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Research Article

ANALYSIS OF FLY ASH DISPOSAL PROBLEM IN COAL-FIRED STEAM POWER PLANT: STUDY AT PLTU XYZ, INDONESIA

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ABSTRACT

Coal-fired Steam Power Plant (Indonesian: Pembangkit Listrik Tenaga Uap-PLTU) was built to achieve the national electricity demand which is growing now. Activity running on PLTU generates waste which is categorized into hazardous and toxic substances (B3 waste) in large quantities every day and become an unsolved problem until now. This study was aimed to analyze the main problems related to B3 waste management such as fly ash and bottom ash which generated by PLTU. This study uses primary data derived from interviews with expert stakeholders, which then analyzed by using interpretative structural modeling. The main problems in the fly ash and bottom ash management of PLTU-PT XYZ are open handling system of fly ash and bottom ash, weak regulation of TPS permits by local government, TPS designs-which should be silos that do not interact with water, fly ash and bottom handling which not well planned, fly ash and bottom ash disposal which conduct after piling up thus make an expensive cost, fly ash and bottom ash services which focused on Java and wet waste which cause complicated handling and expensive cost. The problem of linkage is the large quantities of fly ash and bottom ash, the expensive of transportation, the amount of landfill that must be non-permeable but it is so limited, and the expensive cost of picking up from the dump.

INTRODUCTION

Electricity is indispensable resource for everyday needs. Therefore, along with population growth and economic growth, the demands for electricity are also increase. To achieve these needs Coal-fired Steam Power Plant was built. Similar with others, PLTU also generates waste from its activities. The main wastes are fly ash and bottom ash. According to Government Regulation No. 101 of 2014, fly ash and bottom ash are categorized in Hazardous and Toxic Substances (B3 waste) and included in specific waste with code B409 for fly ash and B410 for bottom ash. Fly ash and bottom ash are categorized into B3 waste because they contain heavy metal elements. In addition, according to (UNSCEAR, 1993) and also (Bunawas and Pujadi, 1998), coal-fired plants have great potential as radionuclide contaminants to the environment. According to (UNSCEAR, 2000), the average concentration of natural radionuclides contained in coal is 238U element on average of 35 Bq/kg (16-110 Bq/kg), 226 Ra on average of 35 Bq/ kg (17-60 Bq/ kg), 232Th on average of 30 Bq/kg (11-64 Bq/kg) and 40K on average of 400 Bq/kg (140-850 Bq/kg). Therefore, the waste fly ash and bottom ash are categorized into the B3 waste.

B3 is a waste that affects the pollution and destruction of the environment, endangering the environment, health, human survival and other living things. B3

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waste, such as a heavy metals, can enter into the organ of living organisms (Riani, 2012 and Riani, *et al.*, 2017), and will impact to various organs of the body (Riani, 2015), and result in defects in the embryos on the womb (Riani, *et al.*, 2014). Likewise the radionuclides contained in the waste, it will enter the ecosystem and then accumulate into the body, and even also accumulate into the tissues of human body (Thayib, 1990). Therefore, the evaluation of the amount of radioactive substances in coal becomes very important to be done (Flues, *et al.*, 2006).

Considering on the widely negative impacts caused by B3 waste, the coal-fired steam power plant industry attempts to manage the B3 waste they have generated. This management aims to prevent and minimize the potential occurrence of pollution and/or environmental damage caused by B3 waste. B3 waste generated by PLTU in the form of fly ash and bottom ash is produced continuously as long as the plant is operating, so it becomes so high in number. Therefore, the PLTU is taking responsible since the B3 waste is generated, through the principle of reuse, recycle, and recovery (3R), managed to be reused, or until it destroyed. PLTU is also given the freedom to manage its own B3 waste in accordance with the regulation or may entrust to the outsourcing with B3 waste management license.

PLTU is operating continuously and uninterrupted, so the fly ash and bottom ash wastes are generated in very large quantities, in along with the capacity of the power plant. On the other hand, the wastes are contain of toxic metals and natural radionuclides (Flues et al., 2006), that is why the fly ash and bottom ash are called B3 wastes (Riani, 2017), it is because they contain various types of radionuclides (Lu et al., 2006).

