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Economic Feasibility and Technical Considerations of Oil-to-Oil Conversions

by

D. F. Dunphy
Manager, Plant Improvement Engineering Department
RILEY POWER INC.
a Babcock Power Inc. company
(formerly Riley Stoker Corporation)

R. H. Sirois
Manager, Plant Improvement Business Development
RILEY POWER INC.
a Babcock Power Inc. company
(formerly Riley Stoker Corporation)

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ECONOMIC FEASIBILITY AND TECHNICAL CONSIDERATIONS OF OIL-TO-COAL CONVERSIONS

by
D. F. DUNPHY, Manager
Plant Improvement Engineering Department
and
R. H. SIROIS, Manager
Plant Improvement Business Development
RILEY STOKER CORPORATION
WORCESTER, MASSACHUSETTS

INTRODUCTION

American homes and factories need an ample and reliable source of electricity. Given the policy of increasing our use of domestic fuels, the current tight regulatory constraints and scarce capital, the utility industry today must use innovation to provide the needed supply of electric power.

A great number of alternatives are being investigated by utilities and their suppliers to convert from the use of foreign to domestic fuels. The specific objectives are:

1. To generate the required power safely and economically with acceptable risk.
2. To preserve capital and equipment.
3. To maintain the quality of our environment.

This paper discusses the design, economies and performance of the conversion of an oil-fired utility boiler to coal firing.

FUEL CONVERSION

A major factor to be considered in any program to convert fuel sources is the impact it has on foreign fuel supplies. The 1978 Power Plant Industrial Fuel Use Act dictates that new units must be designed for coal firing, and previously enacted (now rescinded) legislation stipulating that natural gas shall not be used as a boiler fuel after 1990. This, combined with the present trend to coal, signifies that any reasonable conversion program must consider coal as being the sole or primary fuel souce.

A 1980 survey of oil-fired utility boilers 50 MW and larger performed by the Mitre Corporation for DOE, identified 220 boilers with a total capacity of 30,165 MW as coal-designed and burning oil.

It also identified 245 boilers with a total capacity of 63,279 MW as oil-designed and presently firing oil. The survey indicates that 50% of the oil-designed units are 400 MW or larger and that 83% are less than 20 years old. Figures 1 and 1a, respectively, represent the size and age distribution of these units.

