. Inefficient use of raw materials and energy in production processes are reflected as wastes.

1.3 Guidance for M&E Balance

- For a complex production stream, it is better to first draft the overall material and energy balance.
- While splitting up total system, choose, simple discrete sub-systems. The process flow diagram could be useful here.
- Choose the material and energy balance envelope such that, the number of streams entering and leaving, is the smallest possible.
- Always choose recycle streams (materials and energy) within the envelope.
- The measurement units may include, time factor or production linkages.
- Consider a full batch as the reference in case of batch operation.
- It is important to include start-up and cleaning operation consumption (of material and energy resources (M&E)).
- Calculate the gas volumes at standard conditions.
- In case of shutdown losses, averaging over long periods may be necessary.
- Highlight losses and emissions (M&E) at part load operation if prevalent.
- For each stream, where applicable, include energy quality (pressure, temperature, enthalpy, (Kcal/hr, kW, Amps, Volts etc.).

The material and energy (M&E) balances should be developed for entire production system and it could also be equipment-wise M&E balance could help assess performance of the equipment, which in turn help identify and quantify energy and material avoidable losses. In manufacturing system problems, it could be of immense help even in designing the equipment itself.

1.4 Steps in Mass and Energy Balance Calculation:

Basically, mass and energy balance calculation checks if directly or indirectly measured energy and mass flows are in agreement with the mass and energy conversion principles. In order to use it correctly, a step by step approach is advocated. Steps can be identified as:

1. Clearly identify the problem to be studied. In case of manufacturing system problems, we have to identify material removal process such as turning, milling, grinding, etc., as every one of them runs on different principles and the mechanics of material removal are quite different.
2. Define a boundary that encloses the complete system or sub-system or the equipment to be analyzed.
3. The enclosing boundary such that measurements is accurate and easy.
4. Select the appropriate test period depending on the type of process and product. Calculate the energy and mass flow based on the measurements in step 3.
5. Check the mass and energy balance. If the balances are outside the acceptable limits, then repeat the measurements.
6. The energy release or use in endothermic and exothermic processes should be considered in the energy balance.

These show the need for increasing energy efficiency, and the potential for exergetic improvement in energy productivity in industry. Poor thermodynamic performance is mostly result of exergy losses in combustion and heat transfer. So, there is need for heat, mass, and energy balance study in thermodynamics. There is no comprehensive curriculum development from undergraduate to graduate study with regard to sustainability. One of the main objective s of our engineering curriculum should be to prepare our graduates who can realize the impacts of technology on environment and develop solutions that minimize negative impact on environment. The Mechanical Engineering curriculum provides a strong foundation in Thermodynamics, Solid Mechanics, Fluid Mechanics, Heat Transfer and Design. There is urgent need for inclusion sustainability in mechanical engineering curricula. ABET 2010 and 2013 now require graduates should be able to design a system, component or process to meet the desired needs within realistic constraints of economy, environment, society, political, ethical, health and safety, manufacturability, and sustainability. This shows that sustainability considerations must be integrated into engineering curriculum as it has become consumer choice process for products. The implementation of green technology in product development and environmentally conscious manufacturing, energy and efficiency must become integral part of modern sustainable business and therefore, the engineering and technology education.

2. **Basic Principles**. Representing the manufacturing system as a box in the figure below, the mass and energy going into the box must balance with mass and energy coming out.

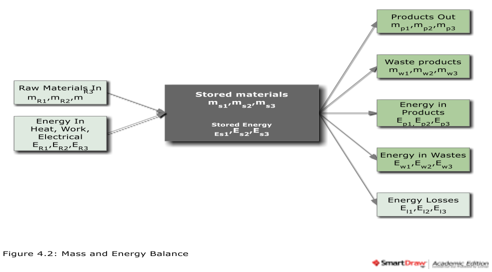


Figure 4: Mass and Energy Balance

The law of conservation of mass leads to material balance equation; Mass in = Mass out + Mass stored

Raw Materials = Products + Wastes + Stored Materials

$$\sum m_R = \sum m_p + \sum m_w + \sum m_s \quad \text{(Where } \sum \text{ denotes the sum of all terms)} \quad (1)$$

$$\sum m_R = \sum m_{R1} + \sum m_{R2} + \sum m_{R3} = \text{Total Raw Materials} \quad (2)$$

$$\sum m_p = \sum m_{p1} + \sum m_{p2} + \sum m_{p3} = \text{Total Products} \quad (3)$$

$$\sum m_w = \sum m_{w1} + \sum m_{w2} + \sum m_{w3} = \text{Total Waste Products} \quad (4)$$

$$\sum m_s = \sum m_{s1} + \sum m_{s2} + \sum m_{s3} = \text{Total Stored Products} \quad (5)$$

It is possible that in a manufacturing systems more than one product, i.e., p =1, 2, 3,…, n are being manufactured. The energy input is the embodied energy for separate products and materials. Waste materials in the manufacturing systems (particularly machining) and the chips being created after machining. We need energy during machining and must be included in the energy balance equation. Just as mass follows the law of conservation, so is energy conserved in manufacturing operations. The embodied energy into the operation and the energy used for manufacturing must balance the energy coming out and energy stored.

2.1 Energy Balances

Energy takes many forms such as heat, kinetic energy, chemical energy, potential energy but because of inter-conversions it is not always easy to isolate separate constituents of energy balances. However, under some circumstances certain aspects predominate. Therefore, energy balances tend to focus on particular dominant aspects and so a heat balance, for example, can be useful description of important cost and quality aspects of process situation. Then after some preliminary calculations, the important ones emerge and other minor ones can be lumped together or even ignored without introducing substantial errors. Energy balances can be calculated on the basis of external energy used per kilogram of product, or raw material processed, or on dry solids or some key component. The energy consumed in food production includes *direct energy* which is fuel and electricity used on the farm, and in transport and in factories, and in storage, selling, etc.; and *indirect energy* which is used to actually build that machines, to makes the packaging, to produce the electricity and the oil and so on. In SI system there is only energy unit, the *Joule*. In some heat balance, people still use British Thermal Unit (BTU).

Embodied Energy in + Energy Used in Manufacturing = Energy Out (Embodied Energy in the Products)

$$\sum E_E = \sum E_{e1} + \sum E_{e2} + \sum E_{e3} = \text{Total Embodied Energy} \quad (6)$$

$$\sum E_m = \sum E_{m1} + \sum E_{m2} + \sum E_{m3} = \text{Total Manufacturing Energy} \quad (7)$$

$$\sum E_w = \sum E_{w1} + \sum E_{w2} + \sum E_{w3} = \text{Total Energy Embodied Wasted in Chips)} \quad (8)$$

$\sum E_l = \sum E_{l1} + \sum E_{l2} + \sum E_{l3}$ = Total energy loss to atmosphere (in form of heat) (9)

$\sum E_{eo} = \sum E_{eo1} + \sum E_{eo2} + \sum E_{eo3}$ = Total Embodied Energy out (10)

For the energy balance equations 6 & 7 should be added on the left side of equality and equations 8, 9, & 10 should be on the right side. We can show the complete energy balance equation as

$$\sum E_E + \sum E_m = \sum E_w + \sum E_l + \sum E_{eo} \qquad (11)$$

Energy balances are often complicated because forms of energy can be interconnected, but overall the quantities must balance. The thermodynamic analysis of resources used in manufacturing processes is shown below.

