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Review

Evolution of waste management strategies in industries: from passive to proactive

Hailu Terefe[1]*, Temesgen Gashaw[1] and Bikila Warkineh[2]

[1*]Center for Environmental Science, Addis Ababa University, Ethiopia
[2]Department of Plant Biology and Biodiversity Management, Addis Ababa University, Ethiopia

This paper is a review of various articles and documents on development of waste management approaches in industries. It provides information on advancement of waste management approaches as human awareness to environment increases and demonstrates the benefits of proactive waste management measures in industries. Most polluting industries in the world were established by the time the earth had the capacity to provide raw materials and absorb wastes. However, with increasing industrialization and urbanization virgin raw materials seriously declined and waste loads dramatically increased. As a result waste management strategies progressively evolved. In 1960s waste avoidance measures through foul and flee, dilute and disperse, concentrate and contain; in 1970s purification units at the end of emission pipes; in 1980s resource recovery through recycling and energy saving strategies were used as solutions to the problem of wastes on the environment. Furthermore, from 1990s onwards proactive measures by Cleaner Production technologies focusing on the source of waste generation to reduce, reuse and recycle wastes into valuable resources became the best solution for sustainable management of wastes and to enhance the performance of industries. Cleaner production technologies assured marvelous evidences for sustainable development by allowing industries to produce more efficiently and gain incredible economic, environmental and social benefits with less input utilization and less environmental impacts.

Keywords: Cleaner production, environment, industries, waste and pollution, waste management

INTRODUCTION

Most polluting industries in the world were established in the era of abundant raw materials, less competition for energy, and “limitless” sinks for waste disposal (Hart and Milstein, 1999). However, as human population increased with continuous civilization and improvements of living standards, the demand for resources and services correspondingly increased. As industrialization continued to fulfill these demands, it also put significant pollution burdens on earth and developed consuming large quantities of virgin resources at an increasing rate (Hart and Milstein, 2003; Nowosielski *et al*., 2007). Due to lack of recognition to waste problems on the environment, no action was taken until mid 20th century (UNIDO, 2002). Hence, the pollution from increasing urbanization and industrialization makes one of the largest environmental challenges faced by today’s world. Nevertheless, from 1960s on wards industries have been taking various measures towards controlling wastes and preventing pollutions, and restoring the natural environment (USEPA, 1998; UNEP, 2004; Mohanty, 2011).

***Corresponding Author:** Hailu Terefe, Center for Environmental Science, Addis Ababa University, Ethiopia Email: terefehailu@gmail.com, Tel.: +251911198554, PO. BOX, 1176.

In the 1960s the amount of waste generated was considered small enough to be diluted in the environment; and dilution was considered the solution to pollution (UNIDO, 2002; Kgabi and Mokgwetsi, 2009).So, industries were discharging wastes on water bodies without any prior treatment to reduce their toxicity on the environment. Later in 1970s industries started to treat wastes before dumping them (also termed “end-of pipe” approach); and in 1980s recycling and recovering resources but also application of energy saving techniques became popular, which were improvements on “end of pipe” approach (UNIDO, 2002). Nevertheless, with massive industrialization and urbanization, such waste management techniques and strategies alone became unacceptable. In addition, landfills are becoming economic and environmental burdens on society due to resource competition and as major sources of methane and nitrous oxides which are powerful greenhouse gases (GHGs). Besides, land costs, construction of landfills, collection of wastes, transport and disposal became very expensive (Sherif and Fadi, 2014). Thus it became important to move on strategies of ‘waste prevention, reduction and recycling’ at source rather than ‘waste disposal’ in costly landfills.

Although lack of knowledge on technological solutions, financial issues and short term policies are challenging, the attitudes of governments and industries towards pollution prevention have been showing progressive and positive changes (EEA, 1997). In recent decades, there has been a paradigm shift from Pollution Control to Pollution Prevention (P2) (USEPA, 1998; Nowosielski *et al*., 2007). Pollution control refers to the measures taken to manage pollution after it has been generated; whereas pollution prevention is the reduction or elimination of pollution at the source and throughout the process using Cleaner Production technologies that many industries are implementing these days (UNIDO, 2002).