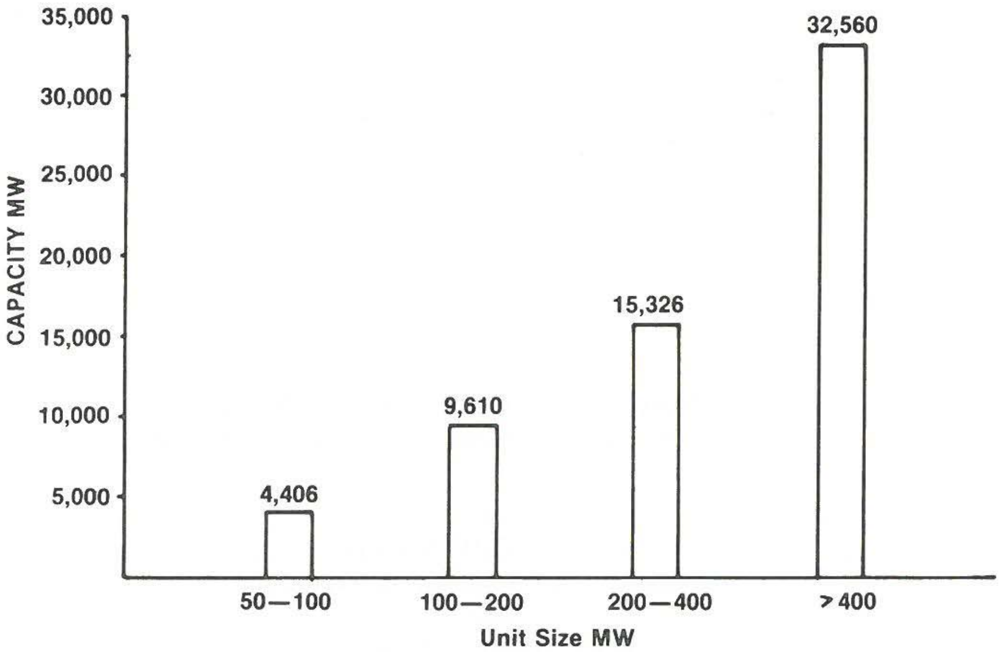

Figure 1   Size Distribution of Oil-Designed Units

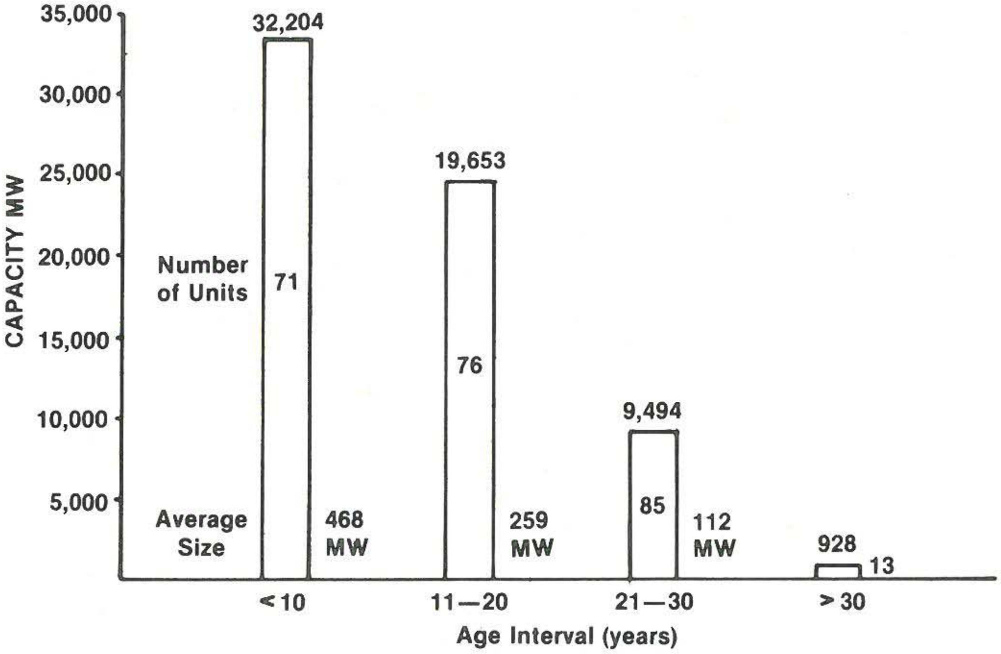

Figure 1a Age Distribution of Oil-Designed Units

This paper addresses the conversion study of an oil-designed utility boiler to coal firing. At the outset of this study, it was agreed, because of economic resrictions, that the dimensions of the furnace and convection pass width and depth would not be changed. The original design configuration is shown in Figure 2.