It also compounded by the fly ash and bottom ash many which not handled properly, so a lot of number that has exceeded its shelf life. According to Government Regulation of No. 101 (2014), the shelf life of fly ash and bottom ash is only 365 days, while the regulation of B3 Waste Temporary Storage permit granted by the Regent/Head District is valid for five years and may be extended forward. One of PLTU that has a strategic role is PT X in South Sumatra Province. PT. X has a capacity of 2 × 135 Mega Watt (MW), which supplies some of the electricity needs in the region. However, PT X faces various problems that need to be solved immediately.

Activities running on PT X generate B3 waste in large number, but its waste problem has not been managed properly until now. On the other hand, the previous studies that lead to the aforementioned issues is minimal, and more focused to technical studies, such as The utilization of fly ash for concrete manufacture (Hidayat, *et al.*, 2002), The use of fly ash for acid soils (Sengupta, 2002), Fly ash characterization of PLTU Suralaya and its evaluation for refractory castings (Aziz, *et al.*, 2006), Radioactivity levels of 238U and 232Th primordial radionuclides in open coal mining areas (Arif, 2006), The use of coal ash and humic materials as ameliorants on ex-mining reclamation land (Oklima, 2014), to improve soil chemistry (Iskandar, *et al.*, 2003) and for peatland (Iskandar, *et al.*, 2008), fly ash with the variety of uses (Ahmaruzzaman, 2010), the use of humic material and fly ash for mine land reclamation (Herjuna, 2011) and other similar research. Besides things mentioned above, the problems of on PLTU in many lines seems to relate each other and make it more complicated. In an attempt to fix it, all appear to become priority to be first handled. Therefore, in order to simplify the problem solving in PT X, it is necessary to analyze pointed on waste fly ash and bottom ash management thus it will expect to be structured and easier to manage afterwards. This research was aimed to analyze the main problems related to B3 waste management activities i.e., fly ash and bottom ash of PLTU activities.

RESEARCH METHODOLOGY

This research was conducted at PLTU X, located in Sumatera Island on June to October 2017. In this research, primary and secondary data were collected. Primary was obtained through direct interviews with respondents by answering the questionnaires. It also obtained from comprehensive information to the experts with specified purposively consist of local DLHD, manager of PLTU PT X, B3 waste recipient, university, and community elder around PTX.

The data then were analyzed using ISM (Interpretative Structural Modeling) techniques which used to formulate the alternatives policy in the future (Marimin, 2005). This technique can help a group to identify the relationship between concept /idea and the determinant structure in a complex problem. ISM may be used to develop several types of structures, including structural influences (e.g. “support” or “worsening”), priority structures (e.g. "more important than" or "to be learned before") and categories of concept/ideas (e.g. "have the same category with") (Saxena, 1992). Analysis steps with ISM techniques are bellows (Kanungo and Batnagar, 2002):

1. Identification of element: Each element of a system will be identified and listed. This probably leads the successful to entire research, brain storming, etc.

2. Contextual relationship: A contextual relationship between each element is established and depending upon the objective of the modeling exercise.

3. Structural Self Interaction Matrix (SSIM): The matrix that represents the respondent's perception of each element to the directed relationship between elements. Four symbols are used to present the type of relationship that can exist between two elements of the system under consideration. The four symbols mentioned are:

V: Represents the relation of the elements Ei to Ej, but not in the reverse direction.

A: Represents the relation of the elements Ej to Ei, but not in the reverse direction.

X: Represents the inter-relation between Ei and Ej elements, both directions

O: Represents the elements Ei and Ej are unrelated.

4. Reachability Matrix (RM): Reachability Matrix which provides a symbolic change of SSIM into a binary matrix. The following conversion rules apply:

- If the relation Ei to Ej = V in SSIM, then the element Eij = 1 and Eji = 0 in RM.
- If the relation Ei to Ej = A in SSIM, then the element Eij = 0 and Eji = 1 in RM.
- If the relation Ei to Ej = X in SSIM, then the element Eij = 1 and Eji = 1 in RM.
- If the relation Ei to Ej = O in SSIM, then the element Eij = 0 and Eji = 0 in RM.

The Initial RM then modified to show all the direct or indirect reachability, that is if Eij = 1 and Ejk = 1 then Eik = 1.

