Guidelines for Induced Flue Gas Recirculation

Volume 1: Reducing Air/Gas System Resistance and Enhancing Fan Capacity

TR-113815

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REPORT SUMMARY

This document guides users through a logical sequence, or “road map,” of activities and decisions for optimizing solutions for fans, ducts, and related equipment in fossil plant combustion air and gas systems.

Background

Important reasons for analyzing fossil plant combustion air and gas systems include:

- Improving on the original air or gas system performance to accommodate the addition of air pollution control equipment, such as induced forced draft fan gas recirculation (IFGR) or other modifications.
- Improving fan performance design deficiencies or degradation, such as less-than-design performance or improper forced draft fan inlet vane problems.
- Adding higher flows for current or planned fuel combustion compared to the original design flows; for example, switching from high-sulfur to low-sulfur coal.
- Enhancing air and gas system performance to achieve better plant performance; for example, lowering auxiliary power consumption and increasing excess air to achieve less boiler slagging.

This report provides a logically ordered methodology for optimizing several specific aspects of fossil plant combustion air and gas systems.

Objective

To provide a step-by-step “road map” approach for guiding users through a logical sequence of activities and decisions leading to an optimized solution for ducts, related equipment, and fans.

Approach

The project team developed a “road map” approach consisting of a logical sequence of activities and decisions for optimizing fossil plant combustion air and gas systems. They designed the road map to lead to solutions for increasing air and flue gas flow capabilities in gas-, oil-, and coal-fired boilers in retrofit applications, particularly for adding IFGR on gas-fired boilers.

Results

This guideline presents an ordered methodology, or road map, that leads users through the necessary steps for completing required analyses and improvements to fossil plant combustion air and gas systems. Road maps and their associated activity description tables use a hierarchical

structure to organize the analysis and decision making process into phases, tasks, steps, and activities. This document presents specific road maps for

- Reducing duct pressure losses by cutting losses in turns and removing flow path restrictions.
- Improving equipment performance.
- Modifying or replacing fans.

EPRI Perspective

The methodology described in this document is easily understood, and utilities should be able to quickly and effectively apply road map activities to their own plants. Although these guidelines were developed as a part of a program for gas-fired units using IFGR, they are useful for resolving problems in coal- or oil-fired units with marginal forced draft (FD) fan capacity.

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Keywords

Flue gas
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Fan
Duct
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1 INTRODUCTION

Overview

Frequently, there are important reasons for analyzing fossil plant combustion air and gas systems. Some examples are:

- Improving on the original air or gas system performance to accommodate the addition of air pollution control equipment, such as, induced forced draft fan gas recirculation (IFGR) or other modifications.
- Air and gas equipment and system problems, deficiencies, and other causes resulting in reduced fossil boiler output. For example, air preheater leakage will reduce combustion airflow to the boiler burners and increased flow rates in the gas system.
- Excessively high pressure losses in the air and gas paths because of sharp changes in flow path shape and direction, undersized ducts, inadequate flow turning vanes, flow measuring equipment, and restricted equipment flow paths. Examples are air preheater, bag house flow pressure loss.
- Fan performance design deficiencies or degradation; such as, less than design performance or improper forced draft fan inlet vane problems.
- Higher flows are needed for current or planned fuel combustion compared to the original design flows; for example switching from higher sulfur to low sulfur coal.
- Improving air and gas system performance to achieve better plant performance. Some examples are lowering auxiliary power consumption, and increasing excess air to achieve less boiler slagging.

Methodologies for improvement to the following areas are addressed in this report:

- Reduced duct pressure losses by reducing losses in turns and removing flow path restrictions.
- Improved equipment performance.
- Fan modifications and replacements.

This guideline document uses a step-by-step “road map” approach to guide users through a logical sequence of activities and decisions leading to selecting an optimized solution for ducts and related equipment, and fans. The road maps provide guidelines for increasing air and flue gas flow capabilities in gas, oil and coal-fired boilers when needed in retrofit applications, particularly for the addition of induced forced draft fan gas recirculation (IFGR) on gas-fired boilers.

Background

Although these guidelines were developed as a part of a program for gas-fired units using induced forced draft fan gas recirculation, or IFGR, they are useful for resolving problems in coal- or oil-fired units with marginal FD fan capacity.

IFGR involves injection of flue gas into the combustion air for mitigating NO_x production on steam generating units firing natural gas. The details of IFGR are reported in other EPRI documents. However, a brief general description of IFGR relative to this project is provided near the conclusion of this introductory chapter.

Guideline Format and Content

The road maps are diagrams that lead users through the steps usually needed for completing the required analysis and improvements.

An overall road map and narrative descriptions are provided for a general understanding of the methodology presented in this guideline document and to guide users to the needed detailed information. The detailed information consists of road maps and associated activity description tables for the needed activities for the air and gas fans and systems.

Road map activities and descriptions for the following are provided:

- Obtaining and using applicable operating data usually available from control room and other plant instrumentation.
- The need for conducting performance tests.
- Identification of calculations for analyzing design and performance.
- Initial basic financial calculations to estimate the cost benefit of performance improvements to be used to guide (limit in the case of low cost benefit justification) users to the Road Maps that will usually be applicable.
- Discussion on the decision step.

The road maps and activity description tables use a hierarchical structure to organize the analysis and decision making process into phases, tasks, steps, and activities as illustrated in Table 1-1.

Users of this guideline document should be able to quickly understand the overall analysis methodology, as well as be able to proceed to implement the detailed analysis activities for the specific plant(s). Detailed descriptions of fan and duct system calculations, testing, and other analysis are not presented in this report because this information is available in existing references. Brief descriptions are provided for some of the important performance impacts of the air and gas systems on other plant equipment.

Table 1-1
Structure of Road Maps

Phase 1	Task 1	Step 1	Activity 1.1
			Activity 1.2
		Step 2	Activity 2.1
			Activity 2.2
	Task 2	Step 1	Activity 1.1
			Activity 1.2
		Step 2	Activity 2.1
			Activity 2.2
Phase 2	Task 1	Step 1	Activity 1.1
….	….	….	….

System and Equipment Scope

Applicable systems, equipment, and components included in this guideline document are:

Combustion Air System and Equipment

- Steam, condensate, or glycol air heater coils.
- Combustion air preheater.
- Ducts and turning vanes.
- In-duct flow measuring devices.
- Dampers.
- Forced draft (FD) fans, including inlet silencer and duct, inlet vanes, casing, rotor, driver, variable speed coupling, and discharge duct.

Flue Gas System and Equipment

- Air preheater.
- Ducts and turning vanes.
- Flue gas emission control equipment including electrostatic precipitators, baghouses, flue gas desulfurization (FGD) systems, and chimney/stack.
- Flow measuring devices.
- Dampers Induced draft (ID) fans including inlet duct, inlet vanes, casing, rotor, driver, variable speed coupling, and discharge duct.

Induced Flue Gas Recirculation

Induced flue gas recirculation (IFGR) is a proven method of achieving NO_x reductions. IFGR flow in the range of 6 to 10% (expressed as a percentage of the total amount of flue gas exiting the economizer at any given boiler load) may result in NO_x reductions in the range of 40% to 50%.

IFGR involves injection of flue gas into the combustion air for mitigating NO_x production on steam generating units firing natural gas. Retrofit application of this technique to an existing boiler requires installation of a duct to transport flue gas from the economizer gas outlet flue, air preheater gas outlet, or induced draft fan outlet(s) to the inlet of the forced draft fan(s). This combustion (flue) gas stream is mixed with combustion air and conveyed to the burners.

The first application of IFGR to a large utility boiler was demonstrated at Entergy's Willow Glen Generating Station Unit 3, a 525 MW natural gas fired. IFGR has also been applied to Units 2 and 3 at Houston Lighting & Power's Robinson station. Prior to these three utility-scale applications, IFGR has been used for a number of years on small industrial boilers. IFGR is a demonstrated viable, low-cost NO_x control technology for utility boilers.

Introduction of flue gas into the combustion air (IFGR) reduces the forced draft (FD) fan's ability to supply full-load airflow. If a unit has marginal air system performance because the FD Fans deliver less-than-expected air flow, the system resistance is higher than expected, the fuel changed requiring more air, or other reason(s), then little or no flue gas can be injected into the combustion air without incurring unit load reductions (unit derating). Avoiding or minimizing unit derating involves improving fan performance, duct pressure losses and leakage, and/or optimizing air system equipment operation. The required flue gas system flow at unit full load also increases with IFGR with the potential to cause unit deratings requiring a similar analysis as for the air system. The option to operate the unit with IFGR with deratings and not spend the money needed to modify the air or flue gas systems may be the best economic choice. For some units IFGR with the resulting NO_x emission reduction may only be needed during a portion of the year, which lessens the derating financial impact.

It is very important to investigate the higher temperature air/gas mixture impact to the FD fan to eliminate the potential for fan failures. Higher temperature can cause thermal distortion of the fan wheel, windbox, and other components, and/or exceed the allowable temperatures for the fan wheel, rotor, inlet vane components, shaft bearings and other temperature sensitive components. Moisture in the fan and secondary air duct needs to be thoroughly investigated.

2 METHODOLOGY

Figure 2-1 provides an overall diagram or road map of the air and gas systems evaluation and decision process. The Overall Road Map illustrates a five phase process for data collection, evaluation, and decision making that includes:

- Phase 1 - Determination of the need for improvement.
- Phase 2 - Initial financial analysis.
- Phase 3 - Analysis of air and gas system resistance.
- Phase 4 - Analysis of fan capacity enhancements.
- Phase 5 - Decisions.

The following narrative sections provide a more description of the methodology of each phase.

Methodology for Phase 1 – Determination of Need

Identification, evaluation, and selection of the favorable air and gas systems enhancements are very dependent on careful consideration of the goals to be attained and the criteria to be used to choose and rank alternative strategies. The tasks in Phase 1 focus on technical considerations for determining whether improvements are needed and identifying desired attributes for system improvements to meet operational goals. These attributes are used to identify candidate plant combustion air or gas system equipment and component modifications to be analyzed in the following phases; in other words, identifying the required improvements.

In most cases, this phase will require collection and evaluation of plant design and operating data and a comparison of predicted and actual performance.

Methodology for Phase 2 – Initial Financial Analysis

Generally, two situations are typical:

1. The decision to implement air and gas system improvements requires a cost/benefit justification, or

2. The improvements are needed for the ongoing operation of an important plant and cost justification is not needed for the decision process.

