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Safe and Environmentally Sound Ship Recycling in Bangladesh

Work Package 2:
Planning the Management of Hazardous Materials

Common Hazardous Waste Treatment, Storage & Disposal Facility:

Design Options for the Environmentally Sound Management of Hazardous Waste in Chittagong, Bangladesh

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Design Options for the Environmentally Sound Management of Hazardous Waste in Chittagong, Bangladesh

1 Executive Summary

The inventory of hazardous wastes generated from the ship recycling industry in Chittagong and from the surrounding industrial areas were developed through a survey under *Work Package-2* (WP-2) of the Safe and Environmentally Sound Ship Recycling (SENSREC) Project. **Tables 1 and 2** in this report have been imported from the “Hazardous Waste Assessment Report” published as one of the earlier deliverables under WP-2. These tables display the estimates of hazardous wastes generated by the ship recycling yards and from other industries in Chittagong region, respectively.

It is evident from the inventory assessment that the ship recycling sector has been producing sizable and comparable quantities of landfillable and incinerable wastes. However, the industrial sectors cumulatively generate nearly negligible landfillable wastes; but generate comparatively large quantities of incinerable wastes.

The data of ships dismantled in Chittagong over the past seven years was studied and the opinions of experts were considered before arriving at any conclusion regarding growth rate of recycling yards. In that light it was concluded that the ship recycling sector in Chittagong could grow at a rate of 4% in the near future.

Table 3 has been imported from the “Hazardous Waste Assessment Report” which summarizes the expected growth rates of different industrial sectors in Bangladesh and the corresponding comments made by different experts consulted by the team. Clearly, the rates are different for the sectors that were a focus of this report. In the light of expert opinion, it was concluded that the average of 6% growth rate for industrial growth in the coming decade will be possible for Bangladesh with fair certainty.

In any case, availability of a reliable "Common Hazardous Waste Treatment, Storage & Disposal Facility (CHW-TSDF)" is an important requirement for effective management of hazardous wastes. Like common effluent treatment plants (CETPs) where government and industry associations/companies participate in operation and maintenance, the operator of the CHW-TSDF facility can be a government agency, quasi-governmental agency, an industry association, a joint venture or a private sector company. Hazardous waste treatment is an expensive process that demands specialized supervision and instrumentation.

It is envisaged that the development of the CHW-TSDF can be implemented by adopting actions and expenditures in two stages. In “Stage 1”, one facility should be constructed with landfill for the total inventory and an incinerator for ship recyclers only, plus the proportionate wastewater treatment facility. Thus, the TSDF shall serve as the common centralized facility for providing environmental utility services, initially to the ship recycling yards in Chittagong and thereafter to other industries around Chittagong, for disposing the hazardous wastes in a safe and environmentally sound manner.

Of the land required for creating a TSDF for management and disposal of hazardous wastes, a substantial footprint will be required to provide for several essential services at the TSDF site. It appears that one would need a plan area of about 20 acres (8 hectare footprint) for the proposed CHW-TSDF in Chittagong.

It is recommended that the Government should provide free land and infrastructure like water-supply, treated wastewater pipeline for disposal, power supply, approach roads and compound wall to stop access from local communities.

The TSDF, for both stages of development, will cost approximately USD 11.5 million (i.e. USD 6 million for Stage 1 and USD 5.5 million for Stage 2) - excluding the cost for land, utilities and project management (Refer to **Table 6** in the detailed report for further details on cost break-up). These estimates may be amended as a result of ongoing work. The CHW-TSDF could be built over 18 to 24 months by creating a dedicated team by the Government of Bangladesh.

It is to be reiterated that the above calculations are assuming that there will be yearly 6% growth in industrial sectors and approximately 4% growth in ship dismantling sector. However, this is probably not the case for each and every sector. Some may not grow at all while some may grow beyond our expectation. In any case, the country will progress over the years and so it is likely that the amounts of solid and liquid wastes will grow.

In addition, there will be more sectors, generating more wastes – which will be established as time progresses. However, as industries graduate to a more progressed status, there should be waste minimization due to the application of advanced technologies. Also, it is expected that industries will adopt reduce, recycle and reuse-based practices (3Rs) and some minimization of emissions will happen. These factors will escalate the generation rate of the wastes over the period of coming 10 years - which has been assumed to be the life of the facility.

The advanced industrial sectors, including ship recycling yards and other industries, in the future years will certainly be more thorough in sending larger quantities of wastes to the waste management facility and the overall wastes to be handled and treated will essentially grow in the regimes where better compliance can be achieved.

Finally, it is worth noting that the designs and estimates may contain inaccuracies due to the approximate nature of the inventory and a host of assumptions made in the course of development of this concept and cost estimates. Clearly, the systems designed on the basis of such an inventory and the costing based on several assumptions has given rise to at best “the approximate estimates”.

2 The Context

It is envisaged that a Common Hazardous Waste Treatment, Storage and Disposal Facility (CHW-TSDF) for Chittagong shall serve as the common centralized facility for providing environmental utility services to the ship recycling yards in Chittagong as well as to other industries around Chittagong, for disposing the hazardous wastes in a safe and environmentally sound manner.

At the outset, let us understand the glossary of typical terms used in connection with some of the terms commonly used in the field of hazardous waste management. The treatment, storage and disposal facilities, or TSDFs, refers to the facilities that receive hazardous wastes for treatment, storage or disposal. The activities of a TSDF include the following:

Treatment – The character or composition of hazardous wastes are altered in a 'treatment process' that follows various processes, such as incineration or oxidation. Some treatment processes enable waste to be recovered and reused in manufacturing settings, while other treatment processes significantly reduce the amount of hazardous waste.

Storage – The 'storage' facility ensures temporarily holding of hazardous wastes until they are treated or disposed of. Hazardous waste is commonly stored prior to treatment or disposal, and must be stored in containers, tanks, containment buildings, drip pads, waste piles, or surface impoundments.

Disposal – 'Disposal' refers to a permanent process of containing hazardous wastes. The most common type of disposal facility is a landfill, where hazardous wastes are disposed of in cautiously constructed units designed to protect groundwater and surface water resources.

CHW-TSDF – A 'Common Hazardous Waste Treatment, Storage and Disposal Facility' typically refers to the arrangement or setup created for several generators of hazardous wastes. There may be an individual industrial facility having a TSDF for their own use, in which case it will not be called a "common" facility. There are different business models currently in operation. The facility may be owned by a private entrepreneur as a stand-alone "business or industry" to provide professional technical services for the management of hazardous wastes for a variety of industries or it may be owned and operated by the industries in a cooperative manner. The facility may be designed to receive wastes from one sector (*e.g.* the CHW-TSDF in

Alang, India, is a dedicated facility receiving wastes only from ship dismantling yards) or the facility may cater to several industrial sectors.

3 What Are Hazardous Wastes?

Any material becomes "waste" when it is discarded without expecting to be compensated for its inherent value. When improperly treated, stored, transported or disposed of or managed, these wastes may have adverse impacts on human health or the environment. All economies generate wastes that can be hazardous to human health and the environment.

Hazardous waste is solid waste, or combination of solid wastes, which because of its quantity, concentration, or physical, chemical, or infectious characteristics may (a) cause, or significantly contribute to, an increase in mortality or an increase in serious irreversible, or incapacitating reversible, illness; or (b) pose a substantial present or potential hazard to human health or the environment when improperly treated, stored, transported, or disposed of, or otherwise managed (RCRA §1004(5)).

According to the United States Environmental Protection Agency (US-EPA), hazardous waste may be defined as "posing a substantial threat to human health or death or posing a substantial threat to human health or the environment when improperly managed." Waste may be defined as hazardous, which meets one of the following four characteristics:

Ignitability - Wastes that pose fire hazards during routine management. Fires not only present immediate dangers of heat and smoke, but also can spread harmful particles over wide areas.

Corrosivity - Wastes requiring special containers or segregation from other wastes because of their ability to dissolve toxic contaminants.

Reactivity - Wastes that tend to react spontaneously, to react vigorously with air or water, to be unstable to shock or heat, to generate gases or to explode.

Toxicity - Wastes that, when improperly managed may release toxicants in sufficient quantities to pose a substantial hazard to human health or the environment.

Due to the lack of adequate awareness, political will and analytical capabilities, in some developing countries hazardous wastes may be dumped together with construction wastes or household wastes, resulting in a public health hazard. The paramount challenge that needs to be addressed, though, is the amount of untreated and abandoned hazardous wastes in many developing countries. The challenge is far reaching in terms of both the ecology and environment as well as public health. The major bottleneck is the lack of waste treatment, handling and disposal facilities in these countries.

There are two schools of thought, which exist in the domain of hazardous waste management, namely; [a] pre-process the wastes at the point of generation before loading and transporting them to the dedicated facility; and [b] send the hazardous wastes for direct disposal to the facility without any pre-treatment operations at the site of generation.

In any case, availability of a reliable "Common Hazardous Waste Treatment, Storage & Disposal Facility (CHW-TSDF)" is an important requirement for effective management of hazardous wastes. Like common effluent treatment plants (CETPs) where government and industry associations/companies participate in operation and maintenance, the operator of the CHW-TSDF facility can be a government agency, quasi-governmental agency, an industry association, a joint venture or a private sector company. Hazardous waste treatment is an expensive process that demands specialized supervision and instrumentation.

4 Inventory of Hazardous Wastes in Chittagong Yards & Industries

The inventory of hazardous wastes generated from the ship recycling industry in Chittagong and from the surrounding industrial areas were developed through a survey under *Work Package-2* (WP-2) of the Safe and Environmentally Sound Ship Recycling (SENSREC) Project. **Tables 1 and 2** in this report have been imported and adapted from the “Hazardous Waste Assessment Report” published as one of the earlier deliverables under WP-2. These tables display the estimates of hazardous wastes generated by the ship recycling yards and from other industries in Chittagong region, respectively.

More specifically, as presented below, **Table 1** shows an estimation of the hazardous waste generated from the ship recycling industry in Chittagong, while **Table 2** represents the quantification of hazardous waste derived from other industries in the Chittagong region.

Table 1: **Estimates of hazardous waste quantities generated from the Chittagong ship recycling yards, Chittagong Port (MT/yr)**

Disposal Method	Recent Trend Minimum (MT/yr)	Recent Trend Maximum (MT/yr)	Average of the Range (MT/yr)	10-yr lifetime capacity @ 4% growth rate (MT)
Incinerable Wastes	5,400	6,400	5,900	71,000
Landfillable Wastes (Toxic + Inert)	7,500	10,300	8,900	107,000
Alternate gainful use or send to Municipal Solid Waste landfill			Nil	Nil
Grand Total			**14,800**	**178,000**

It is evident from the inventory assessment that the ship recycling secor has been producing sizable and comparable quantities of landfillable and incinerable wastes. However, the industrial sectors cumulatively generate nearly negligible landfillable wastes; but generate comparatively large quantities of incinerable wastes.

Table 2 **Estimates of hazardous waste quantities generated by industries in Chittagong by waste type and disposal method (MT/yr)**

Waste Type	Total waste generation rate (MT/yr)	Disposal Methods			
		Incineration (MT/yr)	Landfilling		Alternate gainful use or Municipal Solid Waste landfill (MT/yr)
			Toxic waste landfill (MT/yr)	Inert landfill (MT/yr)	
Tundish lining	25'192				25'192
ETP sludge	19'165	3'443	324		15'397
APC Dust	11'131				11'131
Contaminated solid waste	3'965	3'965			
Contaminated packaging	3'626	3'626			
Oily crude tank sediments	1'459	1'459			
Contaminated plastic waste	1'282	707			575
Bleaching earth	910				910
Spent Lubricants	251	251			
Flesh	222				222
Maintenance scrap	124	124			
Oil and grease	89	89			
Chemical residues	88	88			
Trimming dust	72				72
Raw hides cutting	66				66
Shaving dust	54				54
Asbestos	40			40	
Other contaminated materials	25	24		1	
Waste glasswool & insulation	8			8	
Yearly Sub-Total (MT/yr)	**67'768**	**13'777**	**324**	**49**	**53'619**
Episodic and aperiodic waste	678	138	3	0	536
Yearly Total (MT/yr) #	**68'600**	**14'000**	**400**		**54'200**
10-yr lifetime capacity @ 6% growth rate (MT) #	**904'200**	**184'500**	**5'300**		**714'400**

\# Rounded-off numbers

Note: In addition to the results shown above, biomedical waste generation from the hospital and health sector is estimated at 800 MT/yr (based on 6'400 beds). A dedicated facility will have to be created for it in Chittagong.

5 Methodology Adopted for Projection of Wastes Disposed in 10-Years of Life-Time of the TSDF

While it is understandable that it would be extremely difficult to predict the growth rates for the future years, it was necessary to take into account some reasonable growth rates when arriving at wastes generated over the 10-year period. Therefore, an attempt was made by the team engaged in inventorization-related activities.

The data of ships dismantled in Chittagong over the past seven years was studied and the opinions of experts were considered before arriving at any conclusion regarding growth rate of recycling yards. In that light it was concluded that the ship recycling sector in Chittagong could grow at a rate of 4% in the near future.

Table 3 has been imported from the "Hazardous Waste Assessment Report" which summarizes the expected growth rates of different industrial sectors in Bangladesh and the corresponding comments made by different experts consulted by the team. Clearly, the rates are different for the sectors that were a focus of this report. In the light of expert opinion, it was concluded that the average of 6% growth rate for industrial growth in the coming decade will be possible for Bangladesh with fair certainty.

Table 3: Expected growth rates of different industrial sectors in Bangladesh

Industry Sector	Sector growth projection	Comment on growth rate
Cable	3-5%.	Registered and unregistered cable manufacturers are growing in number due to the ship breaking activities. The demand is on a rise due to housing and industrial expansions. Eastern cables has a higher installed capacity than what it currently produces and will increase production as demand increases.
Cement	4-6%	Though the production capacity is higher than local demand, the export growth is compelling. The industries in Chittagong are planning to expand. Year on year growth basis the growth is expected to be between 4-6%.

Industry Sector	Sector growth projection	Comment on growth rate
Chemical	10-12%	During the inventory survey, the major players in this sector have reported about 10% year on year growth.
Fertilizer	2-5%	Most of the fertilizer industries are remaining closed for a considerable portion of the year due to shortage in natural gas supply. The grim business outlook prevents new investment. Since the government is planning to import LNG in the near future, the situation may change.
Glass	7-8 %	It was heard from PHP glass that they are going to double their capacity. We can consider 7-8 percent growth to accommodate the doubled capacity.
Paints	7-10%	Elite paint, Berger paints, etc. are reporting a steady growth rate of 7-10%.
Paper	10-12%	There is still considerable potential of growth. In the new exclusive economic zones (EEZs), considerable investments are made in the ready-made garment sector, which consumes a lot of paper. Due to the proximity to the port, pulp based paper industries prefer Chittagong as a location. The sector is supposed to double with the doubling of the ready-made garment sector.
Refinery	7-8%	Installed capacity of ERL will be tripled in the next 3-5 years. As the country's demand is increasing, new refineries from the private or public sector may come into play in next ten to twenty years. Growth rate of 7% is considered to adjust the tripling of capacity of ERL.
Rerolling	7-10%	Current production surplus is more than 50% of the total domestic demand. However, the export is increasing. Therefore, potential for growth exists. In our recent visit to BSRM we came to know that they are doubling their capacity. Other existing big players are also establishing new facilities while new rerolling mills are also in the process of establishment. We can consider 7-10% year on year growth to reflect the planned expansion.

