Enhancement of the Central Heating Plant Economic Evaluation Program (CHPECON)

by
Mike C.J. Lin and John Kinast

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costs, plant life, etc., and also to resolve issues raised
during beta testing. An addendum to the User Manual was
written to describe the use of enhancements to the
program, and recommendations for further program
improvement were made.

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13. ABSTRACT (Maximum 200 words)

Fiscal year 1986 Defense Appropriations Act (PL-99-190) Section 8110 directs the Department of Defense (DOD) to implement the rehabilitation and conversion of central heating plants to coal firing, where a cost benefit can be realized. To help Army installations comply with this law, the U.S. Army Construction Engineering Research Laboratories (USACERL) has developed the Central Heating Plant Economic Evaluation Program (CHPECON), a PC-based software program that includes a series of screening and life cycle cost estimating models to determine when and where specific coal combustion technologies could be implemented in DOD central heating plants using coal, gas, or oil.

This study incorporated several new heating plant options to enhance CHPECON's current retrofit screening and life cycle cost models with a sensitivity analysis capability that may relate to changes in boiler load, fuel price, escalation factors, discount rate, operations and maintenance (O&M) costs, plant life, etc., and also to resolve issues raised during beta testing. An addendum to the User Manual was written to describe the use of enhancements to the program, and recommendations for further program improvement were made.

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Foreword

This study was conducted for Naval Facilities Engineering Service Center (NFESC) and Assistant Secretary of Defense (Production & Logistics) under Military Interdepartmental Purchase Request (MIPR) No. N0537A94MP00007; Work Unit N0537-A94MP00007, "Further Enhancement of CHPECON Program." The technical monitors were Steven Guzinski, NFESC and Millard Carr, ODUSD/ES/C&I.

The work was performed by the Utilities Division (UL-U) of the Utilities and Industrial Operations Laboratory (UL), U.S. Army Construction Engineering Research Laboratories (USACERL). The USACERL principal investigator was Dr. Mike C.J. Lin. Martin J. Savoie is Acting Chief, CECER-UL-U; John T. Bandy is Operations Chief, CECER-UL; and Gary W. Schanche is Chief, CECER-UL. The USACERL technical editor was William J. Wolfe, Technical Resources Center.

COL James T. Scott is Commander and Acting Director, and Dr. Michael J. O'Connor is Technical Director of USACERL.

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1 Introduction

1.1 Background

The fiscal year (FY) 1986 Defense Appropriations Act (PL-99-190) Section 8110 directs the Department of Defense (DOD) to implement the rehabilitation and conversion of central heating plants (CHPs) to coal firing where a cost benefit can be realized. The target set by this act was to increase coal use by 1.6 million short tons of coal per year over 1985 coal consumption levels by 1994. The language of the Act further states that 300,000 tons* of this amount should be anthracite coal.

To help Army installations comply with this act, the U.S. Army Construction Engineering Research Laboratories (USACERL) has developed the Central Heating Plant Economic Evaluation Program (CHPECON), a PC-based software program that includes a series of screening and life cycle cost estimating models to determine when and where specific coal combustion technologies could be implemented in DOD central heating plants. This study was undertaken to incorporate several new heating plant options, and to evaluate retrofit coal technologies as potential options. These enhancements to the economic evaluation program will improve CHPECON's utility as a tool to select and rank potential DOD sites for coal conversion.

1.2 Objectives

The objectives of this project were to enhance CHPECON's current retrofit screening and life cycle cost models with sensitivity analysis capability, and to resolve issues raised during beta testing at the Naval Facilities Engineering Service Center (NFESC).

1.3 Approach

The Central Heating Plant Economic Evaluation Program (CHPECON) was analyzed (Chapter 2) and specific modules were reprogrammed to expand the program's sensitivity analysis capabilities already provided for new plants, to facilities being

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* Metric conversion factors for standard units of measure used throughout this report are listed on p 10.

considered for retrofit of coal technologies. Issues raised during beta testing at the NFESC, and noted enhancements were incorporated into the program (Chapter 3). An addendum to the User Manual was written to describe the use of enhancements to the program (Chapter 4).

1.4 System Requirements

The current version of CHPECON was developed on a Pentium™ personal computer with 16M memory, operating with MS-DOS 6.22. The recommended minimum system to be considered for operation of the model is a 386DX processor with 2M memory and MS-DOS 3.3 or above. The program is currently written in Microsoft FoxPro©, compiled for execution speed. As a compiled program, it allows standalone operation without requiring additional utilities or the original development environment.

1.5 Scope

This work developed models to investigate the feasibility of converting Army and Navy CHPs to coal firing. The models developed are generally applicable to industrial or large commercial facilities. The economic evaluation program for screening and life cycle costs will serve as a tool to select and rank potential Army and Navy sites for coal conversion.

1.6 Metric Conversion Factors

Metric conversion factors for standard units of measure used throughout this report follow:

1 in.	=	25.4 mm
1 lb	=	0.453 kg
1 psi	=	6.89 kPa
1 (short) ton	=	907.184 kg
1 gal	=	3.78 L
°F	=	(°C × 1.8) +32
1 Btu	=	1.055 kJ

1.7 Mode of Technology Transfer

The complete update for CHPECON, consisting of the program and an updated database containing natural gas properties, is distributed on 1.4M, 3.5-in. floppy disks and will be made available to current CHPECON users within the DOD directly from USACERL. It is anticipated that the software will be made publicly available on request, for a copy-based fee, from:

Resource Center Enterprises
1408 W. University St.
Urbana, IL 61801
tel.: 1-800-428-4357

2 Background of Enhancements to CHPECON

The enhancements to CHPECON focused on the retrofit models. This section provides the additional material concerning the retrofit model enhancements as an addendum to the *Central Heating Plant Economic Evaluation Program, Volume 1: Technical Reference* (Lin et al. 1995, vol 1). Each of the following sections focuses on one element of this effort.

2.1 Cost Sensitivity Analysis for Retrofit Cases

The purpose of this effort was to implement the required procedures that would permit a parametric sensitivity analysis on various cost aspects considered in the CHPECON program for facilities under consideration for retrofitting coal technologies. This ability has been part of CHPECON for new plant facilities. The sensitivity analysis will allow the user to understand the effects that variations to one parameter have on the base case economic analysis of a given central heat plant. The analysis is also helpful in determining the areas in which cost or efficiency improvements would yield the most beneficial effects on life cycle cost.

The major cost categories included in the cost sensitivity analysis for retrofits are:

- capital costs
- primary fuel costs
- auxiliary energy costs
- operating and maintenance costs — labor portion
- operating and maintenance costs — nonlabor portion
- major repair and replacement costs
- electricity cost credit (for cogeneration).

In addition to the above categories of costs, the discount rate is also included in the sensitivity analysis. To implement the sensitivity analysis, an additional series of calculations are performed at the end of the standard cost analysis section, adjusting one or more values and determining the effect of the changes on the life-cycle cost and levelized cost of service.

2.2 Calculation Procedures for Implementation of Retrofit Cost Sensitivity Analysis

The basic approach to implement the Retrofit Cost Sensitivity Analysis portion of the program is to:

1. Complete a cost analysis on a particular screening model case
2. Vary the major factors that make up the life-cycle cost, and recompute the life-cycle cost based on the modified values

Once the costs for every year of operation are known, as determined by the cost analysis, they can be varied and a new life-cycle cost calculated based on the modified values. In the modified cost model (which is executed for this option), each cost for a given year of operation is stored in an array. The same information as for the general cost model is included in the sensitivity analysis report at this point.

To determine the life-cycle cost for the changes that result from the sensitivity analysis, the present value of each year's cost is first calculated by:

$$\text{Present\_value} = \text{Future\_value} / (1 + \text{discount\_rate})^{\text{years}} \qquad \text{[Eq 1]}$$

The present value of each year's operating and maintenance costs is then summed to produce a total, and the investment costs are added:

```
Life_cycle_cost (LCC) =
        PV_Investment + PV_Primary_fuel_cost_year_1 + PV_Auxiliary_energy_cost_year_1
            + PV_O&M_labor_year_1 + PV_O&M_non_capital_non_labor_year_1

        + PV_O&M_capital_related_non_labor_year_1
            + PV_major_repair_replacement_year_1                                    [Eq 2]
        . . . . .

        + PV_Primary_fuel_cost_year_n + PV_Auxiliary_energy_cost_year_n
            + PV_O&M_labor_year_n + PV_O&M_non_capital_non_labor_year_n

        + PV_O&M_capital_related_non_labor_year_n + PV_major_repair_replacement_year_n
```

The levelized cost of service (LCS) is calculated from the life-cycle cost and the total energy delivered by:

$$\text{LCS} = \text{LCC} * (i * (1 + i)^l / ((1 + i)^l - 1) / d \qquad \text{[Eq 3]}$$

where:

i = annual interest or discount rate (percent)
l = life of facility (years)
d = annual steam delivered.

Two files are created to contain the results of the sensitivity analysis. These permanent files are given the same name as the screening model with an extension of "@SL" and "@SS". "@SL" is the extension for files containing the long form of the sensitivity analysis report, and "@SS" is the extension for files containing the short form of the sensitivity analysis report. For example, a case stored in the file "QWERTY.DBF" and listed as "QWERTY" in the screening and cost model listings, will have two sensitivity analysis files named "QWERTY.@SL" and "QWERTY.@SS", which can both be accessed by CHPECON for printing at a later time. These files remain in the working directory after the analysis is completed, until the user manually deletes them. In addition, a database file, GRPHDATA.@$@, is created to hold the calculated results that are then used by the graphics modules.

2.3 Assumptions and Defaults for Cost Sensitivity Analysis

The logical range of values for a sensitivity analysis depend on the type of variable being varied and the likelihood that a specific value will occur. To prevent the user from entering values outside these ranges, the practical limits established for the range of the new plant cost variations were maintained in this retrofit cost sensitivity analysis. The lowest minimum value that can be selected is 1 percent of the cost, and the highest minimum value that can be selected is 100 percent of the cost. An acceptable step size is programmed to be at least 1 percent and no more than 50 percent, allowing at least one step, and two steps for a wide range of limits. The lowest maximum value that can be selected is 100 percent of the cost, and the highest maximum value is 1000 percent. Placing these limits ensures that the initially calculated costs are included as part of the analysis, and that some limits are in place. When the type of variation is not formulated on 100 percent as the baseline case, e.g., discount rate variation, the programmed limits are adjusted, as described below.

The default retrofit values, which appear on-screen and are used if not modified by the user, need to be varied from the values used for the new plant. The retrofit sensitivity analysis for costs (operating, maintenance, and capital) is a modification of the retrofit analysis currently in place in CHPECON. A review of the ranges of adjustability for the energy, labor, supply, maintenance, repair, escalation rates, discount rates, and plant life variations showed that they should be applicable to the retrofit sensitivity analysis without major alteration. The initial cost variation is the major difference between retrofit and new plant analyses. For this reason, the range of variability for initial cost of new plants could not be used for retrofitted facilities (a range of 80 to 120 percent of the calculated new cost was available).

The method selected to analyze the impact of these costs is to determine all costs based on the worst case scenario (requiring the most extensive work to retrofit the components into the existing facility) and allow the user to vary the resulting cost from 30 to 200 percent of the base-case calculated value. This will result in the modeling of a wider range of initial costs than with the other models; in this way, the impact of a very unlikely case scenario for a retrofitted facility should be covered in the analysis. This will also provide coverage of the ranges of costs expected for those facilities with good potential for retrofits, by allowing the lower percentage. Reviewing the individual parameters indicated that allowing adjustments across individual components would only shift the overall initial cost within this range, e.g., the impact of varying coal handling equipment from 50 to 150 percent would have similar impact to varying ash handling or piping through the same range; all are initial costs occurring near the beginning of the life cycle cost, the default values of which represent functional or logical limits.

Underlying the selection of practical limits for each of the parameters varied is the concept of "constant dollars," as described in the *Life-Cycle Cost Manual for the Federal Energy Management Program* (Rugg 1980, p 16). This concept assumes that most future prices will vary in accordance with the general rate of inflation, i.e., that future dollars will have the same equivalent purchasing power. Because CHPECON has been written so that the rate of inflation is removed from the calculations through the use of constant dollars, the variations that may be seen for the various parameters are due to real changes, such as fuel or manpower availability, or to new technology.

For *Primary fuel cost variation, Auxiliary energy cost variation, O&M labor cost variation, O&M nonlabor cost variation, Repair/replace cost variation,* and *Initial cost variation,* the range of variation of 80 to 120 percent was selected because the variations that have occurred historically have been in this range. For the primary fuel and auxiliary energy costs, the initial values are calculated from the LCCID energy cost data as provided by USACERL.

For *Discount rate variation,* the variation directly affects the discount rate used to calculate the life cycle cost. This variation differs from the previous values because it does not modify another cost, but is applied directly to all costs. The recommended minimum value is zero percent, because a negative value would imply that a lender was willing to pay a borrower for the opportunity to establish a loan with the borrower. The 12 percent recommended upper limit is a value that has historically not been approached in the United States. The programmed limits for the minimum are from zero percent to the default discount rate used by the program, and the maximum limits are from the default discount rate to 20 percent, with a minimum step size of 0.1 percent.

For *Primary fuel escalation rate*, the default values selected are -3 to 6 percent. This allows the variation of the primary fuel cost to increase from 3 percent slower per year to 6 percent faster per year than the costs indicated by the LCCID fuel cost data. The programmed limits for the minimum are from -3 to zero percent, and the maximum limits are from zero to 6 percent, with a step size of from 1 to 3 percent.

For *Plant life variation*, the minimum and maximum suggested values are 10 years to 25 years. The minimum was selected because it is normally not considered practical or logical to invest in a facility and use it for one-third or less of its useful life. The maximum of 25 years is a prescribed limit by the provisions of the Energy Security Act of 1980 (Rugg 1980, p 44). The programmed limits for the minimum are from 10 to 24 years, and the maximum limits are from the minimum + step years to 25 years. The step size must be at least 1 year and no more than the difference between 25 years and the minimum.

2.4   Boiler Load Sensitivity Analysis for Retrofit Cases

The purpose of this effort was to implement a procedure that would perform a sensitivity analysis on the effect of varying boiler load on a particular installation considered in CHPECON. The boiler load sensitivity analysis will allow the user to understand the results and impact of changing boiler loads for an existing facility. This could occur for a number of reasons, including longer-term seasonal variations, variations in the base's population due to ramp-up or scaling-back efforts, or a change in the focus of the site. This ability is provided by modifications and additions to the existing program modules of CHPECON.