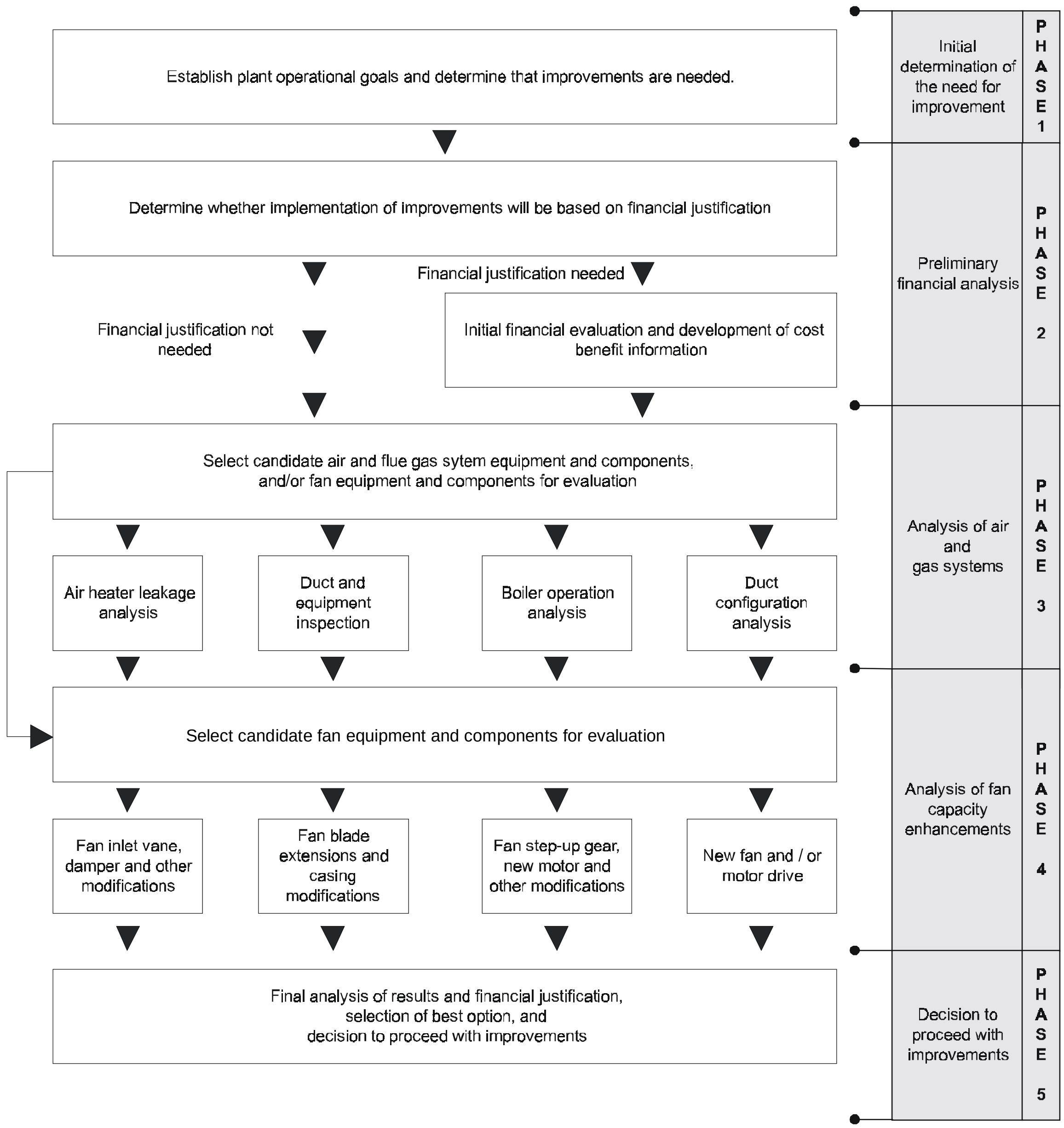

Figure 2-1
Air and Gas Systems Evaluation and Decision Process

The methodology for a typical cost/benefit analysis, as would be required for the first situation presented above, is described in this section of the guideline document.

In many instances, assessment of financial aspects of alternative strategies is developed near the end of the evaluation process. The financial analysis results may be used in this context to eliminate or select among strategies, but are not methodically used to develop favorable candidates. This approach can be appropriate and effective in many situations. However, a implementation of an Initial Financial analysis that is used earlier in the evaluation process, can assist in identifying scenarios that have a high potential for attaining the desired goals. For example, if the Initial Financial analysis shows a low potential benefit-to-cost ratio for the projected improvement, the User will usually limit the analysis to less costly options. One option is to continue operations with the current equipment and duct systems and incur the reduced revenue because of unit deratings

Methodology for Phase 3 – Analysis of Air and Gas System Resistance

Analysis of plant operational goals, desired attributes for system improvements, and financial criteria from the preceding phases will lead to selection of one or more candidate system improvements for analysis in Phase 3. Phase 3 represents an initial analysis of typical system improvements to reduce resistance in the air and gas systems that have been successfully implemented. These improvements are generally considered to be effective for achieving plant operational goals at a reasonable cost and with limited disruption of plant operation; minimum outage schedule time. The Phase 3 Analysis evaluation may indicate that a single system improvement can achieve the required results or, alternatively, that a combination of improvements is needed or is the best selection. In some cases, none of the candidate improvements may be applicable and consideration of fan improvements (Phase 4), which are often more expensive may be appropriate. If the improvements analyzed in Phase 3 achieve operational goals, the analysis can proceed to directly to Phase 5, Decision to Proceed or fan improvements can be investigated to compare with Phase 3 options.

The Phase 3 analysis addresses the following analysis of air and gas systems, equipment, and components for candidate improvement and modification:

- Air preheater leakage and pressure drop analysis.
- Duct and equipment inspections for leakage.
- Boiler operational data analysis.
- Duct configuration analysis.

These analyses are used to identify candidate improvements and modifications to reduce system flow and resistance. Some commonly implemented improvements and modifications include (but are not limited to):

- Reducing air preheater and duct leakage.
- Replacing high differential pressure air flow measuring devices.
- Installing or modifying duct turning vanes.
- Changing the contours of existing ducts, and the design of internal bracing (these modifications may require CFD or 3D scale modeling for proper implementation).
- Locating and repairing duct system leaks; e.g., expansion joints, duct cracks.
- Reducing boiler excess air or burner vane setting to reduce pressure loss.

The Phase 3 analysis procedures may involve performing detailed computations for fans, ducts, and other components.

Methodology for Phase 4 – Analysis of Fan Modifications

This phase is similar in approach to Phase 3, but involves options that focus on the fans. Often Phase 3 options are more cost effective than Phase 4 fan modifications because Phase 3 options usually reduce operating costs with reasonable capital expenditures requiring fairly short unit outages. However, there may be reasons for a specific plant to initially consider fan modification options initially. For example, complete replacement of a fan is usually an expensive and complicated option. But, if the existing fans are in need of significant maintenance and repairs, the cost of a new fan might not be prohibitive. Other possibilities are the need for a major improvement on a strategically important unit, IFGR implementation, installation of a new baghouse, FGD System or other equipment.

Examples of improvements and modifications considered in Phase 4 are:

- Adding blade tips to existing fans.
- Fan wheel replacement.
- Fan and motor replacement.
- Adding a supplemental fan.

Methodology for Phase 5 – Decision to Proceed

The methodology for this phase provides suggested technical criteria for comparing and deciding among alternative improvement and modification strategies. A typical financial analysis example is also provided. Finally, a brief description of the steps needed for implementing the improvement and verifying the results is provided.

3
ROAD MAP FOR PHASE 1 – DETERMINATION OF NEED

Overview

Phase 1 is comprised of two tasks to determine whether air and gas systems improvements are needed to meet plant operational goals. Conceptually, this phase focuses on providing technical data to answer two fundamental questions pertaining to plant performance:

1. Are the current air and gas systems below operational requirements?

2. Are new air and gas systems components to be added; e.g., IFGR, additional precipitator, sections, improved air preheaters?

If the answers to the Question 1 and 2 are Yes, the applicable Phase 1 Tasks 1 and 2 activities need to be implemented. Plant, fan, and duct system operating information is needed when implementing these activities. If no actual operating data exists, then the data needs to be obtained through testing. If new equipment or components need to be added to the air/gas systems, an analysis is needed to determine the impact of the needed changes.

Figure 3-1 and Table 3-1 through Table 3-3 provides a road map diagram and associated activity descriptions for Phase 1.

