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Current Practices: Solid Waste Management from Zero Liquid Discharge Wastewater Treatment

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ABSTRACT

A study was conducted to identify current practices used by power plants to manage their solid waste residuals from zero liquid discharge (ZLD) operations treating flue gas desulfurization (FGD) wastewater. Because there are such few FGD ZLD systems in operation not only in the United States but also worldwide, the study scope was expanded to include non-FGD ZLD operations, as well. Only two of the seven facilities interviewed in this study operate ZLDs on FGD water; therefore, much of the current practices summarized in this report may have limited applicability for FGD blowdown applications.

The study is based on numerous interviews of coal-fired power plant personnel in the United States, Europe, and South Africa. The main focus of the study is the information from seven coal-fired U.S. power plants. Of these, two plants have thermal ZLDs operating on FGD purge waters, four have thermal ZLDs operating on non-FGD plant wastewaters, and one plant deals with the FGD purge water by blending/recycling plant water management. The study also draws on information from interviews with personnel from five power plants in Europe and South Africa. All of these plants operate thermal FGD ZLDs. The experience from 15 combined-cycle plants visited in the United States is also described.

Most of the U.S. coal-fired stations interviewed have their on-site landfills for solids disposal. The various solids generated are either mixed before landfill deposition or are transported and discarded individually. One plant interviewed sends its solids off-site to an industrial landfill. Several of the plants in Italy send their FGD ZLD residual salt to Germany, where it is used for salt mine stabilization. Most combined-cycle plants interviewed send their ZLD residual to municipal landfills.

One currently operating FGD ZLD system in the United States takes its FGD ZLD brine blowdown stream and solidifies/stabilizes it with fly ash for subsequent deposition in its landfill. A similar system at a Southeastern plant is currently under construction, with a second one planned for a sister station.

Keywords
Brine concentrator
Ground water
Landfill
Leachate
Toxicity characteristic leaching procedure (TCLP)
Zero liquid discharge (ZLD)

EXECUTIVE SUMMARY

A study was conducted to identify the current practices used by coal-fired power stations for the handling and disposal of waste solids generated from flue gas desulfurization (FGD) purge water treatment processes using thermal zero liquid discharge (ZLD). Because there are few FGD ZLD facilities currently operating worldwide, the study was expanded to also include the disposal methods used for conventional (non-FGD) ZLDs, as well as FGD residuals and solids disposal from coal-fired power stations in general.

The objective of the study was to understand the current practices of power plant solid waste disposal for FGD ZLD waste residuals. Review of non-FGD ZLD solids disposal methods serves to provide information about related waste disposal experience. The overall information gained can support the effort to define future R&D priority needs in the solids waste disposal area, which is gaining attention as more FGD ZLD treatment systems are being considered.

The study is based on numerous interviews of coal-fired power plant personnel in the United States, Europe, and South Africa. The main focus of the study is the information from seven coal-fired U.S. power plants. Of these, two plants have thermal ZLDs operating on FGD purge waters, four have thermal ZLDs operating on non-FGD plant wastewaters, and one plant deals with the FGD purge water by blending/recycling plant water management. The study also draws on information from interviews with personnel from five power plants in Europe and South Africa. All of these plants operate thermal FGD ZLDs. The experience from 15 combined-cycle plants visited in the United States is also described.

Various means of dealing with and handing of residual waste solids are used. Most of the U.S. plants contacted send their waste materials—including fly ash, bottom ash, FGD-generated gypsum, and the dewatered salts from ZLD operations—to their on-site landfills.

Two U.S. power stations use or are construction a FGD ZLD system consisting of a brine concentrator only (without a crystallizer to take the brine concentrate to dryness). Fly ash is used instead to solidify/stabilize the brine concentrator blowdown, with the solid or near-solid residual product deposited in the landfill. Although the stabilized residuals can pass the paint filter and toxicity characteristic leaching procedure test, the soluble components such as sodium or calcium chloride are susceptible to leaching, so that proper landfill management is critical. Further stabilization to limit or prevent such leaching may be possible by use of other solidification reagents in addition to the fly ash.

More research needs to be done with this solidification/stabilization approach to establish appropriate formulations and performance guarantees, as well as to test and establish that the material will not degrade and induce new problems over the lifespan of the landfill.

Different landfill designs or management options can be used to minimize the generation of leachate flow. Common to all of these efforts is to minimize the contact of rain water with the deposited materials. This can be done by capping the landfill with impervious materials or stabilizing the deposited solids by use of reagents to prevent water from penetrating the mounded material. Capping is usually done using synthetic membranes and/or clay. Proper storm water management is critical in preventing the comingling of rain water with leachate. Well-designed

leachate collection systems limit the contact time with the solids, thereby reducing the amount of dissolution and resultant concentrations in the leachate.

The collected landfill leachate is dealt with in various ways. Most common for the plants interviewed is spraying of this liquid over the landfill for dust control and compaction. A few facilities bring the leachate back to the plant for temporary storage in waste ponds. Some plants considered blending the leachate with the ZLD feedwater. Power stations in arid regions often do not encounter sufficient rain water to generate much, if any, leachate.

This study builds on previously published EPRI work, including the EPRI report *Thermal Flue Gas Desulfurization Wastewater Treatment Processes for Zero Liquid Discharge Operations* (1021215).

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1
INTRODUCTION

1.1 General Outline

This report describes the methodology used by some coal fired power stations to dispose of their ZLD solid waste residuals. The goal of the study was to identify current practices for power plant ZLD solid waste disposal practices with the intended focus on the management of the solid waste residuals from FGD ZLD operations.

Since the number of FGD ZLD systems worldwide is very few, the scope of this survey was expanded to include coal fired plants using ZLD water management in general. One major difference between conventional and FGD ZLD system residuals is that, depending on the plant water management integration approach, many conventional ZLD solids residuals can pass paint filter and TCLP scrutiny without prior conditioning. By contrast, FGD ZLD residuals, depending on treatment method, may contain various trace metals/elements, which may require special handling and disposal.

The information presented is based on interviews of 11 coal fired power plants in the U.S., Europe and South Africa. Additional information had been obtained from previous EPRI ZLD studies conducted in recent years. This study builds on other ZLD information recently published by EPRI, including:

- *Thermal Flue Gas Desulfurization Wastewater Treatment Processes for Zero Liquid Discharge Operations* (1021215), December 2010
- *Evaluation of Thermal Zero Liquid Discharge Treatment Technologies for Combined Cycle Gas Turbine Power Plants* (1022162), December 2011
- *Summary of Zero Liquid Discharge (ZLD) Water Management Installations at U.S. Power Plants* (1015592), December 2008

The overall experience with FGD ZLD solid waste residuals is very limited at this time. The above cited technical summary "Thermal FGD Wastewater Treatment Processes for Zero Liquid Discharge (ZLD) Operations" describes the potential applicability, limitations and concerns regarding FGD ZLD systems, including capital and operating costs, reliability, as well as solids disposal. The same report also provides a summary of solids disposal methodology used at the various plants operating to date. In the two years since publication, there are more FGD ZLD systems either planned or are under construction, but none have become operational in the U.S. during this time interval.

The solid waste disposal means employed by the power stations worldwide with operating FGD ZLD systems consist of salt disposal at industrial landfills, shipments to salt mines where the salts are used for salt mine stabilization and mixing of ZLD brine concentrate with fly ash for subsequent landfill disposal. In the latter case, the brine concentrate is not taken to dryness in a dryer or crystallizer, but is mixed with fly ash, which causes the brine to solidify or partially solidify due to cementing and pozzollanic reactions. It must be noted that the overall FGD ZLD

experience is very brief, with the first plants having been commissioned in Europe starting in 2009. The U.S. experience of mixing the FGD ZLD blowdown with fly ash for subsequent landfill disposal has only been operational since 2010/2011.

1.2 Scope and Goals

The goal of this study is to provide a summary of the waste solids disposal methods currently in use at some of the coal burning U.S. power stations.

2
OVERVIEW: FGD PURGE WATER TREATMENT WITH ZERO LIQUID DISCHARGE TECHNOLOGY

2.1 Zero Liquid Discharge System Definition

Strictly speaking, "zero liquid discharge" means what the phrase implies: "no liquid discharge from the facility." For this report, ZLD for FGD purge water treatment applications implies no liquid discharge from the FGD operation and the use of thermal evaporation to achieve this goal.

