

**Evaluation of Wet-to-Dry Retrofits for Bottom Ash
Handling Systems at Coal-fired Power Plants Owned
by a Midwestern Utility Company**

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EPRI Project Managers

P. Chu
C.J. Veatch

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Intercontinent Engineers, Inc.
3051 Oak Grove Road
Suite 106
Downers Grove, IL 60515

Principal Investigator
R. Rehal

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ABSTRACT

On April 19, 2013, the U.S. Environmental Protection Agency (EPA) proposed draft Effluent Limitations Guidelines (ELGs) for the steam electric power industry. In these guidelines, EPA proposed eight options (including four preferred options) for technological process retrofits. Implementation of these options would affect a number of power plant waste streams. The most restrictive of EPA's preferred options would limit the discharge of bottom ash sluice water from coal-fired generating units with rated capacities greater than 400 megawatts (MW).

To develop proactive management plans, a Midwestern utility company (The Company) and the Electric Power Research Institute (EPRI) initiated engineering case studies of wet-to-dry retrofits for bottom ash handling systems at seven coal-fired units located at five of The Company's facilities. These studies were intended to estimate, evaluate, and compare the capital and operating costs associated with installing dry bottom ash handling technologies at each facility. This information will allow The Company to prepare long-term budgets, which factor in impending ELGs. A team consisting of an engineering firm, a mechanical contractor, an equipment vendor, and engineers from The Company toured each site and selected the most effective dry bottom ash handling system to meet site-specific needs—given estimated outage times, likely operations and maintenance (O&M) costs, existing water management strategy, and space available under and around the boiler. Cost estimates developed for each unit include quoted costs for vendor-supplied equipment, as well as subsequent balance-of-plant, structural, mechanical, and electrical installation costs.

While many factors were evaluated at each site, the key factor driving technology selection was the available space under and immediately around the boiler. Because it offered reduced water demand and reduced O&M costs, a mechanical drag system (MDS) was most economical—but only when sufficient space was available. At facilities where sufficient space was not available, installing a remote mechanical drag system (RMDS) was the preferred approach.

Keywords

Bottom ash handling

Water management

Mechanical drag system

Pneumatic ash handling

EXECUTIVE SUMMARY

Effluent Limitation Guidelines (ELGs) proposed by the U.S. Environmental Protection Agency (EPA) may restrict the discharge of bottom ash transport water for coal-fired units greater than 400 megawatts (MW). In anticipation of these restrictions, a midwestern utility company (The Company) is considering potential wet-to-dry retrofits for bottom ash handling systems at seven of their coal-fired units located at five power plants. These retrofits would update existing bottom ash handling systems to move ash from the bottom of the boiler to a temporary storage location without discharging transport wastewater or maintaining an ash storage pond. This report explains the requirements, processes, and results of seven engineering case studies undertaken to identify the capital and operating costs inherent in such wet-to-dry retrofits. The following facilities and units (case studies) are described in this report:

- Plant 1 Unit A
- Plant 2 Unit A
- Plant 2 Unit B
- Plant 3 Unit A
- Plant 4 Unit A
- Plant 4 Unit B
- Plant 5 Unit A

This research was undertaken for two reasons. First, there is industry-wide interest in establishing the total costs associated with wet-to-dry bottom ash handling retrofits. Because few retrofits have been performed to date, it is important to identify the steps and considerations required for making accurate cost estimates. Second, The Company needs this information to determine the total installed and operating costs for bottom ash system retrofits at seven specific units it owns. Cost estimates will determine the feasibility of the proposed retrofits at each of these units. These cost estimates are Class 5 order of magnitude for screening and feasibility.

The cost estimates generated for this report are not for an engineering, procurement, and construction (EPC) project. EPC project costs vary widely depending on who takes the lead role: the engineer, the contractor, or the equipment vendor. Each party has unique expertise and views risk in certain areas differently. The choice of EPC project leader also determines costs for equipment, engineering, and installation.

This report shows costs based on the assumption that the utility will subcontract direct to the balance-of-plant (BOP) engineer, the equipment vendor, and the installation contractor. This choice gives a better breakdown of individual costs to the utility. Using the costs in this report, a utility can estimate the cost of an EPC project by determining the potential project lead and the amount of risk assumed for that lead. There will be a contingency associated with that risk.

Establishing cost estimates at each of the seven units owned by The Company was a multi-step process. Project teams conducted an extensive walk-down at each site during which they gathered relevant information, measured dimensions, and identified site-specific challenges. To gather as much information as possible and discuss potential issues collaboratively as they arose, the project team at each site included personnel from Intercontinent Engineers, Inc. (a consulting

architectural engineering firm), United Conveyor Corporation (the ash-handling component supplier), Day Mechanical Systems (the mechanical/electrical contractor), and the host utility engineering team. The team collected information and drawings for existing bottom ash handling systems to characterize structures, clearances, and layouts. Relevant information included existing power use, maintenance costs, water use, water sources, operating times, and ash flow rates.

With this information in hand, personnel from Intercontinent Engineers, Inc., United Conveyor Corporation, and the host utility chose the most economical bottom ash handling system available for each unit, based on the following criteria:

- Space under the existing boiler
- Space near the boiler inside the boiler house for fabrication during construction
- Space and clearance between the boiler and the outside wall of the boiler house for dewatering and transport conveyors to access loading areas
- Space outside the plant building for ash loading, truck access, and a storage building
- Comparison of current operations and maintenance (O&M) costs with anticipated O&M costs for each technology considered.

After the bottom ash handling system was chosen, cost estimates were developed based on The Company's customer requirements and engineering requirements collaboratively determined by personnel from Day Mechanical Systems, United Conveyor Corporation, and Intercontinent Engineers, Inc. Total cost estimates were based on the following:

- United Conveyor Corporation system engineering, fabrication, equipment, material, and delivery costs
- Balance-of-plant engineering costs, determined by current rates specified in host utility engineering services agreements
- Structural, mechanical and electrical installation costs, based on rates charged by a local small- to mid-sized utility contractor
- Balance-of-plant material and equipment costs

The following bottom ash handling systems were considered at each unit:

- ***Mechanical Drag System (MDS)***. This system, which completely replaces existing bottom ash hoppers below the boiler, consists of chain-mounted flight bars submerged in a water trough. These bars continuously evacuate bottom ash that has been quenched in the trough water. As it is conveyed up the dewatering ramp, the ash is dewatered by gravity, reaching a moisture content of about 20% by weight. The ramp deposits the dewatered ash in a storage area for removal.
- ***Remote Mechanical Drag System (RMDS)***. This system, which dewateres ash in much the same way as the MDS, is located remotely from the boiler. The RMDS offers the advantage of retaining the existing bottom ash hoppers but using yard space for the bulk of the equipment. The existing wet impounded hoppers collect the bottom ash and piping conveys it in batches to a remote trough. As the ash moves from the trough up a dewatering ramp, it is dewatered by gravity to a moisture content of about 20% by weight. The ramp deposits the

dewatered ash in a storage area for removal and trough water recirculates back to the wet impounded hoppers.

- ***Pneumatic Dry Transport (PDT) System.*** This system, a truly dry option, collects bottom ash in a dry hopper underneath the boiler and cools it using air that is piped into the hoppers. At predetermined intervals, specialized pneumatic piping (entirely free of moisture) transports bottom ash from the hoppers to a storage bin and silo.

Table ES-1 summarizes the retrofit technologies selected for each bottom ash handling case study. Table ES-2 compares the costs of individual case studies.

**Table ES-1
Summary of Retrofit Technologies Selected for Bottom Ash Handling Case Studies**

Facility	Case Study	Bottom Ash Flow (gallons/minute)	Proposed Retrofit Technology	Reasons for Selection	Proposed Number of Retrofit Units	Conveyance Piping (feet)	Recirculation Piping (feet)	Vendor Equipment Cost	Installation Cost	Annual O&M Cost
Plant 1	Unit A	500	RMDS	Reduced outage time, no clear conveyance path, access	1	1,500	3,000	\$3,750,000	\$1,379,000	\$889,000
Plant 2	Unit A	2,050	MDS	Sufficient space around boiler, reduced O&M	1	NA	NA	\$4,300,000	\$1,303,000	\$1,746,000
	Unit B	2,050	MDS		1				\$1,303,000	
Plant 3	Unit A	1,240	RMDS	Reduced outage time, restricted space	1	600	1,200	\$3,750,000	\$1,293,000	\$583,000
Plant 4	Unit A	1,380	RMDS	Restricted space	1	1,500	3,000	\$3,500,000	\$1,457,000	\$571,000
	Unit B	3,200	RMDS							
Plant 5	Unit A	4,000	RMDS	Reduced outage time, reuse of existing equipment, no clear conveyance path	1	800	1,600	\$4,000,000	\$1,463,000	\$976,000

O&M = operations and maintenance
MDS = mechanical drag system
RMDS = remote mechanical drag system
1 gallon/minute = 0.063 liters/second
1 foot = 0.305 meter

**Table ES-2
Comparative Costs of Individual RMDS Case Studies**

Facility	Case Study	Proposed Number of Retrofit Units	Vendor Equipment Cost	Major Vendor-supplied Equipment
Plant 1	Unit A	1	\$3,750,000	<ul style="list-style-type: none"> • 2 Low-pressure recirculation pumps (200 horsepower [149 kilowatts]) • 2 High-pressure recirculation pumps (200 horsepower [149 kilowatts]) • 1 Hydraulic Power Unit (60 horsepower [45 kilowatts]) • 2 Sump pumps (20 horsepower [15 kilowatts]) • 2 Overflow return pumps (50 horsepower [37 kilowatts]) • 2 Overflow surge tanks • 1,500 feet (457 meters) conveyor piping • 3,000 feet (914 meters) recirculation piping • Footprint = 25 x 150 feet (8 x 46 meters)
Plant 3	Unit A	1	\$3,750,000	<ul style="list-style-type: none"> • 2 Low-pressure recirculation pumps (200 horsepower [149 kilowatts]) • 2 High-pressure recirculation pumps (200 horsepower [149 kilowatts]) • 1 Hydraulic power unit (60 horsepower [45 kilowatts]) • 2 Sump pumps (20 horsepower [15 kilowatts]) • 2 Overflow return pumps (50 horsepower [37 kilowatts]) • 2 Overflow surge tanks • 600 feet (183 meters) conveyor piping • 1,200 feet (366 meters) recirculation piping • Footprint = 25 x 130 feet (8 x 40 meters)
Plant 4	Unit A	1	\$3,500,000	<ul style="list-style-type: none"> • 2 Low-pressure recirculation pumps (200 horsepower [149 kilowatts]) • 2 High-pressure recirculation pumps (200 horsepower [149 kilowatts]) • 1 Hydraulic power unit (60 horsepower [45 kilowatts]) • 2 Sump pumps (20 horsepower [15 kilowatts]) • 4 Overflow return pumps (50 horsepower [37 kilowatts]) • 2 Overflow surge tanks • 1,500 feet (457 meters) conveyor piping • 3,000 feet (914 meters) recirculation piping • Footprint = 25 x 150 feet (8 x 46 meters)
	Unit B			

Facility	Case Study	Proposed Number of Retrofit Units	Vendor Equipment Cost	Major Vendor-supplied Equipment
Plant 5	Unit A	1	\$4,000,000	<ul style="list-style-type: none"> • 2 Low-pressure recirculation pumps (200 horsepower [149 kilowatts]) • 2 High-pressure recirculation pump (200 horsepower [149 kilowatts]) • 1 Hydraulic power unit (60 horsepower [45 kilowatts]) • 2 Sump pumps (20 horsepower [15 kilowatts]) • 2 Overflow return pumps (50 horsepower [37 kilowatts]) • 1 Overflow surge tank • 800 feet (244 meters) conveyor piping • 1,600 feet (457 meters) recirculation piping • Footprint = 25 x 150 feet (8 x 46 meters)

Note: These costs are Class 5 order of magnitude. No upfront, detailed engineering was performed by United Conveyor Corporation. The listed 200-horsepower pump sizes could change depending on placement of equipment and layouts. The margin of error for a Class 5 cost estimate is roughly +/- 100% and all specifications and performance characteristics are subject to change.

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DEFINITIONS AND ACRONYMS

BOP	balance of plant
C	Centigrade
CS	commercial standard
ELGs	Effluent Limitations Guidelines
EPA	U.S. Environmental Protection Agency
EPC	engineering, procurement, and construction
F	Fahrenheit
hp	horsepower
HPU	hydraulic power unit
HVAC	heating, ventilating, air conditioning
I&C	instrumentation and control
kWh	kilowatt-hour
MCC	motor control center
MDS	mechanical drag system
MW	megawatt
NPDES	National Pollutant Discharge Elimination System
O&M	operations and maintenance
PDT	pneumatic dry transport (system)
RMDS	remote mechanical drag system
The Company	midwestern utility company

1

INTRODUCTION

This report summarizes the costs for retrofitting wet bottom ash handling systems at five coal-fired power plants owned by a midwestern utility company (The Company). Retrofit costs were identified by engineering case studies in which wet systems were retrofit to move ash from the bottom of the boiler to a temporary storage location without discharging transport wastewater or maintaining an ash storage pond. Because the process of evaluating wet systems for potential retrofit to dry systems is relatively new to the power industry, this report documents the steps taken and personnel needed to perform such evaluations. Finally, the report compiles the capital and operations and maintenance (O&M) costs associated with each potential retrofit. This information will inform The Company's long-term planning.

Many factors come into play when choosing a system for handling and storing bottom ash at each specific power plant. While water management approaches at each power plant can be a factor, it is likely that current or anticipated federal, state, and local effluent discharge regulations may have the largest impact on the decisions made at coal-fired power plant. The bottom ash is the slag that builds up on the heat absorbing surfaces in the furnace, super heater, and re-heater. Bottom ash produced in coal boilers has traditionally been quenched and handled by using water. Specifically, when the slag falls downward—due to its own weight, load changes, or soot blowing—into the wet impounded bottom ash hoppers, it is cooled by the water in the hoppers before being sluiced to a pond via water pipes. Because the Effluent Limitation Guidelines (ELGs) proposed by the U.S. Environmental Protection Agency (EPA) may restrict the discharge of bottom ash transport water for coal-fired units greater than 400 megawatts (MW), this method of bottom ash handling is being reconsidered.

Additional drivers for The Company included potential concerns about National Pollutant Discharge Elimination System (NPDES) limits at select power stations, as well as a need for the land that was currently occupied by the bottom ash pond.

Table 1-1 summarizes the unit characteristics and statistics reviewed for wet-to-dry retrofit engineering case studies of bottom ash handling systems. The studies were conducted at seven generating units representing five power plants. An initial survey of the bottom ash handling procedures at each of The Company's sites revealed that six of the units in question currently use ash ponds for bottom ash storage. Located at each site, these ponds receive bottom ash that is transported from ash hoppers via existing ash sluice piping and bottom ash sluice pumps that move the water stream. Only Plant 1 Unit A handles bottom ash differently, employing a dewatering bin system at the end of the sluice pipes to separate the bottom ash from the sluice water. While the destination of bottom ash at this unit differs slightly from the destination at other units, the fact that bottom ash is being sluiced with water offers The Company an opportunity to install a closed-loop or fully dry bottom ash handling system at Plant 1 Unit A.

**Table 1-1
Summary of Wet-to-Dry Retrofit Engineering Case Studies for Bottom Ash Handling Systems**

Facility	Case Study	Bottom Ash Flow (gallons/minute)	System Type	Water Source	Operation (hours/day)	Operation (days/year)	Ash Handling (tons/day)	Economizer Ash Handling
Plant 1	Unit A	500	Dewatering bin	Intake 20% Recirculated 80%	24	340	70	Handled dry with fly ash
Plant 2	Unit A	2,050	Ash pond	Intake 5% Ash pond recirculated 95%	3	330	100	Same system as bottom ash, separate sluice line
	Unit B	2,050	Ash pond	Intake 5% Ash pond recirculated 95%	3	330	100	Same system as bottom ash, separate sluice line
Plant 3	Unit A	1,240	Ash pond	Intake 100%	6	290	30	Handled wet with bottom ash
Plant 4	Unit A	1,380	Ash pond	Intake 100%	1	300	15	Handled dry with fly ash
	Unit B	3,200	Ash pond	Intake 100%	3	300	15	Handled dry with fly ash
Plant 5	Unit A	4,000	Ash pond	Intake 90% Cooling tower blowdown 10%	7	335	105	Handled wet with bottom ash

1 gallon/minute = 0.063 liters/second

1 ton/day = 907.18 kilograms/day

For each engineering case study, the approach to cost estimation taken in this report is presented in tables, while the proposed retrofit system and design is described in various process flow diagrams, site location drawings, system drawings, and a water balance. The purpose of this report is to summarize the engineering case studies of bottom ash handling technology retrofits undertaken at seven Company generating units, including the key design considerations and associated costs. The report contains essential information that will help The Company to define its goals and develop long-term plans.

The key design and cost considerations include:

- Current and expected bottom ash production rates, conditions, equipment locations, and boiler clearances at each unit
- Possible locations for new systems at each power plant
- Engineering, equipment, and installation costs for each project
- Outage time necessary for each proposed retrofit
- Current and expected water demands at each unit
- Total power likely to be consumed by the new ash handling system compared to power use required by existing equipment
- Comparison of current operations and maintenance (O&M) costs with anticipated O&M costs for each technology considered.

To better illustrate the conditions unique to each unit, this report provides process flow diagrams, as well as drawings that illustrate water balances, equipment plans, elevations, and site locations.

2

TECHNOLOGIES AVAILABLE TO RETROFIT WET BOTTOM ASH HANDLING SYSTEMS AT COAL-FIRED POWER PLANTS

Mechanical Drag System

The installation of a mechanical drag system (MDS) is an extensive retrofit, as it has to completely replace the wet impounded bottom ash hoppers that currently sit below the boiler. The MDS, which looks like a large trough with a conveyor belt coming up out of one end, moves ash using chain-mounted flight bars that are submerged in the water trough below the boiler (Figure 2-1). Because there is no long-term storage capacity in the water trough under the boiler, the ash is continually evacuated by mechanical means and dewatered by gravity on the incline. A low speed, high torque hydraulic power unit (HPU), including a hydraulic pump and hydraulic reservoir, provides power to the drag conveyor. The drive motor and gear reducer are flexibly coupled to the head shaft to produce maximum torque at near-stall conditions. Figure 2-1 illustrates a typical MDS.

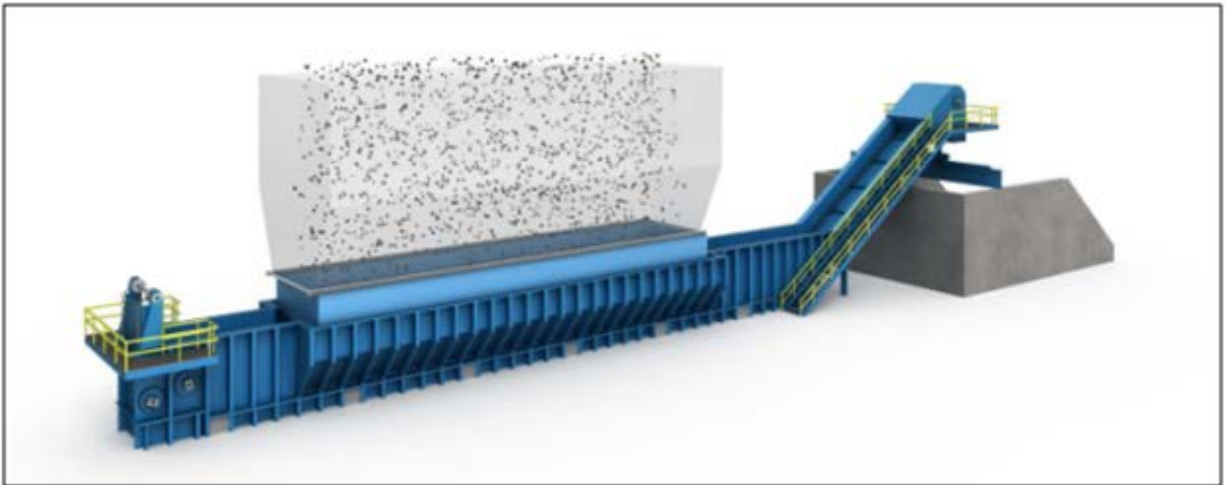


Figure 2-1
Mechanical Drag System
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Water management in an MDS involves continuously pumping makeup water into the trough to maintain an adequate water level and to manage the temperature in the trough. The optimal temperature for the water in the MDS ranges from 70 to 100 °F (Fahrenheit), or 21 to 38 °C (Centigrade). As the bottom ash is conveyed up the dewatering slope, the angle of the slope and the rate at which the conveyor moves are set to dewater the ash to a roughly 20% moisture content. The water that drains out of the conveyed ash runs back down into the trough.

Once it is conveyed up and out of the dewatering ramp, the bottom ash is funneled into a transfer chute and then to a clinker grinder/crusher to rid the ash of any large pieces of slag or other

material. The clinker grinder deposits the ground-up bottom ash into a concrete-sided collection pit, often located inside an enclosure, when required by environmental conditions or dust management practices. This collection pit is a temporary storage site, as the ash must be transferred to a permanent landfill or sent away for beneficial use. Transferring the bottom ash from the collection pit to its final destination is an easy process that uses a front-end loader to remove and load the dewatered ash into a transportation truck.

Because there is a possibility that future environmental regulations may restrict the discharge of bottom ash transport water to surface waters, reasonable accommodations have been made for the unlikely event in which the MDS trough would have to be fully drained. These accommodations include the cost of a 20,000-gallon (75,708-liter) water storage tank, added as if it were part of the basic equipment provided by the vendor.

Advantages of an MDS

- Installing an MDS dictates the replacement of the old and often deteriorated bottom ash hoppers, clinker grinders, and ash sluice pumps/piping
- The MDS is the lowest-priced option compared to other equipment reviewed
- The MDS involves continuous removal of fallen bottom ash; it is not a batch process
- The MDS features the lowest power consumption compared to other equipment reviewed
- Employing an MDS eliminates the need for an ash pond for bottom ash storage

Disadvantages of an MDS

- Employing an MDS requires long outage periods for demolition and installation
- The costs associated with the demolition of existing bottom ash hoppers are notable
- The boiler house must have ample physical space for the contractor to use during MDS installation under the boiler and MDS component fabrication around the boiler
- Installation of a concrete-sided pit requires access to an exterior wall of the boiler house, but access may be unavailable or restricted in plants with more than two units

Note: The optimal space needed for fabrication depends on the size of the MDS as it sits under the boiler section. The water-filled vessel will be quite large, but its size will vary depending on the specific boiler size and type. Typically, there should be enough room around the boiler for the contractor to set up scaffolding, store equipment and tools for fabrication, and fabricate portions of the MDS.

Remote Mechanical Drag System

The remote mechanical drag system (RMDS) resembles the MDS, but is located outside of the boiler building and away from the bottom of the boiler (Figure 2-2). During normal operation, the bottom ash falls into the existing wet impounded bottom ash hoppers and is processed by the existing clinker grinders. The bottom ash is moved from the clinker grinders to the remotely located RMDS using the existing sluice piping (if it is still viable) and sluice pumps that often can be downgraded depending on the distance to the RMDS. This layout allows for the same performance as that expected from an MDS without having to fit the equipment inside the boiler building.