Road Map for Phase 1 – Determination of Need

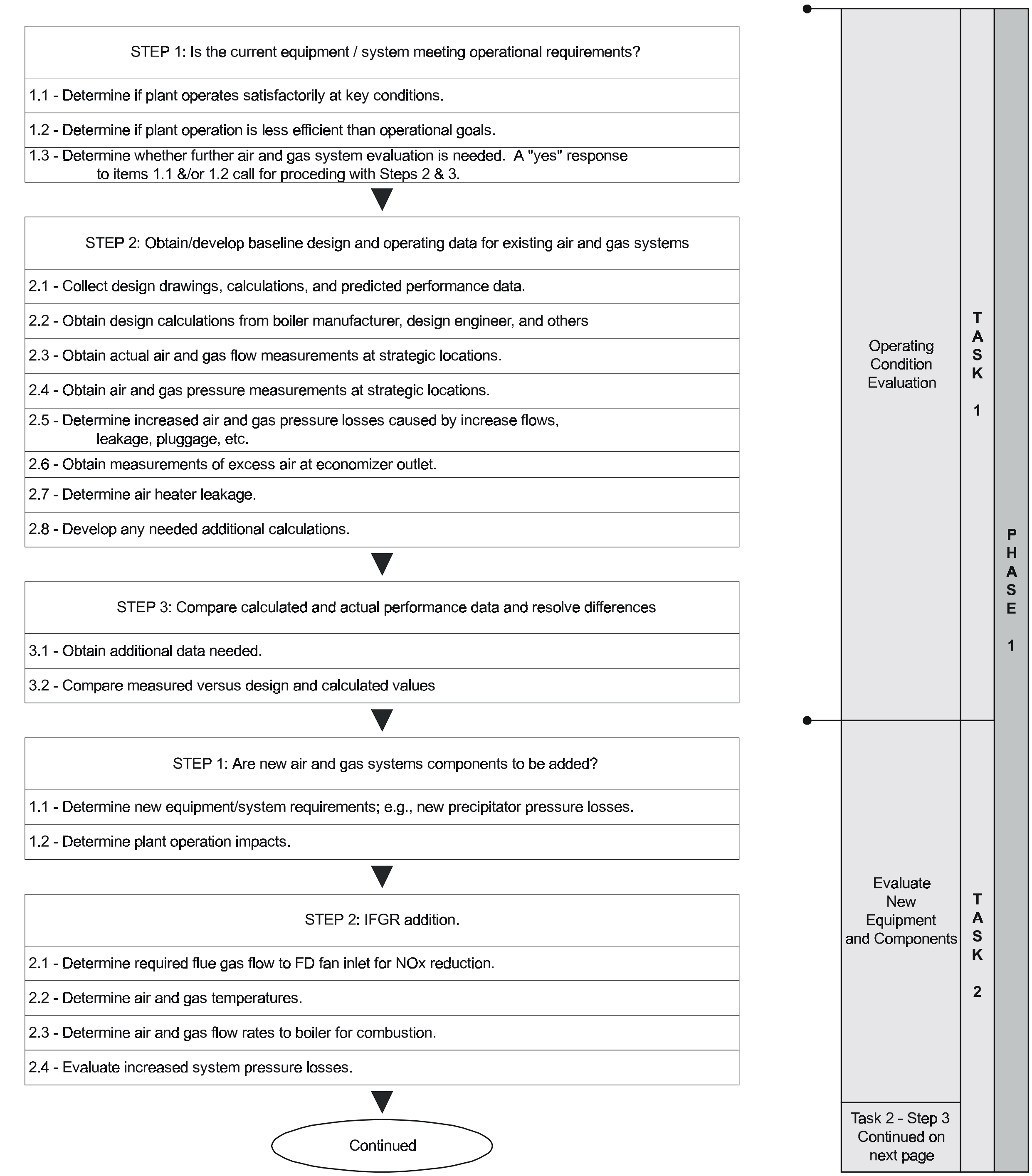

Figure 3-1
Road Map for Phase 1 – Determination of Need

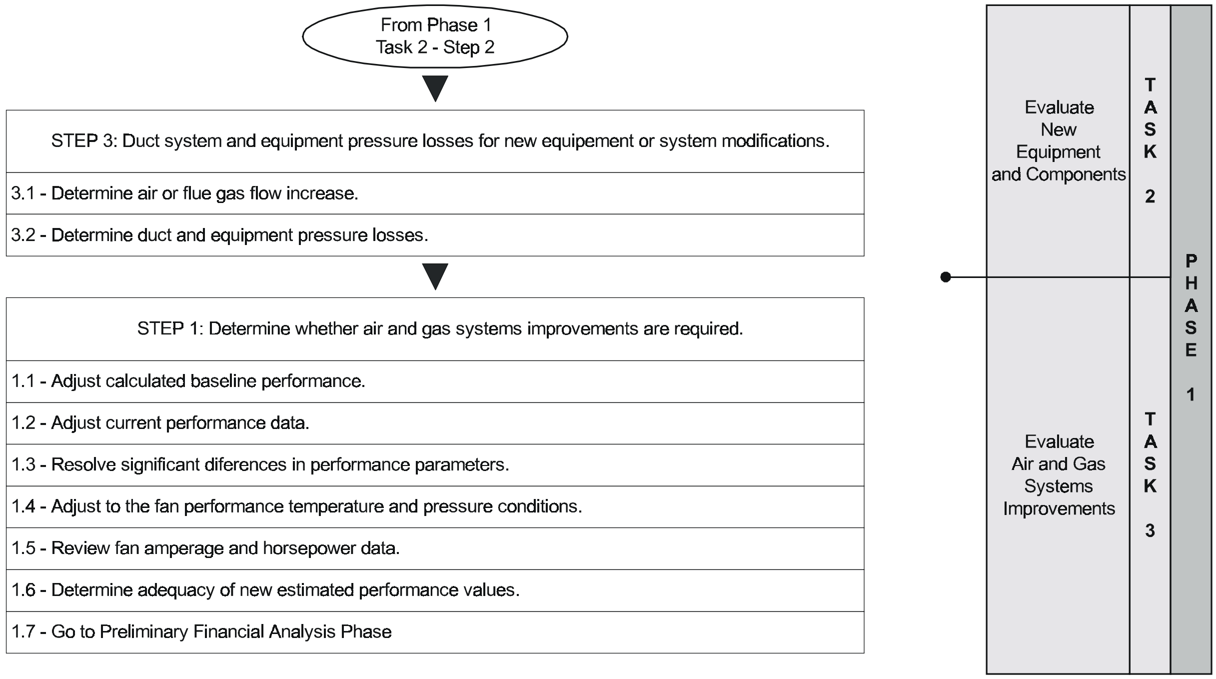

Figure 3-1
Road Map for Phase 1 - Determination of Need (continued)

Task 1 - Evaluate System Operating Condition

Objectives

Successful analysis and evaluation of the current operating condition and for improving plant air and gas system performance requires accurate definitions of the design basis and operating parameters of the existing plant. The objective for this task is to establish plant design and baseline performance data and to compare predicted and actual (measured) plant performance data.

Several activities address the need to measure various air and gas system parameters, such as flow and pressure, at strategic locations. Often permanent plant instrumentation is not available to provide these data or measurements available from the plant control system may not be sufficiently accurate to provide useful data. Specific data collection or testing programs must be developed for each plant, as appropriate. Procedures for conducting such testing and data collection are beyond the scope of this guideline document.

Activity Descriptions

Table 3-1
Operational Requirements Evaluation Road Map Activities

Step	Activity	Operating Condition Evaluation Activity Description	Criteria, References, and Comments
1	Is the current equipment / system meeting operational requirements?		
	1.1	Does the plant operate satisfactorily at the highest loads, applicable ambient conditions, with the selected poorest fuel and appropriate equipment conditions?	If desired operating performance can be met then the analysis may not need to proceed further.
	1.2	Is the plant operating efficiency satisfactory?	Improvements can reduce auxiliary power and increase operating efficiency.
	1.3	If the answers to the proceeding are YES, then end the air and gas system evaluation.	
2	Obtain and develop baseline design and operating data for existing air/gas systems.		
	2.1	Collect applicable and available design drawings, design calculations, and predicted performance data for the air and gas systems fans, boiler, ducts, flow measuring instrumentation, etc. Predicted performance data should include fan performance curves (pressure v. flow), fan data sheets, predicted air and gas flow, pressure, and temperature parameters from boiler combustion calculations, and duct pressure drop calculations.	Locating this information, especially boiler air and gas flow and duct pressure loss calculations, is often difficult. It may be necessary to develop new baseline calculations.
	2.2	Obtain actual air and gas flow measurements at strategic system locations at a plant operating load as close to maximum load as possible. Often permanent plant instrumentation is not available to provide these data. Generally, measurements from the plant control system may not be sufficiently accurate to provide useful data. Continuous emission monitoring instrumentation usually provides sufficiently accurate data for the gas flow that the chimney. Alternatively, flow measurements can be made using pitot tube duct traverses. Another option is measuring fuel input and taking gas Orsat analysis. Using two measurement methods is often helpful to confirm that sufficiently accurate flow measurements have been obtained.	If station instrumentation is used, instrumentation and measurement accuracy needs to be sufficient for use in this analysis. Calculation of required air and flue gas flows can be found in many references.
	2.3	Fan amperage and horsepower will assist in defining the fan system operating point. Also, this information could show that a major fan performance problem exists.	There are many references on fan performance.

Table 3-1
Operational Requirements Evaluation Road Map Activities (continued)

Step	Activity	Operating Condition Evaluation Activity Description	Criteria, References, and Comments
	2.4	Obtain air and gas flow, pressure, temperature measurements at strategic points in the system; such as, fans, air preheater, air heater coils, windbox, burner, economizer, and stack. Generally pressure measurements at upstream and downstream of equipment, as appropriate are needed as a minimum.	If station instrumentation is used, instrumentation and measurement accuracy needs to be sufficient for use in this analysis.
	2.5	Determine increased air and gas pressure losses needed to account for pluggage, deterioration, etc.	
	2.6	Obtain measurements of excess air at the economizer outlet.	
	2.7	Determine the amount of air preheater leakage by measuring excess air in the flue gas upstream and downstream of the air preheater.	Historical data can be very helpful in determining performance deterioration, e.g., air preheater leakage.
	2.8	Develop any needed additional calculations and data to provide a sufficiently complete baseline for use in the remainder of the analysis.	
3	Compare calculated and actual performance data and resolve differences.		
	3.1	Measured, calculated, and baseline design data often do not correlate initially. Commonly, additional measurements, calculations, and analysis are needed to get reasonable agreement.	
	3.2	Comparing measured versus design flow and pressures may show deficiencies that can be corrected to achieve the needed improvements.	

Task 2 - Evaluate New Air and Gas Systems Components or Operation

Objectives

In some instances, improving plant performance, environmental emission compliance, reliability, or maintainability involves the addition of new equipment or components into the air and gas systems. An example is the addition of induced forced draft fan gas recirculation, or IFGR, for mitigating NO_x production in the boiler. Other common equipment additions or replacements include new air preheater heat exchanger surfaces (baskets), and new electrostatic precipitators, baghouses or FGD Systems.

Air and gas systems flow and pressure profile changes may also result from changes in plant operating parameters without addition of new equipment and components. An example of an operational change is alteration of boiler excess air levels.

The objective of this task is to determine the required air and gas system flow, temperature and pressure requirements that result from planned addition of new equipment and components or changes to plant operation.

Activity Descriptions

Table 3-2
New Components and Operation Evaluation Road Map Activities

Step	Activity	New Equipment, Components, and Operation Evaluation Activity Description	Criteria, References, and Comments
1	Are new air and gas systems components to be added?		
	1.1	Determine the new equipment and system requirements by obtaining information from the manufacturer, contractor, or engineer designing the modifications and/or obtain data from other similar plants.	
	1.2	Determine whether plant operation will be adversely impacted by the addition of the new equipment.	
2	IFGR system addition.		
	2.1	Determine the required flue gas flow to the FD fan inlet to obtain the desired boiler combustion NO_x rate reduction	Increasing flue gas recirculation reduces boiler NO_x emission rate.
	2.2	Determine the inlet temperature to the FD fans at high unit load and ambient temperatures.	Mixing flue gas, usually at about 300F, with inlet air raises the temperature of the gas entering the FD fan. This causes a reduction in FD fan oxygen mass output. The impact of the increased temperature on the fan rotor, wheel, and blades needs to be investigated. The impact on other equipment and the duct system also needs to be investigated. Equipment and system failures can occur if air operating temperatures exceed design temperatures.
	2.3	Determine the new air and gas flow rates for the boiler fuel combustion rate and excess air requirements.	
3	Pressure losses or flow increases from new equipment and systems or modified operation (other than IFGR) Examples are, new precipitator or burners, higher boiler burner pressure losses, new air preheater heat exchanger surfaces (baskets), change in boiler excess air.		
	3.1	Determine the required air or flue gas flow increase.	
	3.2	Determine the required duct and equipment pressure losses increase for the increased air/gas flow or for the new equipment.	Data from manufacturers, contractors, and engineers is often needed. Data from similar plants is often useful.

Task 3 - Evaluate Air and Gas Systems Improvements

Objectives

The objectives of this task are to evaluate the effect of increased or decreased flows and pressure losses on the capacity of the FD and ID fans, as appropriate. This involves analyzing FD and ID fan performance curve(s).

