ARTICLE

Green Manufacturing

*Major General T. M. Mhaisale, VSM

"Earth provides enough to satisfy every man's need, but not every man's greed"

- Mahatma Gandhi

Introduction

The world has entered a very crucial phase where the four Es (elements) which are going to determine the future of the mankind: ecology, equity, economics and emerging green technologies (EGTs). The scientists have come to the conclusion that the maximum carrying capacity of the mother earth is 9 t0 10 billion. This is based on calculations, of the available resources on the Mother Earth, and the rate of consumption of these natural resources, carried out at Harvard Business School, (Wolchover, N. (2011)). As per the UN estimate, by 2050, the population of the earth will be 9 billion, and by 2100, it will be 10 billion, as against the existing 7.8 billion [Dorling D. (2020)]. This implies that exactly in another 4 decades, we are on the verge of reaching a breaking point. Needless to say, the environment assumes a predominant role due to its negative impact due to release of GHG (greenhouse gases) gases and increasing degradation of natural resources. followed by the people issues such as social equity, job opportunities, health and safety, fair practices, et al. Businesses are meant to generate profit, and their success in economy is indispensable for their very existence. The technologies are providing an enabling and force-multiplier effect.

Manufacturing activity is central to the growth and prosperity of the mankind and is an unstoppable sequel to industrial revolution. This was the primary reason for the European dominance over the entire world, immediately after the industrial revolution in 1760. However, in view of the altered dynamics characterised by rising environmental population, reckless exploitation of natural resources, including water and fossil fuel for generation for energy; manufacturing technologies and practices need to be perceived and implemented from a fresh perspective. That is where GM will play an increasingly pervasive role in addressing these problems, which have a deleterious impact on the quality of a human life. There is also a need to differentiate between sustainable manufacturing and GM. GM includes all practices connected with environmental concerns that constantly incorporate environmentally sound manufacturing processes and products. GM considers this decrease or elimination of waste and pollutants, from the start. It also considers prevention, recycling and green product design (eco-designs). Sustainable manufacturing is the creation of manufactured products through economically sound processes that minimize negative environmental impacts while conserving energy and natural resources and have a minimal negative social impact too. We will confine our scope to GM in this paper. However, it must be appreciated that the products under GM must also provide the necessary product safety and ease of use features.

What is Green Manufacturing?

A nation that destroys its soils destroys itself. Forests are the lungs of our land, purifying the air and giving fresh strength to our people. – Franklin D. Roosevelt, 32nd President of USA. Green Manufacturing is a process or system which has a minimal, non-existent, or negative impact on the environment (Dornfeld D. (2013)). The definition proposed by the U.S. Department of Commerce is, 'the creation of manufacturing products that use materials and processes that minimise negative environmental impacts, conserve energy and natural resources, are safe for employees, communities and consumers and are economically sound.' The term green implies a process which reduces the environmental impact of a manufacturing process or system as compared to the earlier state. This implies that a GM process has the effects of: consuming minimum raw and natural resources including water and energy, producing minimum waste, consuming less coolants, minimising GHG emissions, toxic liquid and solid waste. GM promises to address the problems of the conventional manufacturing on the environment as well as degradation of natural

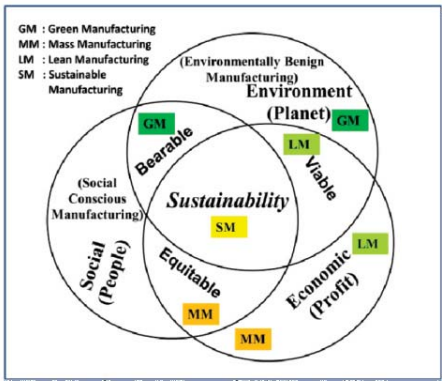

Figure No. 1: Manufacturing in Context of Triple P Sustainability Concept
Source: Dornfeld D. (2013)