Industry Sector	Sector growth projection	Comment on growth rate
Tannery	8-10%	There were 19 tanneries of which 17 have been closed. The remaining two have halted production due to ban by DoE for not having ETP. One is establishing an ETP to remain in the business besides doubling the capacity. If the TSDF is established, the possibility of new entrants increases. Therefore, it is reasonable to consider a 10 year doubling time which is equivalent to 8-10% year on year growth.
Textile	10-12%	Many new exclusive economic zones (EEZs) are planned, with a number of them in Chittagong, in which considerable investments are made in the ready-made garment sector. 10-12% growth rate will hold, if everything remains calm, since the industry is doubling in five years on an average.

The methodology adopted for calculation of the “multiplication factor” to be used for the projection of wastes disposed in 10-years of life-time of the TSDF is displayed in **Table 4**.

A 4% growth rate (for growth in compound proportions) was assumed for the ship recycling sector and 6% growth rate was assumed for the industrial sectors and the following multiplication factors were estimated over the life-time assumption of 10-years by using the factors shown in **Table 4**.

It is clear from the above table that the current inventory of the ship recycling industry should be multiplied by 12.01 to arrive at a ball-park 10-year projection of total waste to be disposed of in the facility over its lifetime at the rate of 4% growth. Similarly, the current inventory of industrial sectors should be multiplied by 13.18 to arrive at a ball-park 10-year projection of total waste to be disposed of in the facility over its lifetime at the rate of 6% growth.

Table 4: The "multiplication factors" used for projection of wastes disposed in 10-years of life-time of the TSDF

Year	Units of Waste accumulated at the end of the current year @ 4% Growth rate	Units of Waste accumulated at the end of the current year @ 6% Growth rate
1	1.00	1.00
2	1.04	1.06
3	1.08	1.12
4	1.12	1.19
5	1.17	1.26
6	1.22	1.34
7	1.27	1.42
8	1.32	1.50
9	1.37	1.59
10	1.42	1.69
Multiplication Factor	**12.01**	**13.18**

6 The Tentative Design Basis for the Proposed TSDF

Table 5 demonstrates the tentative design basis for the proposed TSDF in Chittagong. The current inventories were multiplied by the corresponding growth rates (factor = 12.01 for ship recycling sector and factor = 13.18 for industrial sectors).

The data for annual waste generation rates were referenced from the "Hazardous Waste Assessment Report" corresponding to three methods of disposal, namely: incinerable wastes (19,900 MT/yr), landfillable wastes (9,300 MT/yr) and wastewater including bilge water, scrubber effluents, landfill leachates as well as sewages generated by workers' cafeteria and toilet-bath facilities (175 m3/day). These waste generation rates correspond to the cumulative emissions from ship dismantling yards and industries around Chittagong.

Table 5: Tentative "Design Basis" for the proposed TSDF in Chittagong

Sr No.	Disposal Method	Estimated Inventory		Tentative Design Basis		
		From the ship breaking yards (MT/year)	From the industrial areas (MT/year)	From ship breaking yards 10-yr lifetime capacity @ 4% growth rate (MT)	From industries 10-yr lifetime capacity @ 6% growth rate (MT)	Total Waste 10-yr lifetime capacity (MT)
1	**Incinerable** Wastes	5,900	14,000	71,000	184,500	**255,500**
2	**Toxic & Inert** Landfillable Wastes	8,900	400	107,000	5,300	**112,300**
3	Bilge water + Scrubber Effluents + Landfill Leachates + Sewage?	100 m^3/day	75 m^3/day	0.45 million m^3	0.35 million m^3	**0.80 million m^3**

As stated earlier, the growth rate of 4% (for growth in compound proportions) was assumed for the ship recycling sector and 6% growth rate was assumed for the industrial sectors and the appropriate multiplication factors were used to estimate the cumulative quantities of wastes to be subjected to the proposed TSDF over the life-time assumption of 10-years of the facility.

7 Site Layout and Ground Plan of the Proposed TSDF

The site layout and ground plan for a typical TSDF has been presented below in **Figure 1**.

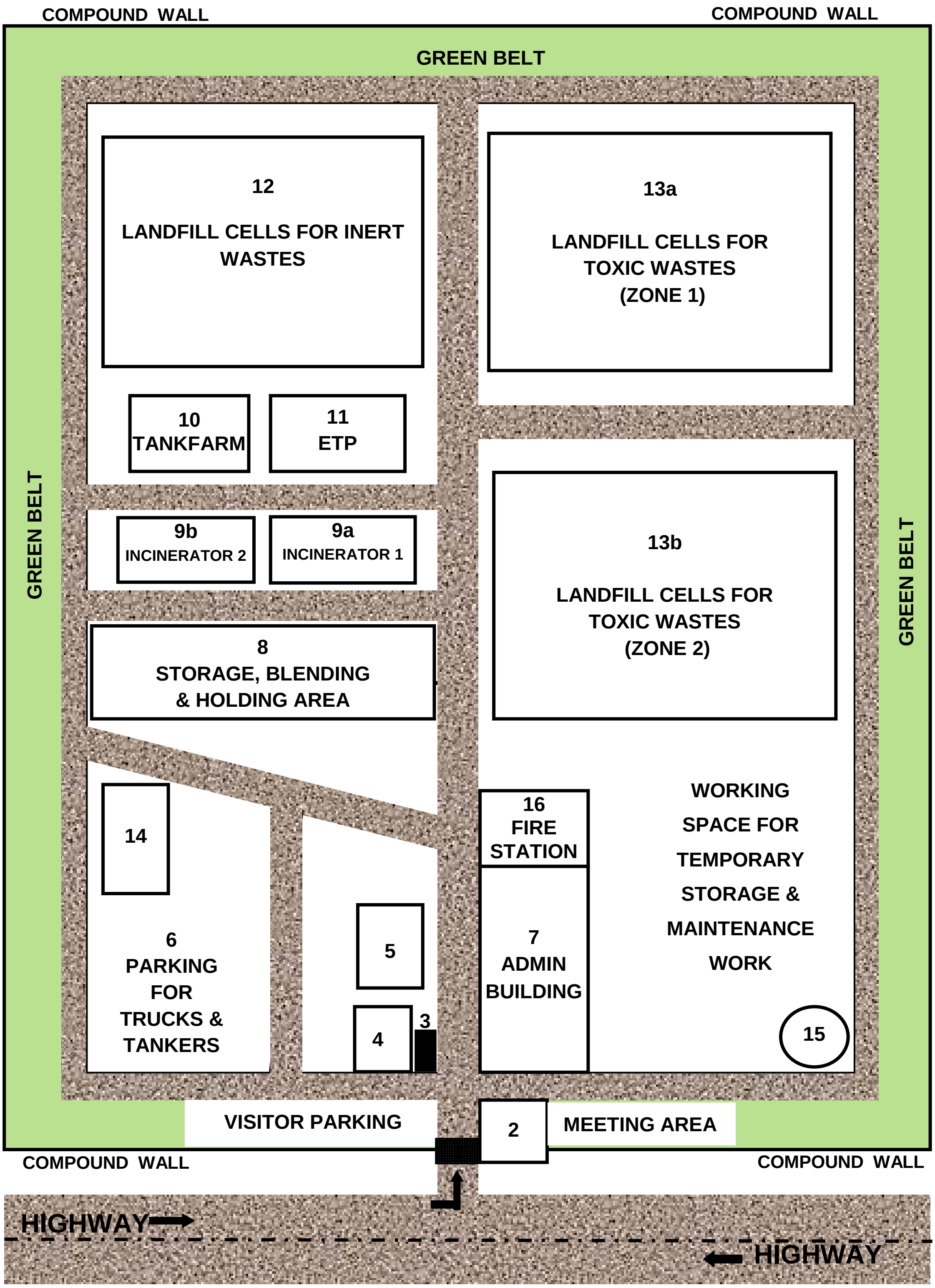

Figure 1: Layout and the ground plan for a typical TSDF site
(Legend for the layout can be found on the next page)

<u>Legend</u> for Figure 1 *i.e.* the Ground Plan of a typical TSDF Site:

1	Secure entrance gate
2	Security and reception office
3	Weigh bridge
4	Quality & quantity records office, Laboratory
5	Dining hall, Workers' recreation, Doctor's room
6	Parking for trucks and tankers
7	Administrative building
8	Hazardous waste storage, blending and holding zone
9	Incineration plant, Stage 1 (Location 9a) and Stage 2 (Location 9b)
10	Tank farm to hold liquid wastes and waste oils
11	Effluent Treatment Plant (ETP)
12	Landfill cells for inert wastes
13	Landfill cells for toxic wastes (Zone1, Location 13a and Zone 2 Location 13b)
14	Toilet-Bath complex
15	Overhead Water Tank
16	Fire Station

The schematic representation is not to scale and it has been presented for illustrating a typical configuration and layout of the landfills, incinerators, effluent treatment farm vis-à-vis other utilities and administrative infrastructure. It is well recognized that the real-life situation would have a non-regular geometric shape to the assigned 10-15 hectare plot of land for building the facility.

8 Staged Approach to Development of the TSDF and Capital Costs

It is envisaged that the development of the TSDF can be implemented by adopting actions and expenditures in two stages. In "Stage 1", one facility shall be constructed with landfill for the total inventory and an incinerator for ship recyclers only plus the proportionate wastewater treatment facility.

As shown in **Table 6**, it appears that one would need a plan area of about 20 acres (8 hectare footprint) for the proposed CHW-TSDF in Chittagong. The TSDF, for Stage 1 of development, will cost approximately USD 6 million - excluding the cost for land, utilities and project management.

In "Stage 2", however, the facility established in Stage 1 can be augmented by establishing the additional incinerator for industrial wastes. It can be established adjacent to the "Stage 1" incinerator meant for ship recyclers. In that case, the incremental wastewater generated by the scrubber of the new facility will be treated by augmenting and upgrading the existing Effluent Treatment Plant (ETP) (established in Stage 1). Also, separate land will not be required because it is recommended in the proposed approach that adequate land should be provided for up-front in Stage 1 itself.

As shown in **Table 6**, it appears that one would need additionally USD 5.5 million for establishing the incinerator and the appropriate augmentation of the facility during development of "Stage 2".

Yet another approach could be that the new incinerator can be established adjoining the industrial wastewater treatment facility (Common Effluent Treatment Facility *i.e.* CETP) in an industrial zone in Chittagong so that wastewater generated by this incinerator can be subjected to treatment in that CETP.

If funding for both stages were to be made available at the start of the project, it is recommended that "Stages 1 and 2" be implemented together.

Finally, it is useful to note that the costs depicted in **Table 6** are approximate because they are based on several assumptions. For example, the base costing was referenced to today's costs in India to build such a project. There are several other techno-commercial assumptions made to arrive at the costs in million USD – including that of 8% inflation and also for the growth rates of the ship recycling industry and other industries in Bangladesh.

Table 6: Break-up of land and capex requirements for the proposed TSDF in Chittagong corresponding to both the stages

Stage 1

Sr No	Waste to be treated and disposed off	Land Needed for landfill cells plus approach road and working space adjoining it (plan area) hectare i.e. ha	Land Needed for landfill cells plus approach road and working space adjoining it (plan area) acre i.e. ac	Funds Needed in 2016 million USD
1	Landfillable Wastes	1.40	3.46	2.50
2	Incinerable Wastes (Stage 1)	1.50	3.71	1.90
3	Bilge water + Scrubber Effluents + Landfill Leachates + Sewage?	1.00	2.47	0.22
4	Civil Work, storage and blending sheds, site development, infrastucture, chemical laboratory (modest), fire fighting facility, green belt, etc.	3.90	9.64	1.18
	TOTAL =	**7.80**	**19.28**	**5.80**
		hectare	**Acre**	**million USD**

Stage 2

Sr No	Waste to be treated and disposed off	Land (hectare)	Land (acre)	Funds (million USD)
5	Incinerable Wastes (Stage 2)	Nil	Nil	4.92
6	Remodel and augment the existing ETP to treat Scrubber Effluents from the new incinerator	Nil	Nil	0.28
7	Additinal Civil Work, storage and blending sheds for the new incinerator	Nil	Nil	0.37
	TOTAL =	**Nil**	**Nil**	**5.57**
		hectare	**Acre**	**million USD**

9 Cautionary Notes

It appears that one would need a plan area of about 20 acres (8 hectare footprint) for the proposed CHW-TSDF in Chittagong. It is recommended that the Government should provide free land and infrastructure like water-supply, treated wastewater pipeline for disposal, power supply, approach roads and compound wall to stop access from villagers. Then, the TSDF can be built over 18 to 24 months and it will cost approximately USD 11 million (excluding the cost for land, utilities and project management). It should be noted that these estimates may be amended as a result of ongoing work.

Of the land required for creating a TSDF for management and disposal of hazardous wastes, a substantial footprint will be required to provide for the following services at the TSDF site:

a. Analytical laboratory, waste receiving and handling

b. Parking of trucks, tankers and vehicles of workers and visitors

c. Blending of wastes and pre-processing

d. Thermal treatment

e. Treatment of leachates & effluents

f. Organization and administration

g. Worker's dining, recreation, welfare and medical facility

h. Fire safety, disaster management, space for providing ring road around the entire plot for emergency use in case of fire, flood, explosion and accidents

i. Green belt of minimum 20 meter width (40 meter width would be even better); all around the facility

The designs and estimates may contain inaccuracies due to the approximate nature of the inventory. Systems designed on the basis of such an approximate inventory and the costing based on that could be at best approximate.

It is to be noted that the above calculations are assuming that there will be yearly 6% growth in industrial sectors and about 4% growth in ship dismantling sector. However, it is probably not true about each and every sector. Some may not grow at all while some may grow beyond our expectations. In any case, the country will progress over the years and so it is likely that the amounts of solid and liquid wastes will grow.

In addition, there will be more sectors, generating more wastes – which will be established as the time progresses. However, as the industries graduate to more progressed status; there will be waste minimization due to application of advanced technologies. Also, it is expected that industries will practice reduce, recycle and reuse-based practices (3Rs) and some minimization of emissions will happen.

These factors will escalate the generation rate of the wastes over the period of coming 10 years - which has been assumed to be the life of the facility.

The advanced industrial sector in the future years will certainly be more thorough in sending larger quantities of wastes to the waste management facility and the overall wastes to be handled and treated will essentially grow in the regimes where better compliance will be achieved. Although, one cannot predict that the overall influencing factors will compensate with each other and the net change in yearly production of wastes will be insignificant or otherwise. In summary, no one can predict the future. Effort has been made in this exercise to use the best "defendable" basis in the given situation for designing the CHW-TSDF.

Finally, it is envisaged that the Common Hazardous Waste Treatment, Storage & Disposal Facility (CHW-TSDF) will be an "Integrated Hazardous Waste Management Facility". What makes any such facility an "integrated" one? Any typical CHW-TSDF project would need to address the following issues seriously and thoroughly:

1. Role of Waste Generators
2. Role of Waste Transporters
3. Operations and Work Zones
4. Resources Required & Emissions
5. Health, Safety & Environmental Issues
6. Financial & Business-related Issues

10 Critical Questions to be Addressed by the Government of Bangladesh

The Government Authorities in Bangladesh will have to facilitate the creation of the TSDF by providing free land and infrastructure like water-supply, treated wastewater pipeline for disposal, power supply, approach roads and compound wall to stop access from villagers. In this context, four important questions need to be answered:

1. Whether the Government of Bangladesh would be imposing requirements for treatment, storage and disposal of hazardous wastes generated by the ship recycling yards in Chittagong once the TSDF is ready to receive hazardous wastes from the ship recycling industry?