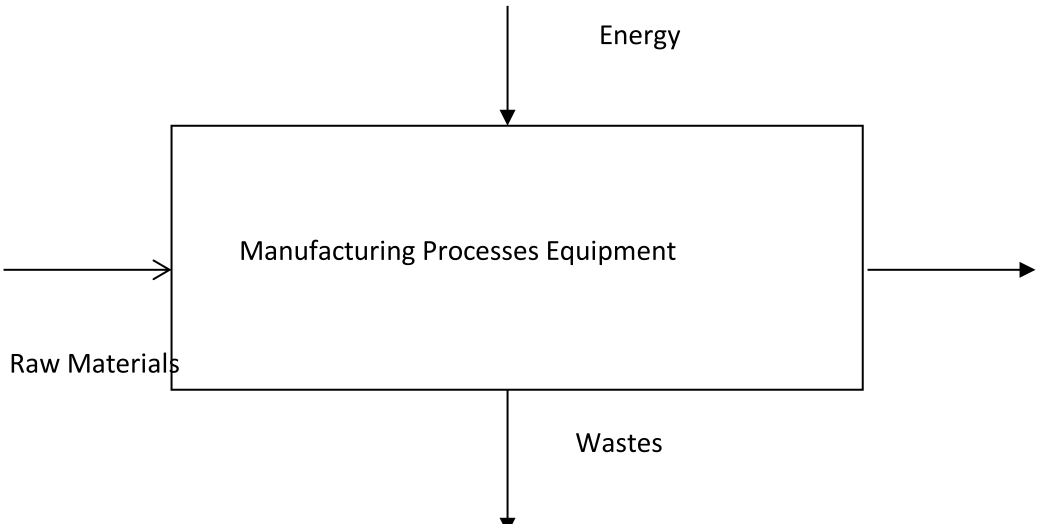


Figure 5: Resources Analysis in Manufacturing Processes

Figure 5 above shows the inputs of raw materials and energy into the manufacturing equipment and outputs of product and wastes. Product is useful part coming out of manufacturing systems and wastes are scrap, chips, and heat. The ecology

2.2 Heat Balances

The most common important energy form is heat energy and the conservation of this can be illustrated by considering operations such as heating and drying. In these, e*nthalpy* (total heat) is conserved and as with mass balances so *enthalpy* balances can be presented for various items of equipment or process stages, or round the whole system (plant), and it is assumed that no appreciable heat is converted to other form of energy such as work.

Enthalpy (H) is always referred to some reference level or datum, so that the quantities are relative to this datum. Working out energy balance is then just a matter of considering the various quantities of materials involved, their specific heats, and their changes in temperature or state (as quite frequently latent heats arising from phase changes are encountered). Figure 6 below illustrates the heat balance.

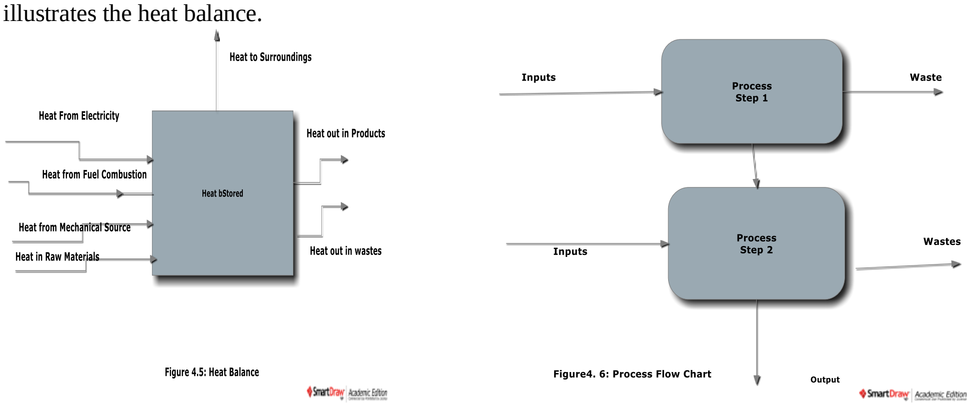


Figure 6: Concept of Heat Balance

Heat is absorbed or evolved by some reactions in processing but usually the quantities are small when compared with the other forms of energy entering into the system such as sensible heat and latent heat. Latent heat is the heat required to change, at constant temperature, the physical state of materials from solid to liquid, liquid to gas, or solid to gas. The units of specific heat are J/kg K and sensible heat change is calculated by multiplying the mass by the specific heat by the change in temperature i.e. $m.c.\Delta T$. The units of latent heat are J/kg and total latent heat change is calculated by multiplying the mass of material, which changes its phase by the latent heat. Having determined these factors that are significant in the overall energy balance, the simplified heat balance can then be used with confidence in energy studies. Sustainable Engineering should be an important part of Mechanical Engineering program to take care of modern interpretation of this rapidly changing field. Unlike the classical environmental engineering topics (e.g. water sanitation, brownfield remediation) many new environmental engineering and sustainability challenges require strong quantitative skills, as taught in mechanical engineering. Renewable energy technologies require skills in material science and physics, climate change research requires individuals trained in fluid mechanics and environmental transport, sustainable building design requires deep knowledge of heat and mass transfer in complex geometries. Mechanical engineers design and solve issues for all kinds of devices, from small toys to large machines that help to run ships, automobiles and generators. Mechanical engineers design many of the parts, pieces and equipment that people use daily. Their jobs may take them from an office environment to a manufacturing plant and to the outdoors to ensure their designs are working properly. The principles of mass balance, energy balance, and heat balance must be included in mechanical engineering curriculum at every step.

3. ABET Requirements of Mechanical Engineering

The Mechanical Engineering Program has a traditional ABET accredited four-year curriculum involving mechanics, vibrations, thermodynamics, fluid flow, heat transfer, materials, control theory, and mechanical design. Graduates of this program are expected to have the following skills, knowledge, and abilities to work professionally in mechanical system areas including design and realization of such areas.

New requirements of sustainability in thermal and design engineering should be included in ABET criteria. Mechanical Engineers should apply principals of green design to develop appropriate, cost effective, and high performance mechanical, and energy systems integrated into the projects. ABET should include: Reduce waste, re-use parts & components at end of life, rework & refurbish suitable parts, recycle as far as possible and remanufacture so far economical. The added importance should be given to the teaching of: Optimizing energy and water conservation; effect of design on GHG emissions; Proving appropriate and sensible control systems and devices; insuring ease of system maintenance and operations; Allowing for future flexibility and adaptability. These considerations will enhance engineering benefits to consumers by allowing for better coordination, increased sustainability, and benefit at no additional cost. They need to play an increasing role in the promotion of a sustainable society. How engineers are educated has a significant effect on the way in which they work and the way in which they understand their role in sustainability. This paper explored the need for engineers to be educated in sustainability and provides an excellent vehicle for understanding of sustainability principles.