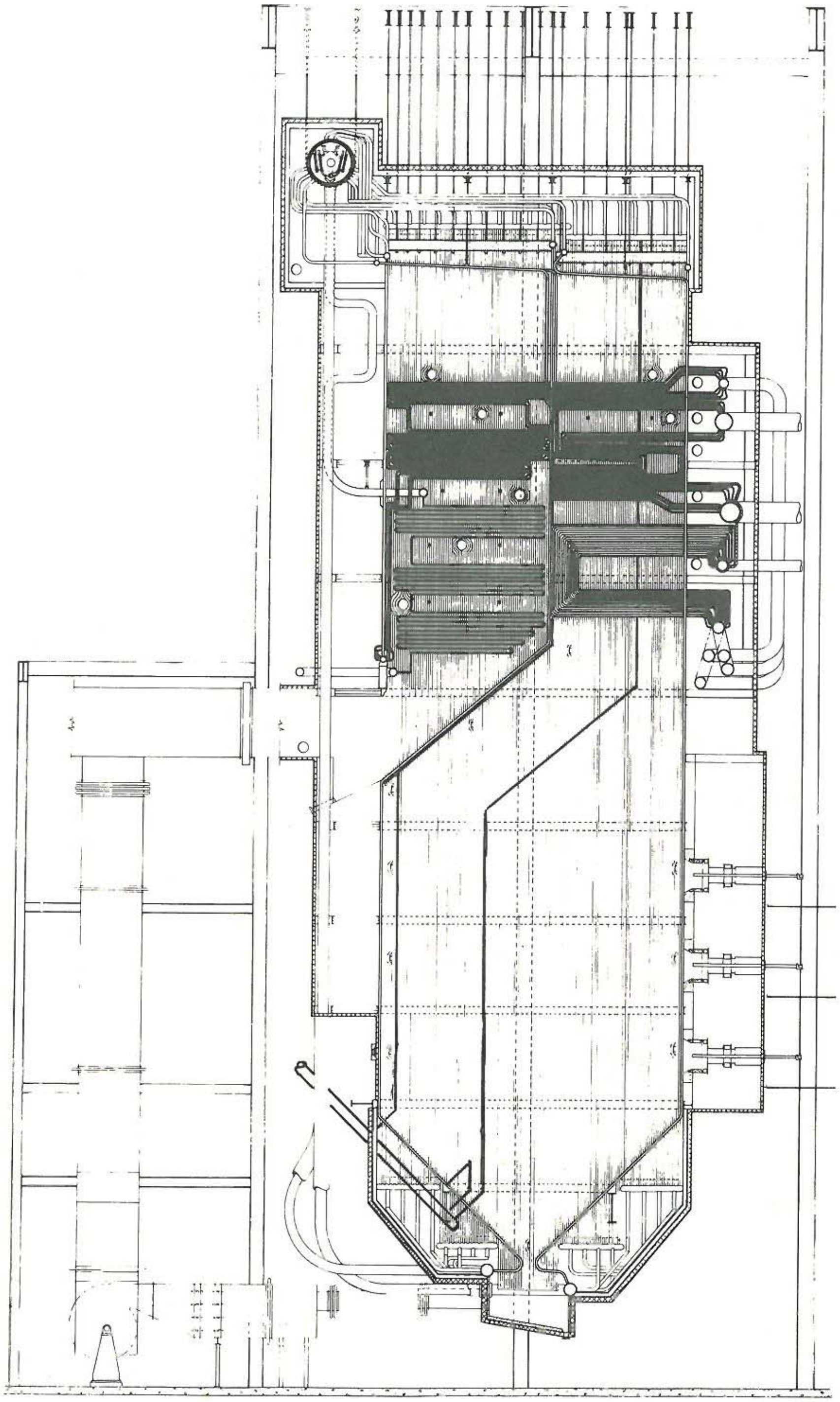

Figure 2 Unit #3, Dan E. Karn Plant, Consumers Power Company

The unit is Karn #3 at Consumers Power Company, and was designed and built by Riley Stoker Corporation. It is a front-fired unit and was designed to burn Canadian crude oil. No considerations were given to future coal. The maximum capacity of the unit is 2,100,000 kg/hr (4,650,000 lbs/hr) with an operational pressure of 898 kg/cm^2 (1980 psig). The superheat and reheat steam temperature is 513°C (955°F) and the feedwater temperature is 184°C (363°F). Thirty Riley #7 double register burners are mounted on the front waterwall in three rows of ten. A radiant high temperature superheater on 686 mm (27 in) centers is located above the furnace. The total reheater is located above the radiant superheater and is on 229 mm (9 in) centers.

A primary superheater is located in the convection pass, with a final leg passing across the furnace above the reheater and discharging into a header located in the front enclosure. The economizer is a spiral-weld type with three fins per inch. When the unit was purchased, high boiler efficiency was not a consideration; therefore, airheaters were not a part of the offering.

COAL SELECTION

To maximize coal-firing capability and reduce required retrofit work, the coal should be bituminous and within the range shown in Figure 3. The fuel that was used in this study is a low slagging and fouling coal with characteristics as shown in Figure 4.

High heating value	≥ 6389 kcal/kg (11,500 Btu/lb.)
Moisture content (as received)	≤ 10%
Volatile matter (as received)	≥ 26%
Volatile matter/fixed carbon	≤ 1
Sulfur (S)	≤ 1.3%
Hargrove grindability index	≥ 45
Ash (as received)	≤ 10%
Ash softening temperature H = W	≥ 1371°C (2500°F)
Slagging index (B/A x S)	≤ 0.6
Fouling index (B/A x Na_2O)	≤ 0.2
Chlorine	≤ 0.25%
Sodium oxide (Na_2O)	≤ 1.5%
Iron oxide (Fe_2O_3)	≤ 10%
Silica/alumina (SiO_2/Al_2O_3) ratio	≤ 2

Legend: B/A = base/acid ratio

Figure 3 Coal Selection Criteria

Proximate Analysis	**As Rec'd**	**Dry**	**Ultimate Analysis**	**As Rec'd**	**Dry**
Moisture	5.3%	——	Moisture	5.3 %	——
Volatile	34.8%	36.7%	Carbon	70.27%	74.2%
Ash	10.0%	10.6%	Hydrogen	4.75%	5.0%
Fixed Carbon	49.9%	52.7%	Nitrogen (calc)	1.43%	1.5%
	100.0%	100.0%	Oxygen (diff)	7.39%	7.8%
K Cal/Kg (Btu/lb)	6939.4 (12,491)	7327.8 (13,190)	Sulfur	0.86%	0.9%
Initial deformation	+ 2700 + 1482	2600°F 1467°C	Ash	10.00% 100.0 %	10.6% 100.0%
(H = W)		2630°F 1443°C			
Softening (H = ½W)		2680°F 1471°C			
Fluid		2700°F 1482°C	Grindability Index		47.0