5. Level partitioning: that is performs in order to classify the elements into different levels of an ISM structure. For this purpose, two sets are associated with each Ei element of the system. A Reachability Set (Ri) is a set of all elements that can be reached from the Ei element and an Antecedent Set (Ai) is the set of all elements that element Ei can be reached by.

6. Canonical matrix: grouping together elements in the same level develops this matrix. The resultant matrix has most of its upper triangular of the element as 0, and the lower triangular of the element is 1. This matrix is then used to prepare a Digraph.

7. Digraph: A pattern (term) derived from Directional Graph and as the name suggest is a graphical representation of elements, direct relationships and hierarchy levels. Initial graph is prepared on the basis of the canonical matrix. This is then pruned by removing all transitivity into final digraph form.

8. Structural model: ISM model derived from the transfer of all element numbers with the description of the actual elements. ISM can provide an obvious representation of a system of elements and the flow of relationships.

RESULT AND DISCUSSION

The judgment from experts of the problems faced by PT XYZ in fly ash and bottom ash waste management are follow. According to their view, there are essentially 19 sub elements of problems need to be solved related to fly ash and bottom ash waste management. The results of the assessment of the 19 sub-elements have a driver power, different rank and level from each other. The 19 sub elements can be seen in Table 1.

Assessment result from the expert in contextual relationship between sub elements of program objectives using V, A, X and O approaches. The approach is used to obtain the direct relationship and hierarchical level of the program objectives contribution. Each individual expert's opinion value is then aggregated to get the combined value. Individual or combined assessment is done based on reachability matrix and revision matrix. The verification results of fly ash and bottom ash waste management model are further divided into four sectors based on the value of its power driver. The four sectors are autonomous, dependent, linkage and independent. In this study, the four sectors can be seen in (Fig. 1).

In their opinion, the main problems of fly ash and bottom ash waste management are in the independent sector and seven sub elements are mentioned there (Fig. 1). In an entire of seven elements, the essential element (the highest value of driver power problem) is a fly ash and bottom ash sub-element that is done outdoor, thus it will be mixed with water when it's rain (in the water). In other countries, the handling of wet ash is commonly done by made of its shelter pond and labeled as coal ash pond (Bara, *et al.*, 2005; Lokeshappa and Dikshit, 2012; Pandey, 2012, Sung-Joo, *et al.*, 2012; Tyra, *et al.*, 2002). Furthermore, it is said that the coal ash pond is using the surface impoundment disposal system for wet ash, so the shape of the pond is made of an impermeable layer which generally made by geotextiles and geomembranes and the wet ash will placed above.

Table 1. Sub elements of the problem/issue element on fly ash and bottom ash waste management in PT XYZ.

No	Problems	Driver Power	Rank	Level
1	The policy about TPS was made later	4	6	2
2	The company which handling the fly ash and bottom ash collection is located in Java	6	5	3
3	Mistake in handling fly ash and bottom ash disposal, which is done after piling up thus cause the high cost	13	3	5
4	Fly ash and bottom ash handling outdoor which will mix with water when it rains (in the water)	17	1	7
5	TPS design which should in form of silo, so will not interact with the water	16	2	6
6	Fly ash and bottom ash beneficiaries in the location of the study is very limited and focused only in Java	13	3	5
7	High cost of taking the fly ash and bottom ash from storehouse	10	4	4
8	Fly ash and bottom ash which have a short of shelf life (1 year permit)	4	6	2
9	Fly ash and bottom ash contains of the hazardous B3	6	5	3
10	Fly ash and bottom ash flew when it's carried up	1	7	1
11	Permit period of landfill is different with the initiator's monitoring obligation	1	7	1
12	Wastes which taking out from wet storage (difficult to handle and expensive cost)	13	3	5
13	Fly ash and bottom ash handling which is not planned properly	16	2	6
14	Total landfill of fly ash and bottom ash that should be non-permeable is in lack	10	4	4
15	High cost of fly ash and bottom ash transportation	10	4	4
16	Weak regulation on TPS permits (especially on site selection)	16	2	6
17	Fly ash and bottom ash are generated in large quantities	10	4	4
18	Less innovation for the utilization	4	6	2