Cleaner production strategy is a new environmental protection strategy, which has changed from simple terminal waste management to pollution prevention and efficient resource uses in the entire production process (UNIDO, 2002; Nowosielski *et al*., 2007). Thus, the objective of this paper is to review and present the evolution of waste management approaches parallel to advancement of human awareness about the environment and the benefits of Cleaner Production techniques with supportive exemplar industries. The progression of waste management strategies are presented in chronological order as follows.

PASSIVE WASTE MANAGEMENT STRATEGIES (UNTIL 1960s)

Passive waste management strategies were used by almost all industries in early 1900s and in some countries and industries these days as well. The philosophy behind it is that the environment provides inexhaustible resources and infinite absorption and dilution capacity for wastes. As a result, waste problems were avoided instead of fundamentally solved (EEA, 1997; Nowosielski *et al*., 2007; Kgabi and Mokgwetsi, 2009). Such waste management strategies are summarized in three categories (a-c) bellow (EEA, 1997).

a) Foul and Flee: It is an environmental migration from degraded and less comfortable sites to relatively resourceful and convenient sites. For example, when non-sustainable agricultural practices in Germany resulted in soil degradation and acidification, peoples in Germany were migrating to better places before and after the beginning of their calendar. Nevertheless, some times, there has been no space left to foul and flee without conflicts with neighbors. This method is a typical attitude in situations with a low population density but due to increasing population pressure, it is hard to get free spaces for such activity implying that foul and flee could not be sustainable environmental solution; hence, other way out for environmental problems were brought into practice in 1960s; i.e. dilute and disperse.

b) Dilute and Disperse: This was the new waste management practice in 1960s and was totally based on the assimilative capacity of the natural environment. Effluents from industries were added to large bodies, which had the capacity to dilute and disperse wastes. Dilute and disperse seemed to be adequate to make waste disappear in atmosphere and water by the so called principle- "the solution of pollution is dilution". As a result of it, the color, smell, and taste of contaminated waters may not have any or much differences from the uncontaminated ones. For this reason, seas and oceans had become a huge dumping ground for the world wastes (EEA, 1997; Kgabi and Mokgwetsi, 2009). Their effect might not pronounce when there were small industries. However, with enormous industrialization and urbanization, heavy metals and other diluted wastes start to cycle and get accumulated in sediments or biomass leading to contamination risks. Since this method was not an inclusive solution to the environment, it elicited looking for other better way of waste management strategies: concentrate and contain.

c) Concentrate and Contain: This method seemed successful for waste disposal on land such as controlled disposal of toxic or nuclear wastes. Yet, due to deterioration of the containers and/or the control, such harmful wastes leak to the environment and incur serious economic and environmental costs. An example for the risk of such waste management strategy can be seen from the costs of Lebanon landfills (Sherif and Fadi,

Table 1. Leachate Seepage from Landfills in to the Aquifer and its Associated Costs (Million Dollars) at Lebanon in 2012 (Sherif and Fadi (2014).

Input	Unit	Naameh Landfill	Hbaline Landfill	Total
Waste Quantity Landfill	ton/day	2,211	108	2,318
Density conversion of compacted waste	ton/m^3	0.30	0.30	0.30
Waste volume	m^3/day	7,468	364	7,832
Leachate level	%	50%	50%	50%
Leachate quantity	m^3/day	3,734	182	3,916
Leachate infiltration rate	%	2%	10%	2%-10%
Quantity of water polluted/m^3 of leachate	m^3/day	50	50	50
Daily water polluted by leachate	m^3/day	3,734	909	4,643
Yearly water polluted by leachate	m^3/year	1,362,914	331,955	1,694,870
BML water treatment OMEX Cost	US$/m^3	7	7	7
Extra water treatment OMEX Cost	US$/m^3	15	15	15
Net water treatment OMEX Cost	US$/m^3	8	8	8
CASWD	**US$ Million**	**11.5**	**2.8**	**14.3**
Lower bound at 1% infiltration rate	US$ Million			5.5
Upper bound at 12% infiltration rate	US$ Million			65.4

