Repowering Existing Fossil Steam Plants

Ву

William C. Stenzel, P. E. — <u>SEPRIL</u> Dale M. Sopocy, P. E. — <u>SEPRIL</u> Stanley E. Pace — <u>SEPRIL</u>

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ABSTRACT

Increased competition among power generating companies, changes in generating system load requirements, lower allowable plant emissions, and changes in fuel availability and cost accentuate the need to closely assess the economics and performance of older electric generating units. Generally, decisions must be made as to whether these units should be retired and replaced with new generation capacity, whether capacity should be purchased from other generation companies, or if these existing units should be repowered.

These decisions usually require the evaluation of many factors including; environmental discharge limits, permitting requirements, generating load demand increases, fuel cost increases, transmission requirements access and options to improve existing facilities (e.g., increasing efficiency and output), . Many of these factors need to be evaluated over a range rather than one specific value to test for sensitivity of the selection to future uncertainties. The analysis is usually complicated due to the interaction of all the factors involved. Computer products that integrate performance and financial analysis can provide substantial value by enabling the user to evaluate the applicable plant options and a range of inputs. The SOAPP[®] (State-of-the-Art Power Plant) family of software products provides easy to use tools for rapid, thorough and economical evaluation of plant options.

Repowering evaluation methodology typically used in the United States, technology options, and the SOAPP repowering software now available to facilitate evaluations are reviewed in this paper.

INTRODUCTION

Repowering is an important alternative for achieving generating plant and system improvements including some or all of the following possibilities:

- reduction of overall system fuel usage and/or costs
- reduction of O&M costs
- reduction of emissions and other discharges
- least cost option for increasing generation capacity
- minimization of capital cost expenditures

Evaluations for repowering projects must encompass a wide range of business aspects, load growth forecasts, financial parameters, environmental regulations, fuel cost ranges, legal issues and other factors to capture the important benefits of these types of projects. The evaluation is further complicated by the changing regulations for utilities affecting the level of competition in the power generation market.

REPOWERING EVALUATON METHODOLOGY

A repowering analysis usually follows steps similar to those summarized below:

• Determine the generation system goals; e.g., the amount and value of the needed additional power, emission reductions, fuel availability and costs, transmission requirements and/or limitations, forecasted generation load schedules, target electricity market price and/or other requirements and goals.



- Determine the existing plants that can be repowered to meet the generation goals by identifying the important site restrictions (i.e., emission limits), condition of the existing equipment, and other important information.
- Identify candidate repowering technologies (Combined Cycle, Hot Windbox, Combustion Turbine with Supplemental Boiler, Combustion Turbine with Feedwater Heating, Generator, GCC, CFBC, PFBC) and perform an initial analysis to reduce the repowering options to the most competitive technologies.
- Development the design, operation parameters, capital costs, schedules and economics for applicable repowered plants and optional new plants.
- Select the best option(s) based on economics and other factors.

Starting with a determination of the generation and business goals is the important first step, which leads to the identification of the most competitive repowering opportunities. Often, there is a tendency to begin repowering studies with evaluations of older units because of higher operating costs and approaching retirement. However, this can lead to over looking the best options that can be achieved with repowering newer larger capacity units. For example, retiring the older units and providing a larger increase in new generation with the newer unit(s) can yield maximum return on investment.

BUSINESS GOALS

In addressing the business issues, there are two important relationships to establish early in the evaluation process. These relationships are unique for each generation system or power pool into which a unit will be dispatched. One of these relationships is frequently referred to as the "lambda curve," which represents the short-term marginal cost (usually calculated on an hourly basis) versus percent of total available hours of generation. The lambda value is the incremental variable cost of power generation for the next added increment of system power increase, either from a unit already on-line or from a unit to be started. It is typically calculated on an hourly basis and used to determine which competing generating unit of a regional generation system will be used to provide the next needed increment of power on the lowest variable cost basis. This will determine the equivalent percentage of time each year that a generation unit with its characteristic variable cost of generation can competitively be used based on the power needs of the system. However, the need for voltage and frequency control, and other power delivery system requirements will also affect the selection of which units to dispatch. These power delivery needs will often favor the dispatch of units near major loads, providing additional benefits from repowering older, load-center located units. Representative curves for four competing power generators are shown in Figure 1.

Figure 1: LAMDA Curves

The other relationship is cumulative generation versus production costs for all of the power generation units in a competing region or pool. A typical curve is shown in Figure 2. The horizontal line seg-

ments represent the cumulative annual electrical generation by all units at the cost indicated on the vertical scale.