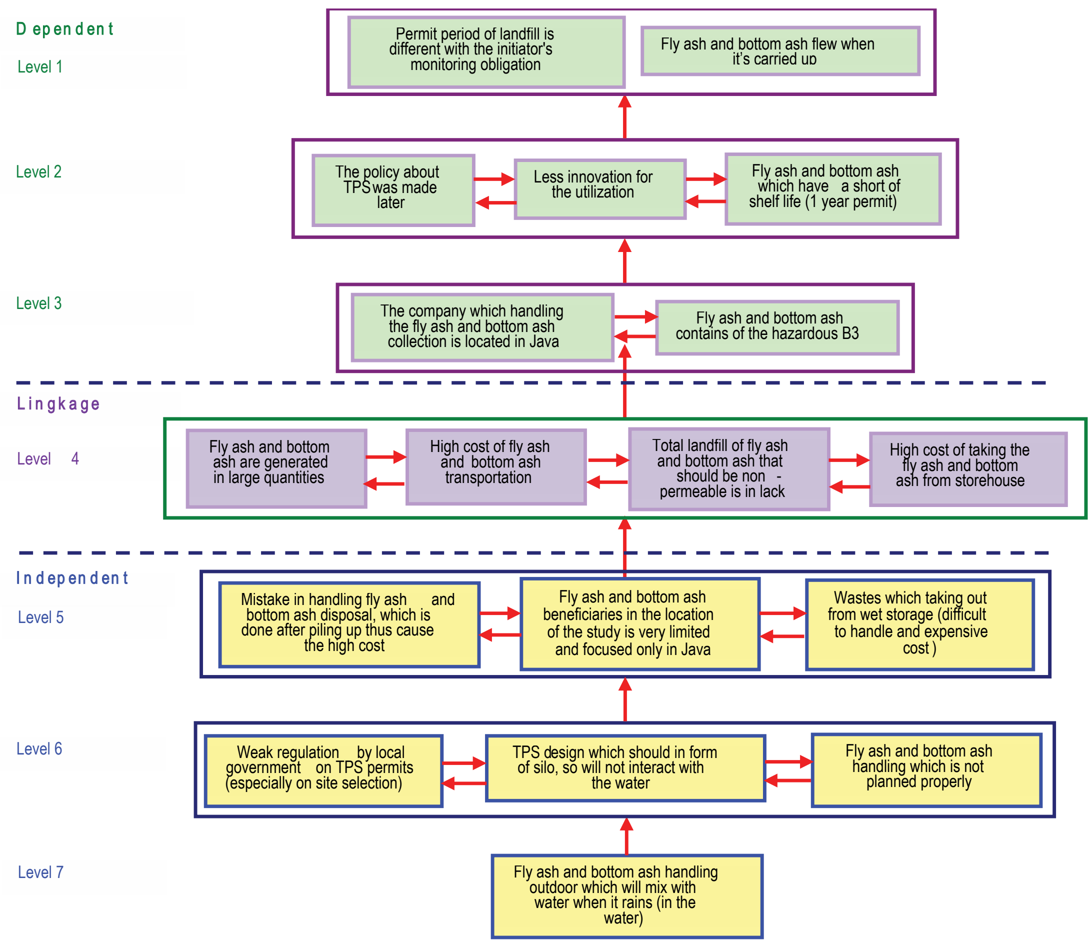

Fig. 1 Hierarchical diagram of elements problems in fly ash and bottom ash management.

Meanwhile in Indonesia, coal ash pond is not meant to be a pond for storing wet ash as happened in PLTU XYZ, but it is intended as a pond that holds the leachate water.

The fly ash and bottom ash wet handling system are generated from coal combustion, which conducted in PLTU PT XYZ basically is a surface impoundment disposal system. This system is novelty in Indonesia, and because it is unusual, it becomes more difficult in handling. In this condition, just to take it will require a special technique. In addition, the ash is also difficult to be accepted by users who generally require fly ash and bottom ash in dry conditions. On the other hand, according to (Government Regulation No. 110, 2014) on Hazardous and Toxic Waste Management (B3) fly ash and bottom ash which is generated from coal combustion process at PLTU, boiler and industrial furnace are categorized as B3 specific source with B409 and B410 in code. Therefore, wet conditions in handling, which will cause the B3 potentially dissolved in water, also causes the important for more specific treatment immediately. So, it is necessary to consider the innovation technology to make the fly ash and bottom ash remain in dry condition.