Table 2. Land Devoted for Waste Dumps and Costs of Passive Dumps at Lebanon in 2012

Transfer, segregation, recycling and composition station	Area (m2)	10% losses 1st Ring over # years of existence (US $ million)	4% Losses 2nd Ring over # years of Existence (US $ million)	Total Over # years of Existence (US$ million)
Total Municipal Dumps	265,756	9.5	44.1	53.6
Total Debris and Construction Dumps	415,630	42.3	206.1	248.4
Total	**681,386**	**51.8**	**250.2**	**302.0**
Lower Bound				241.6
Upper Bound				362.4
High risk Dumps considered for CASWD				
High risk Municipal Dumps	32,925	1.3	7.1	8.3
High risk Debris and construction Dumps	122,500	5.5	27.3	32.6
Total	**155,425**	**6.8**	**40.9**	**40.9**
Lower Bound				32.7
Upper Bound				49.1

Source: Sherif and Fadi (2014)

2014). As it can be seen in Table 1 above 1,362, 914 m^3/year and 331,955m^3/year of water was polluted by leachate seepage from Naameh and Hbaline Landfills respectively. This charged Lebanon a total cost of 14.2 million SU Dollars per year to treat the contaminated underground water.

In addition to contamination costs of waste disposal on landfills, land costs are getting expensive. For instance, Lebanon devoted land value ranging from 241.6 up to 362.4 million US Dollars for solid waste dumps which could have been invested for other economic plans (Table 2) (Sherif and Fadi, 2014).

The evidences showed above elucidate that passive waste management strategies fail to bring sustainable solutions for pollution problems on the environment. Nevertheless, the efforts made so far advanced towards reactive waste management strategies which are better than the passive methods.

Table 3. Recycling and Recovery of Packaging Waste in France in 2009. Cabral *et al.*, (2013)

Material	Packaging Waste Generated (Ton)	Total Recycling[a] (Ton)	Total Recovery[b] (Ton)	Recycling Rate (%)	Recovery Rate (%)
Glass	3,133,377	1,966,000	1,966,000	62.7	62.7
Plastic	2,046,728	460,540	1,167,525	22.5	57.0
Paper/Cardboard	4,283,537	3,721,400	4,124,698	86.9	96.3
Metals	717,684	432,289	437,088	60.2	60.9
Wood	2,641,660	500	673	18.9	25.5
Total	**12,822,986**	**7,080,229**	**8,368,311**	**55.2**	**65.2**

[a] Total recycling includes material recycling and other forms of recycling like composting.
[b] Total recovery includes total recycling and incineration with energy recovery.

REACTIVE WASTE MANAGEMENT STRATEGIES (BEFORE 1990S)

End-of Pipe Approach (In 1970s)

Recognizing the limitations in passive waste management methods such as dilute and disperse, concentrate and contain, technologies were developed in 1970s to purify wastes and pollutants at the end of the emission pipes (EEA, 1997; Nowosielski *et al*., 2007). Although end-of-pipe approach was effective to a certain extent, it generally produces by-products like sludge which has to be dumped or burned that consequently causes other environmental impact. Furthermore, the system does not reduce the amount of waste production; it transfers pollution from one medium to another medium; it does not eliminate pollution entirely and had limitations to solve environmental problems in their whole complexity. In addition, eco-efficient technologies for end-of pipe waste treatments are so expensive (http://doka.ch/HellwegPECKIndEcol05.pdf). Hence, end-of pipe methods often resulted in increased costs with no appreciable benefits to industries in terms of enhanced materials or energy uses (Staniškis, 2001). As a result, recycling wastes and resource recovery methods were evolved in 1980s; which were actually better mechanisms of resource use and waste minimization tactics over the end-of pipe strategy (Gavrilescu, 2005; Nowosielski et al., 2007).

