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Enhancement of Central Heating Plant Economic Evaluation Program for Retrofit to Coal

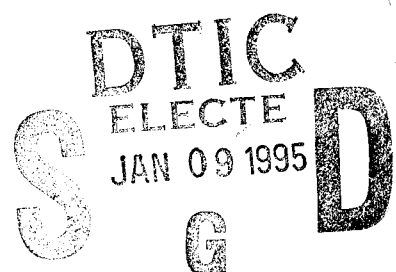
by

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Public Law 99-190 requires the Department of Defense (DOD) to increase the use of coal for steam generation. However, DOD also has an obligation to use the most economical fuel. Supporting the coal conversion effort, the U.S. Army Construction Engineering Research Laboratories (USACERL) has developed a computer program for engineering personnel at Major Army Commands, installation, the Defense Logistics Agency, and other DOD facilities to analyze the technical and economic feasibility of specific coal-combustion technologies at central heating plant facilities on military bases.

The program, Central Heating Plant Economic Evaluation (CHPECON), can model plants that have a capacity of 50,000 to 600,000 MBtu/hr of steam, with individual boiler sizes from 25,000 to 200,000 MBtu/hr. The technologies examined include coal-fired stoker and fluidized-bed boilers, oil/natural gas boilers, and coal-slurry boilers.

This report documents enhancements to existing CHPECON procedures for analyzing the retrofit or reconversion of a central heating plant to coal firing. They include: improving the screening and scoring process for boiler facilities considered for retrofit; adding options for converting a facility back to coal firing; detailing retrofit costs; upgrading economic analysis of a retrofit from an operating cost evaluation to a life-cycle analysis; and expanding the economic analysis to include examination of the condition of existing equipment.



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FOREWORD

This study was conducted for the Assistant Chief of Staff for Installation Management, ACS(IM), Directorate of Facilities and Housing, under the Coal Conversion Studies Program, which is administered by the Energy Policy Directorate of the Office of the Assistant Secretary of Defense, Production & Logistics, Energy Policy (OASD P&L/EP). Millard Carr is the Program Manager. Funding was provided under Military Interdepartmental Purchase Request (MIPR) V56HZV-89-AC-01, dated 20 November 1989, Work Unit R-Army-TACOM, "Coal Conversion Strategies for the Army, Retrofit Model Enhancement." The technical monitor was Qaiser Toor, DAIM-FOF-U.

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ENHANCEMENT OF CENTRAL HEATING PLANT ECONOMIC EVALUATION PROGRAM FOR RETROFIT TO COAL

1 INTRODUCTION

Background

The Fiscal Year 1986 (FY86) Defense Appropriations Act (PL-99-190, Section 8110) directed the Department of Defense (DOD) to rehabilitate and convert its central heating plants to coal firing where a cost benefit could be realized. The act set a FY94 coal consumption target of 1.6 million short tons* per year beyond DOD's 1985 U.S. coal consumption. The FY87 Defense Authorization Act (PL-99-500, Section 9099) reaffirmed the 1.6 million ton target, and added that it should include 300,000 tons of anthracite coal. This stipulation was to offset decreasing anthracite coal use on U.S. Army Europe (USAREUR) installations in Germany resulting from their connection to district heating systems. The FY87 Defense Authorization Act (PL-99-661, Section 1205) also affects the DOD's coal conversion program by directing that the primary fuel source in any new heating system be the most life-cycle cost effective. This means that the DOD cannot require a new plant to burn coal unless it can also show that coal will be more economical than oil, gas, or other fuels over the life of the plant.

To help the Army comply with these requirements, the U.S. Army Center for Public Works (USACPW) requested the U.S. Army Construction Engineering Research Laboratories (USACERL) to provide technical studies and support for the Army's Coal Conversion Program. A series of screening and life-cycle models were developed to determine when and where specific coal combustion technologies could be implemented (Lin 1992a, 1992b).

Objectives

The primary objective of this project was to enhance the screening and life-cycle cost models of the Central Heating Plant Economic Evaluation (CHPECON) computer program. These changes will empower CHPECON to better analyze the feasibility of retrofitting or reconverting a central heating plant to coal firing. The enhancements include retrofits only partially covered in the prior version of CHPECON. Other additions were retrofit options for converting a boiler plant that had originally been designed for coal firing and had been converted to another fuel, back to coal. This process is called reconversion.

Other features were added to the CHPECON program to upgrade its user-friendliness, and are documented here.

* A metric conversion table is located on page 72.

Approach

The plant sizes examined in the model have a capacity of 50,000 to 600,000 MBtu/hr of steam, with individual boiler sizes from 25,000 to 200,000 MBtu/hr. The technologies examined include coal-fired stoker and fluidized bed boilers, oil/natural gas boilers, and coal slurry boilers. As originally developed, CHPECON allows a user to select a military base, characterize the base through heating load parameters, identify a particular boiler technology, select a coalfield for simulated use, and answer general questions about the acceptability of the facility. The evaluation technique provides a consistent approach for evaluating competing technologies through the development of economic measures of project acceptability, including total life-cycle cost and levelized cost of service. The model provides sufficient flexibility to vary critical design and operating parameters.

This report discusses the various aspects of the retrofit enhancement project. This includes the rationale for the various types of retrofits considered, additions to the screening analysis that document the condition of existing equipment, the new cost elements used for determining the installed cost of retrofitting an existing boiler (including those based on existing equipment condition), and the evaluation of the life-cycle cost for the facility with the retrofit.

Also included in this report are sections covering the user interface for CHPECON where it has changed to incorporate reconversion analysis.

Scope

The models developed are generally applicable to industrial or large commercial-size facilities. The economic evaluation program for screening and life-cycle costs will serve as a tool to select and rank potential Army sites for coal retrofit or reconversion.

Mode of Technology Transfer

It is recommended that the information presented in this report be disseminated in a Public Works Technical Bulletin (PWTB). It is also recommended that the CHPECON computer program be given to the Army major commands (MACOMs) for distribution to each installation for long-range utility planning. Costs of utilities should be updated by the users to keep the estimated values current. If sufficient interest exists, a user support group may be established for this program to maintain and update the existing software or documentation.

2 RETROFIT CONVERSION OPTIONS CONSIDERED

The types of facilities and the limitations of various boiler/burner technologies restrict the number of potential combinations for retrofit. This chapter discusses the issues involved in the various combinations and the rationale for their inclusion or exclusion in the list of conversion options incorporated into the CHPECON program.

Issues in Conversion to Solid Fuel

The primary issues to be addressed in converting a boiler or boiler house to coal firing are: layout and size of the boiler(s), the arrangement of components around the facility, and the room or space that is available for the placement of auxiliary facilities. These issues provided general guidelines that led to the retrofit options incorporated into the CHPECON program. The feasibility of any individual option must be fully evaluated by qualified engineers before proceeding with any conversion.

Combustion Issues in Conversion

The biggest issue in considering the retrofit of a boiler to coal firing is the capability of the boiler to accept a lower combustion intensity and still deliver the necessary levels of steam. The primary difference between the various fuels is combustion intensity, or the amount of energy released in a given volume. (Shah, Blazek, and Laurens 1990, pp 10-15) This affects the size of the firebox needed to contain the combustion process, the temperatures reached (which the boiler must withstand), the heat-exchanger type, and arrangement to withdraw the heat from the combustion products effectively. Natural gas firing has the highest combustion intensity, and flames from gas burners are typically the shortest. Oil firing is somewhat lower and results in greater flame lengths. Micronized coal is next, followed by pulverized coal, with the longest flame of these fuels. The above four fuel types can be burned in a similar manner, with a "jet" of fuel and air moving into the combustion space where the energy is released. Spreader stoker and moving grate boilers exhibit the lowest combustion intensity, and differ in that the coal is distributed over a surface in a layer, or bed, where combustion occurs.

Conversion to any form of solid coal firing for natural gas-only boilers would be extremely difficult because of the great discrepancy between combustion intensities. The only approach that has had much success is placing the burners external to the original boiler and directing the combustion products into the boiler. This allows the combustion to occur in an external chamber designed to handle it. The slagging coal combustor (Blazek et al. 1990) takes this approach and is therefore a potential candidate for natural gas to coal conversion.

Conversion to micronized coal firing for heavy oil or oil/gas boilers is possible because the combustion intensities and flame lengths are similar. This helps to ensure that the boiler can provide adequate space for combustion to occur. In addition, the heat transfer that can be achieved with micronized coal is similar to oil; conversion is possible without extensive modifications to the heat exchangers. Another issue that is critical to conversion is a boiler's ability to handle fly ash and bottom ash. For micronized coal combustion, the small amount of ash left in the coal is entrained as fly ash in the combustion products.

Conversion to traditional pulverized coal for oil or oil/gas boilers is generally not considered to be feasible due to the lower combustion intensities and greater flame lengths encountered with pulverized coal. An exception to this is the slagging coal combustor, which takes the coal flame and swirls it in a

cylindrical combustor before injecting the combustion products into the boiler. This accommodates the longer flame lengths and has the advantage of containing the slag in the combustor, leaving much less flyash in the combustion gases than traditional pulverized coal burners do. Reducing flyash reduces the erosion on heat-exchanger tubes and other boiler components.

Conversion to fluidized bed combustion for coal firing may be feasible. Atmospheric fluidized beds are preferred over pressurized fluidized beds because of the potential difficulty in establishing and maintaining the boiler shell to contain the pressurized gases. Of the two major types of atmospheric fluidized beds, the bubbling bed is considered to be better for retrofit than the circulating bed. The circulating bed requires more height for the bed and more room for the separator to trap the bed particles than is typically available in an existing boiler house, including stoker boilers. The bubbling bed is much shorter and may be accommodated in existing structures.

Conversion to bed-based coal firing requires enough horizontal area for the coal to be spread out for combustion. It also requires additional vertical room for the complete combustion of the coal, as fine particles are lifted by the underfeed combustion air. Most oil, gas, and oil/gas boilers do not have enough room to contain the volume and area requirements of bed-based coal firing approaches. As a result, there is no option for conversions of this type.

Oil and gas boilers that were originally constructed for coal and had been converted to oil or gas firing are suitable for conversion (or more appropriately reconversion) to their original form.

Heavy oil-fired boilers are an exception to the general rule on oil boilers. Due to heavy oil's composition (including a number of contaminants) and physical properties, it burns at a rate closer to coal than to oil and gas. These boilers are also typically equipped with soot blowers and ash removal systems that can be modified to handle coal combustion. As a result, heavy-oil boilers can be considered for more conversion options than light-oil/gas boilers.

Other Issues in Conversion

The type and condition of the physical site plays a part in the consideration of the conversion potential. For example, coal bed-based boilers need a way to collect bottom ash. Oil and gas boilers do not need this and typically do not have a basement (or equivalent level) where bottom ash can be collected. Conversion of such a facility actually requires jacking up the boiler and either digging a basement and replacing the boiler, or inserting a bottom ash collection section under the raised boiler. This is one reason why oil/gas to coal conversion can be expensive.

Typically, coal is stored in overhead bunkers from which it is drawn and fed to the boilers below. If the building was originally designed for coal boilers and was later converted to oil or gas and the overhead bunkers are still in place, this method of feeding the boilers can be reactivated. If the structure is lightweight, some form of ground storage and horizontal transport (possibly a screw conveyor) is required. However, this method makes it harder to measure the amount of coal fed to a boiler. Using pulverized and micronized coal presents fewer problems moving coal to the boiler since the ground-up coal is carried pneumatically.

In addition to feeding the coal and removing bottom ash, the equipment for removing flyash and treating the stack gases requires room around the boiler and appropriate routing of the stack gases. Like many other factors affecting a particular conversion, this can only be addressed on a case-by-case basis with site inspection.

Slurry Substitution for Oil

Conversion to coal slurry firing for oil boilers is included as an option because it represents the substitution of one liquid fuel for another. Although the burners, controls, and other components are different, a coal slurry boiler does not need to be significantly different from an oil boiler. Problems in bottom ash and flyash handling are not present because the components that contribute to ash production are removed during the process of creating the slurry. However, coal slurry conversion from gas-only boilers may not be possible because a boiler optimized for the high combustion intensity and short flame lengths produced by natural gas would not be able to accommodate the different burning characteristics of the coal slurry.

Oil/Gas to Coal Conversions

Many coal boilers have been converted to oil and/or gas firing. The conversions are usually done to take advantage of the reduced fuel costs and lower maintenance requirements of a boiler running on oil or gas. Most conversions were accomplished by removal of the grate subsystem and insertion of burners and fuel lines. Reworking of the refractory material may have also been done to cover openings for handling coal and ash.

Coal boilers can also be augmented (instead of completely converted) using the same procedures to allow firing with oil or gas as an alternate to coal or co-firing with coal. Components handling flue gas treatment can either be left in place (such as mechanical collectors) or removed (such as baghouses). The actual handling is determined in part by the pressure drop of the component and the level of maintenance required if the component were left in place. For example, a baghouse with a bag in place will cause a pressure drop that must be overcome by the fans moving the combustion products through the bag. Since there are far fewer particulates produced by oil or gas firing to be captured by the bag, the energy spent overcoming the additional pressure drop accomplishes nothing beneficial. Removing the bag lowers the power consumed by the fans, since a baghouse without a bag is essentially an open box through which the stack gases flow.

The conversion of oil/gas boilers converted from coal back to coal operation, or reconversion, consists of the replacement of the components removed when the boiler was originally converted. Since the boiler was designed for operation with a bed of coal, with enough room for combustion of the coal, an appropriate method of removing ash, and with heat exchangers capable of handling the heat output from burning coal, reconversion may be the most straightforward conversion option that can be considered through CHPECON.

Conversion back to coal-fired operation has been defined as conversion back to the original configuration. Placing a traveling grate into a boiler that was designed for a dump grate spreader stoker would require significant redesign of other related subsystems, e.g., the coal feeder. The cost for conversion to an alternate grate is dependent on the particular physical configuration of the boiler. Because changing to a different grate is site-specific, there are no costs available to use in the CHPECON analysis.

Coal Gasification

Coal gasification processes for synthesis gas (low Btu) production were commercialized in the 1950s. The technology has been advanced, and permits running a gas or oil/gas boiler on the synthesized gas from coal gasifiers. The differences between burning natural gas (high Btu) and synthesized gas (low Btu) are smaller than the differences in burning natural gas and coal. Burning synthesized coal gas is therefore considered to be a feasible conversion approach. The primary difference is that burners must introduce a higher volume of synthesized gas to the boiler to compensate for the lower energy content.

3 SCREENING MODEL ANALYSIS

A computer-based screening model was developed as part of CHPECON to aid Army planners with the preliminary evaluation of potential sites for retrofits and reconversions of coal-fired central heat plants. The screening model is menu-driven, prompting the user to supply information describing the facility's characteristics and energy needs. Based on the supplied inputs and internal database information, the program lists the relevant plant parameters. In addition to calculated outputs, a subjective weighted analysis output provides an assessment of the feasibility of retrofit and reconversion projects.

The screening model contains questions relating to a variety of central heating plant topics. The user is requested to provide information on each of these topics to assist the program in developing conceptual sizing and cost data. These topics include the following:

- Plant site information
- Heating plant monthly loads, Plant Maximum Continuous Rating (PMCR) calculation
- Conceptual boiler number/sizing choices
- Fuel search
- Water requirements/availability
- Plant/boiler performance estimates
- Plant area requirements/availability
- Fuel storage area requirements/availability
- Subjective weighted factors.

The functions of the screening model and its operation through CHPECON are detailed in the report *Central Heating Plant Economic Evaluation Program* (Lin et al. 1992a). Only the changes required to incorporate the enhanced retrofit and reconversion functions are discussed below. This includes a description of the procedure to input the state of existing equipment, and a review of the user interface of CHPECON for the screening model.

Retrofit and Reconversion Considerations

Several screening factors apply to retrofit and reconversion options. First, no special considerations are required for the fuel specification. Any fuel that is acceptable for a new plant is assumed to be acceptable for a retrofit or reconversion project for the same type of boiler. For example, a reconversion to a traveling grate spreader stoker accepts the same range of coal properties that a new traveling grate spreader stoker boiler does. Second, emission factors in retrofit and reconversion projects should be equivalent to those in a new plant. In other words, retrofit and reconversion work should include a provision that the plant emission levels be equivalent to a new facility of the same type. Emission standards are also assumed to be no different for a retrofit/reconversion facility than for a new plant. Finally, the subjective screening questions for retrofits and reconversions are identical to the questions for new plants. These subjective questions are important in helping to determine the overall feasibility of the retrofit/reconversion project from a number of perspectives that cannot be easily quantified.

Current Equipment Condition

As part of the overall screening process that determines a military base's suitability for a coal-fired retrofit for existing boilers, the state of the current equipment needs to be considered. This is necessary to consider the potential cost impact of the retrofit being evaluated. For example, if an existing boiler facility is operating with a suitable water treatment system for preparing boiler feedwater, the cost for installing a new water treatment system is not needed.

In some of the technology options for retrofitting a boiler, it is possible that part of the existing facility can be used with little or no modification. A boiler that had been converted from coal firing to oil firing and is being considered for reconversion back to coal firing, may have a number of operational or semi-operational pieces of equipment. For example, the rails and associated equipment for unloading coal from rail cars may have been left in place because there was not any need for their removal. Reconversion back to coal firing can use existing equipment with minimal effort; there are provisions in CHPECON to allow for this retrofit cost savings.

To specify a quantitative measure for the condition of the existing equipment, four different tiers were defined for use in CHPECON. The four equipment condition levels are defined as follows:

1. Replacement required. This level covers the conditions that require a complete replacement of the existing equipment. This might be necessary because the existing equipment has significantly degenerated beyond the point it can be repaired or have parts replaced. Outdoor equipment that has rusted beyond repair is one example. This option also covers situations where the equipment has been removed or was never in place.
2. Not functional. Equipment in this category is in place but is not operational. This equipment could, however, be rebuilt at significantly less expense than direct replacement.
3. Functional. This condition level represents equipment that is usable in its current state but requires a minimal effort to ensure that it can be used for the retrofitted facility. Equipment that could fit into this category is anything that can be easily torn down, cleaned, and rebuilt, such as a pump.
4. Operational. This condition level covers equipment that is currently in operation and would need no effort to ensure its continued operation in a boiler facility that has been retrofitted for coal firing. An example of this is the water treatment system that is needed for the existing facility (whether retrofitted or not) anyway.

The equipment (capital) costs incurred in the retrofit are based on these categories of equipment condition. The labor, freight, bulk material, and related costs are also affected by the equipment condition indicated by the user. In general, estimates of the costs for removing existing equipment and modifying the installation to accept new equipment have been included in the cost analysis described later in this report.

The following paragraphs outline equipment categories and the allowable conditions for each of them.

Boiler Burner Assembly

The retrofit of an existing boiler consists of the installation of the grates, coal feeds, and related equipment, with the possible removal of the existing burners. In some cases, an existing burner assembly

may be left in place as an alternate or emergency backup. In the case of the coal gasification option (generating low-Btu gas for use in natural gas boilers), the burner assembly retrofit consists of the gasification equipment and the modifications necessary to properly run the natural gas burners on low-Btu gas. These burners must be replaced—this is the heart of the retrofit.

Rail and Truck Equipment for Coal Unloading

This equipment consists of the equipment for handling the truck trailers and/or rail cars for coal unloading. As a user option for this category, it can also include a reclaim system that recovers coal spilled while unloading. For the installation of a retrofit technology that is a reconversion of a boiler originally designed to operate on coal, three possible options are allowed depending on the state of the equipment: replacement or new equipment required, not functional (requires major work), and functional (needs minor servicing). This recognizes the possibility that the equipment is still in place even though the boiler was converted to operation on another fuel.

A simple retrofit (not reconversion) has only one option—new equipment is required. An oil— or gas-fueled boiler would not normally be equipped with this type of machinery and would need all new equipment.

Car Dumper for Coal Unloading

The acceptable options in a reconversion are: replacement or new equipment required, not functional (requires major work), and functional (needs minor servicing). This recognizes that the car dumper may be usable even though it may not have been used recently.

The only option for a simple retrofit is that new (replacement) equipment is needed.

Coal Pile Runoff Pond

The coal pile runoff pond receives rainwater from the storage areas for coal. The procedure for sizing this pond is described in *Ground Storage of Coal* (Technical Manual [TM]5-848-3), and uses the rainfall from the worst storm in 10 years with a duration of 24 hours for the location. The screening analysis uses a conceptual size that will accommodate 4 in. of rain over the area of the coal piles with an average pond depth of 4 ft. (the equivalent of the above TM criteria).

If the retrofit option under consideration is a reconversion (back to the original coal firing from a previous conversion), the runoff pond may have been left in place. The area may not have been needed enough to justify the removal of standpipes, groundwork, and pond liners. Recognizing that the pond may still be present the allowable options are: replacement or new equipment required, not functional, and functional. Replacement would be required if the old pond was removed, if one had never existed, or the existing pond required extensive work. A "not functional" pond would be indicated if the pond was present but required major work before use, such as draining and replacement of some of the liner. A "functional" pond would be one that needs only minor repair, such as replacement of a broken standpipe or reinforcement to some of the earthwork around the pond.

The option for a retrofit of a boiler originally fired with another fuel (not coal) is installation of a new pond. Coal firing is the only process that requires an area for storing and containing rainwater runoff; it is exceptionally unlikely that a facility designed for burning another fuel would have a preexisting pond capable of accommodating the runoff.

