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Elements of Green Supply Chain Management

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Abstract
The purpose of the paper was to highlight the elements of green supply chain. The rise in greenhouse emissions and pollution of the environments by firms has precipitated the need for organizations to realign their supply chain operations with a view of conserving the scarce resources. Firms in the hospitality industry rely on energy and water as their key resource inputs in ensuring that they offer better services to clients. The paper looks at how firms can implement several elements of green supply chain in their processes.
This is a conceptual paper and the methodology used is a desktop research in which in depth literature review is done to highlight how firms can incorporate green supply chain tools in their supply chains. The analysis is based on previously conducted research from books and relevant journals and articles.
The findings of the paper confirm that firms need to implement green supply chain elements as a continuous process to achieve sustainability in the supply chain processes. The study concludes that firms need to enhance the levels of implementing green supply chain practices in managing their operations. This is an emerging supply chain management paradigm that will enable firms to realize long term sustainability in their operations.
Key words: Green Supply Chain Management Elements

1.0 Introduction

1.1 Green Supply Chain Management

Along with the rapid change in global manufacturing scenario, environmental and social issues are becoming more important in managing any business. Green supply Chain Management (GSCM) is an approach to improve performance of the process and products according to the requirements of the environmental regulations (Hsu & Hu, 2008). The rise in greenhouse emissions and pollution of the environments by firms has precipitated the need for organizations to realign their supply chain operations with a view of conserving the scarce resources. Green supply chain management is defined as “green procurement+ green manufacturing+ green distribution+ reverse logistics”. The idea of GSCM is to eliminate or minimize waste (energy, emissions, and chemical/hazardous, solid wastes) along supply chain (Hervani, Helms, and Sarkis, 2005)

Environmental issues under legislation and directives from customer especially in the US, the European Union (EU), and Japan become an important concern for manufacturers. As a more systematic and integrated strategy, GSCM has emerged as an important new innovation that helps organizations develop “win-win” strategies that achieve profit and market share objectives by lowering their environmental risks and impacts, while raising their ecological efficiency (Van Hock, 2000).

A green supply chains aims at confining the wastes within the industrial system in order to conserve energy and prevent the dissipation of dangerous materials into the environment (Torres, Nones, Morques, & Evgenio, 2004). It recognizes the disproportionate environmental impact of supply chain processes within an organization. It recognizes the disproportionate environmental impact of supply chain processes within an organization. GSCM is the summing up of green purchasing, green manufacturing, green packing, green distribution and marketing. GSCM is to eliminate or minimize waste in the form of energy, emission, hazardous, chemical and solid waste (Olugu, Wong, & Shaharoun, 2010).

Green Supply Chain Management (GSCM) has emerged as an important new approach for enterprises to achieve profit, efficiency and market share objectives by reducing environmental risk and impact (van Hoek, 1999; Hu and Hsu, 2010). With a sudden rise of environmental movements, legislations and concerns during the past decade, a consensus is forming that issues of environmental pollution accompanying industrial development should be addressed together with supply chain management, thus contributing to the initiative of GSCM (Sheu, J.B., Chou, Y.H. and Hu, C.C., 2005).

1.2 Problem Statement

Green supply-chain management (GSCM) is gaining increasing interest among researchers and practitioners of operations and supply chain management. The growing importance of GSCM is driven mainly by the escalating deterioration of the environment, e.g. diminishing raw material resources, overflowing waste sites and increasing levels of pollution. However, it is not just about being environment friendly; it is about good business sense and higher profits. In fact, it is a business value driver and not a cost centre (Wilkerson 2005). Therefore, it's important for firms to understand all the elements of green supply chain so as to ensure that they implement them comprehensively.

Greening the supply chain has numerous benefits to an organization, ranging from cost reduction, to integrating suppliers in a participative decision-making process that promotes environmental innovation (Bowen, F.E., Cousins, P.D., Lamming, R.C. and Faruk, A.C., 2001; Hall, 2003; Rao, 2002). A growing number of corporations are developing company-wide environmental programs and green products sourced from markets around the world (Min and Galle, 1997).