2.5   Calculation Procedures for Implementation of Retrofit Boiler Load Sensitivity Analysis

The basic approach for implementing the Boiler Load Sensitivity Analysis section for retrofitted systems is to:

1.   Determine the baseline average monthly steam flows for the site under study
2.   Vary the average monthly steam flows for the case under study, then run a complete cost model analysis to determine life cycle costs with the new average steam flows
3.   Iterate step 2 for each of the user-supplied variation steps between the minimum and maximum values.

During its operation, one file is created to contain the results of the sensitivity analysis. This permanent file is given the same name as the screening model with an extension of "@LS". For example, a case stored in the file "QWERTY.DBF" and listed as "QWERTY" in the screening and cost model listings, will have a boiler load sensitivity analysis file named "QWERTY.@LS", which can be accessed by CHPECON for printing at a later time. Any generated boiler load sensitivity file remains in the working directory after the analysis is completed, until the user manually deletes it.

2.6 Assumptions and Defaults for Retrofit Boiler Load Sensitivity Analysis

It is assumed that the basic operation of the facility remains unchanged due to varying boiler loads, except in those areas that would be changed because they are connected to the load, such as fuel or water consumption. Timing for major facility maintenance would remain on the same schedule as for the facility, i.e., there are no changes based on either a relaxed or an increased demand profile.

The minimum acceptable limit on AMSF (average monthly steam flow) is from 40 percent of the baseline values to 100 percent (no change). The maximum acceptable limit on AMSF is from 100 to 150 percent of the baseline. The step size variation for this is from 1 to 20 percent. The values that are generated are modified to include 100 percent as a reference. For example, if 50 percent is the minimum, 150 percent is the maximum, and 20 percent is the step size, the following values are used to modify the baseline AMSF: 50, 70, 90, 100, 110, 130, and 150 percent.

2.7 Multiple Run Analysis

The purpose of this effort was to implement a procedure that would exhaustively iterate through a range of coalfields combined with the appropriate coal technologies, based on the input entries from a single screening model data file. Life cycle costs for each of the combinations of coalfield and coal technology would be calculated. Results of the multiple run analysis would be presented in the report from the program for this type of analysis with each technology and coalfield combination sorted in order of increasing life cycle costs.

2.8 Calculation Procedures for Implementation of Retrofit Multiple Run Analysis

After some experience with CHPECON, it was determined that a form of automated analysis was the only realistic method to comprehensively evaluate the possible boiler technology and coalfield combinations for a large number of different sites. Although it would be feasible to manually iterate through each combination, the amount of time required to operate the program and manually collate the results was considered prohibitive. As a result, the ability to automate the sizing and costing of boiler facilities for a given military base was added to the CHPECON program in this task. In this effort, the multiple run analysis has been added to the retrofit class of cases.

The multiple run analysis option requires that a screening model case already exist for the military base that is to be studied. This ensures that the basic information about the facility is present — heating load requirements, location, and type of system. This also allows the user to have answered the general questions about availability of auxiliary facilities (such as water and sewer lines) that are common to any boiler facility.

When first started, the option runs an analysis with any boiler technology that is independent of a selected coalfield, such as slurry boilers, since these use processed fuels delivered in a fashion similar to fuel oil, and do not directly depend on having a coalfield with the right fuel properties in close proximity to the base. After this, the program goes to the top of the file containing coalfield information, selecting the first coalfield. It then sequentially steps through the boiler technologies. For each technology, the option checks the allowable parameters database file to determine whether boilers based on the current technology can use the coal from the currently selected coalfield. If the technology and coalfield are not compatible, the program advances to the next technology.

If the technology is compatible with the coalfield, the program continues its analysis. The retrofit boiler sizing uses the existing boiler sizes entered by the user and adjusts the resulting outputs based on the effects of the retrofit. The loads experienced by the simulated retrofit facility are the previously entered load data. In this regard, the retrofit analysis differs from the new plant facility multiple run analysis because boilers cannot be sized to fit the exact conditions; the facility that is being retrofitted defines the capacity of the boilers.

If the technology is compatible with the coalfield properties, the program continues with the analysis. It computes the life cycle cost for the facility using default answers for each of the questions that normally appear when conducting a cost model analysis. The

overall cost of the facility is then stored in the report file. At the end of each technology sequence, the program advances to the next coalfield, and begins the technology cycle again.

A total of three files are created during the operation of the multiple run analysis. Two are temporary files that are given a unique filename with the default extension ".DBF", which are deleted at the end of the process. However, adequate room on the hard disk is needed to establish them even though they are later removed. The actual size needed depends on the operating parameters selected by the user for the multiple run analysis. The worst case would be 3k for the one file, and 680k for the other (the size of the coalfield database).

A temporary file is generated to hold the information from the screening model. The multiple run option has been written to draw on the information from the screening model case that has been stored to gain the information necessary to provide a comprehensive evaluation. This file is modified with the new parameters based on each of the coalfield and boiler technology combinations. It is then used for the costing model to determine the life cycle cost for each combination.

A second temporary file is created to contain a copy of the information on coalfields within a user-selected distance of the military base. If the range selected by the user is large enough, the entire coalfield database can be selected to evaluate its potential. This temporary file differs from the coalfield in that it is accessed in order of increasing distance from the military base. This means that the closest coalfields are evaluated first.

A permanent file is created to contain the results of the multiple run analysis, and given the same name as the file containing the screening model with an extension of "@MR". For example, a case that is stored in the file "QWERTY.DBF" and is listed as "QWERTY" in the screening and cost model listings, will have a multiple run analysis file named "QWERTY.@MR", which can be accessed by CHPECON for printing at a later time. Unlike the other two files, this file remains after the analysis is completed, until the user manually deletes it from the working directory.

The option for multiple boiler/coalfield run analysis for retrofits draws heavily from the previously written sections of CHPECON, including the new plant multiple run analysis. In doing this, the overall size of the CHPECON program is minimized even though additional functions have been added.

2.9 Assumptions for Retrofit Multiple Run Analysis

The primary assumption for the multiple run analysis for retrofitted facilities is that the boiler facility will attempt to meet the load specified by the user independent of whether the PMCR of the overall facility matches the design PMCR if it were a new plant. The response of a retrofitted boiler with respect to a new boiler of similar type is assumed to be the same, i.e., no allowances are made for transient operation or derating.

3 User's Manual Addendum Covering CHPECON Enhancements

The enhancements to CHPECON focused on the retrofit models. This section provides the additional material concerning the retrofit model enhancements as an addendum to the *Central Heating Plant Economic Evaluation Program, Volume 2: User's Manual* (Lin et al., 1995, vol 2). Each of the following sections focuses on one element of this effort.

3.1 Installation of CHPECON

The CHPECON program and data files are compressed and stored in four executable files:

1. CHP9508.EXE
2. CHPDBF-A.EXE
3. CHPDBF-N.EXE
4. CHPDBF-C.EXE.

These files are stored on 3.5-in., 1.4M double-sided, high density floppy disks. They are installed using the SETUP.EXE program found on the first disk.

These instructions assume that the computer is set up and running MS-DOS 3.3 (or greater). The user needs to understand how to start the computer, access the DOS prompt (if Windows or other environment is normally entered during startup), and enter commands via the keyboard.

To install CHPECON:

1. Start the computer and get to the DOS prompt (if it is not already there).
2. Put the floppy disk marked *CHPECON Setup* into the floppy drive. Select the floppy drive as the default by entering the command **A:<Enter>**, substituting the appropriate drive letter if the floppy is not Drive A.
3. If necessary, change to the root directory by entering the command **CD <Enter>**.

4.   Begin the installation by entering the command **SETUP<Enter>**.

5.   SETUP will display its opening screen, announcing that it is for setting up CHPECON and basic information about CHPECON. The user is presented with buttons to select either to **<u>C</u>ontinue** or **E<u>x</u>it**. The selection highlight (the double-line border around the button) can be switched between the two buttons by pressing the **<Tab>** key, and the selection is confirmed by pressing **<Enter>**. Alternatively, the buttons can be selected by using the Alt-key command, i.e., **<Alt-C>** to continue and **<Alt-X>** to exit. This type of input is used throughout setup.

6.   On continuing, SETUP displays a text box prompting the user for the source of the setup files. It should be the floppy drive, e.g., **A:**. If not, enter the source of the files, then continue.

7.   On continuing, SETUP displays a text box prompting the user for the destination of the setup files, e.g., where the program, database, index, and case files should be stored. It should be on a local hard disk or network drive with enough capacity to hold all the files (at least 3 MB). Enter the complete drive/path, then continue. If the drive is invalid, a message box will appear to notify the user of this. If the drive is valid but the directory is not, SETUP will automatically create the directory path specified by the user.

8.   On continuing, SETUP displays a set of options to install either: Army Base files, Navy Base files, or Comprehensive Base files (including both Army and Navy). These can be selected using Alt-key, like the buttons. Once the option or radio button next to the desired set of files is highlighted, continue.

9.   Using the information entered, SETUP will install the files from the setup floppies. When prompted for the next disk, remove the current one and replace it with the requested disk.

10.   When done, SETUP will announce that CHPECON is set up and ready to run, then exit to DOS.

At this point, the program and data files have been installed. CHPECON will create additional files for indexes and other areas as necessary.

The program can operate from a minimum configuration (monochrome monitor and 80-column printer). If the system has a color monitor or a printer that can print at other than 10 characters per inch, select the System Utilities option from the main menu of the program to change the display colors and the top, bottom, and left margins for printing. To run CHPECON:

1.   Start the computer and get to the DOS prompt (if it is not already there).

2.   Select the logical disk drive where CHPECON is to be installed, by entering the command **C:<Enter>**, substituting the appropriate drive letter for C if necessary.

3. Change to the directory by entering the command **CD \CHPECON<Enter>**, again substituting the appropriate directory name for CHPECON if necessary.

4. Start the program by entering the command **CHPECON<Enter>**.

After the program starts, it displays the introductory screen which includes the version date, and waits for a key press or until 3 seconds has passed to continue. It then displays a purpose statement and a disclaimer about the program. After waiting for a key press for another 3 seconds, the program continues with its checking routine.

As it starts, it checks for the presence of the database files necessary for operation. If one or more are not found, CHPECON displays a message listing the missing files and announcing that it cannot continue until they are present. It then returns to DOS.

If the required database files are present, CHPECON verifies the presence of the index files, rebuilding indexes as necessary. Once this is completed, CHPECON displays the main menu.

The rest of the operation of the program is covered in the CHPECON User's Manual.

3.2 User Interface—Cost Sensitivity Analysis for Retrofit Cases

This enhancement to CHPECON adds the ability to perform a parametric cost sensitivity analysis on central heating plants under consideration for retrofitting coal technologies. The results of a sensitivity analysis will allow the user to understand the effects that variations to one parameter have on the base case economic analysis of a given central heat plant. The analysis also helps determine the areas where cost or efficiency improvements would yield the most beneficial effects on life cycle cost.

The major cost categories included in the cost sensitivity analysis for retrofits are:

- capital costs
- primary fuel costs
- auxiliary energy costs
- operating and maintenance costs — labor portion
- operating and maintenance costs — nonlabor portion
- major repair and replacement costs
- electricity cost credit (for cogeneration).

In addition to the above categories of costs, the discount rate is also included in the sensitivity analysis.

When running, the program will pause after the cost model is completed to allow the user to adjust the minimum, step, and maximum values for each of the variations implemented in the sensitivity analysis. When changing the values, the program will automatically adjust the values if allowable limits are exceeded.

The printing functions operate in a similar fashion to the other segments of CHPECON. When the option is selected, a list of files for that format are displayed. Once those files that are to be printed are highlighted by the user, the program proceeds to printing.

The default minimum, step and maximum values (those that are displayed when the screen is first shown in a sensitivity analysis run) can be changed under the system utility option. Once selected, the same screen as that after the cost model segment is shown, for the user to enter the default values.

Two files are created to contain the results of the sensitivity analysis. These are permanent files that are given the same name as the screening model with an extension of "@SL" and "@SS". The extension "@SL" indicates files containing the long form of the sensitivity analysis report, and the extension "@SS" indicates files containing the short form of the sensitivity analysis report. For example, a case that is stored in the file "QWERTY.DBF" and is listed as "QWERTY" in the screening and cost model listings, will have two sensitivity analysis files named "QWERTY.@SL" and "QWERTY.@SS", which can be accessed by **CHPECON** for printing at a later time. These files remain in the working directory after the analysis is completed, until the user manually deletes them. In addition, a database file, GRPHDATA.@$@, is created to hold the calculated results, which are then used by the graphics modules.

3.3   User Interface for Implementation of Retrofit Cost Sensitivity Analysis

The user interface has been based on the format developed in CHPECON. A series of menus guide the user through the necessary questions to complete an analysis. The main menu screen for CHPECON (Figure 1) offers the user the option to access the sensitivity analysis. Once the sensitivity analysis option is selected, the menu shown in Figure 2 is displayed, allowing the user to run a retrofit sensitivity analysis, in addition to any new plant sensitivity analysis, or print existing reports. The **Quit** option returns the user to the previous CHPECON main menu.

```
┌─────────────────────────────────────────────────────────────────────┐
│ ┌─────────────────────────────────────────────────────────────────┐ │
│ │ Central Heating Plant Economics Evaluation Program     06/08/95  │ │
│ │ Main Menu                                                        │ │
│ └─────────────────────────────────────────────────────────────────┘ │
│                                      *                                │
│       1 -- Screening Models          *    6 -- Update Databases       │
│                                      *                                │
│       2 -- Cost Models               *    7 -- System Utilities       │
│                                      *                                │
│       3 -- Multiple Run Analysis     *                                │
│                                      *                                │
│       4 -- Sensitivity Analysis      *                                │
│                                      *                                │
│       5 -- Load Sensitivity Analysis *    Q -- Quit (exit program)    │
│                                      *                                │
│                                                                       │
│                                                                       │
│                  ↑↓                                                   │
│           Use  │ ▼ to move highlight or enter first character to select option │
│                       Run cost sensitivity analysis                   │
└─────────────────────────────────────────────────────────────────────┘
```

Figure 1. Initial menu screen for CHPECON with cost sensitivity highlighted.

```
┌─────────────────────────────────────────────────────────────────────┐
│ ┌─────────────────────────────────────────────────────────────────┐ │
│ │ Central Heating Plant Economics Evaluation Program     06/08/95  │ │
│ │ Main menu — sensitivity analysis °                               │ │
│ └─────────────────────────────────────────────────────────────────┘ │
│                                                                       │
│         1 -- New plant                                                │
│                                                                       │
│         2 -- New plant with cogeneration                              │
│                                                                       │
│         3 -- New plant with third-party cogeneration                  │
│                                                                       │
│         4 -- New plant with consolidation                             │
│                                                                       │
│         5 -- Retrofit plant                                           │
│                                                                       │
│         P -- Print report                                             │
│                                                                       │
│         Q -- Quit (return to main menu)                               │
│                                                                       │
│              ↑↓                                                       │
│        Use  │ ▼ to move highlight or enter first character to select option │
│            Retrofit existing plant, using general cost factors for upgrades │
└─────────────────────────────────────────────────────────────────────┘
```

Figure 2. Menu screen for sensitivity analysis.