On-site Recycle Approach (In 1980s)

Recycling involves collecting, processing, and reusing materials that would otherwise be dumped as wastes. On-site recycling of wastes provide considerable amount of resource recovery and cost reduction. For example, Mijaylova *et al.* (2004) discovered 90% fresh water reduction, the recovery of more than 95% of chromium and sulfide, 90% of grease, 65% of protein and zero discharge of wastewater using in-house wastewater treatment techniques at tanneries of Mexico. In economic terms from the recovery of proteins and greases the tanneries gained 144,000 USD/year with investment payback period of 7- 12 months depending on the size of tanneries and scenario options. Likewise, Cabral *et al.* (2013) identified considerable resource recovery in waste package recycling system of France (Table 3).

The above Table shows recovery of 65.2% of the generated packaging wastes. This is pretty appreciable in terms of substituting virgin resources. Their report also indicated sustainable economic gains. Hence, the financial return above the various hidden benefits that can be obtained from maintaining sustainable environment is an encouraging business demonstrating that recycling wastes is one of the attractive environmental management strategies.

Often, critics of recycling are that more energy and cost may be incurred in getting materials to the recycling facility than is saved from the recycled products. Other limitations include market demand and technical issues. To recycle economically there has to be a demand for the recycled product. In addition, some technical difficulties may happen from the fact that wastes are heterogeneous in nature (WRAP, 2010; Cabral *et al.* 2013). Whatever the case may be, recycling techniques in waste management strategy can provide multiple benefits provided that it is technically and economically feasible.

Some of the benefits of recycling wastes include reducing the demand for raw materials by extending their life and maximizing their value; reducing ecological damage, pollution and waste generation associated with raw materials extraction and use; reducing transport costs and pollution from transporting raw materials; saving energy in the production process; reducing emission to air and water in the production process; reducing disposal impact (less waste goes to land fill and incinerators); creating employment opportunities and so on (Nowosielski *et al*., 2007). Thus, recycling not only helps to reduce the overall amount of waste sent for disposal, but also helps to conserve natural resources by replacing the need for virgin materials (World Bank, 1998).

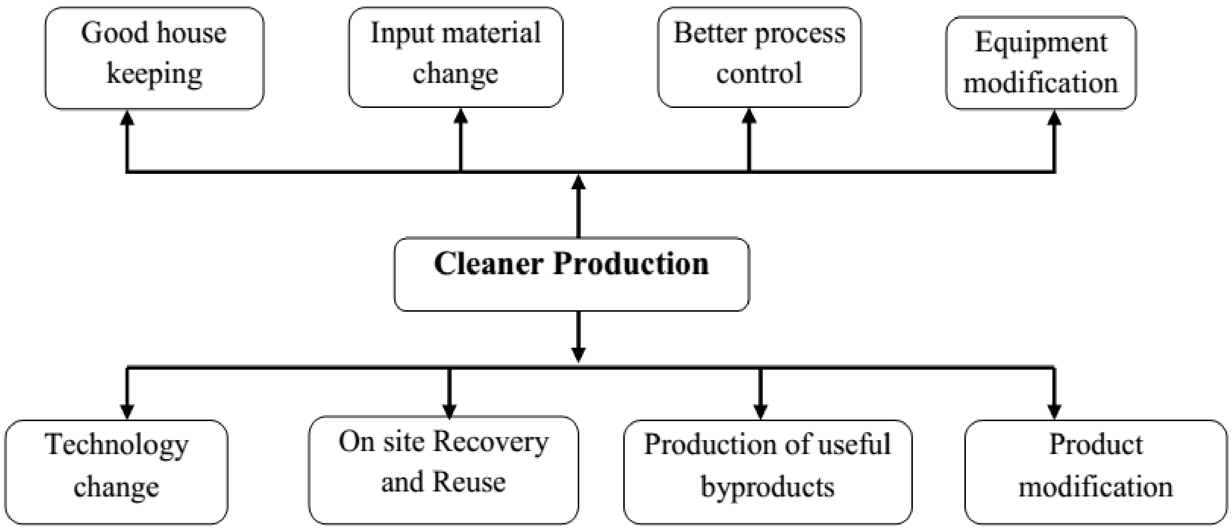

Figure 1. Schematic representation: elements of Cleaner Production system (UNIDO-UNEP, 2010).