Activity Descriptions

Table 3-3
Air and Gas Systems Improvements Road Map Activities

Step	Activity	Air and Gas Systems Improvements Evaluation Activity Description	Criteria, References, and Comments
1	Determine whether air/gas system(s) improvements are required?		
	1.1	The fan and duct system calculated, design baseline performance is adjusted to the fan performance temperature/pressure conditions and is marked on the fan performance curve (shows flows, static pressures, fan horsepower).	There are many references that provide example calculations on adjusting fan design performance to other operating conditions.
	1.2	The fan and duct system current measured performance is adjusted to the fan performance temperature and pressure conditions, and are marked /added to the fan performance curve.	
	1.3	Significant differences between the design and measured values need to be resolved.	More accurate calculations, use of more applicable references, and/or more accurate measurements will sufficiently resolve the differences.
	1.4	The new fan and system requirements (flow and pressure), if applicable, are adjusted to the fan performance temperature and pressure conditions, and are marked on the fan performance curve.	
	1.5	A determination is made at this point in the analysis using the preceding fan curve information for the applicable design, operating, and/or required new performance that the fan and air/gas system performance is satisfactory or that improvement needs to be investigated. The new system resistance must be determined prior to establishing the modified performance requirements of the fan. The new system resistance can be estimated graphically or calculated, if the characteristics of the original system are known.	
	1.6	The next step is either the Financial Justification or selecting the candidate air and flue gas system equipment and components and/or fan equipment and components for evaluation.	

4
ROAD MAP FOR PHASE 2 – INITIAL FINANCIAL ANALYSIS

Developing a list of options and determining the best choice for improving air/gas system performance can be greatly benefited by first performing an initial financial analysis. The financial analysis will guide investigation of the most likely economic choices.

Each option has economic consequences. There are four traditional ways of evaluating the economics of a project.

- Net Present Value
- Internal Rate of Return
- Benefit-Cost Ratio
- Payback Period

Developing results for all or some of the above financial criteria is often necessary, but the net present value (NPV) of the cash flows is the most common way of dealing with the decision making process. This report will proceed based on the approach of using NPV for the financial ranking of options. Options may have positive or negative NPVs. An emission improvement project may concentrate analysis of options with the least negative NPVs. Further screening may eliminate options that are unacceptable for non-economic criteria. The remaining option with the highest NPV and non-economic performance is then considered the most desirable option.

No decision rule can assure success. Much of the information used to forecast cash flows has a degree of uncertainty. As a result of deregulation in the marketplace the future value of generation maybe highly uncertain. There are techniques available, derived from approaches used by the financial community to value options contracts, which better address market uncertainties. These advanced valuation techniques should considered for the final financial evaluation and decision making[1]. However, for the preliminary screening process, a NPV assessment is satisfactory for sorting among the options.

The value of an option is the difference between the income (benefits) minus the costs. Since this is will be a net present value analysis the evaluation period will need to be established. The evaluation period will likely be equal to the estimated remaining operating life of the unit. The benefits are revenues derived from the unit including the value of any increased output. These revenues can be from electricity and steam sales, as well as, ancillary services.

[1] *Using Option Valuation Theory to Analyze Generating Plant Investment and Retirement Decisions,* EPRI, Palo Alto, CA: 1997, TR-107635

Costs can be separated into two general categories.

- Variable Operating: variable operating costs and consumables are directly proportional to the amount of energy produced and are referred to as incremental costs. They are generally expressed in mills/kWh or $/MWh. Variable O&M costs include the following:
  - Consumables.
  - Disposal Charges.
  - Purchase of emission allowances.
  - Raw water and waste water discharge.
  - Quantities of ash, chemicals, reagent, waste, etc., which are multiplied by the unit price (e.g., $/ton) for these items.
- Fixed costs: The portion of total O&M costs that are essentially independent of capacity factor, consisting of Operating Labor, Maintenance Labor, Maintenance Material, and Overhead Charges.

The EPRI Technical Assessment Guide (TAG™)[2] provides detailed examples of present value calculations. The key elements in calculating present value are[2]:

- All options should be evaluated over the same time period.
- A consistent approach needs to be applied regarding when costs and revenues are present valued from, e.g. costs and revenues for a given year can be recognized annually at the end of the year and the present value calculated for the estimated start date of the project start.
- Consistency must exist between the discount rate and whether the projections are in constant dollars or current year dollars.

The manner in which project costs are to be treated can complicate an analysis. A decision to capitalize the cost of a project means that the project cost will be depreciated of a number of years. For the purpose of initial screening and adequately accurate final financial comparisons for projects of the type addressed in this report it usually assumed that all the costs will be expensed in the year incurred. However, users may want to use other financial comparison methods that are required or available for the specific plant, project or organization.

The financial analysis needs to incorporate fuel and other expense escalation, as well as revenue escalation. A base case usually needs to be developed to compare each of the options to. A spreadsheet (a pro forma) showing annual revenues and expenses, and the NPV calculation is very useful. The spreadsheet can be used to test the options with different fuel costs, electricity revenue, etc.

The Initial Financial Phase input should incorporate the information developed in Phase 1 – Determination of Need. For example, if the unit is currently experiencing a reduction in output because of inadequate air or gas system performance, the Initial Financial Analysis would show

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[2] *TAG, Technical assessment Guide, Fundamentals and Methods, Electricity Supply,* EPRI, Palo Alto, CA: 1997, TR-100281-R7, Volume 3

the approximate capital cost expenditure that would equal the increase in revenues based on the target NPV. After completing the Initial Financial Analysis – Phase 2, the Analysis of Air and Gas Systems the Final Financial Analysis needs to be developed as outlined in this phase or as determined for the specific project.

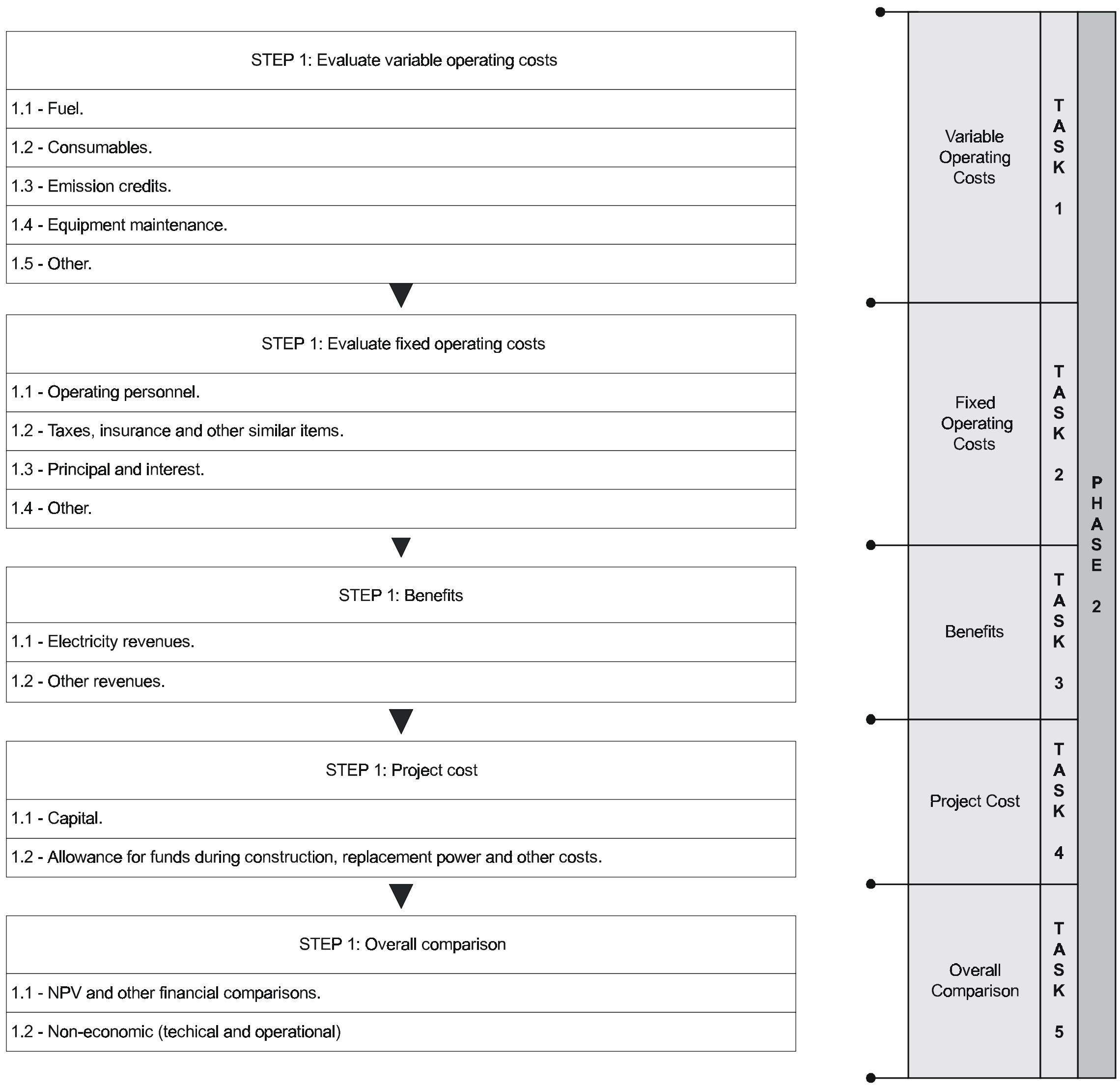

Figure 4-1
Road Map for Phase 2 – Financial Analysis

Figure 4-1 provides a road map diagram and Tables 4-1 through 4-5 provide activity descriptions tables for Phase 2.

Task 1 - Determine Variable Costs

Objectives

The objective of this task is to determine the applicable variable costs. The information shown here is generally applicable and needs to be modified for the specific project based on the specific project and organization business goals and policies. These expenses need to be based on a forecasted load schedule for the unit.

Table 4-1
Evaluate Variable Operating Costs

Step	Activity	Activity Description	Criteria, References, and Comments
1	Variable Operating Costs		
	1.1	Fuel.	Total or differential fuel costs for the base case and the optional case need to estimated for the forecasted project unit load operation; usually including fuel escalation.
	1.2	Consumables.	This cost would be for additional water, chemicals and other similar items.
	1.3	Emission credits.	SO_2 or other applicable emission credits (expenses) need to be included.
	1.4	Equipment maintenance.	Equipment maintenance expenses that change or are different between the options need to be estimated and included.
	1.5	Other.	Additional expenses not included above.

Task 2 - Determine Fixed Costs

Objectives

The objective of this task is to determine the applicable fixed costs. The information shown here is generally applicable and needs to be modified for the specific project based on the specific project and organization business goals and policies. These expenses need to be based on a projected life of the unit.