2. Whether the Government of Bangladesh would be imposing the requirements for treatment, storage and disposal of hazardous wastes generated by the industries in the City of Chittagong and the surrounding industrial clusters in the adjoining peri-urban areas once the TSDF is ready to receive hazardous wastes from these industries?

3. What plans the Government of Bangladesh would have for providing about 20 acres (8 hectare) suitable land free of cost for building this project and facilitate the CHW-TSDF project by providing infrastructure like water-supply, treated wastewater pipeline for disposal, power supply, approach roads and compound wall?

4. Is the Government of Bangladesh able to contribute any proportion of funds towards what is needed for the development of the CHW-TSDF?

11 Critical Questions to be Addressed by the BSBA

The BSBA may contribute to the development of the Common Hazardous Waste Treatment, Storage and Disposal Facility (CHW-TSDF) for Chittagong. In this context, three important questions need to be answered by BSBA:

i) Whether the BSBA would recognize the inevitability of creating the Common Hazardous Waste Treatment, Storage and Disposal Facility (CHW-TSDF) for responsible management of wastes generated by the ship recycling yards in Chittagong?

ii) Whether the BSBA would be imposing the requirements for treatment, storage and disposal of hazardous wastes generated during ship recycling onto the yards in Chittagong?

iii) Is the BSBA able to contribute any proportion of funds towards what is needed for the development of the CHW-TSDF?

12 Critical Questions to be Addressed by the Industry Associations and Individual Industries

Industry associations and the large polluting industries (individually) may also contribute to the development of a Common Hazardous Waste Treatment, Storage and Disposal Facility (CHW-TSDF) for Chittagong. In this context, three important questions need to be answered by the industry associations and the large polluting industries:

a) Whether the association and industries would recognize the inevitability of creating the Common Hazardous Waste Treatment, Storage and Disposal Facility (CHW-TSDF) for responsible management of wastes generated by them in and around Chittagong?

b) Whether the industry associations and the large polluting industries would be imposing the requirements for treatment, storage and disposal of hazardous wastes generated during their operations in and around Chittagong?

c) Are industry associations and individual large industries willing to contribute any proportion of funds towards what is needed for the development of the CHW-TSDF?

13 Tariff-structure for the Proposed TSDF

It is obvious that the costs per unit weight (or volume) of the wastes received at the Common Hazardous Waste Treatment, Storage and Disposal Facility (CHW-TSDF) will have to be decided in a rational manner and in consultation with the significant stakeholders. Who will be the significant stakeholders – whose opinions must be incorporated in a well-articulated protocol set-up for deciding the tariff rates? This can only be answered after completing the following two important steps:

i) The critical questions asked to the three most important stakeholders should be answered satisfactorily (refer to the preceding sections, *viz*. sections 10, 11 and 12).

ii) The Ministry of Industries, Ministry of Environment and the other empowered ministries and departments (or agencies) in the Government of Bangladesh will have to collectively agree upon the nature, character and functions of the empowered agency or enterprise or some institutional arrangement for undertaking the task of building and operating the proposed CHW-TSDF.

In other words, once the so-called "business model" is decided and once the extent of the involvement of the Government is finalized, it would be easier to lay down the protocol for deciding the tariff rates. In parallel, efforts are underway wherein different business cases are being developed for the proposed TSDF and an attempt will be made to compare them – especially in the context of Bangladesh.

In any case, the Committee empowered to decide the tariff structure will certainly consider the costs associated with operating the infrastructure of landfills and incinerators. They will include in the abovementioned operating costs the share of prorated servicing of the loans for setting up of the TSDF for meeting the capex costs (if any) as well as the appropriate taxes and levies as per the laws of the land.

In addition, it is recommended that the costs incurred in establishing as well as operating some specific components have to be taken into account while deciding the tariff rates. Some significant cost overheads associated with the operation and maintenance of a typical TSDF are listed below to provide practical guidance to the Committee empowered to decide the tariff structure:

1. Financial Assurance for Closure/Post-Closure Care: After the completion of the active operational life of a TSDF, the operator has to ensure closure and proper post-closure monitoring of the facility for approximately 30 years. They must prepare a cost estimate that reflects how much it would cost to hire a third-party contractor to close the facility. These estimates provide the base figure for the amount of financial assurance a facility must provide:
    - Cost Estimates: It must reflect the cost of hiring a third party to conduct all activities outlined in the closure and post-closure plans. Costing based on projected costs for an entire post-closure period of 30 years, unless reduced or extended by the implementing agency.
    - Cost Adjustments: Closure and post-closure cost estimates must be adjusted annually for inflation until closure is completed.
2. Accident Liability Requirements: TSDF owners and operators must also be able to compensate third parties for bodily injury or property damage that might result from hazardous waste management at a facility. Funds should be available to compensate affected third parties suffering bodily injury or property damage. All TSDFs must demonstrate liability coverage for sudden accidents. In addition, TSDFs with land-based units (*e.g.*, landfills) must also demonstrate liability coverage for non-sudden accidents.
3. Financial Assurance for Workforce: Welfare policies for the technical and non-technical work force along with capacity building and skill upgradation are

essential for effective organization and administration. Financial issues include capital expenditure, operational and maintenance cost, other financial assurance *etc.* are to be taken into account for smooth operation of the CHW-TSDF.

4. Transportation and Handling of the Wastes by a Skilled Workforce: Hazardous wastes should be transported and handled under skilled supervision and by a trained labor force. The manpower engaged in handling the wastes should be given proper training such as fire fighting, spill control, emergency reporting *etc.* The capacity building and training of the non-administrative workforce (labourers and drivers) will also add to the cost incurred in operation.
5. Occupational Health and Safety Considerations: The cost of medical treatment for the workforce is borne by the owner of the facility. This should include an on-site medical facility, annual and half-yearly health checkups and compensatory provisions. The facility should take all the measures to comply with national and international labour acts. In addition, workers engaged in special wastes handling such as asbestos removal should undergo pre-employment and periodical medical examinations at regular intervals to ascertain whether they are medically fit to undertake the activity.
6. Cost of Installing Supportive Infrastructure at the TSDF: There is a requirement for supporting infrastructure and equipment for the smooth functioning of TSDF operations. These installations include an effluent treatment plant for wastewater and leachate treatment, and environmental monitoring and mitigation measures for prevention of air, water (surface and ground) and soil pollution.
7. Environmental audits should also be routine activities in TSDFs to check the compliance and competence of the plant. Green belts or the buffer zones are required to be installed in the facility for trapping emissions and particulate matter and to add to the aesthetic appeal of the facility.

In summary, the tariff rates for hazardous waste disposal are generally decided on the basis of the quantity and type of the wastes. The waste disposal processes are mainly of three types, namely landfilling, stabilization and incineration. The above listed factors should also be taken into consideration while estimating the total disposal cost along with applicable charges like ESCROW charges (for post-closure monitoring of the facility), toll charges for interstate movement of wastes, handling charges and other applicable costs. The typical tariff structure in **Table 7** below depicts the rates actually charged currently by the CHW-TSDF businesses in India.

Table 7: Suggested Tarrif-structure for Disposal of Hazardous Wastes into Landfills and Incinerators

Sr. No.	Disposal Pathway	Disposal Rate in BDT/MT (Excluding Taxes, Transportation & Tolls)
1	Direct Disposal into Landfill	2,600 ± 25%
2	Disposal into Landfill after Stabilization	Rate = Cost of Direct Landfill (1+Bulking Factor) + Cost of Additives+ Handling charges of BDT 300 per MT Typically works out to 4,700 ± 25%
3	Direct Incineration	36,000 ± 25%
4	Disposal into Incinerator after Blending and Pre-treatment	Rate = Cost of Incineration + Cost of Additives+ Handling charges of BDT 300 per MT Typically works out to 40,000 ± 25%
5	Comprehensive analysis charges per sample	Typically BDT 23,000 per sample plus applicable taxes

14 Conclusions and Recommendations

a. The envisaged Common Hazardous Waste Treatment, Storage and Disposal Facility (CHW-TSDF) for Chittagong shall serve as the centralized facility for providing environmental utility services initially to the ship recycling yards in Chittagong and thereafter to other industries around Chittagong, for disposing hazardous wastes in a safe and environmentally sound manner.

b. It appears that one would need a plan area of about 20 acres (8 hectare footprint) for the proposed CHW-TSDF in Chittagong. Of the land required for creating a TSDF for management and disposal of hazardous wastes, a substantial footprint will be required to provide for several essential services at the TSDF site.

c. It is recommended that the Government should provide free land and infrastructure like water-supply, treated wastewater pipeline for disposal, power supply, approach roads and compound wall to stop access from villagers.

d. The TSDF, for both stages of development, will cost approximately USD 11.5 million (*i.e.* USD 6 million for *Stage 1* and USD 5.5 million for *Stage 2*) - excluding the cost for land, utilities and project management.

e. It should be noted that these estimates may be amended as a result of ongoing work. If the above facilitation is organized, the CHW-TSDF can be built over 18 to 24 months by creating a dedicated team by the Government of Bangladesh.

f. It is to be noted that the above calculations are assuming that there will be yearly 6% growth in industrial sectors and about 4% growth in the ship dismantling sector. However, rates of growth may vary by sector. Some may not grow at all while some may grow beyond our expectations. In any case, the country will progress over the years and so it is likely that the amounts of solid and liquid wastes will grow.

g. The designs and estimates may contain some inaccuracies due to the approximate nature of the inventory. Systems designed on the basis of such an approximate inventory and the costing based on that could be at best approximate.

h. In addition, there will be more sectors, generating more wastes – which will be established as the time progresses. However, as the industries graduate to more progressed status, there will be waste minimization due to application of advanced technologies. Also, it is expected that industries will promote reduce, recycle and reuse-based practices (3Rs).

i. These factors will escalate the generation rate of the wastes over the period of coming 10 years - which has been assumed to be the life of the facility.

j. The advanced industrial sector in the future years will certainly be more thorough in sending larger quantities of wastes to the waste management facility and the overall wastes to be handled and treated will essentially grow in the regimes where better compliance is achieved.

Appendix 1

Site Selection Considerations

Site selection is a complex process involved in the design of CHW-TSDFs that incorporates numerous criteria, factors and regulations. Those selecting potential sites should be mindful of the potential impacts to the surrounding areas of CHW-TSDF operations as well as the proximity of the site to waste generating industries.

The location of CHW-TSDF should be carried out on the basis of water bodies, highways, flood plains, critical habitat area, wetlands, airports, water supply wells, and coastal regulation zone and groundwater table. Areas of permitted waste management units and facilities where treatment, storage, or disposal of hazardous waste will be conducted cannot be located within an area of a fault that has experienced movement any time during the Holocene epoch or floodplain or salt dome formations, salt bed formations, or underground mines or caves.

The site selection shall be carried out on the basis of topographic maps, soil maps, transportation maps, groundwater and flood plain maps, wind rose diagrams, land use and water use plan, aerial and satellite imaging, rainfall and seismic data, preliminary boreholes and geophysical investigations. Sub-soil, hydro-geological, topographical and seismic investigations must be carried out at site to understand the nature of site. The Environment Impact Assessment (EIA) studies are essential aspects for clearance which include scoping, public hearing, impact assessment and potential damage to wildlife, vegetation, crops and physical structures.

A thick impervious layer between the bottom of the landfill and top of the groundwater table, sufficiently big size to have 20 years of operation, good dispersal of air pollutants, public acceptance, safe distance from residential arears (present and future) are the major factors that should be taken under consideration while siting a hazardous wastes TSDF.

Appendix 2

Technology Options for TSDF

Wastes Storage: Hazardous waste is commonly stored prior to treatment or disposal, and must be stored in containers, tanks, wastes piles *etc*. maintained as per the guidelines of pollution control authorities. The storage sheds may be of two types: "Temporary" and "Intractable". Intractable storage sheds are provided for complex wastes (if there is any discrepancy observed in the wastes or disposal criteria). The storage area may consist of different cells for storing different kinds of hazardous wastes. In designing these cells, all the safety considerations should be taken into account.

Storage area for incinerable wastes should be provided with the flameproof electrical fittings, automatic smoke, heat detection system, adequate fire fighting systems for avoiding any kind of mishap (CPCB, 2010a). Unloading of wastes in storage sheds should only be done under the supervision of the well trained and experienced staff. Proper fork-lifters, gantry, chain shackles, cranes, suction pumps with non-flammable electrical connections be made available (CPCB, 1999). The regulatory requirements for these types of storage units are found in title 40 of the Code of Federal Regulations (CFR) in part 264 and part 265 (USEPA 40 CFR §264 and §265, 2014).

Treatment: Un-stabilized wastes may contribute potentially in the generation of hazardous leachate, which lead to the contamination ground water system. The contaminants constituting the wastes must be physically and chemically bound by some material so that there would be no risk of consolidated stress and leaching of hazardous contaminants.

Most commonly used pre-treatment techniques include solidification, stabilization, chemical fixation and encapsulation. Pre-processing technologies such as S/S technique can be used for immobilization of contaminants preferably heavy metals, but it can also be used for different waste streams including organic waste also. The various methods for treating the wastes before its final disposal into secured landfills are as follows:

- **Solidification**: Solidification is a process that involves the mixing of additive material in the wastes in order to convert the wastes mix into solid monolith like structure. It includes physical dewatering of the wastes and the improvement of the physical properties such as strength, compressibility, and permeability. It is generally applied to such wastes in which there is high moisture content but no heavy metal concentration (ETP Sludge from steel wire industries).

- **Stabilization**: Stabilization is a term, which includes dewatering/solidification as well as chemical bonding of the additive material/particles with the contaminants. The contaminants of the wastes samples get converted into chemically more stable form. It is usually done for wastes containing toxic metals such as lead, chromium, mercury, nickel etc.

- **Encapsulation**: Encapsulation is defined as the enclosure or entrapment of the wastes by some material such as chemically bonded phosphate ceramic encapsulation, polyethylene encapsulation, Sulphur polymer stabilization/ solidification.

Disposal of Wastes into Landfills: There are mainly two methods for final disposal of hazardous wastes; disposal in secured landfills and thermal treatment by incineration. Thermal oxidation through incinerator is one of the proven technologies for destruction of hazardous waste in all the forms *i.e*. solid/semi-solid/liquid and gaseous, based on the feeding system, so as to render them innocuous in the form of non-toxic and non hazardous residues.

Hazardous wastes landfills are defined as waste disposal unit, which is designed and constructed in such a way that it causes minimum impact to the environment (Dutta *et al.,* 2006). Landfill shall have to be designed and constructed as per the guidelines of pollution control authorities. Components of Secure Engineered Landfill are liner system, leachate collection and removal system, leak detection system, daily/ intermittent cover, gas removal system, capping and closure system, storm water drainage system and redundant liner at bottom.

Disposal of Wastes through Thermal Processes: Destruction of complex hazardous waste requires knowledge to judge the compatibility of various wastes for the purpose of homogenisation of waste to be fed to the incinerator. Operation & maintenance of thermal processes and pollution control devices at the incinerator demands skill and experience with respect to compliance with the environmental regulations prescribed for the common hazardous waste incineration facilities.