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resources. Let us consider the practice of GM with respect to the three pillars of sustainability. We can see that the practices such as GM, lean manufacturing, sustainable manufacturing, environmentally sustainable manufacturing, mass manufacturing; have all cropped up in the context of mapping of manufacturing in the context of Triple P (Planet, People, Profit) approach. The same can be seen in Figure No.1. GM will be relevant where environmental and social issues overlap, as also purely for the environmental issues. Lean manufacturing will be relevant where we have the overlap of both environment and economy, as also where economy is a relevant issue. Therefore, the stress in this case is on lean manufacturing, whereby consumption of resources, eco-efficiency, environmental pollution and other impact on economy become the determining factors. However, when both social and economic parameters are satisfied, one goes in for mass manufacturing. Hence the philosophy of more at less for more (MLM) philosophy becomes more applicable in this case.

Key Performance Indicators

European Commission developed EMAS (Eco-management and Audit Management System: which was an environment management instrument) for the purposes of enabling organisations to asses, manage and continuously improve their environmental performance. It was started in1993. It has laid down following factors as performance key indicators as per the latest version which came into effect from 11 January 2010 (all are on an annual basis). We have a similar document laid down by the OECD (Organisation of Economic Cooperation and Development) through OECD Sustainable Manufacturing Toolkit [oecd.org (2011)]

(a) Consumption of energy

(b) Generation of alternate energy from the renewable energy sources

(c) Different natural resources used as raw materials

(d) Total water annual consumption

(e) Total generation of waste

(f) Total generation of hazardous waste

(g) Use of land

(h) Total emission of Greenhouse Gases (GHG)

(I) Total air emission

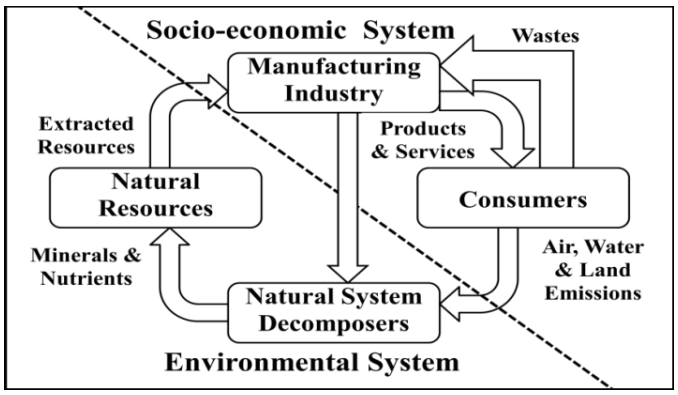

Figure No. 2: Different Perspective of GM
Source: Paul I., Bhole G. and Chaudhari J. (2014)

However, these parameters must have a measuring unit defined, must be measurable accurately, their targets for achievement must be laid down and compared at a pre-determined frequency (normally yearly).

One must appreciate that, all systems are interdependent, notwithstanding the fact that the human being is in dire need of nature and not vice versa. Keeping this mind, a different system of a perspective of sustainability can be seen in Figure No. 2. Here all sub-systems of sustainable manufacturing are shown. In this perspective, manufacturing subsystems (manufacturing industry, products and services), coexist alongside human (consumers), ecological, and natural subsystems (natural system decomposers and natural resources). Therefore, sustainability as a philosophy must be considered in conjunction with the broader environmental and socioeconomic systems [Paul I., Bhole G. and Chaudhari J. (2014)]. Therefore, it is implied that GM, which is a part of sustainable manufacturing, involves green operations, (which is also referred to as product stewardship) in a way, are a part of the environmental resources management system. Hence the products, processes, resources extraction and consumption, emission of greenhouse gas (GHG) emissions, water pollution, land pollution and emission of other toxic materials should be considered in a holistic manner.