After selecting the retrofit analysis, the list of existing files is displayed (Figure 3), allowing the user to view the filenames and other pertinent data to locate the case for the analysis.

The cost analysis section of the program is the same as the Cost Model selection, and is documented in the *Central Heating Plant Economic Evaluation Program* (Lin et al. 1995, vol 1). The cost analysis is called after indicating the screening model file to be used for analysis.

```
--File-- CT --Case description----------------------------------
24RMICRO      RT NRL Washington
CWS           RT Joliet Army Ammunition Plant
RT01          RT Joliet Army Ammunition Plant
RT02          RT Joliet Army Ammunition Plant
RT03          RT Joliet Army Ammunition Plant
RT1           RT Joliet Army Ammunition Plant
RT19          RT Joliet Army Ammunition Plant
RT1M          RT Joliet Army Ammunition Plant
RT1Q1         RT Joliet Army Ammunition Plant
RT2           RT Joliet Army Ammunition Plant
RT3           RT Joliet Army Ammunition Plant
RT39          RT Joliet Army Ammunition Plant
RT39-A        RT Joliet Army Ammunition Plant
RT39-B        RT Joliet Army Ammunition Plant
RT39-C        RT Joliet Army Ammunition Plant
RT39-D        RT Joliet Army Ammunition Plant
RT4           RT Joliet Army Ammunition Plant
RT5           RT Joliet Army Ammunition Plant
                    << end of list >>


              Enter file name:
              blanks to quit
```

Figure 3. Retrofit case selection screen.

After completing the cost model analysis, CHPECON presents the screen shown in Figure 4. If the user desires, alternate values can be entered for the minimum, step, and maximum values for each of the varied parameters. Once the values are set (indicated by accepting the values shown), the sensitivity analysis is performed. As this occurs, the lower portion of the screen is used to indicate the progress of the program, displaying the parameter being varied and the currently used factor.

```
Central Heating Plant Economics Evaluation Program          file: RT01
Facility Financial Statement                        Retrofit plant (RT)


Min value Step value Max value
Primary fuel cost variation:         80%    10%    120%
Auxiliary energy cost variation:     80%    10%    120%
O&M labor cost variation:            80%    10%    120%
O&M non-labor cost variation:        80%    10%    120%
Repair/replace cost variation:       80%    10%    120%
Initial cost variation:              30%    10%    200%


Discount rate variation:             0.0%   1.0%   12.0%
Primary fuel escalation rate:        -3%    1%     6%
Plant life variation:                10 yr  1 yr   25 yr

Accept / Change values? (A/C)   << A >>
```

Figure 4. Parameter variation screen for sensitivity analysis.

Table 1. Default values for retrofit cost sensitivity analysis.

Parameter	Min value	Step value	Max value
Primary fuel cost variation	80%	10%	120%
Auxiliary energy cost variation	80%	10%	120%
O&M labor cost variation	80%	10%	120%
O&M non-labor cost variation	80%	10%	120%
Repair/replace cost variation	80%	10%	120%
Initial cost variation	30%	10%	200%
Discount rate variation	0.0%	1.0%	12.0%
Primary fuel escalation rate	-3%	1%	6%
Plant life variation	10 yr	1 yr	25 yr

The default values for the range are shown in Figure 4, and are listed in Table 1. It is important to note that the step value specified for each of the parameters must be positive to effect the move from the minimum to the maximum values.

At the end of the calculations, the results of the analysis can be reviewed graphically on screen if desired. The system must be equipped with an EGA- or VGA-compatible display system to view the graphics screens. After the sensitivity analysis has been completed, the screen is displayed (Figure 5). From this, the effect on life cycle cost for one of the parameters can be graphically reviewed. As with other menus, using the <Up> and <Down> keys moves the highlight bar to select an option, which is then executed by pressing the <Enter> key. Alternatively, pressing the letter key that is highlighted on the menu options automatically selects and executes the option. Any parameters not available are shown in a shadowed color.

An additional option is a composite presentation of the first six parameters. The definition of the variations and their computations are similar, unlike the other parameters, and can be directly compared on the same graph (i.e., the X-axis scale is compatible).

Once a particular option is selected, CHPECON switches to the graphics display mode and presents the results. The graph that is displayed can be printed to either a Postscript printer or a LaserJet-compatible printer connected to parallel port LPT1 by pressing "P" or "L", respectively, when the graph is displayed. It switches back to the menu after the user presses a key other than "P" or "L". After reviewing the results graphically, the user selects **Quit** to leave this menu and continue.

After the sensitivity analysis is completed, the user is presented with the option of printing the **Short format report**, the **Long format report**, **Both formats**, or **None** (Figure 6). After performing any necessary printing, the program returns to the sensitivity analysis menu.

```
        Primary fuel cost variation
        Auxiliary energy cost variation
        O&M labor cost variation
        O&M non-labor cost variation
        Repair/replace cost variation
        Initial cost variation
        Composite cost variation
        Existing plant salvage value
        New salvage value
        Discount rate
        Primary fuel escalation rate
        Site/plant life

        Quit
```

```
Select parameter to view graphically, or Quit to continue
For graphics print, press 'P' for Postscript, 'L' for LaserJet
Press any other key to return here from graphics display
```

Figure 5. Sensitivity analysis graphical presentation selection screen.

```
Central Heating Plant Economics Evaluation Program file: RT01
Facility Financial Statement Retrofit plant (RT)
```

```
     Min value Step value Max value
      Primary fuel cost variation:    80%   10%   120%
   Auxiliary energy cost variation:   80%   10%   120%
        O&M labor cost variation:     80%   10%   120%
    O&M non-labor cost variation:     80%   10%   120%
    Repair/replace cost variation:    80%   10%   120%
             Initial cost variation:  30%   10%   200%


        Discount rate variation:     0.0%   1.0%   12.0%
     Primary fuel escalation rate:    -3%    1%     6%
            Plant life variation:    10 yr  1 yr  25 yr

        Accept / Change values? (A/C)          << A >>

print report:        Long   Short     Both   None
```

Figure 6. Screen at end of analysis offering the user an option to print.

The reports that have been generated and stored also can be accessed for printing through the *Print report* option of the sensitivity analysis menu. The screen in Figure 7 is first displayed, allowing the user to indicate whether the **Short format**, **Long format**, or **Both** types of reports be displayed for selection. Once the type of report is indicated, CHPECON displays the screen shown in Figure 8. On screen, the type of report (long or short) is indicated in the column headed **Rpt**.

```
 ┌──────────────────────────────────────────────────────────────┐
 │ Central Heating Plant Economics Evaluation Program   06/15/95 │
 │ Sensitivity analysis — report selection for printing          │
 └──────────────────────────────────────────────────────────────┘

 Display

    Long format sensitivity analysis reports

    Short format sensitivity analysis reports

    Both long and short format reports

 for print selection



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

Figure 7. Sensitivity analysis report type selection.

```
 P --File--    Rpt   Type   Description

 --- more ---
 PICANP      ‖ L ‖  NP  ‖ Picatinny Arsenal þ Coal-Oil Slurry
 PICANP      ‖ S ‖  NP  ‖ Picatinny Arsenal þ Coal-Oil Slurry
 RT01        ‖ L ‖  RT  ‖ Joliet Army Ammunition Plant - Heavy Oil Stoker to Dump
 RT01        ‖ S ‖  RT  ‖ Joliet Army Ammunition Plant - Heavy Oil Stoker to Dump