TOWARDS PROACTIVE WASTE MANAGEMENT STRATEGIES BY CLEANER PRODUCTION TECHNOLOGIES TO REDUCE, REUSE and RECYCLE WASTES AT SOURCE (AFTER 1990s)

Cleaner Production reflects a proactive, "anticipate and prevent" philosophy surfaced as a result of increased awareness about environmental degradation mainly due to unsustainable resource uses and inappropriate waste disposal practices (Centric Austria, 2005; Gavrilescu, 2005). Proactive environmental strategy addresses environmental problems at their source instead of reacting to them after the wastes are generated (Centric Austria, 2005; Nowosielski *et al*., 2007). It embraces the famous three R's Philosophy of sustainable waste management techniques: Reduce, Reuse, Recycle (Mohanty, 2011; Van Acker *et al*., 2010). This approach provides a chance to incorporate many cleaner production practices which can result in ecological, economic and social benefits.

These days' eco-businesses have been focusing on activities that can prevent, limit or correct environmental damages to air, water and soil, as well as problems related to noise and ecosystems. Cleaner Production is a practical approach of moving towards sustainable development by allowing industries and service providers to produce more with less: fewer raw materials, less energy, less waste, less toxic and GHGs emissions; and normally less environmental impact and greater sustainability; being both environmentally and economically beneficial (UNEP, 2004; Centric Austria, 2005; Nowosielski *et al*., 2007). The implementation of Cleaner Production programs involve simple and low-cost to complex and expensive techniques and technologies. Common managerial and technical elements implemented in Cleaner Production systems are given in Figure 1 above (UNIDO-UNEP, 2010).

Cleaner Production strategy needs managerial and technological interventions. It requires strong commitment from business owners and governments to effectively implement the elements of Cleaner Production techniques; and the driver for the commitment should be the multilateral benefits of the strategy. Cleaner Production plan protects the environment, the consumer and the worker while improving the industrial efficiency, profitability and competitiveness (EEA, 1997; UNIDO, 2002; Centric Austria, 2005; Gavrilescu, 2005; Nowosielski *et al*., 2007). For these golden reasons, these days, a number of industries are implementing proactive environmental measures through Cleaner Production strategies. Consequently, they are receiving economic, environmental and social benefits. Success stories can be seen from industries at different parts of the world (Centric Austria, 2005; Ning *et al*., 2009; TECH MONITOR, 2009; UNIDO-UNEP, 2010; SECO, 2011); here only three examples are given.

CHANDARIA INDUSTRIES LTD, Kenya

This is a paper manufacturing and conversion company in Kenya. By implementing cleaner production strategy, the company increased its resource use efficiency (energy productivity by 40%, materials productivity by 48% and water productivity by 181%) while reducing pollution (carbon intensity by -28%, waste water intensity by -64% and waste intensity by -42%). The industry gained an annual saving of 633,600 USD, obtained ISO 9000:2001 certifications in Quality Management System, obtained Cleaner Production awards in the year 2007 to 2009, and received the Company of the Year Awards in

Table 4. Economical and Environmental Benefits of Chandaria Industrial Ltd. from Cleaner Production System (UNIDO-UNEP, 2010)

Principal Options Implemented	**Benefits** **Economic**		**Resource Use**	**Pollution Generated**
	Investment (USD)	Cost saving (USD/yr)	Reduction in energy use, water use and/or materials use /yr	Reduction in waste water, air emissions and/or waste generation/yr
Energy Management	4,802	260,000	Reduced 5,367,429 kwh	Reduced air emissions: 1,456 ton CO_2-eq.
Water Management		216,000	Reduction in water use 150,000m^3	Reduction in waste water Reduced pollution load to sewer: BOD from 750mg/l to 380 mg/l
Material Management		352,000	Reductions in materials use: 3,200 tons Better quality raw material	Reductions in waste generation: 900 tons Reduced sludge disposal
Total of all		**633,600**		