Green Manufacturing Value Chain

GM follows a typical cycle, which is given in Figure No. 3. It begins with the design of a product. This is also known as eco-design. Here we design the product for a minimum

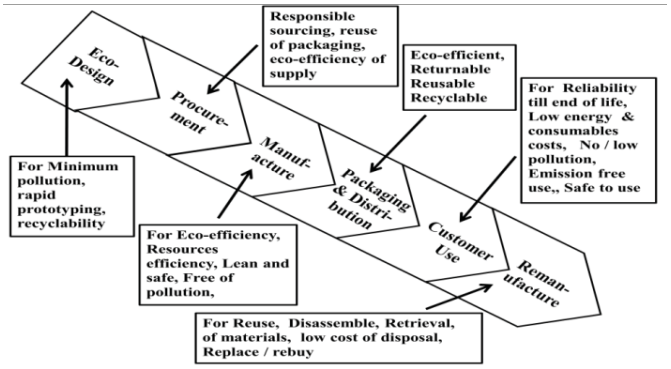

Figure No. 3 : GM Value Chain

environmental impact. This includes reduction of pollution control, reduction of GHG emissions, liquid and solid toxic substances, and recyclability. We resort to rapid prototyping, so as to ensure that the prototype (minimum viable product) is available for testing as early as possible. Thereafter we go to procurement, where responsible sourcing is the method of ensuring that the supplier himself meets the criteria of a green material. Moreover, recirculation of packaging, and eco-efficiency of supply has is taken into consideration. In the manufacturing phase, we ensure eco-efficiency (minimum use of resources including energy sources and water), freedom from pollution and lean and safe manufacturing. In lean manufacturing we ensure use of a minimum material, minimum storing of material [using JIT (just in time) concept], prevention of generation of waste, et al. Here is where EGTs will be extremely useful. For packaging and distribution of the product to the customers we ensure that the packaging is returnable, reusable, and recyclable (in case it is of material such as paper, single usage plastic, glass, et al). The product when being used

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by the customer till the end of its life, must be safe, should not generate any kind of pollutants or GHG emissions, should use less energy and other consumables. After the customer has used the product till its end of life, the product must be either re-manufacturable for reuse, should be easily disassembled, mono-materials could be extracted from the same, or it should be safely, cheaply and conveniently disposable, without any pollution or waste generation. Hence many times, this value chain is also considered as a close loop.

R6 Concept as Adjunct to Green Manufacturing

The product must have minimum carbon footprint throughout its life cycle; be safe to use / dispose off; and use minimum of resources, energy and water. Here is where the principle of R6 must be explained. The product must be sound from point of view of rethink/reinvent, refuse, reduce, recycle, reuse / repair/ reclaim, replace / rebuy, in order to qualify itself as a green product [Alatervo S. (2013)]. At design stage itself we have to question and rethink whether the product could be used for something else also, whether the same could be reinvented so that a better product from point view of eco-efficiency and reduction of pollution with a better LCSA (Life Cycle Sustainability Analysis) methodology available. The user may refuse to the necessity of the product itself, adopting a minimalist approach. The product could be recycled or reused. The product could also be reclaimed, repaired or reused as this will leave behind no carbon footprint. Next time while replacing or rebuying the product, point about the maximum of recycled or green content in the new product needs to be considered, as that will contribute to the reduction of carbon footprint.

Ecosystem for Green Manufacturing

The ecosystem required for Green Manufacturing is shown in **Figure No. 4.** It starts with the corporate culture whereby the green practices must become a part of the culture of the organisation. This apart, a certain degree of maturity in following the concept of lean thinking and manufacturing is necessary. However, the board of directors must not only support this, but also become its driver and watch guard. The board of directors must play an active role in policy formulation, building of capacities and capabilities, formulating a strategy towards achieving this goal and earmarking resources for the same. This apart, it must oversee and monitor the progress through the management. We need EGTs to be used, which must carefully evaluate and identified. The tools such as LCSA, R6, eco-design, eco-innovation, lean manufacturing, and others as necessary must be not only used, but the competency of

