Review Article

Green Manufacturing: A Primer

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Abstract Green manufacturing refers to modern manufacturing that guarantees comprehensive consideration of environmental impact and resource efficiency. It is the renewal of production processes and the establishment of environmentally-friendly operations in the manufacturing industry. It is all about sustainability. It has become a major trend in the 21st century manufacturing industry. This paper provides a brief primer on green manufacturing.

Introduction

The world is faced with challenges of climate change (global warming), high pollution, environmental deterioration, high resource consumption rates, and threats of resource scarcity. The manufacturing sector in particular is now utilizing many critical resources and producing wastes at unsustainable rates. Through manufacturing, the most of the harm has been done by the developed and developing nations. Manufacturing companies consume a lot of energy and use a lot of chemicals and toxic materials. Consequently, a large amount of pollutants is discharged during the manufacturing process [1]. Statistics show that 70% of the global environmental pollution is caused by manufacturing. Since manufacturing is the largest sector of the American economy, the implementation of green manufacturing (also known as manufacturing for environment) becomes imperative as the environmental crisis is getting worse [2].

Two types of manufacturing systems that emphasize waste minimization have emerged: Lean and Green manufacturing (GM). These are regarded as the most competitive manufacturing systems in the world. Lean Manufacturing ensures employees follow standardized procedures for avoiding improper waste disposal and maintain clean workplace. It tries to avoid waste and overproduction. Green manufacturing minimizes waste and pollution. GM is also known as environmentally conscious manufacturing (or environment-oriented manufacturing), which requires environmental responsibility. Traditional manufacturing techniques are transforming Lean and Green manufacturing to benefit the Earth and the bottom line. Researchers have attempted to "build a bridge" between Lean and Green manufacturing systems, in hope that the rapid deployment of Lean can serve as a catalyst to implementing Green manufacturing [3].

Meaning of GM

The term "green manufacturing" (GM) was coined to reflect a new manufacturing paradigm which implements various green strategies and methods too become eco-efficient. The term can be considered at in two ways.

First, GM involves manufacturing of "green" (sustainable) products. Second, GM reduces emission an minimize waste.

Thus, green stands for ecological sustainability and GM is at the center of sustainability revolution. Green manufacturing is a sustainable approach that involves using energy, water, and other resources efficiently to achieve balance with nature. As shown in the green manufacturing process cycle in Figure 1 [4], GM is about reducing or eliminating any negative impact on the environment by a company's manufacturing facilities. It involves manufacturing practices that do not harm the environment during the manufacturing process [4].

Drivers of GM

In order to stay competitive, manufacturing companies are expected to implement green manufacturing and increase product complexity. This is becoming essential in the eyes of customers, investors, and authorities. Failure to comply may lead to fines, penalties, and customers choosing to go to the competitors.

The twelve common drivers of GM include financial benefits, company image, environmental conservation, compliance with regulations, stakeholders, green innovation, supply chain requirements, customers, employee demands, internal motivations, market trends, and competitors. Commitment from the top level management is the most critical factor in the implementation of green manufacturing [6].

International organizations such as the United Nations, World Bank, and Carbon War Room are making notable progress to promote green manufacturing. Stakeholders, customers, and government are increasingly asking companies to be more environmentally responsible with respect to their products and processes. Their reasons for this requirement include regulatory requirements, product stewardship, public image, and potential competitive advantages.

Characteristics of GM

The four "R"s (Reduce, Reuse, Recycle, and Remanufacturing) are one main strategy of green manufacturing. The 4R principles of green manufacturing are illustrated in Figure 2 and explained as follows [7].

- *Reduce:* This requires decreasing the consumption of resources (e.g. energies, water, materials) and emission of wastes.
- *Reuse:* This requires reusing the products with the aim of prolonging the life of the products and reduce the waste.
- *Recycle*: There are two ways of recycle. One of which recycle produces the same kind of new products, the other is when recycle is transferred into raw materials of other products.
- *Remanufacturing:* This is an approach to recover the old products back to the ones close to new products

Applications of GM

Here we present some examples where green manufacturing technologies have been applied successfully.