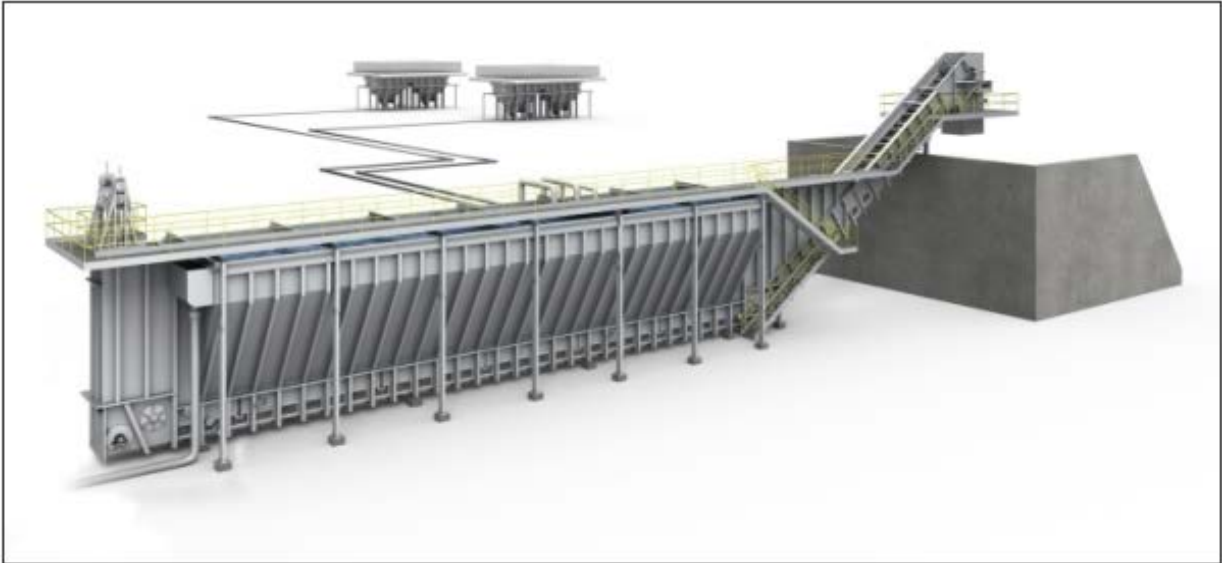


Figure 2-2
Remote Mechanical Drag System
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Once the sluiced bottom ash is deposited into the trough, the process continues as it would in an MDS. First, the bottom ash settles through the water onto the submerged flight chain conveyor. Then it is slowly conveyed up a dewatering slope at the angle and rate necessary to dewater the ash to a roughly 20% moisture content. After dewatering, the bottom ash is funneled into a transfer chute and deposited into a concrete-sided collection pit for temporary storage. A front-end loader can be used to remove and load the dewatered ash into a transportation truck for conveyance to permanent landfill storage or beneficial use. The water that drains from the bottom ash and collects below the dewatering conveyor is returned to the trough. However, unlike the MDS, the water in the trough must be recirculated back to the bottom ash hoppers using recirculation pumps.

Because the RMDS removes bottom ash intermittently (not continuously like the MDS), the number of bottom ash sluicing batches per day depends on ash generation rates and bottom ash hopper capacity. Thus, when choosing the size of RMDS required, designers must look at plant needs over the course of the day as well the maximum instantaneous demands of the system during a batch.

When considering an RMDS, the cost and logistics components of these engineering studies include a 20,000-gallon (75,708-liter) water storage tank to accommodate complete drainage of the water-filled trough for maintenance.

Advantages of an RMDS

- Installing an RMDS can be accomplished with little or no outage time, as it is compatible with the same wet impounded bottom ash hoppers and sluice piping already present
- Employing an RMDS eliminates the need for an ash pond for bottom ash storage
- Employing an RMDS closes the water loop with regard to bottom ash sluice water, as the water can be recirculated

Disadvantages of an RMDS

- In terms of power consumption, operating an RMDS can be costly compared to the other technology options since the sluice pumps must be rated highly enough to move sluice water to a remote location
- An RMDS retains the existing bottom ash sluice pipes, jet pumps, sludge pumps, and wet impounded hoppers—all of which can be costly to maintain
- An RMDS installation adds recirculation pumps that require new power distribution equipment, conduit, and cable—and consume additional power
- RMDS trough size must be increased to accommodate settling

Pneumatic Dry Transport System

Like MDS systems, pneumatic dry transport (PDT) systems (Figure 2-3) must be fabricated in sections near the boiler before being installed underneath the boiler. During installation, the existing wet ash hoppers are removed and sloped walls are added to the base of the boiler so that discharged ash can fall directly into the new dry ash hoppers. As the ash falls into the dry hoppers, the small pieces pass through a grating that stops clinkers and slag, which are processed by jaw crushers. Once the hoppers fill with ash, doors close and air is forced into the now-sealed hoppers to cool the ash. The resulting heated air is sent to the boiler, where it helps to prevent heat loss and promote more complete carbon combustion. After cooling, the bottom ash flows via a vacuum conveying system to a storage silo. This is a temporary storage silo; the ash is later transferred by truck to a permanent landfill or offsite for beneficial use. This type of system has the potential to develop clinkers big enough to cause bridging and clogging at the grid doors. Other utilities have employed PDT and similar technologies without bridging and clogging problems, but the potential for such problems exists.

Advantages of a PDT System

- A PDT system eliminates all water use during bottom ash conveying
- A PDT system eliminates the need for a dedicated bottom ash pond
- A PDT system allows ash conveyance over long distances and through crowded boiler buildings
- Power consumption for new PDT blowers, crushers, and drives should be roughly equal to or less than that of the existing ash sluice water pumps

Disadvantages of a PDT System

- Installing a PDT system requires long outage periods to demolish existing wet bottom ash impounded hoppers and install dry equipment
- PDT systems add cost due to the need for a temporary storage silo
- Larger units (above 200 MW) may have issues with clinkers clogging transition openings



Figure 2-3
Pneumatic Dry Transport System
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The decision matrix shown in Figure 2-4 can be used to select a bottom ash handling technology.

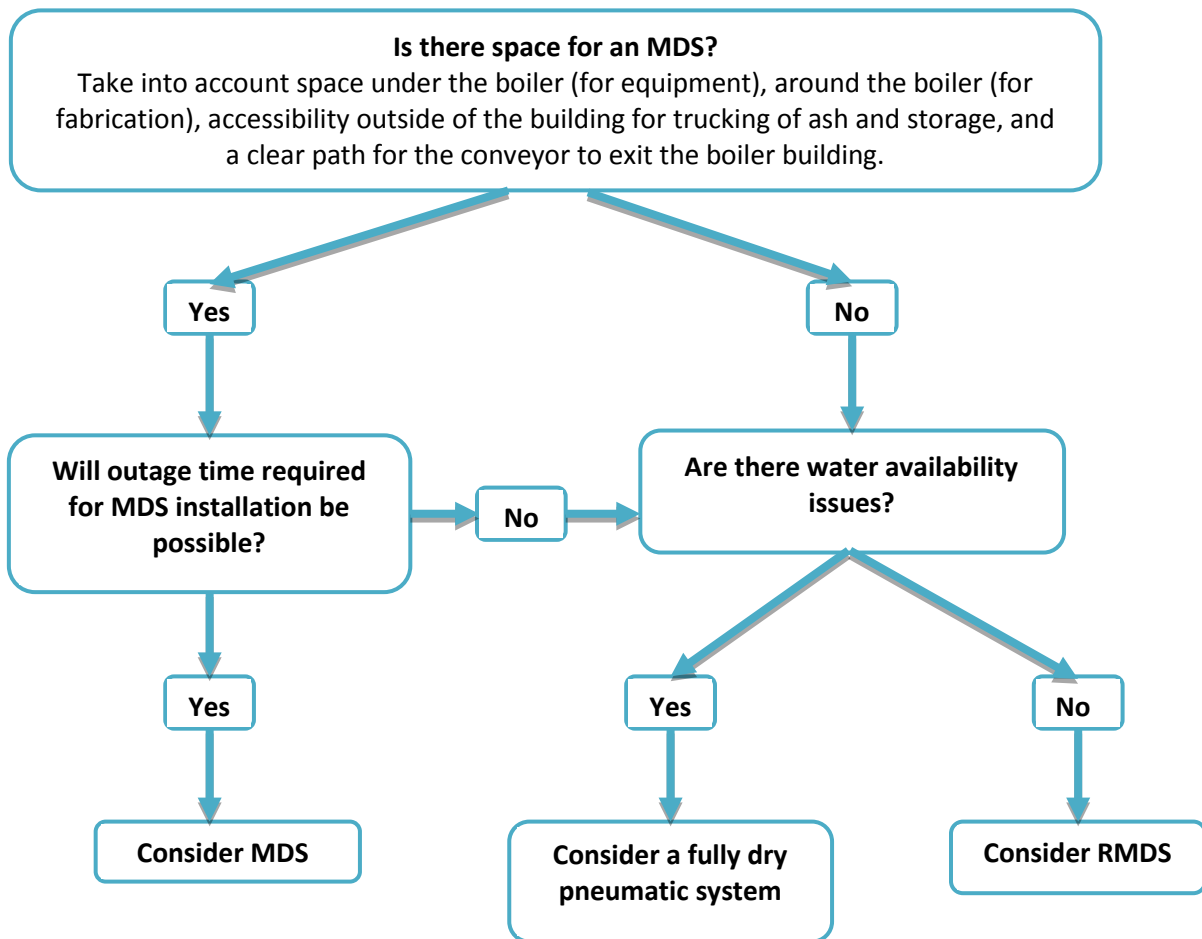


Figure 2-4
Decision Matrix for Selecting a Bottom Ash Handling Technology

The engineering case studies described in Sections 3 through 7 outline the following for each unit:

- The reason for considering a switch to MDS, RMDS, or PDT system technology
- The technology selection process and an overview of site-specific considerations that drive selection
- A process flow diagram for the selected technology, accompanied by figures showing the site layout
- A summary of capital costs—including assumptions, equipment list, and balance-of-plant engineering details
- A breakdown of anticipated O&M costs compared to O&M costs for the existing system
- A water balance
- A schedule for implementation

3

PLANT 1 UNIT A

This section presents a proposed retrofit for the existing bottom ash handling system at Plant 1 Unit A. A brief description of the existing system is given in Table 3-1.

Site Description

Unit: A

Owner: A Midwestern Utility Company

Capacity: 380 MW

Existing Bottom Ash Handling System: Dewatering bin

Table 3-1

Plant 1 Unit A—Description of Existing Bottom Ash Handling System

System Type	Bottom Ash Water Use (gallons/day)	Water Source	Operation (hours/day)	Operation (days/year)	Bottom Ash Handling (tons/day)	Economizer Ash Handling
Dewatering bin	720,000	Intake 20% Recirculated 80%	24	340	70	Handled dry with fly ash

Water use = water pumped (make-up water plus recirculated water)

720,000 gallons/day = 2.73 million liters/day

70 tons/day = 63,503 kilograms/day

Currently, Plant 1 Unit A handles bottom ash in a (mostly) closed loop, mitigating the discharge of bottom ash sluice water. The system collects ash in wet impounded hoppers placed below the boiler and then sluices it to remotely located tank farms. As in most multi-stage dewatering bin systems, each batch of sluice water is directed into one of two identical tanks. Having two tanks available allows ash and sluice water to fill one bin while ash in the other bin settles, dewateres to about 20% water content by weight, and is unloaded into transport trucks. Water removed from the ash during dewatering overflows into the settling tank. In the settling tank, the fine ash carried with this overflow water settles to the bottom of the tank and then transfers back to a dewatering bin, where it is removed with the next batch of ash. Water leaving the settling tank collects in the surge tank, where recirculation pumps return the water to the wet impounded bottom ash hoppers. The bottom ash handling system currently in service at Plant 1 Unit A incurs high operating costs and high maintenance costs (due to excessive clogging and corrosion) that drive investigation of a different closed-loop system.

Proposed RMDS Retrofit

After touring the facility and speaking with on-site engineers, investigators proposed that—due to equipment interference—an RMDS would be the best retrofit for handling bottom ash at Plant 1 Unit A. Given the rate of ash production, The Company decided to install only one

RMDS on Unit A to collect and dewater the bottom ash slurry from the existing bottom ash hoppers (Figures 3-1 and 3-2).

The RMDS will be located west of the existing dewatering bin system, along the road currently used by trucks that unload bottom ash from the dewatering bins (Figure 3-3). Because the RMDS must be housed in a temperature-controlled building, placing it along this access road will give front-end loaders unrestricted access to the dewatered ash while the trucks continue to operate in their existing loading area.

Installation of an RMDS will satisfy one key customer requirement—a very short outage time for system interconnects. This requirement is satisfied because delivery, installation at the remote location, and fabrication of the RMDS can be done while Unit A and the existing bottom ash handling system are still in operation. Plant personnel can make final interconnections and bring the system on-line at the most opportune time.

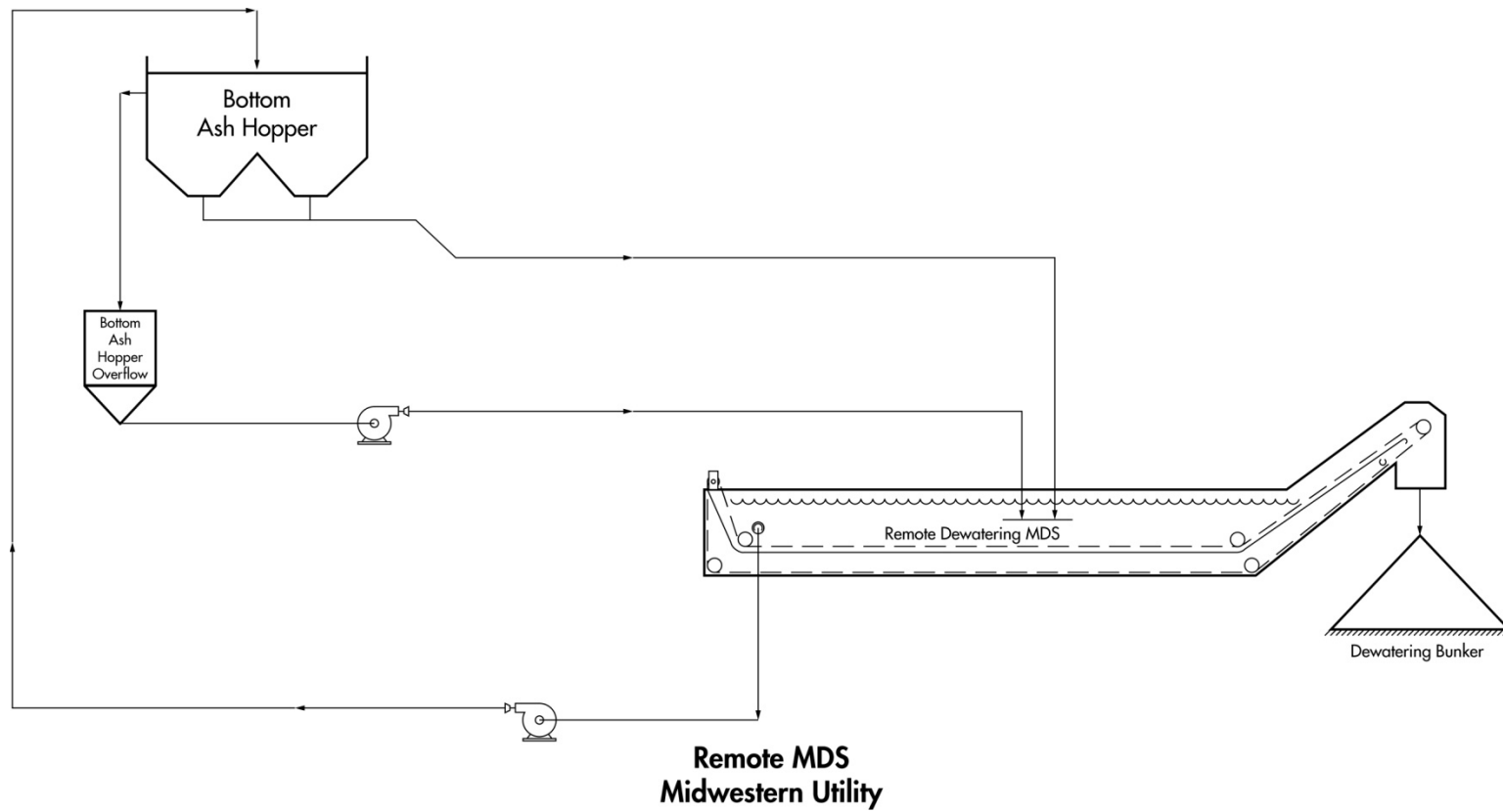
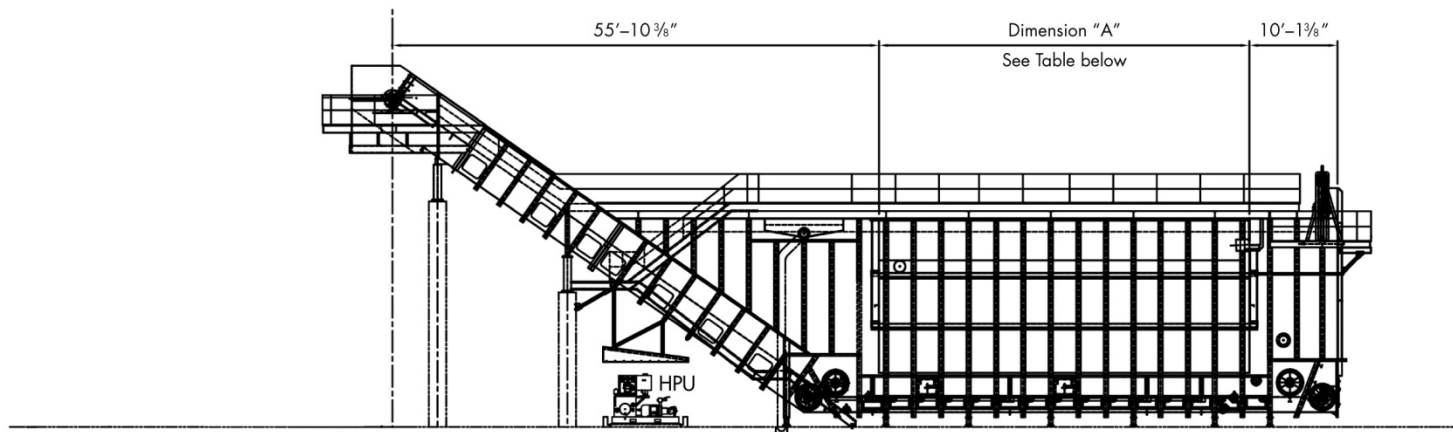
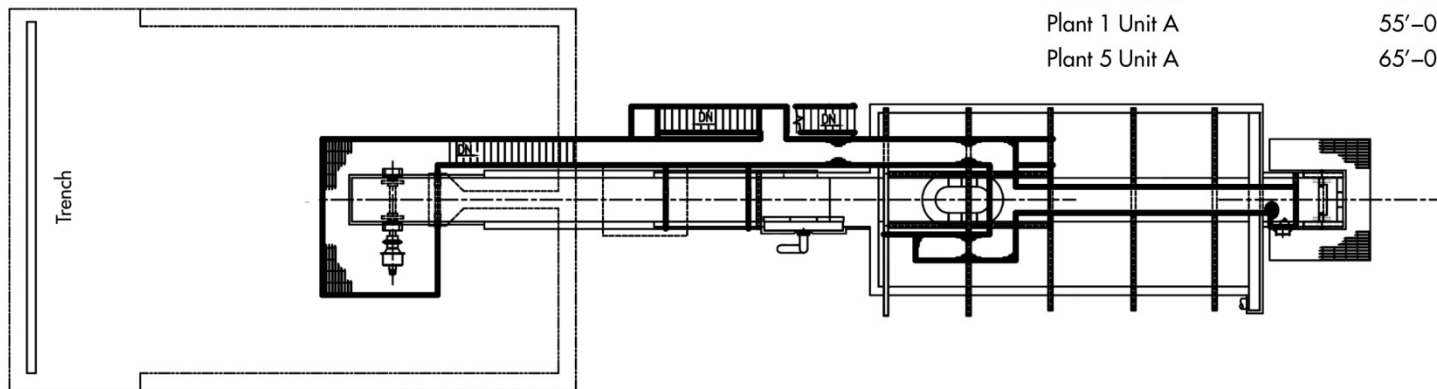


Figure 3-1
Plant 1 Unit A—RMDS Retrofit Key Flow Diagram



Plant & Unit	Dimension "A"
Plant 4 Units A & B	45'-0"
Plant 3 Unit A	45'-0"
Plant 1 Unit A	55'-0"
Plant 5 Unit A	65'-0"



**Wet to Dry Conversion
Remote Mechanical Drag System
Preliminary General Arrangement**

**Figure 3-2
Plant 1 Unit A—RMDS Retrofit Plan and Elevation View**

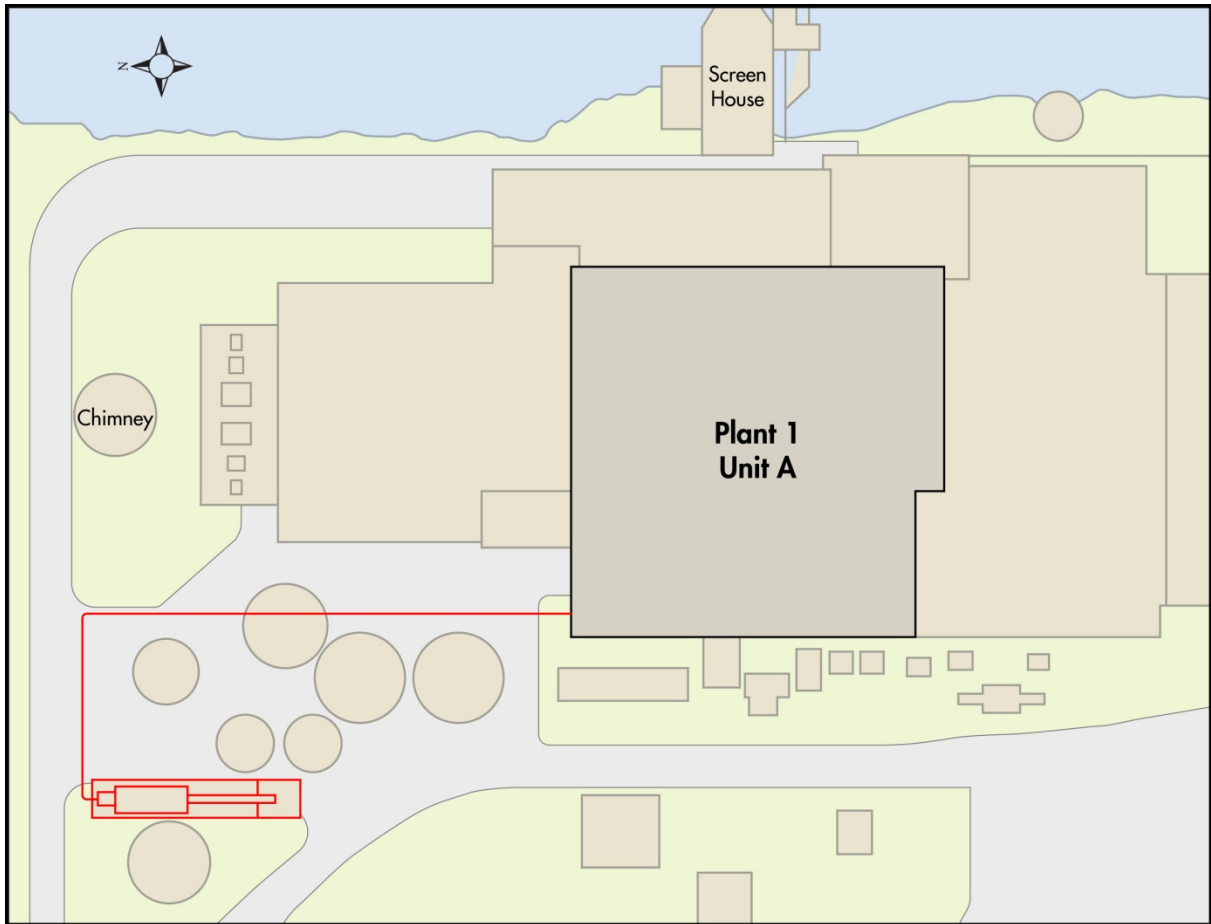


Figure 3-3
Plant 1 Unit A—RMDS Retrofit Location Plan

Other Technologies Evaluated for Retrofit

Several bottom ash handling systems were evaluated for potential implementation at Plant 1 Unit A. The Company was particularly interested in an MDS since they knew it could potentially reduce O&M costs in the long term. While physical space under the boiler (for installation) and around the boiler (for component fabrication) are often factors that eliminate an MDS from consideration, Plant 1 Unit A appeared able to accommodate an MDS. But a major obstacle was the lack of a clear path for conveying ash out of the plant, even if several tanks and electrical cabinets were removed and relocated. To install an MDS, The Company would have to abandon a large portion of the storage warehouse located just east of the boiler building and retrofit the rest to accommodate the ash removal system and bunker. Trucks would have to back 350 feet (107 meters) down a road running along the east side of the plant to access the new bottom ash removal area. The Company perceived these renovations to offer a greater cost and logistical challenge than installing an RMDS.