	Percentage		**Percentage**
Silicon dioxide	56.09	Potassium Oxide	2.49
Aluminum Oxide	28.26	Manganese Dioxide	ND
Titanium dioxide	2.25	Phosphorus Pentoxide	0.43
Iron Oxide	6.23	Sulfur Trioxide	1.63
Calcium Oxide	0.67	B/A	0.12
Magnesium Oxide	0.58	Slagging Index (B/A x S)	0.10
Sodium Oxide	0.18	Fouling Index (B/A x Na_2O)	0.20
Silica/Alumina (SO_2/Al_2O_3)	1.98		

Figure 4 Coal Characterisitcs

DESIGN PARAMETERS

The principal furnace design parameters are:

- Radiant surface heat release
- Plan area heat release
- Volumetric heat release
- Furnace exit gas temperature

These four parameters play a major role in controlling slagging, fouling and erosive tendencies of coal. Figure 5 shows the range for furnace design parameters when firing low slagging coals.

Silica to alumina ratio is considered a good indicator of ash abrasiveness. This ratio shows whether silica is present in the form of highly abrasve quartz or less abrasive clay. If the ratio is greater than 2, quartz is most likely present and the ash is abrasive. Having found the ratio to be less than 2, we agreed that the maximum allowable flue gas velocity would be 1341 m/min (4400 ft/min).

Design Parameter	**Range**
Volumetric heat release	165,710 - 207,138 W/m^3 14,000 - 20,000 Btu/ft^3-hr
Radiant surface heat release	189,300 - 315,500 W/m^2 60,000 - 100,000 Btu/ft^2-hr
Plan area heat release	5.05 x 10^6 - 6.94 x 10^6 W/m^2 1.6 - 2.2 x 10^6 Btu/ft^2-hr
Furnace exit gas temperature	1093 - 1316 °C 2000 - 2400°F

Figure 5 Furnace Design Parameters

UNIT MODIFICATIONS

In order to maximize capacity and make the conversion economically feasible, major modifications and additions were required. These modifications and additions are listed below and are shown in Figure 6.

1. Modify the furnace hopper and lower headers and feeder tubes. The offset hopper design allows for a drag chain ash removal system and eliminates the need for excavation.
2. Modify the lower section of the downcomers to match the furnace hopper design.
3. Modify the lower furnace casing to match the furnace hopper design.
4. Replace the high tempertaure superheater and reheater with a pendant radiant superheater and reheater. The four furnace waterwall platens remain intact. This increases the effective radiant surface and allows a maximum generating capacity of 75% of the original MCR.
5. Increase the waterwall screen height to maintain flue gas velocities within specified range.
6. Replace the finned economizer with a bare tube economizer to decrease the possibility of ash fouling and erosion.

7. Replace the primary superheater with a new design which penetrates the convection roof and terminates in the penthouse.
8. Add crossover pipes (including the desuperheaters) connecting to the radiant superheater inlet header.
9. Add a new low temperature reheater in the convection pass behind the waterwall screen. Add crossover pipes with desuperheaters from the low temperature reheat outlet header to the radiant reheat inlet header.
10. Revise the cold reheat, hot reheat and main steam piping to meet the existing piping arrangement.
11. Add an ash hopper to the economizer breeching.
12. Replace the steam coil airheaters with three Ljungstrom airheaters. One will supply hot air to the primary air system.
13. Add three Glycol coils for cold-end protection of the three Ljungstrom airheaters.
14. Increase the capacity of the superheater steam temperature control system.
15. Add an additional steam temperature control system to the reheater.
16. Add two long retractable sootblowers and forty wall blowers.
17. Adjust the main structural support system to accept the relocated loads.
18. Replace all ducting (air and flue gas) to the rear of the boiler to suit the new arrangement.
19. Rotate the existing F.D. fan to suit the new arrangement.
20. Add the precipitators and I.D. fans. Scrubbers are not required.
21. Add the coal preparation equipment, starting from the bunker discharge, including:
    - Six gravimetric coal feeders
    - Six Riley #506 Crusher Dryers
    - Three double-ended Riley Ball Tube Mills
    - All coal piping
    - Six Riley Centrifugal Classifiers
    - All coal handling equipment from the coal pile to and including the bunkers
22. Add one primary air fan with complete ducting to the mills plus tempering air ducts.
23. Remove the existing gas recirculation system which discharges into the lower furnace hopper area. This system will not be used.
24. Add thirty #7 Riley Controlled Combustion Venturi (CCV) low NO_X burners in the existing burner openings.