 ↑↓  <PgUp> <PgDn> to move highlight
 +/- to select/unselect report, <ENTER> to print
```

Figure 8. Sensitivity analysis report selection for printing.

The type of screening model that was the basis for the analysis is indicated in the column headed **Type**: NP for new plants, CG for cogeneration new plants, TP for third party cogeneration, CN for consolidation-based new plants, and RT for retrofit plants.

A selection is made by moving the highlighting bar with the <Up> and <Down> keys to the desired file, and pressing the <+> key to tag it. Pressing the <-> key untags a file for printing. Tagging more than one file allows the user to print multiple files from one selection screen. Once the desired files are tagged, pressing <Enter> will cause the program to print the report files. Printing can be output to either the printer or ASCII text files. If printed to an ASCII text file, the file name is the same as the

analysis file, with the extension ".$SL" or ".$SS" for the long or short formats, respectively. If no files are selected, the user is asked to confirm that printing is not requested, then either continues or returns to the menu based on the answer.

3.4 Review of Output From Retrofit Cost Sensitivity Analysis

To describe the results of the sensitivity analysis on life cycle cost and the levelized cost of service (LCS), a case using information about Joliet Ammunition was used. The facility uses dump grate spreader stoker boilers, operating with fly ash reinjection. Table 2 contains the summary of the basic life cycle cost analysis from the CHPECON program, and is the basis for the following discussions.

The following sections describe each of the variations that the sensitivity analysis implements.

3.4.1 Primary Fuel Initial Cost

The primary fuel cost is the most substantial ongoing cost of the boiler facility. It typically represents the largest annual operating cost, and thus plays a major part in the overall life-cycle cost of the plant.

Varying the primary fuel's initial cost consists of adjusting each year's operating cost by the amount defined in the sensitivity analysis. For example, to study the effect of an initial cost of the primary fuel that is 20 percent less than the value used by the cost model, the cost stored for each year would be reduced to 80 percent of its value. This is the equivalent of reducing the initial cost by 20 percent and then calculating the

Table 2. Life cycle cost summary base case values for sensitivity analysis examples.

+ PV 'Adjusted' Investment Costs	=	$34,887,614.00
+ PV Energy + Transportation Costs	=	$32,373,830.00
+ PV Annually Recurring O&M Costs	=	$25,174,578.00
+ PV Non-Annually Recurring Repair & Replacement	=	$2,415,074.00
+ PV Disposal Cost of Existing System	=	$0.00
+ PV Disposal Cost of New/Retrofit Facility	=	$0.00
Total Life Cycle Cost (1993)	=	$94,851,096.00
Levelized Cost of Service (1996 start)	=	7.69 $/MMBtu
Levelized Cost of Service (1996 start)	=	9.20 $/1000 lb steam

outlying years based on the standard fuel escalation rates. Table 3 shows the effect of varying the primary fuel initial cost.

3.4.2 Primary Fuel Escalation Rate

Varying the primary fuel escalation rate consists of adjusting each year's operating cost by the amount defined in the sensitivity analysis, compounded over the years of operation. For example, to study the effect of a 3 percent decrease in the escalation rate of the primary fuel, the cost stored for each year would be reduced to 0.97^n of its value, where n is the operating year. For the first year, the cost would be reduced by 3 percent; the second year would see a reduction of $(3\%)^2$, or to 0.9409 of the initial value; and so on. Varying the escalation rate simulates the effect of a lower than expected rate of cost increase (with respect to inflation). The primary fuel escalation rate variation can also be thought of as an adjustment to the energy escalation rates that are contained in the program. These energy escalation rates are specified by the U.S. Department of Energy, and are incorporated into CHPECON through a link to the LCCID program.

The variation allowed for the escalation rate is from a reduction of 3 percent to an increase of 6 percent. The effect of varying the primary fuel escalation rate is shown in Table 4.

3.4.3 Auxiliary Energy Cost

Varying the auxiliary energy cost consists of adjusting each year's operating cost by the amount defined in the sensitivity analysis. For example, to study the effect of auxiliary energy costing 20 percent less than the value used by the cost model, the cost stored for each year would be reduced to 80 percent of its value. This adjustment is similar to the cost variation established for the primary fuel initial cost sensitivity.

Table 3. Example of primary fuel initial cost variation.

Change	PV Primary Fuel	Life Cycle Cost	LCS, $/1000lb steam
80%	25,880,806	88,380,895	8.572
90%	29,115,906	91,615,996	8.886
100%	32,351,007	94,851,097	9.200
110%	35,586,108	98,086,198	9.513
120%	38,821,209	101,321,298	9.827

Table 4. Example of primary fuel escalation rate variation.

Change	PV Primary Fuel	Life Cycle Cost	LCS, $/1000lb steam
-3%	23,335,281	85,835,371	8.325
-2%	25,917,142	88,417,232	8.575
-1%	28,898,678	91,398,768	8.865
0%	32,351,007	94,851,097	9.200
1%	36,358,504	98,858,594	9.588
2%	41,021,285	103,521,375	10.040
3%	46,458,144	108,958,233	10.568
4%	52,810,029	115,310,119	11.184
5%	60,244,155	122,744,245	11.905
6%	68,958,853	131,458,943	12.750

For boilers that serve as cogeneration facilities, when the auxiliary energy cost is varied, the credit taken for the electricity that was generated is also increased or reduced by the same amount. The rationale for this is that the electricity credit should be less because the electricity that is offset, that would have been purchased, costs less. Table 5 shows the effect of varying auxiliary energy costs.

3.5 Operating and Maintenance—Labor Portion

Operating and maintenance costs for each year are composed of a labor portion for the staff, a nonlabor, noncapital-related portion for materials and supplies, and a nonlabor portion that is proportional to the cost of various equipment. Varying the labor portion of O&M costs simulates a change to either salary rates or staffing levels (or a combination of the two). The implementation is to adjust each year's labor O&M by the fractional change. An example of the effect of this variation is shown in Table 6.

3.6 Operating and Maintenance—Nonlabor Portion

The nonlabor portion of the operating and maintenance cost covers the materials, supplies, and maintenance that occurs on an annual basis for the facility. The procedure is to adjust each year's nonlabor O&M by the fractional change desired by the analysis. An example of the effect of this variation is shown in Table 7.

Table 5. Example of auxiliary energy cost variation.

Change	PV Auxiliary Energy	Life Cycle Cost	LCS, $/1000lb steam
80%	18,258	94,846,532	9.199
90%	20,540	94,848,815	9.199
100%	22,822	94,851,097	9.200
110%	25,104	94,853,379	9.200
120%	27,387	94,855,661	9.200

Table 6. Example of O&M labor cost variation.

Change	PV O&M Labor	Life Cycle Cost	LCS, $/1000lb steam
80%	7,373,981	93,007,602	9.021
90%	8,295,728	93,929,349	9.110
100%	9,217,476	94,851,097	9.200
110%	10,139,224	95,772,844	9.289
120%	11,060,971	96,694,592	9.378

Table 7. Example of O&M nonlabor cost variation.

Change	PV O&M Nonlabor	Life Cycle Cost	LCS, $/1000lb steam
80%	12,765,681	91,659,677	8.890
90%	14,361,391	93,255,387	9.045
100%	15,957,101	94,851,097	9.200
110%	17,552,811	96,446,807	9.354
120%	19,148,521	98,042,517	9.509

3.7 Major Repair and Replacement Costs

Major repair and replacement costs are related to the nonannual expenses that occur every 2, 3, 5, or more years that are involved with major component maintenance. One example of this is the liner replacement required to maintain the efficiency of bag-houses. The spacing of these costs is irregular, and is the reason that the approach using an array of yearly values for each category of expense was adopted. This gives the program the ability to properly calculate the sums of the present values for these costs. As for most of the other factors, the procedure is to adjust each year's nonlabor

O&M by the fractional change desired by the analysis. An example of the effect of this variation is shown in Table 8.

3.8 Initial Cost

The initial cost of the facility consists of the capital, bulk material, freight, installation labor, indirect costs, engineering expenses, etc. Variation of the initial cost would affect the life-cycle cost directly and would not be a matter of concern if the variation affected only the initial capital cost component. However, one portion of the annual mainte-nance is computed as a fraction of the capital cost. Furthermore, the major repair and replacement costs are also computed as fractions of the capital costs for each comp-onent. To study the effect of varying the initial cost, factors including the initial plant cost, the nonlabor, capital-related O&M costs, and major repair and replacements costs are all adjusted by the same amount, before calculating the life-cycle cost of the facility. The recognition that changes in initial capital costs will impact future expenditures for capital-related items benefits the accuracy of the sensitivity analysis. Table 9 shows the effect of varying the initial cost of the facility.

3.9 Discount Rate

The discount rate is a measure of the cost of money. The discount rate used in the CHPECON program represents a *real* interest rate, which means that an inflation premium is not included; CHPECON uses the discount rate for federal life cycle costing projects published annually in CFR Title 10, Part 436, subpart A, "Life Cycle Cost Methods and Procedures." The discount rate is the one variation that affects every cost because it is the value used to calculate the present value of each year's cost. The allowed discount rate variation is from zero to 20 percent. Negative discount rates are disallowed. The maximum value of 20 percent represents an upper limit that has never been surpassed in the United States.

Table 8. Example of repair/replace cost variation.

Change	PV Repair/Replace	Life Cycle Cost	LCS, $/1000lb Steam
80%	1,932,059	94,368,082	9.153
90%	2,173,566	94,609,589	9.176
100%	2,415,074	94,851,097	9.200
110%	2,656,581	95,092,604	9.223
120%	2,898,088	95,334,112	9.246

Table 9. Example of initial cost variation.

Change	PV Initial Cost	Life Cycle Cost	LCS,$/1000lb Steam
30%	10,466,284	63,931,856	6.201
40%	13,955,045	68,348,890	6.629
50%	17,443,807	72,765,925	7.057
60%	20,932,568	77,182,959	7.486
70%	24,421,330	81,599,994	7.914
80%	27,910,091	86,017,028	8.343
90%	31,398,853	90,434,062	8.771
100%	34,887,614	94,851,097	9.200
110%	38,376,376	99,268,131	9.628
120%	41,865,137	103,685,166	10.056
130%	45,353,899	108,102,200	10.485
140%	48,842,660	112,519,234	10.913
150%	52,331,422	116,936,269	11.342
160%	55,820,183	121,353,303	11.770
170%	59,308,945	125,770,338	12.199
180%	62,797,706	130,187,372	12.627
190%	66,286,468	134,604,407	13.055
200%	69,775,229	139,021,441	13.484

The example in Table 10 shows the effect of varying the discount rate. Increasing the discount rate decreases the present value of project costs by weighting the distant future cash flows less heavily. Decreasing the discount rate increases the present value of project costs by giving greater consideration to distant cash flows.

Changes to the discount rate will influence the relative importance of capital versus operating costs. For example, decreasing the discount rate will increase the relative importance of annually-occurring operating and maintenance costs in the life cycle cost analysis. However, capital and installation costs occur at the beginning of the plant's life, and the present value of these costs is relatively insensitive to changes in the discount rate. Thus, higher discount rates place an emphasis on capital costs, while lower discount rates consider operating and maintenance costs to a greater extent.

3.10 Plant Life

Variation in plant life shows the effect on life cycle cost of spreading the investment cost of the facility over a different number of years of operation. The minimum value for the plant life sensitivity is 10 years, with the maximum reaching a federally-imposed limit of 25 years. Criteria regarding the treatment of facility lifetime can be found in *Energy Prices and Discount Factors for Life Cycle Cost Analysis: Annual Supplement to NBS (National Bureau of Standards) Handbook 135* and *NBS Special Publication 709*. The analysis is implemented by eliminating costs for years greater than the desired life, and calculating the life-cycle cost on the remaining years of operation. This analysis is useful when considering the effects of unplanned service

Table 10. Example of discount rate variation.

Change	Life Cycle Cost	LCS,$/1000lb steam
0.0%	151,179,224	14.663
0.5%	142,432,531	13.815
1.5%	127,212,846	12.338
2.5%	114,519,559	11.107
3.5%	103,861,346	10.073
4.5%	94,851,097	9.200
5.5%	87,182,418	8.456
6.5%	80,611,698	7.818
7.5%	74,944,358	7.269
8.5%	70,024,274	6.791
9.5%	65,725,608	6.375
10.5%	61,946,468	6.008
11.5%	58,603,977	5.684
12.0%	57,074,810	5.535

termination in future years, such as military base closings.

The effect of decreasing the expected lifetime of the facility can be seen in Table 11. A shorter lifetime produces a lower life cycle cost because fewer years of fuel and nonfuel operating costs will have occurred. However, the levelized cost of service increases as the plant life decreases. This is because the facility's installed cost is averaged over a smaller total steam output since the annual production is delivered for fewer years. The extreme example for this would be a facility that was built and operated for just 1 lb of steam; the levelized cost of service would be the installed cost of the facility.

3.11 User Interface — Boiler Load Sensitivity Analysis for Retrofit Cases

This enhancement lets CHPECON perform a sensitivity analysis on varying boiler loads for a particular installation considered for retrofit technology in CHPECON. The results of a boiler load sensitivity analysis will allow the user to understand the results and impact of changing boiler loads for an existing facility. This could occur for a number of reasons, including longer-term seasonal variations, variations in the base's population due to ramp-up or scaling-back efforts, or a change in the focus of the site.

One file is created to contain the results of the sensitivity analysis. This is a permanent file that is given the same name as the screening model with an extension of "@LS". For example, a case that is stored in the file "QWERTY.DBF" and is listed as "QWERTY" in the screening and cost model listings, will have a boiler load sensitivity analysis file named "QWERTY.@LS", which can be accessed by CHPECON for printing at a later time. Any boiler load sensitivity file created remains in the working directory after the analysis is completed, until the user manually deletes it.

3.12 User Interface for Implementation of Retrofit Boiler Load Sensitivity Analysis

Table 11. Example of plant life variation.

Change	Life Cycle Cost	LCS, $/1000lb Steam
10 yr	65,184,600	11.848
11 yr	67,561,126	11.392
12 yr	69,962,502	11.035
13 yr	72,195,312	10.723
14 yr	74,407,965	10.468
15 yr	76,552,529	10.252
16 yr	78,705,784	10.076
17 yr	80,640,647	9.906
18 yr	82,568,095	9.765
19 yr	84,369,056	9.635
20 yr	86,784,061	9.595
21 yr	88,547,455	9.500
22 yr	90,165,403	9.407
23 yr	91,726,747	9.324
24 yr	93,396,847	9.266
25 yr	94,851,097	9.200

The user interface is based on the format as developed in CHPECON. A series of menus guide the user through the necessary questions to complete an analysis. The main menu screen for CHPECON (Figure 9) shows the option to access the boiler load sensitivity analysis. Once the boiler load sensitivity analysis option is selected, a menu (Figure 10) appears, allowing the user to run a retrofit sensitivity analysis, in addition to any new plant analysis, or to print existing reports. **Quit** returns the user to the previous CHPECON main menu.

After selecting the base case from the list of available files, the user is presented with the screen shown in Figure 11. At this point, the user is asked to enter the desired values for the minimum, maximum, and step size. The values must be accepted (by answering Yes to the question) before proceeding to the question about continuing the analysis. Answering **No** returns to the menu, while answering **Yes** starts the analysis itself. Once started, the program displays the screen shown in Figure 12. As each life cycle cost is computed, the value is displayed on the screen. After completing the run, CHPECON pauses for the user to press a key, then returns to the menu.

The reports that have been generated and stored can be accessed for printing through the *Print Report* option of the multiple run analysis menu. Once selected, CHPECON displays the screen shown in Figure 13. A selection is made by moving the highlighting bar with the <Up> and <Down> keys to the desired file, and pressing the <+> key to tag it. Pressing the <-> key untags a file for printing. Tagging more than one file allows the user to print multiple files from one selection screen. Once the desired files are tagged, pressing <Enter> causes the program to print the report files. Printing can be output to the printer or to ASCII text files. If printed to an ASCII text file, the file name is the same as the analysis file, with the extension ".$LS". If no files are selected, the user is asked to confirm that printing is not requested, then either continues or returns to the menu based on the answer.

```
┌─────────────────────────────────────────────────────────────────────────┐
│ ┌───────────────────────────────────────────────────────────────┐         │
│ │ Central Heating Plant Economics Evaluation Program    06/08/95 │         │
│ │ Main Menu                                                     │         │
│ └───────────────────────────────────────────────────────────────┘         │
│                                                                           │
│   1 -- Screening Models            6 -- Update Databases                   │
│                                                                           │
│   2 -- Cost Models                 7 -- System Utilities                   │
│                                                                           │
│   3 -- Multiple Run Analysis                                              │
│                                                                           │
│   4 -- Sensitivity Analysis                                               │
│                                                                           │
│   5 -- Load Sensitivity Analysis   Q -- Quit (exit program)               │
│                                                                           │
│                                                                           │
│           ↑↓                                                             │
│     Use         to move highlight or enter first character to select option│
│                                                                           │
│                    Run boiler load sensitivity analysis                    │
│                                                                           │
└─────────────────────────────────────────────────────────────────────────┘
```

Figure 9. Initial menu screen for CHPECON with boiler load sensitivity highlighted.

```
┌─────────────────────────────────────────────────────────────────────────┐
│ ┌───────────────────────────────────────────────────────────────┐         │
│ │ Central Heating Plant Economics Evaluation Program    06/15/95 │         │
│ │ Main menu — load sensitivity                                  │         │
│ └───────────────────────────────────────────────────────────────┘         │
│                                                                           │
│       1 -- New plant                                                      │
│                                                                           │
│       2 -- New plant with cogeneration                                    │
│                                                                           │
│       3 -- New plant with third-party cogeneration                        │
│                                                                           │
│       4 -- New plant with consolidation                                   │
│                                                                           │
│       5 -- Retrofit plant                                                 │
│                                                                           │
│       P -- Print report                                                   │
│                                                                           │
│       Q -- Quit (return to main menu)                                     │
│                                                                           │
│           ↑↓                                                             │
│     Use         to move highlight or enter first character to select option│
│                                                                           │
│       Retrofit existing plant, using general cost factors for upgrades     │
│                                                                           │
└─────────────────────────────────────────────────────────────────────────┘
```

Figure 10. Menu screen for boiler load sensitivity analysis.

```
      Minimum load fraction variation:    50 %

      Maximum load fraction variation:   150 %

              Load fraction step size:    10 %

           Accept values? (Y/N)  Y

           Proceed with analysis? (Y/N)  Y
```

Figure 11. Variation limits entry screen for boiler load.

```
              Working on 150% load factor   (50% -- 150%)
      Change  Total Load, klb steam   Life Cycle Cost   LCS,$/1000lb steam
       50%            396,720           71,303,101          14.454
       60%            476,064           75,274,329          12.716
       70%            555,408           79,245,557          11.474
       80%            634,752           83,216,785          10.543
       90%            714,096           87,188,013           9.819
      100%            793,440           91,159,241           9.239
      110%            872,784           95,130,469           8.765
      120%            952,128           99,101,697           8.370
      130%          1,031,472          103,072,926           8.036
      140%          1,110,816          107,044,154           7.749
      150%          1,190,160          111,015,382           7.501



      Press any key to continue...
```

Figure 12. Boiler load sensitivity analysis cost report screen.