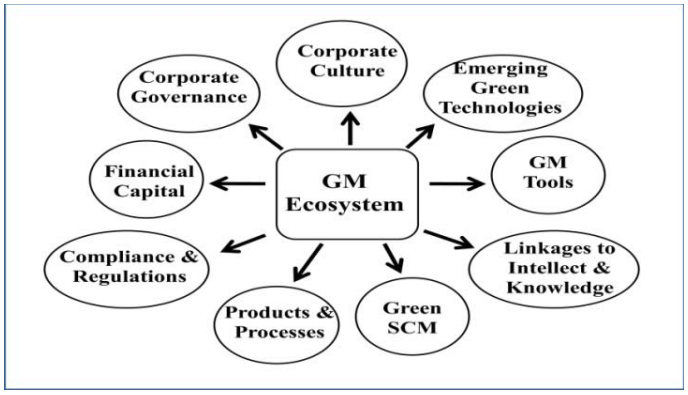

Figure No. 4: Ecosystem for Green Manufacturing

the organisation as such, must be augmented in their effective leveraging. Linkages with the R&D, academia and other institutions of excellence in GM, must be actively probed as that will ensure the inflow of emerging ideas and open innovation. Necessary compliance and regulations as necessary must be ensured, as these are compliance requirements. Necessary finances including funds from investors, own reserves and government subsidies must be availed of. The company has also to ensure that the green supply chain suppliers are properly evaluated, as the raw materials and input services and utilities also must be governed by the green concept. Lastly, due analysis must be carried out and mechanism for the same must be instituted so that products and services meeting with the specifications and regulations along with cost-benefit analysis are identified for the production line.

Green Manufacturing Tools

What are the GM tools? The GM tools are thematic in nature such as LCSA, R6, DfEI, DfM, DfD&D, eco-design, PDCA (Plan, do, check and act), lean manufacturing, green supply chain management, and others. The concepts of R6 and green supply chain management have already been discussed separately. The explanation of the others is briefly described here.

(a) LCSA. This is the complete life-cycle sustainability analysis tool where the complete cost and environmental as well as social impact, over the entire life cycle is calculated. This extends at all stages of the product, right from procurement of raw material, production, while in use with the customer and disposal. This LCSA approach has been advocated by Ramon Arratia (Arratia R. (2012)), which results in resource efficiency. The paper alludes to a report produced by Accenture and World Economic Forum in 2012, whereby they have suggested that $ 2 Trillion worth of economic output could be at risk by 2020, if global economies fail to respond to shortage of only one resource, iron. Similar is the case with the other natural resources such as water, energy, materials, food, et al. The evolving regulatory frameworks around the world are veering towards rewarding manufacturers of products that are more resource efficient. That is where the advantage of LCSA giving the designers a clear objective to guide the design of their products, focusing on key impacts rather than merely creating 'feel-good' green gimmicks, has been highlighted.

(b) Lean Manufacturing. Lean manufacturing is a methodology that focuses on minimizing waste within manufacturing systems while simultaneously maximizing productivity. It is centred around 5 principles : value of the product and services; value stream which is the totality of the product's life cycle staring from raw material, manufacturing, packaging and distribution, use and disposal; understanding flow so as to eliminate waste all along the chain: pull meaning that product is manufactured only when required; and perfection meaning continuous improvement. Lean removes 8 kinds of waste: defects, excess processing, overproduction, waiting, excess inventory, excess transportation, excess motion and non-utilised talent. Lean manufacturing ensures practices such as Lean Six Sigma and others, which have a primary ain of ensuring efficient use of raw materials and prevention of generation of waste.

c) Eco-design. Eco-design consists of integrating environment protection criteria over its entire life span during the design stage itself. This will involve design for eco-efficiency (minimal use of resources, energy and water), design for manufacturability, design for functionality, design for minimal use of resources