4. Sustainability and Thermodynamics

It is generally recognized that thermodynamics and fluid mechanics are very complex and challenging field for mechanical engineers and these courses explained further in thermal and fluid mechanics labs. These courses are also further explored through simulation in advanced Computer Aided Engineering lab. A thermodynamic system is defined as a physical entity of a complex structure that consists of a finite set of constitutive elements having: 1) a known type of such constituent, 2) defined internal constraints that control interactions between constituents, 3) a known nature of internal forces, and 4) explicitly listed generalized coordinates that describe all actions of external forces. All engineering systems whether in design or manufacturing should follow the rigorous thermodynamic definition of system. The sustainability approach tries to identify how far from equilibrium (vs surroundings) a process and /or its outcomes are at any instant of the life cycle. Manufacturing system sustainability assessment is the philosophy that a change of a property of a raw material under processing in open manufacturing system or assembly line. It contributes to a certain degree to an overall outcome of all the interactions between material flows and surroundings. At the end of useful life, it returns to environment (landfill), and it started its journey from its extractions from mines. This is a full life cycle or a full sustainability. In engineering curriculum, we start from materials and end at the end of manufacturing processes, without considerations to energy requirements before materials being processed and what happens to the systems & components at the end of life. It is conceivable to consider such systems as closed systems instead of open system and all the thermodynamic properties of exergy and /or entropy generation should be applied for sustainability. Energy resources of various kinds help in running industries producing useful products for human development. However, it also creates pollution and environmental degradation of atmosphere, land, and water. And we know there is no substitute for water and air. Many of these side effects of production and consumption give rise to resources depletion and environmental hazard world over. We can make best use of thermodynamics by focusing on bio-physical resources and using aggregate measures of the second law regarding conversion of resources, such as energy change and entropy production.

Thermodynamic concepts have been utilized by practitioners in a variety of disciplines with interests in environmental sustainability, including ecology, economics and engineering. Widespread concern about resource depletion and environmental degradation are common to them all. It has been argued that these consequences of human development are reflected in thermodynamic parameters and methods of analysis. Exergy', a quantity which follows from the First and Second Laws of Thermodynamics, has been viewed as providing the basis of a tool for resource and/or emissions accounting. It is also seen as indicating natural limits on the attainment of sustainability. This indicates the scope for increasing energy efficiency, and the extent of energetic 'improvement potential', in each of these areas. Poor thermodynamic performance is principally the result of exergy losses in combustion and heat transfer processes. Mass, energy, and exergy balancing should be incorporated in all engineering courses to account for sustainability. These are not applicable to steady or quasi-steady and closed systems. Such analysis tools are applicable to diverse materials processing operations, such as machining, heat treatment, forming & forging processes, diffusion and phase change processing, etc. Sometimes these systems are inefficient in terms of energy and our graduates should be sufficiently exposed to these tools. There is clear relationship between energy efficiency and quality of product. There is need for integrating such concept at early stage in thermal engineering and transported to other design and manufacturing courses. Here an outline of basic Thermodynamics course including sustainability considerations is presented.

1) First law of Thermodynamics:
   Heat, Work, thermal efficiency and difference between various forms of energy.
   a) Heat Balance equations and examples.
   b) Energy Balance equations & problems.
   c) Mass Balance equations and problems
   d) Steady-flow energy equation; Open and closed systems (mass balance).
   e) Conservation of energy (Energy Balance problems & examples).
2) Ideal Cycle Analysis;
   a) Estimate thermal efficiency; energy balance, loss of energy.
   b) Work as a function of pressure and temperature.
   c) Mechanical Equilibrium.
   d) Thermal Equilibrium (Thermal Balance).
3) Applications of first law of thermodynamics;
   a) Thermodynamic cycle & Heat engines
   b) Otto cycle
   c) Brayton cycle
4) Applications of Steady-flow energy equation:
   a) Mass balance or conservation of mass equations & examples.
   b) Conservation of energy
   c) Steady flow energy equation
   d) Enthalpy & applications.
   e) Examples applications of steady flow equations. Adiabatic considerations.
5) Second law of thermodynamics (concept of Entropy);
   The Second Law of Thermodynamics could be interpreted as tendency of everything to return to an elemental state. The link between the efficiency of resources utilization, energy consumption, and GHG emission is real and second law of thermodynamics should be studied from this angle. The relation between engineering, economic, and society are illustrated by sustainability and is shown below by Venn diagram shown in Figure 1. The Venn diagram in Fig.1 shows the practical framework for the use of thermodynamic ideas and analysis in second law in larger concept of environmental sustainability**. Fig.2** shows all practical parameters for sustainability underpinned by thermodynamic principles. Thus, the topics under second law of thermodynamics to be covered are outlined below.
5. Irreversible Processes
   a. Reversible Processes and examples.
   b. Entropy and environment
   c. Mass, Energy & Exergy balance for continuous, transient and variable-mass manufacturing systems.

6. Green Design and Manufacturing for Sustainability

In the design and manufacturing stream of mechanical engineering, the solid mechanics plays most significant part. All the basic theories of mechanics are helpful in component and system design including manufacturing. However, the mechanical engineering doesn't include the concept of environmental degradation due the decision made during design phase. Actually the design effects the manufacturing and manufacturing in turn effects the environment. We need to include in mechanical engineering the sustainable or green design including the concept of manufacturing for sustainability. Mechanical Design in itself has no ecological dimension, but its impact on the manufacture and use of product is immense. Decision at design stage constrains the avenue of possible change down the line or later on the life of product. The concept for Design for Environment (DOE), or Sustainable Design should be integrated very closely in the engineering mechanics and/or Mechanical Engineering Curricula. It should not only emphasize on Green Manufacturing but all the aspects later in the life cycle of the new product including use, end-of-life, and disposal. The very concept of a new product should raise the question the need for the product could be by reusing, reconfiguration, and remanufacturing. It will not only save materials, engineering, lower GHG emission, lower carbon footprint, and increase profit for the industry.

6.1 Sustainable design

Sustainability is defined as a requirement of our generation to manage the resource base such that the average quality of life that we ensure ourselves can potentially be shared by all future generations. Sustainability is the ability to continue a defined behavior indefinitely.