Figure 2: Typical Regional Cumulative Generation versus Production Cost

The lambda curve can be used to estimate the annual hours of operation expected for a unit depending on the dispatch price. Figure 2 is used to understand how the repowered unit will interact with the other units in the region or power pool. This relationship is important because if the end result of repowering is to simply displace one of the owner's existing units, little is gained. However, if the repowering displaces a competitor's unit or the subtraction of the displaced unit is more than compensated for by the generating cost improvement from the repowered unit, it may be a strategy that warrants the investment.

REPOWERING OPTIONS

The major combustion turbine-based repowering options currently being evaluated are:

- Site repowering (CT/HRSG/ST)
- Boiler replacement with a combined-cycle unit (CT/HRSG)
- Hot windbox repowering (HWBR)
- Feedwater heater repowering (FWHR)

Solid fuel repowering options being evaluated are:

- Boiler replacement/modification for atmospheric fluidized bed combustion (AFBCR)
- Boiler replacement and addition of combustion turbine for pressurized fluidized bed combustion (PFBCR)
- Boiler replacement and addition of gasification combined cycle (GCCR)

COMBUSTION TURBINE BASED REPOWERING OPTIONS

Site Repowering

Site repowering involves demolishing the existing unit, except for possibly the cooling water system and switchyard, and constructing a new combined-cycle or other type of plant. Sometimes called a "brown field" unit, site repowering has the advantage of being able to utilize the best available combined-cycle technology without having to make compromises to match the older, existing components or systems. When compared to constructing a new unit on a new site there can be savings in the permitting process, transmission access, and socioeconomic considerations for the local area that can make this the preferred option for new investment in generating assets. The plant performance would usually be identical to a new "greenfield" unit. The capital cost savings, excluding the value of the land and depending on the extent of reuse of existing facilities, per net total kW of generation is usually in the range of \$106-\$300 (USD).

Combined Cycle Repowering

The most common type of repowering being implemented in the U.S. is combined cycle (CC) repowering, where the existing boiler is replaced by a combustion turbine and a heat recovery steam generator. Shown schematically in Figure 3, this approach increases the unit's net generating capacity by about 150-200%, reduces the heat rate by up to 30-40% and reduces NO_X emissions. Due to the relatively large capacity increase, this approach is normally considered for older units less than 250 MW with steam pressures up to 12.4 Mpa (1800 psi).



Figure 3: Combustion Turbine - Heat Recovery Steam Generator (Combined Cycle) Repowering

The issues, which must be addressed in CC repowering, include optimizing the existing steam turbine performance with the new combined-cycle components or installing a new steam turbine. Optimizing

the existing steam turbine includes deciding whether to retain the existing feedwater heaters and how to maximize steam turbine output. Optimizing the older plant performance is important for the repowered unit to be able to compete with a new unit, even if it has lower capital costs. New steam turbines, main transformers and other equipment add to the capital cost, but may be justified by gains in output, efficiency or to provide reliable operation. The capital cost per net total kW of generation is usually within the range of \$450-\$750 (USD).

Hot Windbox Repowering

Hot windbox repowering (HWBR) consists of installing one or more combustion turbines exhausting into the windbox of an existing boiler (Figure 4). HWBR technologies can add from 0-25% additional capacity to the unit, improve the efficiency by 10-20%, improve part load efficiency and cycling capability, and reduce NO_X emissions. HWBR appears to be competitive for larger, newer oil/gas-fired units. The efficiency improvement and increased output are usually the main benefits.

HWBR has the highest degree of technical complexity of all the combustion-turbine-based repowering options. The combustion turbine exhausts into the windbox or the primary air ducts in place of a portion of the airflow from the original fans. The air heaters may need to be modified based on the revised air and gas flows, and the ductwork must be upgraded to accommodate the higher temperature and larger volume of air. The furnace burners must be modified or replaced because of the lower oxygen content of the flow from the combustion turbine exhaust. Furthermore, the lower oxygen content of the convective parts of the furnace may be necessary. Other necessary modifications can include bypass ducts for admitting variable amounts of combustion turbine exhaust directly to the back end economizer section, a steam air heater to allow independent operation of the existing boiler when the combustion turbine is not available, an induced draft fan to reduce the back pressure on the combustion turbine, and a combustion turbine bypass stack for unit startup.



Figure 4: Hot Windbox Repowering

If the varying portion of the load is provided by the steam turbine generator, the unit can operate down to approximately 50% load with little change in efficiency (Figure 5).