Car Heating/Thawing Equipment

Car heating or thawing equipment warms incoming fuel deliveries for proper unloading. Because the equipment from a facility's coal days may still exist, a reconversion allows three levels of equipment condition: replacement, not functional, and functional. A facility converting from another fuel that was not originally coal would not have had this equipment; the only option in this case is to install new equipment, if required. In the cost analysis, the user indicates whether car heating or thawing equipment is needed.

Coal Silo

The coal silo is used for short-term storage of coal and is an option selected for inclusion in the cost analysis. Coal silos may have been present if the facility originally had used coal. To accommodate this, a reconversion allows three levels of equipment condition: replacement, not functional, and functional. A facility converting from another fuel that was not originally coal would not have had silos for coal storage, so the only option in this case is to install new equipment, if it is required.

Slurry Fuel Handling and Storage Equipment

The only option for the condition of equipment required for slurry fuel unloading and storage is replacement. Coal slurry firing is a relatively recent technique and would not have been around long enough to have been converted to another fuel that is being considered for reconversion.

Ash Handling, Storage, and Treatment Equipment

The ash-handling equipment can only be found on boilers originally designed for coal. As a result, the options for existing ash equipment for a reconversion are: replacement, not functional, and functional. A facility being converted from another fuel that was not originally coal would not have required ash handling, so the only option in this case is to install new equipment.

Mechanical Collector

As with the previous equipment, the mechanical collector would only be found on boilers originally designed to handle coal. Therefore, the options for mechanical collectors for a reconversion are: replacement, not functional, and functional. A facility converting from another fuel that was not originally coal would not have required a mechanical collector for flyash collection, so the only option here is to install new equipment.

Baghouse

Baghouses are used for filtering combustion products to trap the finer flyash that has not been picked up by previous equipment in the stack gas path. A facility converting from another fuel that was not originally coal would not have required a mechanical collector for flyash collection, so the only option here is to install new equipment.

Since a baghouse would only be found on a boiler originally designed to handle coal, the options for the condition of existing baghouses for a reconversion are: replacement, not functional, and functional. The replacement option would be necessary if the baghouse was actually removed or is structurally weakened. A functional state would indicate that it can be used with minor repairs. This would be true if bags were present in the baghouse. However, the bag would have probably been removed when a different fuel was used because it would not be needed and its removal would decrease the energy

requirements of the boiler fans (as the pressure drop associated with the bag is gone). Therefore, most baghouses would probably fit into the not functional category because they would require installation of new bags and some effort to verify that the house and surrounding lines are ready to accommodate the additional pressure drop due to the bag.

Induced Draft Fans

Induced draft fans pull the boiler flue gas from the boiler through equipment such as the mechanical collector, dry scrubber, and baghouse, and exhaust the gases into the boiler stack flue. A facility converting from another fuel that was not originally coal would not have required an induced draft fan, so the only option in this case is new equipment. When a facility has been previously converted from coal-fired boilers, the presence of induced draft fans is more likely. Therefore, the options for induced draft fans for a reconversion are: replacement, not functional, and functional.

The replacement option would cover situations where the induced draft fan had been removed or is inoperable (physical examination is required to determine its state). A functional state would indicate that it can be used after minor repairs. This would be true if the fan were left in place and only needed to be serviced to ensure proper lubrication and replace missing components (possibly belts for the drive). However, if the fan was left in place for some time and experienced extensive wear or rust, or was removed and stored and is still available, it would fit in the category of not functional because of the effort required to make it operable.

Water Treatment Facility and Testing Lab

The equipment associated with processing boiler feedwater before delivery to the boiler is one class of equipment that must be functional regardless of the type of fuel that the boiler uses. Because of this, an existing boiler facility considered for retrofit study through CHPECON would already be using water treatment. Since it is likely that the facility can be used after the retrofit, only two options are allowed. Either a replacement water treatment facility is required, or the facility is operational and needs no work. The first option accommodates the possibility that a new system is required to replace a worn existing system. Acknowledging that the system is operational allows the cost analysis to proceed without considering additional expense for a new water treatment facility.

Storage and Treatment Tanks

Tanks associated with boilers also need to be functional independent of the type of fuel the boiler uses. Because of this, again, the only two options allowed are replacing the tanks or not, if they are operational and need no work. The first option accommodates the possibility that new tanks are required to replace the existing tanks. The operational state allows the cost analysis to proceed without considering additional expense for new tanks.

Facility Pumps

The boiler and associated pumps are equipment that needs to be functional independent of the type of fuel the boiler uses. Again, only two options—replacing the pumps or pumps are operational and need no work—are available.

Air Compressors

Air compressors are also components that may be present for boilers of all types, independent of the fuel. They are used both for general facility air and for instrument air. Two options, either replacement air compressors or air compressors are functional and need no work, are available.

Pond Neutralization Equipment

The pond neutralization equipment uses programmable controllers for caustic, coagulant, and acid feed rates and pH control. Options for existing equipment for pond neutralization are replacement or new equipment required, not functional (requires major work), or functional (needs minor servicing).

Storm Sewer System

The storm sewer system is present on a facility independent of boiler type or presence. However, it is possible that the sewer system may be inadequate for handling rainwater and wash water from the ash and coal areas. To allow for the possibility that the sewer system needs to be upgraded or replaced, the allowable options for the storm sewer system are: replacement sewer system is required, not functional (requires major work), or functional (needs minor servicing). Although the actual cost for a replacement sewer system can only be determined after a detailed engineering study, the options permit recognition of a broad range of costs. The condition of the sewer system was not considered to be operational because retrofitting for coal requires (at minimum) connecting new drains for the coal and ash areas to existing lines.

Piping for Slurry Fuel

The only option available for slurry fuel piping is the installation of new equipment. Coal slurry firing is a relatively recent technique and has not been around long enough to have been converted from coal to another fuel now up for reconversion.

Boiler Facility Stacks

Any boiler facility will have some form of stacks for carrying the flue gas above the level of surrounding buildings. For many reasons, an existing facility may have stacks that are suitable for coal-fired operation. However, the simplest gas and oil boiler stacks may not be adequate, even if modified, which would require direct replacement. To cover these possibilities, the options for existing stacks are: replacement or new stacks required, not functional (requires major work), or functional (needs minor servicing).

Diesel Generator Equipment

Backup diesel generators can be found in any boiler facility. The options for existing diesel generator equipment are either functional, but requires servicing, or the generators are operational and need no work. Backup electrical power generation is required at a boiler facility and should be usable for the boilers after being retrofitted.

Electrical Substation Equipment

An existing boiler facility is equipped with some form of electrical substation due to the amount of power consumed in a relatively small area. In general, they are reasonably oversized to accommodate any significant changes to the facility's equipment. This oversizing can be used to the advantage of a retrofit

to coal by covering the additional load brought on by the coal handling equipment and induced draft fans (these being the largest power-consuming components that would be added). The functional substation option has been incorporated to allow for the minor reworking of the substation that might be required. Because an existing substation could be used, the options for the substation are either that it is functional but needs servicing, or it is operational and needs no work.

4 SCREENING MODEL USER INTERFACE

The CHPECON program was modified to include new retrofit enhancements. This chapter outlines the changes and important considerations in the retrofit analysis screening model. Program operation documented in *Central Heating Plant Economic Evaluation Program* (Lin et al. 1992a) remains the same.

After startup, CHPECON presents the main menu screen shown in Figure 1, the general option categories.

```
Central Heating Plant Economics Evaluation Program          02/24/93
Main Menu

1 -- Screening models
2 -- Cost Models
3 -- Multiple Run Analysis
4 -- Sensitivity Analysis
5 -- Load Sensitivity Analysis
6 -- Update Databases
7 -- System Utilities
Q -- Quit (exit program)

-----
Use ↑↓ to move highlight or enter first character to select option
-----
Determine a base's general suitability for a coal-fired or oil/gas boiler
plant
```

Figure 1. CHPECON Main Menu Screen.

When the user selects **1 -- Screening Models**, CHPECON displays the general type of boiler facility study shown in Figure 2. The first four options cover the various new boiler facility analyses the CHPECON was written to evaluate. The fifth, **5 -- Retrofit plant**, analyzes the feasibility of a retrofit technology for an existing boiler facility.

```
Central Heating Plant Economics Evaluation Program          02/24/93
Main Menu -- screening model

1 -- New plant
2 -- New plant with cogeneration
3 -- New plant with third-party cogeneration
4 -- New plant with consolidation
5 -- Retrofit plant
Q -- Quit (return to main menu)

-----
Use ↑↓ to move highlight or enter first character to select option
-----
Retrofit existing plant, using general factors for upgrades
```

Figure 2. CHPECON Screening Model, Case Type Menu Screen.

The screen shown in Figure 3 results when the retrofit plant option is selected. From this, individual cases (files) can be generated, deleted, and printed.

```
Central Heating Plant Economics Evaluation Program          02/24/93
Main Menu -- screening model                             Retrofit plant (RT)
```



```
1 -- Create new case
2 -- Use existing case
3 -- Delete existing case from storage
4 -- Print case study
Q -- Quit (return to screening model menu)
```



```
-----
Use ↑↓ to move highlight or enter first character to select option
-----
Produce a new screening model evaluation
```

Figure 3. CHPECON Screening Model, Case Analysis Menu Screen.

Once 1 — Create new case is selected, the screen in Figure 4 appears. A unique eight-character file name must be specified for data storage, which the program checks for acceptance before using.

```
--File--          CT          --Case description-----
6407CG            CG            NAS WHITING FLD MILTON
6407NP            NP            NAS WHITING FLD MILTON
6432CG06          CG            NAS WHITING FLD MILTON
6432CGNG          CG            NAS WHITING FLD MILTON
6432NP06          NP            NAS WHITING FLD MILTON
6432NPNG          NP            NAS WHITING FLD MILTON
A01              NP            JOLIET ARMY AMMUNITION PLANT
A02              NP            JOLIET ARMY AMMUNITION PLANT
A1               NP            Joliet Army Ammunition Plant
A2               NP            Joliet Army Ammunition Plant
A3               NP            Joliet Army Ammunition Plant
A4               NP            Joliet Army Ammunition Plant
A5               NP            Joliet Army Ammunition Plant
A6               NP            Joliet Army Ammunition Plant
B1               NP            Joliet Army Ammunition Plant
B10              NP            Joliet Army Ammunition Plant
B11              NP            Joliet Army Ammunition Plant
B12              NP            Joliet Army Ammunition Plant
B13              NP            Joliet Army Ammunition Plant
```



```
Enter file name to use: RT3 (must be new)
? to list more files or blanks to quit
```

Figure 4. Filename Specification Screen.

After entering a file name, the user selects a military base/location for the study. Figure 5 displays the available base entries. An enhancement from the original interface, this screen allows the user to either pick the base name from the displayed list or input the name directly (previously, the user could

only pick from a list of 142 bases). Once the facility is specified, the program continues executing the screening model, from the emission region specification to the boiler load input section. The user can access average boiler load data from the INVENTORY database files, included in the CHPECON program.

```
Joliet Army Ammunition Plant
Joliet Army Ammunition Plant
Kansas Army Ammunition Plant
Lake City Army Ammunition Plant
Letterkenney Army Depot
Lexington-Blue Grass Army Depot
Lima Army Tank Center
Lone Star Army Ammunition Plant, Texarkana
Longhorn Army Ammunition Plant
Louisiana Army Ammunition Plant
Mcalester Army Ammunition Plant
Milan Army Ammunition Plant
Mississippi Army Ammunition Plant
Mobile/Bates Field
Monterey, Presidio Of
Montgomery/Dannelly Field
Natick Research and Development Center
Navajo Depot Activity
New Cumberland Army Depot
Newport Army Ammunition Plant
Use <↑> <↓> <PgUp> <PgDn>, <Enter> to accept, <Esc> to quit or type in
search string (JOL)
```

Figure 5. Military Base/Location Selection Screen.

If the INVENTORY data is accessed, the screen shown in Figure 6 is displayed. The average monthly loads listed help determine the sizing of the boilers, as a check to ensure the retrofitted boilers will adequately meet the load. The user either enters the average monthly loads or modifies the values retrieved from the INVENTORY database. The values can be adjusted or the user can manually enter a PMCR value.

The user then proceeds to the program section for entering the general boiler house information on facility leakage, blowdown rates, amount of condensate return, and incoming condensate and makeup water temperatures. These values are required to determine makeup water requirements and incoming enthalpies of the boiler feedwater—important to the overall efficiency calculations.

After general boiler house information, the user selects the retrofit technology to be analyzed. This is done from one of the two screens shown in Figures 7 and 8. Figure 7 lists retrofit technologies; Figure 8 lists the boiler reconversion options. One technology must be selected specifying the number of boilers and their current sizes. Then a coalfield with compatible properties is selected by the user. Fuel area sizing is selected next based on the specified number of days storage to be maintained on the base.

The user must next answer general questions to determine if the facility is suitable for coal-fired operation.

CHPECON then asks the enhanced general facility and construction questions. The questions are shown in Figures 9 through 16. They deal with issues that concern both new and retrofitted facilities, including whether a base would be disrupted in any way by the movement of people and equipment during

Enter the process load (unrelated to heating) that the plant will experience: 0 million Btu/hr
(or 0 if there is no process load)

Enter average monthly steam flows (AMSF) in million Btu/hr
-PMCR- (1000 lb/hr steam
@ 150 psi, 367 °F)

	AMSF	-PMCR-
Jan	166	197
Feb	147	177
Mar	121	195
Apr	88	199
May	46	199
Jun	32	195
Jul	32	197
Aug	29	193
Sep	42	198
Oct	55	197
Nov	112	199
Dec	130	198

Selected PMCR: 200 thousand lb steam/hr

Accept values / Edit entries / oct-mar Only /
Modify pmcr manually (A/E/O/M) « »

Figure 6. Monthly Average Boiler Load Specification Screen.

Heavy Oil Stoker to Dump Grate Spreader Stoker w/ f/a/r
Heavy Oil Stoker to Dump Grate Spreader Stoker w/o f/a/r
Heavy Oil Stoker to Vibrating Grate Spreader Stoker w/ f/a/r
Heavy Oil Stoker to Vibrating Grate Spreader Stoker w/o f//r
Heavy Oil Stoker to Recip. Grate Spreader Stoker w/ f/a/r
Heavy Oil Stoker to Recip. Grate Spreader Stoker w/o f/ar
Heavy Oil Stoker to Traveling Grate Spreader Stoker w/ /a/r
Heavy Oil Stoker to Traveling Grate Spreader Stoker w/ f/a/r
Heavy Oil Stoker to Traveling Grate Stoker
Heavy Oil Stoker to Chain Grate Stoker
Heavy Oil Package System to Coal-Oil Slurry
Heavy Oil Package System to Coal-Water Slurry
Heavy Oil Package System to Bubbling Bed
Heavy Oil Package System to Micronized Coal
Heavy Oil Package System to Low Btu Gas (gasification)
Heavy Oil Package System to Slagging Coal
Coal Stoker to Slagging Coal

«« Next screen »»

Figure 7. Retrofit Boiler Technology Selection—First Screen

the retrofit. Another important issue considered is the possible presence of asbestos in any area being disturbed by the work. Older facilities being considered for retrofit may be more likely to encounter problems with asbestos due to its widespread use up through the 1970s.

```

«« Previous screen »»

Reconversion--Dump Grate Spreader Stoker w/ f/a/r
Reconversion--Dump Grate Spreader Stoker w/o f/a/r
Reconversion--Vibrating Grate Spreader Stoker w/ f/a/r
Reconversion--Vibrating Grate Spreader Stoker w/o f/a/r
Reconversion--Reciprocating Grate Spreader Stoker w/ f/a/r
Reconversion--Reciprocating Grate Spreader Stoker w/o f/a/r
Reconversion--Traveling Grate Spreader Stoker w/ f/a/r
Reconversion--Traveling Grate Spreader Stoker w/o f/a/r
Reconversion--Chain Grate Stoker

```

Figure 8. Retrofit Boiler Technology Selection—Second Screen.

```

Central Heating Plant Economics Evaluation Program          file: RT3
Retrofit plant (RT)

```

```

Contractors are near the base: yes
Asbestos present in CHP-related areas: no
Building and equipment foundation support adequate: yes
Special Site cleanup required before construction: no
Site accessible for construction personnel and equipment: yes
Soil suitable for minimizing wastewater seepage: yes
Sufficient level ground for the CHP: yes
Adequate utility access for CHP connections: yes
Interference from terrain issues: yes
Sufficient construction storage area (wastes): yes
Free of infrastructure constraints: yes
Interference from other construction: yes

«« Next screen »»

```

Figure 9. Retrofit General Questions Screen 1.

After reviewing the enhanced set of general questions, the user proceeds to the new section for inputting the condition of existing equipment, as shown in Figure 17. Each item represents an equipment category for analysis. A highlight bar indicates the currently selected equipment, which can be moved with the <Up> and <Down> keys. Pressing the <Enter> key generates a list of allowable conditions for the equipment type. As for the general list, <Up> and <Down> move the highlight bar and <Enter> selects the equipment condition.

Once the equipment condition is fully specified on the first screen, the program automatically moves to the second screen (an example of this is shown in Figure 18).

Only options that apply to a given retrofit technology are available, although all are shown. Questions that are not applicable are displayed in a shadowed format, indicating they are not available. Before all the applicable equipment categories are reviewed, the options to move to the next screen, prior screen, and quit the section are inactive. After everything has been answered once, the user can move between the two screens to make any final adjustments before exiting this section.

Central Heating Plant Economics Evaluation Program file: RT3
Retrofit plant (RT)

«« Previous screen »»

Staff available for coordinating activities: yes
Flood problems or potential problem: no
Adequate sites for cleared material: yes
Seismologically stable site: yes
Asbestos present in disturbed areas: no
Site conditions materially differ from normal: no
Adequate sources for construction material: yes
Zoning regulations that need to be addressed: no
Staff available for inspection/supervision: yes
Scheduled equipment removal dependent on CHP: no

«« Next screen »»

Figure 10. Retrofit General Questions Screen 2.

Central Heating Plant Economics Evaluation Program file: RT3
Retrofit plant (RT)

«« Previous screen »»

Coal supply contracts: Mine to base direct
Gas purchase contracts: domestic or Canadian producer or marketer
Oil supply contracts: long-term oil pipeline contract
Rail track condition adequate for delivery: yes
Sufficient room for rail extensions on site: yes
Special access setups required: no
Railroad right-of-way accessible (flat terrain): yes

«« Next screen »»

Figure 11. Retrofit General Questions Screen 3.

Once the equipment condition section is completed, review applicable emission regulations to check for any problems with meeting air pollution standards. After this, the user is returned to the Figure 3 menu.

Appendix A contains an example printout of CHPECON's Screening Model Analysis for Retrofits.

Central Heating Plant Economics Evaluation Program file: RT3
Retrofit plant (RT)

«« Previous screen »»

Threatened or endangered species present: no
Local opposition to emissions of a CHP: no
Site near areas sensitive to acid rain: no
Site impacted by soil/shore erosion and related issues: no
Site part of a protected wetlands: no

«« Next screen »»

Figure 12. Retrofit General Questions Screen 4.

Central Heating Plant Economics Evaluation Program file: RT3
Retrofit plant (RT)

«« Previous screen »»

Archaeological and historic properties nearby: no
Special sites (parks, airports, etc.) nearby: no
Industrial contamination of water supply an issue: no
Ambient noise regulations in effect: no
Neighbors adjacent to base, affecting CHP location: no
Sufficient room to comply with noise regulations: yes
CHP area considered a cultural resource: no
Similar construction projects successful: yes
Community's economic situation conducive to project: yes

«« Next screen »»

Figure 13. Retrofit General Questions Screen 5.

Central Heating Plant Economics Evaluation Program file: RT3
Retrofit plant (RT)

«« Previous screen »»

Access to transmission lines for CHP: yes
Staff capable of maintaining CHP instruments: yes
Distribution system able to use CHP output: yes
Adequate traffic control supplies: yes
Staff using procedures compatible with proposed CHP: yes

«« Next screen »»

Figure 14. Retrofit General Questions Screen 6.

Central Heating Plant Economics Evaluation Program Retrofit plant (RT)	file: RT3
---	-----------

«« Previous screen »»
Outside agencies available for ash disposal: yes Ash & other discharges considered hazardous: no Wastewater disposal possible without treatment: yes Other pollutant-emitting equipment limitations: no Tradeable air emission credits possible: yes Local regulations cover waste handling and disposal: no
«« Next screen »»

Figure 15. Retrofit General Questions Screen 7.

Central Heating Plant Economics Evaluation Program Retrofit plant (RT)	file: RT3
---	-----------

«« Previous screen »»
Base has access to secure fuel supply: yes Base security affected by CHP operations: no Base security affected by CHP construction: no Potential for a change in the mission of the base: unlikely Current activities interfere with CHP construction: no
«« Next screen »»

Figure 16. Retrofit General Questions Screen 8.

«« Previous screen »»	
Boiler assembly: replace w/ new Rail / truck equipment for coal unloading: replace w/ new Car dumper for coal unloading: Coal pile runoff pond: Car heating or thawing equipment: Coal silo: Slurry fuel handling/storage equipment: Ash handling / storage / treatment equipment: Mechanical collector: Baghouse / bag / associated equipment: Induced draft (I.D.) fan:	Replacement or new equipment required Not functional -- requires major work Functional -- needs minor servicing
«« Next screen »»	

Figure 17. Sample of Equipment Condition Detail on Existing Equipment Screen.