Many progressive companies, such as Wal-Mart, Tesco, Hewlett Packard, and Patagonia, have capitalized on the opportunities of green supply chain management and are therefore very concerned with the environmental burden of their supply chain processes. Throughout the supply chain, customers and therefore firms designing and operating supply chains are particularly sensitive to reducing their carbon emissions (Hoffman, 2007).

2.0 Literature Review

2.1 Conceptual Framework

The conceptual framework for the study was developed based on the framework of green supply chain management by Hervani, Helms, and Sarkis, (2005) who postulate Green supply chain management elements as involving green procurement, green manufacturing, green operations and reverse logistics and finally waste management as independent variables.

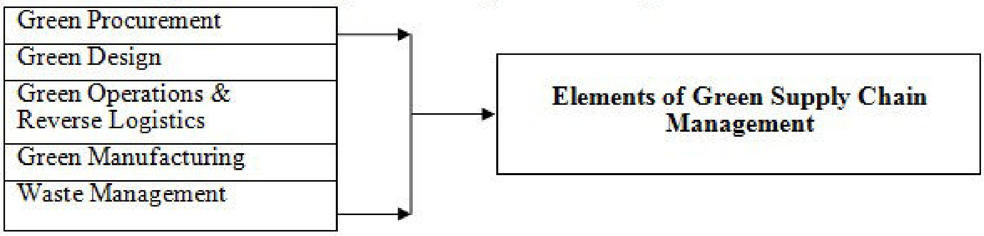

Figure 2.1: Conceptual Relationship of Elements of Green Supply Chain Management

2.2 Green Supply Chain Management (GSCM)

In the case of a single organization, the creation of "green" supply chain makes it a significant competitive advantage in decreasing the costs (to create new markets for businesses), more organic and better cooperation with the suppliers. Moreover, at the national level, green supply chains can help to change the market's orientation to become more "green", together with the creation of incentives for small and medium-sized enterprises to implement right practices to improve environmental protection (Gilbert, 2001).

The traditional green initiatives are associated with many weaknesses and problems. The end-of-the-pipe approach does not eliminate pollutants, but merely transforms them from one medium to another (Sarkis, 2006). Moreover, focusing green practices inside organization may expose the organization to negative environmental performance of other organizations in its supply chain. For instance, the poor environmental performance of small suppliers can affect badly the performance and image of buying companies. In addition, community stakeholders often do not distinguish between an organization's environmental practice and the practices of its suppliers (Rao, 2002; Sarkis, 2006). In recent years, a more externally-oriented approach has been emerged where a firm extends its environmental responsibility beyond its boundaries and tries to reduce sources of waste and pollution throughout its entire supply chain.

This extended responsibility occurs across multiple organizations, upstream and downstream the supply chain, and take different names including product stewardship, closed-loop supply chain, in addition to green supply chain (Canning & Hanmer-Lloyd, 2001).

Activities of "green" supply chain are addressed to the four areas found in the traditional supply chain, such as upper and lower flows, and the activities occurring within the organization and logistics processes (Emmett and Sood, 2010):

1) The company's activities in the field of production might be connected, for example, with the Green Design, Green Procurement or cooperation with the suppliers to convince them to be more green" in their actions,
2) Following-up the businesses on the activities associated with the products' consumption until their total use. Is included here, for the business activity, the recovery and recycling processes, waste management and inventories' disposal from the defaulting companies' warehouses ,
3) The activities taking place within the company, "green" supply chains are focused on the activities such as Green Design, Green Packaging and Production,
4) The logistics processes are distinguished by activities such as JIT (Just-In-Time), fulfilment, lot size management, quality management, and all of them are closely related to the environmental aspects.