- *Automotive Industry:* Green Manufacturing is used the automotive industry to differentiate themselves from their competitors. The major automotive companies shave been lining up recently to show off their green credentials. For example, BMW promotes its green manufacturing programs. The company replaces high-solvent paints with water-based ones when possible. Toyota's assembly plant generates green power from local landfill gas. The company's Prius has come to symbolize green motoring in parts of the world. Environmental protection is high on the agenda of Mercedes-Benz. Other automakers such as Ford, General Motors, Honda, and Chrysler have followed suit.
- T*ransportation:* Electric vehicles, fuel cells, and bio-diesel are some examples of this category. Governments around the world are tightening the regulations on emission caused by transportation.
- *Textile Industry*: This industry gathers the agricultural, chemical fiber, textile, apparel, retail, service and waste management sectors. Antibacterial textile structure is used as a potential replacement of synthetic fabrics or cotton fabrics. Carpet industry is an early environmental mover within the textile industry. It is advanced with respect to sustainable manufacturing practices [8,9].

- *Computer Industry:* Apple is a optimizing the energy efficiency of their hardware tools. Motorola improves recyclabilty, minimizes packing, and reduces hazardous materials. All Samsung vendor facilities desire to be 1SO 14000 compliant.
- *Other Companies:* Other companies that have taken similar measures include GM, Ford, IBM,. IKEA, Dell, Johnson & Johnson, and Nike. **Wal-Mart, t**he world's largest retailer, is betting on hybrid technology to power its truck fleet.

Benefits

GM is regarded as the winning strategy to be adopted by manufacturers worldwide.

Manufacturing a product that has the least impact on resources and the environment can yield both economic and environmental benefits for the company. GM will have several benefits and challenges in the years to come. Green manufacturing can lead to lower raw material costs, production efficiency gains, reduced environmental, and occupational safety expenses, and improved corporate image. Some of the benefits of GM are explained below [10]:

- *Cost Reduction:* Energy and water costs are a major concern for manufacturers. Using sources of renewable energy (such as wind, solar and geothermal energy), increasing recycling, and going paperless for bills/documents can save on energy and supply costs.
- *Tax Incentives:* There are credits and incentives offered both at the state and federal levels to help manufacturers offset the costs while making the switch. Tax incentives can be leveraged to invest into new technologies and boost company's productivity.
- *Adherence to regulations:* Although green manufacturing is a good for business and environment, it may be mandatory. Companies may be compelled to pay fines and punishment for violations of anti-pollution legislation. Companies who go green are more eligible for government contracts.
- *Reputation Boost:* As consumers show interest in sustainability, taking your business into that arena can be a great reputation boos and increase your overall sales. When companies go green, it shows in their customer response.
- *Environmental Friendliness:* Every non-sustainable measure impacts the environment. A company can help the environment by simply optimizing existing operations and reducing your reliance on energy resources..
- *Society Impact*: Going green can make your company more marketable. Future generations will benefit from improved air and water quality, and more renewable energy sources.

Challenges

While green manufacturing can significantly reduce our carbon footprint, it can be difficult for companies to do it cost-effectively. A major challenge for engineering managers is to determining in advance the costs of embarking on green manufacturing. Not all nations have or enforce emission guidelines. This will compel companies in the United States to make a business strong case to consumers that they should purchase their products rather than those imported from abroad.

Implementing and operationalizing GM in enterprises is a challenge. Another major concern is how to assess the impact of green manufacturing because there is lack of appropriate performance measures.

Conclusion

Green manufacturing will increasingly be an important issue because it is a crucial component in the international effort towards "sustainable development." It is the only realistic means of realizing modern manufacturing sustainable development. For this reason, green manufacturing has received growing interest in the last few years. It is fast becoming a necessary business practice in the manufacturing industry. It is here to stay.

The field of green manufacturing has a bright future. For more information on the field, one should consult the book in [11] and other books on GM available on Amazon.com. One should also consult the two journals

devoted to GM*: International Journal of Precision Engineering and Manufacturing-Green Technology* and *Green Manufacturing Research Journal.*

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