«« Previous screen »»	
Water treatment facility / testing lab: replace w/new Storage tanks / treatment tanks: replace w/new Facility pumps: replace w/new Air compressors for facility: replace w/new Pond neutralization equipment: replace w/new Storm sewer system: replace w/new Piping for slurry fuel: Boiler facility stacks: replace w/new Diesel generator equipment: functional Electrical substation equipment: functional	
Quit	

Select equipment category and press <Enter> to specify condition

Figure 18. Second Screen for Existing Equipment Condition Input.

5 CAPITAL/INSTALLATION COSTS

Facility Reconversion Capital Cost

This section includes cost equations that determine the capital cost for reconversion projects. A reconversion project applies to a facility that originally operated on coal and was reconfigured to operate on another fuel that is now being converted back to coal firing. The major equipment costs for reconversion projects are broken into subsections, with different costs for each boiler technology.

There are four cost classifications for most major capital equipment categories in reconversion projects. These classifications allow the user to indicate the general condition of existing equipment. The options are: Functional, Not Functional, Replacement, and Operational. The Functional category indicates that the component exists and is presently operational. However, performing minor repairs or maintenance is often done on such equipment when an extensive project such as a retrofit is undertaken. The Not Functional category indicates the equipment exists but is not ready for operation. Major repairs or complete overhaul are necessary to make it operational. The Replace category indicates the component (or components) either does not exist or must be scrapped and replaced with a new unit. All three levels have different cost implications depending on the individual system component. For most equipment categories, three cost equations will be presented, corresponding to the Functional /Not functional/ Replacement options. In some cases, only two cost equations are presented, such as Functional or Replacement because a major overhaul would be as expensive as a complete replacement.

Once equipment costs are determined based on the condition of the existing plant, the freight, bulk material, direct labor, and indirect (labor associated) costs are added to the equipment costs. These costs are discussed further after the discussion of each of the equipment costing subsections.

Major boiler facility equipment cost subsections that will be covered in this chapter are:

- Boiler
- Coal handling
- Ash handling
- Mechanical collector
- Dry scrubber & lime system
- Baghouse & ID fan
- Boiler water treatment
- Tanks
- Pumps
- Air compressors
- Wastewater treatment
- Piping
- Instrumentation
- Electrical
- Building & services
- Site development
- Spare parts, tools, mobile equipment.

Approach for Capital and Installation Cost Factors

The retrofit portion of the CHPECON analysis program assumes that existing boilers and auxiliary equipment can be converted to alternative fuel use. This is true for many of the older boilers that may originally have been designed for coal combustion but were converted to oil and/or gas.

The exact costs of converting an existing facility to an alternative fuel can only be determined by a detailed study of the facility. Some auxiliary equipment (such as water treatment and boiler feedwater pumps) can be used as is because their operation is unaffected by fuel choice. Other components, such as the coal delivery and ash-handling subsystems, may be used if the facility was originally coal-fired and the components were left in place when it was converted to oil or gas firing. The degree to which existing components can be used must be determined by a careful examination of required performance. Some equipment can be used even after an extended period of inactivity (such as piping), if properly "mothballed." Other equipment might need extensive repair or complete replacement. Motors and belts are examples of such equipment. Without the opportunity for a detailed design study and full evaluation of existing equipment, only a factored estimate of the cost for reactivating equipment can be made.

In situations where the facility was never fitted with coal-handling equipment, new subsystems must be built or installed. The installed cost of each component is usually higher in an existing facility (depending on its design) than it is in a new facility because additional effort is required to modify existing equipment to accommodate new components. Some final decisions are made at the time of installation unless detailed information is known about the configuration. Because of the potential for unplanned downtime due to problems transitioning between new and old equipment, detailed planning and study of the existing facility is required.

The techniques for pricing a retrofit of an existing boiler are similar to those used in repowering or life extension of an existing facility. Reviewing published material in this area indicated there is some interest in this as organizations attempt to maximize the useful life of a facility. However, most of the information here focuses on review and evaluation techniques and provides few cost details.

The cost factors used in the retrofit section are based on the costs for new equipment used in the other sections of CHPECON (modified for use with the categories of equipment condition described in the Current Equipment Condition Section). The four categories again, are: Replacement required, Not functional, Functional, and Operational. The new facility analysis options in CHPECON rely on a capital equipment cost and various cost ratios to determine installed cost. The retrofit costs are determined the same way:

- Where existing equipment is operational and can be used without additional labor, the program calculates no cost.
- Where equipment condition warrants replacement or new equipment is needed because it was never present, the full new equipment capital cost is used. Related factors for labor, bulk material, and freight are either the same as those for a new facility or higher. Increases in the cost factors were made based on the need for additional labor or materials. Freight costs were increased to reflect the need for transport of existing equipment away from the facility and moving new equipment in.
- Where existing equipment is functional, the cost to ensure that it will operate properly in the retrofitted facility is minimal. Average costs were based on annual and periodic maintenance for components. This included such systems as the water pumps, stack, ash handling, scrubber, and fans. An average factor of 10 percent of the cost of new equipment was considered appropriate.

- Where existing equipment is not functional, a significant portion of the overall equipment needs to be overhauled so it will operate properly in the retrofitted facility. Cost estimation for this category is more inexact because of the high dependency on the actual condition of the equipment. Costs were determined based on an evaluation of the components that may need to be replaced in various categories and the differences between new, annual, and periodic maintenance costs. An average factor of 50 percent of the cost of new equipment was considered appropriate. Cost factors for labor, bulk material, and freight were adjusted to reflect the likelihood of increased time and hardware for removing existing equipment and installing new components.

Boiler Retrofit Costs

The user may select the CHPECON option of evaluating the boiler retrofit of an existing facility. A retrofit project generally involves the conversion of a noncoal facility to coal firing. A retrofit project is not a conversion. The facility has not previously operated on coal, unlike a reconversion project where original coal equipment or infrastructure may still be present. This section includes all retrofit conversion costs for each of the following cases:

- Heavy oil stoker to dump grate spreader stoker with fly ash reinjection
- Heavy oil stoker to dump grate spreader stoker without fly ash reinjection
- Heavy oil stoker to vibrating grate spreader stoker with fly ash reinjection
- Heavy oil stoker to vibrating grate spreader stoker without fly ash reinjection
- Heavy oil stoker to reciprocating grate spreader stoker with fly ash reinjection
- Heavy oil stoker to reciprocating grate spreader stoker without fly ash reinjection
- Heavy oil stoker to traveling grate spreader stoker with fly ash reinjection
- Heavy oil stoker to traveling grate spreader stoker without fly ash reinjection
- Heavy oil stoker to traveling grate stoker
- Heavy oil stoker to chain grate stoker
- Coal stoker to slagging combustion
- Heavy oil package boiler to slagging combustion
- Heavy oil package boiler to coal-oil slurry (COS)
- Heavy oil package boiler to coal-water slurry (CWS)
- Heavy oil package boiler to micronized coal (micronized coal is 70 percent through 325 mesh)
- Heavy oil stoker to fluidized bed combustion
- Heavy oil package boiler to low-Btu gas (gasification)

For each of the above boiler retrofit technologies (except gasification) a series of cost algorithms are provided for converting the boiler to the target technology. Costs for other aspects of the analysis are also included, such as preliminary engineering, permit development, owner management, contractor management, site acquisition, site development, detail engineering design, construction contingency, startup, spare parts, initial facility consumables (operational supplies), tools, etc. Remember that the eventual costs incurred during a retrofit should be determined by a detailed study before any work begins.

The heavy oil package boiler to low-Btu gas (gasification) retrofit option differs from the other retrofit options because it also covers costs for the gasification plant and the boiler modification costs. These generic cost programs were developed to provide a budget cost estimate for each of the retrofit technologies. Actual retrofit costs are very dependent on such things as boiler type and design, physical boiler plant design and layout, total facility layout, and location and specific site parameters. To develop

a reasonable estimate of the costs for a facility, assuming a favorable set of conditions for the retrofit, the cost algorithms were developed for generic facilities with the following attributes:

1. Enough physical room to install:
 - a. New fuel receiving, handling, preparation, and delivery systems.
 - b. New ash-removal and storage equipment/systems.
 - c. New air-pollution control equipment/system.
 - d. New boiler/combustion control system.
 - e. Fuel-burning equipment.
 - f. Necessary ductwork, piping, etc., to connect the new equipment.
 - g. New boiler equipment, such as the air heater for coal-water mixture combustion, the fluid-bed combustion system, or the ash pit for the slagging combustor.
2. No major boiler/equipment modifications.
3. No major structural changes or modifications.
4. Adequate electric bus system that can support the modification technology with little or no additional expense.
5. Facility will receive fuel by truck or railroad car only.
6. Auxiliary fuel system can adequately support the retrofit design technology.
7. Facility/boiler condition does not require major nonretrofit component/system repair or replacement.

In the following subsections, each retrofit technology is individually discussed with its applicable category cost algorithms. The retrofit budget estimate is developed by adding the equipment category cost estimates. This total represents the cost of a horizontally-designed retrofitted boiler/facility. The base costs in the program are fourth-quarter 1988 dollars. Excluded from the boiler costs are items such as foundations and tie-ins for electrical wiring, controls, and piping to and from the boilers. These items are part of the associated installation costs listed as labor, bulk materials, and construction indirects. The boiler estimated costs are a function of boiler type, outlet steam pressure, temperature, and steam flow maximum continuous rating (MCR).

Boiler Retrofit Capital Cost

Heavy Oil Stoker to Coal Stoker Retrofit

- New grate, seals, refractory, grate support structure, etc.
- New combustion controls, grate drives, etc.
- New secondary or overfire air fan
- New windboxes, coal fines removal system, etc.
- ash pits.

One boiler: Range 20,000 to 200,000 MBtu/hr

Cost \$ = $(2.38)(PMCR) + 180,000$

[Eq 1]

Two boilers: Range 40,000 to 400,000 MBtu/hr

Cost \$ = $(1.92)(PMCR) + 350,000$

[Eq 2]

Three boilers: Range 60,000 to 600,000 MBtu/hr
Cost \$ = (1.77)(PMCR) + 520,000 [Eq 3]

Four boilers: Range 80,000 to 600,000 MBtu/hr
Cost \$ = (1.65)(PMCR) + 650,000 [Eq 4]

Five boilers: Range 100,000 to 600,000 MBtu/hr
Cost \$ = (1.40)(PMCR) + 800,000 [Eq 5]

Coal Stoker to Slagging Combustor Retrofit

- New combustion controls
- New slagging combustors
- Boiler modification for combustors
- Slag collection system for combustors.

One boiler: Range 20,000 to 200,000 MBtu/hr
Cost \$ = (2.33)(PMCR) + 180,000 [Eq 6]

Two boilers: Range 40,000 to 400,000 MBtu/hr
Cost \$ = (2.35)(PMCR) + 300,000 [Eq 7]

Three boilers: Range 60,000 to 600,000 MBtu/hr
Cost \$ = (1.45)(PMCR) + 500,000 [Eq 8]

Four boilers: Range 80,000 to 600,000 MBtu/hr
Cost \$ = (1.20)(PMCR) + 650,000 [Eq 9]

Five boilers: Range 100,000 to 600,000 MBtu/hr
Cost \$ = (1.00)(PMCR) + 800,000 [Eq 10]

Heavy Oil Package Boiler to Slagging Combustor Retrofit

- New combustion controls
- New slagging combustors
- Boiler modification for combustors
- Slag collection system for combustors.

One boiler: Range 20,000 to 200,000 MBtu/hr
Cost \$ = (2.40)(PMCR) + 200,000 [Eq 11]

Two boilers: Range 40,000 to 400,000 MBtu/hr
Cost \$ = (2.45)(PMCR) + 325,000 [Eq 12]

Three boilers: Range 60,000 to 600,000 MBtu/hr
Cost \$ = (2.00)(PMCR) + 550,000 [Eq 13]

Four boilers: Range 80,000 to 600,000 MBtu/hr
Cost \$ = (1.50)(PMCR) + 780,000 [Eq 14]

Five boilers: Range 100,000 to 600,000 MBtu/hr
Cost \$ = (0.95)(PMCR) + 800,000 [Eq 15]

Heavy Oil Package Boiler to Coal-Oil Slurry Retrofit

Cost per Boiler = $0.836 \times \text{MCR} - 2200$ [Eq 16]

Heavy Oil Package Boiler to Coal-Water Mixture Retrofit

Cost per boiler = $0.95 \times \text{MCR}$ [Eq 17]

Heavy Oil Package Boiler to Micronized Coal Retrofit

- New burner controls
- New micronized coal and igniters burners
- Boiler modification for burning micronized coal
- Boiler ash collection system.

One Boiler: Range 20,000 to 200,000 MBtu/hr
Cost \$ = (1.3)(PMCR) + 175,000 [Eq 18]

Two boilers: Range 40,000 to 400,000 MBtu/hr
Cost \$ = (1.5)(PMCR) + 225,000 [Eq 19]

Three boilers: Range 60,000 to 600,000 MBtu/hr
Cost \$ = (2.5)(PMCR) + 350,000 [Eq 20]

Four boilers: Range 80,000 to 600,000 MBtu/hr
Cost \$ = (2.7)(PMCR) + 550,000 [Eq 21]

Five boilers: Range 80,000 to 600,000 MBtu/hr
Cost \$ = (2.9)(PMCR) + 700,000 [Eq 22]

Heavy Oil Stoker to Fluidized Bed Combustion Retrofit

Cost per boiler = $2.130 \times \text{MCR} + 114,000$ [Eq 23]

Heavy Oil Package Boiler to Low-Btu Gas (Gasification) Retrofit

Gasification plant: Cost \$ = 21,399,000 [Plant Size/ 6×10^9] [Eq 24]
Where: Plant Size = Btu/day = (MBtu/hr)coal \times higher heating value [HHV] \times 24 hr/day \times 0.75

Boiler Modification Costs

One boiler:
Cost \$ = (1.4)(PMCR) + 100,000 [Eq 25]

Two boilers:
Cost \$ = (1.6)(PMCR) + 175,000 [Eq 26]

Three boilers:
Cost \$ = (2.1)(PMCR) + 275,000 [Eq 27]

Four boilers:
Cost \$ = (2.4)(PMCR) + 400,000 [Eq 28]

Boiler Reconversion Costs

In addition to the analysis of retrofit projects, CHPECON can now be used to evaluate reconversion projects. All the boiler cost equations are linear and are shown as a function of the steam production rate or maximum continuous rating (MCR) of the boiler. The cost equations are based on a bituminous coal. For other coals, the boiler cost equations are multiplied by the following factors:

Anthracite:	1.00
Sub-bituminous:	1.08
Lignite:	1.12

Typically, as the fuel decreases in heating value (Btu/lb basis), the ash and moisture content increase. As these values increase, the boiler must be made somewhat physically larger to accommodate

these poorer fuels. Therefore, the cost increases. Anthracite, a very good coal, has a smaller percentage of volatile matter and requires almost the same boiler size, but a different design. Therefore, the cost is estimated to be the same as the cost of a bituminous coal boiler. The reconversion cost per boiler is:

$$\text{Stoker Boilers, cost per boiler} = 112,000 + 1.867 \times \text{MCR} \quad [\text{Eq 29}]$$

Additional costs may be incurred as discussed below.

The desuperheater includes a pressure reducing valve (PRV) to reduce main steam pressure and temperature to the lower system requirement level. This allows a high-pressure system to provide steam to heat the feedwater. The desuperheater estimated cost for retrofit, if it is present, is \$4,000 for all systems.

The air heater is necessary for CWS boilers only (all other boilers include either an economizer or air heater). The heater is a regenerative type sized to produce up to 450 °F combustion air. The air heater comes complete, including a structural framework and supports, insulation and lagging, inlet and outlet duct breeching, baskets, and a basket washer or blower.

The air heater estimated cost is calculated as:

$$\text{Cost} = 9.8 \times (\text{combustion air, actual cubic feet per minute [ACFM]}) + 85,000 \quad [\text{Eq 30}]$$

Coal Handling System for Reconversion

The coal handling system is divided into the following categories: Truck Receiving, Truck Receiving with stock and reclaim system, Rail Receiving, Rail Receiving with stock and reclaim system, Car Heating, Coal Silo, Car Dumper, Coal Pile Runoff Pond, and Rail. To determine coal handling costs, the program requires the user to input whether rail or truck will be used, if a stock/reclaim system should be included, if car heating is required, if a coal silo is required, and if so, how many days of storage is required for the coal silo. The estimated reconversion cost of these systems are:

Truck Receiving

$$\text{Replacement} = 5000(\text{TPH}) + 100,000 \quad [\text{Eq 31}]$$

$$\text{Not functional} = 2500(\text{TPH}) + 50,000 \quad [\text{Eq 32}]$$

$$\text{Functional} = 500(\text{TPH}) + 10,000 \quad [\text{Eq 33}]$$

Where: TPH is tons per hour
Maximum cost is @ 150 TPH

System does not include:

- Stock/Reclaim System
- Silo

Truck Receiving with Stock/Reclaim

Replacement cost = $6550(\text{TPH}) + 140,000$ [Eq 34]

Not functional cost = $3275(\text{TPH}) + 70,000$ [Eq 35]

Functional cost = $655(\text{TPH}) + 14,000$ [Eq 36]

Where: TPH is tons per hour
Maximum cost is @ 150 TPH
System does not include silo

Rail Receiving

Replacement cost = $2400(\text{TPH}) + 775,000$ [Eq 37]

Not functional cost = $1200(\text{TPH}) + 387,500$ [Eq 38]

Functional cost = $240(\text{TPH}) + 77,500$ [Eq 39]

Where: TPH is tons per hour
Maximum cost is @ 250 TPH

System does not include:

- Silo
- Stock/reclaim system
- Car heating

Rail Receiving with Stock/Reclaim

Replacement cost = $4350(\text{TPH}) + 760,000$ [Eq 40]

Not functional cost = $2175(\text{TPH}) + 380,000$ [Eq 41]

Functional cost = $435(\text{TPH}) + 76,000$ [Eq 42]

Where: TPH is tons per hour
Maximum cost is @ 250 TPH

System does not include:

- Silo
- Car Heating

Car Heating

Replacement = $367(\text{TPH}) + 23,000$ [Eq 43]

Not functional = $184(\text{TPH}) + 11,500$ [Eq 44]

Functional = $37(\text{TPH}) + 2300$ [Eq 45]

Where: TPH is tons per hour
Maximum cost is @ 250 TPH

Coal Silo

$$\begin{aligned}\text{Replacement} &= (\text{tons of storage}) + 40,000 && [\text{Eq 46}] \\ \text{Not functional} &= 0.5 \times (\text{tons of storage}) + 20,000 && [\text{Eq 47}] \\ \text{Functional} &= 0.1 \times (\text{tons of storage}) + 4000 && [\text{Eq 48}]\end{aligned}$$

Car Dumper

This includes rotary car dumper, house, positioners, railroad overpit, pit, and coal hopper. The car dumper installed cost is estimated as:

$$\begin{aligned}\text{Replacement} &= 2,200,000 && [\text{Eq 49}] \\ \text{Not functional} &= 1,100,000 && [\text{Eq 50}] \\ \text{Functional} &= 220,000 && [\text{Eq 51}]\end{aligned}$$

Railroad

The railroad track cost is based on its current condition.

$$\begin{aligned}\text{Replacement} &= 85.00 \text{ per track foot} && [\text{Eq 52}] \\ \text{Not functional} &= 42.50 \text{ per track foot} && [\text{Eq 53}] \\ \text{Functional cost} &= 8.50 \text{ per track foot} && [\text{Eq 54}]\end{aligned}$$

Coal Pile Runoff Pond

The pond receives storm water runoff from the long-term coal storage area. Technical Manual TM5-848-3 requires that the pond be able to contain runoff from a 10-year, 24-hour storm with 2 ft of freeboard. The sizing method uses an average pond water depth of 4 ft and sizes the pond for 4 in. of rain in 24 hours, with no absorption. Major costs include excavation and liners. The pond cost is estimated as follows:

$$\begin{aligned}\text{Replacement} &= 1.20 \text{ per square foot} && [\text{Eq 55}] \\ \text{Not functional} &= 0.60 \text{ per square foot} && [\text{Eq 56}] \\ \text{Functional} &= 0.12 \text{ per square foot} && [\text{Eq 57}]\end{aligned}$$

Fuel Handling

The fuel handling subsection is used in the coal-slurry boiler plants. This subsection consists of the long-term storage tanks and transfer pumps. The size and number of long-term storage tanks are determined in the equipment sizing section. The cost is:

$$\begin{aligned}\text{Replacement} &= (0.179)(\text{gallons}) + 83,000 && [\text{Eq 58}] \\ \text{Not functional} &= (0.0895)(\text{gallons}) + 41,500 && [\text{Eq 59}] \\ \text{Functional} &= (0.0179)(\text{gallons}) + 8300 && [\text{Eq 60}]\end{aligned}$$

The day fuel storage tank cost is:

$$\begin{aligned}\text{Replacement} &= (0.553)(\text{gallons}) + 200 && [\text{Eq 61}] \\ \text{Not functional} &= (0.277)(\text{gallons}) + 100 && [\text{Eq 62}] \\ \text{Functional} &= (0.055)(\text{gallons}) + 20 && [\text{Eq 63}]\end{aligned}$$

Ash Handling for Reconversion

The ash removal and handling system is a pneumatic ash system. The system includes: the pneumatic ash conveying system (piping); air-operated fly ash intake valves; manual-operated bottom ash intake valves; air-operated branch line gates; mechanical exhausters with motors, temperature and vacuum gauges, vacuum relief valve and dust detectors; and ash receiver/bag filter with valves and a double vacuum breaker. The size (and therefore, cost) of the system is based on the amount of ash in the fuel, boiler type, and other equipment (such as dry scrubbers) that adds material that the ash system must handle.