Thermal ZLD systems in general are defined as wastewater treatment by evaporation in a brine concentrator. The brine concentrator blowdown is then either further evaporated in a crystallizer or disposed of by other means, usually by solar evaporation. Some vendors are reluctant to call their systems brine concentrators so that the term evaporator is used as applicable to the installation(s) from such vendors.

One alternative for FGD purge water treatment described in this report is the mixing of brine concentrator/evaporator blowdown with fly ash, which results a solid or pasty material suitable for landfill deposition.

For clarity, the term "conventional" ZLD in this report refers to treatment of general (non-FGD) wastewaters (mainly cooling tower blowdown) in a brine concentrator followed by a crystallizer or evaporation pond.

Due to the typically high TDS and chloride content of the FGD purge water, the only proven ZLD technology to date is the treatment via evaporation. Thermal evaporation is typically carried out with a brine concentrator operated in a seed slurry mode. (See the EPRI report *Thermal Flue Gas Desulfurization Wastewater Treatment Processes for Zero Liquid Discharge Operations* [1021215] for a discussion on this process technology.) The blowdown from the brine concentrator is either sent to evaporation ponds or further concentrated in a crystallizer, where the solids are taken to dryness. Alternately the brine is solidified using fly ash or other solidification agents. The use of only a crystallizer (without an upstream brine concentrator) is also possible, but would normally be used only for small purge water streams. One such system is currently treating the FGD wastewater at a coal fired plant in China and three "crystallizer only" operations are treating FGD purge water from waste-to-energy facilities in Europe.

The suspended solids in the FGD purge water are removed either in a settling pond or a clarifier before entering the ZLD. Depending on the purge water chemistry and the ZLD or solid waste disposal designs, the purge water may additionally be subjected to: lime treatment to remove alkalinity and metals; specialized metals removal by chemical addition such as sulfide, TMT-15 or other; and lime-soda softening. The details of this ZLD pretreatment are discussed in the EPRI report *Thermal Flue Gas Desulfurization Wastewater Treatment Processes for Zero Liquid Discharge Operations* (1021215).

The crystallizer concentrate is normally followed by a filter press or centrifuge to dewater the solids. The filtrate is returned to the crystallizer and the solids disposed of in a landfill or, in case of most of the current European installations, they are used for salt mine stabilization.

Detailed descriptions of the brine concentrator, crystallizer and dewatering technologies for these applications can also be found in the EPRI report *Thermal Flue Gas Desulfurization Wastewater Treatment Processes for Zero Liquid Discharge Operations* (1021215).

2.2 Zero Liquid Discharge Brine Solidification Stabilization

2.2.1 General Outline

The brine slurry residual from a brine concentrator is typically sent to a crystallizer for further evaporation to dryness or is discharged to solar evaporation ponds. An alternative to this approach is to use fly ash to solidify the relatively small, residual stream. (This approach may not be feasible for larger brine blowdown rates due to the lack of plant fly ash availability.)

The solidification/stabilization of the residual brine concentrates from FGD ZLD purge water treatment may be of interest to plants, especially if they generate Class C fly ash and have on-site landfills available for waste disposal. This technology approach may offer several advantages over the use of a crystallizer to evaporate the brine concentrator blowdown to dryness. Crystallizers are not only capital and energy intensive, but also pose more operational and maintenance challenges compared to other treatment systems.

ZLD systems, treating cooling tower blowdown and miscellaneous plant wastes, typically process a relatively low TDS and benign feedwater consisting of mainly sodium chloride and sodium sulfate with some calcium and magnesium and silica components. FGD purge waters, by contrast, are composed of mainly calcium and magnesium chloride, high alkalinity plus trace metals as well as selenium and boron, which make the water more challenging to treat. The high levels of calcium and/or magnesium chloride pose processing problems not as much for the brine concentrator, but for the crystallizer. Since most chloride salts are very soluble they concentrate in the crystallizer resulting in very high operating temperatures (due to the high boiling point rise) and in a very corrosive environment, which adversely affects the energy consumption and requires selection of high alloyed material in the crystallizer.

The FGD ZLD design approaches to mitigate the high crystallizer temperature issue have been employed or are being proposed:

1. Transform the calcium and magnesium chlorides to the more benign and lower boiling sodium chloride by subjecting the ZLD feed stream to lime-soda softening. This exchanges the calcium and magnesium with sodium leaving a sodium chloride solution.
2. Employ no front end softening, but use a crystallizer that operates under vacuum, which greatly reduces the operating temperature and, thereby, the corrosivity in the crystallizer.

Both of the above alternatives are valid and may be considered viable design options. It must be noted, however, that to date, the FGD ZLD systems using a vacuum crystallizer are still using front end softening as a pretreatment. High vacuum crystallizers have been proposed by several ZLD vendors, but none are operational in the service as described in Option 2 above.

The end product from the crystallizers using front end softening is dry salt, typically consisting of mainly chlorides. These salts by themselves are not stable and are prone to leaching in the landfill.

The presence of trace metals and boron in the residual salt cake depends on the front end treatment. Boron, due to its propensity to form large sticky salts, can cause a problem in the brine concentrator and possible also in the crystallizer. Remedies for the boron problem in brine concentrators are beyond the scope of this study, but are discussed in the EPRI report *Thermal Flue Gas Desulfurization Wastewater Treatment Processes for Zero Liquid Discharge Operations* (1021215).

Due to the lack of an operating system in this service, the characteristics of the residuals from the above described design Option 2 are not known. This approach may entail a further drying process for the small residual stream.

A third alternative that addresses and eliminates the need of the front end softening and the use of a crystallizer altogether is the solidification/stabilization of the brine concentrator blowdown using fly ash and or plus possibly other solidification agent(s).

2.2.2 Solidification Process

Solidification/stabilization of FGD ZLD brine concentrator blowdown with subsequent landfill deposition is currently practiced at one U.S. power plant. A similar system is under construction at another power station and planned for a sister station in the near future. The premise of the brine solidification approach is relatively simple. Pretreatment for the brine concentrator in this application is limited to solids removal in a pond or clarifier, aided by ferric chloride and polymers.

The clarified feed then goes to a brine concentrator where it is concentrated about ten times. The actual concentration factor is a function of the feed's chemical composition and TDS. Scaling in the brine concentrator is minimized by use of a seed slurry process. The hot blowdown slurry is then dewatered before being pumped to a holding tank for subsequent mixing with fly ash and/or other solidification agent(s). After mixing and a brief curing time, sufficient for the product to begin to solidify/stabilize, it is transported to the landfill for disposal.

As previously described, the advantage of this operation is that the ZLD treatment does not require front end softening or a (vacuum) crystallizer. Softening translates to costly chemical consumption and sludge generation. Crystallizers are high in capital and require significant energy. Depending on the type of energy source used, the crystallizer energy consumption ranges from 200 to 250 kWh per 1,000 gallons for vapor compression cycles or about 8 MM BTU per 1000 gallons of plant steam (about 30% less when a thermal compressor is employed).

When operating a solidification/stabilization process, the plant generates its own solidification agent, i.e. fly ash. Unless the fly ash is otherwise sold, this approach allows the plant to utilize its own combustion by-product without incurring chemical costs for the brine stabilization process.

The fly ash required for the solidification is Class C, which has not only pozzollanic but also self-cementing properties. Class F fly ash has pozzollanic properties, but needs an additional reagent like Portland cement or lime to solidify.

In general, sub-bituminous and lignite coals yield Class C, and bituminous and anthracite coals Class F fly ash. Their pozzollanic and cementing properties are defined by their respective chemical makeup with regard to mainly silica, iron, aluminum and calcium oxides. Class C fly ash has significantly higher levels of calcium oxide, which gives it its cementing property. The Class C and F classifications are defined by ASME standards, which are establish for use as concrete additives.

The amount of fly ash needed to solidify/stabilize the brine will vary on the brine and fly ash compositions. The brine to reagent ratio will be different for each application and will be affected by the type of coal burned (affecting the fly ash composition), how the FGD water balance is operated, the FGD makeup water chemistry (brine composition) and other process and operating variables. Good design practice would, therefore, call for bench testing prior to a solidification/stabilization system design. Such testing would consist of examining various liquid to solids formulations in order to find the proper fly ash to brine ratio to achieve the performance goals.