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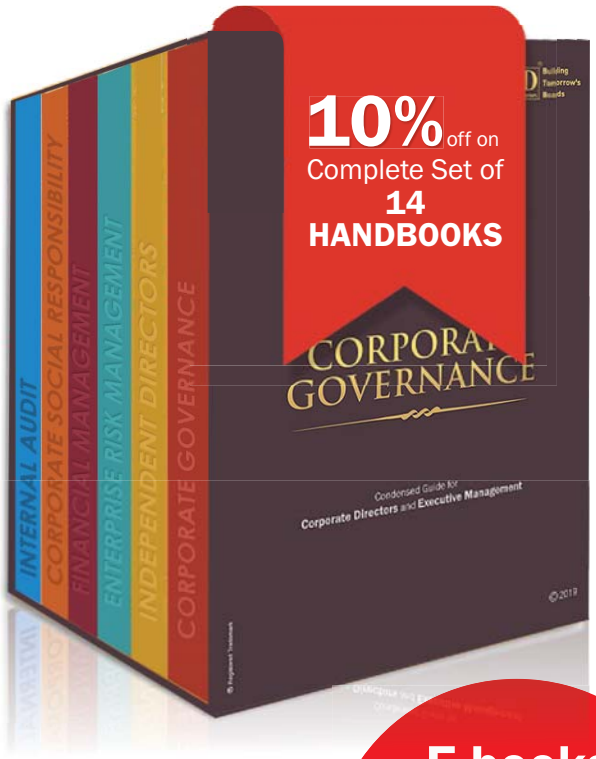

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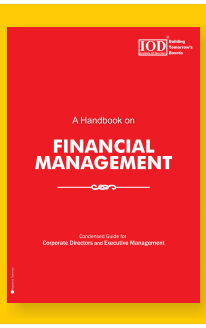

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during use, ease of use, minimisation of pollution and waste generation along the entire life cycle after manufacturing. The main criteria taken into account are: consumption of raw material, manufacturing, packaging and transportation, consumer use, r end of life (recovery and recycling). It is an extremely specialised tool.

(d) PDCA. This is a thematic tool, which leads to continuous improvement by going through Plan-Do-Check-Act cycle. The parameters are measured as each stage and reset during planning in each cycle to attain continuous improvement.

Emerging Green Technologies (EGTs)

Technology is the crucial driver for economic growth and competitiveness, of the company as well as the nation. Emerging green technologies are therefore the harbingers of the growth, productivity and prosperity of any nation, and that is the reason as to why the leading countries such as USA, Germany, UK, Japan and others have a considerable investment in order to invent, promote, and leverage EGTs. The technologies which ensure efficient use of natural resources including water and fuels, reduction / elimination of pollution and wastage along the value chain, cleaner production of products or services (UNIDO (2014). How do you define EGTs? As per UNIDO : EGTs are defined as a mix of technologies that have already reached a certain technological maturity, but still have comparatively low market shares around the world (for example, electric vehicle), and technologies that are still in a comparatively early stage of technological maturity, although in principle already applicable in daily life (sensor technologies in Industrial Revolution 4.0) This UNIDO study also highlights that the opinion regarding increase in productivity with EGTs as against the productivity remaining the same, is almost evenly divided, although the outcome in respect of improvement in other parameters (environmental protection and social impact) was unanimously good. It will be appreciated that EGTs hold a great promise for the metamorphosis of the mankind itself, as they have a profound impact on all the parameters of GM, particularly, resources efficiency and control of pollution and the transformation of organisational culture as such. The continuous propensity of the mankind to coming out with innovations will lead to a greater number of EGTs with greater efficiency and effectiveness.

Evaluation of Green Supply Chain Suppliers

As pointed out in the ecosystem for GM, green supply chain management (SCM) is an indispensable constituent of the GM. It is the responsibility of the manufacturer not only to ensure that the supplier follows the green practices, it is also obligatory on his part to ensure that the supplier also upgrades his capacity and capability through handholding and necessary assistance, if so required. There are four broad criteria here. A study on GSC management and green-supplier evaluation, establishing evaluation criteria for green suppliers [Guo J. and Tsai S. (2015)]. The evaluation criteria system used in this study comprises four dimensions and 12 criteria as is shown in figure No.5 The four dimensions and detailed content are as follows:

(a) **Green Production:** This comprises of green design, green material use, waste reduction, and energy conservation.

(b) **Green Manufacturing Environment:** The elements covered under this are: reduction of air pollution, reduction of wastewater discharge, and reduction of harmful substance use.

(Source Guo J. And Tsai S. (2015)

(Manufacturing Environment: Transportation)

© Green Management: This will cover: green management system, green selling, and green corporate image.