NO_X

NO_X was identified as a major potential concern in converting oil-fired units to coal. It is also a major design consideration in new coal-fired generators. Additionally, anticipated New Source Performance Standards (NSPS) for coal are expected to become increasingly stringent, as indicated in Figure 7. Although the anticipated guidelines are not in force today, we are still working towards them. In addition, the EPA is expected to issue soon a ''bubble'' pollution control strategy. This would sanction higher-than-allowed emissions at some existing plants if they are balanced with lower-than-allowed emissions at other plants and may be key in formulating future generation strategies.

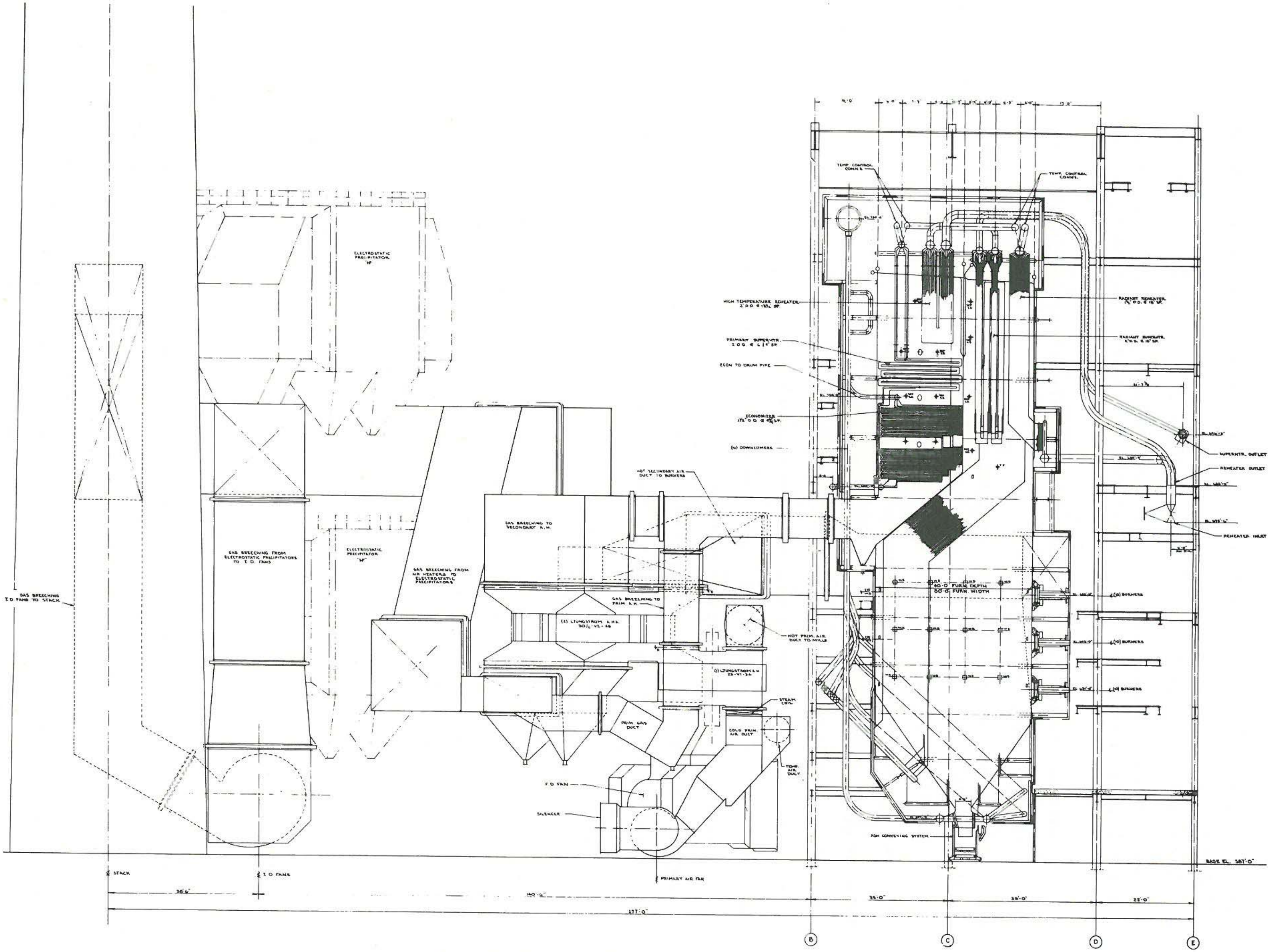

Figure 6   Proposed Modifications to Karn Plant