Various components of common incineration facility include proper transportation, storage, analytical laboratory facilities, feeding mechanism, incineration system (rotary kiln & post combustion chamber), gas cleaning system, tail-gas monitoring facilities with automatic on-line monitoring & control facilities, ash/slag management, bleed/ scrubber liquor management and measures for health protection of workers (UNEP, 2003).

Appendix 3

Requirements of the Other Machinery

A treatment, storage and disposal facility requires the following operational machinery:

Handling of Wastes: Several equipment for earth moving and material handling are required for unloading of wastes from trucks and tankers as soon as the transporters arrive at the facility. Also, the specialized equipment are required for blending and charging the wastes into thermal treatment. In addition, several dedicated vehicles and material handling facilities would be required for transporting and loading the hazardous wastes into landfill cells. The following listing is not comprehensive but highlights some of the essential components: *e.g.* proper fork-lifters, gantry, cranes, suction-pumps with flammable electrical connections electrical fittings, dozers, compacters, back-hoe loaders and DG sets.

Equipment Required in Laboratory: A typical modern laboratory needs several analytical instruments to undertake comprehensive analyses as well as for conducting finger printing tests. Some of the more important analytical equipment are: AAS graphite furnace, AO_x analyser, TKN analyzer, GC with ECD, water purification system with RO, fume hoods, precision balances, UV-VIS double beam spectrophotometer, voltage regulator, noise level monitor, glove box, meteorological data acquisition system, refrigerator, continuous extractor, fax/telex, muffle furnace, hot air over, freezer, Kjeldhal apparatus, air compressor, pH meter, evaporators, COD assembly, vacuum pump, stack emission monitoring kit, microwave digester, conductivity meter, high volume air sampler with RSPM, micropipettes, Millipore suction system for SS, toxic gas monitors, dragger tube & app. Set, BOD incubator, centrifuge, flask shaker, heating mantles, magnetic strirrer with hot plates, rotary shaker, stop watch, water bath, flame photometer, ammonia distillation assembly, automatic burettes, air conditioners, sampling van, electronic typewriter, zero head space extractor, flash point analyser, bomb calorimeter, volatile organic sampling, GC/MS with purge and trap, infrastructure like DG sets, electrical fittings, air conditioning of cold rooms etc.

Safety Equipment: Fire hydrant systems, water sprinklers, fire extinguishers and equipment for active fire fighting.

Appendix 4

Requirements of Supportive Infrastructure and Utilities

The TSDF requires administrative and non-technical facilities and systems for smooth and efficient operations. The various supporting infrastructural installations include vehicles, mechanical and electrical workshops, operational building with basic amenities like washrooms for administrative staff, workers and transporters, cafeteria, medical rooms and recreation for the personnel.

The other requirements include control systems, illumination, facility approach roads and internal service roads and their subsequent maintenance, fencing, trenches and aesthetic maintenance of site.

Green Belt-Buffer Zone: This refers to the planting area within premises along the boundary adjoining or abutting the TSD facility. It is a segment within the building setback line from the road reserve line that is meant for the planting of trees and plants which are indigenous to the site. The width of the green buffer varies according to the road classification by Land Transport Authority. A green belt will help to screen fugitive dust generated from the roads.

Laboratory continuously works to suggest the improvements required in the process and system for waste handling as well as disposal. Prior to sending hazardous waste to the facility for treatment, storage or disposal, the generators are required to send the sample of the consignment of the hazardous waste to the operator along with the information on the process(s) of its generation, so as to facilitate the determination of pathway for treatment and disposal. Based on the analysis report and waste characterization, TSDF operator shall decide the suitable pathway for treatment, storage and disposal.

Every consignment is thoroughly analyzed using the laboratory facility at the TSDF or the waste generators get the waste samples analyzed using commercial accredited laboratories. This analysis is termed as “Comprehensive Analysis” (CA). Likewise, “Finger Print Analysis” (FPA) is also undertaken by TSDF operator to compare and contrast the waste characteristics *vis-a-vis* comprehensive analysis reports available on records. For carrying out CA and FPA, the suitable laboratory is required equipped for monitoring all the pollutants having significance for operations of the TSDF as well as stipulated by the regulators.

The personal protective equipment (PPE) includes safety shoes, helmets, various types of gloves, aprons, dust respirators, ear plugs, goggles *etc.* taking employee strength into consideration and distributed to facility employees and contractor's employees.

The site must have sufficient fire-fighting equipment that include fire hydrants, sprinklers, foams etc. Capacity building programmes for workers must be initiated to create awareness along with regular medical checkups to understand the health aspects of the workers. For handling such hazardous wastes and materials, especially asbestos, a competent agency may be appointed to reduce occupational and environmental risks.

Appendix 5

System for Transportation of Wastes

Hazardous waste transporters play a crucial role in hazardous waste management system by delivering hazardous waste from its point of generation to the TSDF. This includes transporting hazardous waste from a generator's site to a facility that can recycle, treat, store or dispose off the waste. It can also include transporting partially treated hazardous waste to TSDF site for further treatment or disposal.

Spill risk is high during loading, transportation and unloading. This is the reason why the transportation of HW is required to be highly regulated and organized. HW transportation regulations cover the transportation of HW outside of an installation *e.g.* on the pathway from the waste generator premises to the TSDF. The off-site transportation requirements involve proper awareness about the following points:

1) **Manifesting Procedures**: The uniform "hazardous waste manifest" is the tracking tool used to ensure hazardous waste sent to a treatment, storage, and/or disposal facility actually reaches its destination. It is the control and transport document that goes with the waste from its generation site to its final destination. Each party has a record of the transaction and the waste can be accounted for in transport and disposal. This greatly reduces the potential for illegal dumping and releases to the environment at any stage of handling these wastes. Hazardous waste shall not be accepted for transport without a uniform hazardous waste manifest documents [Form 8700-22, USEPA 40 CFR §264 and §265, 2014; Form no. 7 of Hazardous and other wastes (M&T) rules, 2016] that has been properly completed and signed by the generator and transporter. A person transporting hazardous waste in a vehicle shall have a manifest in his or her possession while transporting the hazardous waste.

2) **Valid Authorization**: The transporter shall have valid authorization for transporting the hazardous wastes as per Hazardous and Other Wastes (M&T) rules, 2016 in India. As per USEPA rules they should have EPA Identification (ID) Numbers, issued by U.S. Environmental Protection Agency (U.S. EPA ID Number). All hazardous waste transporters and permitted treatment, storage and disposal facilities must have ID numbers, which are

used to identify the hazardous waste handler and to track the waste from its point of origin to its final disposal (“From Cradle to Grave”).

3) **Containers**: To be made up of appropriate leak proof material with mechanical stability in order to avoid any leakage of contaminants in the surrounding areas.

4) **Labeling**: The containers should be properly labelled with all the necessary information written on it, in order to understand the potential hazards and remedial measures/first aid required at the time of emergency/spillage, contact person in case of emergency *etc.* [Form 8 of Hazardous and Other Wastes (M&T) rules, 2016].

5) **Transportation Vehicle**: The transportation vehicles shall be designed suitably (with proper colour coding) to handle and transport the hazardous wastes of corrosive, toxic, flammable and reactive nature. Authorized dedicated vehicles should be used for transportation of the wastes. It should have compliance (permits, licences and insurance) with all statutory requirements applicable in the state (The Motor Vehicles Act, 1988). The vehicle should be equipped with first aid kits, spill control equipment and fire extinguishers and driver shall be properly trained to deal with emergencies [Hazardous and other wastes (M&T) rules, 2016].

6) **Emergency Reporting**: The generator shall provide the transporter with relevant information regarding the hazardous wastes *i.e.* the hazardous nature of the wastes and measures to be taken in case of emergency [Transport emergency (TREM card): form 10 of hazardous and other wastes (M&T) rules, 2016]. If a spill or discharge of hazardous waste occurs at a transfer facility, the transporter must take appropriate immediate actions to prevent further releases of hazardous waste and protect human health and the environment. The transporter must clean up any hazardous waste discharges in a timely manner so that the spill no longer presents a hazard. They must also immediately identify the character, source, amount and areal extent of the spill. Within 15 days of a reportable incident, the transporter must send a written incident report to the Department.

7) **Packaging**: The containers must be able to withstand normal handling and retain integrity for minimum period of six months. Regulatory requirements for packaging, labelling and transportation of hazardous wastes are provided in rule 7 of Hazardous and other wastes (M&T) rules, 2016.

Appendix 6

System for Chain of Command and Movement of Hazardous Wastes

A common waste treatment and disposal facility such as Treatment, storage and disposal facility (TSDF) for management of hazardous wastes generated from industries is one of the essential components for the proper management of hazardous wastes. Recently, there have been many efforts are being made to send the hazardous wastes generated from different industries to TSDF, a centralized location for treating, storing and handling the wastes. It is helping the medium and small scale industries to comply with the Hazardous Waste (MH&T) Rules (2016).

Industrial wastes generated from various industries can be broadly classified into recyclable and non-recyclable wastes. The recyclable wastes such as spent acids, spent solvents etc. will go to the recycling units and non-recyclable wastes has to be dispatched to the TSD facilities through authorized vehicles. These TSD facilities are equipped with various testing facilities for carrying out waste analysis such as flash point, LOI (loss on ignition), calorific value, heavy metals *etc.*

The schematic representation of disposal pathways for hazardous waste disposal is given in **Figure A6.1**. First comprehensive analysis of waste sample is done in order to make a decision on the appropriate disposal technique for the wastes. The major criterion which decides the disposal pathway is calorific value, presence of biodegradable organics and presence of toxic metals.

Once the bulk waste is received at the TSD facility, the operator, so as to ascertain direct land disposal shall perform fingerprint analysis of the waste sample. The tests performed in fingerprint analysis mainly consisting of parameters such as paint filter test (for free liquids), pH, calorific value, flash point, reactive sulphide, reactive cyanide, chemical compatibility and any other specific parameter as per the requirement.

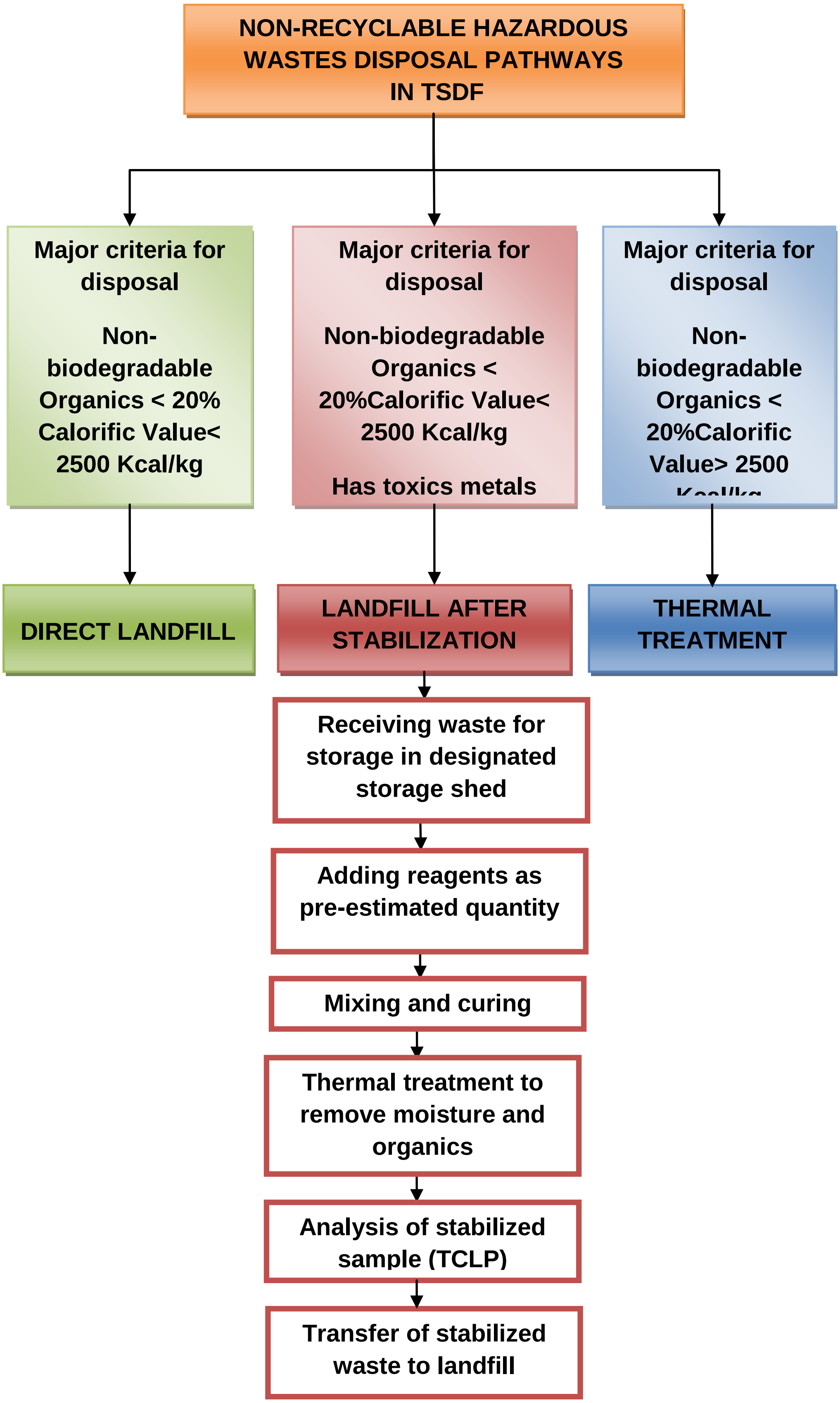

Figure A6.1 Storage and movement of hazardous waste consignent within TSDF based on waste disposal criteria

Finally, the consignment is transferred to one of the following work-zones within the TSDF:

- Temporary storage shed
- Intractable storage shed
- Automatic smoke detection system
- Heat detection system
- Adequate fire fighting systems
- Flameproof electrical fittings
- Specification of spillage/leakage to be considered
- Loading and unloading of wastes under skilled supervision

Appendix 7

Suggestions for Sophistication and Systematization of TSDF Management

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Bar-coding and Labeling for Electronic Identification: The consignment, once received, is subjected to comprehensive chemical analysis and then fixed with a bar-code. The bar-code helps in electronic tracking of the consignment within TSDF and the status of treatment, storage, blending, or disposal can be instantaneously ascertained.

'Waste Tracking System' within the CHW-TSDF: A chronological record of the quantity, nature and origin of the waste and, where relevant, the destination, frequency of collection, mode of transportation and treatment. The records shall be preserved for at least three years except in the case of establishments and undertakings transporting hazardous wastes - which must keep such records for at least one year (Directives 2008/98/EC). Biennial reports have to be prepared and submitted to the regulatory authority (USEPA 40 CFR §264-E and §265-E, 2014). Whenever hazardous waste is transferred within a member state, it shall be accompanied by an identification document, which may be in electronic format, containing the appropriate data and authorizations (Directives 2008/98/EC).