(Fig. 1) shows that Quadrant IV is an independent element, which contain of priority problem. There are seven sub elements in Quadrant IV. This independent element is a free variable that has a large driving force on fly ash and bottom ash waste management, but it does not depend on the system in PLTU PT XYZ. As for the other sub elements of independent, except sub element of the fly ash and bottom ash handling outdoor (level 7) are sub elements in levels 6 and 5, as follows:

1. Weak regulation by local government on TPS permit of fly ash and bottom ash (especially on-site selection)

2. TPS design which should in form of silo, so will not interact with the water

3. Fly ash and bottom ash handling which is not planned properly

4. Mistake in handling fly ash and bottom ash disposal, which is done after piling up thus cause the high cost

5. Fly ash and bottom ash services in the location of the study is very limited and focused only in Java

6. Wastes which taking out from wet storage (difficult to handle and expensive)

To describe the obvious sequence, the hierarchical of problem elements in fly ash and bottom ash waste management can be seen in (Fig. 1).

Quadrant III is also known as element in linkage sector. In this study, there are four sub elements in Quadrant III/linkage sector, which is fly ash and bottom ash in large quantities due to combustion operates every day, an expensive cost of transportation because it must be delivered long distance to Java, total landfill of fly ash and bottom ash that should be non-permeable but it is in lack and an expensive cost of taking the fly ash and bottom ash from storehouse. These four sub elements mean that one action on each sub element will impact to the other sub elements.

In addition, the feedback effect of the sub elements in linkage sector will also increase the impact of fly ash and bottom ash waste management. In this case, the position of priority element makes its management to be more difficult. This is because the current handling in form of wet ash makes it difficult and the cost is higher. Considering of the electricity is always needed, PLTU must operate continuously. This condition cause the ash are generated in large quantities, while the landfill is so limited, and resulted in the shipping cost which is generally located in Java is very expensive.

In dependent sector that contains elements at level 3 to level 1, it means that the seven priority elements are highly dependent on the system and do not have high driving force. Level 3 is a fly ash and bottom ash collecting company in Java and Fly ash and bottom ash contain hazardous B3. Level 2 containing the Policy about TPS which was made later, the lack of innovation for utilization and the fly ash and bottom ash which have short of shelf life (only 1 year permit). Last at level 1 is the different period between the landfill permit and the initiator's monitoring obligation and the fly ash and bottom ash which flew when it’s carried up. In this dependent sector, the factor of dependence and driving force (Driver Power) is low, so the sub element inside tends to be dependent. This indicates that sub elements for achieving the goal cannot stand alone, but it is highly dependent on the other sub elements target.

Open handling system (outdoor) is also become main problem in fly ash and bottom ash waste management because it will mix with water (in the water). This difficulty is allegedly occurs due to Indonesia is more familiar with dry fly ash and bottom ash waste management, while the wet condition fly ash and bottom ash is almost never done. This is evident from the notion of coal ash pond which is a surface impoundment disposal system for wet ash from coal combustion (Lokeshappa and Dikshit, 2012; Pandey, 2012; Sung-Joo, *et al*., 2012), while in Indonesia is not interpreted as a pool to accommodate the ash (fly ash and bottom ash), in wet conditions, but instead interpreted as a leachate water container, that is coal pond for leachate from coal stockpile and ash pond for leachate from ash disposal. Therefore, the handling technology has not been efficient and effective until now, as happen in dry ash handling.

Another major problem in Indonesia related to fly ash and bottom ash waste management is the weakness of local government's regulation of TPS fly ash and bottom ash permits (especially on site selection). This condition occurs due to the PLTU itself is allegedly do not has an appropriate land either in the wide and the distance from the community (which should be far away), the side land where adjacent to the waste were generated so it obliged to propose the location as the TPS of fly ash and bottom ash. On the other hand, local government as permit issuer are allegedly less to investigate the TPS location in comprehensive survey. This condition is also suspected due to triggering factors in the form of acceleration development program for PLTU in accordance with the promulgation of (Minister of Energy and Mineral Resources Decree No. 5899.k/20/MEM/2016 regard to the electricity supply in 2016-2025). These reasons are ultimately makes inappropriate location as TPS of fly ash and bottom ash. In the other words, the reckless on analyze the condition of these locations and the urgent needs of electricity have an impact on TPS permit which is given.