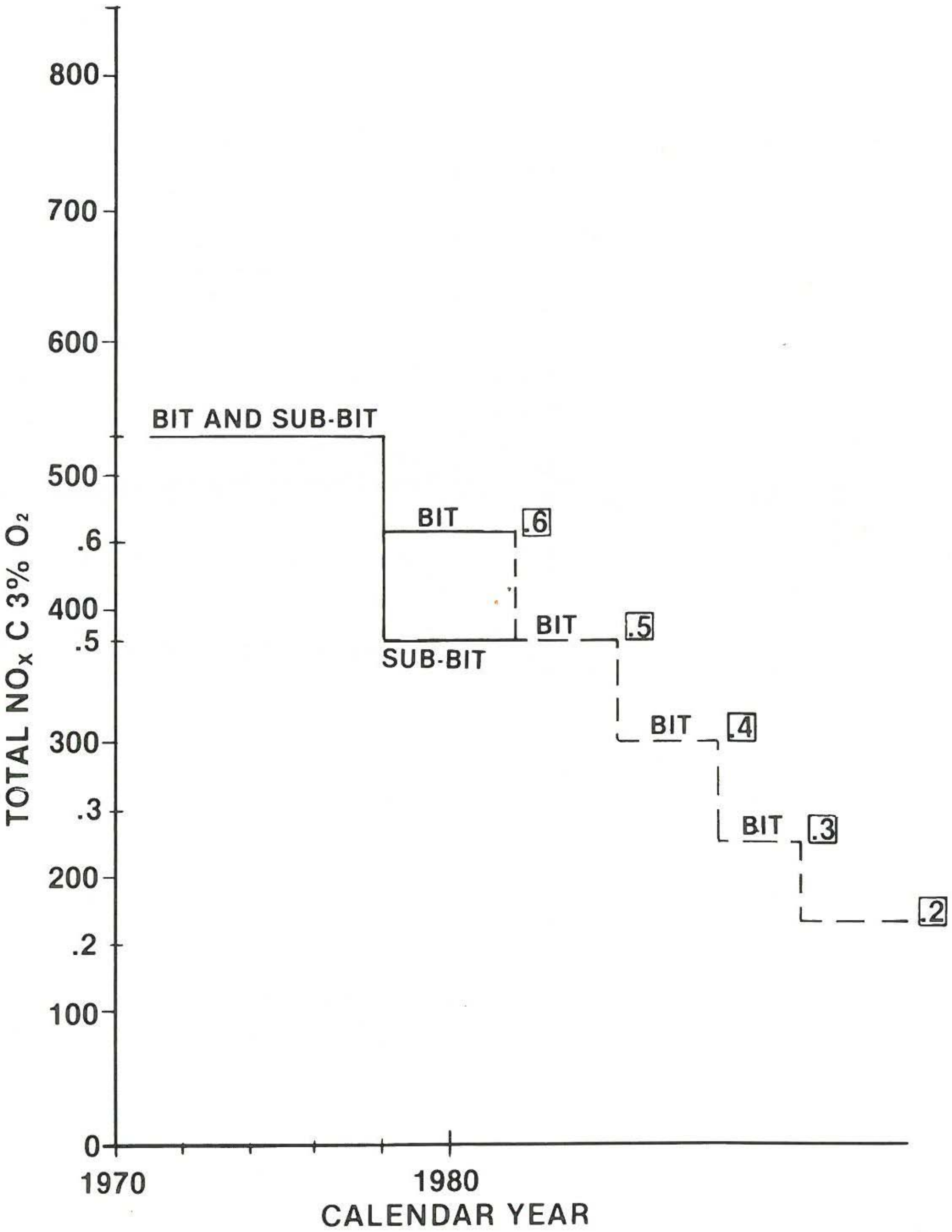

Figure 7 New Source Performance Standards

Riley Stoker has developed the coal-fired CCV burner capable of significantly reducing NO_X emissions, while maintaining unit operation, performance and efficiency. The concept responsible for producing a successful design is optimum air/fuel mixing to accurately control the combustion process and rate.

Performance data taken on a 400 MW front-fired pulverized coal unit and an opposed-fired 350 MW unit indicate NO_X reduction of 37% and 56%, respectively (Figure 8). These burners corrected the specific emission problems on these units. The simplicity of design makes these burners attractive as a retrofit to reduce NO_X emissions on a fuel conversion or boiler uprating project.