A variant to the HWBR approach includes a HRSG to reduce the temperature of the combustion turbine exhaust and produce additional steam. With this approach the existing windbox can be retained but will need to be enlarged, or the boiler will not produce the full steam output. This repowering configuration is commonly known as warm-windbox repowering and is used primarily to achieve heat rate reductions.

The combustion turbine contributes a relatively small amount of the total power to the HWBR configuration. Therefore, the final efficiency of a HWBR unit will be dominated by the efficiency of the larger steam cycle. For this reason, the more efficient existing units will be preferred candidates for HWBR.

Cost estimates based on studies in the U.S. show a range of \$150-250/kW based on net total repowered unit capacity. These estimates are comparable to results of actual installations in the Netherlands, where most of the recent HWBR experience has been recorded.

Feedwater Heater Repowering

In feedwater heater repowering (FWHR), the combustion turbine exhaust gas is used heat feedwater in an existing Rankine-cycle power plant. The steam normally used for feedwater heating provides more power from the steam turbine-generator, if its design limits are not exceeded, or for power augmentation for the combustion turbine. Existing feedwater heaters can be retained to allow conventional operation when the combustion turbine is out of service. A typical FWHR cycle is illustrated in Figure 6.



Figure 6: Feedwater Heater Repowering

FWHR should be considered when additional peaking capacity is needed. The existing fossil steam unit alone can be used for base or intermediate load service and the combustion turbine can be started

up to produce up to a 6% improvement in efficiency for the overall FWHR fossil steam unit at peak loads periods. Furthermore, the incremental fuel efficiency of the on-line combustion turbine can range up to about 50%.

The capital cost for FWHR, based on the total net capacity of the repowered unit, ranges from \$90-110/kW for smaller fossil steam units to \$75-80/kW for larger units.

The development of the intercooled aeroderivative (ICAD) gas turbine will offer additional opportunities for FWHR repowering. With high simple cycle efficiencies in the range of 42-44%, and relatively low exhaust temperatures of 800-875°F, the ICAD appears to be ideally suited for FWHR, where the gas turbine can be dispatched for intermediate load applications. The incremental efficiency of ICAD in combined-cycle operation approaches 60%. This cycle configuration is being evaluated for new plants as well as repowering. For example, an advanced supercritical coal-fired fossil steam plant with efficiencies of 42-46% could be expected to operate with efficiencies of 45-49% in a feedwater heating hybrid cycle using an ICAD gas turbine.

Supplemental Boiler Repowering

Supplemental boiler repowering (SBLR) is similar to feedwater heating repowering except that the combustion turbine exhausts to a HRSG which provides steam to the steam turbine instead of providing feedwater to the turbine/boiler cycle. The economics of this cycle depend greatly on the ability to use the additional steam efficiently in the turbine generator or the need to recover lost generation based on boiler limitations.



Figure 7: Supplemental Boiler Repowering

SOLID FUEL BASED REPOWERING OPTIONS

Low cost opportunity fuels can present situations where repowering with solid fuel based technologies offers the most advantageous situation. Solid fuel repowering options can provide increased fuel flexibility, which can be of strategic importance when the price and availability of fuel sources is uncertain. In general, solid fuel repowering options require a larger capital investment. Therefore, the repowered unit will need a high capacity factor to provide the basis to recover the investment.

AFBC Repowering

In atmospheric fluidized bed combustion (AFBC) repowering all or major portions of the existing boiler are replaced by a fluidized bed combustion process (Figure 8). The steam conditions of the new boiler are either designed to match the requirements of the existing steam turbine or the higher pressure and temperature requirements of a new steam turbine when economics show that the installation of a higher/pressure temperature, more efficient, cycle is more economical.



Figure 8: Atmospheric Fluidized Bed Combustion Repowering

This type of boiler provides advantages including the following; the capability to burn a wide range of fuels, lower combustion temperatures to minimize NO_X formation and the option for bed sorbent reduction of SO_2 emissions.

Designs are available for units ranging from 10 to approximately 300 MW. Relative to combustion turbine based repowering, efficiencies are low, around 34% and capital costs are high at \$800-\$1,200/kW. However, fuel cost savings can justify these types of projects.