Implementation of Contingency Plan and Emergency Procedures: Suitable emergency procedures have to be formulated and implemented during operations tackling of emergency situations arising out of the proposed operations. Procedures for the following emergency situations shall be formulated for:

- ✓ Equipment failure during operation of incinerator
- ✓ Fire
- ✓ Spillage of hazardous wastes
- ✓ Accidents during regular operations
- ✓ Possible danger due to storage of compressed gases (LPG, Liquid Oxygen, refrigerants) and contained hazardous materials
- ✓ Possible danger due to spillage of fuel oil, lubricating oils
- ✓ Natural disasters (cyclone, earthquakes, tsunami)

Risk Prevention Mitigation and Emergency Preparedness: Risk assessment and minimization has to be carried out for the TSDF facilities to mitigate the occurrence of disasters. During the operation of the TSDF following risks may occur:

- Fire (oil and LPG)
- Exposure to hazardous materials like asbestos or glasswool
- Exposure to Fumes / Gases
- Natural disasters

Reporting of Disaster: When any disaster occurs, the TSDF will immediately inform the Disaster Management Center (DMC). With all available information, the DMC will act as per the Contingency Plan and also will immediately communicate to the District headquarters. The contingency plan has to be continuously updated and necessary changes have to be incorporated.

Mitigation of Disaster: At the TSDF there is risk of fire and explosion at the incinerators(s). The TSDF should have its own fire-fighting arrangements comprising of fire-water storage tanks and various types of portable fire extinguishers namely Dry Chemical Powder type and CO_2 type and foam. Any emergency starts as a small incident that may become a major accident if not controlled in time. During idle shift/ holidays, the security personnel have to interact and provide guidance to combat the incident like fire, chemical spills. An emergency organization chart is prepared by appointing key personnel and defining their specific duties that will be handy in emergency. The main management responses at facility is required for:

- Any fire or explosion in the service buildings, process area, storage areas.
- Emergency Response for Incinerator Plant.

The main course of action for mitigation measures include:

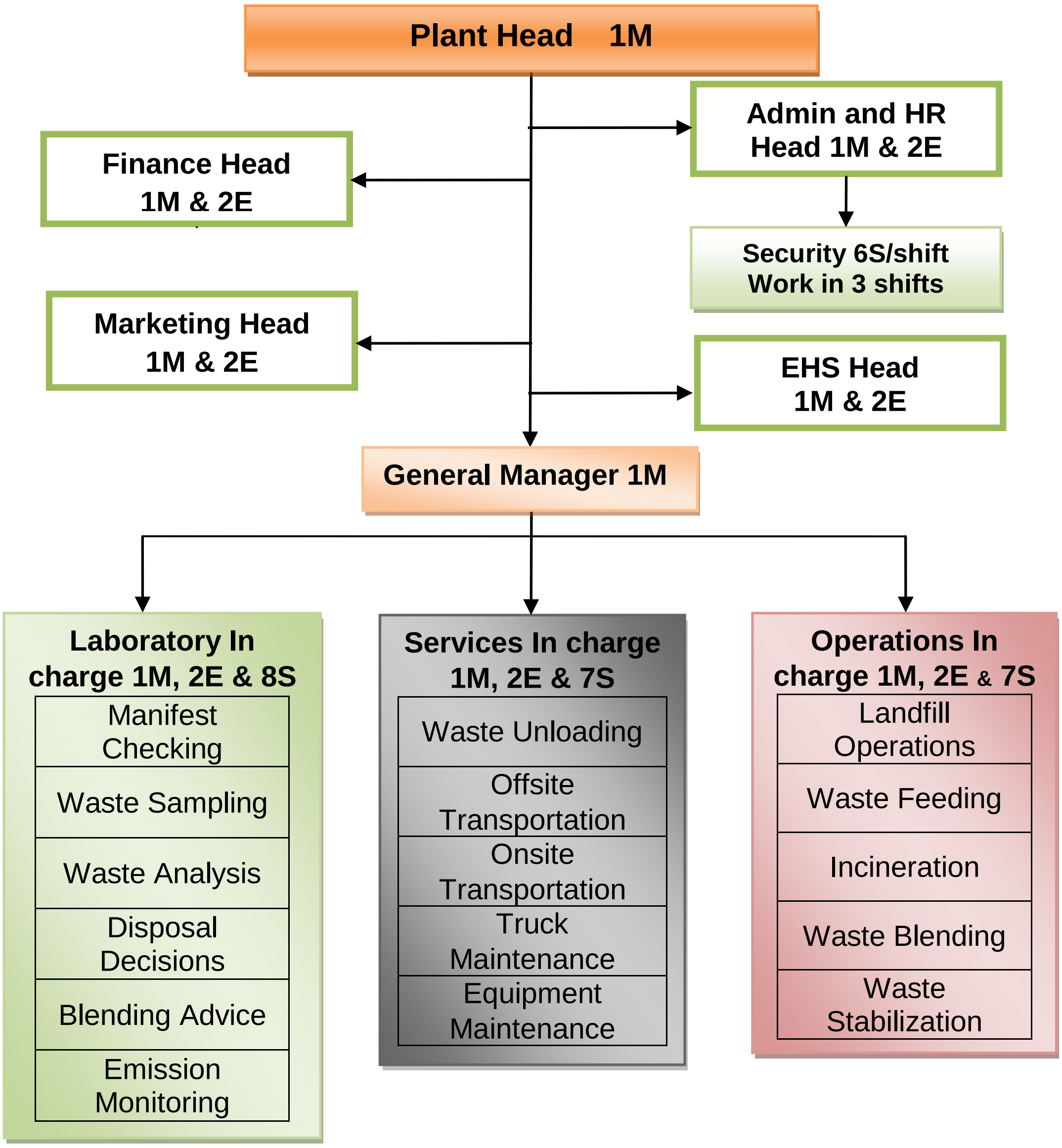
- Immediate action essential as the first few seconds count.
- Immediate steps to stop fire alongside raising alarm to contain fire.
- Stop all operations and ensure closure of all isolation valves.
- Plant personnel assemblage at a nominated place.
- All vehicles except those that are required for emergency use should be moved away from the operating area in an orderly manner at pre nominated route.

- Electrical system except the lighting and fire fighting system should be isolated.
- Fire hydrant systems are essential to be kept in good working condition to initiate robust action.
- Block all roads in the adjacent area and provide containment of nearby facilities and human shelters to prevent drastic issues at and nearby facility.

The Post-emergency Follow-up: It is essential to ensure proper functioning of the facility. The consumed fire extinguishers must be laid horizontally to indicate that they have been expended. As effective and immediate communication of emergency is vital in the process of emergency handling, under section 41B of The Factories Act (1948), the disclosure of information regarding chemicals and their hazards to the workers, general public, local authority and the factory Inspectorate is compulsory. The communication system at site must be facilitated through internal communication for informing the emergency, outside key personnel, emergency services, neighboring factories and public in the vicinity. The medical services shall be available for the possible emergency cases like treatment for burns, injuries and maybe some asphyxiation cases.

Appendix 8

Typical Organogram for the CHW-TSDF Operations



Legend: **M:** Manager, **E:** Executive and **S:** Staff

Notes

a)	Managers work in the general shift	About 8 managers required
b)	Departmental executives work in the general shift	About 15 executives required
c)	Departmental staff works in two shifts	About 25 staffs required
d)	Administrative staff works in the general shift	About 6 staffs required
e)	Janitorial & upkeep staff works in in two shifts	About 9 staffs required
f)	Security staff works in three shifts	About 15 staffs required
g)	The above organogram totals about 80 personnel on permanent basis.	
h)	Additional contractual manpower required may be approx. 50 workers for menial tasks.	

Appendix 9

Co-processing and the Other Measures

There could be several “transition measures” possible and it is strongly recommended that they should be articulated and discussed department-wise as well as researched through inter-departmental and inter-ministerial brain-storming. Following are some of the potential ideas proposed and presented in brief for bringing out the possibilities and need for undertaking this task rather seriously:

Co-processing Incinerable Wastes in Cement Kilns: Wastes having high calorific values can be used in energy intensive industries such as cement, lime, steel, glass and power generation. Wastes materials used in co-processing are referred to as alternate fuels and raw materials (AFR). A wide range of hazardous waste materials may be co-processed such as; ETP sludge, paint sludge, refinery sludge and TDI tar (CPCB, 2010b).

There are liquid hazardous wastes such as used oil, solvents or end-of-line products from the transport sector, which may also be used as AFR. Some materials can be delivered as single batches directly to the cement plant, while other may be pre-processed to meet the required conditions. Regular quality control of the collected and delivered substances will help to ensure a smooth use of the AFR in kiln.

In some cases kilns can be used for the safe disposal of hazardous waste such as obsolete pesticides, polychlorinated biphenyl (PCB) or outdated pharmaceutical products, which may not have appropriate material or energy value but can be disposed in cement kiln without impacting the product quality. However, for this type of treatment, regulatory authorities and cement plant operators must come into individual agreements and standards on a case-to-case basis in consultation with the pollution control authorities.

All wastes cannot be used for co-processing, keeping in view of the environment, health, safety and operational concern. The wastes listed ahead are normally not recommended for co-processing till otherwise proved/evidenced-biomedical wastes, asbestos containing wastes, electronic scrap, entire batteries, explosives, corrosives, mineral acid wastes and radioactive wastes.

Commercial Centralized Storage Sheds: The concept of "Centralized Storage Sheds" for hazardous wastes by means of a collective effort, has assumed reasonable gravity by being especially purposeful for cluster of industrial units. Centralized storage sheds will not only help the industries in mitigating pollution, but also act as a step towards cleaner environment.

Many industries cannot store huge quantum of hazardous wastes in the limited space available in their premises and therefore the burden of installing storage sheds, falls heavy on them. Realizing this practical problem, the scheme for promoting combined facility for storing hazardous wastes for clusters of industrial units can be proposed and also to provide technical support to them. The industries will be charged accordingly by the facility.

Onsite Pre-treatment of Hazardous Wastes: The generator should take appropriate measures for managing hazardous wastes generated from the industry. In on-site pre-treatment, the generator can keep an objective of neutralization, change in form, render it less hazardous, safer to transport and reduced in volume and also includes addition of absorbent materials. Dewatering, neutralization or absorbent-mix are the common practices that can be followed.

On-site Storage by Waste Generator: The generator/occupier cannot store the waste on-site for more than 90 days and more than 10 tonnes weight [Hazardous and other wastes (M&T) rules, 2016]. But in unavailability of TSDFs in the region, "On-site storage" by waste generator is one of the essential components of environmentally sound management of hazardous wastes. By knowing the nature of raw materials, intermediate products, bye-products, co-products and discarded products, the industry owner can find the characteristics of the wastes.

The physical stations/sources in the factory from where it comes are also of a routine & common knowledge. There should preferably earmarked drums or closed trolleys where the respective hazardous waste may be dumped by the workers. Incompatibility will be automatically observed, if colour-coding is fixed on the receiving drums. The drums be of adequate size, the frequency of removal be good enough as to avoid overflow.

Record keeping must be good and should include remarks of daily inspection on abnormalities, drum-rupture, rains *etc*. The generator should ensure on-site spillage control system in their work-zones. The storage shed should be designed as per the guidelines given by pollution control authorities depending upon the characteristics of the wastes.

Abundant precaution and foresight should be exercised while selecting site for construction of the on-site storage sheds. The site should be at such a location where flooding or inundation should be a remote possibility. In addition, using a tall plinth could be the additional safeguard incorporated in the design of shed to give additional protection from floods and inundation events.

Effort has been made to present some of the salient recommendations for on-site storage in **Appendix 10**.

Appendix 10

Guidance for On-site Storage of Hazardous Wastes

As per the prevailing wisdom, typically, any kind of toxic substances, raw materials, hazardous intermediates or products should be stored in the designated warehouses and storage areas as briefly as possible. One of the major concerns has been related to the potential problems in storage areas where leakage or spill or decay of containment could give rise to some kind of uncontrolled corrosion, effervescence of noxious gases, undesirable exothermic reactions or production of more toxic and at times unknown substances. Needless to mention the potential hazard posed by large stock-piles of any hazardous wastes resulting from industrial operations. Clearly, the problems and imminent threats posed by on-site storages of industrial wastes, especially the hazardous wastes, could be uncountable and the generators of wastes as well as the regulators often make efforts to not store the wastes on-site and send them for further treatment and disposal as soon as possible.

Having stated this context, there is one more reality faced by nearly all the developing economies of the world – that there exist few or no facilities for lawful and scientific treatment and disposal of hazardous wastes. In such circumstances, halting the industrial operations and waiting until the legal disposal facility is developed would be impractical and unsustainable. As a result, many have made efforts to develop guidelines for on-site storage of hazardous wastes on the premises of the industry. Alternately, in the vicinity of the generator, dedicated facilities could be developed somewhere else by the respective generator and store the wastes by taking all the precautions so as to minimize the risk and hazard of the stock-piles.

Two points of discussion could be:

i. What could be considered as the defendable “permissible period” for the temporary on-site storage of hazardous wastes by the generators?

ii. What could be considered as the defendable “architecture and safeguards” for the temporary on-site storage yards (or shed) of hazardous wastes to be developed and operated by the generators?

Appendix 10.1 Legally Permissible Duration for On-site Storage

Legally permitted durations for temporary storages vary from country to country. For example, while many western European countries limit temporary storage to 28 or 90 days, in Norway the generator may store the waste for up to one year - regardless of size, providing the regulations on storage design and management are met. As stipulated in the US Federal Regulations, the time span for storing wastes on-site would be decided and permitted on the basis of the rate of waste generation as well as the characteristics of the hazardous wastes.

Typically, environmental regulatory regime permits the “large quantity generators” to accumulate hazardous waste up to 90 days in standard storage areas. The “medium quantity generators”, however, may accumulate hazardous waste up to 180 days in standard storage areas, or store for up to 270 days if they have to transport waste over 300 km. But, there is an upper limit stipulated in any case. There is no duration limit for small quantity generators. In any case, at any time, the generator is prohibited from exceeding 6,000 kg of hazardous wastes on-site at any given time. Yet when the total quantity of waste exceeds certain specified limits, the generator has up to only three days to comply with the regulatory requirements (UNEP and ISWA, 2002).

In India, the generator of the hazardous wastes cannot store the wastes on-site for longer than 90 days and more than 10 tonnes (*i.e.* 10,000 kg) cumulative weight as per the Indian regulation, namely: Hazardous and Other Wastes (Management and Transboundary Movement) Rules of 2016.

In case of Bangladesh, special regulatory instrument or amendment to any suitable prevailing instrument will have to be considered so that the generators of hazardous wastes can be permitted to store hazardous wastes on-site in properly designed and regulated storage yards or sheds (or in the vicinity of the place of generation) to be developed and operated by the respective generator. The legally permitted durations for such on-site temporary storages will have to be stipulated in the neighborhood of 3 to 4 years because it will take at least 3-years to construct and commission the proposed Common Hazardous Waste – Treatment, Storage and Disposal Facility (CHW-TSDF).