```
      P --File-- Rpt Type Description

      --- top of list ---

      NP1   ‖ S  ‖ NP  ‖ Joliet Army Ammunition Alant· Dump Grate Spreader Stoke

      RT01  ‖ S  ‖ RT  ‖ Joliet Army Ammunition Plant · Heavy Oil Stoker to Dump





      ↑↓ to move highlight

      +/- to select/unselect report, <ENTER> to print
```

Figure 13. Boiler load sensitivity analysis report printing.

3.13 Review of Output from Boiler Load Sensitivity Analysis

The output from the boiler load sensitivity analysis is contained in the report that the program generates. It is composed of three parts: (1) the information about the site, (2) the baseline boiler loads (average monthly steam flows), and (3) the variation and its effects. Table 12 shows an example of the first section, which is similar to the site information of the other reports generated by CHPECON. The example uses Joliet Army Ammunition Plant weather data and arbitrarily selected Average Monthly Steam Flows. Table 13 lists a sample baseline boiler loads section of the report.

The example of the load sensitivity analysis in Table 14 shows the information that resulted from the analysis. It consists of the annual steam flow delivered at the given boiler load factor, and the associated life cycle cost and levelized cost of service.

It should be remembered when evaluating the results of this analysis that there is no determination as to whether the facility is capable of delivering above or below the design capacity to the extent the analysis can use. A detailed design analysis and more complete knowledge about the actual steam flow requirements is necessary for this.

Table 12. Boiler load sensitivity analysis report—site information section.

Base Information	
State: IL - Illinois	Base DOE Region: 2
PMCR: 244,000 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	

Table 13. Boiler load sensitivity analysis report—baseline boiler loads section.

Average Monthly Steam Flows (million Btu/hr)					
Jan	Feb	Mar	Apr	May	Jun
175	165	135	100	55	40
Jul	Aug	Sep	Oct	Nov	Dec
36	34	47	65	110	130

Table 14. Boiler load sensitivity analysis report—load sensitivity analysis section.

Change	Total Load, klb steam	Life Cycle Cost	LCS,$/1000lb Steam
50%	396,720	71,303,101	14.454
60%	476,064	75,274,329	12.716
70%	555,408	79,245,557	11.474
80%	634,752	83,216,785	10.543
90%	714,096	87,188,013	9.819
100%	793,440	91,159,241	9.239
110%	872,784	95,130,469	8.765
120%	952,128	99,101,697	8.370
130%	1,031,472	103,072,926	8.036
140%	1,110,816	107,044,154	7.749
150%	1,190,160	111,015,382	7.501

3.14 User Interface — Multiple Run Analysis for Retrofit Cases

After some experience with CHPECON, it was determined that a form of automated analysis was the only realistic method to comprehensively evaluate the possible boiler technology and coalfield combinations for a large number of different sites. Although it would be feasible to manually iterate through each combination, the amount of time required to operate the program and manually collate the results was considered prohibitive.

This enhancement to CHPECON adds the ability to perform an overview analysis for a particular installation considered for retrofit technology in CHPECON. The analysis exhaustively iterates through a range of coalfields combined with the appropriate coal technologies, based on the input entries from a single screening model data file. Life cycle costs for each of the combinations of coalfield and coal technology are calculated. The results of the multiple run analysis are presented in the report from the program for this type of analysis with each technology and coalfield combination sorted in order of increasing life cycle costs. This permits the user to quickly review the possible combinations and focus on those that appear most desirable.

The multiple run analysis option requires that a screening model case already exist for the military base to be studied. This ensures that the basic information about the facility is present — heating load requirements, location and type of system. This also allows the user to have answered the general questions about availability of auxiliary facilities (such as water and sewer lines) that are common to any boiler facility.

When first started, the option runs an analysis with any boiler technology that is independent of a selected coalfield, such as slurry boilers, since these use processed fuels, delivered in a fashion similar to fuel oil, do not directly depend on having a coalfield with the right fuel properties in close proximity to the base. After this, the program goes to the top of the file containing coalfield information, selecting the first coalfield. It then sequentially steps through the boiler technologies. For each technology, the option checks the allowable parameters database file to determine whether boilers based on the current technology can use the coal from the currently selected coalfield. If the technology and coalfield are not compatible, the program advances to the next technology.

If the technology is compatible with the coalfield, the program continues its analysis. The retrofit boiler sizing uses the existing boiler sizes entered by the user and adjusts the resulting outputs based on the effects of the retrofit. The loads experienced by the simulated retrofit facility are the previously entered load data. In this regard, the retrofit analysis differs from the new plant facility multiple run analysis because boilers cannot be sized to fit the exact conditions; the facility that is being retrofitted defines the capacity of the boilers.

If the technology is compatible with the coalfield properties, the program continues with the analysis. It computes the life cycle cost for the facility, using default answers for each of the questions that normally appear when conducting a cost model analysis. The overall cost of the facility is then stored in the report file. At the end of each technology sequence, the program advances to the next coalfield, and begins the technology cycle again.

A total of three files are created during the operation of the multiple run analysis. Two are temporary files that are given a unique filename with the default extension ".DBF", which are deleted at the end of the process. However, adequate room on the hard disk is needed to establish them even though they are later removed. The actual size needed depends on the operating parameters selected by the user for the multiple run analysis. The worst case would be 3k for the one file, and 680k for the other (the size of the coalfield database).

A temporary file is generated to hold the information from the screening model. The multiple run option has been written to draw on the information from the screening model case that has been stored to gain the information necessary to provide a comprehensive evaluation. This file is modified with the new parameters based on each of the coalfield and boiler technology combinations. It is then used for the costing model to determine the life cycle cost for each combination.

A second temporary file is created that contains a copy of the information on coalfields within a user-selected distance of the military base. If the range selected by the user is large enough, the entire coalfield database can be selected to evaluate its potential. This temporary file differs from the coalfield in that it is accessed in order of increasing distance from the military base. This means that the closest coalfields are evaluated first.

A permanent file is created to contain the results of the multiple run analysis, and given the same name as the file containing the screening model with an extension of "@MR". For example, a case that is stored in the file "QWERTY.DBF" and is listed as "QWERTY" in the screening and cost model listings, will have a multiple run analysis file named "QWERTY.@MR", which can be accessed by CHPECON for printing at a later time. Unlike the other two files, this file remains after the analysis is completed, until the user manually deletes it from the working directory.

3.15 User Interface for Implementation of Multiple Run Analysis For Retrofit Cases

The user interface is based on the format as developed in CHPECON. A series of menus guide the user through the necessary questions to complete an analysis. The main menu screen for CHPECON (Figure 14) reflects the options to access the multiple run analysis. Once the multiple run analysis option is selected, the menu in Figure 15 is shown, allowing the user to run a retrofit multiple run analysis, in addition to any new plant analysis, or print existing reports. The **Quit** option returns the user to the previous CHPECON main menu.

```
Central Heating Plant Economics Evaluation Program          06/08/95
Main Menu

1 -- Screening Models              6 -- Update Databases

2 -- Cost Models                   7 -- System Utilities

3 -- Multiple Run Analysis

4 -- Sensitivity Analysis

5 -- Load Sensitivity Analysis     Q -- Quit (exit program)



        Use ↑↓ to move highlight or enter first character to select option
     Run combined screening/costing for multiple coalfield/technology analyses
```

Figure 14. Initial menu screen for CHPECON with multiple run analysis highlighted.

```
Central Heating Plant Economics Evaluation Program          06/15/95

Main menu — multiple runs


        1 -- New plant

        2 -- New plant with cogeneration

        3 -- New plant with third-party cogeneration

        4 -- New plant with consolidation

        5 -- Retrofit plant

        P -- Print report

        Q -- Quit (return to main menu)


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

Figure 15. Menu screen for multiple run analysis.

After selecting the particular type of system to be considered in the multiple run
analysis, the list of available screening model data files is shown for the user. Once
the selection is made, the program proceeds to the coal range selection screen, as shown
in Figure 16.

```
┌──────────────────────────────────────────────────────────────────┐
│                                                                    │
│      Coalfields are identified as possible candidates based on     │
│      proximity to the selected base, and on properties that are    │
│      compatible with the selected boiler technology.               │
│                                                                    │
│                                                                    │
│      Distance from base to include:   250 miles                    │
│                                                                    │
│                                                                    │
│       Fields searched:      2428          selected:       133       │
│                                                                    │
│            anthracite:        0           lignite:         0        │
│            bituminous:      133      sub-bituminous:       0         │
│                                                                    │
│                                                                    │
│                                                                    │
│                                                                    │
│       Search with a different distance? (Y/N) Y                     │
│                                                                    │
└──────────────────────────────────────────────────────────────────┘
```

Figure 16. Coal range selection screen.

The user must indicate the maximum distance that a coalfield can be from the facility site (calculated based on latitude and longitude) to be considered a candidate for the multiple run analysis. This feature allows the user to limit the number of coalfields being considered. If all coalfields should be considered as potential candidates, a value of all nines (9999) should be entered, because no coalfield is more distant for sites in the continental United States. While scanning the coalfield database, the program informs the user of the number of selected coalfields and their types (e.g., bituminous).

After having selected a suitable distance for coalfield inclusion, the user is asked for confirmation to proceed with the analysis. Once confirmed, the program begins the analysis portion of the multiple run analysis. The program displays a screen (Figure 17) to inform the user of the progress being made in the analysis. It follows the logic described above, through the coalfields, and through the coal technologies for each field. After completing the multiple run analysis with the screening model data and the range of coalfields, the program returns to the menu for the multiple run analysis (Figure 15).

The reports that have been generated and stored can be accessed for printing through the *Print report* option of the multiple run analysis menu. Once selected, CHPECON displays the screen shown in Figure 18. A selection is made by moving the highlighting bar with the <Up> and <Down> keys to the desired file, and pressing the <+> key to tag it. Pressing the <-> key untags a file for printing. Tagging more than one files allows the user to print multiple files from one selection screen.

```
    Using coalfield # 4 of 12

    Using boiler technology # 30
```

Figure 17. Progress display for multiple run analysis.

```
   P --File-- Description
      --- top of list ---
   6407CG     ‖  ‖    NAS WHITING FLD MILTON
   6407NP     ‖  ‖    NAS WHITING FLD MILTON
   6432CG06   ‖  ‖    NAS WHITING FLD MILTON
   6432CGNG   ‖  ‖    NAS WHITING FLD MILTON
   CG1        ‖  ‖    Joliet Army Ammunition Plant
   I01        ‖  ‖    Rock Island Arsenal
   J4         ‖  ‖    Joliet Army Ammunition Plant
   NP1        ‖  ‖    Joliet Army Ammunition Plant
   RT01       ‖  ‖    Joliet Army Ammunition Plant
   RT03       ‖  ‖    Joliet Army Ammunition Plant
   RT1        ‖  ‖    Joliet Army Ammunition Plant




            ↑↓ to move highlight

            +/- to select/unselect report, <ENTER> to print
```

Figure 18. File selection and printing screen.

Once the desired files are tagged, pressing <Enter> will cause the program to print the
report files. Printing can be done to either the printer or ASCII text files. If printing
to ASCII text files, the file name is the same as the analysis file, with the extension

".$MR". If no files are selected, the user is asked to confirm that no printing is requested, then either continues or returns to the menu based on the answer.

Table 15 lists sample output from the multiple run analysis. It consists of the basic details about the coalfield, for identification. It also lists the technology considered, the number of boilers that were determined for the site, the year for the calculations of the life cycle cost, and the end results: the life cycle cost and capital cost for a facility using the technology and coalfield. The listing is sorted in order of increasing life cycle cost, i.e., the lowest LCCs will be shown first.

Table 15. Sample multiple run analysis output.

```
Coal state: IN              County: GREENE
Location: JH&L COAL CO PIT NO 7
Latitude: 390458            Longitude: 871250        Distance from base: 174
Rank: B                     Code No: W188946
Boiler type                 31 -- Coal Stoker to Slagging Coal
Number of boilers: 4        LCC Year: 1993
LCC: 89,632,463             Capital cost: 34,490,955


Coal state: IN              County: VIGO
Location: BLUE HOLE NO 1 PIT
Latitude: 392204            Longitude: 871627        Distance from base: 154
Rank: B                     Code No: W188944
Boiler type: 30 -- Heavy Oil Package System to Slagging Coal
Number of boilers: 4        LCC Year: 1993
LCC: 91,411,194             Capital cost: 34,795,595


Coal state: IN              County: CLAY
Location: STRIP
Latitude: 392531            Longitude: 870552        Distance from base: 153
Rank: B                     Code No: W192632
Boiler type: 16 -- Heavy Oil Stoker to Dump Grate Spreader Stoker w/o f/a/r
Number of boilers: 4        LCC Year: 1993
LCC: 93,304,262             Capital cost: 34,468,279


Coal state: IN              County: SULLIVAN
Location: STRIP
Latitude: 391148            Longitude: 872106        Distance from base: 164
Rank: B                     Code No: W192635
Boiler type: 31 -- Coal Stoker to Slagging Coal
Number of boilers: 4        LCC Year: 1993
LCC: 94,552,174             Capital cost: 35,772,375


Coal state: IN              County: SULLIVAN
Location: BIRDSONG MINE
Latitude: 391235            Longitude: 871440        Distance from base: 165
Rank: B                     Code No: W194388
Boiler type: 23 -- Heavy Oil Stoker to Traveling Grate Stoker
Number of boilers: 4        LCC Year: 1993
LCC: 96,460,524             Capital cost: 35,394,455
```

4 Resolution of Beta-Test Issues

The purpose of this effort was to resolve the questions developed during the use of CHPECON since its development through 1994. In some instances, they represented program problems, or "bugs"; in other instances, they were related to problems in operation. Each item of concern is listed with its resolution below.

4.1 Averaging of Yearly Steam Production

4.1.1 Issue

This question relates to the issue of selecting data from multiple years for a facility that has detailed information stored within the Inventory program to which CHPECON links to access this data. A methodology to link into different years' data, retrieve, and average to provide a composite load will be defined and implemented as part of this effort.

A question that will need to be answered is the problem of "0." In the current database, it either represents a true no-load monthly average situation for the facility (such as in summer), which should be averaged, or it represents a null value (no answer known). To accomplish this, some provision will be made to allow the user to select (include in average) or reject a value (exclude it from the average).

4.1.2 Resolution

This request focused on an additional function to the Inventory database interface. The Inventory program (a separate application developed by USACERL) is a source of data on heating loads from military bases. Prior modifications to CHPECON permitted the user to access yearly load data from one or more buildings or facilities. This item requested the ability to average multiple years of data for the building loads when combining them into the expected load for a central heating plant under consideration.

To achieve this, the entire user interface was rewritten. The option now operates in the following manner. The user is asked whether the Inventory database is to be used as part of defining a new case for study. After indicating that it should be used, the

military base entry is either found automatically or is identified by the user. Once a base is identified, the individual buildings or other systems that have been entered are retrieved, and the years that have load data are found. The user is then presented with a list of the buildings and years so that one or more of the entries can be identified to be used for load data. Pressing <Space> alternately tags or untags the entries, and pressing <Enter> proceeds with those selected. Loads from different buildings are added to produce a summary of the loads for each month. If 2 or more years of the same building are selected, these entries are averaged together before being added into the sum of all loads. The user has the option, before selecting the building/year load data, of indicating whether zero (0) loads should be included in averages or discarded. For those times when they are discarded, the remaining loads are averaged before adding into the sum of all loads. Once the user has selected the building/year data, the program runs through the calculations and continues with the analysis of the new case.