Table 4-2
Evaluate Fixed Operating Costs

Step	Activity	Activity Description	Criteria, References, and Comments
1	Evaluate fixed operating expenses		
	1.1	Operating personnel.	These expenses often do not differ for the various options.
	1.2	Taxes, insurance and other similar items.	These expenses often do not differ for the various options.
	1.3	Principal and interest.	If the project cost will be expensed in the first year as assumed in this report, these costs don't change between the options.
	1.4	Other.	Additional expenses not included above.

Task 3 - Benefits

Objectives

The objective of this task is to determine the applicable benefits, revenues. The information shown here is generally applicable and needs to be modified for the specific project based on the specific project and organization business goals and policies. These expenses need to be based on a projected life of the unit.

Table 4-3
Evaluate Benefits

Step	Activity	Activity Description	Criteria, References, and Comments
1	Evaluate Benefits		
	1.1	Electricity revenues.	These revenues depend on many factors including; the unit dispatch position in the local generating system, weather, availability, the performance and outage schedule of other units, plant auxiliary power usage. Competition prevalent today puts great emphasis on low generating costs and it is important to incorporate this emphasis in this step.
	1.2	Other revenues.	Other revenues can be flyash, steam, and other sales.

Task 4 - Determine Project Cost

Objectives

The objective of this task is to determine the applicable project costs. The information shown here is generally applicable and needs to be modified for the specific project based on the specific project equipment, system and construction requirements.

Table 4-4
Project Cost

Step	Activity	Activity Description	Criteria, References, and Comments
1	Project Cost		
	1.1	Capital cost estimate development needs to incorporate the equipment, system, material and other expenses.	Reasonably accurate budget prices can usually be obtained from equipment suppliers, engineers and contractors. Previous projects a very good source. Project specific conditions need to be incorporated, e.g., access to the area where the modification work is needed, weather conditions, schedule. There are references that provide construction cost estimating information. EPRI Report TR-109380, *Guidelines for the Fluid Dynamic Design of Power Plant Ducts* has duct cost information.
	1.2	Allowance for funds during construction, replacement costs and other costs.	*TAG, Technical assessment Guide, Fundamentals and Methods, Electricity Supply*, EPRI, Palo Alto, CA: 1997, TR-100281-R7 provides descriptions and explanations on incorporating these costs.

Task 5 - Overall Comparison

Objectives

The objective of this task is to develop the Overall Comparison of the Options. During the Initial Financial Analysis the expenses, benefits and capital cost estimates will be approximate. However, this information will be very helpful to identify which air and gas system and fan options to analyze. After completing the Phase 3 and 4 analyses a Final Financial Analysis using the same steps is usually needed.

Table 4-5
Overall Comparison

Step	Activity	Activity Description	Criteria, References, and Comments
1	Overall Comparison		
	1.1	NPV and other financial comparisons.	Use of the procedure provided in *TAG, Technical assessment Guide, Fundamentals and Methods, Electricity Supply*, EPRI, Palo Alto, CA: 1997, TR-100281-R7 is usually needed.
	1.2	Non-economic (technical and operational).	A comparison of the differences in operations construction schedule, emissions, operator and maintenance requirements, availability, and other relevant matters needs to be developed.

5
ROAD MAP FOR PHASE 3 – ANALYSIS OF AIR/GAS SYSTEM RESISTANCE

Air and gas system resistance improvements often lead to resolution of duct and fan system performance inadequacies at the lowest cost and least interruption of plant operations. Some examples of deficiencies and findings are outlined below:

- Data will show a significant increase in flue gas excess air if air preheater leakage is high.
- High differential air preheater pressure indicates pluggage.
- High forced draft fan airflow, with coincident low economizer excess air, indicates duct system leakage.
- High induced draft fan gas flow, with coincident low inlet pressure or inadequate furnace pressure, indicates gas duct system leakage, poor duct configurations, and ineffective or lack of turning vanes.
- High boiler excess air indicates the need to boiler requirements and/or review control settings.
- High air or gas system pressure losses indicate that duct configuration and/or turning vanes may be a problem.

The activities outlined below are most commonly used to resolve these problems. However, there occasionally will be problems that are not addressed here.

Figure 5-1 and Tables 5-1 through 5-4 provide a road map diagram and activity descriptions for Phase 3.

Data from Phase 1 and the financial information from Phase 2 are used to select the Phase 3 Tasks to be investigated. After completing the chosen Tasks and the potential improvements are identified the analysis can proceed to Phase 4 - Analysis of Fan Modifications or to Phase 5 – Decision to Proceed.

Road Map for Phase 3 – Analysis of Air/Gas System Resistance

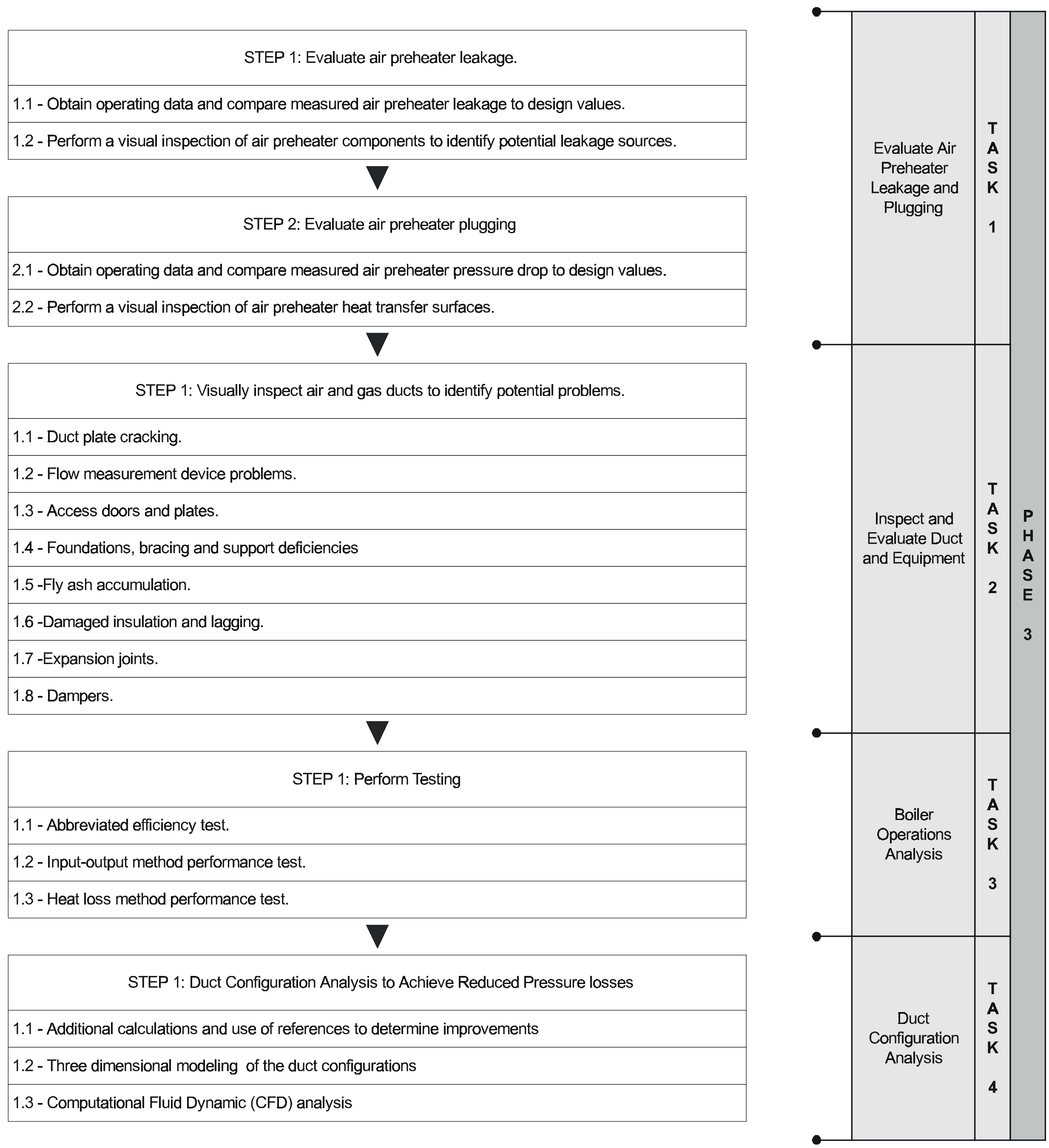

Figure 5-1
Roadmap for Phase 3 – Analysis of Air/Gas System Resistance

Task 1 - Evaluate Air Preheater Leakage and Plugging

Objectives

The objectives of this task are to evaluate air preheater leakage and plugging to ascertain whether corrective actions or improvements are justified. Air preheater leakage affects the quantity of air flow to the boiler and flue gas flow from the air preheater to the chimney. Plugging increases the air and gas side pressure drops across the air preheater. Higher flows and pressure losses increase the required forced draft and/or induced draft fan capacity. Both parameters affect plant performance.

Types of Air Preheaters

Air preheaters improve boiler efficiency by recovering heat energy leaving the boiler in the flue gas and transferring the heat energy to the combustion air. Air preheaters may be classified according to the principal of their operation as either recuperative or regenerative. In a recuperative air preheater, heat is transferred directly from the hot flue gas located on one side of a heat transfer surface to the combustion air on the other side. Air preheaters operating on the recuperative principal are generally tubular type. In a regenerative air preheater, heat from the hot flue gas is transferred indirectly to the combustion air through some intermediate heat storage medium. The rotating plate type regenerative air preheater (sometimes referred to generically by the tradename Ljungstrom) predominates in the electric power industry.

Air Preheater Leakage

Leakage of relatively higher pressure combustion air into the low pressure gas stream is a factor affecting the performance of many air preheaters. Air preheater leakage has a negligible effect on the heat transfer efficiency of the air preheater; there is no difference in the heat transferred to the air stream from the gas stream because of leakage. However, gas temperature leaving the air preheater is decreased by the cooler air, which can cause corrosion and other problems.

There are two types of leakage in the rotary regenerative air preheater, gap leakage and carryover. Gap leakage takes place through gaps between rotating and stationary parts. Carryover leakage is the air carried into the gas stream from each rotor heating surface compartment as the surface passes from the air stream to the gas stream. The quantity of carryover leakage depends on the diameter and depth of the rotor and the speed of revolution. Infiltration is another source of air preheater leakage. This is outside air infiltration into the lower pressure gas streams. Carryover leakage remains constant during operation, but gap leakage and infiltration can increase and cause problems.

Gap leakage may increase for various reasons; e.g., improper setting of the seal clearances, corrosion, design limitations, wear, corrosion and other deterioration. Air to gas leakage rates are approximately 10% to 15% for rotary regenerative air preheaters employing conventional sealing systems. Newer regenerative air preheater designs have approximately 5% leakage. Leakage can be reduced by installing new or repairing the existing seals, resetting the clearances, cleaning, etc.