PFBC Repowering

An existing boiler can be replaced by a pressurized fluidized bed combustor (PFBC) to produce steam to drive the existing steam turbine-generator and generate hot gases that drive combustion turbines (Figure 9). PFBC designs are available for units ranging from 80-350 MW. Current operating experience is limited to 150MW. The combustor is maintained at a pressure of 8-16 atmospheres as the fuel contacts the burning fuel bed, which is either the bubbling or circulating type. The combustion turbine exhaust is utilized for final feedwater heating in an economizer The steam conditions of the new boiler are designed to match the requirements of the existing steam turbine. Advanced forms of PFBC include topping combustors, reheat steam turbines, and other forms of heat recovery that boost cycle efficiency.



Figure 9: Pressurized Fluidized Bed Combustion Repowering

Plants that have used PFBC technology have lowered plant heat rate by as much as 15% and increased plant output by as much as 20%. SO_2 and NO_X emissions from PFBC are low. Capital costs are estimated to be \$900-1,500/kW.

GCC Repowering

A gasification combined cycle (GCC) can be used to supply steam to an existing steam turbine in GCC repowering. A gasification system is integrated with combined cycle equipment (combustion turbine/heat recovery steam generator train(s)). High efficiency is obtained by exchanging condensate, feedwater, and steam between the gasification system and the heat recovery steam generator. Gasification converts a solid fuel to a gaseous fuel for the combustion turbine.

In GCC repowering, the plant's existing boiler is replaced by a gasifier, combustion turbine (CT) and heat recovery steam generator (HRSG) (Figure 10). The combustion turbine uses Syngas. Upon exiting the CT, the hot exhaust gases are delivered to the HRSG. Steam is also generated in a heat exchanger in the coal gasification process.



Figure 10: Gasification Combined Cycle Repowering

Most GCC systems are designed for repowering 50-100 MW steam turbine-generators and 150-250 MW of combustion turbine capacity. As in the case of CC repowering, capacity additions are relatively large compared to the size of the existing unit. However, due to the economics it is difficult to justify repowering units less than 250 MW. The addition of the gasification process results in relatively high capital costs, in the range of \$1,200-\$2,000/kW. The gasification process can be phased in after other combustion turbine repowering options are exercised. The gasification process can also be used to produce other products that have commercial value, accelerating the pay back of the initial capital investment. GCC can reduce the heat rate by up to 30-40%.

SOAPP REPOWERING SCREENING MODULE

The SOAPP Repowering Screening Module incorporates the methodology and types of plants discussed in the previous sections of this paper. This is a software tool that simplifies the preliminary repowering evaluation process. Screening in this Module provides the user with guidance as to the best repowering technology for a plant and preliminary performance and cost information. The contents of this module include:

- Chapter 1—Technology Descriptions
 - Basic Principles of Repowering Technologies
 - Repowering Technologies—Combined Cycle, Hot Windbox, Supplemental Boiler, Feedwater Heating, Generator, GCC, CFBC, PFBC
 - Special Topics
- Chapter 2—Technology Screening
 - > User Input
 - Existing Unit Characteristics
 - Repowering Goals and Repowered Unit Characteristics
 - Existing Equipment Reuse Plan
 - ➢ Screening
 - Design Basis
- Chapter 3—Technology Ranking
 - User Input
 - Performance Analysis
 - Economic Analysis
 - Economic Basis
 - Schedule Requirements
 - Scope of Supply
- Chapter 4—Operating Experience
 - > A list of repowering projects and the type of repowering technology
- Chapter 5—Bibliography
 - ➢ A list of EPRI Reports and other
- Chapter 6—Glossary
 - ➤ A list of key repowering terms

The SOAPP Repowering Screening Module produces a screening analysis and provides a preliminary assessment of the viability of repowering the specified unit and site. For example, the screening analysis may use available land to eliminate repowering for a given land-constrained site. The available area may otherwise set an approximate capacity limitation for a site, if the area can support combustion turbine capacity additions that are less than the maximum amount required for fully repowering the steam turbine(s).

The SOAPP Repowering Screening Module defines major constraints and provides preliminary performance (Figure 11) and cost (Figure 12) estimates, enabling the user to select the single or the most competitive power generation technologies for a rate for more detailed analysis.