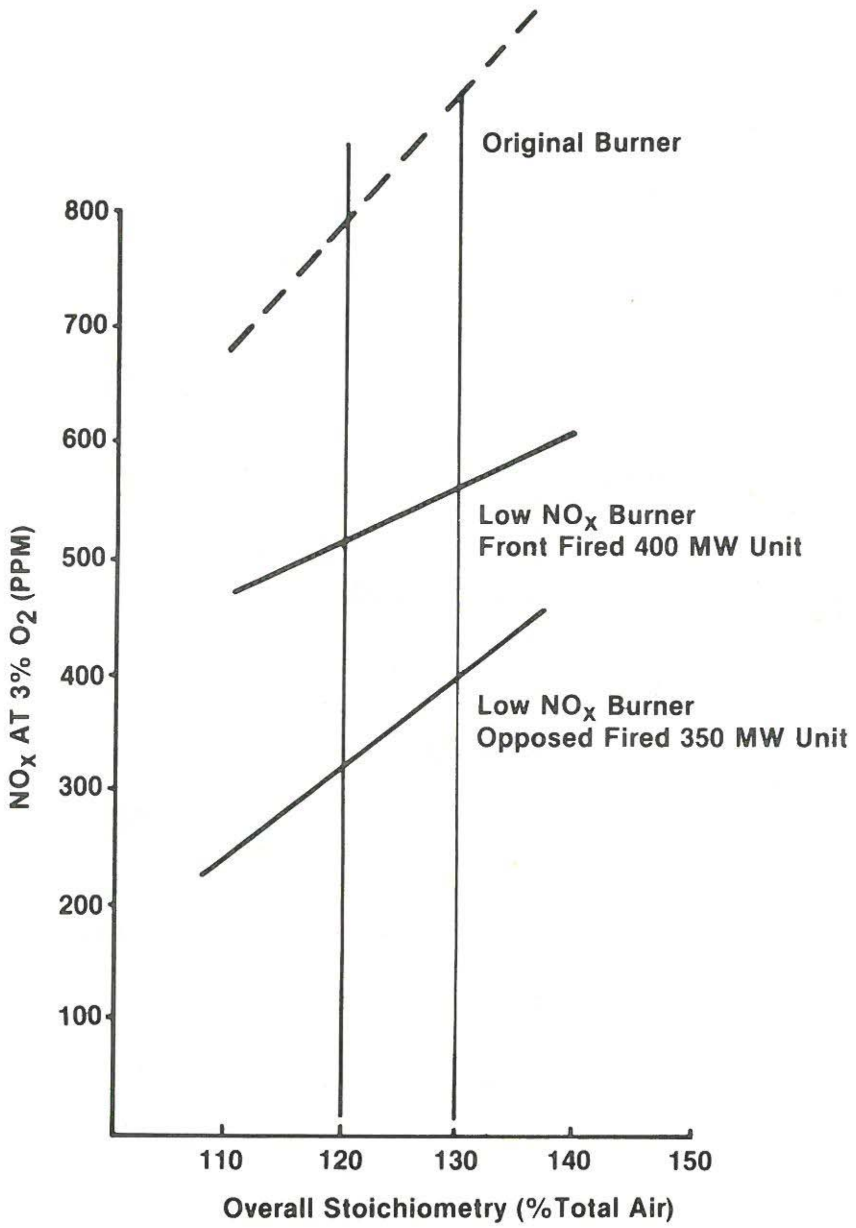

Figure 8 Performance Data Comparison on NO_X

UNIT PERFORMANCE

The outcome of the study showed that the unit could operate with the specified coal and maintain 75% of the original MCR. It also showed that EPA limits could be met. The limitation on capacity is flue gas velocity. Pertinent perfomance data is shown in Figure 9.

Note the difference in efficiency between coal and oil firing resulting from the addition of airheaters. A comparison of predicted stack temperatures shows 243°C (470°F) for full load oil and 143°C (290°F) uncorrected for maximum coal load.

Designation	**Original Oil**	**Maximum Coal**
Steam generation	2,109,204 kg/hr 4,650,000 lb/hr	1,581,903 kg/hr 3,487,500 lb/hr
SH/RH steam temp.	513/513°C 955/955°F	513/513°C 955/955°F
Volumetric H.R.	289,993 W/m^3 28,000 $Btu/hr\text{-}ft^3$	188,495 W/m^3 18,200 $Btu/hr\text{-}ft^3$
Radiant surface H.R.	609,232 W/m^2 193,100 $Btu/hr\text{-}ft^2$	187,880 W/m^2 59,550 $Btu/hr\text{-}ft^2$
Plan area H.R.	6.63×10^6 W/m^2 2.1×10^6 $Btu/hr\text{-}ft^2$	5.2×10^6 W/m^2 1.65×10^6 $Btu/hr\text{-}ft^2$
Furnace exit gas temp.	1343°C 2450°F	1080°C 1975°F
Maximum gas velocity	1829 m/min 6000 ft/min	1247 m/min 4092 ft/min
Boiler Efficiency	84.85%	88.08%

Figure 9 Predicted Overall Performance Data

The study did not include an in-depth review of firing coal/oil mixture (COM) or coal/water slurry (CWS) in the modified unit.