Tubular-type recuperative air preheaters seem to offer the opportunity for zero air leakage. However, there usually is an expansion joint between the floating tubesheet and casing which loosens during operation resulting in air leakage into the gas stream at a rate of approximately 2% for most installations. However, tubular air heaters frequently experience tube corrosion problems and high air leakage rates. Seal and tube replacements are the usual repair.

Leakage decreases the air preheater exit gas temperature and increases the forced draft and induced draft fan auxiliary power requirements. Low air preheater exit gas temperature can lead to air heater, duct, precipitator and other corrosion problems.

Air Preheater Pressure Drop, Fouling, and Plugging

The air and gas side pressure drops across the air preheater will change approximately in proportion to the square of the air and gas weights through the device. An increase in excess air will result in an increase in the air preheater pressure drop. A buildup of deposits on the heating elements will result in higher air preheater resistances with the consequences of increased pressure drop. Pressure drop will also vary with the mean absolute temperature of the fluids passing through the heater as a result of changes in density.

Fouling refers to the deposition of volatile constituents in ash on the convective surface of the air preheater. It is most common at the air preheater cold end where ash particles adhere to acid moistened surfaces. As a deposit begins to form at the cold corner of the air preheater, the problem accelerates. The insulating effect of the initial deposit extends the area of undesirably cold temperatures, thereby increasing the potential area of flyash fouling and eventually causing plugging. These deposits can decrease heat transfer and increase draft loss until they are removed, usually by sootblowing or water washing.

In addition to sulfuric acid, the presence of moisture can result in fouling of air preheater heat transfer surfaces. The presence of moisture not only aids in completion of the acid formation process but also causes fouling by itself. Fouling resulting from the entrance of external moisture into the system cannot be controlled or minimized by cold end temperature variation. Primary sources of external moisture are:

Wet steam discharged through sootblower nozzles,
Air heater coil (hot water or steam) leaks,
Rain water drawn in through unprotected forced draft fan inlets,
Economizer and boiler tube leaks, and
Incomplete air preheater washing.

Air preheater element fouling can also result from the carryover of ash from the economizer or other equipment located in the flue gas stream upstream of the air preheater. For example, selective non-catalytic reduction systems (for NO_x emission control) located upstream of the air preheater may lead to ammonium sulfate and ammonium fluoride deposits on air preheater surfaces.

Plugging is the fouling and eventual closing of heat transfer flow passages by gas-entrained ash and corrosion products. It is most common at the air preheater cold end where ash particles adhere to acid moistened surfaces. Plugging increases air preheater pressure drop and can limit unit load when fan capacity is reached at less than full load. Air preheater deposits are controlled and removed by sootblowing, cold end temperature control, surface design, off-line cleaning and furnace additives depending on the particular application.

Activity Descriptions

Table 5-1
Air Preheater Evaluation Road Map Activities

Step	Activity	Air Preheater Leakage and Plugging Evaluation Activity Description	Criteria, References, and Comments
1	Evaluate air preheater leakage.		
	1.1	Obtain operating data and compare measured air preheater leakage to design values.	ASME Performance Test Code PTC 4.3 describes principals, procedures, and computations for assessing air preheater performance including air preheater leakage. ASME Performance Test Code PTC 4.1 provides an empirical method for determining leakage by use of the percent volume of CO_2 in the gas entering and leaving the air preheater.
	1.2	Perform a visual inspection of air preheater casing, seals, tubesheets and other components, as appropriate, to identify potential contributors to leakage.	
2	Evaluate air preheater plugging		
	2.1	Obtain operating data (see Activity 1.1 above) and compare measured air preheater pressure drop to design values.	ASME Performance Test Code PTC 4.3 describes principals, procedures, and computations for assessing air preheater performance including pressure drop.
	2.2	Perform a visual inspection of air preheater heat transfer surfaces to ascertain the degree of fouling, plugging, and corrosion.	Improved soot blower operation (e.g., use of dry steam or air, more frequent operation, and better positioning) need to be considered. Water washing during unit shutdown, new heat exchange surfaces (baskets) may be needed.

Task 2 - Inspect and Evaluate Duct and Equipment

Objectives

This task focuses on evaluating the condition of the plant air and gas system ductwork to ascertain whether duct deterioration is adversely impacting performance of the forced and induced draft fans. Assessment of duct configuration aspects and the relationship to plant performance is discussed in Task 4, below.

The function of the air and gas systems ducts is to properly convey the combustion air and flue gas between equipment and components. Leakage is a principal symptom of duct deterioration or failure. Leakage can result in the escape of corrosive and erosive gases and can adversely impact fan performance. The primary means for identifying ductwork leakage problems is visual inspection.

Activity Descriptions

Table 5-2
Duct Inspection and Evaluation Road Map Activities

Step	Activity	Duct Inspection and Evaluation Activity Description	Criteria, References, and Comments
1	Visually inspect air and gas ducts to identify the following potential problems: EPRI Report TP-101698, *Operation and Maintenance Guidelines for Draft Fans,* contains guidelines for inspection and maintenance of ducts, expansion joints, and dampers.		
	1.1	Duct plate cracking.	Inspection of the ducts, especially the welds, can vary from a small task to a very large task. Access and locating the leaks can be difficult problems. Leaks are found by seeing daylight, welding gaps or tears, corrosion, damage to the insulation, fly ash patterns, etc. Other techniques include vacuum boxes, sonic sensors, and gas detection equipment.
	1.2	Flow measurement devices. Duct venturi and other flow measuring devices can cause a significant pressure loss.	Removing these devices and replacing with newer flow measuring devices can result in benefit.
	1.3	Access doors and plates. Leakage can occur at access doors and plates.	The devices should be inspected to ascertain that bolts are secured properly, gaskets are in good condition, and insulation is properly installed.
	1.4	Foundations, bracing and duct supports. Deteriorated foundations and inadequate duct supports can cause unplanned stress on the ductwork that can lead to cracking and leakage.	A detailed physical inspection may be required. This may require the unit to be shutdown, construction of scaffolding and other provisions to access the important areas and qualified inspection personnel.
	1.5	Significant and uneven distribution of fly ash accumulation. Fly ash accumulation in a properly designed system should be minimal and relatively evenly distributed.	Fly ash accumulation on the bottom of ducts can act as an insulation blanket. The upper portion of the duct expands faster or greater than the relatively cooler bottom section causing increased stress and possible damage. Misalignment of ductwork because of differential thermal expansion may be particularly evident at expansion joints and support/slide plates. Inspection for fly ash accumulations will require access to the duct interior with the unit shutdown.
	1.6	Damaged insulation and lagging. Damaged insulation and lagging can cause ‘cool spots’ in the duct that result in condensation of acid vapors in the flue gas and resultant corrosion.	A physical inspection may be required.
	1.7	Expansion joints Expansion joints should be inspected for holes, tears, and other sources of leakage. Nut/bolt tightness for a tight seal at the flange is required.	A physical inspection may be required to find tears, loose flange bolts, etc.
	1.8	Dampers Dampers should be inspected to detect the following potential problems: binding linkages and blades eroded or warped blades bearing damage and excessive wear ash buildup limiting blade movement inadequate sealing air	Dampers that are partially open when required to be full open or leaking dampers that are supposed to be closed can cause problems.

Task 3 - Boiler Operation Analysis

Objectives

The object of this task is to determine that the boiler operating performance is meeting what is required. Plant operating data may be sufficient to define the boiler operating performance or the collection and analysis of performance test or other operational data is required. The data is used to identifying primary or contributing factors leading to air and gas system performance deficiencies. Addressing boiler operating deficiencies is not included in this report.

ASME Performance Test Code PTC 4.1, Steam Generating Units, provides instructions for testing steam generating units. The PTC provides detailed instructions for alternative performance testing methodologies and includes a section (Section 7) devoted to providing specific computation procedures, equations, and related graphical data for the methods and an appendix (Section 9) containing useful computational relationships. The primary focus of the performance testing procedures is to determine boiler efficiency, capacity, and other related operating conditions. Additionally, the PTC includes a section (Section 8) describing the determination of characteristics other than the boiler's ability to meet design capacity and efficiency values. In particular, the discussions pertaining to measurements of air leakage, infiltration, draft loss, exit gas temperature, and static pressure of gas and air are relevant to analysis of air and gas system resistance concerns.

The roadmap activities described below are based on use of the testing methodologies described in PTC 4.1. However, the general instructions contained in the PTC and this guideline document can not detail a test strategy that is applicable to every variation in boiler and plant configuration. Project specific test procedures are usually needed.

Activity Descriptions

Table 5-3
Boiler Operation Analysis Road Map Activities

Step	Activity	Boiler Operation Analysis Activity Description	Criteria, References, and Comments
1	Select the test method to be used		
	1.1	Abbreviated efficiency test ASME PTC 4.1 includes a form that specifies the required data and calculation procedures for a simplified boiler test. The abbreviated test considers only the major heat losses and only the chemical heat in the fuel as input. The procedure ignores minor heat losses and credits. The abbreviated test procedure can provide a practical approach for routine testing of boiler performance that requires less data collection and computation than the more rigorous Input-Output and Heat Loss testing methods that form the core tests embodied in PTC 4.1.	In many cases, the abbreviated test may be sufficiently accurate for purposes of providing data for determination of air and gas system performance problems.

Table 5-3
Boiler Operation Analysis Road Map Activities (continued)

Step	Activity	Boiler Operation Analysis Activity Description	Criteria, References, and Comments
	1.2	Input-output method performance test This method is based on the ratio of the heat output to the sum of the fuel input plus heat credits. The input-output method requires the accurate measurement of the quantity and higher heating value (HHV) of the fuel, heat credits and the heat absorbed by the working fuel.	In some cases, the rigorous calculation methodology for the input-output method specified in PTC 4.1 can be applied using data collected from standard plant instrumentation or other simplified data collection schemes. This approach may be sufficiently accurate for purposes of providing data for determination of air and gas system performance problems.
	1.3	Heat loss method performance test This method is based upon accurate and complete information needed to calculate all accountable heat losses and credits. The heat loss method requires the determination of losses, heat credits, ultimate analysis, and HHV of the fuel. The capacity at which the boiler is tested must also be determined.	In some cases, the rigorous calculation methodology for the heat loss method specified in PTC 4.1 can be applied using data collected from standard plant instrumentation or other simplified data collection schemes. This approach may be sufficiently accurate for purposes of providing data for determination of air and gas system performance problems.
	1.4	Determine the impact of any boiler performance deficiencies on the air and flue gas systems.	Pursue corrective actions as needed or as financially justified.

Task 4 - Duct Configuration Analysis

Objectives

The analysis of the duct system flows and pressures determined in the Operating Condition Evaluation (Phase 1 - Task 1) provides the input needed to focus the Duct Configuration Analysis on the potential improvements. Based on the data from this step, locations need to be identified where appreciably higher pressure losses than used in the original design are occurring or where there is an opportunity to reduce high pressure losses. Analyses are then needed to determine improvements as described below.