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nuts	Performance Outputs Economic O	lutnuts					
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80	Variable Name	Units	Existing Unit	AFBC	CTCC	FW/H	
00	Steam Turbine Gross Output	k₩	400,000	400,000	221,987	455,144	
cc	Steam Turbine Gross Output Limit(Fatal Flaw)		N/A	pass	pass	fail	
	Total Combustion Turbine Gross Output	k₩	N/A	N/A	669,737	156,865	
٧H	Unit Gross Output	k₩	400,000	400,000	891,725	612,010	
	Unit Auxliary Power	k₩	32,000	40,139	17,834	37,195	
/B	Unit Net Plant Output	k₩	368,000	359,860	873,890	574,814	
	Electrical Transmission Capacity Limit(Fatal Flaw)		N/A	pass	pass	pass	
CC	Unit Net Plant Heat Rate	Btu/kWh	8,676	12,003	7,688	8,246	
	Boiler Fuel Flow Rate (per Boiler)	lb/h	290,000	196,172	N/A	281,757	
BC	Number of Feedwater Heaters Operating		6	6	N/A	0	
_	Number of Combustion Turbines Operating		N/A	N/A	3	1	
LR	Fuel Flow Rate (per Combustion Turbine)	lb/h	N/A	N/A	92,664	67,815	
	Fuel Flow Rate (per Duct Burner)	lb/h	N/A	N/A	0	N/A	
	Gasifier Fuel Flow Rate	lb/h	N/A	N/A	N/A	N/A	
	Total Unit Water Makeup Flow Rate	1000 gph	1	1	4	1	
	Water Availability (Fatal Flaw)		N/A	pass	pass	pass	
	Unit FGD Water Makeup Flow Rate	gpm	0	0	N/A	0	
	Unit FGD Sorbent Flow Rate	lb/h	0	186,492	N/A	0	
	Unit FGD Waste Flow Rate	lb/h	0	200,266	N/A	0	
	Total Unit Solid Waste Flow Rate	lb/h	31,813	243,241	N/A	30,908	
	Unit Dry Ammonia Flow Rate (per HRSG or Boiler)	lb/h	N/A	45	0	N/A	
	Sulfur Removal Flow Rate	lb/h	N/A	N/A	N/A	N/A	
	Net Increase Coal Storage Area	acres	N/A	0.0	N/A	0.0	
	Net Increase No. 2 Oil Tank Bern Area	actes	N / A	N / A	0.0	0.0	_

Figure 11: Comparison of Preliminary Performance Estimates

Sepowering Screening Module							
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😹 Analysis - [New]							
Inputs	Performance Outputs Eco	onomic Outpu	uts				
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108K	Variable Name	(Luite	AFRC	CTCC	Dial		
AFBC	New Equipment Cest	- Units	202 759 400	167 774 900	121.202.000		
стсс	New Equipment Cost	\$ \$	202,733,400	107,774,000	121,203,000		
	Total Process Capital	4	202 759 400	167 774 900	121 262 600		
	General Facilities	¢	13 179 360	10,774,000	7 882 135		
FWH	Engineering and Home Office Fees	\$	20 275 940	16,777,480	12 126 360		
LIMP	Project Contigency	¢	15 206 960	8 388 738	9 094 771		
HVVD	Process Contigency	\$	15,206,960	8 388 738	9 094 771		
IGCC	Total Plant Cost	\$	266 628 600	212 235 100	159 461 600		
1000	Total Plant Investment	\$	283 886 500	221 611 600	166 138 700		
PFBC	Prepaid Boyalties	\$	0	0	0		
	Preproduction Cost	\$	6 555 132	5 254 176	4 490 682		
SBLR	Inventory Capital	\$	11,637,330	1.061.175	797.308		
	Initial Catalyst and Chemicals Cost	\$	0	0	0		
	Total Capital Requirement	\$	302,078,900	227,927,000	171,426,700		
	Total Operating Labor Cost	\$	1,648,038	2,251,656	2,082,047		
	Total Maintenance Labor Cost	\$	2,377,477	1,541,990	3,039,144		
	Total Maintenance Material Cost	\$	5,170,669	2,340,751	6,319,265		
	Total Overhead Cost	\$	1,326,188	3,723,556	2,571,700		
	Fixed O&M Cost	\$	10,522,370	9,857,953	14,012,160		
	Total Consumable Cost	\$	25,374,580	3,295,066	897,652		
	Total Disposal Charges	\$	16,300,600	0	1,891,616		
	Total Other Variable O&M Cost	\$	1,132,767	11,031,130	4,182,612		
	Total Byproduct Credits	\$	0	0	0		
1	Variable 0&M Cost	\$	42,807,950	14,326,200	6,971,880	-	
	•					•	

Figure 12: Comparison of Preliminary Cost Estimates

SOAPP CC REPOWERING WORKSTATION

The SOAPP CC Repowering WorkStation provides the user with a personal computer software product to further evaluate the combustion turbine/heat recovery steam generator (HRSG) plant design repowering option and develop a conceptual design. The user enters the needed data in four groups; site, economic, unit, and fuel data. Changes made to any of the plant inputs will propagate throughout the drawings, cost estimates, and the remainder of the conceptual design documentation. Therefore, the user is able to quickly view the effects of varying selected parameters on the resulting plant design, performance, layout, and costs. Figure 13 illustrates the SOAPP CC Repowering WorkStation input/file/project organization.