2.3 Green Procurement

Green procurement is defined as an environmental purchasing consisting of involvement in activities that include the reduction, reuse and recycling of materials in the process of purchasing. Besides green procurement is a solution for environmentally concerned and economically conservative business, and a concept of acquiring a selection of products and services that minimizes environmental impact (Salam, 2008).Zsidisin and Hendrick (1998) in a multinational investigation identified key factors for green purchasing including providing design specification to suppliers that include environmental requirements for purchased items, cooperation with suppliers for environmental objectives, environmental audits for supplier's internal management, and suppliers' ISO14001 certification.

Despite the fact that green purchasing is an established concept within the purchasing field, common definitions do not exist. One common definition referred to is the practice of companies taking supplier environmental product and process performance into account when purchasing products and service. Carter and Carter (1998) defined green purchasing as: in order to facilitate reusing and recycling resource reduction, the purchasing department should participate in every activities of supply chain management and should more concretely purchase reused, recycled materials so as to reduce the use of resources as much as possible. Zsidisin and Siferd (2001) defined that green purchasing is a set of principles, methods under premise of full considering the impact on the environment. Zhu and Geng (2002) considered green purchasing as: every department in the enterprise consults decision-making to improve business performance by decreasing the using materials cost and end treatment cost, protecting resources and enhancing the enterprise reputation, etc. Martha and Houston (2010) pointed out the potential aim of green procurement is to eliminate waste, and purchasing department will focus on value by comprehensive considering the total cost in the process of eliminating waste ,which should focus on the business of waste disposal activities.

Usually, it can save more cost in the source of supply chain to prevent waste than at the end of supply chain. Purchasing activity is the key starting point of eliminating waste, so a key factor of the successful green purchasing is the condition of company recycling and reusing waste. Hokey and Galle (2001) proposed that reducing the emissions of exhaust and sewage and so on, not only is the premise of ensuring the implementation of green procurement system, but also is the important way to promote the development of green procurement. The type of companies' resources can influence both the purchasing practice, the technology, equipment and facilities of separating waste can impact the purchasing practice.

Stock (1992) thought that green purchasing can improve a firm's economic position, by reducing disposal and liability costs, conserving resources, and improving an organization's public image. Walton et al. (1998) put forward ten top environmental supplier evaluation criteria, among these, second-tier supplier environmentally friendly practice evaluation was viewed as the second most important criterion. In addition, large customers have exerted pressure on their suppliers for better environmental performance, which results in greater motivation for suppliers to cooperate with customers for environmental objectives (GEMI, 2001). For example, Bristol- Myers Squibb, IBM and Xerox have encouraged their Chinese suppliers to develop environmental management systems in compliance with ISO 14001, while Ford, GM and Toyota have required their Chinese suppliers to be certified with ISO 14001 (GEMI, 2001).

Min and Galle (1997) find that the two most highly rated obstacles to effective implementing green purchasing was cost and revenue. In the process of implementing green procurement, the enterprise is bound to increase investment, training staff costs and the communication costs with suppliers, etc, which hence causes the loss of other investment opportunities (Liu and Zhu, 2009) This study will define these the increase of investment and cost as the corporate environmental management cost. Zhu and Geng (2004) found the suppliers stress had greater impact on the implementation of green supply chain through research. Hou (2007) pointed out that the close cooperation of suppliers and buyers would promote the successful completion of green purchasing activities.

In the process of purchasing and procurement, Suppliers must consider the ultimate disposition of the materials and components that enter the firm, purchasing managers can ask upstream members of the supply chain to commit waste reduction and provide environmentally friendly product. Suppliers, e.g. transport service suppliers and product suppliers, can impact firms' green purchasing activities (Carter and Ellram,1998) and drive green supply chain management (Walker, H., Sisto, L.D and McBain, D, 2008) The availability, characteristics, knowledge, ambitions, equipment and actions of the suppliers can have an impact on purchasing (Knudsen,2003) and green purchasing. To achieve an effective environmental performance, the purchaser must take, and be given, the responsibility and resources for educating suppliers and demonstrate on-going commitment (Murray, 2000).The relationship formed with customers described in terms of communication patterns, cooperation and dependency is addressed in the purchasing literature, and in the environmental purchasing literature. Carter and Ellram. (1998) describe customers as having a direct impact on firms' environmental purchasing activities and Walker et al. (2008) investigates how customers' influence drives green supply chain management. The priorities of the customers can influence the environmental management and environmental purchasing.