In all cases, the mix product should pass the paint filter test, i.e. when placed into a paint filter no water drips from the solidified block during a given time interval. TCLP (or SPLP), unconfined compressive strength (UCS) and permeability may also be of concern for the landfill operation. If necessary a higher fly ash to brine ratio may be required to meet these additional goals. Since there is not enough information currently available, the passing of TCLP or achieving specific strength or permeability goals should be evaluated on a case-specific basis, whether using only Class C or Class F fly ash or in combination with other reagents.

2.2.3 Leaching Properties

Leaching of contaminants from solidified waste is a function of:

- The properties of the waste material
- The hydrologic and geochemical properties of the disposal site
- Landfill management

The Toxicity Characteristic Leaching Procedure (TCLP, EPA SW-846 Method 1311) is used to simulate the behavior of wastes using an organic acid to simulate conditions in a municipal solid waste landfill. TCLP is used to classify a waste material as hazardous or non-hazardous under the federal regulations. The procedure calls for batch leaching of a sample with an organic acid leachant at a 20 :1 liquid to solid ratio. The filtered leachate is then analyzed for the eight regulated metals and organic components (VOC and SVOC). The latter if called for. Since the test calls for the solid sample to be crushed to a 3/8” aggregate size before contacting the water, it has a high surface area exposure to the liquid and is, therefore, rigorous compared to exposing a monolith sample to rain water in a landfill.

The Synthetic Precipitation Leaching Procedure (SPLP, EPA SW-846 Method 1312) is similar to the TCLP, only using acidified deionized water. This test is used to simulate acid rainwater conditions.

Unconfined Compressive Strength

Landfill operators typically require that solidified waste develop sufficient structural strength to support the operation of construction equipment (e.g., dozers, sheep-foots, rollers) on top of these materials. The bearing loads required for the landfill management equipment are on the order of 5 to 20 psi, depending on the specific equipment used and the depth to the solidified material. Unconfined compressive strength (UCS) is a measure of the material's load carrying capability. The UCS criterion will ensure the landfill operator that the material will not impede normal landfill operations. UCS is determined in the laboratory per procedure ASTM D 2216.

Permeability/Hydraulic Conductivity

Aside from the prevailing meteorological conditions, other solids characteristics and the landfill design can influence the manageability of the landfill and the degree of leaching encountered. One such parameter is permeability as tested by hydraulic conductivity of the solidified material.

The permeability of the solidified materials can be important as lower permeability restricts the passage of water through the solidified material, which in turn limits the water contacting the buried material and reduces the amount of substance leached out.

While fly ash can be used to solidify and stabilize the mixture so that will pass the paint filter and TCLP tests as well as gain some compressive strength, it will most likely leach some soluble salts when exposed to water. In order to further reduce leaching solid, additional reagents, such as Portland cement, can be used with the fly ash to improve the product's stability. Other, less costly additives can also be considered. Since the interest in this technology is rising, more work by vendors and the power industry should be done to find suitable reagents and formulations that can produce stable waste residuals for disposal.

2.2.4 Solidification Operation

The solidification of brine slurries can be carried out as batch or continuous operations. The process is relatively simple, requiring the direct contact of the solidification agent(s) and brine for a prescribed mixing time before the material is discharged to a receiving area or container (dump bins or dump truck) where it is allowed to solidify. The essential equipment components necessary consist of:

- Dry solids metering system
- Brine flow control system
- Agitated mixing vessel
- Dust control system
- Discharge chute

Based on installations in other industries, the mixing vessel can consist of one or more (parallel) batch mixing tanks equipped with paddle blades or one or more pug mills (parallel) for a continuous mixing operation. Since fly ash is abrasive and the brine is corrosive and may be hot, the proper materials of construction are required for all wetted surfaces. Rubber lined mixing vessels can be used.

After the prescribed mixing time, the material is discharged into a hopper and routed to the receiving container, typically consisting of a disposal bin or dump truck. Forms or molds could

be used, but their use would be more labor intensive not only at the mixing area but also in the landfill. Use of a drop pad to provide time for solidification/stabilization is also possible. The solids can then be transferred into a disposal bin or dump truck for later transportation to the landfill.

Hardening of the solids typically commences within a few hours so that most mixes can pass the paint filter test within this time frame. Strength development will increase over days and will usually reach its final strength after 30 days of curing. As an indication of the solids' solidification characteristics, strength development in the laboratory is typically measured after 1, 3, 5, 7 days. Unconfined compressive strength (UCS) and TCLP are typically performed after 7 and 28 days and permeability tests after 28 days of curing.

If the mixed material does not solidify/stabilize properly, as can usually be judged within a few hours of curing, it can be further solidified by placing it on a slab and adding more reagents to the mix. This is typically done by use of a front loader or other heavy equipment.

It must be noted that the solidification/stabilization treatment of brine concentrator blowdown with fly ash is very new to the power industry so that the experience of the mixing operation and the effect on the landfill is not well defined. Issues such as solids handling prior to the landfill, landfill management and leaching once deposited will have to be revisited and judged as more experience for this waste management approach is gained over time.

2.3 Landfill Types and Designs

Most power plant landfill cells that have been developed in the last 20 years and are used for fly ash disposal are lined, have leachate collection systems and ground water monitoring. Groundwater monitoring typically continues for 30 or more years after a landfill is retired.

2.3.1 Mine-Mouth Operation

Several of the Southwest plants interviewed are mine to mouth operations where a portion of the depleted mine becomes the deposition site for the plant's solid wastes. Such depositions are officially termed "mine placement." It should be noted that Mine-Mouth operations are limited to only a few areas of the U.S.

Many of these mine placement areas have no leachate collection system and some do not have ground water monitoring. Since many of these facilities are located in arid regions, there is only little or no leachate generated, and often ground water is hundreds of feet below the surface. Transportation to the mine placement sites is often by return trucking or rail. Some facilities do, however, use dedicated waste transportation.

2.3.2 Storm Water and Leachate Collection

Leachate Treatment

The amount of leachate generated depends on many factors including meteorological conditions, landfill design (monolith or cellular), material leachability, material permeability, depth of fill, storm water diversion as well as landfill management.

Most plants interviewed have storm water diversion systems designed to route storm water away from the landfill to minimize comingling with the landfill leachate. The storm water is typically

collected in tanks or small ponds to settle solids before being discharged under an NPDES permit.

Depending on the amount of leachate generated and collected, the means of treatment or disposal varies. Most plants interviewed collect the leachate and then spray it over the landfill deposits for dust control so that it is evaporated and/or partially absorbed in the deposited mass. Many of the facilities in arid regions have little or no leachate so that the plant does not have to address its handling or treatment.

Some facilities plan to return excess leachate, i.e. the amount that cannot be sprayed over the landfill, to the plant for treatment. One plant is returning the leachate to the large wastewater holding pond, which feeds both the FGD and the ZLD systems. Since the returned leachate volume is relatively small, the TDS buildup in the "water loop" is not considered an issue at this facility. The same may not be true for larger leachate flows in combination with smaller wastewater volumes to be treated in a ZLD system. Proper landfill management is critical to keeping the amount of leachate generated to a minimum.

The idea of returning the leachate for treatment in the ZLD is feasible as long as the volume and leachate concentration are relatively small. If this is not the case, then the salt buildup in the "closed water management loop" may be a problem. In this case, a separate leachate treatment system may be required. This could be in the form of a small evaporation system or a dryer. The periodic "trucking off" of leachate to an outside treatment facility is also an option. While leachate treatment is a concern, none of the plants' interviewed seem to have a current leachate problem that would warrant a separate treatment system. The return and comingling of leachate with the plant's wastewater seems to be considered a back-up option.

2.3.3 Landfill Capping

The final step in the life of a landfill is that, once it has reached capacity, it is capped with several feet of material including soil and is then usually re-vegetated. The capping material isolates the landfill deposits and minimizes rainfall infiltration, thereby diminishing further leaching and the potential for ground water contamination. With the bottom containment barrier intact, leachate collection will remain active for some time. Ground water and/or leachate monitoring will continue as specified by the landfill's regulatory requirements and decommissioning plan. Groundwater monitoring is typically required for 30 or more years.