Table 5. Economic and Environmental Benefits of MTALEXACTO Lead Refining Company, Peru, from Cleaner Production System (UNIDO-UNEP, 2010)

Principal Options Implemented	**Benefits** **Economic**		**Resource Use**	**Pollution Generated**
	Investment (USD)	Cost saving (USD/yr)	Reduction in energy use, water use and/or materials use /yr	Reduction in waste water, air emissions and/or waste generation/yr
Change of refractory bricks from 31% to 50% aluminum oxide and installation of a hood on the furnace.	2,470	16,986 (lead sold) 450 (fuel)	Additional recovery of 34.7 tons of lead	19% less lead in the slag, decreased waste quantity
Change of burner and optimization of residual fuel and diesel, and improved mixing of fuel in the refining process	965	1,215	Decrease of residual oil use by 2.66%	Reduced air emission by almost 240 tons CO_2 eq.
Warming of the fuel by taking advantage of the residual heat of the oven	280	184	Decrease of electricity use by 5,760MJ	
Total of all	**3,715**	**18,835**		

creativity and innovation (UNIDO-UNEP, 2010). For this success the company had taken necessary measures to enhance the productivity of energy, water and materials. The management options taken by the company and the corresponding benefits are given in Table 4 above.

METALEXACTO, Peru: This is a Peruvian company that produces secondary lead by smelting and refining used acid batteries. Using resource efficient and Cleaner Production system the company increased its resource productivity (energy by 46%, materials by 2% and water by 23%) while reducing pollution intensities (Carbon dioxide by -31% and waste by -22%). The company earned more than 18,830 USD per year and has got improvements in working practices (UNIDO-UNEP, 2010). The approach followed to reach to this success is presented in Table 5 above.

PAC Foods Supplies: According to the report of Centric Austria (2005), before the company installed Cleaner Production strategy, it was generating significant loads of solid wastes and dumping to the environment. Realizing the economic and environmental challenges of those wastes Mathew, the company owner, proposed a less waste initiative to identify and implement waste reduction options. Based on critical investigation they made, the company took three important management measures to reduce waste generation, environmental pollution and to save resources. The improvements made were:

a) Modification on napkins design: The raised designs on napkins were reduced which enabled the company to ship 23% more napkins and save 294,000 kg of corrugated packaging plus 150 truckload shipments.

b) Modification on drink shipment boxes: Redesigning the boxes allowed the company to achieve 4% reduction in corrugated packing and the saving of 450,000 kg weight.

c) Modification on food containers: Light-weight and non-greasy food containers were converted from paperboard cartons to paper bags and brought a saving of 3,000,000kg worth of packaging.

The measures required an initial investment of 63,000 Euros but allowed a net savings of 210,000 Euros starting from the second year onwards.

CONCLUSION

These days the number of industries radically increased and the environment seriously exhausted due to hostile resource use and venomous waste dumps. As a result waste management strategy became an important issue. Waste management strategies started very late in 1960s and evolved stepwise as human awareness about the environment increased. Passive waste management strategy focusing on waste ignorance or escaping and reactive waste management strategy through controlling wastes after they are generated cannot solve the ever increasing environmental pollution. However, proactive waste management strategies based on Cleaner Production system focusing on waste prevention through source reduction, reuse and recycle allows higher resource use efficiency, elevated energy saving, and excellent working environment. Due to the implantation of proactive waste management strategy, numerous industries in the world such as the CHANDARRIA INDUSTRIAL LTD, METALEXACTO and PAC Food Supplies are gaining marvelous economic, social and environmental benefits. Therefore, proactive waste management plan by Cleaner Production technologies is the best waste management strategy in the world.

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