The amount of ash and the location of its collection systems (bottom ash mechanical collector, dry scrubber, etc.) determines the ash system size. The boiler type (stoker, fluid-bed, coal-slurry) determines the ash conveying systems. The system size and the size and cost of the mechanical exhausters and ash receiver determines costs. These costs, with the ash silo and control system costs, are added to determine the total ash system costs. The ash system reconversion costs are calculated below.

Ash Pipe Length Estimate

$$\begin{aligned} &\text{Bottom Ash Pipe Length (feet)} \\ &= (\text{Building Length} - 25) + (\text{Building Width} + 15) + \text{Ash Silo Height} + 25 \end{aligned} \quad [\text{Eq 64}]$$

Where: Building Length and Width are calculated in Table 1.

$$\begin{aligned} &\text{Settling Chamber Ash Pipe (feet)} \\ &= \text{Mechanical Collector Ash Pipe Length} \end{aligned} \quad [\text{Eq 65}]$$

$$\begin{aligned} &\text{Mechanical Collector Ash Pipe Length (feet)} \\ &= (\text{Building Length} - 25) \end{aligned} \quad [\text{Eq 66}]$$

$$\begin{aligned} &\text{Scrubber Residue Ash Pipe Length (feet)} \\ &= (\text{Building Length}) + (\text{Ash Silo Height} + 25) \end{aligned} \quad [\text{Eq 67}]$$

$$\begin{aligned} &\text{Baghouse Residue Ash Pipe Length (feet)} \\ &= (\text{Building Length}) + (\text{Ash Silo Height} + 25) \\ &\quad + [(\text{Number of Boilers})(\text{Baghouse Size} + 30 \text{ ft}-15 \text{ ft})] \end{aligned} \quad [\text{Eq 68}]$$

Table 1

Width and Length of Boiler Houses

Boiler Type	Width (feet)	Length (feet)
BFBC		
3 Boiler	$[(0.112) (PMCR)/1000] + 57$	$[(0.31) (PMCR)/1000] + 80$
4 Boiler	$[(0.112) (PMCR)/1000] + 57$	$[(0.345) (PMCR)/1000] + 110$
5 Boiler	$[(0.08) (PMCR)/1000] + 65$	$[(0.42) (PMCR)/1000] + 120$
COS		
3 Boiler	$[(0.1429) (PMCR)/1000] + 50$	$[(0.01) (PMCR)/1000] + 130$
4 Boiler	$[(0.1429) (PMCR)/1000] + 50$	$[(0.12) (PMCR)/1000] + 154$
5 Boiler	$[(0.1429) (PMCR)/1000] + 50$	$[(0.129) (PMCR)/1000] + 180$
CWS		
3 Boiler	$[(0.175) (PMCR)/1000] + 62$	$[(0.01) (PMCR)/1000] + 130$
4 Boiler	$[(0.175) (PMCR)/1000] + 62$	$[(0.12) (PMCR)/1000] + 154$
5 Boiler	$[(0.175) (PMCR)/1000] + 62$	$[(0.129) (PMCR)/1000] + 180$
Stoker Boilers		
3 Boiler	$[(0.0913) (PMCR)/1000] + 49$	$[(0.34) (PMCR)/1000] + 89$
4 Boiler	$[(0.0913) (PMCR)/1000] + 49$	$[(0.442)(PMCR)/1000] + 91$
5 Boiler	$[(0.0913) (PMCR)/1000] + 49$	$[(0.433) (PMCR)/1000] + 119$

Key: BFBC = bubbling fluidized-bed combustor
 COS = coal-oil slurry
 CWS = coal-water slurry

Branch Line Gates

Stoker boiler = (Number of boilers) + 5 [Eq 69]
 3-Boiler House: Gates = 8
 4-Boiler House: Gates = 9
 5-Boiler House: Gates = 10

Bubbling fluidized-bed = (Number of boilers) + 4 [Eq 70]
 3-Boiler House: Gates = 7
 4-Boiler House: Gates = 8
 5-Boiler House: Gates = 9

Coal-slurry = (Number of Boilers) + 1 [Eq 71]
 3-Boiler House: Gates = 4
 4-Boiler House: Gates = 5
 5-Boiler House: Gates = 6

Fly Ash Intakes

Stoker Boiler
 (Number of Boilers) $[3 + (0.6)(\text{baghouse approximate sizing})]$ [Eq 72]

Bubbling Fluidized-Bed

(Number of Boilers) $[2 + (0.6)(\text{baghouse approximate sizing})]$ [Eq 73]

Coal Slurry

(Number of Boilers) $[1 + (0.6)(\text{baghouse approximate sizing})]$ [Eq 74]

Bottom Ash Intakes

$2 \times (\text{Number of Boilers})$ [Eq 75]

Ash Pipe System Size

Bottom Ash Pipe Size = $(0.1143)(\text{TPH}) + 5.42$ [Eq 76]

Where:

- If less than 5 TPH, then pipe = 6 in.
- If greater than 40 TPH, then pipe = 12 in.
- Equation to be rounded up to nearest whole number
- TPH = (bottom ash)(3)/2000.

Fly Ash

(Mechanical Collector, Settling Chamber, Scrubber Residue, Baghouse)
Pipe size = $(0.1667)(\text{TPH}) + 3.66$ [Eq 77]

Where:

- If less than 2 TPH, then = 4 in.
- Range 0 to 20 TPH
- Equation to be rounded up to nearest whole number.

Pipe size = $(0.08)(\text{TPH}) + 5.8$ [Eq 78]

Where: Range 20 to 40 TPH

Pipe size = $(0.086)(\text{TPH}) + 5.55$ [Eq 79]

Where: Range 40 to 75 TPH

Pipe Cost Per Foot

Bottom Ash Pipe Cost

Replacement = $(\text{Equation 76})(8.75) + 25$ [Eq 80]

Not functional = $(\text{Equation 76})(4.38) + 12.5$ [Eq 81]

Functional = $(\text{Equation 76})(.875) + 2.5$ [Eq 82]

Fly Ash Pipe Cost

Replacement = $(\text{pipe size})(8.75) + 25$ [Eq 83]

Not functional = $(\text{pipe size})(4.38) + 12.5$ [Eq 84]

Functional = $(\text{pipe size})(.875) + 2.5$ [Eq 85]

Ash Pipe System Cost

Bottom ash pipe = (Equation 64)(Equation 80)	[Eq 86]
Settling chamber ash pipe = (Equation 65)(Equation 81)	[Eq 87]
Mechanical collector ash pipe = (Equation 66)(Equation 81)	[Eq 88]
Scrubber residue ash pipe = (Equation 67)(Equation 81)	[Eq 89]
Baghouse residue ash pipe = (Equation 68)(Equation 81)	[Eq 90]

Total Ash Piping System Cost

Stoker Boiler
Cost = Equation 82 + 83 + 84 + 85 + 86 [Eq 91]

Bubbling Fluidized-Bed Boiler
Cost = Equation 82 + 83 + 84 + 86 [Eq 92]

Coal Slurry Boiler
Cost = Equation 84 + 86 [Eq 93]

Air Operated Branch Line Gate Cost Per Gate

Bottom Ash System Gate Size Costs

1. Replacement = (33.333)(Equation 76) + 1200 [Eq 94a]
Not functional = (17.7)(Equation 76) + 600
Functional = (3.33)(Equation 76) + 120
(Where: Equation 76 = 6 in. to 9 in.)

2. Replacement = (250)(Equation 76) + 1000 [Eq 94b]
Not functional = (125)(Equation 76) + 500
Functional gate cost: = (25)(Equation 76) + 100
(Where: Equation 76 = 10 in. to 12 in.)

Mechanical Collector/System Gate Size Cost/Settling Chamber Gate Size Cost/Scrubber Residue Gate Size Cost/Baghouse Residue Gate Size Cost

1. Replacement = (Equation 77, 78, or 79)(200) + 200 [Eq 95a]
Not functional = (Equation 77, 78, or 79)(100) + 100
Functional = (Equation 77, 78, or 79)(20) + 20
(Where: Equation 77, 78, or 79 = 4 in. to 6 in.)

2. Replacement = (Equation 77, 78 or 79)(33.333) + 1200 [Eq 95b]
Not functional = (Equation 77, 78 or 79)(33.333) + 1200
Functional = (Equation 77, 78 or 79)(33.333) + 1200
(Where: Equation 77, 78, or 79 = 6 in. to 9 in.)

3. Replacement = (Equation 77, 78, or 79)(250) + 1000 [Eq 95c]
Not functional = (Equation 77, 78, or 79)(125) + 500
Functional = (Equation 77, 78, or 79)(25) + 100
(Where: Equation 77, 78, or 79 = 10 in. to 12 in.)

Air Operated Branch Line Gate Costs

Stoker Boilers

$$\text{Replacement} = (\text{Equation 94 a or b})(2) + (\text{Equation 95 a, b, or c})(3) + (\text{Number of boilers}) \quad [\text{Eq 96}]$$

Bubbling Fluidized-Bed

$$\text{Replacement} = (\text{Equation 94 a or b})(2) + (\text{Equation 95 a, b, or c})(2) + (\text{Number of boilers}) \quad [\text{Eq 97}]$$

Coal Slurry Boilers

$$\text{Replacement} = (\text{Equation 95 a, b, or c}) + (\text{Number of boilers}) \quad [\text{Eq 98}]$$

Air Operated Fly Ash Intake Cost

Stoker Boilers

$$\text{Replacement} = (\text{Equation 72})(1400) \quad [\text{Eq 99}]$$

$$\text{Not functional} = (\text{Equation 72})(700)$$

$$\text{Functional} = (\text{Equation 72})(140)$$

Bubbling Fluidized-Bed

$$\text{Replacement} = (\text{Equation 73})(1400) \quad [\text{Eq 100}]$$

$$\text{Not functional} = (\text{Equation 73})(700)$$

$$\text{Functional} = (\text{Equation 73})(140)$$

Coal Slurry Boilers

$$\text{Replacement} = (\text{Equation 74})(1400) \quad [\text{Eq 101}]$$

$$\text{Not functional cost} = (\text{Equation 74})(700)$$

$$\text{Functional cost} = (\text{Equation 74})(140)$$

Manual Bottom Ash Intake Cost

$$\text{Replacement} = (\text{Equation 75})[(\text{Equation 76})(62.5) + 125] \quad [\text{Eq 102}]$$

$$\text{Not functional} = (\text{Equation 75})[(\text{Equation 76})(31.25) + 62.50]$$

$$\text{Functional} = (\text{Equation 75})[(\text{Equation 76})(6.25) + 12.50]$$

Mechanical Exhauster Cost

Stoker and Fluidized-Bed Combustor (FBC)

$$\text{Replacement} = [(\text{Equation 76})(6872) - 7500] (3) \quad [\text{Eq 103}]$$

$$\text{Not functional} = [(\text{Equation 76})(3436) - 3750] (3)$$

$$\text{Functional} = [(\text{Equation 76})(687) - 750] (3)$$

Coal Slurry

$$\text{Replacement} = [(\text{Equation 77, 78, 79})(6872) - 7500] (3) \quad [\text{Eq 104}]$$

$$\text{Not functional} = [(\text{Equation 77, 78, 79})(3436) - 3750] (3)$$

$$\text{Functional} = [(\text{Equation 77, 78, 79})(687) - 750] (3)$$

Receiver Cost

Stoker and Fluidized-Bed Combustor

$$\text{Replacement} = (\text{Equation 76})(5833) + 5000 \quad [\text{Eq 105}]$$

$$\text{Not functional} = (\text{Equation 76})(2917) + 2500$$

$$\text{Functional} = (\text{Equation 76})(585) + 500$$

Coal Slurry

$$\text{Replacement} = (\text{Equation 76})(5833) + 5000 \quad [\text{Eq 106}]$$

$$\text{Not functional} = (\text{Equation 76})(2917) + 2500$$

$$\text{Functional} = (\text{Equation 76})(585) + 500$$

(Range 6 in. to 12 in. pipe. If less than 6 in., then use 6 in.)

Ash Silo with Steel Support, Manhole, Fluidizing System, and Paddle Mixer Unloader

The ash silos are steel, flat-bottom type and come with support steel. They consist of a manhole, relief valve, fluidizing system, a paddle-wheel unloader, an ash floor with steel siding, an enclosure for the ash receiver and stairs, ladders, and platforms. The silos are raised so a truck can drive underneath. The costs are for materials only. Items such as tie-ins, foundations, construction, etc. are accounted for in the associated cost factors. The material costs are provided with the ash system costs.

$$1. \text{ Replacement} = (\text{silo capacity-tons})(588) + 4400 \quad [\text{Eq 107}]$$

$$\text{Not functional} = (\text{silo capacity-tons})(294) + 2200$$

$$\text{Functional} = (\text{silo capacity-tons})(59) + 440$$

(Range 200 to 1200 tons for ash silo capacity)

$$2. \text{ Replacement} = (\text{silo capacity-tons})(166.67) + 510,000 \quad [\text{Eq 108}]$$

$$\text{Not functional} = (\text{silo capacity-tons})(83) + 255,000$$

$$\text{Functional} = (\text{silo capacity-tons})(17) + 51,000$$

(Range 1200 to 2000 tons for ash silo capacity)

Control Costs

Stoker and Fluidized-Bed Combustor

$$\text{Replacement} = (\text{Equation 77})(10,833) - 30,000 \quad [\text{Eq 109}]$$

$$\text{Not functional} = (\text{Equation 77})(5417) - 15,000$$

$$\text{Functional} = (\text{Equation 77})(1090) - 3000$$

Coal Slurry

$$\text{Replacement} = (\text{Equation 77})(10,833) - 30,000 \quad [\text{Eq 110}]$$

$$\text{Not functional} = (\text{Equation 77})(5417) - 15,000$$

$$\text{Functional} = (\text{Equation 77})(1090) - 3000$$

Total System Costs

$$\text{Stoker boiler cost} = \text{Equation 88} + \text{Equation 93} + \text{Equation 96} + \text{Equation 99} + \text{Equation 100} + \text{Equation 102} + (\text{Equation 104 or 105}) + \text{Equation 106} \quad [\text{Eq 111}]$$

$$\text{Fluidized-bed boiler cost} = \text{Equation 89} + \text{Equation 94} + \text{Equation 97} + \text{Equation 99} + \text{Equation 100} + \text{Equation 102} + (\text{Equation 104 or 105}) + \text{Equation 106} \quad [\text{Eq 112}]$$

$$\text{Coal slurry cost} = \text{Equation 90} + \text{Equation 95} + \text{Equation 98} + \text{Equation 99} + \text{Equation 101} + \text{Equation 103} + (\text{Equation 104 or 105}) + \text{Equation 107} \quad [\text{Eq 113}]$$

Boiler Water Treatment

A boiler uses a boiler water treatment system independent of its fuel type. Therefore, two options were defined for it. If the system is operational, it can continue operation with a retrofitted boiler house at no additional expense. If the system needs to be replaced, full costs for a new system are incurred. These are discussed in this section.

Equipment costs for water treatment systems are based on budget costs and escalated costs. The systems were separated into four categories: zeolite softeners, dealkalizers, demineralizer (cation-decarbonation-anion) units and mixed-bed (cation-anion) units. The costs are a function of cubic feet of resin or cubic feet for the decarbonator.

The equipment costs include a skid-type unit with valves, controls, interconnecting piping, and regeneration equipment (for zeolites this includes the brine tank). All installed costs and tie-ins are accounted for in the labor, bulk material, and construction indirects. The retrofit/reconversion equipment costs are determined as follows:

Zeolite Softeners:

$$\begin{aligned} & \text{(Range 20 to 100 cubic feet [cf])} \\ \text{Replacement} & = (352)(\text{cf of resin})(2) \quad [\text{Eq 114}] \end{aligned}$$

$$\begin{aligned} & \text{(Range 200 to 800 cf)} \\ \text{Replacement} & = (248)(\text{cf of resin})(3) \quad [\text{Eq 115}] \end{aligned}$$

Dealkalizer:

$$\begin{aligned} & \text{(Range 20 to 225 cf)} \\ \text{Replacement} & = (430)(\text{cf}) \quad [\text{Eq 116}] \end{aligned}$$

$$\begin{aligned} & \text{(Range 225 to 700 cf)} \\ \text{Replacement} & = (400)(\text{cf}) \quad [\text{Eq 117}] \end{aligned}$$

$$\begin{aligned} & \text{(Range 700 to 1600 cf)} \\ \text{Replacement} & = (370)(\text{cf}) \quad [\text{Eq 118}] \end{aligned}$$

Demineralizer:

$$\begin{aligned} & \text{(Range 20 to 250 cf)} \\ \text{Replacement} & = ((1215)(\text{cf} - \text{resin}) + 130,000)(2) \quad [\text{Eq 119}] \end{aligned}$$

(Range 250 to 1700 cf)
 Replacement = $[(775)(cf - resin)] + 130,000(3)$ [Eq 120]

Mixed-Bed:

(Range 10 to 70 cf)
 Replacement = $[(1620)(cf - resin) + 54,000](2)$ [Eq 121]

(Range 70 to 200 cf)
 Replacement = $[(1135)(cf - Resin) + 54,000](3)$ [Eq 122]

Mixed-Bed for Condensate Polishing:

(Range 10 to 70 cf)
 Replacement = $(1620)(cf - resin) + 54,000$ [Eq 123]

(Range 70 to 200 cf)
 Replacement = $(1135)(cf - resin) + 54,000$ [Eq 124]

Chemical Injection Skid

All boiler facilities have a single boiler system chemical injection skid. The skid contains equipment necessary to inject chemicals into the boiler drum (phosphates, amines, or chelants and/or anti-foaming agents) and an oxygen scavenging chemical (hydrazene or other) into the deaerator. The skid has three 55-gal polyurethane mixing tanks with agitators, piping, and valves. Included with the skid are six positive displacement chemical feed pumps that transfer the chemicals to the boiler drum or the deaerator. The displacement pumps are conceptually sized at 0 to 10 gal per hour and have a discharge pressure of 800 lb per sq in. gage [psig] (for higher pressure units, the drum chemicals would be injected into the feedwater system). The skid is 14 ft by 12 ft and has space for all of the previous equipment plus three 55-gal drums of full strength chemicals. The installed cost of the skid (for a heating facility) is estimated as \$20,000.

Boiler Water Laboratory

The boiler water laboratory analyzes boiler steam and water for purity. The laboratory includes items such as a water sample cabinet with drains, sample coolers (where required), chemical storage compartments, a laboratory bench or table with sink, chemicals, beakers, bottles, flasks, exhaust hood, etc. The estimated installed boiler water laboratory price for a heating facility is \$20,000, or \$0 for a facility with an operational boiler water laboratory.

Deaerator

The deaerator contains two sections, a deaerating heater and a boiler feedwater storage section. Within the deaerating heater, treated water is deaerated by heating the water to its saturation temperature and scrubbing it with steam to carry away the dissolved gases. The water is then transferred to the storage section by gravity flow. The storage section provides holding capacity to cover system load swings and emergency situations.

The deaerators are carbon steel, spray-tray types. The storage tanks (depending on the user's input) have 5 to 30 minutes of water storage. The default value is 10 minutes. The deaerators have 1/8-in. corrosion allowance and come equipped with a deaerator section, steam nozzle, water trays and sprays, thermometers, storage tank, gage glass, oxygen test kit, vacuum breaker, relief valve, etc.

The three-boiler facility has a single deaerator that is sized for a three-boiler feedwater flow. The four- and five-boiler facilities have two identically-sized deaerators that are each sized for 50 percent of the total plant feedwater flow. The estimated costs are:

$$\text{Replacement} = (0.0896)(\text{Water flow} - \text{MBtu/hr}) + 20,590 \quad [\text{Eq 125}]$$

Mechanical Collector

The mechanical collector is put in the flue gas ductwork to remove particulates. The collector is based on a 3-in. pressure drop with an 85 percent collection efficiency at full gas flow. The cost of the collector is estimated as a function of gas flow (in ACFM). The estimated cost is calculated as:

$$\begin{aligned} \text{Replacement} &= (0.40)(\text{ACFM}) + 20,000 \\ \text{Not functional} &= (0.20)(\text{ACFM}) + 10,000 \\ \text{Functional} &= (0.04)(\text{ACFM}) + 2000 \end{aligned} \quad [\text{Eq 126}]$$

Dry Scrubber and Lime System

The dry scrubber is a parallel flow-type unit using lime as a reagent and depositing a dry product at the base and outlet of the scrubber vessel. The unit is designed to treat flue gases from the coal-fired boilers to control acid gases (SO₂ and HCl). The acid gas is removed in the form of dry particulate matter so the exiting flue gas meets EPA requirements.

The unit uses a slurry of slaked lime atomized into fine droplets in the vessel. The reagent contacts the hot flue gases and reacts with the acid gases to form a dry product by evaporation, which is then collected in the bottom of the scrubber and in the baghouse. The atomizers are either rotary or bi-fluid type, designed for easy access and maintainability.