The advantage and driving force for deciding on the higher cost for cellular landfills is that the active cells are filled more rapidly compared to a monolith design and can thus be retired and capped after the cell's active lifespan, which is typically 4 to 10 years. Once capped, that portion of the landfill is deactivated and needs essentially no more operational attention with regard to leachate and storm water control.

Some monolith or cell landfills are capped on an essentially ongoing basis as deposition areas reach their design height. While adding to the landfill management costs, this approach results in the partial deactivation of the landfill with a consequent reduction in leachate generation.

One of the landfills encountered in the western U.S. has the requirement of nightly capping with at least 6 inches of cover. The purpose of this regulatory requirement is for dust suppression. It should be noted that this is typically dictated at municipal landfills to control odors and vectors.

While a daily cover requirement is not commonly required at fly ash landfills, the issue of dust control is gaining more attention. Furthermore, this approach could become relevant and applicable as part of the long term solution to prevent large leachate volumes and release of metals and chlorides from materials that do not stabilize well.

3
CURRENT SOLID WASTE MANAGEMENT PRACTICES

The purpose of this study is to provide information about the current practices used for the disposal of the solid waste residuals resulting from the thermal ZLD treatment of FGD purge waters. As will be seen in the following narrative, the experience with such treatment and practices is very small and very recent. In order to identify additional waste solids information, this study expanded its scope to include the solid wastes generated from conventional, thermal ZLD treatment at coal fired power plants

The solid waste management practices described in this section are arranged by the following ZLD and water management approaches:

1. ZLDs operating exclusively on FGD wastewater as the only feed source
2. ZLDs operating on general plant wastewaters such as cooling tower blowdown
3. Plants that have zero liquid discharge water management, but have no specific ZLD treatment system
4. Plants with FGD ZLDs located in Europe and South Africa
5. Gas-fired combustion turbine facilities with overall ZLD water management

The narrative describes the operational methodology used for the disposal of both solids from FGD as well as conventional ZLD systems at seven U.S. power plants. The following definition is used for the ZLD systems described:

- **FGD ZLD:** FGD purge water treated with a Brine Concentrator (BC) + crystallizer (CRX) unless otherwise specified
- **Conventional ZLD:** General plant wastewaters (non-FGD source) treated with Brine Concentrator (BC) + crystallizer (CRX) unless otherwise specified

Table 3-1 summarizes the essence of the following information by listing the key FGD, ZLD and landfill elements for each of the seven U.S. plants interviewed.

The landfill experience for European and South African FGD ZLD waste disposal are also briefly described as are the solids waste disposal methods at 15 combined cycle plants reviewed for a previous EPRI study (see the EPRI report *Evaluation of Thermal Zero Liquid Discharge Treatment Technologies for Combined Cycle Gas Turbine Power Plants* [1022162]).

Annual landfill deposition volumes are provided for the plants that provided this information.

Table 3-1
Plant Waste Solids Disposal Summary

Plant FGD-Type	Location Plant Size	ZLD Feedwater	ZLD Type ZLD Size ZLD Age	Plant Solid Waste Disposal to Landfill	Landfill Location and Design	Landfill Type and Containment	Leachate/Ground Water Control
Plant A LSFO	Midwest 850 MW	FGD purge water	FGD ZLD (BC only) Feed =30 gpm 2010/11	FGD–ZLD brine stabilized with fly ash Fly ash, bottom ash FGD gypsum	On-site Contiguous 4 cells–15 year life each	Double containment synthetic layers; leachate collection system	Leachate is sprayed over the landfill
Plant B LSFO	Southeast 1700 MW	FGD purge water	FGD ZLD (BC only) Feed = 240gpm Startup 2013/14	FGD–ZLD brine stabilized with fly ash (*must pass TCLP*) FGD gypsum Fly ash, bottom ash Pond dredgings	On-site, Non-contiguous; 10 cells–5 year life each	Double containment synthetic layer& natural substrate; leachate collection system	Leachate sprayed on landfill or returned for treatment
Plant C LSFO	Southeast 1750 MW with 920MW coal fired	Mainly CT blowdown +misc. plant wastewater	Conventional ZLD (BC + CRX) Feed = 1700 gpm Mid 1990 and 2008	FGD–ZLD crystallizer salts mixed with fly ash Fly ash, bottom ash FGD gypsum mixed with fly ash Pond dredgings FGD gypsum	On-site Existing landfill is monolith design; New landfill, cellular landfill is being designed	Monolith with dried fly ash paste layer. Periodic impervious layers added, then additional deposition. New cell design landfill planed with double containment layers	Leachate is routed to a waste pond for solar evaporation (for both current and future landfills)
Plant D LSFO	Southwest 2300 MW	Mainly CT blowdown +misc. plant wastewater	Conventional ZLD (BC + CRX) Feed = 1440 gpm Late 1970s	Bottom ash Unsold fly ash FGD gypsum ZLD solids and brine go to evaporation ponds No soluble salts go to landfill.	Landfill in abandoned coal mine Monolith design	Mine placement on impervious geological formation. No other protective containment	Landfill has leachate monitoring wells. Due to arid environment, no leachate is generated. There are ground water monitor wells.

Table 3-1 (Continued)
Plant Waste Solids Disposal Summary

Plant FGD- Type	Location Plant Size	ZLD Feed Water	ZLD Type ZLD Size ZLD Age	Plant Solid Waste Disposal to Landfill	Landfill Location and Design	Landfill Type and Containment	Leachate/Ground Water Control
Plant E 2 LSFO and 1 Dry FGD	Southwest 900 MW	Mainly CT blowdown +misc. plant wastewater	Conventional ZLD (BC only) Feed = 660 gpm ~ 1980	Bottom ash Unsold fly ash FGD gypsum ZLD solids (gypsum only) Accumulated sludge from cooling tower basins	Landfill in abandoned coal mine. Monolith design with 2 deposition areas	Mine placement on impervious geological formation. Base layer of placement covered with mine spoil for containment	Landfill has leachate monitoring wells. Due to arid environment, no leachate is generated.
Plant F LSFO	Southwest 1800 MW	Mainly CT blowdown +misc. plant wastewater	Conventional ZLD (BC only) Feed = 800 gpm 1975 & early1980's	Bottom ash Unsold fly ash FGD gypsum Misc. plant waste solids (All ZLD residuals go to evaporation ponds)	Landfill in abandoned coal mine Monolith design	Mine placement on impervious geological formation	No leachate collection or monitoring systems Due to arid environment, no leachate is generated.
Plant G Dry lime-stone FGDs	Southwest 450 MW	No ZLD CT blow-down goes to FGD make-up	Conventional ZLD now decom-missioned;	Bottom ash Unsold fly ash FGD gypsum/fly ash Pond dredgings Misc. plant wastes	On-site–-contiguous Monolith design	Regulatory requirement for a thin clay cover of the active landfill section every night	No leachate collection or monitoring systems, but ground water monitoring. Due to arid environment, no leachate is generated.

3.1 Current Practices: FGD Zero Liquid Discharge

Only two U.S. FGD ZLD facilities were interviewed in this effort, of which one has yet to come online. While FGD ZLDs are the current focus of most interest, the available data are very limited. Thus additional work is needed by EPRI and the industry to better understand solids management from FGD ZLDs.

3.1.1 Plant A: 850-MW PRB Coal with Wet FGD and Brine Concentrator

Plant A, located in the Midwest, burns low sulfur Powder River Basin (PRB) coal. The FGD is a limestone forced oxidation (LSFO) design. Two of the plant's power units are scrubbed. The FGD purge water, which contains about 30,000 mg/l TDS and about 10,000 mg/l chloride per design (but in reality has higher TDS but lower chloride levels), is treated in a thermal ZLD system consisting of a clarifier for suspended solids removal followed by a brine concentrator.

Table 3-2
Plant A: 850-MW PRB Coal with Wet FGD and Brine Concentrator

Location Size	FGD Type ZLD Age	ZLD Type ZLD Feed Feed Rate	Waste Solids Management Synopsis
Midwest 850 MW	LSFO FGD 2010/11	FGD ZLD (BC only) FGD purge water 30 gpm	ZLD brine is mixed with fly ash All waste solids go to on-site landfill

The residual brine concentrate slurry is dewatered in a belt filter and the filtrate fed to two parallel paddle wheel mixing vessels where it is used to condition Class C fly ash in a batch operation. The brine rate going to the mixer is about 3 to 4 gpm. The conditioning calls for a fly ash to brine ratio of about 7:1 to 10:1 by weight. A higher moisture content results in an unsatisfactory end product. No other reagents are used in the conditioning. The brine - fly ash mix is discharged from the mixing chambers directly into a dump truck.