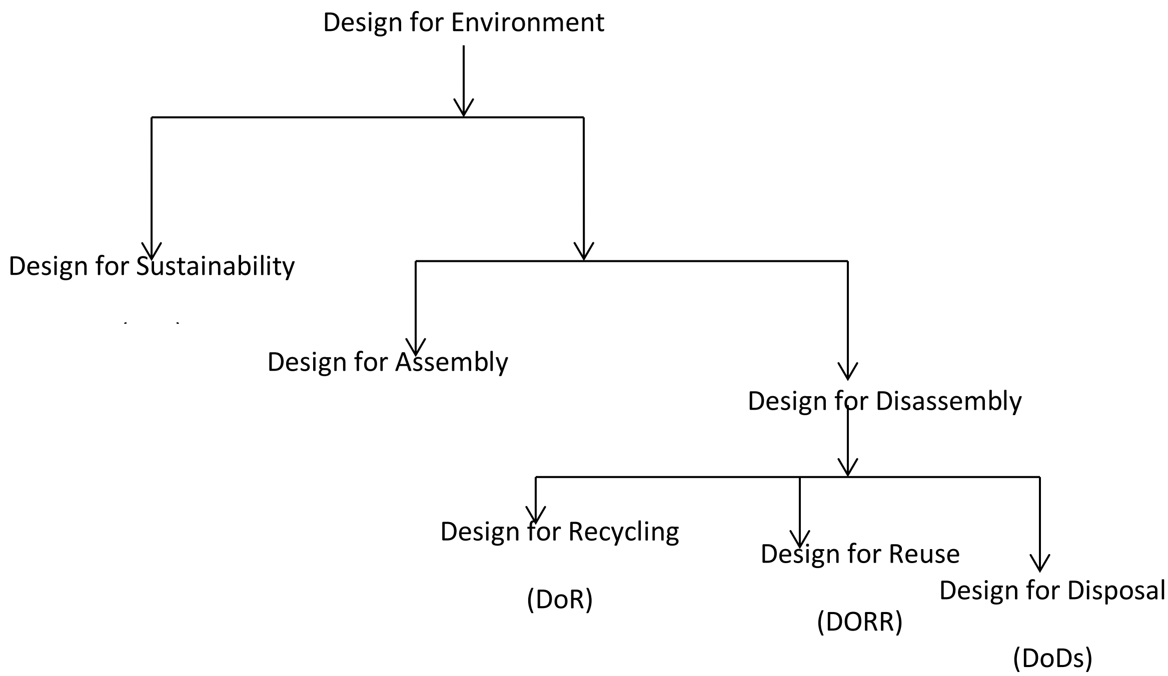


Figure 7: Sustainable Design

Green design and manufacturing promises reduction in materials, energy use, disposal fees, and reduced pollution. Products should be designed keeping in mind the aspects of disassembly and recycling. Engineering curriculum has to catch up with the needs of society in general for sustainability considerations. The end-of-life considerations including recycling and reuse should be integral part of Mechanical Engineering curriculum. The selection of suitable materials, processes, and geometry that satisfies specified and implied green functional requirements should be goal of mechanical design. A curriculum revision and development of two separate courses on Green Design and Sustainable Manufacturing are being proposed. Engineers need an understanding of whole systems, life cycle, and end of life utility of the product and they have been emphasized in the new courses being developed. This is in consistent with National Science Foundation (NSF) objective as well as the requirements of American Society of Mechanical Engineers (ASME). There is need to modify the undergraduate curriculum to include sustainability considerations in mechanical component design and manufacturing courses.

The path towards sustainable engineering education is obvious and the engineering professors should recognize and communicate the epic nature of the sustainability discourse. The engineering education community needs to include sustainable engineering in curriculum. Unfortunately, few engineering schools have made major updates to their courses and curricula over the past few decades. However, making such updates is thwarted by the significant amount of time needed to make changes, the challenge of inserting new material into already crowded courses and curricula, and the lack of a sense of priority about such changes. We need to include in our courses topics such as life cycle assessment, concepts in renewable energy, and methods of waste minimization. Leading institutions in the United States have recognized that sustainable development should have a prominent role in engineering education and practice. The criteria used to accredit engineering education programs have also recognized this need. The Accreditation Board for Engineering and Technology (ABET) requirements for program outcomes and assessment, identifies that besides the knowledge in math, science, engineering principles, and problem-solving, engineering graduates should possess the ability to: function on multidisciplinary teams, communicate effectively, and understand professional and ethical responsibility. A review of courses offered within and outside the School of Engineering show varying ways and to varying degrees' inclusion of sustainability. A Venn diagram for sustainable development is presented in Fig.3. for sustainability the social, environmental, and economic development must be integrated and balanced. The core of the Venn diagram is sustainable, which should guarantee balance environment and economic development, along with equitability of society and the economic development. The environmental degradation due to economic activities must be bearable for society in general.

Our attempt should be to integrate green design and manufacturing within the framework of sustainability in engineering curriculum whichever way the faculty decides. Enhancing the sustainability of manufactured product is a critical subject for the coming generation of engineers. It would result in reduced materials requirements, reduction in energy use, reduced disposal fees, reduced pollution and finally fewer problems for society in general. The aspects of disassembly and recycling should be included in product design. It would help to reduce toxic and otherwise harmful emissions to the environment causing global warming, and ensure sustainability. We should advance the following goals in engineering curriculum for sustainable future: 1. Reduce the use of resources including materials, energy, and water etc., 2. Reduce toxic and otherwise harmful emissions to the environment causing global warming, 3. Manage renewable resources to insure sustainability, 4. Quality and durability: Longer-lasting and better-functioning products will be replaced less frequently, reducing the materials requirements in future, 5. Design for reuse and recycling.

Material selection effects largely on the environmental impact and it should be considered very critical in design and manufacturing. Performance indices to minimize the environmental impact have been developed by Ashby [5] and it should be included in the design courses. Along with the traditional mechanical engineering design tools, the design for environment (DFE) should be integral component of mechanical design and it should be included in the ABET requirements. The extrinsic properties along with the embodied energy, GHG emission, and cost should be included in the design process.

It is proposed here to develop a series of courses on Design and Manufacturing for Sustainability (DMS) or Green Design and Manufacturing for Sustainability (GDMS). These courses would be useful for graduate and undergraduate curriculum. The course will be prepared for a future where Green Design and Manufacturing has zero net impact on the environment. These courses will present traceable information (topics) which are critical to product designers and manufacturing engineers so that they can incorporate sustainability in their occupation and comply with international regulations. The template of a course is presented below in Fig.3. The courses will emphasize on the integration of cost, recyclables, and or reuse during the design and manufacturing stages. For sustainability the life cycle cost consideration is critical and it is included the course outline.

Green design or design for environment (DFE) has the main aim of reducing the waste of material and greenhouse gas (GHG) emissions into the atmosphere. There is enormous cost of materials going to landfills and many of these waste materials may be usable with proper refurbishing and recycling. The designers have the greatest influence on the product's composition and the burden of creating products that is easy to disassemble, reuse and recycle falls largely upon their shoulders. There is need for environmentally friendly design, which can reduce waste, encourage recycling and reuse of the components at the end-of-life, reduce emissions of GHG. The curriculum being developed emphasize on total life cycle of the product from grave-to-grave or at least from grave – to- gate. Some important aspects of design for the environment are; manufacture without producing hazardous waste; use of clean technologies; reduce product chemical emissions; reduce product energy consumption; use of non-hazardous recyclable materials; use of recycled material and reused components; design for ease of disassembly product reuse or recycling at end of life. These issues must be included in curriculum being developed at Manhattan College for sustainable study. The following topics are proposed to be included and integrated in undergraduate engineering curriculum. These topics are presented with examples and problems as module 1 for teaching.

Designs for Assembly

To improve percentage of recycling and reuse appropriate steps must be taken at design stage. Reducing the number of parts or components in the assembly makes it easier to manufacture and assemble. The proper material will also affect the assembly cost. Although slightly different in detail, focus on the following issues is needed. • Material e.g., reduce overall material diversity, avoid the use of laminates or make them out of compatible materials which can be recycled as a mixture, • Fastener, e.g., reduces fastener count and diversity; avoid incompatible adhesives which degrade recyclability of materials, use snap fits where appropriate, • Component design issues, e.g., avoid paints and laminates; build in planes for easy separation and access. Some of functions of one component may be integrated with other components or eliminated altogether to reduce cost. It will encourage recycling and reuse.