RMDS Retrofit Requirements and Capital Cost Evaluation

Table 3-2 lists vendor-supplied equipment to be purchased for this retrofit. The total cost for the new system reflects vendor engineering, system parts and equipment fabrication, and delivery. Because of its size and weight, the RMDS must be shipped in pieces. The number of pieces would depend on vendor preference, as well as site and delivery conditions at the time of purchase.

Table 3-2
Plant 1 Unit A—RMDS Retrofit Equipment Supplied by Bottom Ash Handling System Vendor

Quantity	Unit	Major Vendor-supplied Equipment
1,500	Feet	Bottom ash conveyor piping
3,000	Feet	CS Schedule 40 recirculation water piping
1	Lot	Required pipe supports, connections, expansion joints and fittings
2	Each	Low-pressure recirculation pump with motor (200 horsepower [149 kilowatts])
2	Each	High-pressure recirculation pump with motor (200 horsepower [149 kilowatts])
1	Each	RMDS
1	Each	Hydraulic power unit with motor (60 horsepower [45 kilowatts])
1	Lot	Maintenance access platform with grating, stairway, and handrails at RMDS
1	Each	RMDS local control panel
1	Each	RMDS local jog station
1	Lot	Instrumentation (level probes, speed switches, temperature transmitters, pressure/flow indicators)
2	Each	Sump pump with motor (20 horsepower [15 kilowatts])
2	Each	Bottom ash hopper overflow surge tank
2	Each	Overflow return pump with motor (50 horsepower [37 kilowatts])
1	Each	Engineering/design/field support
		TOTAL COST: \$3,750,000

CS = commercial standard

RMDS = remote mechanical drag system

1 foot = 0.305 meter

Table 3-3 shows estimated balance-of-plant material, labor, and engineering costs for the proposed RMDS retrofit at Plant 1 Unit A.

**Table 3-3
Plant 1 Unit A—RMDS Retrofit Estimated Balance-of-plant Material, Labor, and Engineering Costs**

Item	Description	Total Material Cost	Total Installation Person-Hours	Average Cost Per Person-Hour	Total Labor Cost	Total Cost
1	Structural foundations and slab for 25 x 150-foot (8 x 46-meter) building enclosure and 20,000-gallon (75,708-liter) water storage tank— including excavation, reinforcing, concrete, and formwork	\$45,630	800	\$60	\$48,000	\$93,630
2	Structural foundation supports and footings for RMDS inside building—including reinforcing, concrete, and formwork	\$28,500	320	\$60	\$19,200	\$47,700
3	Pre-engineered 25 x 150 x 25-foot (8 x 46 x 8-meter) building enclosure with 15 x15-foot (6 x 6-meter) roll-up door fabrication and installation	\$75,000	640	\$60	\$38,400	\$113,400
4	Electrical and mechanical for lighting, floor drains and HVAC for building interior	\$10,300	240	\$60	\$14,400	\$24,700
5	Demolition work for removal of existing ash pumps and associated piping	NA	160	\$60	\$9,600	\$9,600
6	Mechanical installation costs for RMDS, on-site fabrication, new pump, piping and pipe support, and 20,000-gallon (75,708-liter) water storage tank installation (See Note 1)	\$140,102	4,950	\$60	\$297,000	\$437,102
7	Electrical power and controls installation costs for RMDS (See Note 2)	\$116,000	960	\$62.50	\$60,000	\$176,000
8	Mechanical installation project site management	NA	480	\$65	\$31,200	\$31,200
9	Electrical installation project site management	NA	240	\$65	\$15,600	\$15,600
10	Pre-engineering, permitting, balance-of-plant engineering structural/mechanical/electrical					\$200,000
11	Utility contingency for project @ 20%					\$229,786
	TOTAL COST					\$1,378,718

Notes for Table 3-3

Note 1: Material costs do not include equipment and piping supplied by bottom ash handling system vendor. Material costs include one (1) 25-ton crane rental, scaffolding, welding materials for fabrication of RMDS, pipe hanger and pipe supports for RMDS, and all balance-of-plant piping for drainage and sump pits.

Note 2: Material costs include wiring, conduit junction boxes, two (2) combination starters for 200-horsepower (149-kilowatt) ash pump motors, two (2) combination starters for 200-horsepower (149-kilowatt) recirculation pumps, two (2) combination starters for 20-horsepower (15-kilowatt) sump pump motors, one (1) combination starter for 60-horsepower (45-kilowatt) HPU motor, and two (2) 50-horsepower (37-kilowatt) overflow return pumps. It is assumed that Plant 1 Unit A has sufficient space in an existing MCC for power equipment. However, there could be significant cost associated with MCC upgrades, if needed.

RMDS = remote mechanical drag system

HVAC = heating, ventilation, and air conditioning

HPU = hydraulic power unit

MCC = motor control center

The balance-of-plant material and labor cost estimates were prepared using the pay rate of an approved Company contractor, who has performed capital project work at Plant 1 in the past. The contractor in question participated in this cost evaluation project, was present for the site tours, and provided input at subsequent meetings with Company engineering personnel. The cost estimates and person-hours are based on the contractor's experience with bottom ash handling retrofits and familiarity with the project site.

Despite the time and effort put into these cost estimates, they—and the evaluations that accompany them—should be considered Class 5 cost estimates. This is because preliminary-phase input from power plant personnel regarding location and/or system evaluation was limited and unforeseen variables at the site will likely determine final costs. Specifically, the evaluations are based only on Company engineering requests and magnitude-of-cost estimates for the following:

- Excavation and site work
- Concrete for foundations, slab, and footings
- Mechanical installation (on-site fabrication of RMDS, installation of RMDS, equipment, piping and pipe supports, heating and ventilation for the pre-engineered building that will cover the RMDS)
- Electrical installation, including power for equipment, heating, and lighting
- Instrumentation and control (I&C)
- Subcontractor labor rates
- Balance-of-plant engineering services during pre-engineering phase, permitting phase, design phase, and construction phase
- Cost of utility contingency for the project

Assumptions in Capital Cost Evaluation

- The system design is as described in the key flow diagram (Figure 3-1)
- Weather conditions will not require work stoppage
- Cost escalation is not included
- Labor rates are equivalent to those of an approved Company contractor
- Soil conditions are assumed to be at least 1.5 kips per square foot (72 kilopascals) for footings and foundations
- The RMDS and the building enclosing it can be installed at the current design location.
- The building will be heated to 45 °F (7 °C) using an electric heater
- The RMDS will be locally controlled via a vendor-supplied panel
- Plant 1 Unit A has existing electrical equipment adequate to power the system
- There is no underground piping or utility interference
- The bottom ash equipment vendor has a +/- 20% factor in the cost estimate
- The estimate does not include sales tax, as the project is assumed to be exempt from sales tax
- The estimate does not include permitting for construction

- The site is balanced cut/fill
- The estimate does not include temporary fencing
- Curbs and gutters are not required for roads or parking areas
- Frost depth is assumed to be 48 inches (122 centimeters)

RMDS Retrofit Estimated Operations and Maintenance Costs

Estimated O&M costs for the RMDS include labor, dewatered ash disposal, power use, and maintenance. These are costs to be incurred after installation, since exact project costs will depend on the final design, landfill disposal site, and staffing for the system at Plant 1.

The proposed RMDS installation is essentially an addition to the existing bottom ash handling system. Because the new system will tie into bottom ash hoppers and clinker grinders that remain in place, there will be no additional O&M costs for these components. Replacing existing ash pumps rated at 800 horsepower (597 kilowatts) with new pumps rated at 530 horsepower (395 kilowatts) (Table 3-4) will offer a notable reduction in O&M costs.

**Table 3-4
Plant 1 Unit A—RMDS Retrofit Estimated Annual O&M Costs**

Item	Annual O&M Cost Equation	Estimated Annual Cost
Labor	Cost = 1 Operator * \$100,000/year where: Operators = 1 for each day of pulling bottom ash + 1 for maintenance (2 total)	\$200,000
Utilities	Cost for 530-hp HPU = [(3 hours*530 hp)*(0.7457 kWh)*(\$0.02 per kWh)]*340 days/year	\$8,063
Bottom ash disposal	Cost = [70 tons/day] * [\$14/ton * 340 days/year]	\$433,200
Maintenance	Cost = 5% * Total installed equipment cost where: \$3,750,000 * 0.05	\$187,500
Drag chain replacement	Estimated with labor @ \$300,000, once every 5 years	\$60,000
	TOTAL ESTIMATED ANNUAL O&M COSTS	\$888,763

O&M = operations and maintenance
 530 horsepower (hp) = 396 kilowatts
 HPU = hydraulic power unit
 kWh = kilowatt-hour
 1 ton = 907.18 kilograms
 70 tons/day = 63,503 kilograms/day

RMDS Retrofit Water Balance

During normal operation, it is assumed that bottom ash conveyed from the RMDS has a moisture content of 20% by weight. It is also assumed that roughly 5% of the makeup water that is added

to the RMDS will be lost to evaporation. Thus, the RMDS will require approximately 125 gallons of makeup water per minute (8 liters per second) to replenish water that leaves in the ash and losses due to evaporation. After each batch of bottom ash is sluiced, high-pressure recirculation pumps drive the remaining conveying water and added makeup water back to the bottom ash hoppers. Given the estimated number of batches per day and the required duration of each sluicing operation, the RMDS will run 360 minutes per day. Thus, it will require 45,000 gallons (170,344 liters) of water per day of operation. Figure 3-4 illustrates the RMDS water balance for Plant 1 Unit A.

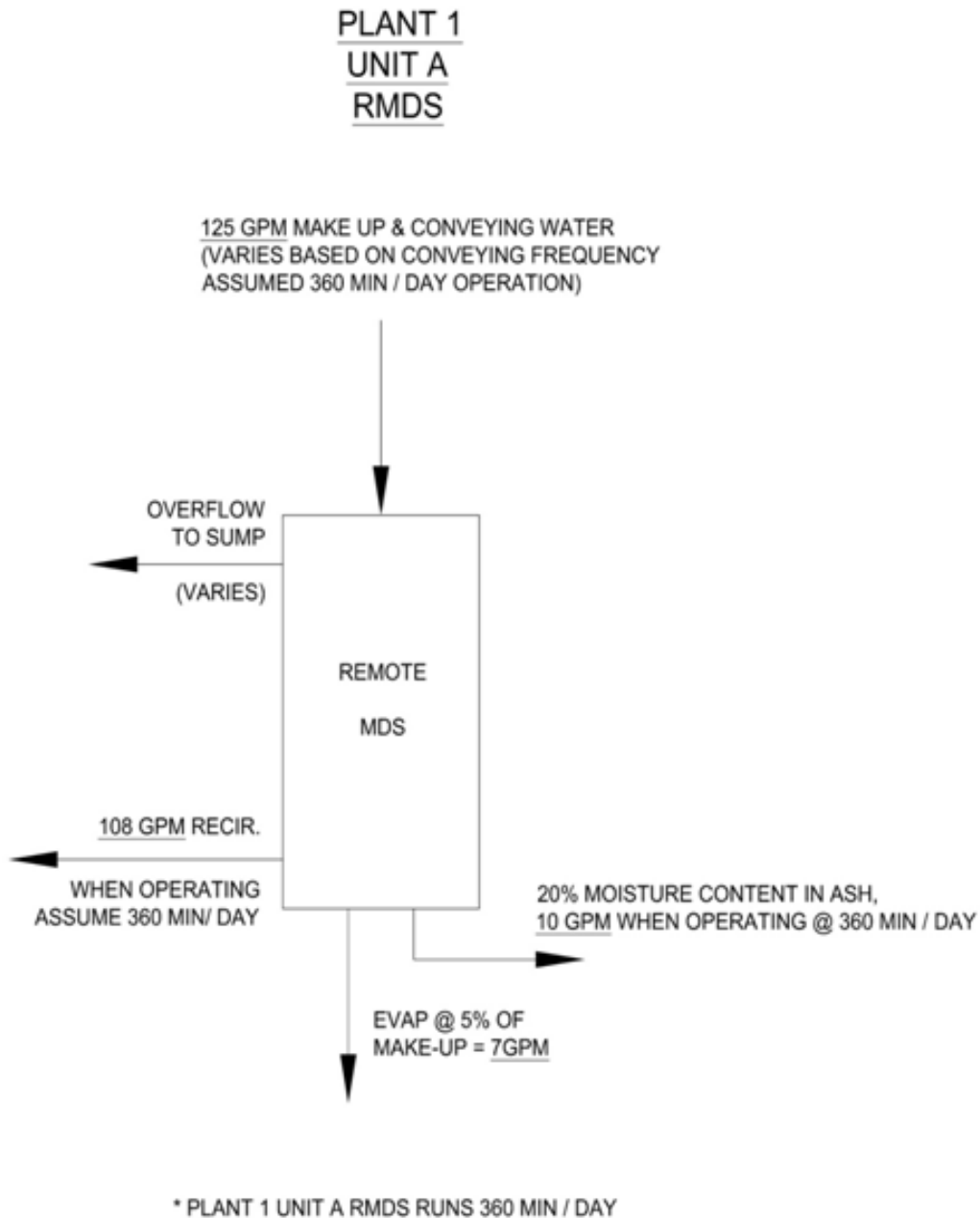


Figure 3-4
Plant 1 Unit A—RMDS Retrofit Water Balance

RMDS Retrofit Proposed Schedule

The proposed schedule for the RMDS retrofit at Plant 1 Unit A (Table 3-5) is based on vendor information for engineering, fabrication, and delivery of the new equipment. The schedule also incorporates input from The Company's approved contractor.

Table 3-5
Plant 1 Unit A—RMDS Retrofit Proposed Schedule

Item	Duration
Vendor engineering, fabrication, and delivery	52 weeks
Balance-of-plant engineering and design	18 weeks
Site preparation	3 weeks
On-site mechanical and structural fabrication	4 weeks
Installation	14 weeks
Plant outage	3 weeks

4

PLANT 2 UNITS A AND B

This section presents a proposed retrofit for the existing bottom ash handling system at Plant 2 Units A and B. A brief description of the existing system is given in Tables 4-1 and 4-2.

Site Description

Unit: A

Owner: A Midwestern Utility Company

Capacity: 512 MW

Existing Bottom Ash Handling System: Bottom ash is sluiced to ash pond

Unit: B

Owner: A Midwestern Utility Company

Capacity: 512 MW

Existing Bottom Ash Handling System: Bottom ash is sluiced to ash pond

Table 4-1

Plant 2 Units A and B—Description of Existing Bottom Ash Handling System

Unit	System Type	Bottom Ash Water Use (gallons/day)	Water Source	Operation (hours/day)	Operation (days/year)	Bottom Ash Handling (tons/day)	Economizer Ash Handling
A	Ash pond	369,000	Intake 5% Ash pond recirculated 95%	3	330	100	See Table 4-2
B	Ash pond	369,000	Intake 5% Ash pond recirculated 95%	3	330	100	See Table 4-2

Water use = water pumped (make-up water plus recirculated water)

369,000 gallons/day = 1.40 million liters/day

100 tons/day = 90,708 kilograms/day

**Table 4-2
Plant 2 Units A and B—Description of Existing Economizer Ash Handling System**

Unit	System Type	Bottom Ash Water Use (gallons/day)	Water Source	Operation (hours/day)	Operation (days/year)	Ash Handling (tons/day)
A	Ash pond	63,000	Same as bottom ash	3	330	16
B	Ash pond	63,000	Same as bottom ash	3	330	16

Water use = water pumped (make-up water plus recirculated water)
 63,000 gallons/day = 238,481 liters/day
 16 tons/day = 14,515 kilograms/day

Currently, Plant 2 handles bottom ash wet and manages it in an ash pond. The system collects bottom ash in individual wet impounded hoppers located below each unit, moves it via hydraulic jet pumps to clinker grinders where it is processed, and pumps the processed ash to a pond through wear-resistant ash sluice piping. The sluicing system—which runs for 3 hours a day in 1-hour batches—requires notable pumping resources but efficiently returns 95% of the needed water back from the pond. The system also handles economizer ash and mill pyrites by tying dedicated sluice lines for these byproducts from each unit into the main lines running to the pond.

The system in service at Plant 2 has experienced high maintenance and repair costs due to excessive wear on equipment, such as clinker grinders and wet bottom ash hoppers. The routine maintenance cost to maximize the performance of jet pumps and sluice nozzles is becoming prohibitive. Over the years, maintenance work has resulted in partial replacement of the clinker grinders and piping, while the bottom ash hoppers and ash sluice pumps remain original to the system.

Proposed MDS Retrofit

The proposed retrofit for the bottom ash handling system at Unit A, as well as Unit B, is a below-boiler MDS. This choice requires ample space under and around the boilers to accommodate two large MDS sections: an upper watertight trough to collect the ash and a lower section to house the drag chain return. Investigators and on-site engineers determined that an MDS would fit under each boiler while leaving enough room in the boiler building to fabricate MDS components, weld the MDS to the boiler seal plates, install a transition hopper lined with refractory, and install an inclined conveyor.

Although Unit A and B occupy the same boiler building, the retrofit will require the purchase and installation of two separate systems, since an MDS cannot be shared between multiple units. Therefore, one complete MDS will be installed under each unit's boiler and each MDS will be sized to collect, dewater, and transfer the specific amount of ash generated by its unit (see Figures 4-1 and 4-2).

Because the dewatered bottom ash from Units A and B will be deposited in two different outside locations, ash-to-truck transfer will require two separate areas. The new bottom ash storage and

truck loading area for Unit A will be located south of the Unit A boiler, just outside the south plant wall in a new enclosure. The new bottom ash storage area (covered by a building) and truck loading area for Unit B will be located north of Unit B, just outside the north plant wall (Figure 4-3). This arrangement will allow the front-end loaders to access the new bottom ash storage locations from the north or south to facilitate loading the trucks when ash is pulled.

While installing an MDS on each unit requires high initial construction cost and effort, the major benefit of the MDS retrofit is that it replaces the existing bottom ash handling equipment, especially the pumps. The retrofit will lower long-term maintenance costs for the plant, while also reducing operating costs due to smaller pumps and reduced water use. However, the retrofit will require a long outage period for each MDS installation. Demolition work to remove all existing bottom ash handling equipment (including ash hoppers, pumps, and clinker grinders) will require a one-time extended outage, with the cost of lost revenue incurred by The Company.

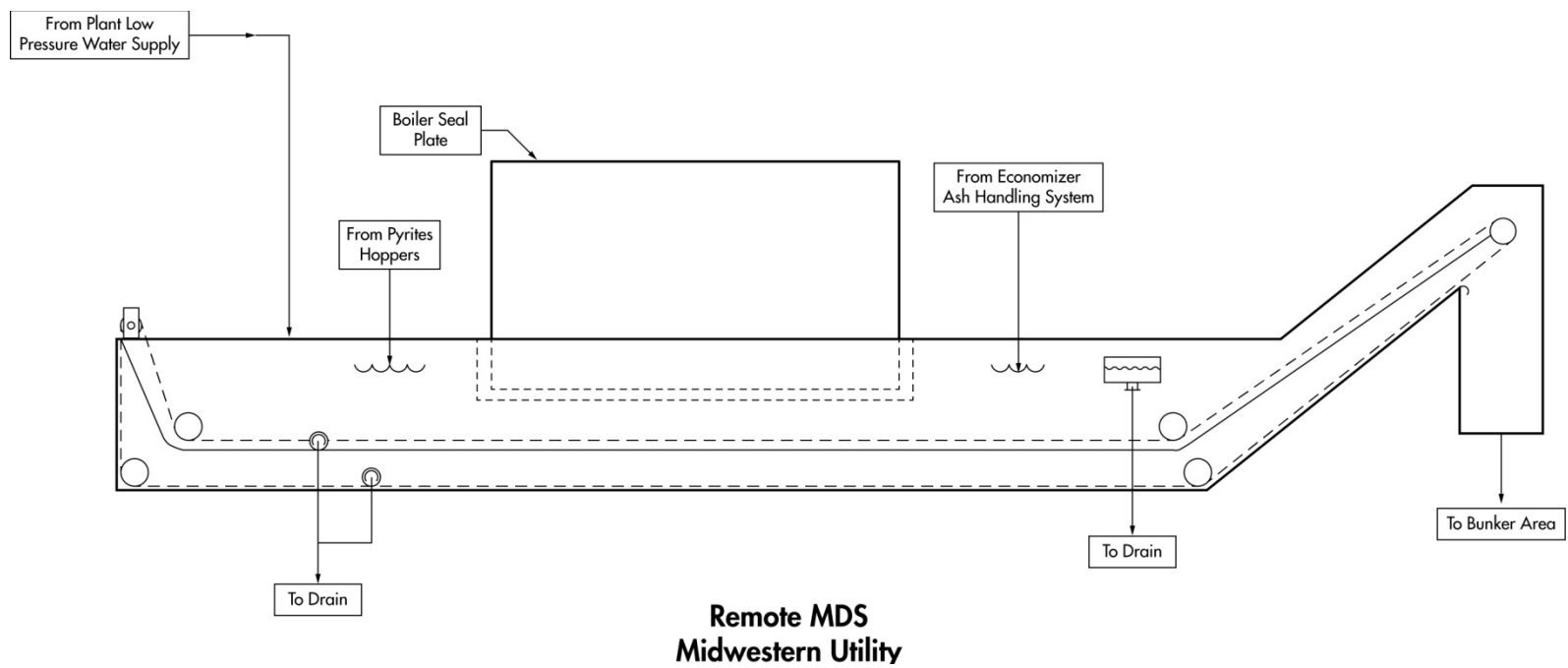
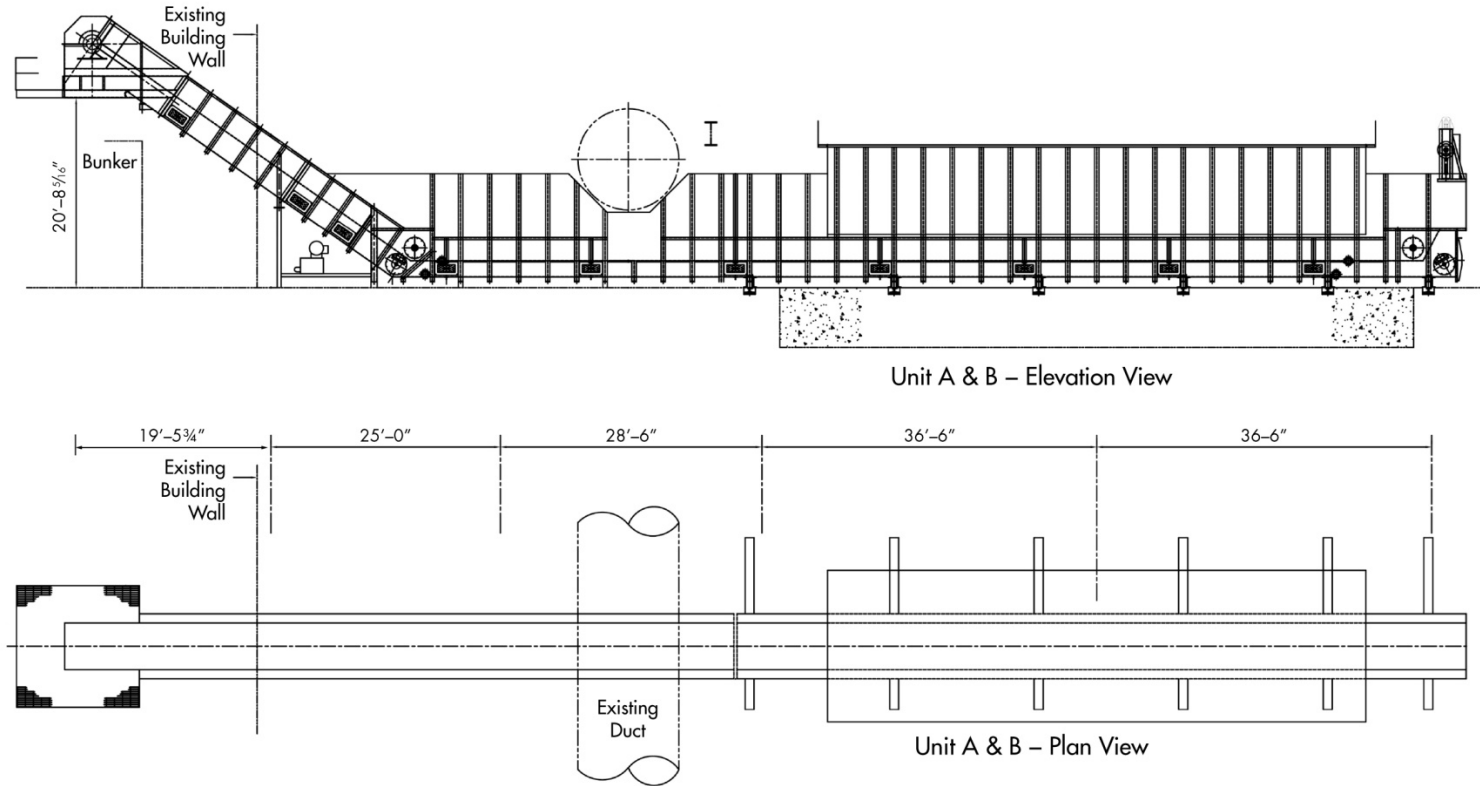