Appendix 10.2 The Basic Architecture of the Shed

The hazardous waste storages, whether on-site or off-site, must be aimed to minimize the possibility of an explosion or any unplanned sudden or gradual release of hazardous waste to air, water or soil. The industrial facilities must have storage sheds which are temporary facilities to store hazardous wastes in dedicated and demarcated areas. The storage sheds are to be used for storing hazardous wastes such as paint sludge, ETP sludge, asbestos, glass wools, paint chips, thermocol, cardboard, PCB contaminated wastes *etc.* The salient design criteria that are to be taken into account are presented below:

Storage shed shall be constructed as per the guidelines given by the pollution control authorities. After review of the existing guidelines for storage of landfillable and incinerable hazardous wastes, following specifications for storage and handling of hazardous wastes are suggested. The major specifications are mentioned below:

- **Location of the storage yard:** The warehouse for storing hazardous wastes should be isolated from habitation, drinking water sources, areas which are liable to flooding, earthquakes and other sources of hazards. There should be easy access for transportation and medical facilities, fire brigades *etc.*

- **Environmental conditions:** The environmental conditions persisting in and round the vicinity of the storage area is an important parameter of concern while designing the dedicated storages. Freezing and thawing, extreme heat and cold conditions, moisture and wind can adversely affect storage of all chemicals. The exposure of wastes to sunlight also may cause some effect if some photochemical reaction occurs. Hence precautionary measures are to be taken into account while designing the storage area.

- **Ventilation:** Adequate ventilation should be provided to prevent build-up of gases. Any area used for storage should have adequate air supply along with exhaust measures to prevent build up of obnoxious odours and harmful gases. It is also considered as a precautionary measure to avoid any kind of mishaps due to improper and negligent handling of hazardous wastes generated from industrial activities. Therefore, the workers should be trained for safe handling and storage of hazardous wastes.

- **Design of storage buildings:** The storage yard should be designed as per the hazard characteristics and quantity of the wastes to be stored with adequate provisions of emergency exits. It should be substantially closed when not in use and capable of being locked. The external walls should be properly covered with steel or similar materials when the risk of fire hazard is minimum. If there is a risk of fire hazard, the external walls must be of solid constructions. Insulation materials like mineral wool and glass fibre (but not asbestos) should also be used in the construction process. Concrete construction will provide adequate fire resistance and physical strength. In order to achieve the desired fire resistance property, reinforced concrete walls should be at least 15 cm (6 inches) thick and brick walls should be at least 23 cm (9 inches) thick. Hollow brick usage is not preferable. In case of concrete blocks without reinforcement, there is a requirement of 30 cm (12 inches) thick wall. Greater structural stability is offered by providing reinforcing columns in fire walls. These fire walls have to be kept independent from the adjoining building structures to prevent the collapse of the structure during accidents like fire. The electrical and piping ducts must be enclosed in fire resistant systems to ensure safe and secure management of the yard. Storage areas should be designed to withstand the load of material stocked and any damage from the material spillage. Adequate storage capacity (i.e. four times of the annual capacity of the hazardous waste incinerator) should be provided in the premises. There should be at least 15 m distance between the storage sheds.

- **Security and administrative requirements:** The shed should be secured by a boundary wall. There should be appropriate distances from the shed boundary and internal roads. Hazardous wastes have to be stored away from both vehicular and foot traffic. Security personnel should be deployed at the storage yard for safeguarding the site. The storage yard should also house a security personnel cabin to ensure the monitoring of the yard all the time. There should be provisions for patrolling the site during night hours. Watchmen and/or use of additional security aids like perimeter lighting *etc*. must be considered.

- **Safety requirements:** Storage areas may consist of different sheds for storing different kinds of incinerable hazardous wastes and sheds should be provided with suitable openings. Flammable, ignitable, reactive and non-compatible wastes should be stored separately and never should be stored in the same storage shed. Storage areas should be provided with flameproof electrical fittings and it should be strictly adhered to. Fire break of at least 4 meters between two blocks of stacked drums should be provided in the storage shed. One block of drums should not exceed 300 MT of waste. Minimum of 1 meter clear space should be left between two adjacent rows of drums in pair for inspection. Fire control equipment shall be installed appropriate to the characteristics of the waste and as the situation demands. A wash room and associated eye wash station must be provided for each storage area.

- **Flooring:** In order to have appropriate measures to prevent percolation of spills, leaks *etc.* to the soil and ground water, the storage area should be provided with concrete floor or steel sheet depending on the characteristics of the waste handled. The floor must be structurally sound and chemically compatible with the wastes. The storage area should be designed with proper stabilised soil strata. The floor shall be a concrete slab or other impermeable material; preferably made up of a non-reactive substance. The impermeable base should be used for the area where drums and containers may be stored. This will help to check any leaks or spills, or any other kind of seepages from moving into the ground strata contaminating soil as well as surface and ground water.

- **Drainage:** Measures should be taken to prevent entry of runoff into the storage area. The storage area shall be designed in such a way that the floor level is at least 150 mm above the maximum flood level. The storage area floor should be provided with secondary containment such as proper slopes as well as collection pit so as to collect wash water and the leakages/spills *etc*. All the storage yards should be provided with proper peripheral drainage system connected with the sump so as to collect any accidental spills in roads or within the storage yards as well as accidental flow due to the fire fighting. In case of suspected contaminated stream at the storage area, the seepage must be collected and removed and handled as hazardous waste.

- **Bunding:** The storage area must be designed and operated to contain any leaks and spills *e.g.* with bunds. Bunding and/or drains shall be provided around the storage area to avoid storm water entering into this area. Proper care must be taken so that the water or moisture doesn't come in contact with the waste containers.

- **Roofing:** Roofing must be able to keep out rainwater and the design should allow fumes and heat to come out. Corrosion resistant materials have to be used for roofing and the wind load at site has to be taken into account while designing the roofs of storage sheds.

- **Emergency exit:** Emergency exits must be provided other than the main door of the storage shed. It should be clearly marked and designed in such a way that they provide easy exit in case of emergency.

- **Housekeeping at the yard:** There should be proper housekeeping and illumination in the storage sheds. This includes procedures for work areas, such as aisles, passageway and dedicated storage sheds where wastes will be stored prior sending it to the disposal facilities.

- **Provision of Space for Inspection:** A separate area has to be provided so that any hazardous wastes which seem to be incorrectly or inadequately packed can be inspected and necessary measures can be taken.

Appendix 10.3 Waste Compatibility

Waste must be categorically segregated and stored in separate compatibility areas. Hazardous wastes can be kept close to each other, with proper care without any harmful chemical or physical reactions. Incompatibility between two chemical substances can result in one of a number of reactions. For example: acid reacts with cyanide solution to release cyanide gas – which is a known poisonous gas.

The chemical compatibility chart given by US-EPA is tabulated in **Figure A10.1**. Many of the entries in this chart are of more relevance to chemical industries. The concept of compatibility, when applied to hazardous waste, refers to the following attributes:

- ✓ The inherent nature of reaction of chemicals when in contact with each other.
- ✓ The interaction of wastes with the containers in which they are stored. For example, acid should not be stored in steel drums, or pressurized materials in weak containers.
- ✓ Compatibility with nearby materials and equipment. For example, containers of flammable materials should be stored with proper consideration of proximity to heat, electrical sources and open flames.
- ✓ Compatibility with the environmental conditions. Few hazardous wastes have very low flash point due to being liable to catch fire even at normal temperature. Some waste streams can undergo photochemical reaction in presence of sunlight.
- ✓ The incompatibility between two chemical substances stored at the shed can eventually result in a number of reactions. Few examples for the chemical reactions are:
  - o The reaction of acid and cyanide solution may liberate cyanide gas which is extremely hazardous.
  - o Likewise bleach with ammonia may produce chlorine gas.
  - o Strong acids stored for disposal if they come in contact with water liberate tremendous heat and other potentially harmful gases.

EPA's Chemical Compatibility Chart
EPA-600/2-80-076 April 1980

A METHOD FOR DETERMINING THE COMPATIBILITY OF CHEMICAL MIXTURES

Please Note: This chart is intended as an indication of some of the hazards that can be expected on mixing chemical wastes. Because of the differing activities of the thousands of compounds that may be encountered, it is not possible to make any chart definitive and all inclusive. It cannot be assumed to ensure compatibility of wastes because wastes are not classified as hazardous on the chart, nor do any blanks necessarily mean that the mixture cannot result in a hazard occurring. Detailed instructions as to hazards involved in handling and disposing of any given waste should be obtained from the originator of the waste

CODE	CONSEQUENCE
H	Heat Generation
F	Fire
G	Innocuous and non-flammable gas generation
GT	Toxic Gas formation
GF	Flammable Gas formation
E	Explosion
P	Violent Polymerization
S	Solubilization of toxic substance
U	May be hazardous, but Unknown

No.	Group	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
1	Acids, Mineral, Non-oxidizing																				
2	Acids, Mineral, Oxidizing																				
3	Acids, Organic		G H																		
4	Alcohols and Glycols	H	H F	H P																	
5	Aldehydes	H P	H F	H P																	
6	Amides	H	H GT																		
7	Amines, Aliphatic and Aromatic	H	H GT	H		H															
8	Azo Compounds, Diazo Compounds and Hydrazines	H G	H GT	H G	H G	H															
9	Carbamates	H G	H GT						G H												
10	Caustics	H	H	H		H				H G											
11	Cyanides	GT GF	GT GF	GT GF					G												
12	Dithiocarbamates	H,F GF	H,F GF	H,GT GF		GF GT		U	H G												
13	Esters	H	H F						H G		H										
14	Ethers	H	H F																		
15	Fluorides, Inorganic	GT	GT	GT																	
16	Hydrocarbons, Aromatic		H F																		
17	Halogenated Organics	H GT	H,F GT					H GT	H G		H GF	H									
18	Isocyanates	H G	H,F GT	H G	H P			H P	H G		H,P G	H G	U								
19	Ketones	H	H F						H G		H	H									
20	Mercaptans and Other Organic Sulfides	GT GF	H,F GT						H G									H	H	H	
21	Metals, Alkali and Alkaline Earth, Elemental	H,F GF	H,F GF	H,F GF	H,F GF	H,F GF	GF H	GF H	GF H	GF H	GF H	GF H	GF,H GT	GF H				H E	GF H	GF H	GF H
22	Metals, Other Elemental & Alloys as Powders, Vapors, or Sponges	H,F GF	H,F GF	G F					H,F GT	U	GF H							H E	GF H		H,F GF
23	Metals, Other Elemental & Alloys as Sheets, Rods, Drops, etc.	H,F GF	H,F GF						H,F G									H F			
24	Metals and Metal Compounds, Toxic	S	S	S			S	S			S										
25	Nitrides	GF HF	H,F E	H GF	H,E GF	GF H			U	H G	U	GF H	GF H	GF H				GF H	U	GF H	GF H
26	Nitriles	H,GT GF	H,F GT	H							U										
27	Nitro Compounds, Organic		H,F GT			H					H E										
28	Hydrocarbons, Aliphatic, Unsaturated	H	H F			H															
29	Hydrocarbons, Aliphatic, Saturated		H F																		
30	Peroxides and Hydroperoxides, Organic	H G	H E		H F	H G		H GT	H,F E	H,F GT		H,E GT	H,F GT					H E	H	E	H,F GT
31	Phenols and Cresols	H	H F						H G										H P		
32	Organophosphates, Phosphothioates, Phosphodithioates	H GT	H GT						U		H E										
33	Sulfides, Inorganic	GT GF	HF GF	GT		H			E										H		
34	Epoxides	H P	H P	H P	H P	U		H P	H P		H P	H P	U								H P
101	Combustible and Flammable Materials, Miscellaneous	H G	H,F GT																		
102	Explosives	H E	H E	H E					H E		H E			H E							
103	Polymerizable Compounds	P H	P H	P H					P H		P H	P H	U								
104	Oxidizing Agents, Strong	H GT		H GT	H F	H F	H,F GT	H,F GT	H E	H,F GT		H,E GT	H,F GT	H F	H F		H F	H GT	H,F GT	H F	H,F GT
105	Reducing Agents, Strong	H GF	H,F GT	H GF	H,F GF	H,F GF	H GF	H G				H GT	H F				H,F E	H E	H GF	H GF	H GF
106	Water and Mixtures Containing Water	H	H						G										H G		
107	Water Reactive Substances	<---EXTREMELY REACTIVE! DO NOT MIX WITH ANY CHEMICAL OR WASTE MATERIAL! EXTREMELY REACTIVE!--->																			

No.	Group	21	22	23	24	25	26	27	28	29	30	31	32	33	34	101	102	103	104	105	106	107
25	Nitrides	E																				
26	Nitriles	H P			S	GF H																
27	Nitro Compounds, Organic	H,E GF				H,E GF																
28	Hydrocarbons, Aliphatic, Unsaturated		H E																			
30	Peroxides and Hydroperoxides, Organic	H E	H G		H G	H,E GF	H,P GT		H P													
31	Phenols and Cresols	GF H				GF H					H											
32	Organophosphates, Phosphothioates, Phosphodithioates	H									U											
33	Sulfides, Inorganic										H GT											
34	Epoxides	H P	H P		H P	H P					H P	H P	U	H P								
101	Combustible and Flammable Materials, Miscellaneous	H,F G				H,F GF					H,F GT											
102	Explosives	H E	H E	H E	E	E					H E	H E		H E	H E	H E						
103	Polymerizable Compounds	P H	P H	P H	P H	P H					P H	P H		P H			H E					
104	Oxidizing Agents, Strong	H,F E	H,F E	H F		H,F E	H,F GT	H E	H F	H F	H G	H F	H,F GT	H,F GT	H,F G	H,F G	H E	H,F GT				
105	Reducing Agents, Strong						H GF	H E			H E	H GF	H,GT GF		H	H GF	H E	H,P GF	H,F E			
106	Water and Mixtures Containing Water	H GF	H GF		S	H GF								GT GF						GF GT		

Figure A10.1 Compatibility chart for storage of hazardous wastes (Source: US-EPA-600/2-80-076)

Incompatible wastes must be placed in separate areas constructed of suitable material. If such wastes are placed together, there could be the potential for hazardous incidents in the form of leaks and spillages, which could ultimately lead to the mixing of the incompatible wastes. Different chemical reactions may take place. Some reactions could produce excessive pressure, thus posing fire or explosion hazards. Others could produce toxic fumes and gases.

Thus, there is a stern need for careful planning of chemical storage. Such requirement is applicable to the waste generator as well as to the treatment facility.

Appendix 10.4 Gear and Equipment for Material Handling

The procedures for safety and operations of the waste handling equipment including cranes, machines, mobile equipment and aerial and man-lift systems as well as the list of qualifications required for the corresponding operators should be articulated. Those documents equipment should be available on site so that wastes handlers can refer to them from time to time and the documents can also be used during training sessions of the workforce.

Hazardous materials being moved or stored need to be contained in some way. The kind of container/ storage unit reflects the type of waste to be stored, and the handling method in use. For example, some containers are more suitable for filling by pumping, and some more suited to filling by shoveling. Drums/containers are specially required for storing liquid hazardous wastes. The specifications of drum/containers are given below:

- **Container material**: The container shall be made or lined with suitable material, which will not react with, or in other words shell be compatible with the hazardous wastes proposed to be stored.

- **Stacking of Containers**: The stacking of drums in the storage area should be restricted to three high on pallets (wooden frames). Necessary precautionary measures should be taken so as to avoid stack collapse. However, for waste having flash point less than 65.5 ^{o}C, the drums should not be stacked more than one metre height.

- **Sampling of wastes**: No drums should be opened in the storage sheds for sampling *etc.* and such activity should be done in designated places outside the storage areas. Drums containing wastes stored in the storage area should be labelled properly indicating mainly type, quantity, characteristics, source, date of storing, *etc*.

- **Labelling Containers**: Each container must be labelled or marked with the words "Hazardous Waste." The label be legible and in good condition. If it becomes difficult to read it should be replaced immediately. Each storage container must also be labelled marked with the accumulation start date.