A cursory look tells us that firing COM will require derating of the unit while still using oil for at least 70% of the total heat input.

When firing CWS in the modified unit, we predict that the capacity of the unit will be the same as straight P.C. firing. The assumptions on which we based our prediction are:

1. A coal-to-water ratio of 70:30 will be used and will be treated as a coal with 30% moisture.
2. Slagging and fouling tendencies will be the same as straight P.C. firing.
3. A burner can be developed that will operate for long periods of time.
4. The flame temperature of CWS is lower than that of straight P.C. firing. This implies lower furnace exit gas temperature, which means lower steam temperature or more surface.
5. NO_x will be controlled. The lower flame temperatures retard the formation of nitric oxide.
6. No additional modifications would be made to the unit to maximize steam temperature.

The technology asociated with CWS firing is not yet commercially developed. To the best of our knowledge, no burner has been built that will withstand the highly erosive characteristics of CWS for long periods of time. Also, CWS is not being produced commerically in quantities required for a conversion of this size.

The economic attractiveness of CWS is highly dependent on the coal/oil price differential. Vendors indicate that CWS can be prepared and sold for $3.00 to $3.50 per million Btu. Projections indicate that CWS presents a favorable economic alternative when oil sells for at least $5.00 per million Btu. The present and future economic attractiveness of CWS depends heavily on how one evaluates the future price and availability of oil.

ECONOMIC FEASIBILITY

The economic feasibility of converting fuel sources is very site specific. Factors such as inadequate land area for fuel storage, inadequate means of fuel transportation to the plant or improper physical plant layout can be serious stumbling blocks to an otherwise economically attractive project. The relative cost of coal—less than 50% of oil on a Btu basis—and the impending deregulation of natural gas also weigh heavily in the economic equation to convert. Figure 10 lists the major factors affecting each alternative to straight heavy oil firing.

	Pulverized Coal	COM	CWS	Oil
Plant Equipment and Associated Labor				
Coal Handling and Storage	X			
Boiler and Auxiliary Equipment Modification	X	Minor	X	
Particulate Collection Equipment	X	X	X	
Ash and Sludge Disposal	X	X	X	
Additional Operating and Maintenance Costs	X	X	X	
Off Site Preparation Plant Costs		X	X	
Fuel Costs	Minimum	Relatively High	Relatively Low	Very High

Figure 10 Major Factors Affecting Conversion Equation

Coal handling and storage facilities are required for pulverized coal. COM and CWS would be transported directly into existing tanks at the plant site.

The costs of fuel oil for a 660 MW unit with a 60% capacity factor is over $165 million a year. Fuel cost differential between coal and oil is so significant that pulverized coal and CWS options are favored. Because a majority of the fixed costs still exist and only 30% of the oil is displaced on a Btu basis, any recommendations to convert to COM should be scrutinized very closely. Unless oil is displaced to the maximum degree, there may be no economic justification for converting to COM. Because CWS technology is so new and there are so few suppliers of this fuel, we would recommend conversion to pulverized coal.

The cost of conversion for this unit, delivered and erected, is 48.5% of the cost of a new 495 MW coal-fired unit. Downtime for completing the conversion at the Karn Station would be twelve months. This prediction is based on two shifts. The calculated heat rate for the converted unit is 11,100 Btu/kW. It is a substantial improvement over the existing unit. The best heat rate at Consumers for a coal-designed unit is approximately 9100 Btu/kW.

CONCLUSION

Regulatory and financial pressures are causing utilities and the suppliers serving them to develop methods to optimize the utilization of resources and existing equipment to meet electricity demands. One potentially viable method is fuel conversion to coal.

Specific and judicious evaluations must be made prior to implementing a program of fuel conversion. Although the program can result in significant short-term operating cost reductions, the effects on long-term reliability must be considered for each specific unit.

NO_X regulations are likely to become more stringent. Reforms expected from the EPA with the "bubble" concept and developments in burner design can result in strategies which will allow possible conversions to coal and eliminate a potential barrier to uprating steam generating capacity.

ACKNOWLEDGEMENT

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