Figure 4-1
Plant 2 Units A and B—MDS Retrofit Key Flow Diagram



Preliminary Layout Drawings
MDS
Plant 2
Units A & B

Figure 4-2
Plant 2 Units A and B—MDS Retrofit Plan and Elevation View

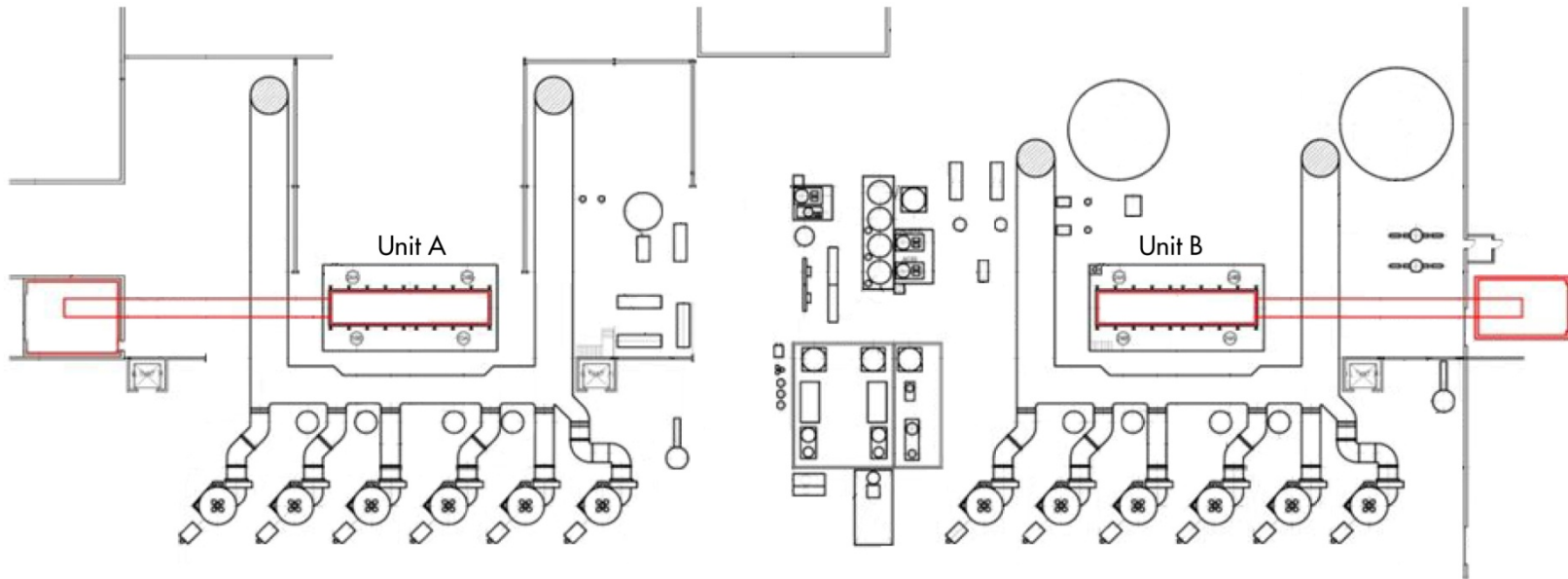


Figure 4-3
Plant 2 Units A and B—MDS Retrofit Location Plan

Other Technologies Evaluated for Retrofit

Several bottom ash handling systems were evaluated for potential implementation at Plant 2 Units A and B—notably an RMDS that could be shared by the two units. However, the cost of equipment and additional material supplied by the vendor, plus the desire to remove existing hoppers and pumps due to their high maintenance, made an RMDS retrofit more expensive than the proposed under-boiler MDS.

Investigators and on-site engineers also reviewed a PDT system, but declined to recommend it because the rated capacities of Units A and B were well above the proven limit of 200 MW for this technology. Concerns that large pieces of material could fall from higher boiler elevations to damage or clog the PDT system also swayed opinion.

MDS Retrofit Requirements and Capital Cost Evaluation

Table 4-3 lists vendor-supplied equipment to be purchased for this retrofit. The total cost for the new system reflects vendor engineering, system parts and equipment fabrication, and delivery. The main upper and lower troughs will be shipped in pieces. The number of pieces will depend on vendor preference, as well as site and delivery conditions at the time of purchase.

Table 4-3
Plant 2 Units A and B—MDS Retrofit Equipment Supplied by Bottom Ash Handling System Vendor

Quantity	Unit	Major Vendor-supplied Equipment
2	Each	MAX®-type MDS
2	Each	Hydraulic power unit with motor
2	Each	Maintenance access platforms (grating/stairs/handrail)
2	Each	MDS local control panel
2	Each	MDS local jog station
1	Lot	Instrumentation (level probes, speed switches, temperature transmitters, pressure/flow transmitters)
1	Each	Hydraulic power unit with motor (60 horsepower [45 kilowatts])
1	Lot	Engineering/design/field support
		TOTAL COST: \$4,300,000

MDS = mechanical drag system

Table 4-4 shows estimated balance-of-plant material, labor, and engineering costs for the proposed MDS retrofit at Plant 2 Unit A; Table 4-5 shows identical costs at Unit B.

**Table 4-4
Plant 2 Unit A—MDS Retrofit Estimated Balance-of-plant Material, Labor, and Engineering Costs**

Item	Description	Total Material Cost	Total Installation Person-Hours	Average Cost Per Person-Hour	Total Labor Cost	Total Cost
1	Structural foundations and slab for 25 x 30-foot (8 x 9-meter) building enclosure and 20,000-gallon (75,708-liter) water storage tank—including excavation, reinforcing, concrete, and formwork	\$42,530	410	\$60	\$24,600	\$67,130
2	Demolition of existing bottom ash hoppers, clinker grinders, structural supports, ash pumps, and piping	\$50,000	960	\$60	\$57,600	\$107,600
3	Structural foundation supports and ash pit fill for MDS under boilers A and B—including reinforcing, concrete, and formwork	\$13,500	240	\$60	\$14,400	\$27,900
4	Pre-engineered 25 x 30 x 25-foot (8 x 9 x 8-meter) building enclosure with 150 x 15-foot (46 x 6-meter) roll up door fabrication and installation	\$25,000	160	\$60	\$9,600	\$34,600
5	Electrical and mechanical for lighting, floor drains and HVAC for building interior	\$8,000	160	\$60	\$9,600	\$17,600
6	Mechanical installation costs for MDS, on-site fabrication, dewatering ramp, boiler plate seal, and conveyor support Installation (See Note 1)	\$200,400	3,800	\$60	\$228,000	\$428,400
7	Electrical power and controls installation costs for MDS system (See Note 2)	\$85,000	800	\$62.50	\$50,000	\$135,000
8	Mechanical installation project site management	NA	480	\$65	\$31,200	\$31,200
9	Electrical installation project site management	NA	400	\$65	\$26,000	\$26,000
10	Pre-engineering, permitting, balance-of-plant engineering structural/mechanical/electrical					\$210,000
11	Utility contingency for project @ 20%					\$217,086
	TOTAL COST UNIT A					\$1,302,516

Notes for Table 4-4

Note 1: Material costs do not include equipment supplied by bottom ash handling system vendor. Material costs include two (2) lift rentals, scaffolding, welding materials for fabrication of MDS, fabrication and installation of boiler plate seal, supports for new MDS ramps, and all-balance-of-plant piping for drainage and sump pits.

Note 2: Material costs include wiring, conduit junction boxes, one (1) combination starter for 60-horsepower (45-kilowatt) HPU motor. It is assumed that Plant 2 Unit A has sufficient space in an existing MCC for equipment.

HVAC = heating, ventilation, and air conditioning

MDS = mechanical drag system

HPU = hydraulic power unit

MCC = motor control center

**Table 4-5
Plant 2 Unit B—MDS Retrofit Estimated Balance-of-plant Material, Labor, and Engineering Costs**

Item	Description	Total Material Cost	Total Installation Person-Hours	Average Cost Per Person-Hour	Total Labor Cost	Total Cost
1	Structural foundations and slab for 25 x 30-foot (8 x 9-meter) building enclosure and 20,000-gallon (75,708-liter) water storage tank—including excavation, reinforcing, concrete, and formwork	\$42,530	410	\$60	\$24,600	\$67,130
2	Demolition of existing bottom ash hoppers, clinker grinders, structural supports, ash pumps, and piping	\$50,000	960	\$60	\$57,600	\$107,600
3	Structural foundation supports and ash pit fill for MDS under boilers A and B—including reinforcing, concrete, and formwork	\$13,500	240	\$60	\$14,400	\$27,900
4	Pre-engineered 25 x 30 x 25-foot (8 x 9 x 8-meter) building enclosure with 150 x 15-foot (46 x 5-meter) roll up door fabrication and installation	\$25,000	160	\$60	\$9,600	\$34,600
5	Electrical and mechanical for lighting, floor drains and HVAC for building interior	\$8,000	160	\$60	\$9,600	\$17,600
6	Mechanical installation costs for MDS, on-site fabrication, dewatering ramp, boiler plate seal, and conveyor support Installation (See Note 1)	\$200,400	3,800	\$60	\$228,000	\$428,400

Item	Description	Total Material Cost	Total Installation Person-Hours	Average Cost Per Person-Hour	Total Labor Cost	Total Cost
7	Electrical power and controls installation costs for MDS system (See Note 2)	\$85,000	800	\$62.50	\$50,000	\$135,000
8	Mechanical installation project site management	NA	480	\$65	\$31,200	\$31,200
9	Electrical installation project site management	NA	400	\$65	\$26,000	\$26,000
10	Pre-engineering, permitting, balance-of-plant engineering structural/mechanical/electrical					\$210,000
11	Utility contingency for project @ 20%					\$217,086
	TOTAL COST UNIT B					\$1,302,516

Notes for Table 4-5

Note 1: Material costs do not include equipment supplied by bottom ash handling system vendor. Material costs include two (2) lift rentals, scaffolding, welding materials for fabrication of MDS, fabrication and installation of boiler plate seal, supports for new MDS ramps, and all-balance-of plant piping for drainage and sump pits.

Note 2: Material costs include wiring, conduit junction boxes, one (1) combination starter for 60-horsepower (45-kilowatt) HPU motor. It is assumed that Plant 2 Unit A has sufficient space in an existing MCC for equipment.

HVAC = heating, ventilation, and air conditioning

MDS = mechanical drag system

HPU = hydraulic power unit

MCC = motor control center

The balance-of-plant material and labor cost estimates were prepared using the pay rate of an approved Company contractor, who has performed capital project work at Plant 2 in the past. The contractor in question participated in this cost evaluation project, was present for the site tours, and provided input at subsequent meetings with Company engineering personnel. The cost estimates and person-hours are based on the contractor's experience with bottom ash handling retrofits and familiarity with the project site.

Despite the time and effort put into these cost estimates, they—and the evaluations that accompany them—should be considered Class 5 cost estimates. This is because preliminary-phase input from power plant personnel regarding location and/or system evaluation was limited and unforeseen variables at the site will likely determine final costs. Specifically, the evaluations are based only on Company engineering requests and magnitude-of-cost estimates for the following:

- Concrete for foundations and slab footings of buildings
- Concrete structural fill of the existing two ash pits, and MDS supports
- Mechanical installation (on-site fabrication of MDS and boiler plate seal, installation of MDS and boiler plate seal, installation of equipment, ramp and conveyor supports, heating and ventilation for the pre-engineered ash storage building)
- Excavation and site work
- Electrical installation, including power for equipment, heating, and lighting
- Instrumentation and control (I&C)
- Subcontractor labor rates
- Balance-of-plant engineering services during pre-engineering phase, permitting phase, design phase, and construction phase
- Cost of utility contingency for the project

Assumptions in Capital Cost Evaluation

- The system design is as described in the key flow diagram (Figure 4-1)
- Labor rates are equivalent to those of an approved Company contractor
- The required outage will be 12 weeks per Unit
- Weather conditions will not require work stoppage
- Cost escalation is not included
- Soil conditions are assumed to be at least 1.5 kips per square foot (72 kilopascals) for footings and foundations
- The MDS and the building enclosing it can be installed at the current design location
- The building will be heated to 45 °F (7 °C) using an electric heater
- The MDS will be locally controlled via vendor-supplied panel
- Plant 2 Units A and B have existing electrical equipment adequate to power the system.
- There is no underground piping or utility interference
- The bottom ash equipment vendor has a +/- 20% factor in the cost estimate

- The estimate does not include sales tax, as the project is assumed to be exempt from sales tax
- The estimate does not include permitting for construction
- The estimate does not include temporary fencing
- Curbs and gutters are not required for roads or parking areas

MDS Retrofit Estimates Operations and Maintenance Costs

Estimated O&M costs for the MDS include labor, dewatered ash disposal, power use, and maintenance. These are costs to be incurred after installation, since exact project costs will depend on the final design, landfill disposal site, and staffing for the system at Plant 2.

The proposed MDS installation will replace the existing bottom ash handling system. Replacing existing ash pumps with one new HPU per MDS will offer a notable reduction in O&M costs (Table 4-6). In operation, the two new HPUs will total 120 horsepower (90 kilowatts).

**Table 4-6
Plant 2 Units A and B—MDS Retrofit Estimated Annual O&M Costs**

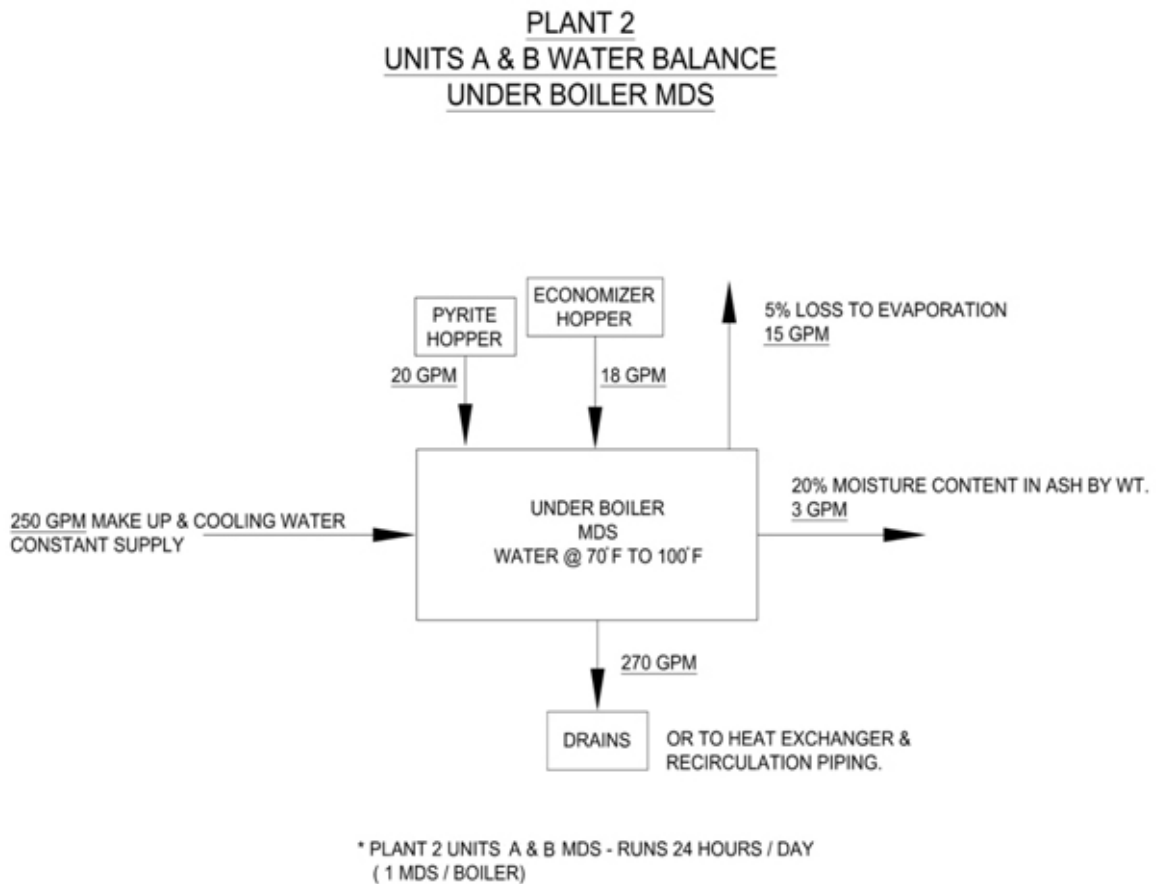
Item	Annual O&M Cost Equation	Estimated Annual Cost
Labor	Cost = 2 Operators * \$100,000/year where: Operators = 1 per Unit for each day of pulling bottom ash + 1 per Unit for maintenance (4 total)	\$400,000
Utilities	Cost for 60-hp HPU = [(24 hours*60 hp)*(0.7457 kWhr)*(\$0.02 per kWhr)]*330 days/year	\$7,087
Bottom ash disposal	Cost = [200 tons/day] * [\$14/ton * 330 days/year]	\$924,000
Maintenance	Cost = 5% * Total installed equipment cost (Units A and B combined) where: \$4,300,000 * 0.05	\$215,000
Drag chain replacement	Estimated with labor @ \$300,000, once every 3 years per Unit per chain	\$200,000
	TOTAL ESTIMATED ANNUAL O&M COSTS	\$1,746,087

O&M = operations and maintenance
 60 horsepower (hp) = 45 kilowatts
 HPU = hydraulic power unit
 kWh = kilowatt-hour
 1 ton = 907.18 kilograms
 200 tons/day = 181,437 kilograms/day

MDS Retrofit Water Balance

During normal operation, each MDS will require approximately 250 gallons of makeup water per minute (16 liters per second) to replace water removed with the conveyed ash (about 20% by weight) and to keep basin water temperature within an acceptable range of 70 to 100 °F (21 to

38 °C). When the volume of makeup water exceeds the volume of water removed with the ash, the MDS overflows into an installed overflow box. As hot water from the MDS flows into the overflow box and is replaced by cool makeup water, the temperature of the basin remains within the acceptable range. Since the overflow water is hot, it cannot be recirculated back into the MDS but must be sent down the plant’s drain. Heat exchangers can be installed (at an added cost) to cool the overflow water so that it can be recirculated instead of discarded. Figure 4-4 illustrates the MDS water balance for Plant 2 Units A and B.



**Figure 4-4
Plant 2 Units A and B—MDS Retrofit Water Balance**

MDS Retrofit Proposed Schedule

The proposed schedule for the MDS retrofit at Plant 2 Units A and B (Table 4-7) is based on vendor information for engineering, fabrication, and delivery of the new equipment. The schedule also incorporates input The Company’s approved contractor.

Table 4-7
Plant 2 Units A and B—MDS Retrofit Proposed Schedule

Item	Duration
Vendor engineering, fabrication, and delivery	65 weeks
Balance-of-plant engineering and design	18 Weeks
Site preparation	3 weeks per Unit
On-site mechanical and structural fabrication	5 weeks per Unit
Demolition and installation	12 weeks per Unit
Plant outage	12 weeks per Unit

5

PLANT 3 UNIT A

This section presents a proposed retrofit for the existing bottom ash handling system at Plant 3 Unit A. A brief description of the existing system is given in Table 5-1.

Site Description

Unit: A

Owner: A Midwestern Utility Company

Capacity: 275 MW

Existing Bottom Ash Handling System: Bottom ash is sluiced to ash pond

Table 5-1
Plant 3 Unit A—Description of Existing Bottom Ash Handling System

System Type	Bottom Ash Water Use (gallons/day)	Water Source	Operation (hours/day)	Operation (days/year)	Bottom Ash Handling (tons/day)	Economizer Ash Handling
Ash pond	447,250	Intake 100%	6	290	30	Handled wet with bottom ash

Water use = water pumped (make-up water plus recirculated water)
447,250 gallons/day = 1.69 million liters/day
30 tons/day = 27,216 kilograms/day

Currently, Plant 3 Unit A handles bottom ash wet, sending it to an ash pond. Sized to meet the daily demands at Unit A, the bottom ash handling system consists of two 600-horsepower (448-kilowatt) ash sluice pumps, two wet impounded bottom ash hoppers, two clinker grinders, two ash sluice nozzles (which move ash from the hoppers to the clinker grinders), hydraulic jet pumps, and wear-resistant sluice piping leading to the pond. Because the bottom ash hoppers have limited storage capacity, bottom ash at Unit A must be cleared six times per day in 1-hour sluicing batches. Unlike bottom ash handling at Plant 2 Units A and B, water does not recirculate back from the pond to the wet impounded hoppers. Therefore, the demand for makeup water is relatively high. Economizer ash is also collected and mixed with bottom ash in the hoppers before being sent to the pond.

The bottom ash handling system currently in service at Plant 3 Unit A is running efficiently, thanks to a policy of routine maintenance and refurbishment. In addition to routine maintenance, recent upgrades have installed new header systems to reduce cavitation in the sluice pumps and rebuilt the clinker grinders. The Company is considering a new bottom ash handling system to change the water management strategy at Plant 3 Unit A.

Proposed RMDS Retrofit

After a thorough evaluation, investigators proposed that an RMDS would be the best retrofit for handling bottom ash at Plant 3 Unit A. The RMDS would act as an addition to the wet impounded bottom ash hoppers already present and in good working condition at Unit A. In the retrofit design, one RMDS would collect and dewater bottom ash slurry from the bottom ash hoppers while operating in a closed loop with respect to water use (Figures 5-1 and 5-2).

The RMDS operates in a closed loop because its basin is designed with enough capacity to store bottom ash sluice water for the duration of the dewatering cycle. At the end of the dewatering cycle, high-pressure recirculation pumps send the remaining sluice and makeup water from the RMDS basin back to the wet impounded bottom ash hoppers under the boiler. Low-pressure recirculation pumps could also send water from the RMDS basin back to the boiler building for seal trough and wall cooling. Finally, because the retrofit design will allow Unit A to retain much of its existing equipment, plant personnel could use the high- and low-pressure water pumps already in place to fill the bottom ash hopper with RMDS basin water during upset conditions.

The RMDS basin has a larger capacity for water storage than the bottom ash hoppers under the boiler of Unit A. Thus, adding makeup water to the RMDS basin to control temperature and ensure minimum probe-monitored water levels will cause the bottom ash hoppers to overflow when the basin water recirculates. To keep this overflow from being sent down the drains in the boiler building, a surge tank will be installed near the bottom ash hoppers. Slurry pumps will be provided as needed to pump overflow water from the new surge tank back to the RMDS.

The RMDS will be located outside of the east plant wall near the existing dry fly ash silo, along the road that currently serves as the fly ash unloading service area (Figure 5-3). Using this road allows front-end loaders to approach the new bottom ash building covering the RMDS from the south and load trucks in the existing loading area. Trucks loaded with bottom ash will drive north along the road, stopping briefly to weigh in at the truck scale also used by departing trucks loaded with dry fly ash.

Installation of an RMDS will satisfy the key customer requirement that outage times for system interconnects be very short. A newly purchased RMDS can be delivered, installed, and partly fabricated while the existing unit and bottom ash handling system are in operation.