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Created by: Creation Date Southern Company Services 10/08/95	Site Input Data SICS Sample Site Data 10/09/95 08:24 PM	
Project Components Project Component	Economic Input Data \$ SCS Sample Economic Data 10/08/95 02:50 PM	
	Fuel Input Data Edit SCS Sample Fuel Data 10/09/95 08:22 PM	

Figure 13: Setting Up a Project Design

The site data group consists of ambient conditions (temperatures, elevation, etc.), site conditions (i.e., cooling water definition), environmental criteria (emission limits), cost estimate parameters, and certain site-specific economic inputs. Figure 14 illustrates the site data variables. This same tabular format is used for the other three groups.

Figure 14: Site Data Input

The unit data group allows the user to define the combustion turbine and auxiliaries, heat recovery steam generator (HRSG) configuration, steam turbine configuration, cooling system selection, and balance of plant equipment. The user can select a combustion turbine model from a list of over 40 models,

sized from 20 to 220 MW. Based on the combustion turbine selected, a default configuration is available if desired; otherwise the user can configure each equipment item and select each design condition separately. The user input screen is similar to the Site Data Screen. A few examples of user plant design input are provided below:

Repowered Unit User Inputs

- HRSG design options
- heat rejection system design options
- boiler feed pump design options
- treated water storage design options
- CT design options
- auxiliary boiler design options
- new buildings/enclosure design options
- fuel oil system design options
- economic sensitivities

User input includes the steam conditions of the existing unit, the existing major equipment on the site, the performance characteristics of this equipment, and a qualitative description of the condition of the equipment. Additional inputs are included to describe available land area and approximate distances between existing equipment and other information. A few examples are provided below:

Plant Parameter User Input

- plant layout/dimensions between major equipment items
- fuel oil tank design parameters
- treated water storage tank design parameters
- closed cooling water system capacity
- steam turbine design parameters
- cooling tower design parameters
- fuel oil forwarding pump design parameters
- make-up water treatment system capacity
- waste water system capacity
- station/instrument air compressor design parameters
- condenser air removal equip design parameters

• circulating water pump design parameters

A user-defined equipment reuse plan is also included in the input, describing which existing items will be reused as-is, refurbished and reused, abandoned and replaced, or demolished and replaced (refer to Figure 15).

Reuse Plan User Inputs

The user has reuse options of Abandon or Remove as well as cost and expenditure date input for the existing plant equipment as shown by these examples:

- existing fuel oil forwarding pumps
- existing water treatment system
- existing waste water treatment
- existing steam turbine
- existing steam turbine electrical systems
- existing circulating water pumps
- existing fuel oil tanks

The fuel data group defines the available fuels and the fuel usage. Primary and secondary fuels are defined, along with a secondary fuel usage factor.