The lime system is an integral part of the dry scrubber system and consists of a lime receiving and handling system, lime day bin, two 100 percent slakers, degritters, lime dilution tank, lime pumps, piping to and from the scrubbers, back flush system, etc. The lime system is sized for the total facility PMCR. The foundations and tie-in costs are included as part of the labor, bulk material, and construction indirects. Also, the long-term lime silo is estimated separately. The dry scrubber-lime system equipment and installation costs are estimated as a function of flue gas flow (in ACFM) into the scrubber. The estimated cost is calculated as:

$$\text{Replacement} = (2.0)(\text{ACFM}) + 240,000 \quad [\text{Eq 127}]$$

The silo serves as long-term storage of the lime for the dry scrubbers. The silo is made of steel and includes a fill pipe, a bin activation system, and a dust-vent collection system. The estimated installed costs are:

$$\begin{aligned} &(\text{Range: 100 to 1200 tons}) \\ \text{Replacement} &= (588)(\text{tons}) + 4400 \end{aligned} \quad [\text{Eq 128}]$$

$$\begin{aligned} &\text{Range: 1200 to 2000 tons} \\ \text{Replacement} &= (166.67)(\text{tons}) + 510,000 \end{aligned} \quad [\text{Eq 129}]$$

Limestone Handling System

This system is used with fluid-bed boilers and includes the long-term limestone silo with fill pipe, bin activator system, dust collection system, and conveyor system to convey limestone from the long-term storage silo to the day storage silo. The estimated cost of the system is calculated as:

$$\begin{aligned} \text{Replacement} &= (270.83)(\text{tons of storage}) + 65,000 && [\text{Eq 130}] \\ \text{Functional} &= 0 \end{aligned}$$

The silo provides long-term storage of limestone for the fluidized-bed boilers. The silo is constructed of steel and includes a fill pipe, a bin activation system, and a dust-vent collection system. The estimated installed costs are:

$$\begin{aligned} &(\text{Range 100 to 1200 tons}) \\ \text{Replacement} &= (588)(\text{tons}) + 4400 && [\text{Eq 131}] \end{aligned}$$

$$\begin{aligned} &(\text{Range 1200 to 2000 tons}) \\ \text{Replacement} &= (166.67)(\text{tons}) + 510,000 && [\text{Eq 132}] \end{aligned}$$

Baghouses and I.D. Fans

The budgeted capital baghouse costs presented below represent a typical baghouse subcontract. The scope of supply includes:

- One baghouse per boiler
- Filter bags
- Internal inlet and outlet manifolds
- Cleaning system
- Preheat system for residue hoppers
- Maintenance enclosures for fabric filters
- External inlet and outlet flue gas ducts
- Control system, programmable logic controller
- Insulation and lagging
- Ash hoppers, two per module
- Access doors, ladders, stairs, platforms, etc.
- Purge air system
- Field supervision during erection
- Startup services
- Freight
- Operation manuals
- Spare bags.

These costs represent equipment material costs only. Tie-ins, construction, and other associated costs are included with the labor, bulk material, and construction indirect costs. Each baghouse cost is estimated as a function of gas flow. The estimated cost is calculated as:

$$\begin{aligned} \text{Replacement} &= (5.087)(\text{ACFM}) + 230,000 && [\text{Eq 133}] \\ \text{Not functional} &= (2.5435)(\text{ACFM}) + 115,000 \\ \text{Functional} &= (0.5087)(\text{ACFM}) + 23,000 \end{aligned}$$

The I.D. fans draw the boiler flue gas out of the boiler, through the mechanical collector, dry scrubber, and baghouse, and exhaust the gases into the boiler stack flue. The fan is sized for the amount of combustion gases plus air leakage in the boiler dry scrubber/baghouse system. Each fan is sized for 100 percent of the flue gas flows plus 15 percent leakage, with a static pressure of 20 in. of water. The foundation, tie-in, etc. costs are included as part of the labor, bulk material, and construction indirects. The equipment cost is estimated as a function of flue gas flow (measured in ACFM) entering the fan. Cost is calculated by the following two sets of equations:

(Range 2000 to 18,000 ACFM)

$$\begin{aligned} \text{Replacement} &= (0.382)(\text{ACFM}) + 3000 \\ \text{Not functional} &= (0.191)(\text{ACFM}) + 1500 \\ \text{Functional} &= (0.0382)(\text{ACFM}) + 300 \end{aligned} \quad [\text{Eq 134}]$$

(Range 18,000 to 110,000 ACFM)

$$\begin{aligned} \text{Replacement} &= \sqrt{[(6935) (\text{ACFM})]} + 9000 \\ \text{Not functional} &= \sqrt{[(3468) (\text{ACFM})]} + 4500 \\ \text{Functional} &= \sqrt{[(694) (\text{ACFM})]} + 900 \end{aligned} \quad [\text{Eq 135}]$$

Pumps

There are four categories of pumps: boiler feedwater pumps (BFWP); plant centrifugal pumps, which include the condensate pumps and the makeup or treated water pumps; miscellaneous centrifugal sump pumps, which include the rail-track hopper pumps, truck hopper pump, reclaim hopper pumps, neutralization tank pumps, brine wastewater sump pump, and the coal pile runoff pond neutralization pumps; and fuel slurry oil pumps. Each pump category is described and priced below. The chemical feed pumps are included in the chemical injection skid.

An existing boiler facility requires these pumps to operate. Therefore, the costs indicated apply only if the pumps need to be replaced. If not, they can be used as is.

Boiler Feedwater Pumps

The boiler facility includes two classes of BFWPs. The first is a motor-driven, multi-stage, centrifugal pump; the second is a steam turbine-driven, multi-stage, centrifugal pump. Estimated costs are a function of pump flow and discharge pressure. The cost includes pump, driver (motor or turbine), valves, starters, governors (turbine), etc. The installation and tie-in costs are included in the labor, bulk material and construction indirect costs. The estimated equipment costs are calculated as:

Motor-Driven BFWP
(300 psig: 10 to 150 gallons per minute [gpm])

$$\text{Replacement} = (45.86)(\text{gpm}) + 2510 \quad [\text{Eq 136}]$$

(500 psig: 30 to 150 gpm)

$$\text{Replacement} = (22.92)(\text{gpm}) + 11,750 \quad [\text{Eq 137}]$$

Turbine-driven BFWP
(300 psig: 20 to 150 gpm)

$$\text{Replacement} = (45.86)(\text{gpm}) + 4000 \quad [\text{Eq 138}]$$

$$\begin{aligned} & (500 \text{ psig: } 30 \text{ to } 150 \text{ gpm}) \\ \text{Replacement} &= (22.92)(\text{gpm}) + 17,500 \end{aligned}$$

[Eq 139]

Centrifugal Pumps

These pumps move water from various areas of the plant to other pieces of plant equipment as needed. The treated water pumps remove the treated water from the storage tank and deliver the water to the deaerator. The condensate pumps remove condensate from the storage tank and also deliver the water to the deaerator. These pumps are of one- or two-stage design, and the head they must operate against is largely a matter of piping loss and static-elevation pressure. These pumps are horizontal, end-section centrifugal types with constant speed motors and come complete with pump, motor, coupling, base plates and guards. The estimated costs are calculated as a function of pump flow. The cost includes pump, motor, coupling, and starter. The installation and tie-in are included in the labor, bulk material, and construction indirects. The estimated equipment cost is:

$$\text{Replacement} = (7.7)(\text{gpm}) 0.94 + 600$$

[Eq 140]

Slurry Pumps

The slurry pumps are positive displacement type with hard-surfaced ductile iron, made to pump a 2000 Seconds Saybolt Universal (SSU) fluid. These pumps are for the coal-oil and coal-water fuel delivery/storage/boiler systems. The estimated costs are a function of pump flow. The costs include pump, motor, and starters. The installation and tie-ins are included in the labor, bulk material, and construction indirects. The estimated equipment cost is:

$$\begin{aligned} & (\text{Range } 10 \text{ to } 300 \text{ gpm}) \\ \text{Replacement} &= (20)(\text{gpm}) + 8000 \end{aligned}$$

[Eq 141]

$$\begin{aligned} & (\text{Range } 450 \text{ to } 600 \text{ gpm [delivery system]}) \\ \text{Replacement} &= \$145,000 \text{ per pump} \end{aligned}$$

[Eq 142]

Sump Pumps

Sump pumps pump water from the various sumps (a pit or tank acting as temporary storage of drainage at the lowest point of a drainage system) of the plant and include the neutralization sump pumps for the water treatment and pond treatment areas. Estimated equipment costs are:

- 100 gpm: Replacement = \$3500 each
- 150 gpm: Replacement = \$3800 each
- 300 gpm: Replacement = \$4000 each

Tanks

The facility has many different sizes of tanks. These are divided into three categories: carbon steel tanks, stainless steel tanks, and fiberglass tanks. Carbon steel tanks include condensate storage, a high-temperature hot water tank, a condensate return tank, fuel (coal-oil, coal-water) storage tanks, and blowdown tanks. The stainless steel tank includes treated water storage, condensate storage, and condensate return tanks. The fiberglass tank is used for underground fuel oil storage.

An existing boiler facility would already have these tanks in an operational condition. Therefore, the costs listed below apply only when tanks need replacement. Otherwise, they can be used as is.

Blowdown Tanks

The estimated cost of the continuous blowdown tank is a function of blowdown entering and is calculated as:

$$\text{Replacement} = (0.05)(\text{blowdown flow} - \text{MBtu/hr}) + 500 \quad [\text{Eq 143}]$$

The estimated cost of the intermittent blowdown tank is calculated as:

$$\text{Replacement} = (2)(\text{cost of continuous blowdown tank}) \quad [\text{Eq 144}]$$

Carbon Steel Tanks

The large carbon steel tanks are dome-roofed, atmospheric-type tanks. These tanks are erected on-site over a suitable foundation. The estimated cost (including erection and foundation costs) is included in the labor, bulk material, and construction indirects. The estimated cost is a function of gallons of storage and is provided by:

$$\begin{array}{l} \text{(Range 50,000 to 5 million gal)} \\ \text{Replacement} = (0.179)(\text{gallons}) + 83,000 \end{array} \quad [\text{Eq 145}]$$

The small carbon steel tanks are for water storage, acid storage, caustic storage, etc. These costs are calculated as:

$$\begin{array}{l} \text{(Range 2000 to 36,000 gal)} \\ \text{Replacement} = (0.553)(\text{gallons}) + 200 \end{array} \quad [\text{Eq 146}]$$

Stainless Steel Tanks

The large stainless steel tanks are atmospheric type, ranging in size from 30,000 to 300,000 gal. These tanks include tank saddles and prefabrication. The labor, bulk material, and construction indirects include the foundations. The estimated cost is a function of gallons of storage and is calculated as:

$$\text{Replacement} = (0.808)(\text{gallons}) + 63,400 \quad [\text{Eq 147}]$$

The small stainless steel tank (under 30,000) costs are calculated as:

$$\begin{array}{l} \text{(Range 2000 to 30,000 gal)} \\ \text{Replacement} = (1.45)(\text{gallons}) + 12,300 \end{array} \quad [\text{Eq 148}]$$

Neutralization Tanks

The neutralization tanks are concrete-lined tanks. The estimated installed cost is calculated as:

$$\begin{array}{l} \text{(Range 1000 to 36,000 gal)} \\ \text{Replacement} = (0.8974)(\text{gallons}) + 7600 \end{array} \quad [\text{Eq 149}]$$

Fiberglass Tanks

These tanks are for storage of No. 2 fuel oil. The tanks are underground, dual wall, and include a fill line, vent lines, a pump-out line, and a leak detection system. The installation costs are included in the labor, bulk material, and construction indirect costs. The tank cost is a function of gallons of storage and is calculated as:

$$\begin{array}{l} \text{(Range 4000 to 24,000 gal)} \\ \text{Replacement} = (1.417)(\text{gallons}) + 9700 \end{array} \quad [\text{Eq 150}]$$

Air Compressors

General facility and instrument air compressors are either reciprocating or rotary screw-type units. Each compressor is water cooled and includes a compressor, motor, guards, intake filters, silencers, oil filter, air receiver, aftercooler, and air dryer. The compressor is conceptually sized in ACFM by the plant size (PMCR). There are two 100 percent air compressors per plant; the estimated cost is a function of the ACFM requirement. If the existing air compressors need replacement, the following cost applies:

$$\text{Replacement} = (101.85)(\text{ACFM}) + 5047 \quad [\text{Eq 151}]$$

Wastewater Treatment

A boiler facility has four types of wastewater flow systems that must be properly handled and disposed of: sanitary waste, process (boiler system) wastewater, storm water, and coal pile runoff pond discharge. Each system's conceptual design is described in the following subsections.

Sanitary Waste

This system collects waste from toilets, sinks, and potable wastewater such as floor drains in offices, the cafeteria, etc. All waste is collected and discharged to an existing sanitary sewer system. The sanitary system cost includes items such as toilets, urinals, sinks, water heaters, drinking fountains, emergency eyewash stations, floor drains, showers, etc. Since the retrofit analysis applies to an existing facility, these costs were already incurred at construction, and are not considered in the retrofit cost analysis.

Process Wastewater

Process wastewater is generated by the boiler systems. This water comes mainly from the treated water system, boiler blowdowns, and equipment cooling water. This water may not contain oil, heavy metals, or other material that would make it unacceptable for discharge to the sanitary sewer system.

The wastewater from the treated water system is pretreated in the neutralization tank. This tank neutralizes the wastewater to an acceptable pH value before it is gradually discharged to the sanitary sewer system. Alternately, the water could be discharged to the coal pile runoff pond or used for ash conditioning. The neutralization tank, piping, and pump costs plus bulk material, labor, and construction contingencies are all included in the costs.

Blowdown Water

Blowdown water is sent to the sewer. The estimated cost of this is included in the blowdown tank and sanitary system costs.

Other Process Water

Other process water from cooling bearings, facility washdown water, etc., is first treated using dirt-settling chambers and/or grease/oil traps. This wastewater can then be sent to the sewer, runoff pond, dry scrubber system, or used for ash conditioning. The estimated cost of treating this wastewater is included with the other equipment/system costs.

Pond Neutralization

The pond neutralization system uses programmable controllers for caustic, coagulant, acid feed rate, and pH control. Each system controller also directs the operation of all automatic valves, pumps, mixers, and conveyors associated with the system. The cost of the pond neutralization, excluding the pumps, is estimated as a function of pond size. The estimated cost of this system is calculated as:

$$\begin{aligned} \text{Replacement} &= (16.43)(\text{pond acres}) + 9000 && [\text{Eq 152}] \\ \text{Not functional} &= (6.57)(\text{pond acres}) + 3600 \\ \text{Functional} &= (1.7)(\text{pond acres}) + 1000 \end{aligned}$$

Storm Sewer System

The storm sewer system includes a storm water collection system that will channel the collected rainwater to an acceptable drainage area. This system will also collect the wash water from the ash and coal area. The drains located in these areas have traps or settling basins to collect the ash and coal particles. The cost of the storm sewer collection and drainage system is estimated as a function of plant size (acres). The system cost does not include a major collection sump. The estimated cost of this system is calculated as:

$$\begin{aligned} \text{Replacement} &= 9450 \times (\text{plant acres}) + 5200 && [\text{Eq 153}] \\ \text{Not functional} &= 3780 \times (\text{pond acres}) + 2080 \\ \text{Functional} &= 950 \times (\text{plant acres}) + 500 \end{aligned}$$

Piping

An existing facility would have the piping required by the boiler house already in place. The only costs for piping would be those for the slurry fuel handling, if that technology is selected.

For COS and CWS systems, fuel piping includes the pipe, valves, fittings, joints, etc., necessary to feed liquid fuel to the boilers from the day fuel tank. The cost of the piping system, with fuel heaters, is estimated as a function of facility size:

$$\text{Replacement} = (1.25) (\text{pounds of steam produced}) \quad [\text{Eq 154}]$$

Fuel storage pipeline for COS and CWS systems includes the pipe, valves, fitting, joints, etc. necessary to distribute a liquid fuel from the fuel receiving area to the long-term storage area and transport the fuel from storage to the facility day tank. The cost of the system is estimated as a function of fuel storage.

$$\text{Replacement} = (0.15)(\text{gallons of storage}) \quad [\text{Eq 155}]$$

Stack

Facility stacks are freestanding chimneys that enclose steel flues (one flue for each boiler). Depending on the number of boilers, the design has one or two chimneys. The 3-boiler facility has a single chimney that houses three individual boiler flues; the four-boiler facility has two chimneys, each housing two boiler flues; the five-boiler facility has two chimneys, one chimney housing two boiler flues, and the second housing three boiler flues. The steel flues are insulated, have stack sampling ports, and are independently bottom-supported. The freestanding chimneys are designed for a wind load of 100 miles per hour (mph) and include testing platforms, a safety ladder to the top, interior and exterior lighting, and Federal Aviation Administration (FAA) lights. The cost of the stack includes erection but does not include the foundation. The foundation cost is included in the labor, bulk material, and construction indirects. The erected cost is calculated as:

Two-Flue Stack:

$$\text{Replacement} = (1456)(\text{stack height}) + 418,000 \quad [\text{Eq 156}]$$

$$\text{Not functional} = (728)(\text{stack height}) + 209,000$$

$$\text{Functional} = (147)(\text{stack height}) + 42,000$$

Three-Flue Stack:

$$\text{Replacement} = (3760)(\text{height}) + 200,000 \quad [\text{Eq 157}]$$

$$\text{Not functional} = (1880)(\text{stack height}) + 100,000$$

$$\text{Functional} = (376)(\text{stack height}) + 20,000$$

The minimum stack height is 100 ft; the maximum is 325 ft.

Instrumentation

Continuous Emission Monitors (CEM)

The CEM system provided includes SO₂, NO_x, and opacity monitors. Monitoring equipment conforms to applicable Federal, state, and local codes. The system has a remote mounted control unit that is microprocessor based. The equipment automatically maintains and generates reports as required by local, state, or federal agencies. Because the instrumentation requirements are different for coal-fired facilities compared to other fuels, the cost model analysis includes the replacement cost:

Single stack two flues:

$$\text{Replacement} = \$350,000$$

Dual stacks two flues per stack:

$$\text{Replacement} = \$600,000$$

Single stack three flues:

$$\text{Replacement} = \$400,000$$

Controls

The control systems for the heating facility are divided into two basic areas of control—the boiler/steam block and yard area. The boiler block includes the controls necessary for the boilers, steam header, and boiler-associated equipment and/or systems. The boiler block control system is a conventional analog or digital control system linking each boiler for total plant control. Each boiler control is configured for single loop integrity and has a single control panel for operations overview, with dedicated annunciator windows, motor control, and status indicators. Also included are auto/manual stations for combustion controls, steam outlet controls, and control switches and status indicators for the boiler auxiliaries.

Each boiler control interfaces with the total boiler system control for regulation of feedwater, fuel, airflow, desired boiler output, steam control, and proper combustion. Boiler auxiliary controls include monitoring and control of heat-cycle equipment, BFWPs, feedwater system, condensate system, auxiliary electrical system, etc. The cost to replace the heating facility controls is estimated as 1 percent of the total boiler cost, or a minimum cost of \$200,000.

Electrical Facilities Equipment Costs

Diesel Generator

The diesel backup generator provides emergency power to enable safe shutdown of the facility with some power for emergency lights, pumps, controls, etc. The generator comes with a diesel engine, generator, automatic start and synchronization, day fuel tank, load following, overload protection, etc. The system is skid mounted. The cost of tie-ins is included in the installation labor, bulk materials and construction indirect costs. The equipment cost is estimated to be a function of kilowatt (kW) output. The diesel generator would already be present in an existing facility. If it is not fully operational, the cost for minor work to make it functional is:

$$\text{Functional} = (46)(\text{kW}) - 9925 \quad [\text{Eq 158}]$$

Substation

The heating facility requires an electrical substation to receive power from the grid. The cost is estimated as an allowance type of cost and is based on two types of substations. One type steps the incoming voltage down from 13.8 kilovolts (kV) to a 480-volt (V) bus system; the other steps the incoming voltage down from 13.8 kV to a 2400-V bus system and then steps down to the 480-V bus. The main reason for the second substation is due to the high horsepower (hp) motors required by the fluid-bed (circulating and bubbling) boiler systems.

The first substation (13.8 kV to 480 V) system is double-ended, and includes two main stepdown transformers with oil-filled breakers, hardware, wire, etc. The cost of the tie-ins is included in the labor, bulk materials, and construction indirects. The equipment allowance cost is estimated to be a function of plant size. The substation would already be present in an existing facility. Should it need repair, the cost for minor work to make it functional is:

$$\text{Not functional cost} = (0.09)(\text{PMCR}) + 60,000 \quad [\text{Eq 159}]$$

The second substation (13.8 kV to 480 V) is also a double-ended system. This substation consists of 13.8 kV primary fused high-voltage disconnect switches, 13.8 to 2.4 kV transformers furnished with

safety and indicating devices plus transition pieces, secondary fused medium-voltage disconnect switches, and all required fused disconnects plus combination motor starters for large horsepower motors (above 125 hp) and low voltage (480 V), switchgear. A tie breaker will be furnished so that the secondary section of the substation can be serviced from either of the high-voltage transformers in case of an unscheduled shutdown. The transformers can be sized so that either one can carry the total purchased power load of the heating plant.

The low voltage (480 V) switchgear can also be a double-ended unit consisting of medium voltage (2400 V), primary switches, 2.4 to 480 kV transformers with above noted accessories plus transition pieces, secondary fused disconnect switch, and a distribution section with draw out circuit breakers to service remote motor control centers. The second substation would already be present in an existing facility. If it is not fully operational, the cost for minor work to make it functional is:

$$\text{Not functional cost} = (0.075)(\text{PMCR}) + 125,000 \quad [\text{Eq 160}]$$

General Facility

The general facility has already been equipped with the necessary electrical equipment (circuit breakers, wiring, lights, cable trays, conduits, etc.). Therefore, the cost model analysis does not accommodate any additional cost in this area.