The conditioned fly ash is deposited in the plant's on-site landfill, which is located on a contiguous part of the station property. Transportation of solids to the landfill entails no public access roads.

With exception of those solids going to beneficial use, all other plant-generated waste solids go to the on-site landfill. The main contributors are:

- Fly ash (not beneficially used)
- Bottom ash (not beneficially used)
- FGD generated gypsum (not beneficially used)

Some fly ash and FGD gypsum have been beneficially used off-site in the past. Such beneficial uses are subject to market fluctuations for building and construction materials.

No operational testing of solids is conducted. The only constraint for deposition is that the materials are firm and contain no free water as would be judged by a paint filter test. The assessment of this prerequisite is done by visual inspection.

The landfill is of a cellular design with the expected design life of each cell being 10 to 15 years. Since some of the materials are beneficially used off-site, the prediction of the annual deposition volumes varies in part with market conditions.

The landfill is protected by a composite liner and is equipped with leachate detection monitors. Each cell is equipped with a leachate collection system. In spite of the annual average rainfall of 32 to 34 inches, there is relatively little leachate generated. It is routed to a small, composite lined holding pond (about 4,000 ft2) and then applied over the landfill for dust control. At this time, no leachate is returned to the plant for retreatment, but this would be an option if the leachate volume exceeds the amount needed for dust control on the landfill surface.

The storm water collection system directs the rain water to a clay lined holding pond where solids are allowed to settle. The water is then discharged as controlled by the plant's NPDES permit.

Since the waste material transportation entails no contact with public access roads, there are no off-site regulatory requirements regarding the transportation of waste solids to the landfill.

The landfill's management and waste transportation are done by a contractor, but the responsibility for all remains with the power station.

The plant states that it is satisfied with its solidification approach and system and has no immediate plans of changing the current operation.

3.1.2 Plant B: 1700-MW Eastern Bituminous Coal with Wet FGD and Two-Stage Evaporator System

This plant, located in the Southeast, currently has a FGD ZLD system under construction, which will use a similar "partial ZLD" approach as described for Plant A. The ZLD treats the FGD purge in a thermal evaporator system consisting of a falling film evaporator (similar to a brine concentrator) followed by a forced circulation evaporator (similar to a crystallizer, but designed for a much lower suspended solids loading in the recirculating brine).

Table 3-3
Plant B: 1700-MW Eastern Bituminous Coal with Wet FGD and Two-Stage Evaporator System

Location Size	FGD Type ZLD Age	ZLD Type ZLD Feed Feed Rate	Waste Solids Management Synopsis
Southeast 1700 MW	LSFO FGD 2013/14	FGD ZLD (2-stage evaporator) FGD purge water 240 gpm	ZLD brine is mixed with fly ash All waste solids go to on-site landfill Waste transportation will include travel over public roads

The FGD purge stream is first routed to a settling pond for suspended solids removal before entering the evaporation system. The feed will then be concentrated about 20 times in a two stage evaporator system. The concentrated brine residual will be mixed with fly ash and then deposited in the on-site landfill. The concentrate volume subjected to solidification is about 12 gpm, i.e. four times larger than that of Plant A.

The results from the predesign effort, conducted to determine a workable solidification formulation that will pass paint filter and TCLP testing, called for a minimum weight based fly ash to brine ratio of 2.3 to 1. No other solidification reagents will be used. The testing indicated that selenium was the most difficult of the regulated components to contain. Leaching tests also showed that much of the salt content, other than the TCLP regulated constituents, will leach upon contact with water. The degree of leaching experienced in the landfill will be subject to the material's permeability as well as the landfill design and management.

Mixing of fly ash and brine will be done in a pug mill in a similar arrangement as that used in Plant A. Operational experience may require an adjustment of the experimentally determined solids to liquid ratio. Although the use of other additives in conjunction to the fly ash was evaluated during the solidification bench testing, it was determined that there was not much value added with regard to the leaching of the soluble components. Due to the non-cementing properties of the plant's fly ash, the end product will not set up as a solid, but will remain a thick paste.

The landfill location is not contiguous to the plant property so that transport over public access roads will be required. This makes passing TCLP a critical factor for the solidified waste product. Should the solids have a hazardous designation in spite of the solidification/ stabilization process, i.e. failing TCLP, then the plant may resort to alternate means of transport to avoid transportation over public roads. (The use of a railroad spur is available, which does not cross public lands.)

Other than the solidified brine concentrate, the only other non-ash solids going to landfill disposal will be from the periodic dredging of the settling pond. The solids going to landfill consists mainly of:

- Fly ash
- Bottom ash
- FGD gypsum
- Stabilized FGD ZLD blowdown
- Pond dredgings
- Miscellaneous plant solid wastes

The landfill will have a cellular design to minimize leaching. Each of the ten, anticipated cells is expected to be active for five years. The cell construction will start at the lowest topographical area with subsequent cells added as needed. The landfill will have a composite design using a mix of a synthetic and a natural substrate, i.e. bentonite or equivalent in combination with a 60 mil HDPE liner. The containment barrier will be equipped with a leachate monitoring system.

The plant's annual rainfall is about equal to the evaporation rate. There is, however, a likelihood of hurricane events. The landfill will have provisions to minimize rainfall intrusion by use of an extensive storm water deflection system, which may include temporary tarping or other coverings. There will be a separate pumping station to pump out accumulated run-off and to transfer it to large holding tanks, designed to hold a 25-year event. The accumulated storm water will either be discharged via an NPDES permit or will be routed to the plant for use.

The brine from the landfill's leachate collection system will either be sprayed over the landfill for evaporation or will be routed to the ZLD system for processing. Since any returned leachate would first be sent to the settling pond, where it would be diluted, the salinity added by the leachate is anticipated to be small enough as not to compromise the ZLD's capacity or operation.

Although the plant will have the overall responsibility, the landfill and waste transportation will be operated in partnership with a contractor.

Based on the experience gained from the waste stabilization and disposal at Plant B, the same owner is planning to build a similar system at another of its power stations. This future system will be about four times as big as the one currently under construction. Lessons learned from the Plant B design and operation will be applied to the future facility.

3.2 Current Practices: Conventional Zero Liquid Discharges

With the limited number of FGD ZLD facilities, the study was expanded to include conventional ZLDs at coal facilities operating on non-FGD waters. As FGD blowdown is quite unique as compared to other power plant wastewaters, the solid waste characteristics will also vary, and the Reader should be cautious in extrapolating these results to FGD ZLD facilities.

The salt residuals from crystallizers from a conventional ZLDs typically consist of mainly sodium chloride and sodium sulfate with lesser amounts of calcium, magnesium and silica. Depending on the plant feedwater, the salts may contain more or less chloride, as compared with the sulfate salts. Of the two salts, sodium chloride readily dewaters and is generally easier to handle and manage. Unless there are unusual components in the plant feedwater or there is contamination from additives within the plant's water management, the residual salts are generally benign and usually pass TCLP.

The residual solids from FGD ZLD crystallizers consist mainly of sodium chloride if there is a softening pretreatment as well as metals treatment for the ZLD feedwater. The solids handling characteristics in this case will be similar to those of the conventional ZLD operation. The level of contaminants contained in the solids will depend on their concentration in the FGD purge water and their removal in the pretreatment system. The residuals may or may not, therefore, pass TCLP.

The residual from a FGD ZLD crystallizer without metals and hardness pretreatment will consist of mainly calcium chloride, some as a double salt complex, plus the metals and other impurities passing through the system, including boron. The calcium chloride may have to be treated in a spray dryer or flaker in order to achieve dryness. Since there is currently no such system in operation, the exact nature of the solids generated or their handling characteristics are not known.

Four conventional ZLD facilities were interviewed, two of which included a brine concentrator and crystallizer, and the remaining two employed a brine concentrator followed by an evaporation pond. Evaporation ponds are limited to arid regions, however the study chose to include these facilities in hopes of learning more about ZLD solid waste management.