Designs for Disassembly

Design for Disassembly (DfD) must be incorporated in the early stages of product design, when the structure of the product is determined. The Design for Disassembly (DfD) saves money including reduces materials wastage, GHG emission, and landfill costs, and above all improves the environment. In traditional engineering design curriculum, the problems of recycling, reuse, and landfill or incineration were barely touched. This requires quite different thinking in a modern engineering education. An example of disassembly problem is presented below as module 1. Below an example for design of disassembly along with cost and the GHG emission estimation is presented.

Example for disassembly: The time to disassemble the screw will depend on the length of the screw, which depends upon the thickness of two parts assembled. If the nominal diameter of the screw is 0.125", then there are 40 threads/inch (UNC) threads or 44 threads/inch (UNF) threads. The time to unscrew the screw is 44(140) =1960TMU=70.56 s. If we assume there 15 screws in this assembly of two steel plates, disassembly time= 15(70.56) s+15 (34.7) (.036) s = 1077.138 s=17.9523 min. Steel plates of 24''x24''x1/2' of 81.2 lbs. are considered. Plates are heavy items and to move those to recycle or reuse bins need help of one more person and both hands have to be used. It is getting control over an object with the hand or fingers and placing the object in a new location. In MTM-1 (Yi et al., 2003), these steps are: Reach, Grasp, and Move. If we take predetermined tomes from tables 3, 7, &4; time for moving one plate is = (23.2+2.0+22.7) =48TMU for moving the plate by 30" However, these plates are heavy of 81.2 lbs., the time elements modified for weight =1.5 x48x81.2 =5846.4 TMU= 210.4704 s =3.5 min. For both the plates, the time to move them would be 7 min. Therefore, the total time for disassembly would be, which seems to be reasonable time to unscrew all 15 screws with flathead screw driver and move the plates about 30" from the workbench. We assume only 25% of the screws are reusable and rest have to be recycled. The degree of difficulty is the relative degree of disassembly of the nuts & screws, which is normally in the range from 1.5 – 2.0. The time of disassembly should be multiplied by the degree of difficulty (dod) factor to accurately estimate the disassembly time. By assuming 25% screws are reused and rest 75% are recycled after shredding, the following steps are taken in estimating the end-of-life (EOL) or the recycling & reuse benefits;

Reuse value = Cost of component ($) – Miscellaneous cost ($)

The miscellaneous cost is composed of collection plus reprocessing costs and it is zero here. Therefore, Reuse value= $per part reused x # of parts reused = $3.00 (here for illustration $ per part is assumed as $1.00, which not true in market). Remanufacture value represents the value of component after disassembly the parts are reprocessed or refurbished before reusing them. The remanufacturing cost sometimes may involve machining, cleaning, removing paint, or cleaning for any corrosion on the part.

Remanufacture value = $per component x # of components – remanufacture cost/component x # of components = $3.00-$0.10 x 3 = $2.70. Primary recycle value here consists of 12 screws and two steel plates. The primary recycles value: Primary recycle value = # of screws x weight/screw x cost of recycled material + # of steel plates disassembled x weight per plate x cost of per pound of material reused = 12 x 0.0625 lb/screw x $0.50/lb + 2 x 81.2 lbs. /plate x $ 0.20/lb = $ 32.9 (Here screws are of alloy steel and plates are of cast iron).

The shredding cost needs to be accounted for in the EOL cost as well.

Shredding Cost =hourly shredding cost/hr. x # of hours used to shred one lb of material x weight of shredded material. The shredding cost is estimated as; $30/hr. x 1/2 hr. /lb x163.15 =$2,447.25

The shredding cost seems very high and recycling may be uneconomical. After shredding material is reprocessed & sent at the entering point of production process.

Embodied energy in recycling; The value of embodied energy in the recycling (Gunoor et al., 1999) is estimated now. The total material of alloy steel and cast iron are 0.72 lbs. and 162.4 lbs. respectively. The embodied energy of fresh material used in production or manufacturing process;

Embodied energy of fresh material = (0.72 lbs. x 0.454 kg/lb x 35 MJ/kg) + (162.4 lbs. x 0.454 x 17 MJ/kg) x 948 Btu = (11.5 + 1253.5) x 948 = 1.2 x 106 Btu

The energy required to process recycled the materials: **Embodied energy for recycled materia**l = (0.72 x 0.454 x 10 MJ/kg + 162.4 x 0.454 x 5.2 MJ/kg) x 948 = (3.3 + 383.5) x 948 = 0.37 x 106 Btu

The energy saved = (1.2 – 0.37) x 106=0.83 x 106 Btu. The savings in terms of dollars could be estimated. Normally energy drawn from electric grid, coal, or heavy oil, etc. differ in price but everyone had different environmental impact in terms of carbon footprint, which is supposed to be main cause of global warning. The energy price is used here as $0.035 /MJ and so the savings in terms of dollars = (0.83 x 106/9.48) x $ 0.035/MJ =$ 31.00.

Carbon footprint estimation; Carbon footprint of fresh material = (0.72 x 0.454 x (2.125 kg/kg) + 162.4 x 0.454 x (1.1 kg/kg)) = (0.7 + 81.1) = 81.8 ~ 82 kg of CO_2 is emitted in atmosphere when we use fresh materials in this process. The Carbon foot print of recycled materials = (0.72 x 0.6 kg/kg + 162.4 x 0.31 kg/kg) x 0.454 = 23 kg. This shows that there is reduction of (82-23) kg =59 kg of CO_2. For this small disassembly process, the reduction in terms carbon footprint is very significant or quantifiable.

Economics of End-of-Life in Design for Disassembly (DfD); The estimated life cost consists of the manufacture, assembly, maintenance, remanufacture and recycling costs as determined by the choice of fastening or joining method. The recycling cost represents (Feldman et al., 2001) the expense of material separation, and not material reprocessing. The assembly and disassembly costs are estimated using time required for disassembly and assembly of various fastening and joining methods.

Recycling Cost; The cost of separating parts made of different materials. where Cr is cost of material recovery equivalent to the product of cost of material recovery (and weight of material recovered ( ). k represents types of material recovered, like, copper, steel, etc.

Repair and maintenance Cost

The repair and maintenance cost consists of disassembly and reassembly expenses, which represents time required for disassembly and reassembly at field labor rate, and the expected cost of part and fastener replacement due to damage incurred during disassembly and assembly.

Remanufacture Cost

The remanufacture cost imposed by the fastening method also consists of expenses related to disassembly, reassembly and the probability of part and fastening method failure.

In general, the remanufacture cost is modeled as follows:

Crm = Remanufacture cost, Td = Disassembly time, Ta = Assembly time, h = Labor rate ($/hr.), = Probability of fastener failure in disassembly and assembly, Cf = Cost of fastener failure, = Probability of part failure in disassembly/ assembly, = Probability of part failure in fastening-method extraction, Cp = Cost of part failure. The probability of part damage during disassembly is defined to be zero, i.e.. The probability of fastener damage in disassembly, i.e. and the general remanufacture cost reduces to: Crm = (Td + Ta)h + Cf + Cp . If the part cannot be repaired, the consequential cost is part replacement cost. In such cases, and. The new cost equation for remanufacturing is: Crm = (Td + Ta) h + Cp. The remanufacture cost will include disassembly and the consequential cost of part and fastener failure. For Pf = 1 and Ppe = 1, the general remanufacture cost reduces to:

Crm= (Td + Ta) h + Cf + Cp.