EPRI Report TR-109380, Guidelines for the Fluid Dynamic Design of Power Plant Ducts, provides guidelines for duct design and configuration, and data for calculating pressure losses. This report provides information for designing new duct and fan installations, but it also has a lot of useful information for improving existing installations. Information provided includes; duct velocity, duct elbows, turning vanes, model studies, pressure loss, fly ash accumulations, fan installations.

Activity Descriptions

Table 5-4
Duct Configuration Analysis Road Map Activities

Step	Activity	Duct Configuration Analysis Activity Description	Criteria, References, and Comments
1	Duct configuration analysis to achieve reduced pressure losses		
	1.1	Additional or more detailed calculations may be needed. Current references may more accurately predict the actual duct pressure losses. Additional or modified vanes can be considered and designed with more predictable results with the more accurate calculations and newer references.	EPRI Report TR-109380, *Guidelines for the Fluid Dynamic Design of Power Plant Ducts,* contains guidelines duct design and configuration, and data for calculating pressure losses. This reference explains the practice of designing for low capital cost with the resulting high pressure losses.
	1.2	Three dimensional models have been frequently used for achieving uniform flow into precipitators. However, 3D models have been used for many other purposes, including air and flue gas ducts and boiler windboxes. These studies use fluid flow concepts to adjust the airflow through the model for close replication of the actual flow conditions. Ductwork 3D models have studied pressure drop and turning vane design, and ash fallout and accumulation.	
	1.3	Computational Fluid Dynamic analysis of air and gas system flows can be also be used to model the air and flue gas system to investigate improved flow conditions. CFD software has the capability of modeling.	

6
ROAD MAP FOR PHASE 4 – ANALYSIS OF FAN MODIFICATIONS

Overview

This phase is similar in approach to Phase 3, but involves options that focus on the fans. Most often, these options would be considered if the system resistance improvements considered in Phase 3 do not meet the required performance goals. However, there may be reasons for a specific plant to initially consider fan modification options initially. For example, complete replacement of a fan is usually an expensive and complicated option. But, if the existing fans were in need of significant maintenance and repairs, the cost of a new fan might not be prohibitive. Another possibility is the need for a major improvement on a strategically important unit.

Common fan analysis and modifications include:

- Inadequate fan performance may be remedied by modifications to inlet vanes, dampers, inlet silencers, larger inlet boxes, better discharge duct (evase') proportions, and added or improved flow guide vanes.
- Fan wheel blade extensions and casing configuration improvements may provide the needed improved performance. Fan shaft modifications and/or new motors may be needed.
- Step-up gears that increase fan speed, new or improved fluid drive couplings, variable speed motors in place of fluid drives and similar options can provide improved fan performance.
- New replacement or additional fans, motors, and auxiliaries may be needed.

The activities described below can identify modifications that can resolve most fan/system problems. The costs for these modifications can be significant. Data from Phase 1 and the financial information from Phase 2 are used to select the Phase 4 Tasks to be investigated. After completing the chosen Tasks and the potential improvements are identified the analysis can proceed to Phase 5 – Decision to Proceed.

Figure 6-1 provides a road map diagram and Tables 6-1 through 6-4 provide activity descriptions for Phase 4.

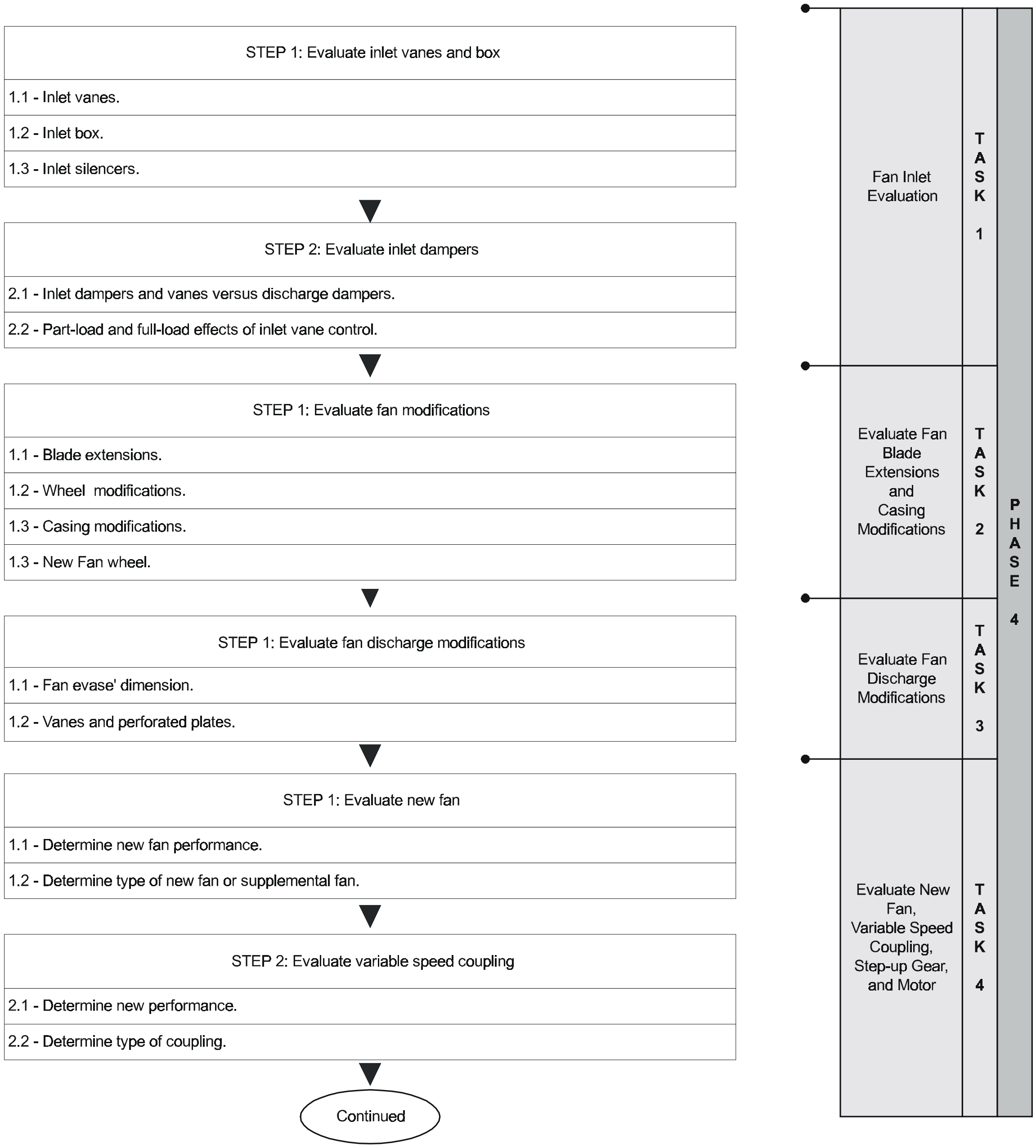

Figure 6-1
Road Map for Phase 4 – Fan Modification Analysis

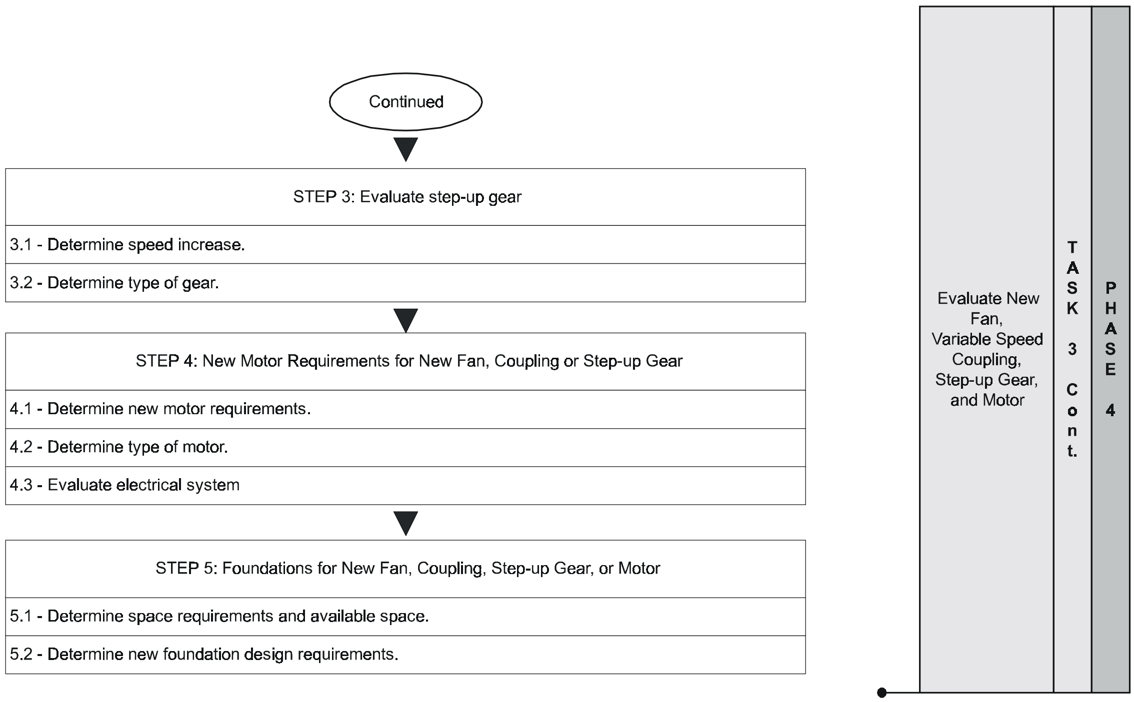

Figure 6-1
Road Map for Phase 4 – Fan Modification Analysis (continued)

Task 1 - Evaluate Fan Inlet Vanes, Dampers, Inlet Box, and Silencer

Objectives

The objective of this task is to evaluate the configuration of the ducts and devices on the inlet of the fan for conformity to good engineering practices. The evaluation will identify candidate modifications or enhancements to decrease system resistance and improve fan performance.

Fan performance can be strongly influenced by the configuration of the fan's inlet connections, vanes, dampers, and silencers. For optimum performance, airflow into the fan should be fairly streamlined and fill the fan blade or rotor passages as uniformly as possible. Excessive turbulence and uneven air flow into the fan increases system resistance, decreases fan capacity and efficiency, and can cause damaging vibration.