3.2.1 Plant C: 1750-MW Combined Bituminous Coal/Wet FGD Plus Natural Gas Facility with Brine Concentrator and Crystallizer

Plant C, located in the Southeast, has a combination of coal and gas fired power units. The combined output from the coal fired units is 920 MW. The FGDs are wet limestone scrubber units, with forced oxidation.

Table 3-4
Plant C: 1750-MW Combined Bituminous Coal/Wet FGD Plus Natural Gas Facility with Brine Concentrator and Crystallizer

Location Size	FGD Type ZLD Age	ZLD Type ZLD Feed Feed Rate	Waste Solids Management Synopsis
Southeast 920 MW coal fired, 830 MW CC gas	LSFO FGD Mid 1990s, expansion in 2008	Conventional ZLD (BC + CRX) Mainly cooling tower blowdown 1700 gpm	FGD purge is clarified and diluted with service water before recycled to the FGD FGD blowdown is via moisture in the solids ZLD salt residuals are mixed with fly ash and sent to the landfill All solid wastes go to the on-site landfill

After dewatering to remove gypsum, the FGD blowdown is routed to an FGD treatment system for flocculent addition followed by clarification in settling tanks. The water then passes to a recirculation tank where it is mixed with makeup water and returned to the FGD. The FGD has no direct purge discharge. This is possible as there is sufficient moisture in the dewatered FGD solids to control the TDS and chloride levels in the scrubber.

The plant is considering the possibility of dedicating one of its current ZLDs to FGD purge water treatment. Since this would require an elaborate ZLD pretreatment system, more study of this option is needed.

The conventional ZLD consists of three parallel brine concentrator plus crystallizer trains, which treat mainly cooling tower blowdown. The crystallizer concentrate is dewatered using a centrifuge, leaving a residual salt cake containing 10 to 15% moisture. The moisture content in the cake can be varied by adjustment of the centrifuge weir. The centrifuge solids are discharged onto a concrete pad where they are mixed with Class F fly ash using a front loader to combine the materials. The fly ash in this service helps to stabilize the salt cake in the landfill. The salt - fly ash mixing ratio is approximately 1 : 1 by weight. Approximately 1,000 tons per year of this mixture is generated and sent to the landfill.

The ZLD salt residual–fly ash mixture is subjected to a paint filter test to ensure that it will be sufficiently stable in the landfill. Should these solids not pass the paint filter test, then additional fly ash is mixed until the material does pass the test.

The dewatered FGD solids are landfilled after also being mixed in a 1 : 1 ratio with Class F fly ash for stabilization. In addition to paint filter testing, this mixture is also tested for its unburned carbon content using the Loss On Ignition (LOI) procedure.

Using a wet sluicing system, the bottom ash is directed to a tank farm where the ash is allowed to settle before being transported to the landfill. Purge water from the sluicing system is sent to a

recycling pond for subsequent reuse. The periodic dredgings from this pond go to the landfill as well. The solids going to landfill consist of mainly:

- Fly ash
- Bottom ash
- ZLD crystallizer salts - stabilized with fly ash
- FGD solids - stabilized with fly ash
- Pond dredgings

The small amount of landfill leachate generated is routed to the combustion waste pond where it is evaporated or conveyed to the recycle basin for use as FGD makeup water. The solids from the pond are periodically removed for subsequent re-deposition in the landfill. There are provisions to segregate storm water runoff by preventing drainage into the landfill containment area.

No direct treatment of leachate is being practiced at this time.

Trucks are used to transport the solids to the landfill, which is located on a contiguous part of the plant property. No special provisions for transportation to the deposition site are required.

The overall landfill is designed for a 100 year life. The currently used landfill management calls for a layering of the solids with the periodic addition of an impervious layer consisting of a dried paste of fly and bottom ash. Upon reaching capacity, the pit will be capped and vegetated with grass. Groundwater monitoring is required for the area surrounding the landfill facility.

A new landfill is being constructed, which will consist of three 30 acre cells with room for additional cells if necessary. The new landfill will be double lined and have a leachate collection and monitoring system. As with the existing facility, the leachate will be routed to the combustion waste pond for evaporation or conveyed to the recycle basin for use as FDG makeup water.

Transportation to and management of the landfill is done in a joint effort with a contractor, where the plant furnishes the trucks and fuel and the contractor the staff and management.

3.2.2 Plant D: 2300-MW Sub-Bituminous Coal, Wet FGD with Brine Concentrator and Crystallizer

Plant D is located in the Southwest. The low sulfur and low chloride coal is delivered to the plant via a dedicated railroad line. Each of the three power blocks has identical LSFO scrubbers, which are in part fed with the lime soda sludge from the plant's makeup water pretreatment system. Plant makeup water, rather than cooling tower blowdown, is used in the FGD due to corrosion concerns in the scrubber. Owing to the low chloride levels in the coal and the relatively low TDS of the makeup water, there is no purge stream from the FGD other than the moisture that leaves with the dewatered gypsum.

Table 3-5
Plant D: 2300-MW Sub-Bituminous Coal, Wet FGD with Brine Concentrator and Crystallizer

Location Size	FGD Type ZLD Age	ZLD Type ZLD Feed Feed Rate	Waste Solids Management Synopsis
Southwest 2300 MW	LSFO FGD Late 1970s	Conventional ZLD (BC + CRX) Mainly cooling tower blowdown 1400 gpm	FGD feed is CT blowdown plus service water FGD purge is used for fly ash wetting ZLD blowdown is clarified: the gypsum solids go to the landfill and the supernatant goes to evaporation ponds All other solids (not sold) go to the on-site landfill

The gypsum from the FGD is currently going to landfill along with the plant's bottom ash. The potential sale of gypsum for industrial use is being pursued, but this may be subject to the washing of gypsum to remove impurities. The possibility of using the gypsum for land augmentation is also being considered.

Fly ash is sold on a trade basis where the value for the material itself essentially equals the transportation cost to the market. The fly ash is backhauled in the trucks that deliver the limestone and other chemicals to the plant. Fly ash that is not sold goes to the landfill. The landfill deposits consist mainly of:

- FGD gypsum
- Bottom ash
- Fly ash (unsold)

The ZLD solid residuals, consisting of gypsum from the brine concentrator and the soluble salts from the crystallizer, are discarded in dedicated evaporation ponds, which are designed to hold these residuals for the life of the plant. No soluble salts are sent to landfill.

The landfill is located on a contiguous portion of the plant property. It is sited on an impermeable geological formation made up of a deep impervious sandstone layer. There are no artificial liners or other materials to seal the landfill. The landfill is equipped with monitoring wells.

The waste hauling to the landfill as well as the landfill management are conducted by a contractor with the ultimate responsibility remaining with the plant.

3.2.3 Plant E: 900-MW SubbutuminousCoal with Wet and Dry FGD, Brine Concentrator, and Evaporation Pond

Plant E, located in the Southwest, receives its sub-bituminous coal from two nearby strip mines and one underground mine via a direct trucking link. The coal contains 0.2 to 0.3% sulfur. Two of the units have LSFO FGDs and the third unit employs a dry limestone scrubber.

Table 3-6
Plant E: 900-MW SubbutuminousCoal with Wet and Dry FGD, Brine Concentrator, and Evaporation Pond

Location Size	FGD Type ZLD Age	ZLD Type ZLD Feed Feed Rate	Waste Solids Management Synopsis
Southwest 900 MW	LSFO FGD and Dry Limestone FGD ~1980	Conventional ZLD (BC only) Mainly cooling tower blowdown 660 gpm	FGD makeup is service water There is no FGD purge stream FGD blowdown is via moisture in the solids ZLD salt residuals are sent to evaporation ponds All other solids (not sold) go to the on-site landfill

The wet limestone FGD purge water is used for fly ash wetting. Using cooling tower blowdown, some of the fly ash is slurried and returned to the dry FGD along with the limestone feed. The FGD limestone makeup is made up using plant service water.

The LSFO generated gypsum is dewatered using a rotary drum vacuum filter, which leaves the solids with a moisture residual of about 15%. The dewatered gypsum is discharged onto a drop pad for subsequent loading and trucking to the mine for "mine placement," along with other plant solid wastes. The gypsum is not sold for commercial use due to the plant's remote location from a potential market. Additionally a gypsum wash system would be required to purify the product. The FGD residuals are trucked to the mine for disposal.