Example of Recycling

A hypothetical example for the recycling of materials from disassembly of a system is presented. The system parts are made essentially of copper and steel, although some other materials are there but they have to be dumped as it could not be recycled. Total weight of the system is about 24 tons. There are 3 (m=3) similar joints but only 2 (n=2) different types of fasteners. However, among the 3 similar joints, 2 fasteners are in contact with same type of materials (g =2). We need different types of tools to disassemble the components of the system and times taken to disassemble the components are:

All times are given in hours. Materials that are shredded are mostly dumped and that is about 10 tons. The shredding equipment is quite efficient and takes only 20 hrs. to shred it. The shredded components are dumped and the weight of dumped material is also 10 tons. The cost of steel recovery is $15/ton and cost of copper recovery is $100/ton. Steel 12 tons and copper 2 tons are recovered. The dumping cost depends on the land price, and other special materials, chemicals, cover etc. are used in dumping. The weight of material dumped is same as shredded material of 10 tons. The cost of dumping is $1,000.00/ton. We will estimate the benefits resulting from reduction in emissions and energy in analysis of recycling including revenue. The benefits from these aspects are presented below.

, where represents the energy savings from using used steel and copper and are reduction in emissions of hazardous gases (GHG) emissions in atmosphere. The steel and copper are recycled 12 and 2 tons respectively. The average embodied energies are 35 MJ/kg for primary production and 10 MJ/ kg for recycled material. The savings in energy resulting from using recycled steel is 25 MJ/kg. Similarly, for copper the saving in energy is (71-17.75) =53.25 MJ/kg. The reduction in carbon dioxide emissions by using steel is (2.125-0.6) =1.52/kg/ kg and the reduction in emissions due to copper recycling is (5.35-1.3) =4.05 kg/kg. (Ashby, 2007). The external cost of emissions should be considered as the cost of containing the hazards due to CO_2 emissions. It should be considered as savings or benefits of recycling. Considering the savings due to reductions in emissions as $5/ton of reduction in CO_2 emissions, the total benefit from reduction in CO_2 is;

. This is the total energy saving due to recycling of steel and copper. The energy cost of $0.031/MJ is for the energy from grid. The benefits due to reduction in emissions is

Total benefits due to recycling on energy savings and reduction in emissions is $84301.5.

The benefit from recycling of both steel and copper (Rm) is calculated as;

Some disassembled mechanical components are difficult to reuse, however, components like, gears, flywheels; springs, etc. are easily reused. Here five gears are reusable after disassembly and the sale price of reused gears as $400.00/gear. Hence, the revenue occurring from reusing of gears is

. The total cost (TC) estimated below.

(Disassembly cost)

Shredding cost (Cs) = , (Cr) = (recovery cost). Dumping cost (DC) = ,

Total cost (TC)= $405.00+$7000+$380.00+$10,000=$17,785.00.

The net profit from recycling =Total Revenue-Total Cost =$ 93715.5 and The Benefit-Cost ratio.

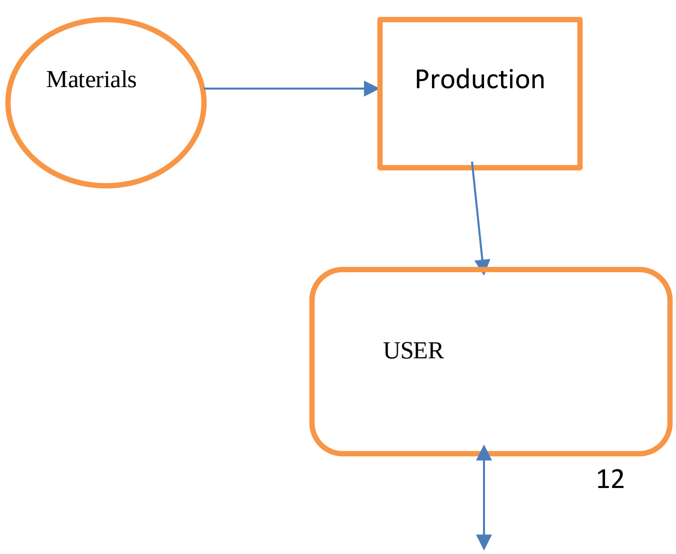
The Benefit cost ratio is greater than 1 and is acceptable. The basic principles of sustainable green design and manufacturing with proper examples need to be included in the curriculum to transform the undergraduate education.

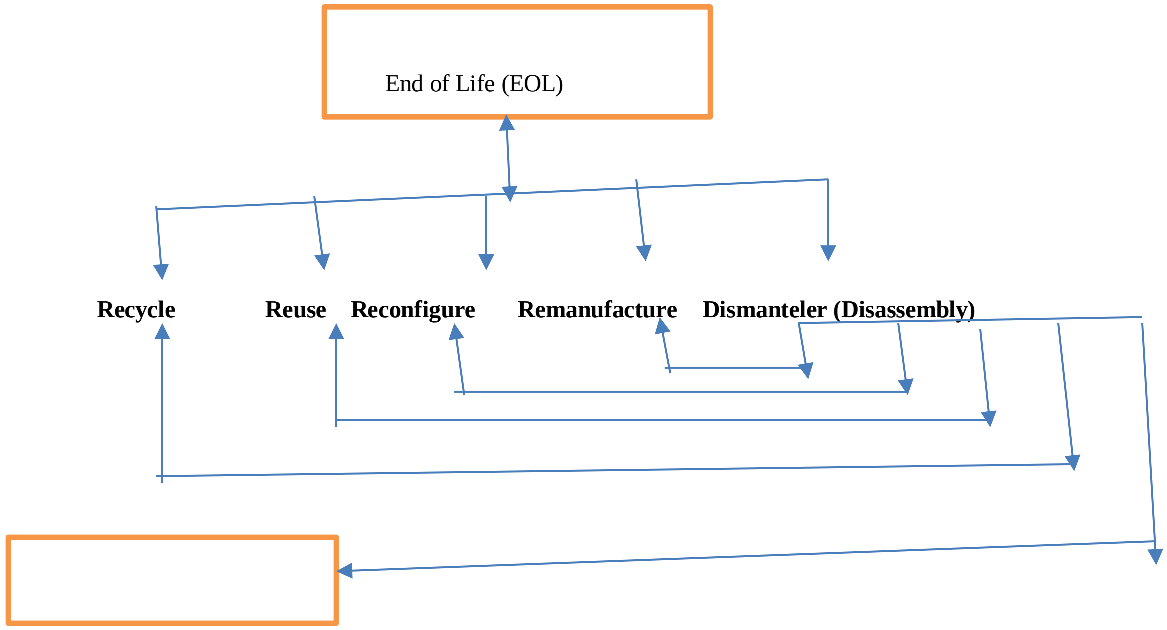
7. Concept of Green Manufacturing

For sustainable manufacturing profit is essential for all primary, secondary, or tertiary industries. Profit will encourage sustainable development. It is essential that costs including operation and maintenance are minimized. The common components of costs and their contribution towards the total cost of products is presented as: manufacturing cost = 40%, Engineering and design cost = 20% Administrative and marketing costs = 25% and Profit = 15%.. This shows that to make th enterprise more sustainable the costs of engineering and manufacturing must be decreased, so that profit increases. However, we must not miss the environmental impact of manufacturing and design. The ecology of production process helps to improve knowledge of various aspects such as use of materials, reduction of waste, and reduction/prevention of pollution during manufacture of the product.