Edit Tools Window User He	lp	wening reforkatau			
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Ana	lysis Options: Calculation Sta	itus	* *		
Conceptual Design Setup Component E	dting Analysis				
Run Selected Analysis		E	auipment Reuse Plan		
1Design Inputs	SCS Sample Project				
All Design Inputs	Equipment Name	Reuse Option	Reuse Option Enacted		
.Heat Balance Results Combustion Turbine Performance Results	Cabling	N/A	N/A		
FB Pri. Fuel At Max. Ambient Temp.	Steam Turbine Bay Structures	N/A	N/A		
- Sec. Fuel At Max. Ambient Temp.	Boiler Bay Structures	Abandon	Abandon		
Pri. Fuel At Perf. Pt. Ambient Temp.	Boiler(s)	Abandon	Abandon		
Pi Evel & Min. Ambient Temp.	Asbestos Removal	N/A	N/A		
Sec. Fuel At Min. Ambient Temp.	Precipitators or Baghouses	Abandon	Abandon		
Steam Cycle Performance Results	FGD Equipment	Abandon	Abandon		
Pri. Fuel At Perf. Pt. Ambient Temp.	Exhaust Stacks/Chimneys	Abandon	Abandon		
"E Sec. Fuel At Perf. Pt. Ambient Temp. Design Lists / Summarian	ID Fans	Abandon	Abandon		
DE guinment List	FD Fans	Abandon	Abandon		
Equipment Reuse Plan	Coal Handling Structres/Equip	Abandon	Abandon		
Motor List	Examination Activities	N/A	N/A		
Performance Summary @ Perf. Pt. Temp	Salvage Value	N/A	N/A		
Design Drawings	Steam Turbine Auxiliaries	N/A	N/A		
E Heat Balance Diagram	Steam Turbine Total	Reuse	Reused Steam Turbine		
Steam System Flow Diagram	Steam Turbine Bypass	Reuse	Reused Steam Turbine Bypass		
El Steam System Piping Diagram	Steam Turbine Elec Sys	Reuse	Reused Steam Turbine Electrical Equip		
El Fuel System Piping Diagram	High Energy (Steam) Piping	N/A	N/A		
General Arrangement Drawing - Plan	Condenser	N/A	N/A		
General Arrangement Drawing - Elevation	Condenser Air Removal	Reuse	Reused SJAE's		
General Arrangement Drawing - Site	Circ. Water Pumps	Reuse	Reused Main Circ Water Pumps, No Helper Circ Water	Pumps	
Ej standard symbol set Schedule	Circ. Water Piping	N/A	N/A		
Project Summary	Heat Rejection System	Reuse	Reused Main Cooling Tower, No Helper Cooling Tower		
Combustion Turbine Detailed Schedule	Condensate Pumps	Reuse	Full Replacement of Condensate Pumps		
HRSG Detailed Schedule	Condensate Piping	N/A	N/A		
Lapital Lost Estimate PSummary of All Systems & Components	LP Feedwater Heaters	Abandon	Abandon		
En ordinandary of the organization of Components	Deaerator Storage Vessel	Abandon	Abandon		
-	Boiler Feed Pump/Drive	Abandon	Abandon		
	Boiler Feed Piping	Abandon	Abandon		
	HP Feedwater Heaters	Abandon	Abandon		
ample					

Figure 15: Equipment Reuse Plan

The economic data group contains the information required to perform the capital and operation and maintenance (O&M) cost estimates. These 33 inputs are broken down into the following groups; time frame (commercial operating date, book life, tax life, etc.), evaluation basis (current or constant dollar analysis), operating basis (capacity factor), escalation rates, unit value costs, tax/insurance rates, and capital structure (common and preferred equity, debt, and investment tax credit).

Validation. The SOAPP CC Repowering WorkStation performs extensive validation procedures. When errors or incompatibilities are identified, the user receives a general notification indicating which data set contains the error. The user can then scan through the section where the error has occurred (problem inputs are highlighted in red), select the offending input, and receive an explanation of the problem. This avoids sorting through long error lists.

Analysis Options. The SOAPP CC Repowering WorkStation organizes the user input into four groups: site requirements, economic parameters, unit designs, and fuel costs. After seeing the initial workstation results, the user often proceeds to create additional groups to optimize for the best economic results. This can be easily done by modifying the initial four components and trying different combinations with these new components. This feature provides the users with exceptional flexibility to run sensitivity analyses, as well as providing a mechanism to use global input groups (i.e., economic parameters). For example, a user could run the W/S using the company standard economic data and the characteristics of a controlled standard site, with a series of unit and fuel groups produced for sensitivity analyses.

When the appropriate input groups have been selected and validated, the workstation automatically performs the configuring, interfacing, calculations, and other operations to the provide the following:

- piping and flow diagrams
- electrical single line diagram
- heat balance diagram
- performance summary
- equipment list and sizing
- equipment reuse plan
- design criteria
- site plan information
- general arrangement drawings
- installation schedule
- capital cost estimate
- O&M cost estimate

The SOAPP CC Repowering WorkStation allows the user to compare calculated performance requirements for major equipment to the existing equipment performance characteristics input by the user. If required, the user can modify the reuse plan or modify the design requirements in order to achieve a viable repowered plant design.

A user-interface design feature called "multiple document interface," or MDI is provided which allows for the simultaneous display of multiple "windows" of information to simultaneously view different pieces of plant design information or to compare the results of two different units. This helps the user to optimize a unit process design for customized site and economic criteria.

Combustion Turbine Performance. Combustion turbine performance calculations produce accurate performance parameters and equipment sizes. The calculations for combustion turbine performance are based on vendor-specific performance curves. Over 40 combustion turbine models are included.

The software is designed to quickly add additional turbines to its database as new information becomes available. The SOAPP software has been designed to remain state-of-the-art by simply updating this database, usually annually. The user can change the combustion turbine performance to customize the basis for the calculations.