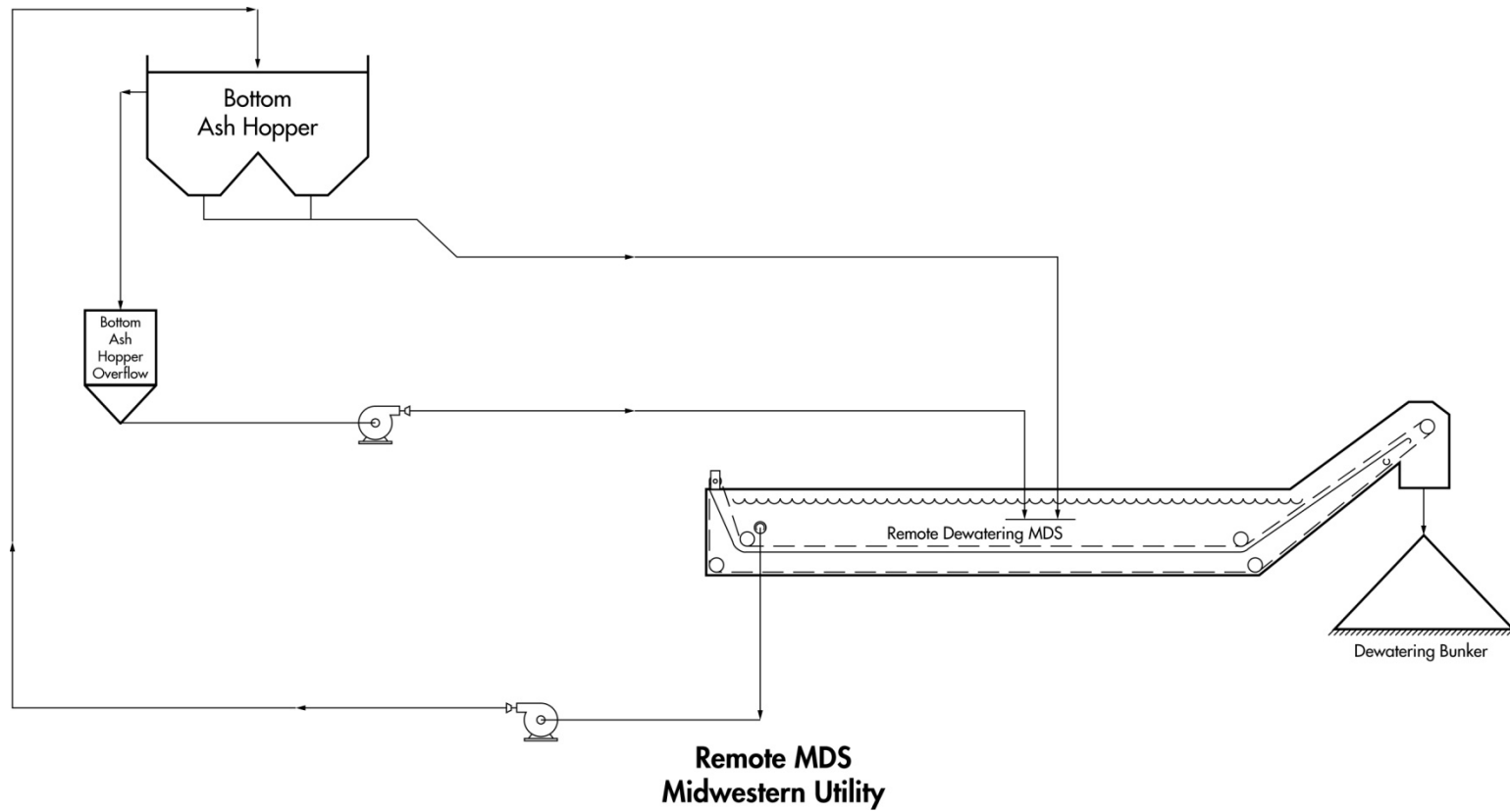
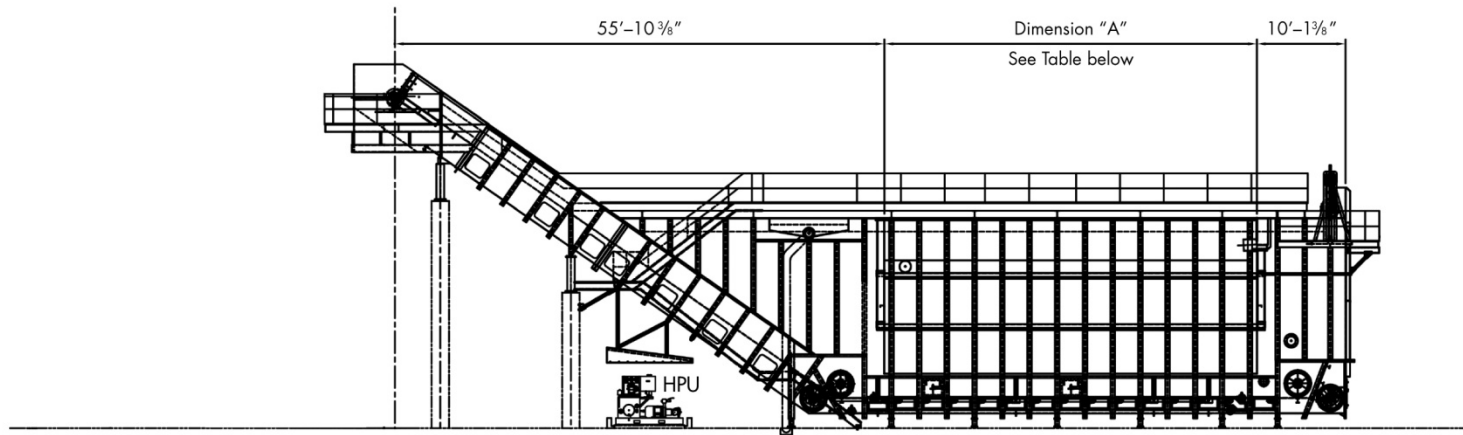
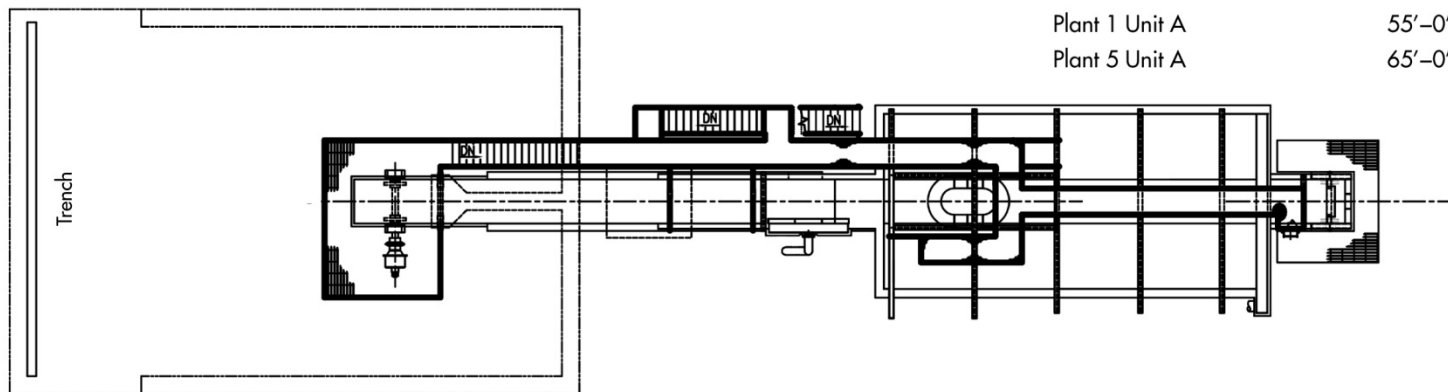


Figure 5-1
Plant 3 Unit A—RMDS Retrofit Key Flow Diagram



Plant & Unit	Dimension "A"
Plant 4 Units A & B	45'-0"
Plant 3 Unit A	45'-0"
Plant 1 Unit A	55'-0"
Plant 5 Unit A	65'-0"



**Wet to Dry Conversion
Remote Mechanical Drag System
Preliminary General Arrangement**

**Figure 5-2
Plant 3 Unit A—RMDS Retrofit Plan and Elevation View**

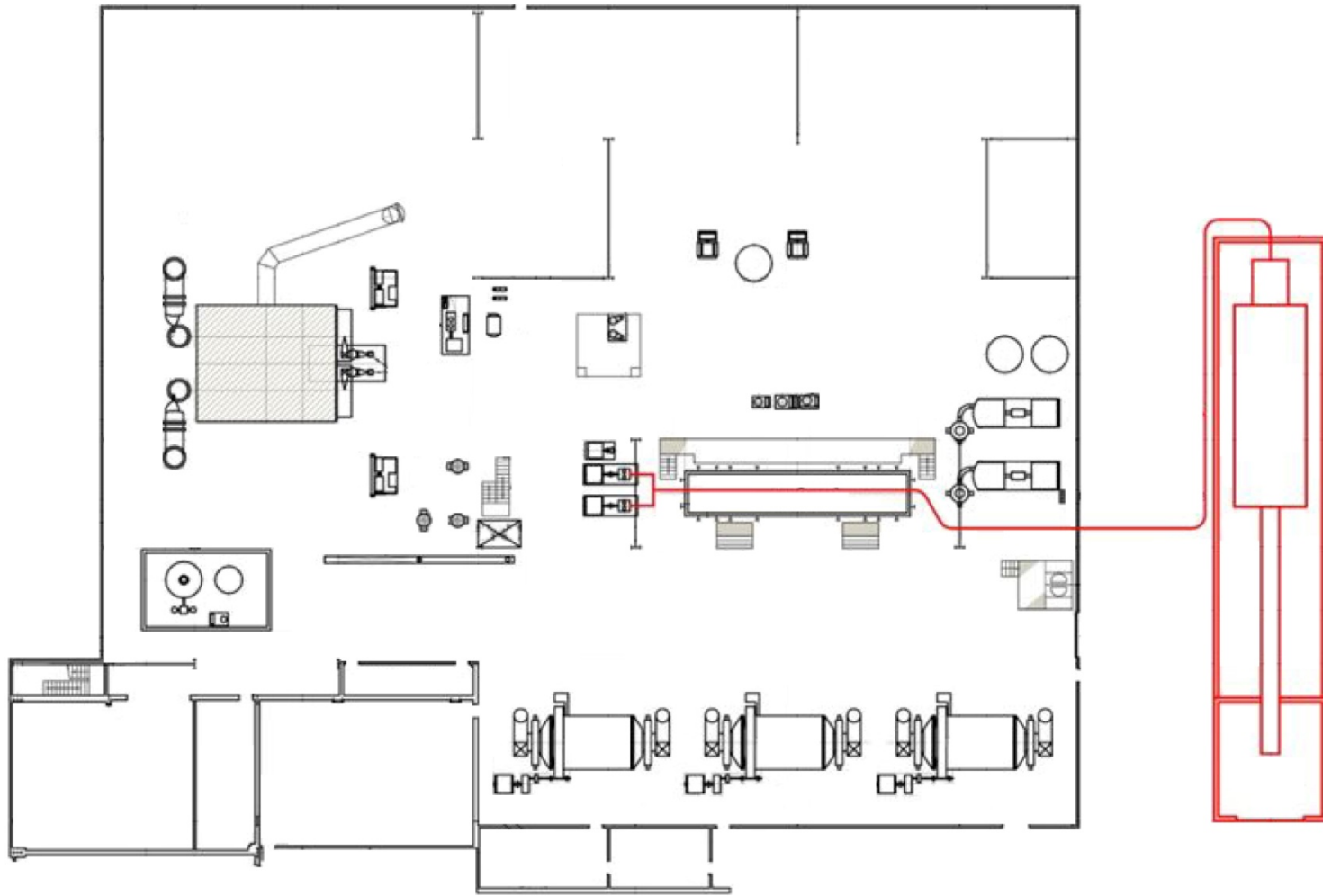


Figure 5-3
Plant 3 Unit A—RMDS Retrofit Location Plan

Other Technologies Evaluated for Retrofit

Several bottom ash handling systems were evaluated for potential implementation at Plant 3 Unit A. A preliminary review confirmed that the minimum space needed for MDS installation was unavailable. An MDS requires space under the boiler for equipment installation and space in the area around the boiler for component fabrication. At Plant 3 Unit A, the MDS dewatering ramp and/or conveyor transport could run through a mezzanine east of the boiler, but it would be too complicated and expensive to alter heavy structural steel obstructing this path through the boiler building.

Investigators also reviewed a PDT system as a retrofit option. A preliminary evaluation revealed that a PDT system would be too expensive, compared to an RMDS, because it would require purchase of a new bottom ash silo and mixer, and creation of a new load-out area. Furthermore, since the existing wet impounded bottom ash hoppers and sluice pumps were in good condition, it would be uneconomical to remove them so that dry hoppers could be installed.

RMDS Retrofit Requirements and Capital Cost Evaluation

Table 5-2 lists vendor-supplied equipment to be purchased for this retrofit. The total cost for the new system reflects vendor engineering, system parts and equipment fabrication, and delivery. Because of its size and weight, the RMDS must be shipped in pieces. The number of pieces would depend on vendor preference, as well as site and delivery conditions at the time of purchase.

**Table 5-2
Plant 3 Unit A—RMDS Retrofit Equipment Supplied by Bottom Ash Handling System Vendor**

Quantity	Unit	Major Vendor-supplied Equipment
600	Feet	Bottom ash conveyor piping
1,200	Feet	CS Schedule 40 recirculation water piping
1	Lot	Required pipe supports, connections, expansion joints and fittings
2	Each	Low-pressure recirculation pump with motor (200 horsepower [149 kilowatts])
2	Each	High-pressure recirculation pump with motor (200 horsepower [149 kilowatts])
1	Each	RMDS
1	Each	Hydraulic power unit with motor (60 horsepower [45 kilowatts])
1	Lot	Maintenance access platform with grating, stairway, and handrails at RMDS
1	Each	RMDS local control panel
1	Each	RMDS local jog station
1	Lot	Instrumentation (level probes, speed switches, temperature transmitters, pressure/flow indicators)
2	Each	Sump pump with motor (20 horsepower [15 kilowatts])
2	Each	Bottom ash hopper overflow surge tank
2	Each	Overflow return pump with motor (50 horsepower [37 kilowatts])
1	Each	Engineering/design/field support
		TOTAL COST: \$3,750,000

CS = commercial standard

RMDS = remote mechanical drag system

1 foot = 0.305 meter

Table 5-3 shows estimated balance-of-plant material, labor, and engineering costs for the proposed RMDS retrofit at Plant 3 Unit A.

**Table 5-3
Plant 3 Unit A—RMDS Retrofit Estimated Balance-of-plant Material, Labor, and Engineering Costs**

Item	Description	Total Material Cost	Total Installation Person-Hours	Average Cost Per Person-Hour	Total Labor Cost	Total Cost
1	Structural foundations and slab for 25 x 130-foot (8 x 40-meter) building enclosure and foundation for 20,000-gallon (75,708-liter) water storage tank—including excavation, reinforcing, concrete and formwork	\$60,300	820	\$60	\$49,200	\$109,500
2	Structural foundation supports and footings for RMDS inside building—including reinforcing, concrete, and formwork	\$25,500	320	\$60	\$19,200	\$44,700
3	Pre-engineered 25 x 130 x 25-foot (8 x 40 x 8-meter) building enclosure with 15 x 15-foot (5 x 5-meter) roll-up door fabrication and installation	\$70,000	620	\$60	\$37,200	\$107,200
4	Electrical and mechanical for lighting, floor drains and HVAC for building interior	\$9,300	220	\$60	\$13,200	\$22,500
5	Demolition work for removal of existing ash pumps and associated piping	NA	160	\$60	\$9,600	\$9,600
6	Mechanical installation costs for RMDS, on-site fabrication, new pump, water tank, piping and pipe support installation (See Note 1)	\$122,100	4,200	\$60	\$252,000	\$374,100
7	Electrical power and controls installation costs for RMDS (See Note 2)	\$116,000	960	\$62.50	\$60,000	\$176,000
8	Mechanical installation project site management	NA	480	\$65	\$31,200	\$31,200
9	Electrical installation project site management	NA	240	\$65	\$15,600	\$15,600
10	Pre-engineering, permitting, balance-of-plant engineering structural/mechanical/electrical					\$200,000
11	Utility contingency for project @ 20%					\$202,320
	TOTAL COST					\$1,292,720

Notes for Table 5-3

Note 1: Material Costs do not include equipment and piping supplied by bottom ash handling system vendor. Material costs include one (1) 25-ton crane rental, scaffolding, welding materials for fabrication of RMDS, pipe hanger and pipe supports for RMDS and all balance-of-plant piping for drainage and sump pits.

Note 2: Material costs include wiring, conduit junction boxes, two (2) combination starters for 200-horsepower (149-kilowatt) ash pump motors, two (2) combination starters for 200-horsepower (149-kilowatt) recirculation pumps, two (2) combination starters for 20-horsepower (15-kilowatt) sump pump motors, one (1) combination starter for 60-horsepower (45-kilowatt) HPU motor, and two (2) 50-horsepower (37-kilowatt) overflow return pumps. It is assumed that Plant 3 has sufficient space in an existing MCC for power equipment.

RMDS = remote mechanical drag system

HVAC = heating, ventilation, and air conditioning

HPU = hydraulic power unit

MCC = motor control center

The balance-of-plant material and labor cost estimates were prepared using the pay rate of an approved Company contractor, who has performed capital project work at Plant 3 in the past. The contractor in question participated in this cost evaluation project, was present for the site tours, and provided input at subsequent meetings with Company engineering personnel. The cost estimates and person-hours are based on the contractor's experience with bottom ash handling retrofits and familiarity with the project site.

Despite the time and effort put into these cost estimates, they—and the evaluations that accompany them—should be considered Class 5 cost estimates. This is because preliminary-phase input from power plant personnel regarding location and/or system evaluation was limited and unforeseen variables at the site will likely determine final costs. Specifically, the evaluations are based only on Company engineering requests and magnitude-of-cost estimates for the following:

- Excavation and site work
- Concrete for foundations, slab, and footings
- Mechanical installation (on-site fabrication of RMDS, installation of RMDS, equipment, piping and pipe supports, heating and ventilation for the pre-engineered building that will cover the RMDS)
- Electrical installation, including power for equipment, heating, and lighting
- Instrumentation and control (I&C)
- Subcontractor labor rates
- Balance-of-plant engineering services during pre-engineering phase, permitting phase, design phase, and construction phase
- Cost of utility contingency for the project

Assumptions in Capital Cost Evaluation

- The system design is as described in the key flow diagram (Figure 5-1)
- Weather conditions will not require work stoppage
- Cost escalation is not included
- Labor rates are equivalent to those of an approved Company contractor
- Soil conditions are assumed to be at least 1.5 kips per square foot (72 kilopascals) for footings and foundations
- The RMDS and the building enclosing it can be installed at the current design location
- The building will be heated to 45 °F (7 °C) using an electric heater
- The RMDS will be locally controlled via a vendor-supplied panel
- Plant 3 Unit A has existing electrical equipment adequate to power the system
- There is no underground piping or utility interference
- The bottom ash equipment vendor has a +/- 20% factor in the cost estimate
- The estimate does not include sales tax, as the project is assumed to be exempt from sales tax
- The estimate does not include permitting for construction

- The site is balanced cut/fill
- The estimate does not include temporary fencing
- Curbs and gutters are not required for roads or parking areas
- Frost depth is assumed to be 48 inches (122 centimeters)

RMDS Retrofit Estimated Operations and Maintenance Costs

Estimated O&M costs for the RMDS include labor, dewatered ash disposal, power use, and maintenance. These are costs to be incurred after installation, since exact project costs will depend on the final design, landfill disposal site, and staffing for the system at Plant 3.

The proposed RMDS installation is essentially an addition to the existing bottom ash handling system. Because the new system will tie into bottom ash hoppers and clinker grinders that remain in place, there will be no additional O&M costs for these components. Replacing existing ash pumps rated at 600 horsepower (448 kilowatts) with new pumps rated at 530 horsepower (395 kilowatts) will offer a notable reduction in O&M costs (Table 5-4).

**Table 5-4
Plant 3 Unit A—RMDS Retrofit Estimated Annual O&M Costs**

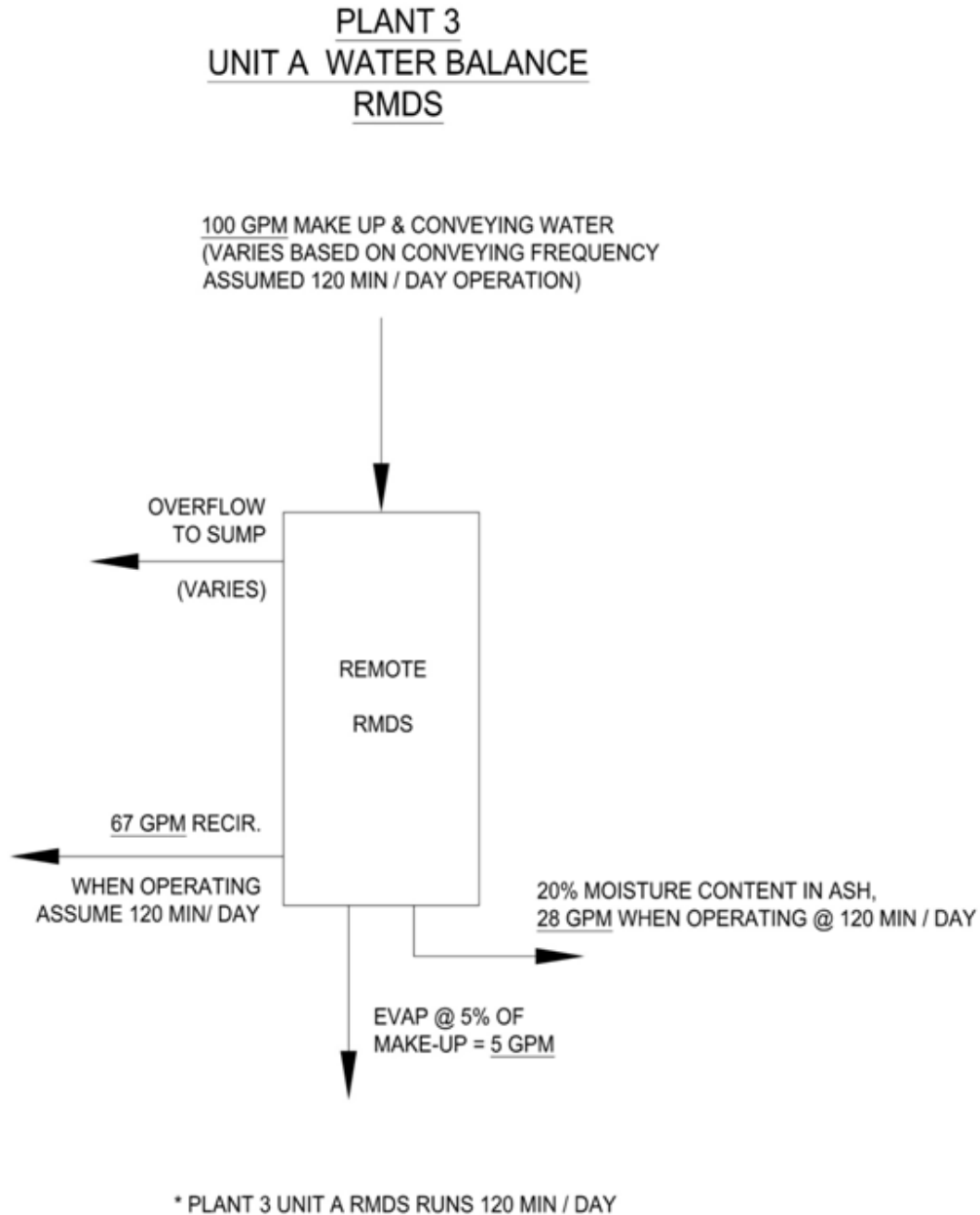
Item	Annual O&M Cost Equation	Estimated Annual Cost
Labor	Cost = 1 Operator * \$100,000/year where: Operators = 1 for each day of pulling bottom ash + 1 for maintenance (2 total)	\$200,000
Utilities	Cost for 530-hp HPU = [(6 hours*530 hp)*(0.7457kWhr)*(\$0.02 per kWhr)]*290 days/year	\$13,753
Bottom ash disposal	Cost = [30 tons/day] * [\$14/ton * 290 days/year]	\$121,800
Maintenance	Cost = 5% * Total installed equipment cost where: \$3,750,000 * 0.05	\$187,500
Drag chain replacement	Estimated with labor @ \$300,000, once every 5 years	\$60,000
	TOTAL ESTIMATED ANNUAL O&M COSTS	\$583,053

O&M = operations and maintenance
 530 horsepower (hp) = 396 kilowatts
 HPU = hydraulic power unit
 kWh = kilowatt-hour
 1 ton = 907.18 kilograms
 30 tons/day = 27,216 kilograms/day

RMDS Retrofit Water Balance

During normal operation, it is assumed that bottom ash conveyed from the RMDS has a moisture content of 20% by weight. It is also assumed that roughly 5% of the makeup water that is added

to the RMDS will be lost to evaporation. Thus, the RMDS will require approximately 100 gallons of makeup water per minute (6 liters per second) to replenish water that leaves in the ash and losses due to evaporation. After each batch of bottom ash is sluiced, high-pressure recirculation pumps drive the remaining conveying water and added makeup water back to the bottom ash hoppers. Given the estimated number of batches per day and the required duration of each sluicing operation, the RMDS will run 120 minutes per day. Thus, it will require 12,000 gallons (45,425 liters) of water per day of operation. Figure 5-4 illustrates the RMDS water balance for Plant 3 Unit A.