- **Condition of Containers:** The containers should be able to absorb impact, in case they are bumped or dropped. They must be free of leaks, structural defects or rust. The outside must be clean and without holes, bulges or cracks. The containers should remain closed at all times, except when waste material is being added or removed. The container must be designed so that its contents will not escape when subjected to normal handling.

- **Compatible Containers**: Each container must be compatible with the hazardous waste to be placed in it. Therefore, the container must be made of materials that will not react with the wastes to be stored. For example, an acid waste must not be stored in a metal container without an appropriate liner, because the acid may corrode the metal, resulting in a release of the hazardous waste.

- **Other factors to consider**: In many cases, reconditioned drums can be safely used to store wastes. In industrialising countries, the re-use of raw materials drums is common practice. New drums may be expensive but re-use drums, or purchasing reconditioned drums (which are usually available for approximately half the cost of new drums) reduces costs. If considering the use of reconditioned drums, it is important to inspect their quality and condition, and to ensure that any previous contents are completely removed, particularly if those contents may be incompatible with the waste. Drums which have previously been used for the same chemicals from which the hazardous wastes result can be used.

- **Tanks:** Tanks are ideally suited for bulk storage of hazardous wastes. They are also useful for accumulating wastes that can be handled by bulk materials handling systems such as pipelines, or belt conveyors. Tanks offer more rigid and integral containment than drums, cans or containers and are easier to inspect for leaks and spills.

- **Loading and unloading of wastes in storage sheds**: It should only be done under the supervision of the well trained and experienced staff.

- **Vehicles for carrying wastes**: The exhaust of the vehicles used for the purpose of handling, lifting and transportation within the facility such as forklifts or trucks should be fitted with the approved type of spark arrester. Doors and approaches of the storage area should be of suitable sizes for entry of fork lift and fire fighting equipment.

- **Arrangement of storage units**: The drums, containers should not be stacked more than two high. Drums containing flammable liquid should not be stacked. There has to be proper demarcation at site on type of wastes stored and proper passage has to be left so that accessibility during any mishap is possible. The storage and handling should have at least two escape routes in the event of any fire in the area.

- **Material Safety Data Sheet (MSDS):** The wastes generator should collect all the necessary information about the hazardous wastes that has to be stored. Especially for chemical wastes, all the information regarding the hazardous characteristics must be listed out. This information is provided in the form of Material Safety Data Sheet (MSDS). This forms an important aspect of recordkeeping in the storage yard which can be used during emergency or accidents like spillages and fire hazards. Clear and comprehensive instructions for safe and environmentally sound handling procedures under normal as well as emergency situations should be provided on-site. The generator should have the list of information for each type of waste stream related to its physical, chemical and biological properties. These characteristics should be clearly understood by the personnel and workers engaged in the handling and storage of the wastes. Following information is required for the effective operation of the storage yards:

  - Physical and chemical characteristics of waste
  - Safety data and instructions (Toxicity, Eco-toxicity, Corrosivity)
  - Storage conditions
  - Protective gears
  - Cleaning, decontamination and spill control instructions
  - First aid instructions
  - Information for doctors
  - Fire fighting instructions
  - Sources of advice

Appendix 10.5 Identification of Material Hazards for Emergency Response

Labelling is an essential component of hazardous waste emergency response. There are several widely used systems for labelling of hazardous materials. The main ones include NFPA 704 Diamond and OSHA HazCom 2012. Each one of the labelling methods has a specific purpose and the NFPA is recommended for emergency response for cases of accidents like fire, spillage, mishap to workers, *etc.*

The NFPA 704 “Standard System for the Identification of the Hazards of Materials for Emergency Response" is developed and maintained by the U.S.-based National Fire Protection Association (NFPA). It extends a simplified and easily understandable system to ensure the specific hazards of a material and extent of severity of the hazard that may occur during an emergency situation. NFPA labelling method is widely used outside buildings, on doors, on tanks, visible to emergency responders during spill or fire.

This identification system addresses mainly four aspects that include the flammability (red colour), health (blue colour), instability (yellow colour), and special hazards (white colour) that could occur as a result of a fire, chemical spillage or similar emergency. The red, blue and yellow colours are coded from 0-4 such that 0 denotes the least hazardous substance and 4 represent the most hazardous substance (**Figure A10.2** and **Table A10.1**). Few symbols are not the part of NFPA, yet these symbols can also be used for representing some special properties including biohazard, corrosiveness *etc.*

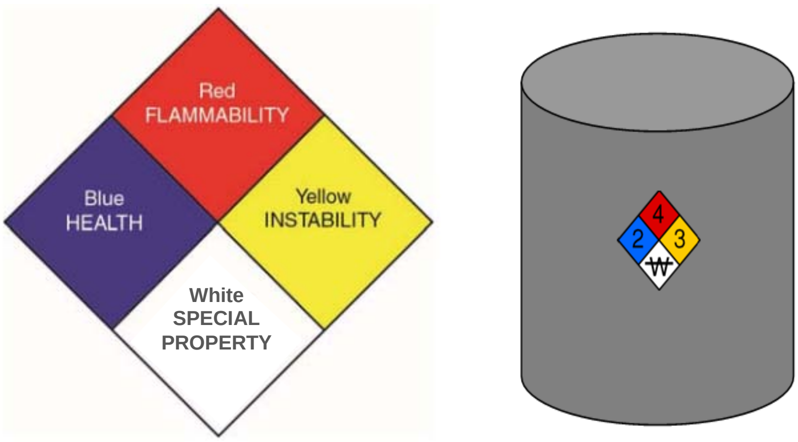


Figure A10.2. NFPA diamond recommended by National Fire Protection Association Massachusetts, USA (2011) that identifies the hazards of a material and the degree of severity of the health, flammability, and instability hazards

Table A10.1: **Standard system** for the identification of the ***Hazards of Materials and Wastes*** recommended by National Fire Protection Association (NFPA), Massachusetts, USA (2011)

Flammability (red)	
0	Materials that will not burn under typical fire conditions.
1	Materials that needs preheating before getting ignited.
2	Must be moderately heated or exposed to relatively high ambient temperature before ignition can occur.
3	Liquids and solids (including finely divided suspended solids) that can be ignited under almost all ambient temperature conditions.
4	Will rapidly or completely vaporize at normal atmospheric pressure and temperature, or is readily dispersed in air and will burn readily.
Health (blue)- Type of possible injury	
0	The materials pose no health hazard. Hence no precautions necessary.
1	Exposure to hazardous material may cause irritation with only minor residual injury.
2	Temporary incapacitation or possible residual injury as a result of intense or continued exposure but not chronic exposure (prompt medical treatment can reduce the gravity of situation).
3	Short term exposure can lead to serious, temporary or moderate residual injury.
4	Very short exposure could cause death or major residual injury.
Instability/reactivity (yellow)	
0	Normally stable even under fire exposure conditions and is not reactive with water.
1	Normally stable, but becomes unstable at elevated temperatures and pressures.
2	Normally unstable and undergoes violent chemical change but do not detonate. At elevated temperatures and pressures, hazardous materials react violently with water, or may form explosive mixtures with water.
3	Capable of detonation or explosive decomposition but requires a strong detonating source, must be heated under confinement before initiation, reacts explosively with water.
4	Readily capable of detonation or of explosive decomposition at normal temperatures and pressures.
Special notice (white)	
OX	Oxidizer, allows chemicals to burn without an air supply.
~~W~~	Reacts with water in an unusual or dangerous manner.
SA	Simple Asphyxiant gas
BIO	Biological hazard (e.g. flu virus, rabies virus).
RAD	Radioactive (e.g. plutonium, cobalt-60).
COR	Corrosive.

Appendix 10.6 Marking and Labelling

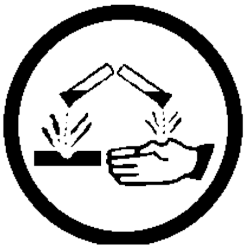
An important aspect of the storage of hazardous waste is its correct marking and labelling (examples illustrated in **Figure A10.3**). This is essential to ensure that proper handling and compatible storage is happening prior disposal. The regulations for marking and labelling of hazardous wastes differ from country to country, but there are some general rules and requirements. For on-site storage, the marking and labeling must convey the nature of wastes, physical state of the waste at a given temperature, waste composition, necessary information on health protection for workers, precautionary measures in case of accidents and emergency contact numbers.

Markings must be durable, and written in English and native languages. They must be clear and easy to understand and placed away from any other markings. They should be in a colour different from and contrasting to the background colour of the container. If old drums or containers are reused all old markings should be removed to avoid confusion.

Reactive Wastes

Toxic Wastes

Ignitable Wastes



Corrosive Wastes

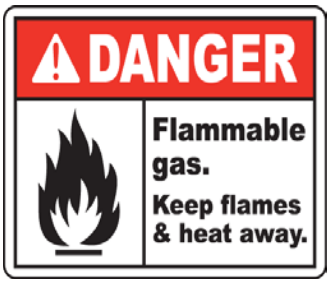


Figure A10.3: Labels to be used on packages, drums, cartons and bags containing various categories of hazardous wastes

All drums, containers and tanks must be clearly labelled with the waste type and hazard posed (see Figure A10.3). Labels should be made of good quality, durable materials which will not be affected by weather. They should not be easily removable. They must be legible and recognizable in daytime and at night.

Appendix 10.7 Measures for Management of Spilled and Leaked Wastes

There shall be a proper spillage control system installed in the storage shed. The workers should be trained about the precautionary measures for handling and storing wastes in the sheds. A proper spillage control system should also be made available. The major specifications are listed below:

- The storage areas should be inspected daily for detecting any signs of leaks or deterioration. Leaking or deteriorated containers should be removed and ensured that such contents are transferred to a sound container.
- In case of spills/leaks dry adsorbents/cotton should be used for cleaning instead of water. Adsorbing agents should always be present to clean up spills immediately.
- Proper slope with collection pits should be provided in the storage area so as to collect the spills/leakages.
- Storage areas should be provided with adequate number of spill kits at suitable locations. The spill kits should be provided with compatible sorbent material in adequate quantity.

Appendix 10.8 Occupational Safety and Sanitation

- **Facilities for sanitation and disaster preparation**: It is recommended that appropriate changing rooms and sanitary and washing facilities should be provided adjoining the storage facility for the benefit of personnel coming in contact with hazardous materials and wastes. Sanitary and washing facilities should be conveniently accessible and situated so that they are not at risk of contamination from the workplace. Appropriate and separate changing rooms and sanitary and washing facilities should be provided for the exclusive use of workers handling wastes like asbestos. It is also recommended that the industrial facility should designate separate and uncontaminated areas for workers to use for eating, drinking and for resting during breaks.

- **Inspection:** The procedures for inspection and maintenance of equipment, and the requirements for third-party inspections and decontamination should be properly laid down. These activities and the result of the inspections should be recorded. The industrial facility should ensure that the quantity and the deployment of tools and equipment are suitable for the corresponding industrial activities.

- **Personal protective equipment**: Information on procedures and equipment used for the protection of employees from various risks associated with industrial processes should be provided. Respiratory protection and hearing conservation programmes should be developed for all employees who could be exposed to excessive levels of contaminants. The personal protective equipment (PPE) includes safety shoes, helmets, various types of gloves, aprons, dust respirators, ear plugs, goggles *etc.* taking employee strength into consideration and distributed to facility employees and contractor's employees.

- **Other safety requirements:** The shed must have adequate fire-fighting equipment that includes fire hydrants, sprinklers, foams *etc*. Capacity building programmes for workers must be initiated to create awareness along with regular medical checkups to understand the health condition of the workers. A competent agency may be appointed for the handling of hazardous wastes, especially asbestos, to reduce occupational and environmental risks. There should be adequate insurance coverage including general liability.

- **Storage and labelling after removal:** The industrial facility's procedures should describe how all wastes generated from various industrial processes should be kept separate from recyclable materials and equipment, clearly labeled for identification and stored in appropriate conditions either temporarily or for a longer term. These should describe how the industrial facility will avoid waste being mixed or contaminated in a way that interferes with subsequent handling, storage, treatment, recycling or disposal.

- **Prohibition on smoking:** Smoking and naked flames must be prohibited in the and around the storage yards where flammables and combustibles are kept. "No smoking" signboards have to prominently displayed in the yard.

Arceivala, S. J. and Asolekar, S. R. (2006). “Wastewater Treatment for Pollution Control” (3rd Edition, 11th Reprint), McGraw Hill Education (India) Pvt. Ltd., New Delhi

Arceivala, S. J. and Asolekar, S. R. (2012). “Environmental Studies: *A Practitioner’s Approach”*, McGraw Hill Education (India) Pvt. Ltd., New Delhi

Asolekar S. R., Key note address entitled *Zero Liquid Discharge* in the Conference organized by Indian Environmental Association during Jan 22nd and 23rd, 2016 at Mumbai, India.

Asolekar, S. R. (2006). Status of Management of Solid Hazardous Wastes Generated during Dismantling of Obsolete Ships in India, presented at the *First International Conference on Dismantling of Obsolete Vessels*, Glasgow, Scotland, UK, September 11-12.

Asolekar, S. R. (2012) Greening of ship recycling in India upgrading facilities in Alang. *Proceedings of 7th Annual Ship Recycling Conference* organized by Informa Maritime Events and Lloyd's List, held in London, UK, December 10-13.

Asolekar, S. R. and Gopichandran, R. (2005). “Preventive Environmental Management – An Indian Perspective”, Foundation Books Pvt. Ltd., New Delhi (the Indian associate of Cambridge University Press, UK)

Asolekar, S. R. and Hiremath, A. M. (2013). India’s Contribution in Preventive Environmental Management of Obsolete Vessels. *Indian Ports and Infrastructure Magazine*, August, 2012, 5-7.

Asolekar, S. R., and Hiremath, A. M. (2013) India’s Contribution in Preventive Environmental Management of Obsolete Vessels. *Indian Ports and Infrastructure Magazine*, 8, 5-7.

Asolekar, S. R., Gopichandran, R., Hiremath, A. M. and Kumar D. (2015). “Green chemistry and ecological engineering as a framework for sustainable development” in an integrated approach to environmental management (eds D. Sarkar, R. Datta, A. Mukherjee and R. Hannigan), John Wiley & Sons, Inc, Hoboken, NJ, USA. (DOI: 10.1002/9781118744406.ch4)

Asolekar, S. R., Hiremath, A. M. and Vasant S. C. (2013) Carbon Foot Printing of Ports in Mumbai. *Indian Ports and Infrastructure Magazine*, February, 2013, 19-21.

CCS101 (2014) The Carbon Capture and Storage Information Source, Greenhouse Gas Abatement in Energy Intensive Industries. Available at <http//ccs101.ca/assets/Documents/ghgt5.pdf> (Last accessed on 20 May, 2014).

Central Electricity Authority, Government of India (2013) CO_2 baseline database for the Indian power sector, user guide, version 8.0, January 2013.

Chowhan, M. V. S., Hiremath, A. M. and Asolekar, S. R. (2013) Carbon Foot printing of

Container Terminal Ports in Mumbai. *In the Proceedings of International Conference on Impact of climate change on Food, Energy and Environment (ICCFEE-2013).* Elsevier Publication ISBN - 978-93-510710-1-3.

CPCB, 1999. Guidelines for setting up of operating facility: Hazardous Waste Management (HAZWAMS/11/1998-99), Government of India.