4.2   Cogeneration Options: Personnel Requirements for Facility

4.2.1 Issue

A 600,000 lb/hr facility requires same number of people whether it is a heating facility or a cogeneration facility. The manpower staffing requirements will be reviewed to check that they are indeed the correct, currently accepted by USACERL values, as documented in previous reports. In addition, recent information will be checked to ensure that the values are still acceptable.

4.2.2 Resolution

The values in the staffing requirements file as it currently exists at IGT were reviewed. The entries reflect the changes that were made to the database when USACERL last requested a re-evaluation of the information. The only conditions that would result in equal staffing levels between heating and cogeneration facilities are for oil and gas systems over 300,000 lb steam/hr.

The original values were developed from the experience of Schmidt Associates and IGT in the generation of the Coal Fired Boiler Evaluation Program (CFBEP). These values represented the staffing requirements of a standalone facility. It was modified at USACERL's request to reflect the fact that some positions were part-time in nature, requiring less than full-time attention for the task, but had been entered as integral positions. Because the military bases that are the focus of CHPECON can permit part time assignments for the central heating plants, fractional staff requirements were introduced.

Figures 19 and 20 show the logic for the staffing of the system. Each chart represents the range of staffing requirements for varying plant maximum continuous ratings (PMCR) for the types of facilities (3 vs. 4/5 boilers, heating vs. co-generation). In Figure 19, the staffing levels for the Maintenance Mechanic position are the same for the 3 and 4/5 boiler configurations. They vary with PMCR levels, recognizing that the larger facilities (over 400,000 lb steam/hr) will require an additional person. In addition, a half person equivalent is added to maintain the additional equipment for a cogeneration facility.

Also in Figure 19 are the staffing requirements for the Maintenance Laborer. The only variation between levels is due to PMCR changes. For the same PMCR, the laborer position does not vary based on heating or cogeneration, or on the number of boilers. However, the combined effect of the Maintenance Mechanic and Maintenance Laborer is to increase the number of people above 200k and again above 400k. For example, a 3-boiler, heating facility with a PMCR of 200k or less has a total of two people (Maintenance Mechanics). A facility with a capacity of 400k or less, but above 200k has three people (two Maintenance Mechanics and one Maintenance Laborer). A facility with a capacity above 400k has five people (three Maintenance Mechanics and two Maintenance Laborers).

In Figure 20, the Maintenance Electrician Position varies due to the number of boilers and type of system (heating/cogeneration), but not with varying PMCR. The Operations Laborer requirements in Figure 20 show variations with number of boilers and PMCR, but not with type of facility. Three boiler facilities have three different levels based on PMCR, while 4/5 boiler facilities have four different levels based on PMCR.

Plant Maximum Continuous Rating, 1000 lb/hr	Maintenance Laborer				Maintenance Mechanic			
	Coal 3 boilers		Coal 4 or 5 boilers		Coal 3 boilers		Coal 4 or 5 boilers	
	Htg	Cgn	Htg	Cgn	Htg	Cgn	Htg	Cgn
550-600 / 500-550 / 450-500 / 400-450	2	2	2	2	3	3.5	3	3.5
350-400 / 300-350 / 250-300 / 200-250	1	1	1	1	2	2.5	2	2.5
150-200 / 100-150 / 50-100 / 0-50	0	0	0	0				

Figure 19. Staffing levels for coal-fired boilers for maintenance laborer and maintenance mechanic positions.
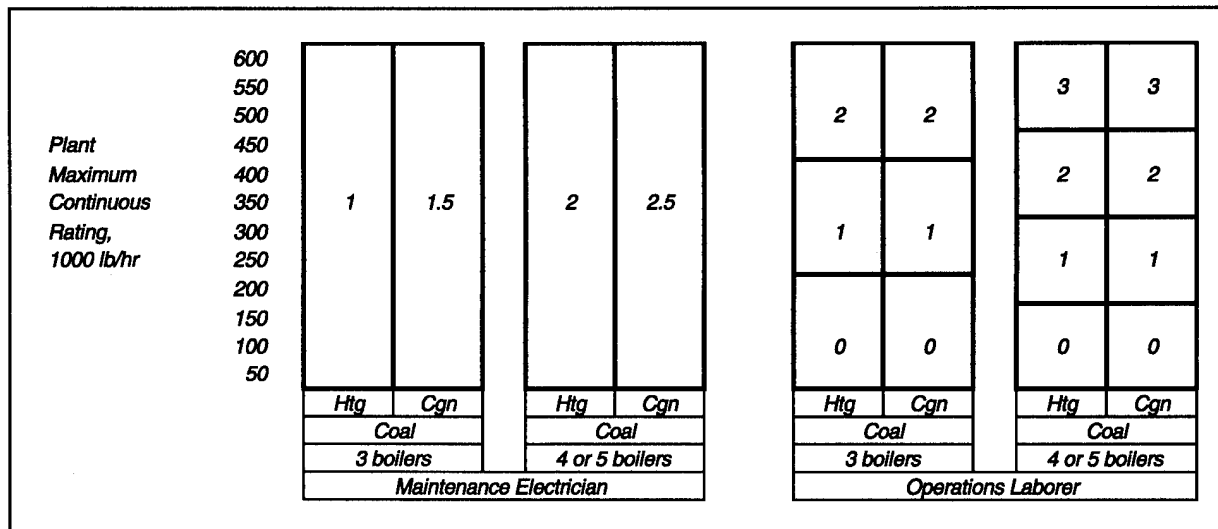
Figure 20. Staffing levels for coal-fired boilers for maintenance electrician and operations laborer positions.

These variations in general can only result in equal staffing levels if the same type of facility is being considered. Otherwise, the variations are logically tracking the type of equipment and demand placed on people by differing types of facility. Note that an individual year with a particular plant manager could arrange staffing to be different than the suggested values from CHPECON; however, it is unlikely that it could be maintained over the 25-year lifetime analyzed by CHPECON, and it is likely that these levels could sustain operation during that time.

4.3 Cogeneration Options: Annual Fuel Usage

4.3.1 Issue

The annual fuel usage for the cogeneration and heating facility models were the same. This will be checked to ensure that the model is properly accounting for all fuel usage, including that for cogeneration above and beyond heating needs (if the situation occurs).

4.3.2 Resolution

The basic concept is that a cogeneration facility can be operated in one of three ways:

1. The average monthly heating load is always above the steam required for cogeneration of electricity.

2. The steam required for cogeneration is above the average monthly heating load for one or more months, but the facility is run to deliver the heating load and any

electricity generated is used; the remaining electricity is obtained from outside the facility.

3. The steam required for cogeneration is above the average monthly heating load for 1 or more months, and the facility is run to meet the greater of the heating load and the electrical generation.

Options 1 and 2 look the same, because the heating load is the deciding factor for the operation of the facility. The program assumes that the cooling tower and related equipment can be eliminated because all of the steam fed through the generators can be used to heat the facility. Option 3 differs because the facility can generate more steam than can be used for heating, requiring cooling towers and other equipment.

A test case was run with electrical loads high enough so that either option 2 or option 3 was feasible. Table 16 lists the results obtained while running under option 2; Table 17 lists the results obtained while running under option 3. A comparison of Tables 16 and 17 shows the expected differences.

Table 16. Results of test case to measure fuel use with cogeneration, option 2.

Parameter	Result
Annual facility output	669,600 thousand lb of steam
annual coal usage	40,136 tons (dry)
PV 'adjusted' investment costs	$ 90,822,866
PV energy & transportation costs	$ 40,855,078
PV cogeneration electricity credit	$ 52,739,818
Total life cycle cost	$ 114,772,756
Levelized cost of service	$ 9.9969 / MMBtu

4.4 Cogeneration Options: Standby Power Charges

4.4.1 Issue

Table 17. Results of test case to measure fuel use with cogeneration, option 3.

Parameter	Result
Annual facility output	1,146,240 thousand lb of steam
Annual coal usage	68,706 tons (dry)
PV 'adjusted' investment costs	$ 92,266,544
PV energy & transportation costs	$ 69,819,762
PV cogeneration electricity credit	$ 90,703,313
Total life cycle cost	$ 119,366,017
Levelized cost of service	$ 10.397 / MMBtu

There needs to be a method to account for the fact that a local utility may still require a fee for maintaining a connection for standby power. Currently, there is no way to know this for all the utilities at continental U.S. bases that require standby power. To accommodate this, the ability to entries for additional charges (either on a kW or kW-hr basis) will be put into the CHPECON program.

4.4.2 Resolution

The incremental costs referred to in this item fall into two categories. The first is a factor based on the electrical demand of the facility. These can be demand charges or

other items such as power factor charges, all on the basis of the total demand of the facility, measured in kW over a distinct time span such as 15 minutes (defined by the utility). The second is a rate based on total consumption, such as a surcharge for maintenance.

To permit CHPECON to include these factors, the cost model requests entry of these charges, along with cost indices and other costs. The demand used to calculate the total rate-based charge is the total rate of the facility as if all utilities were in operation simultaneously (including lights, pumps, etc.). These costs are then used in the life cycle costing routines of CHPECON. (Note: similar functionality was requested in question 16 of a memorandum from NFESC to USACERL.[*] These two changes combined with the third reflect the composite result in the program. The third is a fixed rate monthly charge, which could cover almost any additional recurring expense for a service that the utility is providing, such as maintaining interconnection facilities.)

4.5 Cogeneration Options: Cogen Sizing Conflict

4.5.1 Issue

The noted problem is that the facility seems to be sized for using heating/process loads only, even if the cogeneration requirements are higher. This will be checked and verified.

4.5.2 Resolution

The proper operation of these options for cogeneration sizing was verified. The mode of operation is:

- Heating-mode-only operation is used for determining the facility's design size by using the currently defined equations to correlate monthly data to design sizes. The maximum design size based on each month will be the suggested design size for the facility, subject to user modification.
- For cogeneration mode with the heating/process load dominating, the facility will be sized as if it were a heating-mode-only operation.

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[*] Memorandum from Steven Guzinski (NFESC) to USACERL; Subject: "Questions for USACERL" (28 September 1991); hereafter referred to as NFESC Memo (1991).

- For cogeneration mode where the average cogeneration needs in a given month will be above that of the same month's average heating/process load, the facility will be sized in one of two ways based on user input:
  - If the user desires to limit the electricity output to that based on the heating/process needs after electricity generation, the facility will be sized as if it were a heating-mode-only operation.
  - If the user desires to deliver the maximum amount of electricity independent of the heating/process loads, the facility will be sized using the larger of two values, the first based on heating mode only, and the second based on cogeneration monthly load.

4.6   Installation Costs Seemingly Excessive With Respect to Equipment Costs

4.6.1 Issue

These costs will be checked to verify their proper calculation. Any changes necessary to bring the values in line will be implemented.

4.6.2 Resolution

The costs for the Ash Handling System involve both the capital equipment costs and the related costs for installing the equipment: labor costs, indirect costs, freight costs, and bulk material costs. The labor costs are based on the equipment costs, as for the other equipment. The cost factors used in calculating labor costs for ash handling equipment resulted in an order of magnitude difference from the appropriate cost. This has been adjusted to reflect the correct values.

4.7   Breakdown of Costs for Gas/Oil Facilities Is Different From Those for Coal Facilities

4.7.1 Issue

The information output for the gas/oil facilities will be adjusted where feasible so that it more closely reflects that generated for coal facilities.

4.7.2 Resolution

The information used to develop the coal and the gas/oil facilities were from two different sources. The basis of the calculations are reflected in the report format. For example, individual labor costs were not defined for gas/oil facilities. Applying the general cost factors for individual components can give misleading values for various aspects of the installation costs. As a result, only limited changes could be made to vary the format of the report. The alternative would require significant effort to redevelop the costing routines to mirror the format of the coal-fired equipment, and was beyond the scope of this task.

4.8 Piping and Stack System Cost Discrepancy

4.8.1 Issue

There are significant cost differences between coal and gas/oil facilities. The costs will be checked for proper calculation. In addition, the basic differences between the two types of systems will be described in detail to explain the variance.

4.8.2 Resolution

The costs for a stoker boiler facility and an oil and gas boiler facility were compared to determine the differences between piping costs for each facility and between stack costs for each facility. The facilities were defined for 300,000 lb steam/hr PMCR.

The piping costs were $1,572,458 for the coal facility and $1,264,675 for the oil and gas facility. The oil and gas would be expected to be lower due to the fact that only three boilers are present, instead of the four coal boilers. In addition, there should be some difference because of the size of the facilities, with oil and gas boilers being physically smaller than the coal boilers. Due to this comparison, these costs are in line with what would be expected.

The stack costs were $1,497,189 for the coal boilers and $32,911 for the oil and gas boilers. These costs reflect the basic differences between the two types of stacks. The coal boilers are taller; the building containing the coal boilers are taller, and the stacks must be a multiple of the building height (which varies with boiler size). The oil and gas boilers are smaller, and the stacks are sized independent of boiler capacity. The type of material used in each stack's construction is different. The coal boilers are masonry and metal liners, constructed with thicker walls, with enough strength to support stairways, platforms, and instrumentation. The oil and gas boiler stacks are

prefabricated steel and are much less substantial, in part because they do not need to support as great a height. Due to these differences, the costs are in line with what would be expected.

4.9 Insurance Costs

4.9.1 Issue

The differences between insurance costs for facilities and the need for insurance will be documented. In addition, a provision will be added for more flexibility to allow the user to accept or reject the need for insurance, recognizing the fact that the government is self-insured.

4.9.2 Resolution

The primary reason for insurance costs differences is the basis for the calculations. The original definition for coal-fired boilers included insurance (0.05 percent of the installation cost) and bonding (0.08 percent of the bonded cost, which is estimated as 1.33 times the installation cost). This was subsequently removed from all but the third-party cogeneration option; it was continued in the third-party cogeneration option because most third-parties would be insuring themselves and would not rely on the government's self-insured mode of operation.

The annual insurance cost for oil and gas boilers, listed in the cost analysis, was calculated based on the capital cost of the equipment. The ending values, either insurance and bonding for coal-fired facilities or insurance for gas and oil facilities, were of similar magnitude for comparable capacities, even though the basis was different. To comply with the request for permitting the user the option of including insurance (insurance/bonding) costs, the program routines where these would be calculated were modified to request this information in the analysis.