Most of the fly ash (Class F) from the power units equipped with the LSFO scrubbers is sold for industrial use. All of the fly ash from the power block with the dry FGD goes to the mine for disposal.

The ZLD residual, in the form of brine concentrator blowdown slurry, is clarified in the dual decant basin. The settled solids, consisting of mainly gypsum, are dredged and then sent to the mine. The brine supernatant goes to the evaporation pond. The waste solids going to the mine for deposition are:

- Fly ash (unsold)
- Bottom ash
- FGD waste solids (gypsum plus impurities
- Dewatered brine concentrator gypsum
- Sludge that is periodically scooped out from the bottom of the cooling towers (the river makeup water can have a high TSS loading)
- Grit blasting residuals

Evaporation pond dredgings are not hauled to the mine, but are used as on-site landfill material. The dredgings are deposited in depressions and allowed to decant back to the evaporation pond with the remainder evaporating to dryness.

The solid wastes from the various sources are not comingled and are placed in the mine as they arrive. The landfill consists of two 30 acre monolith placement areas each designed to accept 6.6 million tons of waste material. Each section is designed for a 20 year life. The placement areas are on natural rock formations, which are covered with a layer of spoil (a mixture of rocks, rock fragments, soil and other natural materials that result from surface mining operations) for containment.

Due to the arid environs, the landfill has no leachate collection system, but does have ground water monitoring to detect leachate intrusion. The deposition areas are equipped with a storm water deflection system in the form of drainage channels.

The waste solids are trucked to the mine on a back haul basis. All transportation is on plant roads so that no public access is crossed on the way to the mine. The only regulatory requirement for the transportation operation is based on the air quality permit for truck emissions. Transport is, however, restricted for: speed, time of day, hours of operation and is not allowed after dark. Additionally, the roads must be watered for dust control.

Once filled, the placement areas will be capped with 5 ft of overburden from the coal mine and then covered with 1 ft of top soil, which will be re-vegetated. The capping integrity will be verified by core drilling and the vegetation will be inspected to track the reclamation operation.

There is no testing requirement for the waste materials going to the mine, although the ash is analyzed every four years. The mine and mine placement are operated by a separate holding company.

3.2.4 Plant F: 1800-MW Sub-Bituminous Coal with Wet FGD, Brine Concentrator, and Evaporation Pond

Plant F is located in the Southwest. The sub-bituminous coal for the plant is sourced from an underground mine located near the plant. Until 20 years ago the same mine used to be surface operation before it went underground. A portion of the abandoned strip mine now serves as a landfill for the plant. The coal contains about 0.7 to 0.85% sulfur.

Table 3-7
Plant F: 1800-MW Sub-Bituminous Coal with Wet FGD, Brine Concentrator, and Evaporation Pond

Location Size	FGD Type ZLD Age	ZLD Type ZLD Feed Feed Rate	Waste Solids Management Synopsis
Southwest 1800 MW	LSFO FGD ~1975 to early 1980s	Conventional ZLD (BC only) Mainly cooling tower blowdown 800 gpm	FGD feed is mainly CT blowdown FGD purge water is diluted and recycled to the FGD as makeup ZLD blowdown (slurry) goes to evaporation ponds All solids not going to beneficial use, are sent to mine placement

The plant's four power units are equipped with the same LSFO scrubber type. Makeup to the FGD is plant pond water, which is composed of mainly cooling tower blowdown.

The FGD makeup water is typically 3,500 mg/l TDS but can be as high as 5,000 mg/l as an upper limit. The FGD purge water is discharged to the same pond so that it is essentially 100% recycled. The cooling tower blowdown TDS is about 3,000 mg/l, with the remaining salt contribution to the pond coming from the FGD purge water. The pond, which provides the makeup to the FGD, is supplemented with fresh water as necessary to maintain the pond level.

In order to maintain the water management's salt balance, a portion of the cooling tower blowdown goes to the ZLD system consisting only of brine concentrator treatment. The concentrated brine slurry from the ZLD (including the brine concentrator gypsum) go to the evaporation pond.

All of the FGD gypsum is currently sent to the mine placement. The potential of washing the gypsum to make it a saleable commodity is currently being investigated. The plant's Class F fly ash is sold. With exception of those going to beneficial use, all waste solids are sent to mine placement in the abandoned strip mine, including:

- Fly ash (unsold)
- Bottom ash
- FGD waste solids (gypsum plus impurities)
- Miscellaneous plant solids

The total waste material going to disposal amount to about 2,000,000 tons per year based on the following split:

- 1,500,000 tons/year fly ash and bottom ash
- 500,000 tons/year FGD gypsum and miscellaneous plant solid wastes.

The evaporation ponds are designed for the life of the plant so that there are no pond dredgings that require disposal.

Using dedicated trucks, the waste solids are transported to the mine on non-public roads. There are no regulatory requirements associated with the trucking of the wastes.

The landfill is designed as a monolith operation. It is sized for the life of the plant, which is expected to be another 30 years. Leaching protecting is provided by the natural geological barrier formation. There is very little rainfall or groundwater at the mine location so that there are no leachate collection or monitoring systems. Previous core tests have shown the landfill to be dry. Capping will not be required until the landfill is full. Storm water is collected and discharged via am NPDES permit.

The fly ash, bottom ash and FGD solids are characterized quarterly as composite samples from each power unit. No TCLP or paint filter testing is done for operational or regulatory purposes.

The plant's average rainfall is seven to nine inches annually.

3.2.5 Plant G: 450-MW Sub-Bituminous Coal with Dry FGD, No Zero Liquid Discharge

The plant, located in the Southwest, has two power units that burn sub-bituminous coal, which is delivered directly from the mine located about 20 miles away. The coal has a sulfur content of about 0.5%. Each unit is equipped with a dry limestone FGD so there is no liquid purge from the FGD. The limestone feed is initially made up with service water and then diluted with cooling tower blowdown. The ratio of fresh water to cooling tower blowdown is about 1:3. Use of the cooling tower blowdown in this fashion has allowed the plant to decommission its old ZLD system, which was installed in the early 1980s. A portion of the fly ash and gypsum captured in the bag house is recycled to the FGD feed to take advantage of the products alkalinity, thereby enhancing the SO_2 removal efficiency.

Table 3-8
Plant G: 450-MW Sub-Bituminous Coal with Dry FGD, No Zero Liquid Discharge

Location Size	FGD Type ZLD Age	ZLD Type ZLD Feed Feed Rate	Waste Solids Management Synopsis
Southwest 450 MW	Dry Limestone FGD (ZLD from early 1980s was shut down)	No ZLD	FGD feed is service water plus CT blowdown No FGD purge water All solids go to the on-site landfill

The cooling tower blowdown TDS is in the 4,000 to 5,000 mg/l range. Due to the low makeup water TDS, the cooling towers are able to operate at a concentration factor of 17 or higher, which results in a relatively small blowdown rate. In addition to its use in the FGD, some cooling tower blowdown is also used in the wet bottom ash handling system. Shortage of cooling tower blowdown for the FGD is made up with service water.

All plant waste solids go to the on-site landfill. Due to its high LOI value, the fly ash cannot be classified as Class C or F. As such it is not a salable commodity so that all of the fly ash and gypsum go to the landfill. The list of landfilled waste materials consists mainly of:

- FGD solids (gypsum / fly ash mix)
- Bottom ash
- Fly ash
- Pond sludge dredgings
- Miscellaneous plant solid wastes

The landfill deposition mass amounts to:

- 25 tons/year bottom ash
- 125 tons/year fly ash plus FGD solids
- 50 tons/year coal impurities

All solids going to the landfill are subjected to the paint filter test. TCLP testing is conducted on

the FGD solids every 6 years. The pond sludge dredgings are tested for TCLP with each dredging and deposition occurrence.

Solid wastes are trucked to the landfill on roads that are on contiguous plant property, about 1.5 miles from the power plant. The landfill, designed as a monolith, is protected by a natural clay stone layer. The current landfill is 125 acres in size and has an expected service life that is anticipated to last to 2045.