Site Work

Site Development

The site development cost includes work necessary to prepare a site for construction. This includes work such as site grubbing and clearing (elimination of trees, bushes, etc.), some preliminary ground investigation (core drilling, site history investigation, etc.), some site leveling, control of site drainage, mobilization, etc. Since this is highly site-specific, the program provides only a very rough estimate of this cost. The cost estimate is provided as a function of total site (plant, plus fuel pile, plus runoff pond) acres. Initial cost for new plant construction is estimated as \$2500 per acre, but cost for retrofit or reconversion is estimated to be zero.

Fuel Storage Area

Coal pile storage area development cost represents the work necessary to prepare the site for construction, remove the overburden, and install an impermeable layer under the storage pile and the storage drainage discharge to the pond. The estimated retrofit cost is \$16,500 per acre, or \$0.375 per sq ft.

Slurry fuel storage area development costs represent the work necessary to prepare the site for construction, remove the overburden, and install diked areas around the storage tanks. The estimated cost for new plant construction is \$8250 per acre.

Site Improvements

This category is an allowance provided for such things as site landscaping, building architectural improvements, sidewalks, parking lots, fences, etc. No site improvements should be necessary for a retrofit/reconversion other than the fuel storage area. Therefore, this cost category is zero for the retrofit/reconversion case.

Building

The building is the structure which houses the boilers, feedwater treatment, turbine-generator (cogeneration), plant offices, maintenance, locker rooms, etc. This building is a stand-alone type of structure with insulated metal siding, windows, roof vents, sidewall louvered vents, etc. The building includes concrete slab on grade and grating for upper floor areas. The building comes complete with floors, stairs, platforms, windows, vents, handrails, etc. The rough cost of the building is provided as a function of cubic feet (cf) of building area. The cost for a new facility is estimated as \$4.75 per cf of building volume. For a retrofit/reconversion, the estimated building cost is \$0.475 per cf of building volume.

The existing facility is assumed to be complete and without need for modifications or additions to the following areas: elevator; communications systems (phone stations, attendant console, private automatic branch exchange (PABX), amplifiers, battery, battery charger, paging speakers and horns, wiring systems, and all conduit); fire protection systems; furniture for plant offices, lunch room, locker rooms, maintenance shop area, etc.; and heating, ventilation, and air-conditioning (HVAC) system for the facility's offices, cafeteria locker rooms, and electrical equipment room.

Mobile Equipment, Spare Parts, and Tools

Mobile Equipment

The cost of equipment is provided as an allowance cost per unit. A front-end loader is a 4-wheel-drive articulating type, diesel powered, with foam-filled tires and a 4 cubic yard [cu yd] (6 ton) bucket. It costs \$210,000 each.

A light-duty front-end loader, with 4-wheel-drive, diesel power, foam-filled tires, and a 1 cu yd bucket costs \$75,000 each.

The dump truck is included for general plant use. The truck is sized with a 5-yd dump body and has a 5-ton capacity. It costs \$25,000 each.

The drop box is used for holding lime grit from the slaker and for general plant maintenance use. The box is made of heavy-duty steel construction, has a 40 cu yd capacity, drip-proof seals, and can be picked up with a tilt frame (roll-off) truck or other vehicle. It costs \$8000 each.

Other equipment that would be considered part of a new boiler facility (and is assumed to already be there) that is not included in the retrofit analysis are:

- Forklift, provided for general plant maintenance, that is four-wheel-drive, diesel-powered with pneumatic tires, rated at 5,000-lb capacity.
- Pickup truck with a 3/4-ton carrying capacity, diesel powered, 8-ply tires, meeting all local, state, and Federal safety and emission-control regulations.
- One power sweeper for general internal and external plant maintenance. The sweeper is diesel powered and comes with the wet/dry cleaning option.

Spare Parts

Spare parts for major equipment/systems are required by a new facility. These costs also apply to a retrofit/reconversion plant. These costs are estimated as a function of plant size and equipment costs.

$$\text{Cost} = (\text{Number of boilers}) \times 37,500 + (\text{PMCR}) \times 0.25 + 205,000 \quad [\text{Eq 161}]$$

Facility Consumables

A retrofit/reconversion facility requires an initial inventory of consumables. These are items normally considered as yearly operational needs, but a facility must have an initial inventory to begin operations. Items included in this category are packing seals, grease, oil, small parts (bearings, valves, pipe, fittings, etc.), rags, light bulbs, buckets, mops, cleaning agents, towels, etc. The estimated cost is calculated as:

$$\text{Cost} = (0.20)(\text{spare parts cost}) \quad [\text{Eq 162}]$$

Tools

A retrofit/reconversion facility has two types of tools that need to be included: hand tools, which can be used to maintain the equipment; and major tool room equipment that includes items such as metal lathes, grinders, welders (gas and electric), a drill stand or press, hydraulic press, milling machine, etc. These costs are an allocation and are estimated as a function of plant size. The estimated allowance or cost is:

$$\text{Cost} = 0.04375 \times (\text{PMCR}) + 10,600 \quad [\text{Eq 163}]$$

Freight Costs

This category covers the cost of freighting materials to the project site. This cost is estimated as a percent of equipment cost, and typically ranges from 1.5 to 4.5 percent in the continental United States (CONUS). The value used is 2 percent of the total heating facility costs. The freight costs for bulk materials are included as part of the bulk material costs.

Installation Costs

The installation costs are derived by multiplying a series of factors by the equipment costs. These factors are used to identify the direct labor man-hours and the bulk material dollars. The actual labor costs are calculated by multiplying a wage rate by the direct labor man-hours. The construction indirects are calculated by taking a percentage of the direct labor costs.

Direct Labor Man-Hours

The direct labor man-hours are the total craft man-hours required to build the plant or complete the retrofit/reconversion project. These include costs for skilled workers such as pipefitters, boilermakers, electricians, insulators, painters, laborers, steelworkers, masons, and foremen. These factors, when multiplied by the equipment costs, yield the total direct labor man-hours associated with the installation of that equipment. They account for the labor man-hours for any foundations, structural steel, buildings,

pipng, electrical, instrumentation, painting, or insulation that is required to completely install a particular piece of equipment.

After the labor man-hours are derived, they are multiplied by a union labor productivity adjustment. Table 2 lists these productivity multipliers by state. For example, assume that a New Jersey plant site was chosen. The program would multiply the labor man-hours by 0.97, reducing the total man-hours required to complete the installation. This reduction is due to the New Jersey construction crews being more productive than crews in some other states. Larger multipliers indicate an increase in total man-hours and less productive construction crews.

Direct Labor Cost

The direct labor costs are calculated by multiplying the labor man-hours by the average base wage rate for that plant site. The base wage excludes all payroll benefits and burdens. In CHPECON, the average base wage rate for the proposed plant location is represented by the pipefitters union base wage as presented in Table 2. The pipefitters base wage for each state is an average of the pipefitters union base wage rates for the major cities in that particular state.

Bulk Materials

Bulk materials are any permanent material (other than the equipment) that the plant requires. These include concrete, pipe, wire, conduit, structural steel, etc. Shown in Table 3, the bulk material factor, which when multiplied by the equipment costs, yields the total bulk material costs associated with the installation of that equipment. They account for the materials of any foundations, structural steel, buildings, piping, electrical, instrumentation, painting, or insulation that are required to completely install that particular piece of equipment.

Indirect Costs

Construction indirect costs cover all field indirects, construction services, field staff, payroll benefits, and burdens for direct and indirect labor, small tools and consumables, and the construction equipment. The field indirect costs include all temporary facilities such as service buildings and office trailers, temporary roads, parking, and material laydown areas. Construction services include job cleanup, medical supplies, construction equipment handling and maintenance, field office supplies, and telephone charges. Field staff covers the salaries and subsistence for contractor field staff. Subsistence includes meals, lodging, travel expenses, etc. Also included is the site security, medical, warehouse, and clerical personnel. The payroll benefits include vacation, holidays, sick time, and medical insurance. The burdens include social security, Federal, and state unemployment insurance.

The program uses a range of 75 percent of the direct labor dollars to account for construction indirect costs. This is based on data from a number of similar projects using union construction crews. This percentage will probably increase in open shop scenarios because as labor costs decrease in open shop construction, the percentage for construction indirects tends to increase.

Table 2
Productivity Factors by State

State	Productivity Multiplier	Average Wage
AK	0.87	27.00
AL	1.00	13.00
AR	1.00	8.00
AZ	1.00	17.85
CA	1.00	23.00
CO	1.00	12.00
CT	0.98	18.22
DE	1.00	18.05
FL	1.00	10.00
GA	1.00	10.00
HI	1.00	20.00
IA	1.00	14.77
ID	1.00	17.63
IL	1.21	18.05
IN	0.98	18.17
KS	1.00	11.55
KY	1.13	10.00
LA	1.00	11.97
MA	0.87	18.09
MD	1.00	12.94
ME	0.87	14.35
MI	1.00	16.00
MN	1.00	17.50
MO	1.00	18.00
MS	1.00	9.00
MT	1.00	14.51
NC	1.00	6.75
ND	1.00	9.95
NE	1.00	12.91
NH	0.87	16.00
NJ	0.97	18.44
NM	1.00	11.30
NV	1.00	19.59
NY	1.00	18.50
OH	1.00	18.60
OK	1.00	9.81
OR	1.00	18.31
PA	0.98	17.08
RI	0.87	19.07
SC	1.00	4.45
SD	1.00	6.00
TN	1.00	10.00
TX	1.00	9.50
VA	0.87	14.61
VT	0.87	14.70
WA	1.00	18.00
WI	1.00	16.00
WV	0.93	16.97
WY	1.00	12.00
UT	1.00	14.41

Table 3
Labor Hours and Bulk Material Cost Factors

Replacement Cost Category	Labor	Bulk Material	Freight
<u>Boilers</u>			
Stoker boilers	0.0168	0.12	0.05
CFBC & BFBC boilers	0.0030	0.12	0.05
COS & CWS boilers	0.0013	0.12	0.05
Airheaters	0.020	0.05	0.05
Desuperheater	0.0403	0.18	0.05
<u>Coal Handling</u>	0.0072	0.15	0.02
<u>Fuel Handling</u>			
Long-term storage tanks	0.0266	0.22	0.02
Short-term storage tanks	0.011	0.16	0.02
Slurry pumps	0.0147	0.15	0.02
<u>Ash Handling</u>	0.1337	0.45	0.02
<u>Mechanical Collector</u>	0.0088	0.05	0.02
<u>Dry Scrubber and Lime System</u>			
Dry scrubber and lime system	0.0247	0.4	0.02
Lime silo	0.0185	0.18	0.02
<u>Limestone Handling</u>	0.0247	0.18	0.02
<u>Baghouse and ID Fan</u>			
Baghouse	0.0148	0.28	0.02
I.D. fan	0.0198	0.18	0.02
<u>Boiler Water Treatment</u>			
Zeolite softeners	0.0127	0.15	0.04
Dealkalizer	0.0210	0.15	0.04
Demineralizer	0.0210	0.15	0.04

Table 3 (Cont'd)

	Labor	Bulk Material	Freight
Mixed bed	0.0263	0.18	0.04
Condensate polisher	0.0263	0.18	0.04
Chemical injection	0.0113	0.08	0.04
Boiler water laboratory	0.0076	0.10	0.04
Deaerator	0.0263	0.14	0.04
<u>Tanks</u>			
Condensate storage	0.0339	0.11	0.04
Treated water storage	0.0339	0.11	0.04
Acid and caustic tanks	0.014	0.08	0.04
Blowdown tank - continuous	0.0165	0.14	0.04
Blowdown tank - intermittent	0.0241	0.14	0.04
High-temperature hot water expansion tank	0.0339	0.11	0.04
Condensate return tank	0.0339	0.11	0.04
Facility fuel oil tank	0.0188	0.06	0.04
Neutralization tanks	0.0377	0.03	0.04
<u>Pumps</u>			
Motor-driven BFWP	0.0189	0.1 45	0.04
Turbine-driven BFWP	0.0195	0.055	0.04
Centrifugal pumps	0.0130	0.075	0.04
Circulating water pumps	0.0130	0.040	0.04
Sump pumps	0.0088	0.030	0.04
<u>Air Compressors</u>	0.0089	0.0875	0.04
<u>Wastewater Treatment</u>			
Sanitary system	0.0525	0.70	0.022
Neutralization pond	0.0564	0.125	0.022
Storm sewer system	0.0485	0.30	0.022
<u>Piping</u>			
Stack	0.0386	0.08	0.02
Piping	0.0420	0.5	0.02

Table 3 (Cont'd)

	Labor	Bulk Material	Freight
<u>Instrumentation</u>			
Continuous emission monitors	0.0078	0.5	0.02
Controls	0.0290	0.4	0.02
Not Functional Cost Category			
<u>Coal Handling</u>			
	0.0095	0.15	0.02
<u>Fuel Handling</u>			
Long-term storage tanks	0.0363	0.22	0.02
Short-term storage tanks	0.015	0.16	0.02
Slurry pumps	0.0201	0.15	0.02
<u>Ash Handling</u>			
	0.1847	0.45	0.04
<u>Mechanical Collector</u>			
	0.012	0.05	0.02
<u>Baghouse and ID Fan</u>			
Baghouse	0.0202	0.28	0.02
I.D. fan	0.027	0.18	0.02
<u>Piping</u>			
Stack	0.0451	0.08	0.02
Piping	0.035	0.5	0.02
Functional Cost Category			
<u>Coal Handling</u>			
	0.0130	0.30	0.04
<u>Fuel Handling</u>			
Long-term storage tanks	0.0484	0.44	0.04
Short-term storage tanks	0.020	0.32	0.04
Slurry pumps	0.0268	0.30	0.04

Table 3 (Cont'd)

	Labor	Bulk Material	Freight
<u>Ash Handling</u>	0.243	0.45	0.02
<u>Mechanical Collector</u>	0.016	0.10	0.04
<u>Baghouse and ID Fan</u>			
Baghouse	0.0269	0.56	0.04
I.D. fan	0.036	0.36	0.04
<u>Piping</u>			
Stack	0.097	0.08	0.03
Piping	0.035	0.5	0.03
<u>Building and Services</u>			
Building	0.00065	0.3	0.02

Permit Development Costs

This category provides an estimate to develop, apply and obtain the necessary Environmental Protection Agency (EPA), state and local permits to begin construction. The permit development cost estimate is a function of plant size:

$$\text{Cost} = (2.222)(\text{PMCR}) + 390,000 \quad [\text{Eq 164}]$$

Engineering Costs

This category represents the contract engineering required to design the plant or the retrofit/reconversion project. The cost includes engineering design and project management fees. This category accounts for the cost of preparing the specifications, drawings, soliciting bids for equipment, and preparing bid evaluations. It covers all engineer salaries and overheads such as reproduction, computer services, travel, final drawings, field changes, etc. The estimated cost of these services is 12 percent of the total heating facility cost.

Construction Management Costs

The construction management is responsible for site security, obtaining construction bond, managing construction of the facility, insurance, etc. These services are estimated as 7 percent of the total retrofit cost.

Construction Contingencies

The contingency is intended to cover estimation inaccuracies and any extra tasks needed to complete the project as originally defined. This cost is not intended to cover scope changes. The contingency is estimated as 15 percent of the total cost of the facility through construction.

Owner Management

This category covers the owner's cost of building a project. This includes payment to the main contractor, assuring project quality, schedule management, etc. The estimated cost is 6 percent of total facility costs.

Startup Costs

This covers the cost of the initial startup and troubleshooting of a facility's equipment and systems. The category also includes items such as startup fuel, line and system cleaning, boiler cleaning and blows, turbine starts, purchase power, etc. This estimated cost is calculated as a function of plant size:

$$\text{Cost} = (0.833)(\text{PMCR}) + 133,000 \quad [\text{Eq 165}]$$

6 FACILITY OPERATIONS AND MAINTENANCE COST

This chapter provides an overview of the operations and maintenance costs (O&M) that a retrofit/reconversion facility will incur. The O&M costs for a retrofit/reconversion project will be different than the current O&M costs at an existing facility; the cost characteristics of the facility will resemble the new technology rather than the previous one. Major maintenance costs include periodic equipment rebuilds, baghouse rebagging, major boiler outages, BFWP rebuilds, water treating resin replacement, etc. The total annual cost of the facility for each year of operation is estimated by CHPECON, and these values are used to produce a life-cycle cost criteria for the facility.

Operational Components

The cost components included in this category estimate the routine O&M costs of a retrofit/reconversion heating plant. The major cost items are:

- Labor
- Fuel
- Lime/limestone
- Water
- Sanitary sewer
- Ash disposal
- Electricity
- Chemicals
- Maintenance parts
- Facility consumables
- Facility grounds maintenance
- Insurance
- Mobile equipment
- Stack.

CHPECON assumes that routine retrofit/reconversion O&M costs are identical to the O&M costs of a new plant using the same boiler technology. The formulae used to estimate these costs will not be presented here; they have been extensively documented in the previous report (Lin et al. 1992a).

Major Maintenance

Costs included in this category estimate the major equipment rebuilds. The major cost items included in this category are:

- Boiler Maintenance
- Baghouse Maintenance
- Pumps
- Deaerator
- Coal conveyor system
- Water treatment system
- Stack

- Air heater
- Scrubber/lime system
- Building
- Fans
- Permits.

The major maintenance costs of a retrofit/reconversion are assumed to be identical to new plant maintenance costs using the same boiler technology. Maintenance schedules are also assumed to be equivalent to those in a new plant. The maintenance start date begins with the date of the facility retrofit/reconversion, rather than with its initial construction. The report noted above contains the information on the cost estimating formulae.

7 LIFE-CYCLE COST ECONOMIC ANALYSIS

The life-cycle cost (LCC) economic section of CHPECON is designed to evaluate the relative financial merit of various central energy plant retrofit and reconversion options. This analysis is conducted using discounted cash flow (DCF) techniques that assess the following types of costs: retrofit/reconversion capital investment costs, annual fuel costs, annual O&M costs, nonannual repair and replacement costs, and salvage values or residual costs of disposal. The goal of the CHPECON program is to develop a method for easily and consistently identifying the retrofit and reconversion technology options that display the lowest combination of cost factors and will produce a facility that maximizes LCC efficiency. The various retrofit and reconversion alternatives that fulfill the performance requirements can be ranked according to several economic assessment criteria, and should be considered for implementation according to the outcome of these ranking procedures.

The program is designed to automatically incorporate all relevant cost factors that correspond with the retrofit/reconversion technology selected during the initial screening phase. These costs are assembled according to their chronological occurrence within the project lifetime and are discounted to determine their present values for the year of the study. Relevant cost factors are estimated by the program but may be modified by the user to suit individual situations. A more detailed description of the LCC methodology is found in a previous report (Ruegg 1987).

Assumptions

CHPECON model makes a number of assumptions that are designed to aid the user in performing the LCC analysis. All of the assumptions and methods are consistent with guidelines issued in the "Life-Cycle Costing Manual for the Federal Energy Management Program" (Ruegg 1987). The model's major assumptions are:

1. All future dollar amounts are estimated in constant dollars that do not take the effects of inflation into account. All costs or benefits not escalated in the program are assumed to increase at the same rate as general inflation.
2. The federally-mandated discount rate is used for discounting purposes, although the rate can be easily changed within the program.
3. All costs and benefits are discounted by the appropriate discount rate to reflect their values at the year of study.
4. The study period for the retrofit/reconversion analysis should match the remaining useful life of the facility, but should not exceed 25 years.
5. All energy and O&M costs are assumed to begin at the facility start up, and are treated as occurring at the end of the year in which they take place.
6. All investment costs are assumed to occur as a lump sum expenditure at a single time during the midpoint of construction. In some cases, adjusted investment costs may constitute 90 percent of actual investment costs, which effectively provides a 10 percent credit to Federal energy projects meeting certain criteria. However, the program contains the option of allowing the user to select or override the 10 percent investment cost exclusion.

7. All nonannually recurring repair and replacement costs and salvage values are treated as occurring in a lump sum at the end of the year in which they take place. The net cost or benefit of salvaging equipment consists of the amount that the item can be resold for, minus the cost of removing and selling the item. Salvage values for new or retrofit/reconversion equipment which occur at the end of the study period must be differentiated from salvage values for existing equipment, which occur at the beginning of the study period.

8. Nonfuel cost elements such as O&M costs and repair and replacement costs are not escalated, but are assumed to increase over the life of the facility by the same rate as the level of general inflation. Federal criteria specifies that, "In the absence of reliable, well documented, and reasonably generally accepted information to the contrary, differential escalation rates for nonfuel cost elements should be zero."

Retrofit/Reconversion Considerations

Special considerations are necessary given the nature of the economic analysis for retrofit and reconversion projects. By definition, retrofits and reconversions are modifications of existing facilities. These existing facilities have usually been operating for many years. The initial capital cost figures for the construction of these facilities may not be available, and would be largely irrelevant even if they were. Furthermore, many facilities have operated well beyond the 25-year horizon imposed by Federal LCC guidelines; capital costs have been fully allocated by this time, with annual O&M costs representing the only economic considerations for such facilities.

Because of these special considerations, the retrofit/reconversion LCC analysis does not consider the costs incurred in construction of the existing facility. These costs are considered to be "sunk" and should not become an economic criteria for decisionmaking. The only capital costs considered in the retrofit/reconversion case are the costs for purchase and installation of new equipment. All O&M costs are evaluated after installation of the retrofit/reconversion equipment.