4.10 EPA Testing Costs

4.10.1 Issue

The cost estimates for testing and permit renewal for coal and gas/oil facilities will be checked for correctness in calculation. In addition, the differences between the two will be documented for clarity.

4.10.2 Resolution

The types of testing periodically required of the facility would normally be defined by the New Source Performance Standards (NSPS) issued in December 1987. These are for industrial steam generators (>100 million Btu/h) commencing construction, modification or reconstruction after 19 June 1984 (Source: 40CFR60, Subpart Db [12/18/89]). This definition would cover everything but the smallest facilities that CHPECON is capable of assessing. For consistency, it had been decided to treat any facility evaluated by CHPECON in the same manner for EPA testing and permitting.

The Federal NSPS (Table 18 [Stultz and Kitto 1992]) define maximum emission rates and required reduction in potential emissions for various compounds based on the type of fuel. Coal and oil both require testing of SO_2, NO_x (as NO_2), particulates, and opacity. Gas requires NO_x (as NO_2), particulates, and opacity testing, but excludes SO_2. The values for each component varies based on the fuel, but all aspects must be documented in some fashion. Any of the coal-fired facilities would require the entire range of testing whether they were new or retrofitted. The oil and gas facilities would also require the entire range of testing, because of the potential for operation with fuel oil. As a result, the instrumentation and time requirements for testing would be similar for each type of facility; if testing on both natural gas and fuel oil is done, it may actually be longer than for coal-fired boilers. Only if a facility were exclusively gas-fired could the SO_2 testing be eliminated, which would then result in some reduction of cost. Due to this, the periodic EPA-related testing and permitting costs should be treated as independent of the technology.

State and local requirements usually follow similar testing procedures, but may have different values for acceptable limits. As such, for the purposes of the comparative evaluation in CHPECON, they have been treated as the same and will not require additional testing.

4.11 Sensitivity, Multiple-run, or Load Sensitivity Analysis for the Retrofit Option

4.11.1 Issue

The ability to perform cost sensitivity, multiple-run (boiler/coalfield), and load sensitivity analysis for retrofit scenarios will be added.

Table 18. Selected summary of federal nsps for industrial steam generators > 100 million btu/h commencing construction, modification or reconstruction after 19 June 1984.

Fuel	Pollutant: Technology	Max. Emissions Rate (lb/10^6 Btu) (Note 3)	Req'd Reduction in Potential Emissions, % (Note 3)
Coal	SO$_2$: All	1.2	90 (Note 3)
	NO$_x$ as NO$_2$:		
	Spreader-stoker	0.6	—
	Mass-feed stoker	0.5	—
	Pulverized coal	0.7	—
	Fluidized bed	0.6	—
	Particulate	0.05 (Note 5)	—
Oil (Resid.)	SO$_2$	0.8 or 0.5	90 or 0 (Note 3)
	NO$_x$ as NO$_2$	0.4/0.3 (Note 4)	—
	Particulate	0.10 (Note 5)	—
Gas	SO$_2$	—	—
	NO$_x$ as NO$_2$	0.2/0.1 (Note 4)	—
	Particulate	0.10 (Note 5)	

* Table summarized from Stultz and Kitto (1992), pp 32-35.
Notes:
1. Source: 40CFR60, Subpart Db (12/18/89)
2. For reference only: see source for details.
3. Maximum Emissions Rate and Req'd. Reduction in Potential Emissions must both be met.
4. Higher rate for heat release rates > 70,000 Btu/h ft^3
5. Separate opacity limit of 20% may be controlling.

4.11.2 Resolution

This is the focus of task number 2 in this effort. For details, see Chapter 2, Sections 2.2 and 2.3 of this report.

4.12 Calculation of Tank Sizing for Slurry Storage

4.12.1 Issue

The procedure used to calculate the storage area required for each type of fuel tank will be checked and verified, and adjusted if necessary. Appropriate documentation will be provided to clarify the perceived discrepancy if verified correct.

4.12.2 Resolution

To calculate tank sizing for slurry storage, two identical cases using Rock Island Arsenal for the site and a PMCR of 309,000 lb steam were generated: with coal-oil slurry (Table 19) and coal-water slurry technology (Table 20). The different storage requirements of the coal-water slurry and coal-oil slurry technologies are now being tracked appropriately in CHPECON.

4.13 Changing Oil/Gas Fuels Used Not Tracked

4.13.1 Issue

The proper operation of this function, based on the use of existing cases, will be verified to ensure that switching between fuel types is documented and used in the following cost calculations. The case files storing the basic information will be reviewed to confirm the proper updating of fuel utilization coefficients, and that auxiliary components based on fuel type are also updated appropriately.

4.13.2 Resolution

The concern was that changes made to the types of natural gas / #2 fuel oil / #6 fuel oil with the "use existing case" option, which were used for the screening model and subsequently used in the cost analysis, were not being correctly updated. The problem was caused by the updating of values for the fuels to be used without the removal of the prior entries from the file. This has been corrected.

4.14 Costs Based on Initial and Modified Screening Cases Show Different Results

4.14.1 Issue

The reason for this discrepancy will be explored. The underlying data files will be investigated to make sure that data items are being properly updated when basic information about the facility is changed by the user. Comparisons between initially generated files and files updated using the "Use

Table 19. Calculated tank sizing for slurry storage with coal-oil slurry.

Parameter	Calculated Result
Slurry input	8,589 gal/hr
Tank storage capacity	18,549,000 gal
Storage tank area	8.68 acres
Cost of long term storage tanks	$ 3,640,162

Table 20. Calculated tank sizing for slurry storage with coal-water slurry.

Parameter	Calculated Result
Slurry input	3,309 gal/hr
Tank storage capacity	7,168,000 gal
Storage tank area	3.43 acres
Cost of long term storage tanks	$ 1,489,394

existing case" option will be compared to confirm that the modifications are recorded and that the older terms are removed from the data files. Comparisons between stoker coal, fluidized bed coal, coal slurry, and oil/gas files will be used to ensure that updates are done when switching basic boiler types (the most problematic of conversions due to their complexity).

4.14.2 Resolution

The comparison of results from cost summaries from original and modified screening cases (cases using existing cases as the basis) showed discrepancies between the information. By comparing results from different approaches to the same set of conditions (boiler technology, etc.), the causes of the differences were identified and resolved.

Note that some of the differences result from the fact that the calculations based on the initial cases use values calculated to the precision of the underlying programming environment, FoxPro, while the calculations for modified cases use values that are stored using a lesser precision. This results in variations of one count or more in the least significant digit, which add up to dollars or tens of dollars for costs of individual component areas. These differences cannot be eliminated without an extensive rewriting of the program modules, which was not planned for this task, so these differences will remain.

4.15 Supplementary Costs for Some Items Are Displayed as $0

4.15.1 Issue

The costing procedures used to calculate the appropriate values of direct labor and indirect costs will be checked to determine where the values are either using inappropriate terms or undefined terms, or are not updating cost components appropriately. The routines will also be checked to ensure that both original case studies and modified case studies are treated the same.

4.15.2 Resolution

To check for supplementary costs of items for new plants that were displayed as $0, 51 existing cost model outputs (created during previous phases of CHPECON development) and new cost model outputs were reviewed to check the system for proper current operation. Early cost model outputs demonstrated a few parameters that may not have been calculated properly, e.g., personnel water usage and costs. Modification of the files for checking intermediate values and rerunning the screening model files with the

current version demonstrated that the parameters were being properly calculated now. In one instance, major cooling tower maintenance was listed as $0 because no cooling tower was required. CHPECON was changed so that this item will not be printed if the cooling tower is not needed. A $0 cost for condensate storage tank was listed in another case because zero percent of the condensate was returned, resulting in a zero-gallon storage requirement.

Review of the retrofit costs for facilities showed that auxiliary costs for the boiler burner components were calculated to be $0. It was a direct result of the initial definition of the retrofit costs in the early stages of CHPECON's development (when it was called the *Coal Fired Boiler Evaluation Program*, or CFBEP). Retrofit costs for some components were cited as "package" costs, including all materials, labor, and related factors. The modifications to the program since that time has highlighted the "missing" related costs, which actually aren't missing. To make these costing routines compatible with the others, the modules were modified to reflect those portions of labor, materials, etc., that are part of the "package" cost, and change the capital cost of the components as necessary.

4.16 Source of Natural Gas Composition Displayed on Printout

4.16.1 Issue

An added source of the gas composition will be listed on the screening model report. As noted, it will consist of either a reference that the default values were used, that a specific gas composition from a known source was used, or that the user had entered values, either by modifying a prestored set of numbers or by entering new values.

4.16.2 Resolution

The data specification has been modified to include the identification of the source of natural gas from the list of entries offered to the user. In addition, the user specification routine, which permits using the default natural gas composition as a starting point for an alternate composition, tracks whether the value has been changed from the default and modifies the entry to indicate "- user specified -".

4.17 Apparent Discrepancies Between Micronized Coal and Pulverized Coal Equipment Costs

4.17.1 Issue

The original equations used to calculate appropriate costs for ash handling, coal handling, baghouse, induced draft fan, and dry scrubber will be checked to ensure correctness from the USACERL-accepted version. In addition, checks between components for the same size facility and the same number of boilers will be made. The differences between the two technologies that can result in different costs due to the type of equipment required will be documented.

4.17.2 Resolution

Multiple runs were generated to identify the costs between the two sets of components on an equivalent basis. Coal acceptable to both facilities was selected to ensure that an identical input fuel was used. Equivalent number and sizes of boilers were input, as was the same set of monthly boiler loads to generate the same PMCR. Using these factors, and including the changes made due to other issues, the calculated costs produced by the cost model were almost identical. The parameters used to define the operation of a particular boiler type (e.g., exit temperature, amount of unburned carbon in the ash, amount of air leak after the last heat trap) produce different results for ash collected and gas flow out of the stack, even when using the same facility input parameters. The different amounts of gas flowing from the boiler directly affect the cost of the downstream components, because the capital costs are based on the gas flow. These differences account for the variation between otherwise identical pulverized and micronized coal facilities (after including the changes noted in other sections).

4.18 Facility Installation Cost Differs for Retrofitted Micronized Coal vs. New Plant Pulverized Coal

4.18.1 Issue

The costs will be checked to ensure correctness. The differences due to the types of equipment and installation will be documented. The assumptions underlying the basic retrofit analysis for micronized coal will be reviewed for validity for the types of installation defined.

4.18.2 Resolution

The installation costs for the retrofit cases were calculated using adjusted parameters in equations of the same format as the new facility cases. In some instances, the combination of adjustments resulted in some parts of the installation costs that were below the target values. As a result, some of the component factors have been adjusted to reflect the likely higher cost involved in installing the equipment.

Specifically, components that are installed in open areas, without major adjustment to the structure of the boiler or the building (e.g., water treatment) use the same installation costs as for new equipment. In some instances, the installation costs for a category grouping are different, due primarily to the fact that only some of the components were necessary for the retrofit. For example, with the stack and piping category, the stack may need to be replaced, but the existing piping for the boiler can be retrained in a retrofit, resulting in a lower installation cost. For those components that would involve additional work to put into place (such as removing the old burner before placing the new burner), installation cost factors have been adjusted.

4.19 Electricity Consumption Differences in Cost Model

4.19.1 Issue

The basic calculations required to determine electricity consumption for pulverized and micronized coal utilization will be verified. The apparent discrepancies will be eliminated or documented.

4.19.2 Resolution

Detailed evaluation of the energy cost components in the pulverized coal and micronized coal models indicated that the micronized coal cost model included auxiliary facility costs only (e.g., lighting). Costs for electricity for the boiler equipment (including the micronizing equipment) and diesel fuel were not included. The original retrofit model only compared annual primary fuel costs to determine the potential savings for a retrofitted facility. This has now been added to the cost model.

4.20 Installation Costs on Retrofit Equipment Is at Times Less Than New Plant Installation

4.20.1 Issue

The type of costs involved with retrofitting depend on the types of existing facility structures. The underlying assumptions for the base case for retrofitting will be reviewed for suitability and documented. The addition of the sensitivity analysis to retrofit cases will allow the user to address the concerns noted in this comment.

4.20.2 Resolution

Comparisons of the same boiler technology (e.g., dump grate spreader stoker) using the same coalfield with the same monthly heating load inputs were made to determine differences between otherwise identical facilities. The installation costs for the retrofit cases had been calculated using adjusted parameters in equations of the same format as the new facility cases. It was determined that the combination of adjustments caused some installation costs to fall below expected levels. These factors have been adjusted to reflect the likely higher cost involved in installing the equipment.

4.21 Failure in Meeting Emission Requirements Not Noted in Life Cycle Costing

4.21.1 Issue

The currently available techniques will be reviewed and documented. If available, some provision will be made to incorporate emission treatment-related cost factors into the cost model. Independent of information available, a warning message will be included in life cycle cost reports for any screening case that failed emission regulations.

4.21.2 Resolution

The primary reason for not meeting emission requirements is the presence of higher levels of sulfur than permitted. As noted in USACERL's response to a second memorandum from NFESC,[*] sulfur emissions are categorized in two different ways: (1) by emitting no more than a specified amount based on fuel use ($lb/10^6$ Btu), and (2) by reducing the amount of emissions that were produced a minimum amount below

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[*] Memorandum from Steven Guzinski (NFESC) to Bill Taylor (NAVFAC); Subject: "Present Concerns with USACERL's CHPECON Program" (30 November 1993).

the potential emissions (required reduction of 90 percent). Both parameters must be met when running a facility. In the program, lime or limestone amounts were calculated based on meeting the 90 percent reduction requirement. Due to roundoff errors, the amount reported by the program and stored as a calculated result was numerically less than the amount prescribed by the required reduction. To address this numeric discrepancy, the appropriate program modules have been adjusted to ensure a reduction from the potential emissions of 90.05 percent.

One of the fluidized bed combustion technologies was specifically configured to work at 70 percent reduction; this has been changed so that it is also working at the 90 percent reduction level required.

4.22 Distribution System Explanation Unclear

4.22.1 Issue

The sections relating to the existing distribution system in the consolidation and retro-fit sections of CHPECON will be reviewed and evaluated. Those sections that are not readily understood by nonexperts will be reworded for clarify. In addition, any modifications necessary for the program's operation will be made to ensure CHPECON's usefulness.