**Figure 5-4
Plant 3 Unit A—RMDS Retrofit Water Balance**

RMDS Retrofit Proposed Schedule

The proposed schedule for the RMDS retrofit at Plant 3 Unit A (Table 5-5) is based on vendor information for engineering, fabrication, and delivery of the new equipment. The schedule also incorporates input from The Company's approved contractor.

Table 5-5
Plant 3 Unit A—RMDS Retrofit Proposed Schedule

Item	Duration
Vendor engineering, fabrication, and delivery	52 weeks
Balance-of-plant engineering and design	18 weeks
Site preparation	3 weeks
On-Site mechanical and structural fabrication	3 weeks
Installation	12 weeks
Plant outage	3 weeks

6

PLANT 4 UNITS A AND B

This section presents a proposed retrofit for the existing bottom ash handling system at Plant 4 Units A and B. A brief description of the existing system is given in Table 6-1.

Site Description

Unit: A

Owner: A Midwestern Utility Company

Capacity: 50 MW

Existing Bottom Ash Handling System: Bottom ash is sluiced to ash pond

Unit: B

Owner: A Midwestern Utility Company

Capacity: 149 MW

Existing Bottom Ash Handling System: Bottom ash is sluiced to ash pond

Table 6-1

Plant 4 Units A and B—Description of Existing Bottom Ash Handling System

Unit	System Type	Bottom Ash Water Use (gallons/day)	Water Source	Operation (hours/day)	Operation (days/year)	Bottom Ash Handling (tons/day)	Economizer Ash Handling
A	Ash pond	83,000	Intake 100%	1	300	15	Handled dry with fly ash
B	Ash pond	576,000	Intake 100%	3	300	15	Handled dry with fly ash

Water use = water pumped (make-up water plus recirculated water)

83,000 gallons/day = 314,189 liters/day

576,000 gallons/day = 2.18 million liters/day

15 tons/day = 13,608 kilograms/day

Currently, Plant 4 handles bottom ash wet and manages it in an ash pond. Unlike other wet bottom ash handling systems evaluated in this report, the systems at Plant 4 presented unique challenges due to the age, size, and location of Units A and B. Although the Unit A and B systems are original to the plant, the bottom ash handling equipment is in good working order. Unit A needs only a minor repair on the hopper plate steel, while Unit B is in good working condition with no need for additional maintenance or refurbishment. Since economizer ash is mixed with fly ash and handled dry, the condition of the economizer ash handling equipment is of no concern in this report.

The Unit A system consists of one large, sloped wet bottom ash hopper, one ash sluice pump, a clinker grinder, and wear-resistant ash sluice piping leading from the clinker grinder to the ash pond. Because Unit A has a relatively small boiler that produces little ash, bottom ash is removed

from the hopper in a single, 1-hour batch per day. The Unit B system consists of a wet impounded bottom ash hopper with an overflow tank, one clinker grinder, and two ash sluice pumps. Bottom ash is removed from the hopper three times per day in approximately 1-hour batches. Ash pulled from Units A and B is comingled and sent, via the same piping, to the ash pond located at the southwest end of the plant property. Since water is not recirculated from the pond back to the wet impounded ash hoppers, 100% of the ash sluice water is fresh intake water.

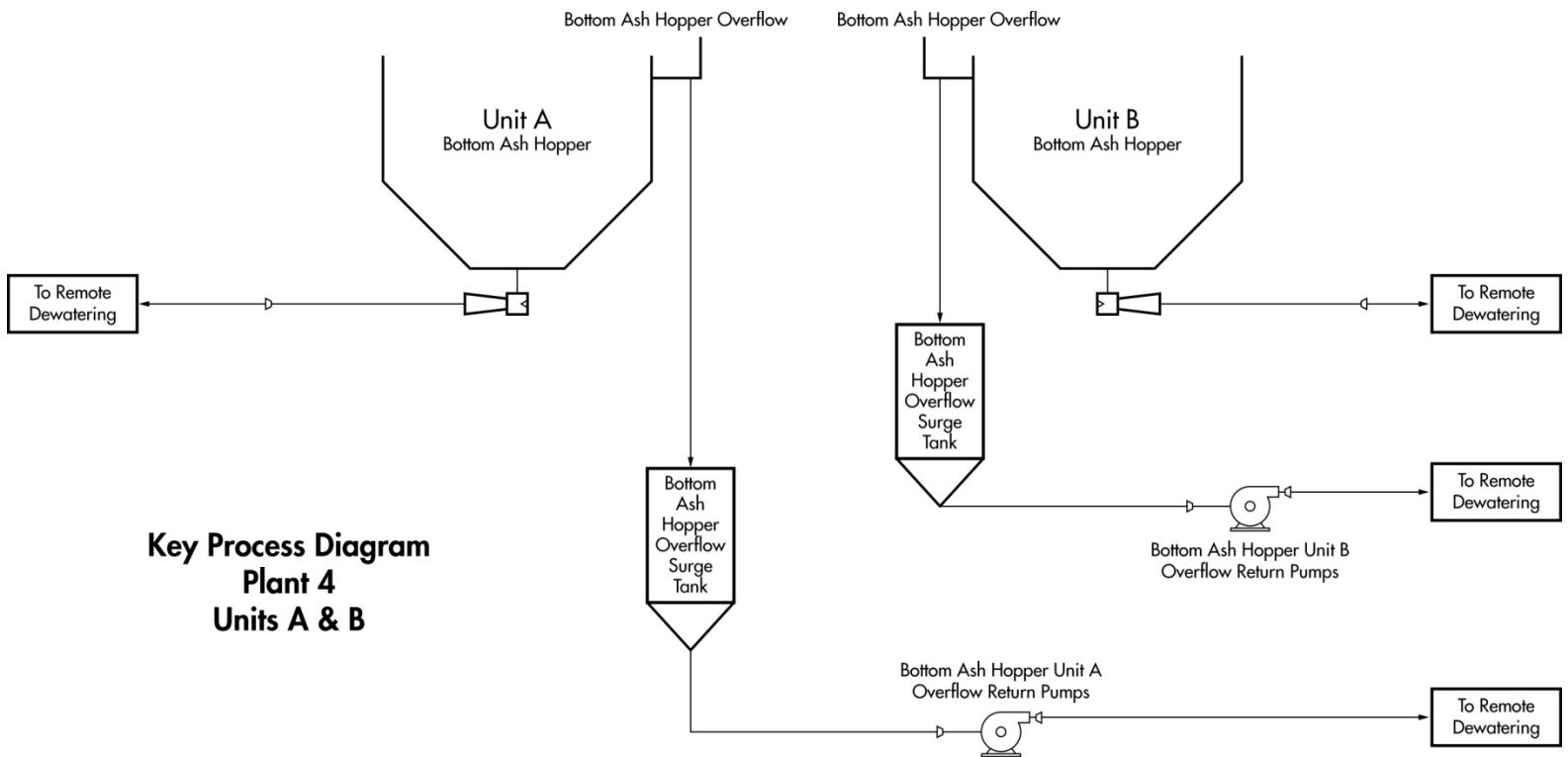
Proposed RMDS Retrofit

After touring the facility and speaking with on-site engineers, investigators concluded that a single RMDS would be the only realistic retrofit option for Plant 4. A single RMDS would have the capacity to collect and dewater the bottom ash slurry from both of the existing bottom ash hoppers, given their rating and ash output (Figures 6-1, 6-2, and 6-3). Placed in a new pre-engineered building, the RMDS would receive and process bottom ash from either unit, leaving the dewatered ash in a concrete bunker protected by the building. A front-end loader would transfer ash from the bunker to transport trucks, as needed.

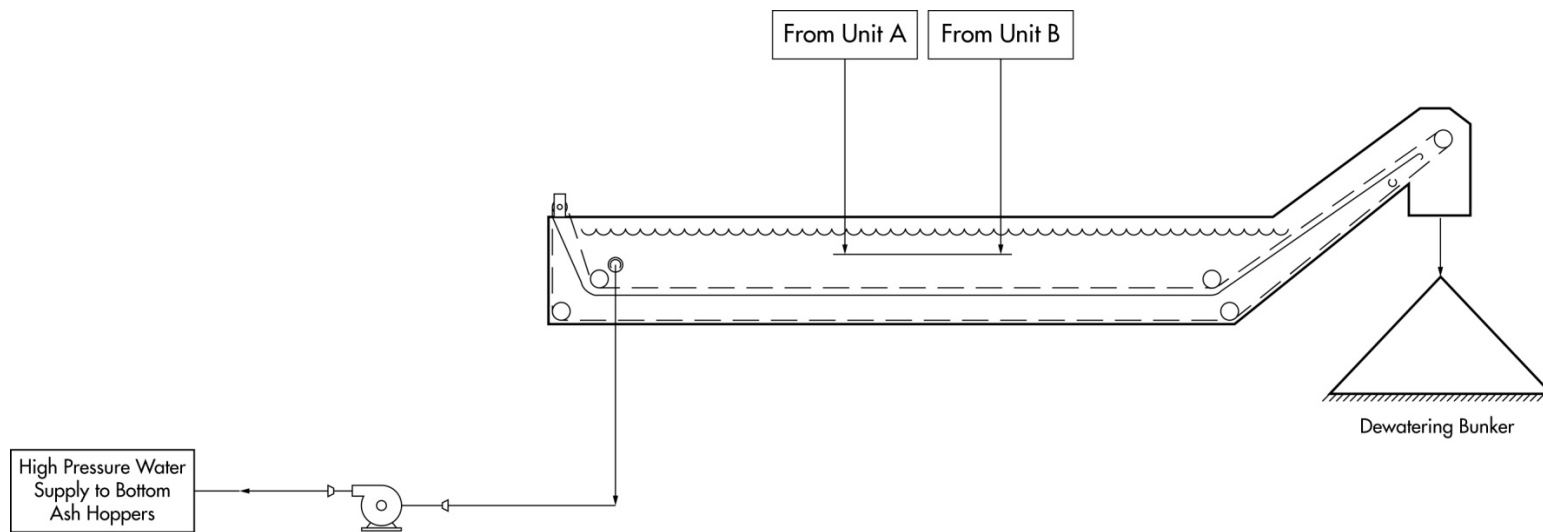
Because the RMDS basin is designed with enough capacity to store bottom ash sluice water, the retrofit includes high-pressure pumps to recirculate that water back to the wet impounded ash hoppers. To further reduce the demand for water, low-pressure recirculation pumps would also send water from the RMDS basin back to the boiler building for seal trough and wall cooling. Finally, because the retrofit design will allow Units A and B to retain much of their existing equipment, plant personnel could use the high- and low-pressure water pumps already in place to fill the bottom ash hopper with RMDS basin water during upset conditions.

The RMDS has a larger capacity for water storage than the combined volume of the wet impounded bottom ash hoppers under the boilers of Units A and B. Thus, adding makeup water to the RMDS basin to control temperature and ensure minimum water levels will cause the bottom ash hoppers to overflow when the basin water recirculates. To keep this overflow from being sent down the drains in the boiler building, a surge tank will be installed near the bottom ash hoppers. Slurry pumps will be provided as needed to pump overflow water from the new surge tank back to the RMDS.

Since distance from the boilers and front-end loader access were the most important considerations, the RMDS will be located just south of the boiler house. The pre-engineered building housing the RMDS will be placed outside of the plant wall near the existing dry fly ash silo, along the road that currently serves as the fly ash unloading service area (Figure 6-4).

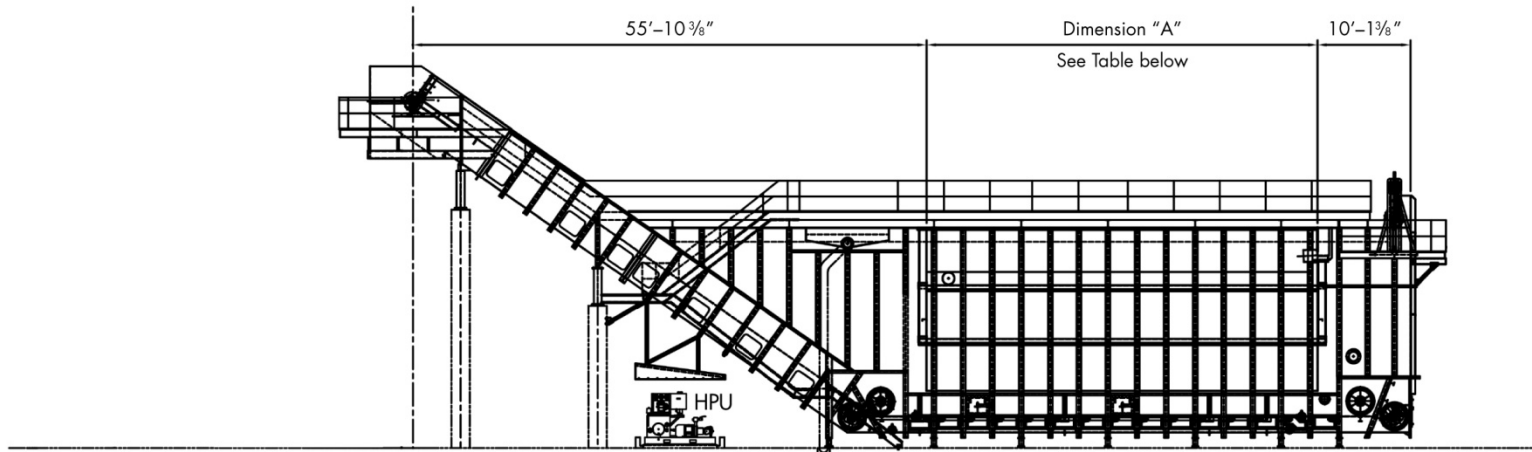


**Figure 6-1
Plant 4 Units A and B—RMDS Retrofit Key Flow Diagram #1**

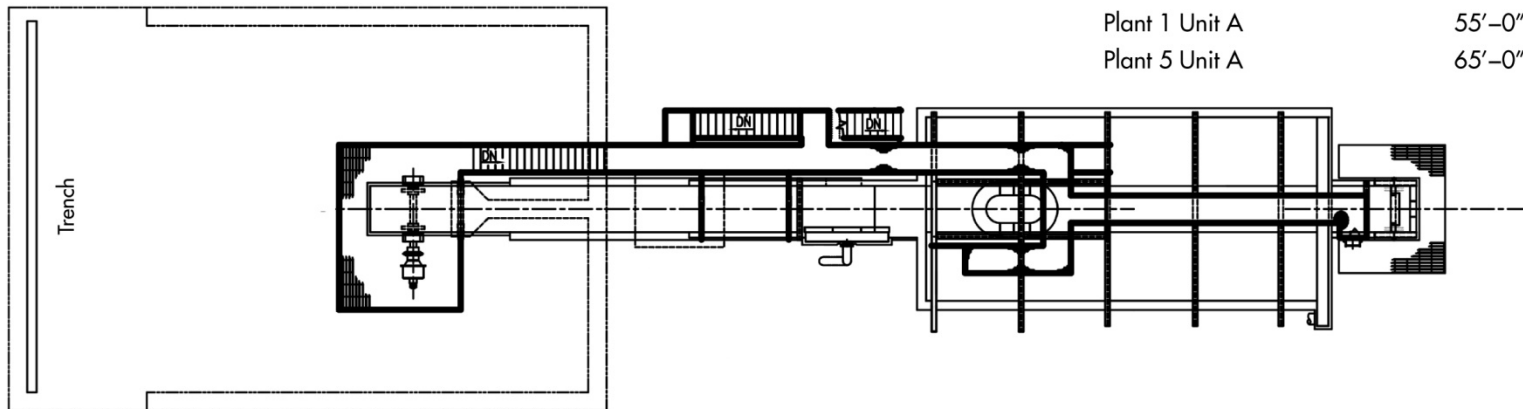


**Key Process Diagram
RMDS
Plant 4 – Unit A & B**

**Figure 6-2
Plant 4 Units A and B—RMDS Retrofit Key Flow Diagram #2**



Plant & Unit	Dimension "A"
Plant 4 Units A & B	45'-0"
Plant 3 Unit A	45'-0"
Plant 1 Unit A	55'-0"
Plant 5 Unit A	65'-0"



**Wet to Dry Conversion
Remote Mechanical Drag System
Preliminary General Arrangement**

Figure 6-3
Plant 4 Units A and B—RMDS Retrofit Plan and Elevation View

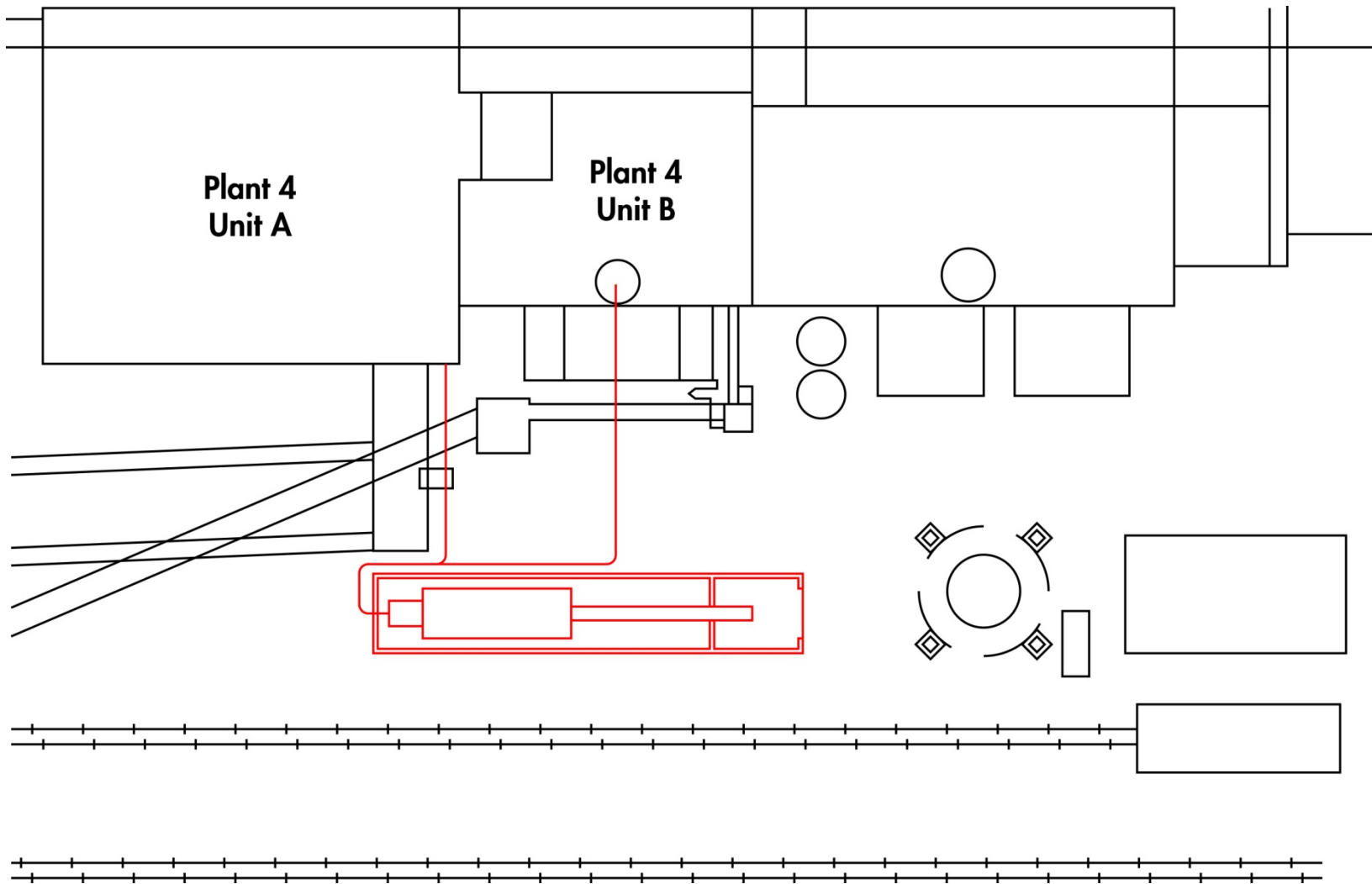


Figure 6-4
Plant 4 Units A and B—RMDS Retrofit Location Plan

Other Technologies Evaluated for Retrofit

While an MDS and a PDT system were also considered for Plant 4, an RMDS proved to be the best retrofit option for several reasons. An MDS requires space under the boiler for equipment installation and space in the area around the boiler for component fabrication. But these requirements are irrelevant if it is cost prohibitive to bring retrofit components to the boilers at Plant 4. There, both of the existing bottom ash hoppers for Units A and B are located in the boiler building basement, bounded by concrete walls on four sides, at a floor level approximately 35 feet (11 meters) below grade, and accessible only by staircases and a very small elevator. Even if it were feasible to place an MDS in this basement location, the dewatered ash would have to be conveyed 35 feet (11 meters) up and out of the basement before being lifted an additional 15 feet (5 meters) to clear the walls of a bunker. Building an ash conveyor in this setting would add cost and could potentially require cutting the foundation walls to accommodate the maximum angles allowed for the dewatering ramp. The Company decided that it would be more economical to sluice ash to an RMDS using the existing wet impounded ash hoppers and related pumps, which are in good condition.

A preliminary evaluation suggested that a PDT system would be suitable for Plant 4 Units A and B, given their space restrictions. However, a cost review showed that installing a new dry bottom ash surge bin, a storage silo, and a conditioning mixer would be much more expensive than continuing to use the wet impounded ash hoppers already present.

RMDS Retrofit Requirements and Capital Cost Evaluation

Table 6-2 lists vendor-supplied equipment to be purchased for this retrofit. The total cost for the new system reflects vendor engineering, system parts and equipment fabrication, and delivery. Because of its size and weight, the RMDS must be shipped in pieces. The number of pieces would depend on vendor preference, as well as site and delivery conditions at the time of purchase.

**Table 6-2
Plant 4 Units A and B—RMDS Retrofit Equipment Supplied by Bottom Ash Handling System Vendor**

Quantity	Unit	Major Vendor-supplied Equipment
1,500	Feet	Bottom ash conveyor piping
3,000	Feet	CS Schedule 40 recirculation water piping
1	Lot	Required pipe supports, connections, expansion joints and fittings
2	Each	Low-pressure recirculation pump with motor (200 horsepower [149 kilowatts])
2	Each	High-pressure recirculation pump with motor (200 horsepower [149 kilowatts])
1	Each	RMDS
1	Each	Hydraulic power unit with motor (60 horsepower [45 kilowatts])
1	Lot	Maintenance access platform with grating, stairway, and handrails at RMDS
1	Each	Local RMDS Control Panel
1	Each	RMDS jog station
1	Lot	Instrumentation (level probes, speed switches, temperature transmitters, pressure/flow indicators)
2	Each	Sump pump with motor (20 horsepower [15 kilowatts])
2	Each	Bottom ash overflow surge tank
4	Each	Overflow return pump with motor (50 horsepower [37 kilowatts])
1	Each	Engineering/design/field support
		TOTAL COST: \$3,500,000

CS = commercial standard

RMDS = remote mechanical drag system

1 foot = 0.305 meter

Table 6-3 shows estimated balance-of-plant material, labor, and engineering costs for the proposed RMDS retrofit at Plant 4 Units A and B.