The landfill operation and waste solids transportation as well as the coal and ash handling is performed by a subcontractor, with the ultimate responsibility of each residing with the plant. There are no regulatory requirements with regard to the transportation of the material going to the landfill.

Minimizing the leachate generation is the storm water diversion system, which uses the clay capping to divert the storm water. The collected runoff is discharged via the state's "Non-extractive Industrial Storm Water Discharge" permit.

The landfill area is equipped with a ground water monitoring system, with a requirement for testing every six months. The landfill has no leachate collection or monitoring system since there are no regulatory requirements for either. There is a regulatory requirement for covering the active section of the landfill with a clay cap of several inches every night for dust suppression.

The plant receives approximately 17 inches of annual rainfall.

3.3 European FGD Zero Liquid Discharge Waste Solid Management

There are currently five FGD plants in Italy. Two of the plants commissioned in 2008/10 have been mothballed since it was found that they could discharge the FGD purge water to industrial waste treatment facilities where it is physically/chemically treated. The gypsum from all of the FGD operations is sold.

Two of the plants visited by EPRI in 2010 sent the dry salt residuals from the FGD ZLD treatment system to Germany where they are used for salt mine stabilization (see the EPRI report *Thermal Flue Gas Desulfurization Wastewater Treatment Processes for Zero Liquid Discharge Operations* [1021215]). All of the Italian ZLDs included pretreatment in the form of lime treatment, metals removal and softening. The lime sludge, which contains trace metals and other contaminants is sent to an industrial landfill. Softening sludges are either reused in the FGD or also sent to industrial landfills.

The largest of the FGD ZLD systems, located in southern Italy, sends all the residuals, including the dry salts, to an industrial landfill.

3.4 South African FGD Zero Liquid Discharge Waste Solid Management

A FGD ZLD system is currently being installed at a 4000 MW coal fired generating plant in South Africa. The waste salts from the FGD ZLD's crystallizers is dewatered with a filter press and the cake then hauled to the plant's on-site landfill along with the other plant solid wastes including fly and bottom ash. No stabilization of the ZLD salts is planned prior to its landfill deposition.

3.5 Combined-Cycle Waste Solids Management

As described in the 2011 EPRI report *Evaluation of Thermal Zero Liquid Discharge Treatment Technologies for Combined Cycle Gas Turbine Power Plants* (1022162), the solids waste management at combined cycle power plants typically consists of sending the solids to a conventional off-site landfill. Since the solid residuals from these plants consists mainly of softening sludge and salts from the ZLD operations, these waste products typically pass paint filter and TCLP testing, making them acceptable at municipal landfills. Passing the paint filter test sometimes requires the use of additives like saw dust or other water absorbing materials.

In rare instances where the plant makeup water contains arsenic and/or other toxins, disposal at non-hazardous landfills is not possible without solids treatment and stabilization. One plant interviewed in Florida mixes the centrifuged crystallizer solids with fly ash (sourced from an adjacent coal fired unit) and transports the mixture on an on-site landfill for permanent disposal.

4
LESSONS LEARNED AND PRELIMINARY CONCLUSIONS

The goal of this study was to provide an overview of the current practices used by coal fired power stations for the handling and disposal of waste solids generated from FGD purge water treatment processes using thermal ZLD systems. Since there are only few FGD ZLD systems in operation in the U.S. and worldwide, the information available for the solids disposal is very limited–and additional work by EPRI and the industry is needed for ZLDs operating on FGD blowdown. Only two of the seven facilities interviewed in this study operate ZLDs on FGD water, thus much of the current practices summarized in this report may have limited applicability for FGD blowdown applications. Considering these significant limitations, the following preliminary conclusions were developed.

With all of the FGD ZLD systems in operation for less than three years, the long term effects of these solid waste residuals on the landfill are unknown. General leaching as well as material breakdown, potentially leading to additional leaching issues in the landfills, has not been studied.

This study found that landfill leaching was handled by landfill management, good storm water control and leachate collection systems that segregate the leachate from storm water intrusion. Leachates, when present, were typically collected and sprayed over the landfill for dust control and evaporation. A few plants had the ability of route excess leachate, i.e. volumes that could not be sprayed over the landfill, for inclusion and treatment within the plant water management system. The latter was, however, more of a backup plan and was practiced at only one of the plants interviewed.

Most landfills, other than ones located in very arid locations, were equipped with leachate and/or ground water monitoring systems. Collected storm water was clarified and typically discharged via an NPDES permit. One plant incorporated the storm water into the general plant water management for beneficial use.

The solid residuals from conventional ZLD and FGD ZLD operations are typically sent to landfills for final deposition. Most of the plants interviewed had their own landfills, which are usually located on contiguous portions of the plant property. Some plants do, however, use industrial landfills for their waste disposal. In all cases, the plant retains the responsibility for the transportation to and deposition of the waste materials.

The amount of ZLD solid waste materials generated and sent to landfill is relatively small compared to the bulk of the landfilled depositions consisting of mainly fly and bottom ash.

There are currently only three FGD ZLD treatment systems operating or being constructed in the U.S. Two of these systems are opting to use fly ash to solidify or stabilize the waste brine with subsequent deposition in their respective landfills. The limited data available suggest that these solids will pass the paint filter test and may also pass TCLP. The soluble components of the landfilled material are, however, susceptible to leaching. The degree of leaching is dependent on

numerous factors including landfill design and management as well as the local meteorological conditions.

In the brine solidification/stabilization process, the use of solidification agents, like Portland cement, in addition to fly ash may further stabilize the solids and reduce the leaching of the soluble, non-regulated components. Although there seems to be an increasing interest in pursuing brine stabilization by using solidification agents, not much work has been done in this area for power plant applications. More power industry and vendor research would be warranted to evaluate and establish promising formulations that could expand the landfill options for power plants in general, and especially for those that do not have on-site landfills. Changing regulatory requirements are an additional unknown.

Various physical means of reducing leaching are employed as part of the landfill management. These can consist of cellular landfill designs, where the cells are deactivated and capped after relatively brief operating life compared to monolith designs. Another approach is to cap the landfill as sections are progressively filled to their designed depth. Once capped, rainwater intrusion is limited so that further leaching from those sections is essentially eliminated. Good landfill management, including proper storm water runoff control is essential for all landfills to minimize leachate generation.

Landfill size demand is a function of the amount of waste material generated for deposition. Any waste material generated that does not have to be landfilled is an obvious benefit. Of the coal plants contacted, some sell their fly ash, subject to market demand. While all of the European plants interviewed sell the FGD generated gypsum, only few of the U.S. seem to do this - although the possibility of selling the gypsum was raised by several plants. The need for a gypsum wash system to remove chloride before the gypsum could be salable was also mentioned. Since many of the U.S. FGD facilities are located in relatively remote locations, their market access may be more limited compared to the European plants.

With the operating experience of thermal FGD ZLDs limited to only a few plants that have been operating for three years worldwide and only two years in the U.S., there are many unknowns, including the solid waste management and disposal issues. Power industry and vendor R&D efforts to identify solid waste residual stability with regard to material strength and the containment of trace metals and other toxins within deposition areas should be expanded. Material integrity of solidified, stabilized or untreated product should be further studied to predict the long term effects on landfills in terms of leaching and general landfill management.

A
ABBREVIATIONS AND ACRONYMS

The following abbreviations and acronyms are used in this report:

BC	brine concentrator
CAPEX	capital expenditure
CC	combined-cycle gas turbine generating station
CF	concentration factor (cooling tower or brine concentrator)
CT	cooling tower
CRX	crystallizer
EPRI	Electric Power Research Institute
FGD	flue gas desulfurization
LOI	loss on ignition
LSFO	limestone–forced oxidation
NPDES	National Pollutant Discharge Elimination System (the permit that regulates discharges to a surface water body)
OPEX	operating expenditure
SPLP	synthetic precipitation leaching procedure
TCLP	toxicity characteristic leaching procedure
TDS	total dissolved solids (the amount of organic and inorganic substances dissolved in solution expressed as mg/l, ppm, or percent)
TSS	total suspended solids (the amount of organic and inorganic substances suspended in water, typically expressed as mg/l, ppm, or percent)
TS	total solids (the amount of dissolved and suspended solids contained in the liquid body expressed as mg/l, ppm, or percent)
WW	wastewater
ZLD	zero liquid discharge

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