CPCB, 2010a. Protocol for Performance Evaluation and Monitoring of the Common Hazardous Waste Treatment Storage and Disposal Facilities including Common Hazardous Waste Incinerators, Government of India.

CPCB, 2010b. Guidelines on Co-processing in Cement/ Power/ Steel Industry, Government of India.

Deshpande P. C., Kalbar, P. P., Tilwankar, A. K., Asolekar, S. R. (2013) A Novel methodology to develop emission factors for pollutants from ship recycling yards based on input output studies. *Journal of Cleaner Production*, 59, 251-259.

Deshpande P. C., Tilwankar A. K., and Asolekar S. R. (2012) A Novel approach to estimating potential maximum heavy metal exposure to ship recycling yard workers in Alang, India. *Science of The Total Environment*, 438, 304-311.

Deshpande, P. C., Hiremath, A. M., Kalbar, P. P. and Asolekar, S. R. (2014) Towards Green Ship Dismantling Scientific Assessment of Health, Safety and Environment Agenda. *In the Proceedings of the International Conference on Ship Recycling* SHIPREC2013 held in Malmö, Sweden, Pages 233-242,WMU Publications 2014,ISBN 978-91-977254-8-4 (Won best paper award).

Directives 2008/98/EC of The European Parliament and of The Council of 19 November 2008 on waste and repealing certain Directives.

Dutta, S.K., Upadhyay, V.P. and Sridharan, U., 2006. Environmental management of Industrial Hazardous Wastes in India. Journal of Environmental Science and Engineering, 48(2), pp.143.

EPA-712-C-96-129 Fish BCF, Ecological effects test guidelines, United States Environmental Protection Agency.

EU Ship Recycling Regulation (2013) European Union Ship Recycling Regulation adopted by the European Council and published in the Official Journal of the EU to become legally binding. The Regulation entered into force on 30 December 2013. Available at <http://maritimesun.com/news/ship-recycling-new-eu-regulation>.

Garmer, K., Shastrum, H., Hiremath, A. M., Tilwankar, A. K. and Asolekar S. R. (2015) Identification and Assessment of Risks in Ship Dismantling Industry: A Three-step Method Approch. *Journal of Safety Science*, Volume 76, Pages 175-189 [Elsevier Publication; IF 2.21/2015].

Garmer, K., Sjöström, H., Hiremath, A.M., Tilwankar, A. K., Kinigalakis, G. and Asolekar, S. R. (2015). Development and validation of Three-Step Risk Assessment Method for Ship Recycling Sector. *Safety Science* 76, 175–189. [IF = 2.21].

Gopichandran, R., Asolekar, S. R., Jani, O., Kumar D. and Hiremath, A. M. (2015). “Green energy and climate change” in “An integrated approach to environmental management” (eds D. Sarkar, R. Datta, A. Mukherjee and R. Hannigan), John Wiley & Sons, Inc, Hoboken, NJ, USA. (DOI: 10.1002/9781118744406.ch5)

Hazardous and Other Wastes (Management and Transboundary movement) Rules, 2016. Ministry of Environment, Forest and Climate Change, Government of India.

Hiremath A. M. and Asolekar S. R. (2010) Environmental Risk Assessment. Poster Presentation *at Ninth National Conference of Indian Environmental Association* in IIT Bombay.

Hiremath A. M. and Asolekar S. R. (2012) Ship Recycling Yards Modernizations and Up gradation. Podium presentation at the *First National Conference on Ship recycling on the Indian sub-continent* organised by Hinode events and services private limited at Hotel Vivanta – by Taj President, Cuffe Parade, Mumbai, India.

Hiremath, A. M. and Asolekar, S. R. (2012) Ballast Water Management Current Status and Future Challenges An Engineering Aspect. Presented in the *National Conference on Water Quality Management* organized by Department of Civil Engineering, Malaviya National Institute of Technology Jaipur, India.

Hiremath, A. M., Chowhan, M. V. S. and Asolekar, S. R. (2013) Realistic Expectations of the Carbon Footprint of Ports in India. Podium presentation at the *First international Conference on Green Port South Asia* organized by Mercator Media Private Limited at Trident Nariman Point Hotel, Mumbai, India.

Hiremath, A. M., Kholgade, N, P., and Asolekar, S. R. (2015) Heavy Metals Exposure to Workers in Ship Recycling Yards through Inhalation and Ingestion (manuscript to be communicated in *Science of Total Environment)* [Elsevier Publication; IF 4.09/2015].

Hiremath, A. M., Pandey, S. K. and Asolekar, S. R. (2016) Development of Ship-Specific Dismantling Plan to improve Health Safety and Environment in Ship Yards *Journal of Cleaner Production*, 116, 279-298. [Elsevier Publication; IF 3.84/2015].

Hiremath, A. M., Pandey, S. K., Kumar, D. and Asolekar, S. R (2014) Ecological Engineering, Industrial Ecology and Eco-Industrial Networking Aspects of Ship Recycling Sector in India. *APCBEE Procedia*, Volume 10, Pages 159-163.

Hiremath, A. M., Pandey, S. K., Salve, A. B. and Asolekar, S. R. (2014) Integrated Risk Assessment Framework for Ship Recycling Sector. *In the Proceedings of the International Conference on Ship Recycling* SHIPREC2013 held in Malmö, Sweden, Pages 41-54, WMU Publications 2014, ISBN 978-91-977254-8-4.

Hiremath, A. M., Raj, R. and Asolekar, S. R. (2015) Minimization of Carbon foot priniting of Ship Recycling through Implication of Cleaner Technologies (revised manuscript under review in *Journal of Cleaner Production*) [Elsevier Publication; IF 3.84/2015].

Hiremath, A. M., Salve, A. B., Pandey, S. K. and Asolekar, S. R. (2014) Comprehensive Account on Dismantling & Recycling of an Oil Tanker Ship in Alang, India. *In the Proceedings of the International Conference on Ship Recycling SHIPREC2013* held in Malmö, Sweden, Pages 175-188, WMU Publications 2014, ISBN 978-91-977254-8-4.

Hiremath, A. M., Tilwankar, A. K. and Asolekar, S. R. (2011) Green Ship Recycling Challenges and Way Forward. Podium presentation at *Third National Conference on Ports and Infrastructure* organised by Saket Projects Ltd. in Ahmedabad, Gujarat, India.

Hiremath, A. M., Tilwankar, A. K. and Asolekar, S. R. (2015) Significant Steps in Ship Dismantling Vis-a-vis Wastes Generated in a Clusater of Yards in Alang A Case Study. *Journal of Cleaner Production*, Volume 87, Pages 520-532. [Elsevier Publication; IF 3.84/2015].

Hiremath, A. M., Tilwankar, A. K. and Asolekar, S. R. (2015). Significant Steps in Ship Dismantling *vis-a-vis* Wastes Generated in a Clusater of Yards in Alang A Case Study. *Journal of Cleaner Production*, 87, 520-532. [IF = 3.84].

ICRA Rating Feature, (2012) Ship Breaking Industry Key Trends and Credit Implications. Available at <www.icra.in>.

IEA (2012) International Energy Agency CO_2 emissions from fuel combustion highlights, 2012 Edition. Available at <http//www.iea.org/co2highlights/co2highlights.pdf> (Last accessed on 3 June, 2014).

ILO (2004) Safety and health in ship breaking: Guidelines for Asian countries and Turkey, Interregional Tripartite Meeting of Experts on Safety and Health in Shipbreaking for Selected Asian Countries and Turkey, Bangkok", ISBN 92-2-115289-8 <http://www.ilo.org/public/english/standards/relm/gb/docs/gb289/pdf/meshs-1.pdf>.

IMO (2013) International Maritime Organization Report on International Shipping Facts and Figures – Information Resources on Trade Safety, Security, Environment. Available at <http//www.imo.org/KnowledgeCentre/ShipsAndShippingFactsAndFigures/Statisticalresources/Documents/December%202011%20update%20to%20July%202011%20version%20of%20International%20Shipping%20Facts%20and%20Figures.pdf> (Last accessed on 26 May, 2014).

IMO (2015) Recycling of Ships: The development of the Hong Kong Convention. Available at <http://www.imo.org/en/OurWork/Environment/ShipRecycling/Pages/Default.aspx>.

Indian Factory Act, (1948) Available at <http//www.delhi.gov.in/wps/wcm/connect/doit_labour/Labour/Home/Acts+Implemented/Details+of+the+Acts+Implemented/The+Factories+Act,+1948/The+Second+Schedule> (Last accessed on 27 February, 2014).

Inventory Guidelines, (2009) Guidelines for the development of the inventory of hazardous materials", Resolution MEPC.179(59), Adopted on 17 July, 2009. Available at <http://www.imo.org/OurWork/Environment/ShipRecycling/Documents/RESOLUTION%20MEPC.179(59)%20Inventory%20guidelines.pdf>.

IPCC (2006) Intergovernmental Panel for Climate Change IPCC Guidelines for National Greenhouse Gas Inventories, Prepared by the National Greenhouse Gas Inventories Programme, Eggleston H.S., Buendia L., Miwa K., Ngara T. and Tanabe K. (eds). *Published IGES*, Japan.

IPCC (2007) Intergovernmental panel for climate change, fourth assessment report: climate change 2007, Available at <http://www.ipcc.ch/pdf/assessment report/ar4/syr/ar4_syr.pdf> (Last accessed on 3 June, 2014).

IRIS (2013) Integrated Risk Information System U.S. Environmental Protection Agency, Available at <http//www.epa.gov/IRIS/>.

ISO (2012) International Organization for Standardization (n.d). Safety aspects. *Guidelines for their inclusion in standards*, ISO/IEC Guide, 51.

ISO (2012) International Organization for Standardization (n.d). Safety aspects. *Guidelines for their inclusion in standards*, ISO/IEC Guide, 51.

ISO (2013) International Standardization Organization ISO 140672013 Available at <https//www.iso.org/obp/ui/#isostdisots14067ed-1v1en> (Last accessed on 3 June, 2014)

ISO (2013) International Standardization Organization ISO 140672013 Available at <https//www.iso.org/obp/ui/#isostdisots14067ed-1v1en> (Last accessed on 3 June, 2014)

ISO 14040 and 14044 (2006) Life cycle assessment. Available at <http://www.iso.org/iso/catalogue_detail?csnumber=38498>.

ISO 14040 and 14044 (2006) Life cycle assessment. Available at <http://www.iso.org/iso/catalogue_detail?csnumber=38498>.

LaGrega, M.D., Buckingham, P.L. and Evans, J.C., 2010. Hazardous waste management. Waveland Press

Kumar S., Pandey S. K., Sawaikar U. and Asolekar S. R., Poster presentation on "Technology for Greening of Ship: Onboard Modular Bilge Water Purification System" " in *SIG Environment Global Business Forum*, organized by IIT Bombay Alumni Association at Taleigao, Goa during Oct 16th and 18th, 2015.

Mahindrakar A. B., Das S. K., Asolekar S. R., and Kura B. (2008) Environmental Issues in the Ship breaking Industry in India. *In the proceedings of the A&WMA's Annual Conference,* Portland, Oregon, USA, June 24-26.

Mahindrakar, A. B. and Asolekar, S. R. (2006) Characterisation, treatment and disposal of paint chip wastes generated in Indian ship breaking industry. *Proceedings of International Conference on Dismantling of obsolete vessels*, University of Glasgow.

MARPOL (1974) Marine Pollution, International Convention for the Prevention of Pollution from Ships. Available at <http://www.imo.org/en/About/Conventions/ListOfConventions/Pages/International-Convention-for-the-Prevention-of-Pollution-from-Ships-(MARPOL).aspx>.

Mikelis, N. (2013) Ship Recycling Markets and the Impact of the Hong Kong Convention. *Proceedings of the International Conference on Ship Recycling (SHIPREC 2013*), World Maritime University, Malmo.

National Fire Protection Association, 2011. NFPA 704, Standard System for the Identification of the Hazards of Materials for Emergency Response. National Fire Protection Association, Quincy, Massachusetts, USA

OSHA (2001) Occupational Safety and health administration factsheet ship breaking. *Occupational Safety and Health Administration, U.S. Department of Labour*.

Pandey S. K., Rao B. and Asolekar S. R., Poster presentation on "Remediation of Beaches, Soils and Sediments" for a Smart City in *SIG Environment Global Business Forum*, organized by IIT Bombay Alumni Association at Taleigao, Goa during Oct 16th and 18th, 2015.

Pandey, S. K., Hiremath, A. M., Salve, A. B. and Asolekar, S. R. (2014) What Difference Can Hong-Kong Convention Make to Ship Recycling in India? *In the Proceedings of the International Conference on Ship Recycling SHIPREC2013* held in Malmö, Sweden, Pages 79-94, WMU Publications 2014, ISBN 978-91-977254-8-4.

Singh R., Vivek J. M., Rao B. and Asolekar S. R. (2016). Significance of Presence of Asbestos in Construction and Demolition Wastes in India. Presented paper in International Conference on Waste Management (Recycle 2016) at IIT Guwahati, Assam during Apr 1st and 2nd, 2016.

Sutar R. S., Motghare V. M., Kollur S. C., Parikh Y. and Asolekar S. R. (2015). Would the persistence of micropollutants compromise reuse options for the treated wastewater? Presented paper in the National Conference on Environmental Monitoring, Assessment and Pollution Control *i.e.* EMAPCO 2015 organized by the SIES Educational Campus at Navi Mumbai, Maharashtra during Dec 10th and 11th, 2015.

The Factories Act, 1948. Directorate General Factory Advice Service & Labour Institutes, Government of India.

The Motor Vehicles Act, 1988. Ministry of Road Transport and Highways, Government of India.

Tilwankar, A. K., Hiremath, A. M. and Asolekar, S. R. (2011) Recommendations for Health, Safety and Environmental Quality (HSEQ) Improvement in Ship Recycling Industry. Podium presentation at the *10th Technical Meeting and Workshop on Green Ship Recycling* organised by the University of Glasgow and Strathclyde in London, UK.

UNEP, 1993. Storage of hazardous materials-A technical guide for safe warehousing of hazardous materials, United Nations Environmental Programme, Industry and Environment Programme Activity Centre (IE/PAC), Paris, France

UNEP and ISWA., 2002. Training Resource Pack for Hazardous Waste Management in Developing Economies.

UNEP, 2003. Basel Convention Technical Guidelines on Incineration on Land. Secretariat of Basel Convention, UNEP, Geneva.

USEPA 40 CFR §264 and §265, 2014. "Standards for Owners and Operators of Hazardous Waste Treatment, Storage and Disposal Facilities". Code of Federal Regulations, Office of the Federal Register.

USEPA 40 CFR §264 -E and §265-E, 2014. "Subpart E—Manifest System, Recordkeeping, and Reporting" Code of Federal Regulations, Office of the Federal Register.

Vivek J. M., Pandey S. K., Joshi R. P. and Asolekar S. R., Poster presentation on "Mobile Wastewater Treatment Facility" " in *SIG Environment Global Business Forum,* organized by IIT Bombay Alumni Association at Taleigao, Goa during Oct 16th and 18th, 2015.

Vivek J. M., Singh R., Sutar R. S. and Asolekar S. R. (2016). Characterization and Disposal of Ashes from Biomedical Waste Incinerator. Presented paper in International Conference on Waste Management (Recycle 2016) at IIT Guwahati, Assam during Apr 1st and 2nd, 2016.

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