2.4 Green Design

Green design has been used extensively in the literature to denote designing products with certain environmental considerations. It is the systematic consideration of design issues associated with environmental safety and health over the full product life cycle during new production and process development (Fiksel 1996). Its scope encompasses many disciplines, including environmental risk management, product safety, occupational health and safety, pollution prevention, resource conservation and waste management.

A common approach is to replace a potentially hazardous material or process by one that appears less problematic. This seemingly reasonable action can sometimes be undesirable if it results in the rapid depletion of a potentially scarce resource or increased extraction of other environmentally problematic materials. Several examples of such equivocal proposals are presented by Graedel (2002).

Azzone and Noci (1996) suggest an integrated approach for measuring the environmental performance of new products, while Arena, U., Mastellone, M.L. and Perugini, F., (2003) assess the environmental performance of alternative solid waste management options that could be used. Design under legislation and regulations have been considered by Barros, A.I., Dekker, R. and Scholten, V., (1998), Bellmann and Khare (1999, 2000), Fleischmann et al. (2001) and Das (2002), while Bras and Mc-Intosh (1999), Guide and Srivastava (1997a, 1997b, 1998), Guide et al. (1999a, 2000a), Inderfurth and Laan (2001) and Ishii, K., Lee, B.H. and Eubanks, C.F., (1995) deal with design for remanufacturing. Bellmann and Khare (2000) and Henshaw (1994) take up design for recycling issues, while Krikke, H.R., van Harten, A. and Schuur, P.C., (1999) consider better choices of material.

Life-cycle assessment/analysis is described as a process for assessing and evaluating the environmental, occupational health and resource-related consequences of a product through all phases of its life, i.e. extracting and processing raw materials, production, transportation and distribution, use, remanufacturing, recycling and final disposal (Gungor and Gupta 1999). The scope of LCA involves tracking all material and energy flows of a product from the retrieval of its raw materials out of the environment to the disposal of the product back into the environment (Arena et al. 2003; Miettinen and Hämäläinen 1997; Tibben-Lembke 2002). Attempts have also been made to develop operational models to help companies understand, monitor and assess life-cycle management (Sanchez, L.G., Wenzel, H. and Jorgensen, M.S., 2004).

2.5 Green Operations and Reverse Logistics

Green operations relate to all aspects related to product manufacture/remanufacture, usage, handling, logistics and waste management once the design has been finalized(Lund 1984). Some of the key challenges of GSCM such as integrating remanufacturing with internal operations (Ferrer and Whybark 2001), understanding the effects of competition among remanufacturers (Majumder and Groenevelt 2001), integrating product design, product take-back and supply chain incentives (Guide and van Wassenhove 2001, 2002), integrating remanufacturing and reverse logistics with supply chain design (Chouinard et al. 2005; Fleischmann et al. 2001; Goggin and Browne 2000; Savaskan et al. 2004) are posed in this area.Rogers and Tibben-Lembke (1999) define reverse logistics as 'the process of planning, implementing, and controlling the efficient, cost-effective flow of raw materials, in-process inventory, finished goods and related information from the point of consumption to the point of origin for the purpose of recapturing value or proper disposal.

Reverse logistics activities differ from those of traditional logistics. Reverse logistics networks have some generic characteristics related to the coordination requirement of two markets, supply uncertainty, returns disposition decisions, postponement and speculation. Green distribution consists of green packaging and green logistics. Packaging characteristics such as size, shape, and materials have an impact on distribution because of their effect on the transport characteristics of the product. Better packaging, along with rearranged loading patterns, can reduce materials usage, increase space utilization in the warehouse and in the trailer, and reduce the amount of handling required (Carter and Ellram, 1998).