Another independent problem is the design of TPS which should be in form of silo that do not interact with water. The open polling station (not in form of silo) causes fly ash and bottom ash become wet, especially when it rains. Then the pool-shaped of TPS will be flooded, so the ash become wet and sunk in the water, it will make difficult in handling. Therefore, to make it easier in handling and also to the buyer, the ideal design for the TPS is in form of silo.

Another independent problem is the handling of fly ash and bottom ash which is not planned properly whereas according to Government Regulation (PP) No. 101 of 2014 on the management of Hazardous and Toxic Wastes (B3), fly ash and bottom ash which is generated from the coal combustion process at the steam power plant, boiler and furnace industries are categorized on B3 specific sources. This condition is allegedly due to PLTU operates continuously, while the speed of ash disposal from is much lower, thus it will choked up. This is because PLTU has problem in disposing its waste, so it is not only because PT XYZ where is far from its fly ash users, but according to (Goodarzi, 2006) it is also caused by coal ash waste user generally only take the fly ash, while bottom ash which is generated amounts to 25-30% is not utilized and only dumped in ash disposal. On the other hand, their buyer cannot be commonly, considering only the beneficiaries who have B3 waste utilization permit from the Ministry of Environment and Forestry (KLHK) only can buy the ash from PLTU. Therefore it makes sense when (Antarasumbar, 2015) states that companies that have a license to utilize, one of them is a cement factory. Unfortunately, that factory is able to absorb only 100 tons of fly ash per day. So, the absorption of PLTU's waste will increase if PT Semen Padang increases their production.

Another independent problem is the mistake in handling fly ash and bottom ash disposal, which is done after piling up thus cause the high cost. This happens because there are not well planned so the fly ash and bottom ash are left to accumulate and pilling up. On the other hand, these conditions will cause another problem. In dry season and drought condition it is potentially flown by the wind, and when the rainy season it is potentially submerged in water, it will cause the leachate water flowing into the river or the ground water, so it can contaminate the surface water.

Another independent problem is the services of fly ash and bottom ash users in the study area which is very limited, and focused only in Java. This is understandable considering that the PLTU is mostly located at coal production sites, such in Sumatra region which has a lot of coal resources, so the cost becomes relatively easier. On the other side, the area with high population and more physical development instead are located in Java, especially in Jakarta and its hinterlands. Therefore, the fly ash and bottom ash users are more focused on Java.

The last independent problem is wastes which taking out from wet storage make it difficult to handle and expensive cost. This condition occurs because Indonesia is more familiar with dry ash handling, while the wet ash handling is require a special technique but not commonly handled in Indonesia. On the other hand, in this submerged condition, the leaching potential become high, although in fact leaching processes of B3 such as heavy metals is different for each element (Hansen, *et al*., 2005; Skodras, *et al*., 2009; Yilmaz, 2015; Jiang-shan, *et al*., 2017).

The leaching potential determinants of fly ash and bottom ash are determined by many factors. These factors include chemical speciation of its composer, pH of the solution, the availability of composed elements which later become leaching, the weathering of ash, etc. According to (Lau and Wong, 2001; Gori, *et al*., 2011; Reinika, *et al*., 2014) the leaching behavior of each element are different depending on what elements exist in the fly ash and bottom ash itself, the character of the element itself, the pH of the solution and the leaching time. Therefore, fly ash and bottom ash storage in this wet condition needs more attention and immediately solved for the handling.

CONCLUSION

The major problem of fly ash and bottom ash management of PLTU activities in PT XYZ are the open handling (outdoor), the weakness regulation on TPS permit especially on site selection, TPS design which should in form of silo so will not interact with the water, fly ash and bottom ash handling which is not planned properly, fly ash and bottom ash disposal which is done after piling up thus cause the high cost, beneficiaries of fly ash and bottom ash which is very limited and focused only in Java, and also wet wastes condition which make difficult in handling and expensive cost. In linkage sector, the sub-element is influence the feedback, so the sub elements which is need more attention are the production of fly ash and bottom ash which in large quantities, the transportation cost of fly ash and bottom ash which are very expensive, total landfill of fly ash and bottom ash that should be non-permeable but very limited and the expensive cost of taking the fly ash and bottom ash from storehouse.

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