These considerations affect the way in which the economic output can be used. For example, the LCC of a retrofit/reconversion project could not be compared to the LCC of a new plant. The new plant analysis includes a large number of costs that are not incurred in a retrofit/reconversion project. The different life expectancy of the two types of facilities will also affect the LCC analysis. The retrofit/reconversion analysis should only be compared to other retrofit/reconversion projects. This provides a true measure of which facilities offer the greatest potential for retrofit/reconversion projects.

LCC Program Output

The life-cycle costing program provides a detailed list of annual cash flows in the major cost categories, and computes two important economic criteria measures. These measures (discussed below) furnish a different perspective on economic performance (total vs. unit costs), and allow the choices between competing retrofit/reconversion technologies to be made with greater certainty. Also, rankings of the retrofit/reconversion projects should be compared in different ways to determine which project is most desirable.

1) The total life-cycle cost (TLCC) is the primary tool for evaluating project worth. The TLCC gives an indication of the discounted value of all costs related to the project over its lifetime, including the costs required to produce the specified amount of facility output. A lower TLCC indicates a lower cost of building, operating, and maintaining the retrofit/reconversion facility. The TLCC discounts all future cash flows to the year of the study, which means that cash flows are valued by their time of

occurrence and interest rate (discount rate). The farther into the future that a cash flow occurs or the higher the interest rate, the more the present value of the cash flow decreases. This conforms to the idea that a dollar today is worth more than a dollar tomorrow. LCC analysis demands that all cash flows are valued in today's dollars. The TLCC is computed in terms of present value (PV) as the sum of the following components:

- + Present value (PV) investment costs [Eq 166]
- + PV energy and transportation costs
- + PV nonenergy O&M costs
- + PV repair and replacement costs
- +/- PV salvage value of existing system
- +/- PV salvage value of new/retrofit/reconversion facility

TOTAL LIFE-CYCLE COST

2) The Levelized Cost of Service (LCS) measures a facilities unit cost of providing output, stated in the desired units of output such as cost per million Btu (MBtu). The term "levelized" denotes that a financially-weighted average of the lifetime service costs is computed. This levelization is required because service costs vary throughout the project lifetime, but a consistent basis of measurement is required to compare projects of differing lives and/or sizes. Because LCS includes both the TLCC and the annual facility output, it provides a true measure of the unit cost of producing thermal output. The LCS equation includes a present value annuity factor (PVA), also called a levelizing factor, which adjusts the life-cycle costs on an annuity-equivalent basis. In general, a lower LCS is more desirable than a higher one. The LCS is computed as:

$$\text{LCS} = (\text{TLCC}/\text{PVA Factor})/\text{Annual Output}, \quad \text{[Eq 167]}$$

where the PVA Factor = $[(1+i)^n - 1]/[i(1+i)^n]$

8 COST MODEL USER INTERFACE

The operation of CHPECON has been modified to include the new work for retrofit enhancement. This chapter outlines the changes and important considerations in the screening model as it pertains to a retrofit analysis. The overall operation of the program remains the same as documented in the *Central Heating Plant Economic Evaluation Program* (Lin et al. 1992a).

After initial startup, CHPECON presents the main menu screen shown in Figure 19. It presents general categories of options available to the user. This chapter covers the program operation when the user selects **2 -- Cost Models**.

```
Central Heating Plant Economics Evaluation Program
02/24/93
Main Menu

1 -- Screening Models          | 6 -- Update Databases
2 -- Cost Models              | 7 -- System Utilities
3 -- Multiple Run Analysis    |
4 -- Sensitivity Analysis     | Q -- Quit (exit program)
5 -- Load Sensitivity Analysis

-----
Use ↑↓ to move highlight or enter first character to select option
-----
Determine a base's general suitability for a coal-fired or oil/gas
boiler plant
```

Figure 19. CHPECON Main Menu Screen.

When option 2 is selected, CHPECON displays the general types of boiler facility studies (Figure 20). The first four options cover the new boiler facility analyses that CHPECON was originally written to evaluate. The new option, the fifth, **5 -- Retrofit plant**, selects analysis of the costs incurred by a retrofit technology at an existing boiler facility.

The basics of the retrofit cost analysis consist of specifying the escalating cost indices to be used in the analysis, the general costs, and specific questions concerning the inclusion of individual equipment items. Upon completion, the program displays the results of the calculations, culminating in the summary screen shown in Figure 21. From this screen, either the long format report, the short format report, or both formats can be printed or printing can be skipped, returning the user to menu upon completion.

The user interface of the cost model has not changed since the prior version of CHPECON because the implementation of the enhancements for retrofit analysis operates in the background.

Appendix B contains an example printout of the Cost Model Analysis for Retrofits produced by CHPECON.

- 1 -- New plant
- 2 -- New plant with cogeneration
- 3 -- New plant with third-party cogeneration
- 4 -- New plant with consolidation
- 5 -- Retrofit plant
- Q -- Quit (return to main menu)

Use ↑↓ to move highlight or enter first character to select option

New boiler plant cost analysis for heating and process loads

Figure 20. Cost Model Menu Screen.

LIFE CYCLE COSTS:

+ PV 'Adjusted' Investment Costs	= \$	6,735,692
+ PV Energy + Transportation Costs	= \$	32,616,843
+ PV Annually Recurring O&M Costs	= \$	14,992,746
+ PV Non-Annually Recurring Repair & Replacement	= \$	2,408,112
+ PV disposal Cost of Existing System	= \$	0
+ PV Disposal Cost of New/Retrofit Facility	= \$	0

Total Life Cycle Cost (1991)	= \$	56,753,394
Levelized Cost of Service (1994 start) = 5.02 \$/lti		
Levelized Cost of Service (1994 start) = 6.00 \$/1000 lb steam		
print report:	Long	Short Both None

Figure 21. Summary of Cost Analysis.

9 SUMMARY

The primary purpose of CHPECON is the production of technical and economic feasibility analyses of central heating plant facilities for military bases. As originally developed, CHPECON allows a user to select a military base, characterize the base through heating load parameters, identify a particular boiler technology, select a coalfield for simulated use and answer general questions about the acceptability of the facility. The evaluation technique provides a consistent approach for evaluating competing technologies through the development of economic measures of project acceptability, including total life-cycle cost (TLCC) and levelized cost of service (LCS). The model provides sufficient flexibility to vary critical design and operating parameters.

The enhancements completed during this project add retrofit analysis capability to the program. They include:

- Improving the screening and scoring process for boiler facilities considered for retrofit
- Adding options for converting a boiler facility back to coal firing
- Detailing cost components for the retrofit option considered by the user
- Upgrading the economic analysis of the retrofit option from a simple operating cost evaluation to a complete life-cycle cost analysis, including the installed costs of the retrofit elements and the expected annual and periodic maintenance based on coal-fired boilers
- Expanding the economic analysis to include the possibility of using existing equipment and estimating the condition of that existing equipment

Several features were also provided to upgrade the user-friendliness of the program. All of these factors will enhance the ability of the CHPECON program to select and rank potential central heating plant technologies and sites. Due to the advancement of technology and the changing nature of the market place, frequent updating of the cost algorithms is highly recommended.

METRIC CONVERSION TABLE

1 in.	=	2.54 cm
1 ft	=	0.305 m
1 sq ft	=	0.093 m ²
1 cf	=	0.028 m ³
1 cu yd	=	7.646 × 10 ⁵
1 acre	=	.4047 sq hm
1 psi	=	6.89 kPa
1 lb	=	0.453 kg
1 short ton	=	907.1848
1 mi	=	1.61 km
1 mph	=	1.609 kms/hr
1 gal	=	3.78 L
°F	=	(°C + 17.78) × 1.8
1 yd	=	0.9144 m
1 Btu/lb	=	0.556 cal/g
1 hp	=	33,479 Btu/hr

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APPENDIX A: Sample Output of CHPECON Screening Model

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*****
** Central Heating Plant Economics Evaluation Program Page 1 **
** File: RT3 Type: Retrofit plant (RT) 02/24/93 **
** Desc: Joliet Army Ammunition Plant **
** Tech: Reconversion--Dump Grate Spreader Stoker w/o f/a/r **
*****

```

State : IL - Illinois
 Location : 41d 31m - 88d 4m
 County : WILL
 Emission regulation region
 # 0 - State and federal only

Annual heating degree days: 6427

***** Boiler Characteristics *****

Type of heating system : Steam

Average Monthly Steam Flows (million Btu/hr)

Jan	Feb	Mar	Apr	May	Jun
166	147	121	88	46	32
Jul	Aug	Sep	Oct	Nov	Dec
32	29	42	55	112	130

Calculated PMCR: 200 thousand lb/hr steam

Boiler technology: Reconversion--Dump Grate Spreader Stoker w/o f/a/r

Boiler sizes (thousand lb steam/hr) :

1: 80 2: 80 3: 80 4: 80

Original boiler sizes :

1: 80 2: 80 3: 80 4: 80

***** Coalfield Properties *****

Coalfield state : IN - Indiana
 Coal code: W191049 desc: STRIP
 Distance from base: 173 miles
 Located at 39d 04m 47s - 87d 15m 22s
 Cmnt:

Proximate Analysis

Rank : Bituminous
 Moisture : 12.70 %
 Volatiles : 35.90 % dry
 Fixed Carbon : 53.70 % dry
 Ash : 10.40 % dry

Ultimate Analysis

Carbon : 71.30 %
 Hydrogen : 5.40 %
 Sulfur : 1.60 %
 Oxygen : 10.20 %
 Nitrogen : 1.10 %
 Ash : 10.40 %

Hrdgrv Grind : 0.0
 Free Swell : 1.0
 Hemisph Temp : 2399 deg F

Heating Value (dry) : 12760 Btu/lb

```

*****
** Coal Fired Boiler Evaluation Program Page 2 **
** File: RT3 Type: Retrofit plant (RT) 02/24/93 **
** Desc: Joliet Army Ammunition Plant **
** Tech: Reconversion--Dump Grate Spreader Stoker w/o f/a/r **
*****

```

***** Boiler Performance @ PMCR *****

Heat input : 272 million Btu/hr
 Coal input : 10.7 tons/hr (dry)
 12.3 tons/hr (incl moisture)
 Blowdown : 5 %

Temperature out of stack : 220 deg F
 Gas flow from stack : 95952 cubic feet/min
 Steam pressure : 150 psig
 Steam temperature : 367 deg F enthalpy : 1195.6 Btu/lb
 Condensate return temp : 150 deg F enthalpy : 118.0 Btu/lb
 Makeup water temperature : 50 deg F enthalpy : 18.0 Btu/lb
 Inlet water temperature : 97 deg F enthalpy : 64.7 Btu/lb

***** Boiler Emissions @ PMCR *****

159.79 lb/hr, NOx emissions (out stack)
 68.10 lb/hr, SOx emissions (out stack)
 1440.22 lb/hr, particulate emissions (from boiler)
 1152.18 lb/hr, particulate emissions (after settling chamber)
 172.83 lb/hr, particulate emissions (after mechanical collector)
 25.92 lb/hr, particulate emissions (after dry scrubber)
 0.13 lb/hr, particulate emissions (after baghouse - out stack)

Ash collected by emis equip @ pmcr: 17.3 tons/day

Total ash output @ pmcr: 26.6 tons/day

***** Area and Water Requirements @ PMCR *****

Building size : 12820 sq ft	Condensate Return : 50 %
Plant area : 1.78 acres	Boiler house leakage : 2 %
Plant height : 71 ft	Water requirements : 300 gpm (est)
Stack height : 177 ft	Railway track length : 753 ft
Sewer dischrq : 50 gpm (est)	Lime needed : 1324 lb/hr

Multiple coal piles for storage
 Long term : 90 days long term storage, on 3.46 acres
 Short term : 3 days short term storage, on 0.23 acres

Total storage area (long + short + others) : 4.69 acres
 Pond size : 0.41 acres

Car thawing shed required: No

```

*****
** Coal Fired Boiler Evaluation Program Page 3 **
** File: RT3 Type: Retrofit plant (RT) 02/24/93 **
** Desc: Joliet Army Ammunition Plant **
** Tech: Reconversion--Dump Grate Spreader Stoker w/o f/a/r **
*****

```

***** Emission Regulation Evaluation @ PMCR *****

This plant passed all emission regulations

NOx:	159.79	163.11	Regulation of: US
		emissions [lb/hr] = 0.6 * input [10^6 Btu/hr]	
Part:	0.13	13.59	Regulation of: US
		emissions [lb/hr] = 0.05 * input [10^6 Btu/hr]	
SOx:	68.10	326.22	Regulation of: US
		emissions [lb/hr] = 1.2 * input [10^6 Btu/hr]	
SOx:	90.01	90.00	Regulation of: US
		reduction = 90 %	
NOx:	159.79	190.30	Regulation of: IL
		emissions [lb/hr] = 0.7 * input [10^6 Btu/hr]	

** Coal Fired Boiler Evaluation Program Page 4 **
** File: RT3 Type: Retrofit plant (RT) 02/24/93 **
** Desc: Joliet Army Ammunition Plant **
** Tech: Reconversion--Dump Grate Spreader Stoker w/o f/a/r **

***** General Site Considerations *****

Development and Construction

Contractors ARE AVAILABLE for CHP construction near the base. The availability of contractors in the neighborhood of the base will ensure the overall cost of the facility will be kept at a minimum.

Score: 5

Asbestos IS NOT PRESENT around the pipelines for the CHP. No special handling or disposal is required.

Score: 5

The site IS CAPABLE of supporting the building and equipment foundation. No additional costs would be incurred for the construction of a CHP.

Score: 5

The site WILL NOT REQUIRE special cleanup. No additional costs would be incurred for the construction of a CHP.

Score: 5

The site IS ACCESSIBLE by construction personnel and equipment. No special arrangements are required.

Score: 5

The soil DOES MEET THE REQUIREMENTS for minimizing wastewater seepage. No additional costs are expected for control measures.

Score: 5

There IS SUFFICIENT LEVEL GROUND for the CHP facility. No additional costs are expected in this area.

Score: 5

There IS ADEQUATE UTILITY ACCESS for the CHP facility connections. No additional costs are expected in this area.

Score: 5

There ARE TERRAIN (UNDERGROUND) CONSIDERATIONS for the CHP facility. The additional costs for removing and/or working around obstacles, such as underground streams or rock formations, are not considered in the CHPEcon cost model.

Score: 0

There IS SUFFICIENT CONSTRUCTION STORAGE AREA for wastes from the CHP facility. No additional costs are expected in this area.

Score: 5

** Central Heating Plant Economics Evaluation Program Page 5 **
** File: RT3 Type: Retrofit plant (RT) 02/24/93 **
** Desc: Joliet Army Ammunition Plant **
** Tech: Reconversion--Dump Grate Spreader Stoker w/o f/a/r **

The site IS FREE OF INFRASTRUCTURE CONSTRAINTS. No additional costs are expected in this area.
Score: 5

There IS OTHER CONSTRUCTION INTERFERING WITH CHP facility construction. Additional costs for working around or integrating the CHP construction with the other activity is not considered in the CHPEcon cost model.
Score: 0

There ARE STAFF AVAILABLE FOR COORDINATION of construction activities. No additional costs are expected in this area.
Score: 5

There IS NOT A PROBLEM (OR POTENTIAL) WITH FLOODING. No additional costs are expected in this area.
Score: 5

There ARE ADEQUATE STORAGE SITES for accepting material removed during construction. No additional costs are expected in this area.
Score: 5

The site IS LOCATED in a stable region. No problems can be expected with regard to earthquakes or other seismic disturbances to buildings or foundations.
Score: 5

There IS NO ASBESTOS present. No additional costs are expected to be incurred in this area.
Score: 5

Conditions DO NOT DIFFER materially from conditions ordinarily encountered. No additional costs are expected in this area.
Score: 5

Adequate sources of construction material ARE AVAILABLE. No additional costs are expected in this area.
Score: 5

There ARE NO REGULATIONS that will affect zoning. No additional costs are expected in this area.
Score: 5

STAFF ARE AVAILABLE to supervise construction. No additional costs are expected in this area.
Score: 5

** Central Heating Plant Economics Evaluation Program Page 6 **
** File: RT3 Type: Retrofit plant (RT) 02/24/93 **
** Desc: Joliet Army Ammunition Plant **
** Tech: Reconversion--Dump Grate Spreader Stoker w/o f/a/r **

There IS NO REMOVAL SCHEDULE that relies upon CHP construction.
No additional costs are expected in this area.

Score: 5

Total: 540/ 595 90%

=====

Fuel Supply and Site Access

Rail transport available: Yes
Highway transport available: Yes
No problems with transportation.

Score: 10

A DIRECT MINE TO BASE SUPPLY CONTRACT for coal can be established. This will ensure that adequate supplies of coal to the base at minimum transport cost.

Score: 5

Track condition IS CAPABLE of supporting coal deliveries. No additional costs are expected in this area.

Score: 5

There IS SUFFICIENT ROOM for coal train unloading. No additional costs are expected in this area.

Score: 5

Railroad access IS OVER FLAT TERRAIN. No additional costs are expected in this area.

Score: 5

There ARE NO SPECIAL SETUPS required for site access. No additional costs are expected in this area.

Score: 5

Total: 235/ 235 100%

=====

Ecology

Endangered species ARE NOT PRESENT on the site. No additional costs are expected in this area.

Score: 5