As a result, they affect network design to a considerable extent. Collection is the first stage in the recovery process in which product types are selected and products are located, collected and transported to facilities for remanufacturing. Used products originate from multiple sources and are brought to the product recovery facility in a converging process (Krikke et al., 1998). Inspection/sorting illustrates the need for skill in the sorting of used products (Ferrer and Whybark, 2000). This may be carried out either at the point/time of collection itself or afterwards (at collection points or at remanufacturing facilities).

The need for environmentally responsible logistics systems is highlighted by Wu and Dunn (1995). The importance of reverse logistics programmes and the process of their development and implementation have also been described in the literature (Poist, 2000 and Stock, J., Speh, T. and Shear, H., 2002). Redesigning logistics networks to accommodate product returns and remanufacturing and re-use of such parts and components can often be profitable and is assuming greater importance in business as well as in research (Tibben- Lembke, 2002). The physical location of facilities and transportation links need to be chosen to convey used products from their former users to a producer and to future markets again (Fleischmann et al., 2001).

Companies need to realize the hidden value in reverse logistics and start to focus in this area (Mollenkopf and Closs, 2005). They need to understand the financial impact of reverse logistics strategies. Srivastava and Srivastava (2005) develop a hierarchical decision-making framework to find the feasibility of profit-driven reverse logistics networks. They find reverse logistics activities profitable for their select category of products. Nowadays, information and communication technologies (ICT) are likely to play a key role in the co-ordination and integration of GSCM activities (Dekker et al., 2004). Problems related to the integration of reverse logistics activities within an organization have been dealt by Chouinard et al. (2005), while Daugherty et al. (2005) find that resource commitment to information technology leads to superior reverse logistics performance.

In recent years, a lot of work related to quantitative approaches in reverse logistics has been published. Shih (2001) discusses in detail the reverse logistics system planning for recycling electrical appliances and computers in Taiwan. Hu, T.L., Sheu, J.B. and Huang, K.H., (2002) present a cost-minimization model for a multi-time-step, multi-type hazardous-waste reverse logistics system. They present application cases to demonstrate the feasibility of their proposed approach. Nagurney and Toyasaki (2005) develop an integrated framework for modelling the electronic waste reverse logistics network which includes recycling, while the framework of Srivastava and Srivastava (2005) incorporates three types of rework facilities. Ravi et al. (2005) use analytical network process (ANP) and balanced score card for analysing reverse logistics alternatives for end-of-life computers.

A large number of multinational corporations are investing in research and development of green products, establishing standards on cutting down the use of environmentally hazardous substances, and requiring supply chain partners to provide inputs that are free from hazardous materials at all levels of the supply chain system. GSCM has been adopted by some leading companies in the reverse logistics, like Dell, HP, IBM, Motorola, Sony, Panasonic, NEC, Fujitsu, and Toshiba (Zhu and Sarkis, 2006). This implies that corporations are now starting to recognize that environmental sustainability can be a source of competitive advantage (Walton et al., 1998). GSCM can also promote efficiency and synergy among business partners, helps to enhance environmental performance and reduces waste to achieve cost savings (Rao and Holt, 2005). The GSCM issue is very significant and relevant because recent studies have shown that the majority of the world's reverse logistics manufacturing will be carried out in Asia within the next couple of decades (Hu and Hsu, 2010).

2.6 Green Manufacturing and Remanufacturing

Green manufacturing is defined as production processes which use inputs with relatively low environmental impacts, which are highly efficient, and which generate little or no waste or pollution. Green manufacturing can lead to lower raw material costs, production efficiency gains, reduced environmental and occupational safety expenses, and improved corporate image. Green manufacturing aims to reduce the ecological burden by using appropriate material and technologies, while remanufacturing refers to an industrial process in which worn-out products are restored to like-new condition (Lund, 1984).