Activity Descriptions

Table 6-1
Fan Inlet Evaluation Road Map Activities

Step	Activity	Fan Inlet Evaluation Activity Description	Criteria, References, and Comments
1	Evaluate inlet duct, vanes, and box.		
	1.1	Inlet vanes guide flow into the fan inlet bell and reduce pressure losses. Inlet vanes can be designed for use with dirty air as well as clean air.	Information from the fan manufacturer, from calculations, a 3D model study, or CFD analysis may be needed. Sufficiently uniform and properly guided flow entry into the fan wheel is required.
	1.2	FD fan inlet box velocities are often quite high, causing high pressure loss.	Reducing pressure losses in this zone may prove to be difficult because usually this is a congested zone with the fan shaft, bearings, possibly inlet vanes, and high air velocity and turbulence.
	1.3	FD Fans are usually located either outdoors and have an inlet silencer or indoors (within a “fan” room). Silencers usually have low pressure losses, but investigating the silencer pressure loss should be done if the fan performance needs to improved.	Obtaining manufacturer information and making measurements of the pressure loss will usually provide sufficient information to determine if an improvement is needed.
2	Evaluate inlet dampers for both FD and ID Fans		
	2.1	Discharge dampers have been used to control flow instead of inlet dampers or vanes. Discharge damper control adds resistance to the system and causes higher part load horsepower at lower unit operating loads.	References are available, which provide discussions on fan pressure/flow curve characteristics and horsepower requirements with inlet dampers, outlet dampers and inlet vanes.
	2.2	Replacing inlet and discharge dampers with inlet vane control can provide better partial load control and motor horsepower, but may not provide any or only a small full load performance improvement.	Replacing inlet and discharge dampers with inlet vane control can provide better partial load control and motor horsepower, but may not provide any or only a small full load performance improvement.

Task 2 - Evaluate Fan Blade Extensions and Casing Modifications

Objectives

Fan blade extensions and casing modifications have been used successfully to increase fan flow and developed pressure. Fan performance improvement is obtained by the blade extensions increasing the fan wheel diameter and casing modifications improve the flow conditions between the wheel and the outlet.

Activity Descriptions

Table 6-2
Fan Blade Extension and Casing Evaluation Road Map Activities

Step	Activity	Fan Blade Extension and Casing Evaluation Activity Description	Criteria, References, and Comments
1	Evaluate fan modifications		
	1.1	Blade extensions result in a larger diameter fan that increases fan flow and pressure to the duct system.	Installing extensions must be done using detailed engineering analysis and design because this requires welding to the existing blades, additional forces and dynamics on the fan wheel and shaft, etc. The fan casing may require modifications. Additional motor horsepower is required. Bearing loading may need to be checked. Fan operating efficiency usually is less because the installed blade shape is usually not ideal. However, this modification has been accomplished successfully.
	1.2	Improving the fan wheel configuration and dimensions can provide increase performance.	Detailed engineering and design is needed because of the need to analyze forces, stresses and vibrations properly and to design for these conditions using the proper materials and welding.
	1.3	Casing Modifications can improve output and efficiency by minimizing recirculating flows, turbulence, and excessive clearances (the “cutoff” dimension) between the wheel and the casing.	Analysis and flow model studies are frequently needed. Casing modifications must consider flow turbulence, vibration, flow efficiency and structure strength.
	1.4	A new fan wheel can have more efficient blade shape and other design features that increase performance.	Maintaining the same housing or minimizing housing changes lowers the modification cost. The existing motor or a new motor may be needed depending on the magnitude of the performance increase required. Fan wheel bearings, couplings, and other auxiliaries may need to be changed.

Task 3 - Evaluate Fan Discharge Modifications

Objectives

Flow from the fan wheel exits the fan through a duct section that is often called the evase’ at high velocity and turbulence, and non-uniform conditions. Often fans are ‘close coupled” (i.e., with a minimum distance between the fan and the adjacent equipment, and abrupt changes in duct size and direction) with air preheaters, chimneys and other equipment without providing an evase’ that provides for proper flow conditions. Adhering to the fairly well established guidelines for the evase’ size and configuration will result in minimum pressure losses. Using vanes, perforated plates and modifying the duct configuration can improve on performance losses (problems) that exist in this area.

Activity Descriptions

Table 6-3
Evaluate Fan Discharge Modifications

Step	Activity	Evaluate Fan Discharge Modifications Activity Description	Criteria, References, and Comments
1	Fan evase' dimensions		
	1.1	Obtain the fan evase' dimensions and compare with guidelines.	Guidelines for evase' configurations are provided in the EPRI Report TR-109380, *Guidelines for the Fluid Dynamic Design of Power Plant Ducts,* and in other references.
	1.2	Vanes, perforated plates and duct configurations can be installed to improve on the flow conditions in this section of the system.	A detailed analysis and design is often needed for these modifications because of the flow conditions, potential for fan vibration and loss of performance, and durability for the vanes and other flow assisting devices. The analysis needs to incorporate calculations and references, and flow model studies are often needed.

Task 4 - Evaluate New Fan, Variable Speed Coupling, Step-up Gear, or Motor

Objectives

These options are usually more capital cost than the other options. In the current competitive electricity market situation significant capital expenditures are often difficult to cost justify. However, there are many situations where these options need to be considered.

New fans, couplings, and/or step-up gears often require new motors and/or new or modified foundations. Motor and foundation activity descriptions are similar for these three modification steps and are provided in their respective Steps. The Motor Step includes the variable speed motor option. Often these modifications need to be looked at in combinations in addition to separately; e.g., a new fan and new variable speed motor may be the best choice.

Available space for new motors, variable speed couplings, step-up gears and motors needs to be determined.

Activity Descriptions

Table 6-4
Fan, Coupling, Step-up Gear, and Motor Evaluation Road Map Activities

Step	Activity	Fan, Coupling, Step-up Gear and Motor Evaluation Activity Description	Criteria, References, and Comments
1	Evaluate new fan		
	1.1	Required new fan performance is determined by calculations (see Phase 1, Task 3) and financial cost justification from Phase 2. Determining the fan performance needs to consider the full range of fuels and load range.	New fans are a major plant improvement project often requiring new motors, new or modified foundations, ducts and dampers, control system and other modifications. Therefore, significant expenditures are involved. Planning includes unit outage time for removal of the existing fan and installing the new fan, e.g., about two months for a 500 MW unit. The fan specified flow and pressure needs to consider full and partial loads, and the financial penalties for oversizing (EPRI report TR – 109380 and other references explain this problem).
	1.2	The type of fans commonly used are centrifugal (radial), or axial. An option not used often, but worth considering is a supplemental small fan; especially for IFGR applications where high temperature flue gas could cause problems to the original FD Fans. Discharge from the supplemental fan could be routed to a location where good mixing with the airflow was favorable. Information is needed from manufacturers for most plants because these fans are usually designed specifically for each application.	Current centrifugal fan designs usually have air foil shaped blades, and high efficiency that can provide a significant improvement over older less efficient fans. With higher efficiency these new centrifugal fans may provide the improved performance needed with the same motors. Inlet control vanes or variable speed couplings or motors are frequently used for flow control. Axial fans have not been used as often as centrifugal fans, especially for ID Fan service because of flyash erosion. Axial fan flow control can be by fixed blades with inlet vanes, variable speed motors or variable pitch blades. Both types of fans have provided satisfactory service. There are many references that describe the characteristics of these fans. An important topic is the shape of the fan pressure/flow performance curve. This curve must be compatible with the full range of unit operation. There are many references providing descriptions of fan characteristics.
2	Evaluate variable speed coupling		
	2.1	The usual reason for variable speed couplings is more economical operation at part load operation. Ease of startup is an advantage, especially for cycling units.	Information is needed from manufacturers for most plants for the specific application.

Table 6-4
Fan, Coupling, Step-up Gear, and Motor Evaluation Road Map Activities (continued)

Step	Activity	Fan, Coupling, Step-up Gear and Motor Evaluation Activity Description	Criteria, References, and Comments
	2.2	There are two main types of variable speed couplings. The hydraulic type will operate the fans at about 98% of motor speed. The mechanical type provides more efficient operation and will operate the fans at full motor speed.	
3	Evaluate step-up gear		
	3.1	Step-up gears can be used to increase fan flow and pressure. The increase is determined by the “fan laws” available in many references. The required fan horsepower increase needs to with the existing motor capability or a new motor is required.	Increasing fan speed needs be thoroughly analyzed to determine that the fan wheel, shaft and other rotating components and bearings are operating safely. A step-up gear may be a good choice in combination with the need to rebuild or replace a fan motor when the current fan capacity is less than needed.
	3.2	There are different gear designs available, but generally there is no significant differences.	
4	Evaluate new motor		
	4.1	A new motor(s) may be needed for a new fan, a speed increasing gear, a fluid drive, replacing a previously undersized or failed motor, or a combination of these options.	An analysis is required to determine if the existing motor has adequate horsepower for the required flow to operate the fan at the needed output (the motor power factor should be investigated).
	4.2	A variable speed or two speed motor can be installed that will provide operational advantages.	A variable speed motor can provide higher efficiency (lower kW) at partial load unit operation and higher speed to increase fan output at full unit load. Usually the advantage of a two-speed motor is more efficient part load operation. There are many references that describe motor options.
	4.3	The electrical system cables, switchgear, transformer rating and other components need to be analyzed for adequacy. The need for modifications to the control system also needs to be investigated.	A detailed analysis needs to be completed.
5	Foundations for new fans, couplings step-up gears or motors		
	5.1	Space for new equipment needs to be determined.	
	5.2	Foundation modifications adding new support for additional equipment to an existing foundation or demolishing the existing foundation and installing a new foundation need to be determined by a detailed design analysis.	Foundation design needs to consider many requirements including; equipment weight and operating loads, soil characteristics, need for piles, weight for vibration dampening, provisions for any differential settlement or thermal expansion.

7 ROAD MAP FOR PHASE 5 – DECISION TO PROCEED

Overview

Phase 5, the Decision to Proceed Phase, is the point when the results of the prior phases are reviewed, updated and finalized. Utilizing Phase 1 Air and Gas Systems Evaluation and Decision Process ladder diagram, Figure 2-1 is appropriate during this phase.

Task 1 - Decision to Proceed

Objectives

The results of the prior phases may show that one of the options is clearly the best selection by providing reasonable return on the additional capital investment and resolving operations issues. In this case the decision to proceed can be made quickly. If the results between the financial and non-financial evaluations result in two or more options providing comparable returns or if the results are not consistent with financial or operating requirements it will be necessary to return to the prior phases and pursue additional or modified options. The steps for the Decision to Proceed follow:

Activity Descriptions

Table 7-1
Decision to Proceed

Step	Activity	Activity Description	Criteria, References, and Comments
1	Decision to Proceed		
	1.1	Final Air and Gas System Analysis	A final review and updating of the Phase 3 and 4 analysis.
	1.2	Final Operational Evaluation.	The plant operating schedule needs to be finalized to incorporate the projected dispatch schedule and number of startups, fuel specification, forecasted plant availability, emissions and other operating parameters.
	1.3	Final Financial Evaluation	The results from a reuse of the Initial Financial Steps based on the above two steps and final cost estimates will input to the Decision to Proceed.