The mechanical engineering design and manufacturing courses should also include the energy required for the product manufacturing energy as well as the embodied energy. The reduction in the total energy not only reduce cost but it will reduce the GHG emissions as energy consumption is directly related to environmental degradation. ABET in their document Engineering Criteria 2000 states that students must be prepared for professional practice through a curriculum that includes "most of the following considerations: economic, environmental; sustainability [italics added]; manufacturability; ethical, health and safety; social; and political." Just may be 80's ABET did not insist on ecological considerations and University can disregard or ignore such ethical concern. In present age due to increasing consumption of materials and energy and increasing GHG emission and consequential pollution and finally global warming, ecological considerations are compelling imperatives which Engineering Schools cannot ignore. These concern has generated immense interest in the Sustainability Science and its inclusion and integration in the Mechanical Engineering Curricula should not be ignored. US universities are beginning to introduce the principles of sustainable development into their curricula.

Green manufacturing is defined as the creation of manufacturing products that use materials and processes that minimize negative environmental impacts conserve energy, and natural resources, are safe for employees, communities, and consumers, and are economically sound. The effect of manufacturing on environment, greenhouse gas (GHG) emissions and global warming should be emphasized in engineering education. Renewable energy sources like wind power, solar power, natural gas, etc. will reduce GHG emissions considerably. Manufacturing processes consumes enormous energy resource and it has significant impact on the environment. Therefore, manufacturing processes courses should emphasize on minimizing the energy requirements for the materials as well as for manufacturing processes, and exergy transformations in manufacturing processes. Integration and application of sustainability considerations in manufacturing can also turn into asset in the competitive global manufacturing atmosphere. Consumers are becoming conscious of goods and services which are environmentally friendly. To cap it all, investors and Wall Street evaluate products and industries based on environmental risks and environmental impact before investing. Therefore, industries are going beyond profit, toward sustainability. The waste minimization requires knowledge of the production process, and tracking of materials from their extraction to their return to earth (cradle-to grave). The Fig. 8 below shows various aspects of Sustainable Manufacturing.





Landfill: Shredder, Parts for recycling, Reuse, other Utilization, Special industrial waste, Destruction, to Landfill

Figure 7: Sustainability in Manufacturing

7.1 Curriculum development in green design and manufacturing for sustainability

The ABET outcome 11 emphasizes that mechanical engineering students should understand the impact of engineering solution on health, safety, the environment and welfare of the public. The course being developed will be able to integrate these considerations into their design and manufacturing practices. The course outline for Green Design and Manufacturing for Sustainability is presented below.

1. Introduction to ecology, sustainability principles, green design and manufacturing of a product.

2. Material Selection; Eco-properties of materials, merit Indices and material Properties Chart,

3. Analytical Techniques; Design for minimization carbon footprint & embodied energy, green design constraints, recycling, reuse, & end-of-life treatment, life cycle analysis, mass & energy balance in manufacturing systems.

4. Computer aided design, FE analysis and green considerations in mechanical component design.

5. Cost estimating & consumer considerations; recycling, reuse, and end of-life (EOL) considerations.

6. Environmentally Benign Manufacturing processes; Green Manufacturing; Theory and Practice, Reduction of energy consumption in material removal & forming processes, Reduction of waste and toxic dispersion of manufacturing, Health & safety considerations in manufacturing.

7. Quality consideration and quality for sustainability, Analysis of snap fit design.

8. International regulations for sustainable design and manufacturing.

7.2 Sustainable Manufacturing

Manufacturers across many industries increasingly emphasize sustainability. Design –for- sustainability (D4S) takes a holistic approach analyzing operational efficiency, safety, functionality, productivity, materials use, ease of operation, and maintenance. The Sustainable Manufacturing would be open to undergraduate and graduate engineering students along with MBA's. The course is designed to be multidisciplinary where project groups will comprise of students from all engineering disciplines including business major. The ABET outcome 9 emphasizes the importance of interacting with people in disciplines outside of mechanical engineering. The course is being developed as a common course for both engineering and MBA students. The various aspects of sustainability will be presented through case studies from real world. The techniques and economics of waste reduction, recycling, cost/benefit analysis including life cycle cost will be presented. Engineering and business students will join in small groups for product development. The course outline is presented below.

1. Introduction to sustainability in manufacturing; Characteristics of successful product development.

2. Net shape manufacturing and minimization of energy; Sustainability measurement throughout life cycle

3. Thermodynamics in manufacturing and Energy analysis

3. Economic analysis; technological advancement for green manufacturing, allocation of resources.

4. Environmental impact & steps to reduce it through redesign, remanufacturing and data mining

5. Green Product specifications; metrics of sustainability & cost model of the product and the process.

6. Sustainability in new product development; selection matrix; combine and improve the concept.

7. Design for manufacturing sustainability; cost, wastage, energy, quality and environmental impact.

8. Managing Green Manufacturing Projects; PERT & CPM, risk in green manufacturing, project evaluation.

<u>Sustainable Engineering Education</u>

Redesign

1. Less material:

Design for Manufacturing, Life

Cycle Analysis

2. Less Power: i. Less GHG emission; ii. Carbon Dioxde Emission

3. Less Resources: End of Life considerations: i. Reuse; ii. Recycle; Reconfiguration.

Engineering Education needs retooling and restructuring of all engineering courses from Undergraduate to Graduate level by:

i. Modifying the Curricula
ii. Introducing some Apex courses
iii. Interdisciplinary courses

Some **Graduate Level Courses** to be developed to include Sustainability in the curriculum are introduced below.

1. Green Mechanical Design

Topics Included:

1. Intro to green design and sustainability; Sustainability, Design for Environment (DfE).
2. Business concerns for green design, metrics for green design. Environmental analysis; footprint indicators, Life cycle assessment,
3. Mathematics for green design; minimization of materials content, Break even analysis for end-of-life calculation, Life cycle accounting, Cost/Benefit analysis.
4. End-of-Life Considerations in Product Development
   4.1 Mathematics of Reuse and Recycling; materials saving, energy savings, Carbon footprint & GHG emission.

4.2 Mathematics of Remanufacturing, Reconfiguration, and landfill.

5. Green Spring Design; material selection based on sustainability, minimize total embodied energy, end-of-life treatment for helical compression and torsion spring, Belleville springs and miscellaneous spring.
6. Design-for-Environment of Gears; Spur gear, Helical gears, worm gears, and Bevel gears, Gear design for least embodied energy, least power consumption in manufacturing of gears, End-of-life considerations for gears, Reuse, recycle, and remanufacturing of gears, life cycle analysis of gears.
7. Use of Bearings and End-of-life considerations; Sliding-contact bearing, materials selection, lubrication selection for least toxicity, design of green bearing; Ball bearings; bearing life estimation, ball bearing selection, reduced environmental footprint by reusing and recycling bearings, recycling of lubricants. Plastic Bearing.
8. Design for Assembly and Disassembly; Press & shrink fits & tolerances, effect on cost and strength of the assembled components, stresses in joints, end-of-life considerations of fasteners, design for environment (DfE) of fasteners, Reuse and Recycling of fasteners, materials power, and energy savings, Life cycle analysis of fasteners.