This is a very important area within green operations. The techniques for minimum energy and resource consumption for flow systems in order to reduce the use of virgin materials are based on three fields of study: pinch analysis (Linnhoff, 1993), industrial energy (Boustead, 1979) and energy and lifecycle analysis (Lee et al., 1995). Hoshino, T., Yura, K. and Hitomi, K., (1995) define remanufacturing as recycling-integrated manufacturing. Industries that apply remanufacturing typically include automobiles, electronics and tyres. Product recovery refers to the broad set of activities designed to reclaim value from a product at the end of its useful life. Pugh (1993) uses mathematical models in evaluating resource recovery options. Various authors categorize and classify the recovery process differently. Johnson and Wang (1995) define it as a combination of remanufacture, re-use and recycle, whereas Thierry et al. (1995) divide recovery into repair, refurbish, remanufacture, cannibalize and recycle.

Traditional production planning and scheduling methods have limited applicability to remanufacturing systems.

Guide and Srivastava (1997c) list the factors which induce complexity in such systems. Guide and Pentico (2003) developed a hierarchical decision model for remanufacturing and re-use, while Guide et al. (2005) analyse the performance of static priority rules for a remanufacturing shop that handles two remanufacturable products.

2.7 Waste Management

Caruso et al. (1993) model a solid waste management system (including collection, transportation, incineration, composting, recycling and disposal) using a multi objective location-allocation model supported by planning heuristics. A decision support system, for urban waste management in a regional area, for evaluating general policies for collection and for identifying areas suitable for locating waste treatment and disposal plants is presented by Haastrup et al. (1998).

Giannikos (1998) uses a multi-objective model for locating disposal or treatment facilities and transporting waste along the links of a transportation network. Bloemhof-Ruwaard et al. (1996), and Richter and Dobos (1999) use other mathematical modelling techniques for waste management. Mourao and Amado (2005) describe a heuristics for a refuse collection application.

The source-reduction/pollution-prevention (SR/P2) strategy focuses on 'preventing' pollution at the source (in products as well as manufacturing processes) rather than 'removing' it after it has been created. It is the concept of preventing the creation of waste rather than managing it after it is generated (Gupta and Sharma, 1995). The term 'pollution prevention' was coined in 1976 by the 3M Company. Dunn and El-Halwagi (1993) develop a methodology for the optimal design of recycle/ re-use process networks to minimize the emission of hydrogen sulphide from pulp and paper plants.

Zhang et al. (1997) list four preferences in their 'waste management hierarchy'. An example of pollution prevention with growing public visibility and product design in the case of internal combustion engines is presented by Hanna and Newman (1995). Disposal has always been a compelling problem and has led to green consciousness. In the case of GSCM, efforts to minimize disposal have been the focus. Bellman and Khare (1999) suggest reducing the economic and environment-related costs of automobile shredding residue (ASR). Various waste management and inventory models take disposal costs into account. Richter and Dobos (1999) analyse economic order quantity (EOQ) repair along with waste disposal with integer set-up numbers. Louwers et al. (1999) include transport costs and waste disposal in their model.

Teunter and Vlachos (2002) focus on the necessity of a disposal option for remanufacturable items. Recent work in the area is related mainly to the study of EMS implementation practices (Hui et al., 2001), total product system concept (Warren, J.P., Rhodes, E. and Carter, R., 2001), life-cycle assessment and management (Arena et al., 2003; Sanchez et al., 2004), management challenges and environmental consequences in reverse manufacturing for the computer industry (White, C.D., Masanet, E., Rosen, C.M. and Beckman, S.L, 2003), a generic functional model for modelling the material and flow of waste from both a physical and cumulative cost perspective (Hicks et al. 2004), revaluing the hierarchy of paper waste management policies in a dynamic general equilibrium model (Samakovlis, 2004), policy evaluations under environmental constraints using a computable general equilibrium model (Masui 2005) and a case study on waste management in a large complex health care organization in UK (Woolridge, A., Morrissey, A. and Phillips, P.S., 2005).