Steam Cycle Calculations. A calculational "engine" performs a heat and material balance water/steam and exhaust gas properties. This engine was derived from the CYCLE portion of EPRI's GATE/CYCLE program. The engine uses one of over 30 different mathematical models, depending on steam cycle, number of pressure levels, deaeration technology, and condensate heater type. The software determines the components needed, the connections required, and the calculational methods applicable. The engine passes temperatures, pressures, enthalpies, and flows from component to component, and iterates to converge on a preset tolerance

Equipment Sizing. The SOAPP CC Repowering WorkStation calculates balance of plant equipment sizes with logic and algorithms that replicate an engineer's work to define the scope and cost of the plant conceptual design. The equipment sizing algorithms depend on user input values and parameters calculated in the combustion turbine and steam cycle. Multiple sets of combustion turbine and steam cycle calculations are performed to accurately reflect the sizing criteria for all equipment items; at maximum and minimum ambient temperatures and with the primary and secondary fuels. The sizing calculations are based on typical engineering practices, not simple database look-up functions.

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- Fuel System Piping Diagram	HEAT RECOVERY STEAM GENERATOR DATA							
General Arrangement Drawing - Plan	HRSG Design							
- El General Arrangement Drawing - Elevation	Number of Heat Recovery Steam Generators (HRSGs)	1						
Le Standard Symbol Set	Number of Pressure Levels	2						
- CSchedule	ST Reheat Cycle	Non-Reheat						
F In Project Summary	High Pressure Drum Pinch Point Temp	15 F						
EIHBSG Detailed Schedule	High Pressure Steam Drum Approach Temp	20 F						
- Capital Cost Estimate	Low Pressure Drum Pinch Point Temp	15 F						
E Summary of All Systems & Components	Low Pressure Steam Drum Approach Temp	20 F						
	HRSG Exhaust Gas Stack Temp	316 F						
	HRSG Exhaust Gas Stack Volumetric Flow							
	HRSG Dimensions	HRSG Dimensions						
SCS Sample	HHSG Height							
Project								

Figure 16: Plant Equipment List Report

Cost Estimates and Schedule. The SOAPP CC Repowering WorkStation estimates capital and O&M costs by a set of algorithms which use previously calculated sizing criteria. Parameters such as motor horsepower, tank dimensions, and piping diameters feed the cost calculations. All cost items not specifically sized in the equipment sizing algorithms are estimated, based on global plant sizing criteria (i.e., total unit MW's). The capital costs and economic user inputs are used by both the O&M cost estimate and the revenue requirements estimate calculational routines. The major equipment sizing parameters are also factored into an installation schedule algorithm, which determines all major activity durations.

DESIGN DOCUMENTATION PRODUCTION

The SOAPP CC Repowering WorkStation can, at the user's request, automatically create CAD drawings based on both user inputs and calculated values. These drawings are created automatically by placing graphical elements required for the plant configuration into a drawing file in the correct location. Actual data, both user inputs and calculated parameters, are displayed in the appropriate locations on the diagrams, as well as standard user and drawing information. The types of drawings produced include flow diagrams, piping diagrams, water balance diagrams, site drawings, and general arrangement drawings. Because these drawings are in the standard DXF format, the user also has the option of viewing and manipulating them directly in CAD packages, such as AutoCAD. Figure 17 shows the 3D site drawing.



Figure 17: 3D Project Site and Plant General Arrangement Drawing

Reports and Lists. The SOAPP CC Repowering WorkStation produces several reports including a performance summary, design criteria, motor list, equipment list, project schedule, bulk materials list, capital cost estimate, O&M cost estimate, and a revenue requirements estimate. These reports are not database-stored text documents, but have an intelligent logic engine that decides what items need to be displayed on paper. The user also has the option to view these documents on the screen before printing. The WorkStation provides a complete, customized set of preliminary design documentation.

CONCLUSION

Repowering options need to be considered in response to competition, load growth, environmental regulations, fuel cost changes and other factors. Many of these factors need to be evaluated over a range of values rather than one specific value to test for sensitivity of the selection to future uncertainties. The analysis is usually complicated due to the interaction of all the factors involved. Computer products that integrate performance and financial analysis can provide substantial value by enabling the user to evaluate the applicable plant options and a range of inputs. The SOAPP (State-of-the-Art Power Plant) family of software products provides easy to use tools for rapid, thorough and economical evaluation of plant options. SOAPP is a registered trademark of EPRI, the Electric Power Research Institute.



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