(d) Green Packaging and Recycling: The three parameters covered herein are: green transportation, green packaging, and product recyclability.

The gradation could be carried out accordingly, through some third agency. The grading is on a scale of 0 to 10. This grading could be carried by some independent agency. The areas needing improvement could be identified and follow up action taken towards achieving the requisite standards.

Advantages of Green Manufacturing

Green manufacturing provides several advantages which are enumerated below. Moreover, through these advantages it also presents the organisation with a unique opportunity of achievements of the UN SDGs – 2030 (United Nations Sustainment Development Goals to be achieved globally by 2030).

(a) Reduction of costs and raw material.

(b) Ensure efficient use of resources including energy and water.

(c) Act as a catalyst for development of alternate renewable sources of energy.

(d) Reduction of emission of GHG gases, fluid as well as solid toxins.

(e) Leads to innovations leading to efficient use of resources and EGTs.

(f) GM results in improvement of the organisational culture, motivation and loyalty of the employees.

(g) By adopting best GM practices, innovation and EGTs, GM makes the organisation future-ready.

(h) GM improves the brand image and brand value of the company.

(I) GM makes the products and processes and the organisation by itself, competitive, an opinion voiced even by the former USA President Barak Obama.

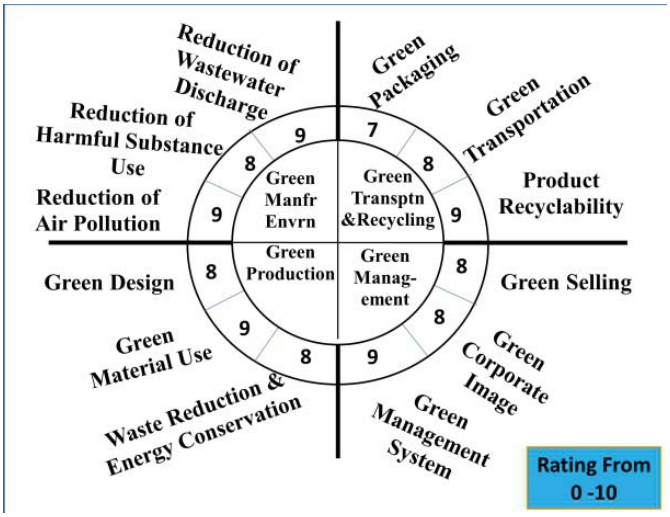

Figure No. 5: Evaluation of Green Supply Chain Suppliers

Conclusion

Green Manufacturing is the renewal of production processes and the establishment of environmentally friendly operations within the manufacturing field. GM not only represents a change in the way these materials are handled, it also emphasizes responsible waste management and recycling in post-production. In addition to reducing environmental stressors, GM can significantly reduce landfill waste. The efforts to achieve sustainable development must be a coordinated venture, with a whole-hearted participation by all stakeholders. Efforts by all the UN agencies such as UNEF (United Nations Environment Program), UNGC (United Nations Global Compact) document, WBCSD (World Business Council on Sustainable Development), IPCC (Intergovernmental Panel on Climate Change), WSSB (World Sustainability Standards Board), et al; have done a phenomenal work, in bringing out methodologies, concepts and necessary standards. Innovative concepts such as green manufacturing which harness the power of EGTs. innovation and green practices and concepts must be harnessed. The world corporate bodies and entities, including those in India, have done a phenomenal work. It is also the duty of the customer to be aware about sustainable development, and to demand such products from the manufacturers. The world has already seen the debilitating impact of COVID-19 all over the globe, although there are many other disasters ravaging some part of the earth all the time. Hence the earth's green cover, biodiversity, atmosphere, ozonosphere, et al; need to be zealously guarded. Hence piecemeal efforts will not provide the desired results. The necessary intergovernmental cooperation in promotion of the EGTs, radical innovations, green practices, necessary compliance and regulatory measures including incentives, and funds on a global scale need to be considered as none of the countries can claim ownership to the mother earth and the spheres surrounding it.

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■