```

*****
** Central Heating Plant Economics Evaluation Program Page 7 **
** File: RT3 Type: Retrofit plant (RT) 02/24/93 **
** Desc: Joliet Army Ammunition Plant **
** Tech: Reconversion--Dump Grate Spreader Stoker w/o f/a/r **
*****

```

There IS NO POTENTIAL for local resident opposition. No additional costs are expected in this area.
 Score: 5

The facility IS NOT LOCATED near areas sensitive to acid rain. No additional costs are expected in this area (in the absence of new air emissions regulations).
 Score: 5

There IS NO POTENTIAL IMPACT from soil / shore erosion. No additional costs are expected in this area.
 Score: 5

There area IS NOT PART of a protected wetlands. No additional costs are expected in this area.
 Score: 5

Total: 215/ 215 100%

=====

Social Considerations

Coal/ash transport feasible: Yes
 Score: 5

Local community resistant to plant: No
 Score: 5

There ARE NOT SITES of significance nearby. No additional costs are expected in this area.
 Score: 5

There ARE NO SPECIAL SITES nearby that would interfere with the CHP. No additional costs are expected in this area.
 Score: 5

Water contamination IS NOT A MAJOR ISSUE in the community. No additional costs are expected in this area.
 Score: 5

There ARE NO REGULATIONS concerning ambient noise. The additional costs to reduce or overcome noise limitations are not considered in the CHPEcon cost model.
 Score: 5

** Central Heating Plant Economics Evaluation Program Page 8 **
** File: RT3 Type: Retrofit plant (RT) 02/24/93 **
** Desc: Joliet Army Ammunition Plant **
** Tech: Reconversion--Dump Grate Spreader Stoker w/o f/a/r **

There ARE NO NEIGHBORS that limit CHP placement. No additional costs are expected in this area.
Score: 5

Sufficient room IS AVAILABLE to insure compliance with noise regulations. No additional costs are expected in this area.
Score: 5

The area planned for the CHP IS NOT A CULTURAL RESOURCE. No additional costs are expected in this area.
Score: 5

Construction projects HAVE BEEN SUCCESSFUL. No additional costs are expected in this area.
Score: 5

The community economic situation IS CONDUCIVE to the start of a large construction project offering local jobs. No additional costs are expected in this area.
Score: 5

Total: 405/ 405 100%

=====

Facility Services

Condition of system is good
Score: 5

Steam distribution system routing is short
Score: 5

Lime available: Yes
Score: 5

There IS DIRECT ACCESS to transmission lines for the delivery of electricity to the CHP. No additional costs are expected in this area.
Score: 5

There IS TRAINED STAFF available for instrumentation calibration and maintenance of the proposed CHP. No additional costs are expected in this area.
Score: 5

** Central Heating Plant Economics Evaluation Program Page 9 **
** File: RT3 Type: Retrofit plant (RT) 02/24/93 **
** Desc: Joliet Army Ammunition Plant **
** Tech: Reconversion--Dump Grate Spreader Stoker w/o f/a/r **

The existing facility's distribution system WILL BE ABLE TO UTILIZE the new CHP steam output without modification. No additional costs are expected in this area.

Score: 5

There IS ADEQUATE TRAFFIC CONTROL supplied by the existing facilities. No additional costs are expected in this area.

Score: 5

The current staff IS UTILIZING WRITTEN procedures and operating the existing facility in such a fashion that the addition of the proposed CHP will be incorporated smoothly. No additional costs are expected in this area.

Score: 5

Total: 260/ 260 100%

=====

Waste Handling and Emissions

Location of ash disposal site: landfill on site
Ash disposal will not pose problems.

Score: 5

There IS ONE OR MORE OUTSIDE AGENCIES with sites that are or can be used for landfill of the collected ash. No additional costs are expected in this area.

Score: 5

Local sewer system available: Yes

Score: 5

Ash and other discharges from the CHP WILL NOT BE classified as hazardous wastes. No additional costs are expected in this area.

Score: 5

Blowdown water and other wastewater CAN BE DELIVERED DIRECTLY to a sewer system. No additional costs are expected in this area.

Score: 5

Other pollutant-emitting plants ARE NOT PRESENT in the surrounding vicinity. No additional costs are expected in this area.

Score: 5

** Central Heating Plant Economics Evaluation Program Page 10 **
** File: RT3 Type: Retrofit plant (RT) 02/24/93 **
** Desc: Joliet Army Ammunition Plant **
** Tech: Reconversion--Dump Grate Spreader Stoker w/o f/a/r **

There IS A POSSIBILITY for generating air emissions credits.
This represents a potential revenue gain for the facility that is
not considered in the CHPEcon cost model.

Score: 5

There ARE NO LOCAL REGULATIONS regarding waste handling and
disposal. No additional costs are expected in this area.

Score: 5

Total: 305/ 305 100%

=====

Military

The base HAS SECURE ACCESS to fuel supplies. No additional costs
are expected in this area.

Score: 5

Outside contractor operations WILL NOT AFFECT base security. No
additional costs are expected in this area.

Score: 5

Construction WILL NOT AFFECT base security. No additional costs
are expected in this area.

Score: 5

A change in base mission is NOT LIKELY. No additional costs are
expected in this area.

Score: 5

Current base activities WILL NOT INTERFERE with plant
construction. No additional costs are expected in this area.

Score: 5

Total: 200/ 200 100%

=====

 ** Central Heating Plant Economics Evaluation Program Page 11 **
 ** File: RT3 Type: Retrofit plant (RT) 02/24/93 **
 ** Desc: Joliet Army Ammunition Plant **
 ** Tech: Reconversion--Dump Grate Spreader Stoker w/o f/a/r **

General Questions Summary

	Total	Max	Rating
Development and Construction	540	595	90
Fuel Supply and Site Access	235	235	100
Ecology	215	215	100
Social Considerations	405	405	100
Facility Services	260	260	100
Waste Handling and Emissions	305	305	100
Military	200	200	100

Boiler technology rating: 10

Feasibility score: 10/10 = 100%

Existing equipment status/condition

Boiler assembly: replace w/ new
 Rail / truck equipment for coal unloading: replace w/ new
 Car dumper for coal unloading: replace w/ new
 Coal pile runoff pond: replace w/ new
 Car heating or thawing equipment: replace w/ new
 Coal silo: replace w/ new
 Ash handling / storage / treatment equipment: replace w/ new
 Mechanical collector: replace w/ new
 Baghouse / bag / associated equipment: replace w/ new
 Induced draft (I.D.) fan: replace w/ new
 Water treatment facility / testing lab: replace w/ new
 Storage tanks / treatment tanks: replace w/ new
 Facility pumps: replace w/ new
 Air compressors for facility: replace w/ new
 Pond neutralization equipment: replace w/ new
 Storm sewer system: replace w/ new
 Boiler facility stacks: replace w/ new
 Diesel generator equipment: functional
 Electrical substation equipment: functional

APPENDIX B: Sample Output of CHPECON Cost Model

Base Information

State: IL - Illinois Base DOE Region: 2
PMCR: 200,000 lb/hr steam Number of boilers: 4

Steam Properties: 150 psi (1195.6 Btu/lb)
Inlet water temp: 97 deg F enthalpy: 64.7 Btu/lb

Coalfield:
Coal code: W191049 desc: STRIP
State: IN - Indiana Distance from base: 173 miles
Coal type: bituminous (properties on a dry basis)
hhv: 12760 Btu/lb fixed carbon: 53.70% volatiles: 35.90%
ash: 10.40% sulfur: 1.60%
Coalfield DOE Region: 2

Boiler Design Parameters

A desuperheater IS required
A stock/reclaim system IS included
A coal silo IS needed
Storage required for coal silo: 3 days
Selected method for coal transport is by BOTH RAIL AND TRUCK
Ash silo diameter: 20 feet
Number of ash silos: 1
Required lime storage: 14 days
A mixed bed for condensate polishing IS REQUIRED
A dealkalizer unit IS INCLUDED
Storage required for the condensate storage tank: 1 hours
Fraction of water in the ash waste generated: 10 %

Plant Design Parameters --- Space Requirements

Approx. building width: 67 feet (used for ash handling)
Approx. building length: 191 feet (used for ash handling)
Air compressor flow rate: 225 cfm
Diesel generator capacity: 500 kW
Fuel storage area: 4.69 acres
Height of the plant: 71 ft (estimated)
Building area: 12820 sq ft (estimated)
Plant area: 1.78 acres (estimated)

Plant Design Parameters --- Material Handling Specifications

Coal handling equipment capacity: 100 tons/hr
Coal silo storage capacity: 770 tons
Fly ash pipe size: 4 inches
Bottom ash pipe size: 6 inches
Total ash collected: 49 tons/day
Total gas flow: 319050 lbs/hr
Fly ash intake: 2 tons/day
Bottom ash intake: 3 lbs/hr
Ash silo capacity: 196 tons
Lime silo storage capacity: 246 tons
Number of facility fuel oil tanks: 1
Acid and caustic storage tank volume: 13537 gallons

Plant Design Parameters --- Water & Water Treatment Specifications

Number of deaerators: 2
Number of resin vessels / train: 1
Number of mixed beds / train: 1
Condensate storage tank size: 12005 gallons
Water storage tank size: 201681 gallons
Number of water treatment trains: 2
Boiler 1: 1 motor-driven feedwater pump -- 154 gpm
Boiler 1: 1 turbine-driven feedwater pump -- 154 gpm
Boiler 2: 1 motor-driven feedwater pump -- 154 gpm
Boiler 2: 1 turbine-driven feedwater pump -- 154 gpm
Boiler 3: 1 motor-driven feedwater pump -- 154 gpm
Boiler 3: 1 turbine-driven feedwater pump -- 154 gpm
Boiler 4: 1 motor-driven feedwater pump -- 154 gpm
Boiler 4: 1 turbine-driven feedwater pump -- 154 gpm
Annual dry scrubber water use: 2,616,624 gallons
Annual personnel water use: 115,412 gallons

Facility Capital Costs

Boiler rebuild costs: \$ 1,096,478
Boiler #1 (80 k-lb stm/hr) rebuild cost: \$ 273,074
Boiler #2 (80 k-lb stm/hr) rebuild cost: \$ 273,074
Boiler #3 (80 k-lb stm/hr) rebuild cost: \$ 273,074
Boiler #4 (80 k-lb stm/hr) rebuild cost: \$ 273,074
Desuperheater rebuild cost: \$ 4,179

Coal Handling Capital Costs: \$ 4,509,671
Rail/truck receiving equipment cost: \$ 2,079,197
Car dumper equipment cost: \$ 2,365,484
Coal pond cost: \$ 22,392
Coal silo cost: \$ 42,597

Ash handling system equipment costs: \$ 477,534
Ash piping system retrofit cost: \$ 83,982
Air operated branch line gate retrofit cost: \$ 6,064
Air operated fly ash intake retrofit cost: \$ 73,722
Mechanical exhauster retrofit cost: \$ 105,731
Manual bottom ash intake retrofit cost: \$ 4,179
Receiver retrofit cost: \$ 41,790
Mixer and unloader retrofit cost: \$ 125,496
Control retrofit cost: \$ 36,566

Mechanical Collector Equipment Costs: \$ 147,747
cost of retrofit-collector #1 : \$ 36,936
cost of retrofit-collector #2 : \$ 36,936
cost of retrofit-collector #3 : \$ 36,936
cost of retrofit-collector #4 : \$ 36,936

Dry scrubber and lime system capital costs: \$ 1,479,569
cost of dry scrb/lime sys #1 : \$ 330,960
cost of dry scrb/lime sys #2 : \$ 330,960
cost of dry scrb/lime sys #3 : \$ 330,960
cost of dry scrb/lime sys #4 : \$ 330,960
Lime silo equipment cost: \$ 155,729

Baghouse and ID fan equipment retrofit costs: \$ 1,883,012
Cost of baghouse #1 retrofit: \$ 444,303
Cost of ID fan #1 retrofit: \$ 26,449
Cost of baghouse #2 retrofit: \$ 444,303
Cost of ID fan #2 retrofit: \$ 26,449
Cost of baghouse #3 retrofit: \$ 444,303
Cost of ID fan #3 retrofit: \$ 26,449
Cost of baghouse #4 retrofit: \$ 444,303
Cost of ID fan #4 retrofit: \$ 26,449

Facility Capital Costs, cont

Water Treatment System Equipment Costs: \$ 805,351
Cost of zeolite softeners: \$ 59,509
Cost of dealkalizers: \$ 388,136
Cost of mixed bed for condensate polishing: \$ 246,160
Cost of chemical injection skid: \$ 20,896
Cost of water lab: \$ 20,896
Cost of 2 deaerators: \$ 69,752

Tank Equipment Retrofit Costs: \$ 452,524

Pump Capital Costs: \$ 176,147

Air compressor equipment replacement costs: \$ 58,433

Waste Water Treatment System Equipment Retrofit Costs: \$ 32,418
Pond neutralization retrofit cost: \$ 9,410
Storm sewer system retrofit cost: \$ 23,008

Piping and Stack System Capital Costs: \$ 1,411,998
Facility stack cost: \$ 1,411,998

Instrumentation Equipment Retrofit Costs: \$ 835,858
Cost of heating/cogen control system retrofit: \$ 208,964
Cost of emission monitor retrofit: \$ 626,893

Electrical System Equipment Retrofit Cost: \$ 241,432
Cost of backup diesel generation retrofit: \$ 13,661
Cost of substation retrofit: \$ 227,771

Spare Parts, Tools and Mobile Equipment Capital Costs: \$ 860,254

Building / area retrofit costs: \$ 532,587
Building retrofit material costs: \$ 451,733
Cost of fuel storage area development: \$ 80,853

Facility Installation Costs

Boiler rebuild installation costs: \$ 884,312
Direct labor cost: \$ 398,663
Indirect cost: \$ 298,997
Freight cost: \$ 54,823
Bulk material cost: \$ 131,828

Coal Handling Installation Costs: \$ 1,989,858
Direct labor cost \$ 698,979
Indirect cost \$ 524,234
Freight cost \$ 90,193
Bulk material cost \$ 676,450

Ash Handling Retrofit Installation Costs: \$ 2,629,698
Direct labor cost: \$ 1,374,432
Indirect cost: \$ 1,030,824
Freight cost: \$ 9,550
Bulk material cost: \$ 214,890

Mechanical Collector Retrofit Installation Costs: \$ 59,323
Direct labor cost: \$ 27,989
Indirect cost: \$ 20,991
Freight cost: \$ 2,954
Bulk material cost: \$ 7,387

Dry Scrubber and Lime System Installation Costs: \$1,753,869
Direct labor cost: \$ 666,692
Indirect cost: \$ 500,019
Freight cost: \$ 29,591
Bulk material cost: \$ 557,567

Baghouse and ID Fan Retrofit Installation Costs: \$ 1,661,793
Direct labor cost: \$ 611,319
Indirect cost: \$ 458,489
Freight cost: \$ 75,320
Bulk material cost: \$ 516,663

Boiler Water Treatment System Installation Costs: \$ 820,613
Direct labor cost: \$ 379,095
Indirect cost: \$ 284,321
Freight cost: \$ 32,214
Bulk material cost: \$ 124,982

Tank Installation Costs: \$ 639,648
Direct labor cost: \$ 332,019
Indirect cost: \$ 249,014
Freight cost: \$ 18,100
Bulk material cost: \$ 40,512

Facility Installation Costs, cont

Pump installation costs: \$ 117,096
Direct labor cost: \$ 57,501
Indirect cost: \$ 43,126
Freight cost: \$ 7,045
Bulk material cost: \$ 9,421

Air Compressor Installation Costs: \$ 39,451
Direct labor cost: \$ 10,189
Indirect cost: \$ 7,641
Freight cost: \$ 1,168
Bulk material cost: \$ 20,451

Waste Water Treatment System Installation Costs: \$ 70,825
Direct labor cost: \$ 35,447
Indirect cost: \$ 26,585
Freight cost: \$ 713
Bulk material cost: \$ 8,078

Piping and Stack System Installation Costs: \$ 2,194,472
Direct labor cost: \$ 1,173,298
Indirect cost: \$ 879,974
Freight cost: \$ 28,239
Bulk material cost: \$ 112,959

Instrumentation Installation Costs: \$ 826,254
Direct labor cost: \$ 235,717
Indirect cost: \$ 176,787
Freight cost: \$ 16,717
Bulk material cost: \$ 397,032

Electrical System Installation Costs: \$ 294,524
Direct labor cost: \$ 120,247
Indirect cost: \$ 90,185
Freight cost: \$ 4,828
Bulk material cost: \$ 79,262

Spare Parts, Tools, Mobile Equipment Installation Costs: \$ 17,205
Freight cost: \$ 17,205

Building Retrofit Installation Costs: \$ 155,616
Direct labor cost: \$ 6,320
Indirect cost: \$ 4,740
Freight cost: \$ 9,034
Bulk material cost: \$ 135,520

File: RT3 Type: Retrofit plant (RT) 02/24/93

Desc: Joliet Army Ammunition Plant

Tech: Reconversion--Dump Grate Spreader Stoker w/o f/a/r

Direct Costs

Direct costs: \$ 7,355,544
Permit development cost: \$ 834,400
Engineering cost: \$ 1,800,122
Construction management cost: \$ 1,050,071
Construction contingency cost: \$ 2,250,153
Owners management cost: \$ 1,121,136
Startup cost: \$ 299,660

Installed Capital Equipment Cost Summary

Total Capital Costs: \$ 15,001,021
Total Direct labor cost: \$ 6,127,913
Total Indirect cost: \$ 4,595,935
Total Freight cost: \$ 397,702
Total Bulk material cost: \$ 3,033,010
Total Direct costs: \$ 7,355,544

Plant installed cost: \$ 36,511,127

File: RT3 Type: Retrofit plant (RT) 02/24/93

Desc: Joliet Army Ammunition Plant

Tech: Reconversion--Dump Grate Spreader Stoker w/o f/a/r

Facility Operating Labor Requirements

Operation personnel requirements

- plant manager: 1
- plant engineer: 0
- plant technician: 0
- plant clerk: 0
- plant secretary: 0
- plant janitor: 0
- operations operator: 4
- operations assistant operator: 1
- operations laborer: 1
- fuel storage operator equipment: 0
- maintenance a mechanic: 2
- maintenance a electrician: 2

Operating staff: 13

Annual Labor Costs: \$ 612,137

Yearly O & M Costs Summary

Annual boiler maintenance costs: \$ 88,862
Annual spare parts costs: \$ 359,680
Annual mobile equipment maintenance costs: \$ 26,580
Annual facility consumables costs: \$ 16,926
Annual O & M (materials/supplies) costs: \$ 623,477
Annual diesel/distillate fuel usage: 16,800 gallons
Annual electricity usage: 5,443,174 kW-hr
Annual lime cost: \$ 192,467
Annual condensate make-up water cost: \$ 130,613
Annual blowdown make-up water cost: \$ 13,061
Annual dry scrubber water cost: \$ 7,849
Annual ash conditioning water cost: \$ 321
Annual facility washdown water cost: \$ 2,340
Annual condensate polisher water cost: \$ 5,788
Annual zeolite softener water cost: \$ 15,018
Annual personnel water cost: \$ 346
Annual chemicals cost: \$ 4,633
Annual sanitary sewer cost: \$ 4,608
Annual ash disposal cost: \$ 223,772
Annual miscellaneous maintenance costs: \$ 22,656
Annual lime usage: 2,405 tons
Study year lime cost: \$80.00/ton
Study year water cost: \$3.00/1000 gallon
Study year ash disposal cost: \$50.00/ton
Study year coal transportation cost: 2.18 cents/ton-mile
Study year cost transportation cost escalation rate: \$0.00 %
(escalation above general inflation)
1991 cost for coal: 1.550 \$/MMBtu
1991 cost for distillate: 0.720 \$/gallon
1991 cost for electricity: 0.053 \$/kW-hr

Periodic Maintenance Costs Summary

- Major boiler maintenance costs (every 8 years): \$ 313,632
- Coal handling system maintenance costs (every 10 years): \$ 450,967
- Major ash handling system maintenance costs (every 7 years): \$ 105,057
- Major scrubber-lime system maintenance costs (every 5 years): \$ 79,430
- Lime conveyor system maintenance costs (every 5 years): \$ 4,765
- Major baghouse maintenance costs (every 3 years): \$ 88,860
- Major baghouse maintenance costs (every 12 years): \$ 124,405
- Major I.D. fan maintenance costs (every 20 years): \$ 40,203
- Major water treatment system maintenance costs (every 10 years): \$ 312,212
- Major deaerator maintenance costs (every 20 years): \$ 17,438
- Motor-driven feedwater pumps maint costs (every 15 years): \$ 16,002
- Turbine-driven feedwater pumps maint costs (every 12 years): \$ 27,739
- Centrifugal pump maint costs (every 18 years): \$ 21,168
- Sump pump maintenance costs (every 20 years): \$ 12,945
- Major stack maintenance costs (every 20 years): \$ 14,119
- Major building maintenance costs (every 20 years): \$ 677,600
- Periodic EPA permit testing/renewal costs (every 3 years): \$ 30,000

Economic Data Summary

Capital Equipment Escalation Factor: 1.045
based on Engineering News Record, Construction Cost Index: 4771.57

Non-Labor Operation & Maintenance Escalation Factor: 1.106
based on Chemical Engineering, M & S Index, Steam Power Comp: 947.10

Operation & Maintenance Labor Escalation Factor: 1.061
based on Engineering News Record, Skilled Labor Index: 4386.55

Construction Labor Escalation Factor: 1.030
based on Chemical Engineering, Construction Labor Index: 272.70

Annual Facility Output: 726,840 thousand lb steam
Steam enthalpy: 1195.6 Btu/lb
Inlet enthalpy: 64.7 Btu/lb
Annual Coal Usage: 38,885 tons (dry)
43,824 tons (wet)

Heating plant efficiency @ PMCR: 83%
Discount Rate: 4.5 %
Coal Transportation Cost: 2.18 cents/ton-mile
Coal Transportation Cost Escalation: 0.00 %
Year of Study: 1991
Years of Operation: 1994 - 2018
10% Investment Cost Exclusion IS NOT applied

 Cash Flow Summary

 1993 adjusted investment: 36,511,127

Year	Boiler Fuel & Tran	Auxiliary Energy	Non-Energy O&M	Repair and Replacement
1994	2,004,109	309,907	1,727,664	0
1995	2,008,462	311,518	1,727,664	0
1996	2,020,179	306,236	1,727,664	118,861
1997	2,031,776	295,355	1,727,664	0
1998	2,038,086	295,193	1,727,664	84,196
1999	2,052,908	297,139	1,727,664	118,861
2000	2,081,875	298,250	1,727,664	105,058
2001	2,105,016	298,257	1,727,664	313,632
2002	2,135,059	300,425	1,727,664	118,861
2003	2,171,982	303,751	1,727,664	847,376
2004	2,215,718	308,480	1,727,664	0
2005	2,261,501	313,056	1,727,664	182,145
2006	2,298,547	315,422	1,727,664	0
2007	2,353,101	318,459	1,727,664	105,058
2008	2,401,535	319,662	1,727,664	219,059
2009	2,425,944	319,538	1,727,664	313,632
2010	2,466,769	322,144	1,727,664	0
2011	2,478,366	324,352	1,727,664	140,030
2012	2,489,964	325,622	1,727,664	0
2013	2,501,562	326,892	1,727,664	1,609,683
2014	2,513,159	327,977	1,727,664	223,919
2015	2,524,756	329,066	1,727,664	0
2016	2,536,369	331,092	1,727,664	0
2017	2,547,966	331,999	1,727,664	495,777
2018	2,559,565	332,906	1,727,664	84,196

 2019 new plant salvage: 0

Fuel Cost Comparison

+ PV 'Adjusted' Investment Costs	= \$ 33,434,333
+ PV Energy + Transportation Costs	= \$ 34,459,559
+ PV Annually Recurring O&M Costs	= \$ 23,459,329
+ PV Non-Annually Recurring Repair & Replacement	= \$ 2,416,489
+ PV Disposal Cost of Existing System	= \$ 0
+ PV Disposal Cost of New/Retrofit Facility	= \$ 0

Total Life Cycle Cost (1991)	= \$ 93,769,711
Levelized Cost of Service (1994 start)	= 8.30 \$/MMBtu
Levelized Cost of Service (1994 start)	= 9.92 \$/1000 lb steam

ABBREVIATIONS AND ACRONYMS

AMSF	average monthly steam flow
ACFM	actual cf/min.
BFBC	bubbling fluidized-bed combustor
BFWP	boiler feedwater pump
Btu	British thermal unit
CEM	continuous emission monitors
cf	cubic foot
CFBC	circulating fluidized-bed combustor
CHPECON	Central Heating Plant Economic Evaluation program
CONUS	Continental United States
DCF	discounted cash flow
DOD	Department of Defense
EPA	Environmental Protection Agency
ETN	Engineering Technical Note
FAA	Federal Aviation Administration
FBC	fluidized-bed combustor
FY	Fiscal Year
HHV	higher heating value
HTHW	high temperature hot water
HVAC	heating, ventilating, and air-conditioning
LCC	life-cycle cost
LCS	levelized cost of service
MACOM	Major Army Command
MCR	maximum continuous rating
OASD	Office of the Assistant Secretary of Defense
PABX	private automatic branch exchange
PMCR	plant maximum continuous rating
PRV	pressure reducing valve
PVA	present value annuity
PV	present value
PWTB	Public Works Technical Bulletin
SQRT	square root
SSU	Seconds Saybolt Universal
TLCC	total life-cycle cost
TPH	tons per hour
USACERL	U.S. Army Construction Engineering Research Laboratories
USACPW	U.S. Army Center for Public Works
USAREUR	U.S. Army, Europe

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