2. Environmentally Benign Manufacturing

1. Introduction to green manufacturing; Life-Cycle thinking in manufacturing, environmental analysis; footprint indicators, predictive simulation and risk analysis, reduce the total life cycle cost, reduce adverse impacts to worker's health.
2. Mathematics for Sustainable manufacture; optimization, minimization cost and energy, end-of-life consideration in grave to grave analysis, Benefit/Cost analysis, Break-even analysis for cost and benefit, sustainable engineering toolkit, GHG emission and estimation,
3. Thermodynamics in Manufacturing Sustainability; Lie cycle assessment, methods for materials and energy balance, estimation of energy consumption in manufacturing operations, Environmental burden of cutting tool design, National emission standards for hazardous air pollution (NESHAP); compressed air, burner control, process control, motors, pumps & fans.
4. Eco-manufacturing Processes; Materials and Process families, Energy requirement of materials, Strategy for minimization of energy and Eco-impact, Life cycle analysis & selection strategies.
5. Milling Machine Life Cycle Assessment and Performance; Narita's algorithm for environmental burden estimation, Burden of coolant & lubrication, Estimation of energy footprint and environmental burden of cutting tool and Milling Machine.
6. Turning Operation and Life Cycle Analysis (LCA) of cutting; Materials & Energy balance, Environmental Burden of single point cutting tool, waste stream after machining, Environmental burden of Dry Vs Wet manufacturing and minimum quantity lubrication (MQL) during machining.
7. Sustainability Considerations in metal cutting; Coolant selection, coolant concentration, contaminant control and removal, representation of eco-indicators of tool materials and estimated energy footprint for tooling, Environmentally Friendly Machining Model.
8. Eco-friendly Foundary Processes; introduction to solidification of Foundry Process, environmental issues and efficiency of metal casting, EPA's environmental statistics for Foundry industries, Energy use compared to metal removal processes, environmentally conscious Sand Casting, Shell molding and investment casting, Heat transfer in casting and continuous casting, solidification time estimates and environmental impact.
9. Eco-Friendly Metal Forming Processes; Design considerations in forming operation, energy estimates and comparison with other manufacturing operations, observations on energy use pattern of different forging operations, mass balance and energy balance, Health hazards of forming industries; forging, rolling, extrusion, and shit metal processes environmental and health impact; energy and power calculations in forging, forming, and sheet metal industries, health hazards of Heavy Metals.

3. Product Development under Sustainability Considerations

This Graduate course is open to majors in Engineering including MBA students from Business School. The course will detail the concept of a Product Development Under Sustainability consideration. It will detail the principles of sustainability, industrial requirement and ecological considerations of a product. It will include a group project and case study.

1, Sustainability; a sense of urgency, emergence of sustainability, global sustainability agenda, response of industry and regulations, rediscovery of ancient values, green expectation, how clean is Green? confronting climate change, no substitute for water, recycling technologies.

2. Design for Sustainability; Sustainable initiative, cleaner production, design for sustainability, Life Cycle Analysis, Design for Disassembly and recycling, material flows and cycles.

3. Industrial Ecology and Sustainability; Global warming; material and heat balance, energy balance, Embodied Energy economics.

4. Economics of Sustainable Engineering; Cost-Volume relation, Life-Cycle Cost analysis, Efficiency and life cycle cost analysis of a pump, reduced energy cost etc, Cost estimating techniques, Benefit-Cost relation for Recycling,

5. Environmental impact & steps to reduce it through redesign, remanufacturing and data mining.
6. Green Product specifications; metrics of sustainability & cost model of the product and the process.
7. Sustainability in new product development; selection matrix; combine and improve the concept.
8. Design for manufacturing sustainability; cost, wastage, energy, quality and environmental impact.
9. Managing Green Manufacturing Projects; PERT & CPM, risk in green manufacturing, project evaluation.

A Group Project will be assigned to each group and it should be designed and manufactured under the sustainability consideration. Case studies will be presented for every topic detailed above related a relevant industry.

Grading Policy:

Test I ---------- 30%, Final ------------30%, Group Project------30%, Quiz----------------10%.

4. Sustainable Engineering Economic Analysis

The course will include the basics of engineering economics for sustainability. It will detail the economic principles as well as industrial practices for sustainability. The regulations for green engineering and product development for most of the industrial economics of the world will be presented with major emphasis on US industries practices.

1. Industrial Ecology and Economics; Why green? Major industrial economy and their practices, Does Green makes sense for industries? Global warming and its effect on economy, Eco-labelling program, Sustainability goes mainstream, evolution of environmental strategies.
2. Economics for Sustainability; Mathematics of Profit Vs. Sustainability, Grave-to-Grave Life Cycle Cost Analysis, Economics of Solid Stat Vs. LED lighting, economics of design for recycling for plastics in electronics.
3. Economic Analysis of Public Sector; From waste to Power and Money, Investment objectives, Viewpoint for Analysis, the Benefit-cost ratio analysis, other effects of Public Projects; Project financing, project duration, quantifying and valuating Benefits and disbenefits, Project Politics & sustainability.
4. Selection of Minimum Attractive Rate of Returns: What is rate of return on Public Projects; Dam, Power station, Highways, etc., Sources of Capital, Cost of Funds, Investing opportunities.
5. Economics of Inflation and Price Change affecting Sustainability; Price trends in Solar Technologies, Meaning and Effects of inflation, Analysis of Constant Dollars Vs. the-current dollars on sustainable development, Inflation effect on after tax estimation.
6. Income Taxes for Corporation; Calculation of taxable income, Economic Analysis taking Income tax into account, Effect on income due to Carbon tax, and monopoly tax, Break-even point and its effect on depreciation, profit, and sustainability.
7. Depreciation and Sustainability; Depreciation and intangible Property, Basics of Depreciation, Depreciation and End-of-life considerations, Depreciation and Asset Disposal, Depletion of resources materials, cost depletion, cash depletion etc.
8. Uncertainty in Future Events; Estimates of Uncertainty estimation and their use in economic analysis for sustainable development, a Range of estimates, Probability and Joint Probability distribution for new green products, Expected value and sustainability, Economic Decision Trees; Risk, Risk Vs. Return as multiple objectives.
9. Future Worth Analysis; Clean and Green, Future Worth Analysis, Payback period of an investment, Sensitivity and Breakeven analysis. Engineering Education and Sustainable Development.

9. Conclusions

This paper presents development of two courses for teaching sustainability in mechanical design and manufacturing along with modules for teaching. These courses offer integration of life cycle analysis, environmental impact, and end-of-life (EOL) considerations for engineering products. Design and Manufacturing are two core (required) subjects for undergraduate in several engineering disciplines including mechanical engineering, aerospace, civil, manufacturing and industrial engineering. In-depth coverage of such topics as environmentally friendly material, sustainability, green design of components, the life cycle cost including disassembly, and environmentally conscious manufacturing with examples and homework will prepare our graduates for tackling the sustainability problems of world. It is an attempt to present some ideas for inclusion and modification of Engineering mechanics, Mechanical Design, Design and Manufacturing, and Manufacturing courses to include sustainability considerations.

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