**Table 6-3
Plant 4 Units A and B—RMDS Retrofit Estimated Balance-of-plant Material, Labor, and Engineering Costs**

Item	Description	Total Material Cost	Total Installation Person-Hours	Average Cost Per Person-Hour	Total Labor Cost	Total Cost
1	Structural foundations and slab for 25 x 150-foot (8 x 46-meter) building enclosure and foundation for 20,000-gallon (75,708-liter) water storage tank—including excavation, reinforcing, concrete and formwork	\$65,630	840	\$60	\$50,400	\$116,030
2	Structural foundation supports and footings for RMDS inside building—including reinforcing, concrete, and formwork	\$28,500	320	\$60	\$19,200	\$47,700
3	Pre-engineered 25 x 150 x 25-foot (8 x 46 x 8-meter) building enclosure with 15 x 15-foot (5 x 5-meter) roll-up door fabrication and installation	\$75,000	640	\$60	\$38,400	\$113,400
4	Electrical and mechanical for lighting, floor drains and HVAC for building interior	\$10,300	240	\$60	\$14,400	\$24,700
5	Demolition work for removal of existing ash pumps and associated piping	NA	240	\$60	\$9,600	\$14,400
6	Mechanical installation costs for RMDS, on-site fabrication, new pump, water tank, piping and pipe support installation (See Note 1)	\$160,102	5,000	\$60	\$300,000	\$460,102
7	Electrical power and controls installation costs for RMDS (See Note 2)	\$116,000	960	\$62.50	\$60,000	\$176,000
8	Mechanical installation project site management	NA	480	\$65	\$31,200	\$31,200
9	Electrical installation project site management	NA	240	\$65	\$15,600	\$15,600
10	Pre-engineering, permitting, balance-of-plant engineering structural/mechanical/electrical					\$215,000
11	Utility contingency for project @ 20%					\$242,880
	TOTAL COST					\$1,457,012

Notes for Table 6-3

Note 1: Material Costs do not include equipment and piping supplied by bottom ash handling system vendor. Material costs include one (1) 25-ton crane rental, scaffolding, welding materials for fabrication of RMDS, pipe hanger and pipe supports for RMDS and all balance-of-plant piping for drainage and sump pits.

Note 2: Material costs include wiring, conduit junction boxes, two (2) combination starters for 200-horsepower (149-kilowatt) ash pump motors, two (2) combination starters for 200-horsepower (149-kilowatt) recirculation pumps, two (2) combination starters for 20-horsepower (15-kilowatt) sump pump motors, one (1) combination starter for 60-horsepower (45-kilowatt) HPU motor, and two (2) 50-horsepower (37-kilowatt) overflow return pumps. It is assumed that Plant 4 has sufficient space in an existing MCC for power equipment.

RMDS = remote mechanical drag system

HVAC = heating, ventilation, and air conditioning

HPU = hydraulic power unit

MCC = motor control center

The balance-of-plant material and labor cost estimates were prepared using the pay rate of an approved Company contractor, who has performed capital project work at Plant 4 in the past. The contractor in question participated in this cost evaluation project, was present for the site tours, and provided input at subsequent meetings with Company engineering personnel. The cost estimates and person-hours are based on the contractor's experience with bottom ash handling retrofits and familiarity with the project site.

Despite the time and effort put into these cost estimates, they—and the evaluations that accompany them—should be considered Class 5 cost estimates. This is because preliminary-phase input from power plant personnel regarding location and/or system evaluation was limited and unforeseen variables at the site will likely determine final costs. Specifically, the evaluations are based only on Company engineering requests and magnitude-of-cost estimates for the following:

- Excavation and site work
- Concrete for foundations, slab and footings
- Mechanical installation (on-site fabrication of RMDS, installation of RMDS, equipment, piping and pipe supports, heating and ventilation for the pre-engineered building that will cover the RMDS)
- Electrical installation, including power for equipment, heating, and lighting
- Instrumentation and control (I&C)
- Subcontractor labor rates
- Balance-of-plant engineering services during pre-engineering phase, permitting phase, design phase, and construction phase
- Cost of utility contingency for the project

Assumptions in Capital Cost Evaluation

- The system design is as described in the key flow diagrams (Figures 6-1 and 6-2)
- Weather conditions will not require work stoppage
- Cost escalation is not included
- Labor rates are equivalent to those of an approved Company contractor
- Soil conditions are assumed to be at least 1.5 kips per square foot (72 kilopascals) for footings and foundations
- The RMDS and the building enclosing it can be installed at the current design location
- The building will be heated to 45 °F (7 °C) using an electric heater
- The RMDS will be locally controlled via a vendor-supplied panel
- Plant 4 Units A and B have existing electrical equipment adequate to power the system
- There is no underground piping or utility interference
- The bottom ash equipment vendor has a +/- 20% factor in the cost estimate
- The estimate does not include sales tax, as the project is assumed to be exempt from sales tax
- The estimate does not include permitting for construction

- The site is balanced cut/fill
- The estimate does not include temporary fencing
- Curbs and gutters are not required for roads or parking areas
- Frost depth is assumed to be 48 inches (122 centimeters)

RMDS Retrofit Estimated Operations and Maintenance Costs

Estimated O&M costs for the RMDS include labor, dewatered ash disposal, power use, and maintenance. These are costs to be incurred after installation, since exact project costs will depend on the final design, landfill disposal site, and staffing for the system at Plant 4.

The proposed RMDS installation is essentially an addition to the existing bottom ash handling system. Because the new system will tie into bottom ash hoppers and clinker grinders that remain in place, there will be no additional O&M costs for these components. Replacing existing ash pumps rated at 650 horsepower (485 kilowatts) with new pumps rated at 530 horsepower (395 kilowatts) (Table 6-4) will offer a notable reduction in O&M costs. The replacement is possible because the RMDS will be closer than the existing pond.

**Table 6-4
Plant 4 Units A and B—RMDS Retrofit Estimated Annual O&M Costs**

Item	Annual O&M Cost Equation	Estimated Annual Cost
Labor	Cost = 1 Operator * \$100,000/year where: Operators = 1 for each day of pulling bottom ash + 1 for maintenance (2 total)	\$200,000
Utilities	Cost for 530-hp HPU = [(4 hours*530 hp)*(0.7457 kWhr)*(\$0.02 per kWhr)]*300 days/year	\$9,486
Bottom ash disposal	Cost = [30 tons/day] * [\$14/ton * 300 days/year]	\$126,000
Maintenance	Cost = 5% * Total installed equipment cost where: \$3,500,000 * 0.05	\$175,200
Drag chain replacement	Estimated with labor @ \$300,000, once every 5 years	\$60,000
	TOTAL ESTIMATED ANNUAL O&M COSTS	\$570,686

O&M = operations and maintenance
 530 horsepower (hp) = 395 kilowatts
 HPU = hydraulic power unit
 kWh = kilowatt-hour
 1 ton = 907.18 kilograms
 30 tons/day = 27,216 kilograms/day

RMDS Retrofit Water Balance

During normal operation, it is assumed that bottom ash conveyed from the RMDS has a moisture content of 20% by weight. It is also assumed that roughly 5% of the makeup water that is added to the RMDS will be lost to evaporation. Thus, the RMDS will require approximately 100 gallons of makeup water per minute (6 liters per second) to replenish water that leaves in the ash and losses due to evaporation. After each batch of bottom ash is sluiced, high-pressure recirculation pumps drive the remaining conveying water and added makeup water back to the bottom ash hoppers. Given the estimated number of batches per day and the required duration of each sluicing operation, the RMDS will run 240 minutes per day. Thus, it will keep 659,000 gallons (2.50 million liters) of water from being sent to the existing ash ponds per day. Figure 6-5 illustrates the RMDS water balance for Plant 4 Units A and B.

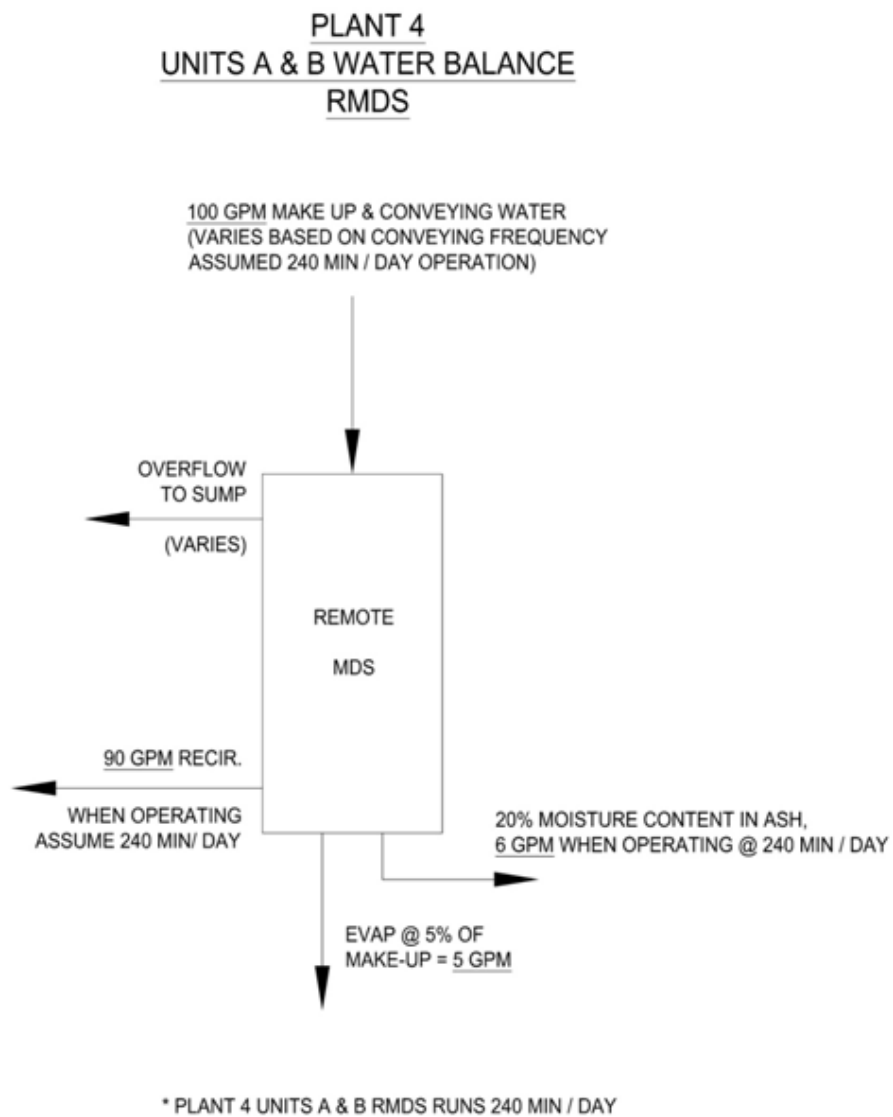


Figure 6-5
Plant 4 Units A and B—RMDS Retrofit Water Balance

RMDS Retrofit Proposed Schedule

The proposed schedule for the RMDS retrofit at Plant 4 Units A and B (Table 6-5) is based on vendor information for engineering, fabrication, and delivery of the new equipment. The schedule also incorporates input from The Company's approved contractor.

Table 6-5
Plant 4 Units A and B—RMDS Retrofit Proposed Schedule

Item	Duration
Vendor engineering, fabrication, and delivery	52 weeks
Balance-of-plant engineering and design	20 weeks
Site preparation	4 weeks
On-site mechanical and structural fabrication	4 weeks
Installation	12 weeks
Plant outage	3 weeks

7

PLANT 5 UNIT A

This section presents a proposed retrofit for the existing bottom ash handling system at Plant 5 Unit A. A brief description of the existing system is given in Table 7-1.

Site Description

Unit: A

Owner: A Midwestern Utility Company

Capacity: 726 MW

Existing Bottom Ash Handling System: Ash pond

Table 7-1

Plant 5 Unit A—Description of Existing Bottom Ash Handling System

System Type	Bottom Ash Water Use (gallons/day)	Water Source	Operation (hours/day)	Operation (days/year)	Bottom Ash Handling (tons/day)	Economizer Ash Handling
Ash pond	1,680,750	Intake 90% Cooling tower blowdown 10%	7	335	105	Handled wet with bottom ash

Water use = water pumped (make-up water plus recirculated water)

1,680,750 gallons/day = 6.36 million liters/day

105 tons/day = 95,254 kilograms/day

Currently, Plant 5 Unit A handles bottom ash wet and sends it to an ash pond. To service the large capacity of Unit A, the bottom ash handling system consists of six wet impounded bottom ash hoppers located below the boiler, two 600-horsepower (448-kilowatt) ash sluice pumps, hydraulic jet pumps outfitted with ash sluice nozzles to move ash to the clinker grinders, and wear-resistant ash sluice piping leading to the ash pond. The bottom ash is removed from all six hoppers two times per day, requiring a total of 420 minutes of sluicing per day. After each batch, most of the water needed for the next batch (90%) is recirculated from the pond back to the ash sluice pumps, while the rest of the water (10%) comes from cooling tower blowdown. In addition to bottom ash, this system also handles economizer ash and mill pyrites by tying dedicated economizer ash and mill pyrite sluice lines for each unit into the main pond-bound lines.

Proposed RMDS Retrofit

After touring the facility and speaking with on-site engineers, investigators proposed that a single RMDS would be the best retrofit for handling bottom ash at Plant 5 Unit A. The RMDS would act as an addition to the wet impounded bottom ash hoppers already present and in good working condition at Unit A. In the retrofit design, one RMDS would collect and dewater bottom ash

slurry from the bottom ash hoppers while operating in a closed loop with respect to water use (Figures 7-1 and 7-2). The bottom ash, which would be pumped directly from the bottom ash hoppers to the RMDS, would be dewatered and then discharged into a concrete bunker located inside the pre-engineered RMDS bottom ash building. This building would be located along the south side of the boiler house where the existing bottom ash piping exits the building (Figure 7-3). A front-end loader can remove bottom ash from the bunker, as needed, and transfer it to trucks for final disposal.

The RMDS operates in a closed loop because its basin is designed with enough capacity to store bottom ash sluice water for the duration of the dewatering cycle. At the end of the dewatering cycle, high-pressure recirculation pumps send the remaining sluice and makeup water from the RMDS basin back to the wet impounded bottom ash hoppers under the boiler. Low-pressure recirculation pumps could also send water from the RMDS basin back to the boiler building for seal trough and wall cooling. Finally, because the retrofit design will allow Unit A to retain much of its existing equipment, plant personnel could use the high- and low-pressure water pumps already in place to fill the bottom ash hopper with RMDS basin water during upset conditions.

The RMDS basin has a larger capacity for water storage than the bottom ash hoppers under the boiler of Unit A. Thus, adding makeup water to the RMDS basin to control temperature and ensure minimum probe-monitored water levels will cause the bottom ash hoppers to overflow when the basin water recirculates. To keep this overflow from being sent down the drains in the boiler building, a surge tank will be installed near the bottom ash hoppers. Slurry pumps will be provided as needed to pump overflow water from the new surge tank back to the RMDS.

Compared to an MDS, and RMDS requires very short outage times for system interconnects and avoids replacement costs by preserving the use of existing wet bottom ash handling components, which are in good working order.

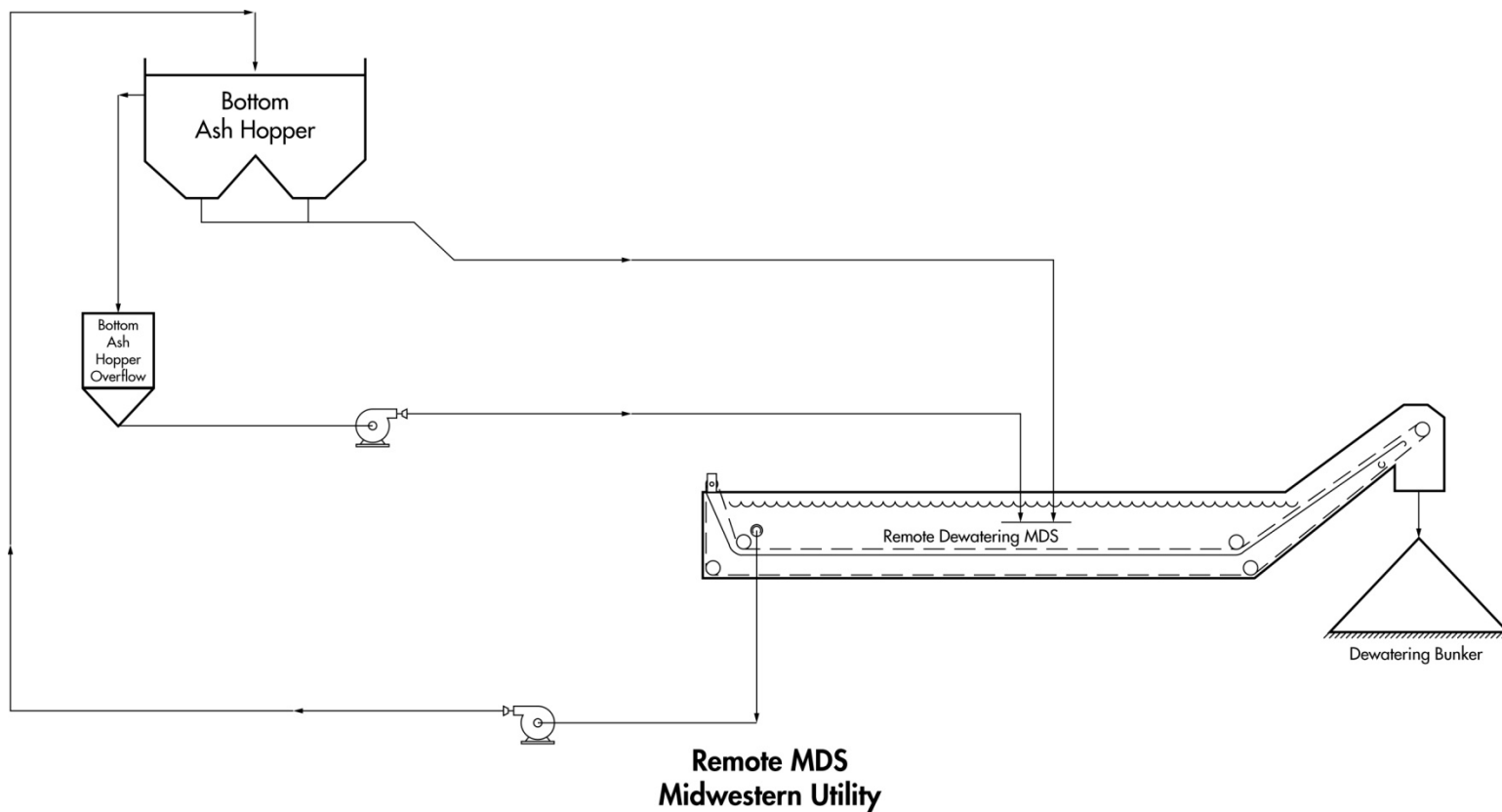
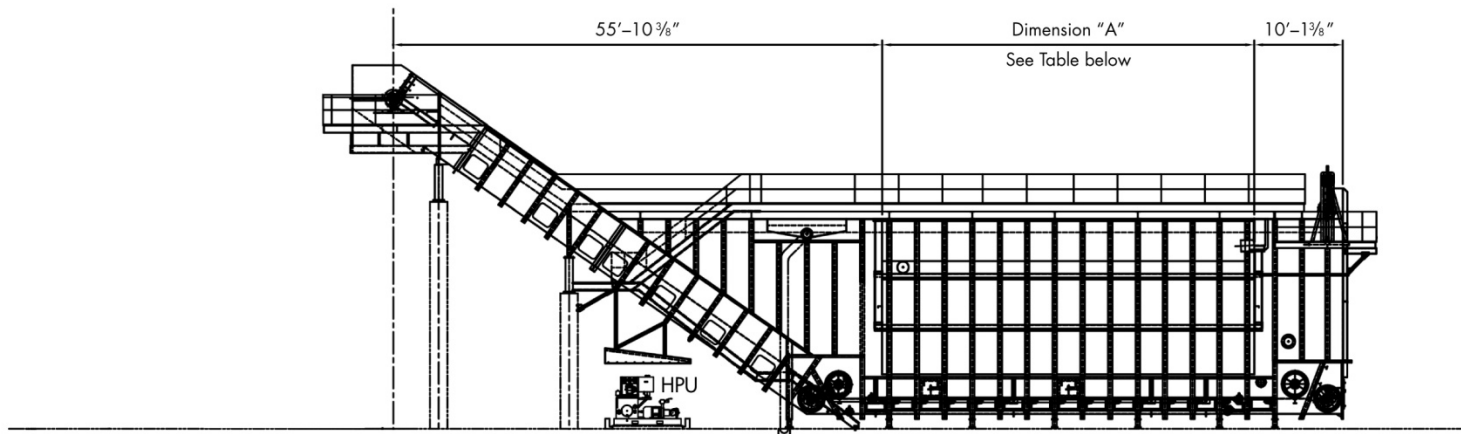
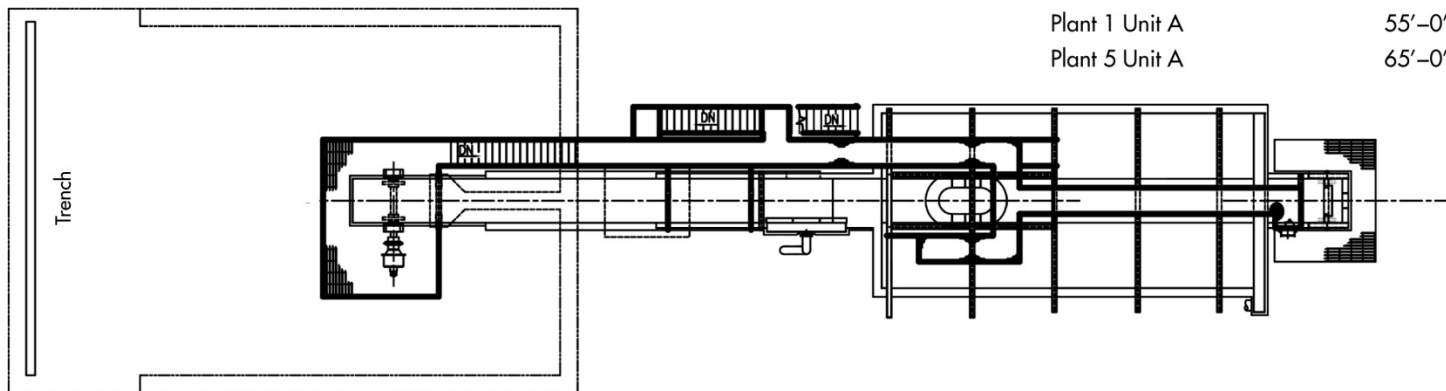


Figure 7-1
Plant 5 Unit A—RMDS Retrofit Key Flow Diagram



Plant & Unit	Dimension "A"
Plant 4 Units A & B	45'-0"
Plant 3 Unit A	45'-0"
Plant 1 Unit A	55'-0"
Plant 5 Unit A	65'-0"



**Wet to Dry Conversion
Remote Mechanical Drag System
Preliminary General Arrangement**

**Figure 7-2
Plant 5 Unit A—RMDS Retrofit Plan and Elevation View**

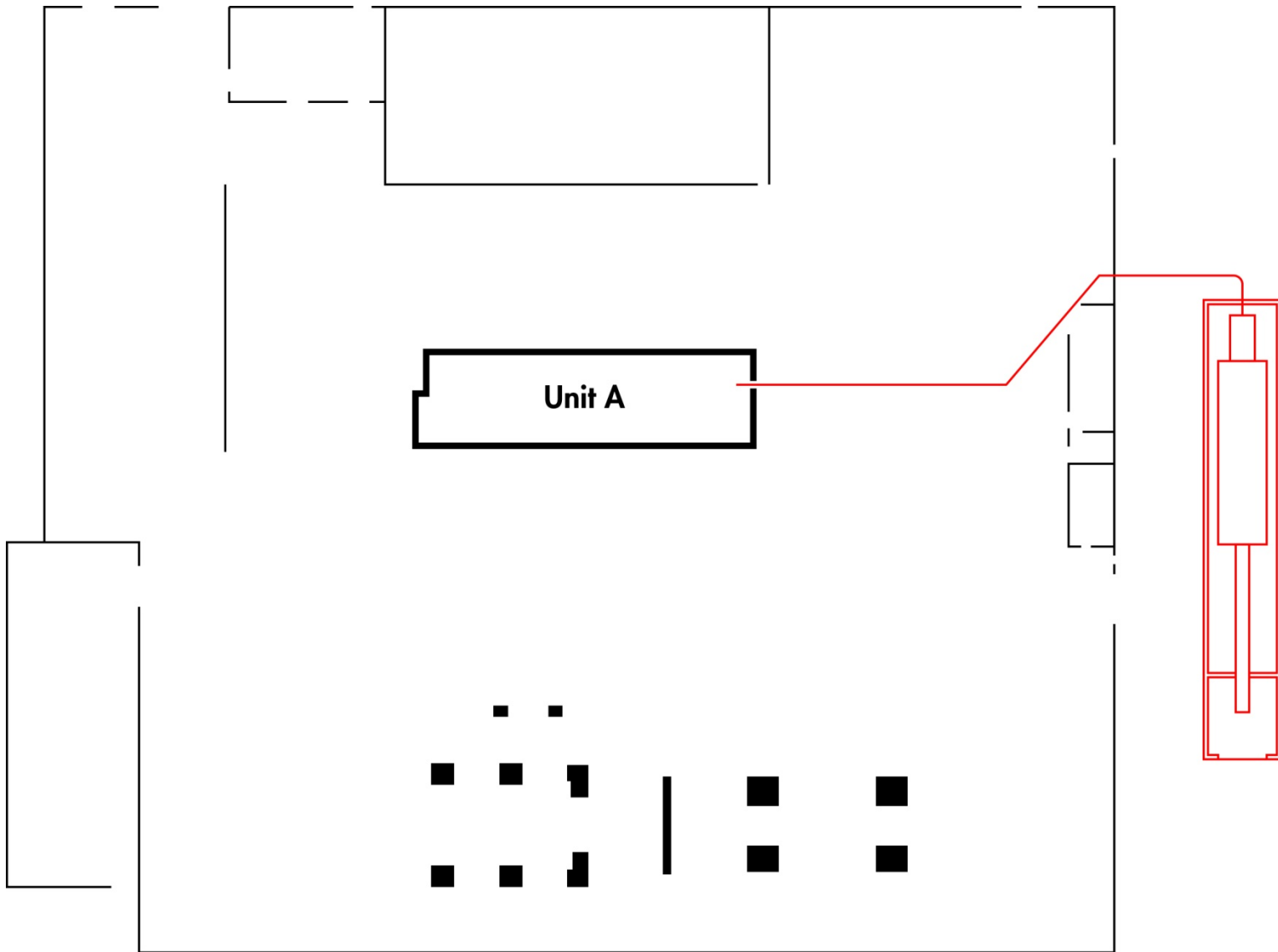


Figure 7-3
Plant 5 Unit A—RMDS Retrofit Location Plan

Other Technologies Evaluated for Retrofit

An MDS was seriously evaluated for use at Plant 5 Unit A. A preliminary review confirmed that the minimum space needed for MDS installation under the boiler was available, but there was no clear space for the ash conveyor and dewatering ramp to operate or exit the boiler building. A potential exit path south of the boiler is obstructed by three coal mills that would be very costly to move. One coal mill, in particular, sits on the centerline of the boiler and restricts any potential exit path, making bottom ash removal via an under-boiler MDS impossible.