3.0 Conclusions

3.1 Green Procurement

Usually, it can save more cost in the source of supply chain to prevent waste than at the end of supply chain. Purchasing activity is the key starting point of eliminating waste, so a key factor of the successful green purchasing is the condition of company recycling and reusing waste. Hokey and Galle (2001) proposed that reducing the emissions of exhaust and sewage and so on, not only is the premise of ensuring the implementation of green procurement system, but also is the important way to promote the development of green procurement.

Initiating green procurement practices has to be a continuous process, which needs to be incorporated as part of the strategic plans of the firms. Firms can implement global green supply chain management elements through ensuring that they include environmental criteria when sourcing for goods to ensure that they only procure from environmentally certified suppliers through ISO 14000 and 14004. In addition, policies need to be designed to ensure that environmentally friendly products are procured.

3.2 Green Design

Design under legislation and regulations have been considered by Barros et al. (1998), Bellmann and Khare (1999, 2000). Life-cycle assessment/analysis is described as a process for assessing and evaluating the environmental, occupational health and resource-related consequences of a product through all phases of its life; through extracting and processing raw materials, production, transportation and distribution, use, remanufacturing, recycling and final disposal (Gungor and Gupta 1999). This is an emerging green concept which has to be looked at as one whose benefits are long term. Green design can take the form of structural designs or product designs; therefore firms can enforce these practices through the use of biodegradable raw material and inputs in the design of products and continuously upgrade their product offering to confirm with environmental requirements.

3.3 Green Operations and Logistics

Firms are currently starting to recognize that environmental sustainability can be a source of competitive advantage in the management of operations (Walton et al., 1998). GSCM can also promote efficiency and synergy among business partners, helps to enhance environmental performance and reduces waste to achieve cost savings (Rao and Holt, 2005). This has been highlighted in recent studies which have shown that the majority of the world's reverse logistics manufacturing will be carried out in Asia within the next couple of decades (Hu and Hsu, 2010). The key inputs any manufacturing set up are energy and water; therefore firms should strive at achieving sustainability through recycling, reuse and reverse logistics. This will enhance their competiveness through enhancing efficiency and synergy among business partners, helps to enhance environmental performance and reduces waste to achieve cost savings

3.4 Green Manufacturing

Green manufacturing involves production processes which use inputs with relatively low environmental impacts, which are highly efficient, and which generate little or no waste or pollution. Green manufacturing can lead to lower raw material costs, production efficiency gains, reduced environmental and occupational safety expenses, and improved corporate image (Atlas and Florida, 1998). This is a very important area within green supply chain management. The techniques for minimum energy and resource consumption for flow systems in order to reduce the use of virgin materials are based on three fields of study: pinch analysis (Linnhoff 1993), industrial energy (Boustead 1979) and energy and lifecycle analysis (Lee et al. 1995). Firms can effectively practice green manufacturing practices through the use of solar energy, recycling of raw materials and utilise biodegradable energy sources in their manufacturing operations.

3.5 Waste Management

Caruso et al. (1993) model a solid waste management system (including collection, transportation, incineration, composting, recycling and disposal) using a multi objective location-allocation model supported by planning heuristics. Giannikos (1998) uses a multi-objective model for locating disposal or treatment facilities and transporting waste along the links of a transportation network. Zhang et al. (1997) list four preferences in their 'waste management hierarchy'. An example of pollution prevention with growing public visibility and product design in the case of internal combustion engines is presented by Hanna and Newman (1995).

Effective waste management needs to focus on 'preventing' pollution at the source in products as well as manufacturing processes rather than 'removing' it after it has been created. Firms can control waste through efficient usage of water instead of having to wait until the waste has accumulated. In addition, disposal cost, especially for equipment has always been a compelling problem and has led to green consciousness. Firms need to ensure that they utilise whole life costing when procuring equipment, by taking disposal measure and costs into account.

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