4.22.2 Resolution

The questions concerning the steam distribution system and the ease with which the facility under consideration can be tied in were reworded for clarity.

4.23 Electrical Distribution System Question Unclear

4.23.1 Issue

The section pertaining to this question will be reworded and the program input modified to accept the reverse of the then current inputs, making adjustments to remain compatible with previously generated case files.

4.23.2 Resolution

The questions concerning the electrical distribution system and the ease with which the cogeneration system can be tied in were reworded for clarity.

4.24 Ability To Move Between Screens in Both Directions Desirable

4.24.1 Issue

The program will be reviewed to determine the feasibility of the requested change, and to the extent allowed within the program's modular construction, will be provided.

4.24.2 Resolution

The original program modules for CHPECON (and CFBEP previously) were written to run sequentially, building on prior entries to complete the analysis. Modules recently added to the overall program have been written so that additional flexibility exists in moving backwards through the order when the user wishes. This item focused on adding that to more routines. The cost model has been augmented so that the screens concerning the cost indices, basic cost factors, etc., can be reviewed as necessary by the user. An example of this is shown in Figure 21.

The screening model has been augmented so that the user can move to the previous and next screens concerning the general questions about the facility. This involved the new heating plant, cogeneration, consolidation, third party cogeneration, and retrofit question sets. Further modifications would need more extensive reorganization and rewriting of the program modules to permit more generalized movement between segments of the program, than was permitted by the time and funding constraints of the task.

4.25 Storage of Escalation Costs

4.25.1 Issue

A new option will be added in the general setup section of CHPECON that will allow the storage of various costs and escalation factors used repeatedly within the cost model. The user will be able to adjust those factors if desired when running the cost model.

4.25.2 Resolution

The proper operation and updating of escalation cost factors and costs was verified to address question 11 in the NFESC Memo (1991), the storage of escalation costs. However, checking for proper operation of this feature highlighted a potential problem: specifically, if escalation cost factors are older than the costs and factors stored for

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┌─────────────────────────────────────────────────────────────────────┐
│┌───────────────────────────────────────────────────────────────────┐│
││Central Heating Plant Economics Evaluation Program      file: RT01  ││
││Economic Analysis Input                          Retrofit plant (RT)││
│└───────────────────────────────────────────────────────────────────┘│
│                                                                       │
│    The Capital Equipment Escalation Factor can be calculated using ONE│
│    of two sources of information:                                     │
│    1.  Engineering News Record Magazine, 'Construction Cost Index.'   │
│    2.  Army Regulation Number 415-17.                                 │
│    Which one will be used for the analysis? 1                         │
│    Current Cost Construction Index for 1993: 4771.57                  │
│    Capital Equipment Escalation Factor for 1988-1993: 1.045           │
│                                                                       │
│    The Total Non-Labor Operating and Maintenance Escalation Factor can│
│    be calculated using ONE of two sources of information:             │
│    1.  Chemical Engineering Magazine., M & S Steam Power Index        │
│    2.  Army Regulation Number 415-17.                                 │
│    Which one will be used for the analysis? 1                         │
│    Current value of Steam Power Component of Marshall & Swift Equipment│
│    Cost Index for 1993:  947.10                                       │
│    Total Non-Labor O & M Escalation Factor for 1988-1993: 1.106       │
│                                                                       │
│                                                                       │
│    Change values / Previous screen / Next screen                      │
│                                                                       │
└─────────────────────────────────────────────────────────────────────┘
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Figure 21. Cost model screen showing options for reviewing previous screens.

energy consumption (from the EVAL??.DAT files from LCCID), the calculation of fuel costs for the appropriate period is impossible because no data is available. Addressing this conflict has been added to the list of items under the work plan.

4.26 Water in Ash Utilization

4.26.1 Issue

The proper operation of those sections pertaining to the amount of water contained in the ash to control its dispersion will be addressed. Proper operation and the ability to adjust values for each of the applicable technologies will be provided.

4.26.2 Resolution

The primary purpose for adding water to the ash collected from the boiler is to promote control of the ash. By wetting it, ash agglomerates rather than being blown about by air currents. The default fraction of water in the water-ash mixture was 10 percent in CHPECON. This change allows the user to select another default from 1 to 50 percent. It will then show up in the Cost Model Analysis as the amount suggested to

the user, which will also be the default value for any analyses that automatically perform some form of costing, such as the Multiple Boiler/Coalfield Option.

The newly entered value will show when the user has entered it. This is done by selecting option **7 — System Utilities**, then **7 — Set default values for cost model**. The values that can be set are displayed, allowing the user to modify them. Including in this is the fraction of water in the mixture to assist in controlling the ash.

4.27 No Comparison to Status Quo

4.27.1 Issue

The status quo option was a separately proposed task not taken up by USACERL. However, the existing documents will be reviewed to determine whether a simplified version of the option can be provided for comparison to the consolidation option output within the time and funding limitations of this task.

4.27.2 Resolution

The status quo option was originally identified as a separately proposed task for CHPECON enhancement. The functions that need to be put into place are:

* new questions developed for status quo
* generation of new calculations for the existing facility
* definition of the data storage formats and integration into the existing routines
* generation of routines for printing
* integration of routines to permit "use existing case" option to and from each of the other model types and the status quo model
* generation of the calculations for costing the general operation of the facility.

Due to the complexity of the effort, the integration of the status quo model remains a separately defined task that could not be handled within this task.

4.28 Costs for Electricity Generation Summary

4.28.1 Issue

The reporting sections of the cost model will be updated to reflect the need to under- stand the electrical cost savings due to cogeneration.

4.28.2 Resolution

The program calculates the cost of the electricity that would have to be purchased if it were not supplied by the cogeneration facility. This "cost" is calculated for each year of the facility's operation and is taken as a credit against the costs for operating the facility. These are summarized at the end of the cost report where the present value of the credit is listed, with the other present values of the annual expenses. The credit for the generated electricity is taken into account when the life cycle cost for the steam produced is considered.

4.29 Incremental Costs for Electricity

4.29.1 Issue

The cost model will be adjusted to allow for user input of incremental costs of electricity, e.g., demand charges and power factor charges.

4.29.2 Resolution

The incremental costs that can occur fall into two categories: (1) a factor based on the electrical demand of the facility, which can be demand charges or other items such as power factor charges, and (2) a fixed rate monthly charge, which could cover almost any additional recurring expense for a service that the utility is providing, such as maintaining interconnection facilities.

To permit CHPECON to include these factors, the cost model requests entry of these charges, along with cost indices and other costs. These costs are then used in the life-cycle costing routines of CHPECON. (Note: similar functionality was requested in Issue 3.4, and the two changes combined reflect the composite result in the program.)

4.30 Flyash Reinjection

4.30.1 Issue

The CHPECON sections pertaining to the calculation of performance for boilers using flyash reinjection will be modified to recognize the benefit of higher carbon combustion through the reinjection process.

4.30.2 Resolution

The parameters used to calculate the efficiency of the boiler and determine the fuel utilization for the facility have been modified to reflect the fact that the reinjection process leaves a lower level of unburned carbon in the stack. This occurs because the flyash is collected and reinjected to have more of the carbon burned. These changes cause a different coal consumption rate to be calculated where appropriate, reflecting the improved efficiency.

4.31 Natural Gas Compositions Should Be Expanded

4.31.1 Issue

The allowable options for natural gas selection will be added for a broader range of sources.

4.31.2 Resolution

A new set of program modules was developed to allow the addition and modification of entries in the natural gas composition database.

4.32 Cogeneration and Consolidation Retrofit

4.32.1 Issue

Possible methods for incorporating these features will be evaluated. If possible within the bounds of the project funding and duration, this will be added. However, if necessary, a separate task will be proposed to produce the desired CHPECON option.

4.32.2 Resolution

The primary question about the issue of retrofitting central heating plant equipment for cogeneration operation is whether this is feasible. A central heating plant of the type analyzed in CHPECON operates at a pressure of 150 psi. A higher pressure is not needed for heating purposes. A cogeneration system of the type analyzed in CHPECON operates at a pressure of 600 psi. The higher pressure is required to drive the turbine generators at an acceptable efficiency. A retrofit of an existing facility that had been

used for heating would require extensive work to replace all the steam lines to handle the extra 450 psi pressure, including the related components such as pumps, valves, etc. Also, the components that cannot take the exposure to the higher temperatures required by the higher pressure steam need to be replaced, involving the firebox components of the boiler, the ash handling equipment, and much of the exhaust gas train. After a review of the possible options, it was decided that a cogeneration retrofit is not feasible.

The consolidation model in CHPECON involves the placement of a central heating plant within a group of buildings formerly served by individual heating equipment. It is highly unlikely that an existing facility not already be used for this function would be sized to serve a number of buildings. For these reasons, it was decided that a consolidation retrofit was also not feasible.

4.33 Rail Car Thawing Question Automatic Prompt

4.33.1 Issue

Various methods for determining the potential need for rail car thawing equipment will be reviewed, and the preferred method embodied into the program, with the ability to override by user input.

4.33.2 Resolution

The average monthly temperatures for the base selected are used to determine whether a rail car thawing or warming shed is desirable. A thawing shed is considered desirable if the lowest average monthly temperature is 32°F or below; a warming shed is considered desirable if the lowest average monthly temperature is 36°F or below. If it is, the program automatically selects that as the preferred option. The program also displays to the user the lowest average monthly temperature used to consider whether the shed is needed.

4.34 Facility Average Electrical Load Question

4.34.1 Issue

The wording of the question addressing the average electrical loading will be modified to fit the requested line.

4.34.2 Resolution

The prompt for the "facility's electric load" has been changed to read "facility's average electric load" in both the main question routine and the review routines for cogeneration.

4.35 Peak Steam Generation Calculation

4.35.1 Issue

The calculations involved with determining peak steam from average monthly values will be checked to determine whether there are any problems in the procedure. Differences noted will be documented, and the program will be modified as necessary

4.35.2 Resolution

The calculation procedures (located in PMCRCALC.PRG) were checked to verify proper performance. It was noted that changes made to the calculations to properly handle the difference between entries in Btu/hr and entries in lb steam/hr were causing the effect. PMCRCALC has been modified so that it properly tracks the type of entry (lb steam/hr or Btu/hr). Another problem is that the type of calculation originally defined works for average monthly temperatures at or above 0°F. Appropriate traps have been put into place to work when monthly temperatures below 0°F occur. In addition, the set of conditions involving the heating design temperature in the coldest month could result in a PMCR for that individual month that is smaller than the steam flow entered for that month. This has also been corrected.

5 Summary and Recommendations

This report has documented the enhancements to a microcomputer program developed for central heating plant economic evaluation (CHPECON). The screening and costing models have been enhanced for facilities considered retrofit boiler technologies. The evaluation method presented provides a consistent approach in evaluating competing combustion technologies with various types of fuel, and the enhancements have extended capabilities for analyzing new plant facilities to those for retrofit. Detailed conceptual facility design, costs, as well as economic measures of project acceptability, including total life cycle costs and levelized costs, are provided.

Sufficient flexibility was allowed in the program to determine sensitivities related to changes in boiler load, fuel price, escalation factors, discount rate, O&M costs, plant life, etc. Due to the volatile nature of fuel pricing and the changes in technology and market place, frequent updating of the cost algorithms appears to be warranted. Additional recommendations follow:

1. Incorporation of *The Central Heating Plant Status Quo Program* into CHPECON would be beneficial. This would provide a baseline for comparing the life cycle costs of alternatives such as retrofit, modernization, and construction of a new plant.

2. Improvement of screening and scoring processes for boiler facilities considered for retrofit is needed. Detailed cost components for the retrofit option and expanded analysis including the possibility of using existing equipment and an estimate of the condition of the existing equipment are required to obtain a more realistic cost estimate.

3. Improvement of the program related to environmental issues such as ash disposal and storage is needed. Expansion of the air pollution control section to meet new Clean Air Act requirements for all fuel sources is also desired. This could have significant effect on the life cycle costs especially for gas/oil-fired boilers that may require NO_x/SO_x control devices.

4. Expansion of the cogeneration analysis program to include an engine-based system, combined cycle gas turbine-based system, and fuel cell is recommended. This will ensure that higher efficiency technologies are not overlooked.

5. Studies of alternative power sources such as biomass, wind, solar, and geothermal are suggested so that the most cost effective fuel can be chosen.

6. Expansion of the cost models to include heating plants less than 50 MBtu/hr, satellite plants, and standalone systems is recommended to cover the majority of the Army plants.

7. Development of models to track the thermal and electric energy requirements for end users, and to develop reliable estimates of maximum, minimum, and average loads are needed. The models may be used in sizing satellite and central energy plants.

8. Development of models for sizing and costing nonelectric chiller systems to include thermal energy storage technologies is recommended. A cooling system is a major energy user and should be considered in overall plant economics.

CHPECON is a very powerful tool for long range utility planning. The enhancements to the program made in this study will make the program more generally useful.

References

Code of Federal Regulations (CFR), Title 10, Part 436, "Guidelines Applicable to Federal Agency In-House Energy Management Programs," subpart A, "Life Cycle Cost Methods and Procedures."

Energy Prices and Discount Factors for Life Cycle Cost Analysis: Annual Supplement to NBS (National Bureau of Standards) Handbook 135 and NBS Special Publication 709, NTIS IR 85-3273-5 (U.S. Department of Commerce, National Technical Information Service [NTIS], Alexandria, VA, published annually).

Lin, Mike C.L., Ralph Moshage, Gary Schanche, Christopher Blazek. Richard Biederman, John Kinast, Janet Gutraj, Dale Conley, and Charles Schmidt, *Central Heating Plant Economic Evaluation Program, Volume 1: Technical Reference*, Technical Report (TR) FE-95/08/ADA293522; *Central Heating Plant Economic Evaluation Program, Volume 2: User's Manual*, TR FE-95/08/ADA293292 (U.S. Army Construction Engineering Research Laboratories [USACERL], January 1995).

Rugg, R.T., *Life Cycle Cost Manual for the Federal Energy Management Program*, NBS Handbook 135 (National Bureau of Standards, December 1980), pp 16, 44.

Stultz, S.C., and J.B. Kitto, *Steam: Its Generation and Use* (The Babcock and Wilcox Company, Barberton, OH, 1992), pp 32-35.

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