RMDS Retrofit Requirements and Capital Cost Evaluation

Table 7-2 lists vendor-supplied equipment to be purchased for this retrofit. The total cost for the new system reflects vendor engineering, system parts and equipment fabrication, and delivery. Because of its size and weight, the RMDS must be shipped in pieces. The number of pieces would depend on vendor preference, as well as site and delivery conditions at time of purchase.

Table 7-2
Plant 5 Unit A—RMDS Retrofit Equipment Supplied by Bottom Ash Handling System Vendor

Quantity	Unit	Major Vendor-supplied Equipment
800	Feet	Bottom ash conveyor piping
1,600	Feet	CS Schedule 40 recirculation water piping
1	Lot	Required pipe supports, connections, expansion joints and fittings
2	Each	Low-pressure recirculation pump with motor (200 horsepower [149 kilowatts])
2	Each	High-pressure recirculation pump with motor (200 horsepower [149 kilowatts])
1	Each	RMDS
1	Each	Hydraulic power unit with motor (60 horsepower [45 kilowatts])
1	Lot	Maintenance access platform with grating, stairway, and handrails at RMDS
1	Each	RMDS local control panel
1	Each	RMDS local jog station
1	Lot	Instrumentation (level probes, speed switches, temperature transmitters, pressure/flow indicators)
2	Each	Sump pump with motor (20 horsepower [15 kilowatts])
1	Each	Bottom ash hopper overflow surge tank
2	Each	Overflow return pump with motor (50 horsepower [37 kilowatts])
1	Each	Engineering/design/field support
		TOTAL COST: \$4,000,000

CS = commercial standard

RMDS = remote mechanical drag system

1 foot = 0.305 meter

Table 7-3 shows estimated balance-of-plant material, labor, and engineering costs for the proposed RMDS retrofit at Plant 5 Unit A.

**Table 7-3
Plant 5 Unit A—RMDS Retrofit Estimated Balance-of-plant Material, Labor, and Engineering Costs**

Item	Description	Total Material Cost	Total Installation Person-Hours	Average Cost Per Person-Hour	Total Labor Cost	Total Cost
1	Structural foundations and slab for 25 x 150-foot (8 x 46-meter) building enclosure and foundation for 20,000-gallon (75,708-liter) water storage tank—including excavation, reinforcing, concrete and formwork	\$65,630	800	\$60	\$48,000	\$113,630
2	Structural foundation supports and footings for RMDS inside building—including reinforcing, concrete, and formwork	\$28,500	320	\$60	\$19,200	\$47,700
3	Pre-engineered 25 x 150 x 25-foot (8 x 46 x 8-meter) building enclosure with 15 x 15-foot (5 x 5-meter) roll-up door fabrication and installation	\$75,000	640	\$60	\$38,400	\$113,400
4	Electrical and mechanical for lighting, floor drains and HVAC for building interior	\$10,300	240	\$60	\$14,400	\$24,700
5	Demolition work for removal of existing ash pumps and associated piping	NA	160	\$60	\$9,600	\$9,600
6	Mechanical installation costs for RMDS, on-site fabrication, new pump, water tank, piping and pipe support installation (See Note 1)	\$160,102	5,200	\$60	\$312,000	\$472,102
7	Electrical power and controls installation costs for RMDS (See Note 2)	\$116,000	960	\$62.50	\$60,000	\$176,000
8	Mechanical installation project site management	NA	480	\$65	\$31,200	\$31,200
9	Electrical installation project site management	NA	240	\$65	\$15,600	\$15,600
10	Pre-engineering, permitting, balance-of-plant engineering structural/mechanical/electrical					\$215,000
11	Utility contingency for project @ 20%					\$243,786
	TOTAL COST					\$1,462,718

Notes for Table 7-3

Note 1: Material Costs do not include equipment and piping supplied by bottom ash handling system vendor. Material costs include one (1) 25-ton crane rental, scaffolding, welding materials for fabrication of RMDS, pipe hanger and pipe supports for RMDS and all balance-of-plant piping for drainage and sump pits.

Note 2: Material costs include wiring, conduit junction boxes, two (2) combination starters for 200-horsepower (149-kilowatt) ash pump motors, two (2) combination starters for 200-horsepower (149-kilowatt) recirculation pumps, two (2) combination starters for 20-horsepower (15-kilowatt) sump pump motors, one (1) combination starter for 60-horsepower (45-kilowatt) HPU motor, and two (2) 50-horsepower (37-kilowatt) overflow return pumps.. It is assumed that Plant 5 has sufficient space in an existing MCC for power equipment.

RMDS = remote mechanical drag system

HVAC = heating, ventilation, and air conditioning

HPU = hydraulic power unit

MCC = motor control center

The balance-of-plant material and labor cost estimates were prepared using the pay rate of an approved Company contractor, who has performed capital project work at Plant 1 in the past. The contractor in question participated in this cost evaluation project, was present for the site tours, and provided input at subsequent meetings with Company engineering personnel. The cost estimates and person-hours are based on the contractor's experience with bottom ash handling retrofits and familiarity with the project site.

Despite the time and effort put into these cost estimates, they—and the evaluations that accompany them—should be considered Class 5 cost estimates. This is because preliminary-phase input from power plant personnel regarding location and/or system evaluation was limited and unforeseen variables at the site will likely determine final costs. Specifically, the evaluations are based only on Company engineering requests and magnitude-of-cost estimates for the following:

- Excavation and site work
- Concrete for foundations, slab and footings
- Mechanical installation (on-site fabrication of RMDS, installation of RMDS, equipment, piping and pipe supports, heating and ventilation for the pre-engineered building that will cover the RMDS)
- Electrical installation including power for equipment, heating, and lighting
- Instrumentation and control (I&C)
- Subcontractor labor rates
- Balance-of-plant engineering services during pre-engineering phase, permitting phase, design phase, and construction phase
- Cost for utility contingency for project

Assumptions in Capital Cost Evaluation

- The system design is as described in the key flow diagram (Figure 7-1)
- Weather conditions will not require work stoppage
- Cost escalation is not included
- Labor rates are equivalent to those of an approved Company contractor
- Soil conditions are assumed to be at least 1.5 kips per square foot (72 kilopascals) for footings and foundations
- The RMDS and the building enclosing it can be installed at the current design location
- The building will be heated to 45 °F (7 °C) using an electric heater
- The RMDS will be locally controlled via a vendor-supplied panel
- Plant 5 Unit A has existing electrical equipment adequate to power the system
- There is no underground piping or utility interference
- The bottom ash equipment vendor has a +/- 20% factor in the cost estimate
- The estimate does not include sales tax, as the project is assumed to be exempt from sales tax
- The estimate does not include permitting for construction

- The site is balanced cut/fill
- The estimate does not include temporary fencing
- Curbs and gutters are not required for roads or parking areas
- Frost depth is assumed to be 48 inches (122 centimeters)

RMDS Retrofit Estimated Operations and Maintenance Costs

Estimated O&M costs for the RMDS include labor, dewatered ash disposal, power use, and maintenance. These are costs to be incurred after installation, since exact project costs will depend on the final design, landfill disposal site, and staffing for the system at Plant 5.

The proposed RMDS installation is essentially an addition to the existing bottom ash handling system. Because the new system will tie into bottom ash hoppers and clinker grinders that remain in place, there will be no additional O&M costs for these components. Replacing existing in-service ash pumps (and a standby pump) rated at 600 horsepower (448 kilowatts) with new pumps rated at 530 horsepower (395 kilowatts) (Table 7-4) will offer a notable reduction in O&M costs. The replacement is possible because the RMDS will be closer than the existing pond.

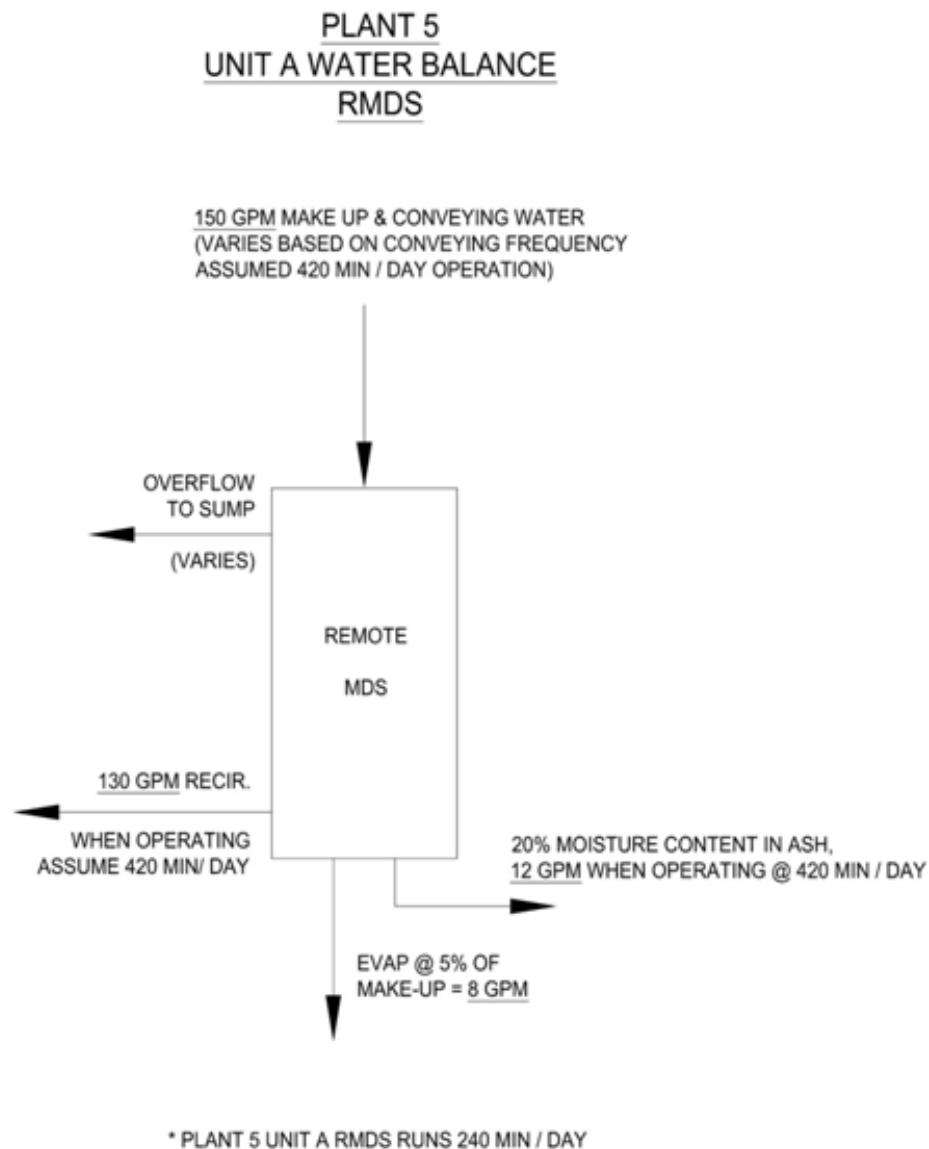
**Table 7-4
Plant 5 Unit A—RMDS Retrofit Estimated Annual O&M Costs**

Item	Annual O&M Cost Equation	Estimated Annual Cost
Labor	Cost = 1 Operator * \$100,000/year where: Operators = 1 for each day of pulling bottom ash + 1 for maintenance (2 total)	\$200,000
Utilities	Cost for 530-hp HPU = [(9 hours*530 hp)*(0.7457 kWhr)*(\$0.02 per kWhr)]*335 days/year	\$23,832
Bottom ash disposal	Cost = [105 tons/day] * [\$14/ton * 335 days/year]	\$492,450
Maintenance	Cost = 5% * total installed equipment cost Where: \$4,000,000 * 0.05	\$200,000
Drag chain replacement	Estimated with labor @ \$300,000, once every 5 years	\$60,000
	TOTAL ESTIMATED ANNUAL O&M COSTS	\$976,282

O&M = operations and maintenance
 530 horsepower (hp) = 396 kilowatts
 HPU = hydraulic power unit
 kWh = kilowatt-hour
 1 ton = 907.18 kilograms
 105 tons/day = 95,254 kilograms/day

RMDS Retrofit Water Balance

During normal operation, it is assumed that bottom ash conveyed from the RMDS has a moisture content of 20% by weight. It is also assumed that roughly 5% of the makeup water that is added to the RMDS will be lost to evaporation. Thus, the RMDS will require approximately 150 gallons of makeup water per minute (9 liters per second) to replenish water that leaves in the ash and losses due to evaporation. After each batch of bottom ash is sluiced, high-pressure recirculation pumps drive the remaining conveying water and added makeup water back to the bottom ash hoppers. Given the estimated number of batches per day and the required duration of each sluicing operation, the RMDS will run 420 minutes per day. Thus, it will require 63,000 gallons (240,000 liters) of water per day of operation. Figure 7-4 illustrates the RMDS water balance for Plant 5 Unit A.



**Figure 7-4
Plant 5 Unit A—RMDS Retrofit Water Balance**

RMDS Retrofit Proposed Schedule

The proposed schedule for the RMDS retrofit at Plant 5 Unit A (Table 7-5) is based on vendor information for engineering, fabrication, and delivery of the new equipment. The schedule also incorporates input from The Company's approved contractor.

Table 7-5
Plant 5 Unit A—RMDS Retrofit Proposed Schedule

Item	Duration
Vendor engineering, fabrication, and delivery	52 weeks
Balance-of-plant engineering and design	20 weeks
Site preparation	4 weeks
On-site mechanical and structural fabrication	4 weeks
Installation	14 weeks
Plant outage	3 weeks

8

SUMMARY OF FACTORS AFFECTING COST

As shown in the seven case studies discussed above, many factors come into play when a utility company chooses a wet-to-dry retrofit system for handling and storing bottom ash at a specific coal-fired power plant. The overall cost of such a retrofit can vary widely, depending on conditions at the power plant and the choices a company makes in response to them. This section summarizes factors affecting the cost of wet-to-dry retrofit technologies considered in this report.

Various factors may motivate a utility company to consider the installation of a dry bottom ash handling system. For The Company whose case studies are discussed in this report, high O&M costs of existing dewatering systems prompted their decision to evaluate installation of an MDS, RMDS, or PDT system. High O&M costs of existing wet systems are due to excessive clogging, corrosion, and heavy wear on clinker grinders and piping. The Company's desire to change water management strategies for its power plants in advance of possible regulation provides further motivation to evaluate alternative closed-loop or fully dry technologies.

Drivers of Technology Selection

The main drivers of technology selection for case studies discussed in this report include:

- Spatial resources
- Outage requirements
- Capital and O&M costs

Table 8-1 summarizes reasons for selecting either an MDS or RMDS for each of the seven case studies. Please note that technology selection is based on site-specific criteria. Thus, equipment needs, estimated costs, and the results of these case studies should not be extrapolated to fit other facilities or the industry as a whole.

**Table 8-1
Drivers of Technology Selection for Bottom Ash Handling System Retrofits**

Facility	Case Study	Bottom Ash Flow (gallons/minute)	Proposed Technology	Reasons for Selection
Plant 1	Unit A	500	RMDS	Reduced outage time, no clear conveyance path, access
Plant 2	Unit A	2,050	MDS	Sufficient space around boiler, reduced O&M
	Unit B	2,050		
Plant 3	Unit A	1,240	RMDS	Reduced outage time, restricted space
Plant 4	Unit A	1,380	RMDS	Restricted space
	Unit B	3,200	RMDS	
Plant 5	Unit A	4,000	RMDS	Reduced outage time, reuse of existing equipment, no clear conveyance path

RMDS = remote mechanical drag system
MDS = mechanical drag system
O&M = operations and maintenance
1 gallon/minute = 0.063 liters/second

Spatial Resources

The main driver of technology is available space under and around the boiler. For many facilities, retrofitting an existing boiler to install an MDS system will be impossible due to restricted space. Room must be available under the boiler to accommodate the following MDS components:

- Dewatering conveyor ramp
- Water trough(s)

Space for the dewatering conveyor ramp must accommodate a 30-degree rise from the end of the boiler/trough to the exterior wall. Likewise, there must be enough room for assembly and/or fabrication of the water trough(s) within the plant, near the boiler.

MDS installation demands ample space around the boiler for scaffolding, welding gear, and movement of parts and equipment. Once outage begins, additional room is needed for demolition and removal of the bottom ash hoppers and other existing equipment that will not be retrofitted.

Of seven case studies, only two (Plant 2 Units A and B) had enough space for installation and operation of an MDS. As described in Section 2, an MDS is the most cost-effective system, with lower capital and operating costs than those of an RMDS. According to United Conveyor Corporation, the MDS drag chain is the only large item that requires regular replacement, approximately once every three years.

When constraints prevent selection of an MDS, facilities must consider other technologies, such as an RMDS or a PDT system. For five of the seven case studies, tight spaces demanded selection of a technology other than MDS. At Plant 1 Unit A, there was insufficient room for the

transport conveyor to exit the building, and an adjacent warehouse kept operators from locating the ash loading area next to the building. At Plant 3 Unit A, large air compressors and heavy structural steel framing for the mezzanine level restricted space at the end of the boiler leading to the outer wall. The need to install MDS equipment in the basement at Plant 4 Units A and B resulted in access problems. Three existing coal mills prevented the installation of a dewatering ramp at Plant 5 Unit A. Thus, restricted space led to RMDS selection at each of these facilities.

Outage Requirements

One advantage of an RMDS over an MDS is reduced outage time for installation. An RMDS generally requires an outage of 3 weeks, at most, for tie-ins of electrical power, ash piping, and water piping. In contrast, an MDS requires an outage of approximately 6 to 12 weeks for demolition and installation. For example, MDS installation at Plant 2 requires an estimated outage of 12 weeks for Unit A and 12 more weeks for Unit B. Each outage period includes demolition time for removal of the existing bottom ash hoppers and installation time for the new system. Prefabrication of the MDS trough can reduce outage time during construction and installation.

Other Factors Affecting Cost

Distance from Boiler to RMDS

By definition, all major RMDS equipment is located far from the boiler. To minimize cost, it is important to keep an RMDS as close as possible to the outside wall of each boiler unit. Electrical costs rise with distance from the nearest available power block, as do piping costs. For example, the installed cost of an above-ground 10-inch (25-centimeter) basalt-lined carbon steel pipe with pipe supports is approximately \$200 per linear foot (0.305 meter), so the cost of piping can be significant if the RMDS must be located more than a few hundred yards from the boiler. Because an RMDS requires longer piping runs and larger pumps to transport sluice water, its piping, pipe support, and pump costs exceed those of an MDS.

RMDS Building

Climate conditions and the likelihood of temperatures that could freeze the water used to convey bottom ash will determine the need for a dedicated building to house an RMDS. Owners of facilities in northern climates will want to house RMDS equipment inside a building.

Redundancy

In the case studies presented here, there is no system redundancy for RMDS units. However, a utility company may elect fully redundant RMDS trains, which would significantly increase costs. Conversely, costs may decrease as the number of boiler units within a facility increases because each individual boiler may not need a separate RMDS. For example, a power plant that has five boiler units may require only three RMDS units. Dedicated piping and pumps would still be needed to connect each boiler to one of the RMDS units. MDS technology does not offer a similar opportunity for cost saving because it requires a separate MDS for each boiler.

Fines Management

Although many facilities will choose not to remove fines, some will elect to remove them using clarification. Treatment equipment for fines management using this technology includes:

- Clarifier
- Reaction tank and mixer
- Chemical feed system
- Polymer feed system
- Sludge holding tank and mixer
- Filter press
- Pumps

Installing a 2,500 gallon-per-minute (158 liter-per-second) clarification system would add \$10 million in treatment equipment costs for a facility.¹

On-site Landfills

New landfill design, permitting, and construction can significantly increase overall capital costs for a utility company. In these case studies, landfill costs were estimating at \$14/ton (907.18 kilograms). However, these costs will vary depending on the disposal site. In most cases, a facility would transport bottom ash to a landfill site by truck; building a conveyor to the landfill will add significant cost.

Existing Equipment Reuse

When selecting a bottom ash handling technology, facility owners should evaluate the potential to include existing equipment in a proposed retrofit. Reuse of existing equipment may reduce RMDS capital costs below those of MDS in certain cases.

Pneumatic Dry Transport System

If water consumption or water availability is a key issue, some facilities may need to evaluate installation of a PDT system that eliminates water use. A PDT system requires a storage silo, a surge storage bin, and an ash-conditioning mixer. Unlike an MDS or RMDS, a PDT system does not reduce boiler efficiency. Thus, it may be an attractive option for a utility company willing to pay the higher costs associated with such a system. A PDT system was evaluated at Plant 4 Units A and B. But higher capital cost, as well as plant engineering and installation costs, for the PDT system prompted facility owners to select an RMDS.

¹ *EPRI Comments on Proposed Effluent Limitations Guidelines Rule*. EPRI, Palo Alto, CA: 2013. 3002002231

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