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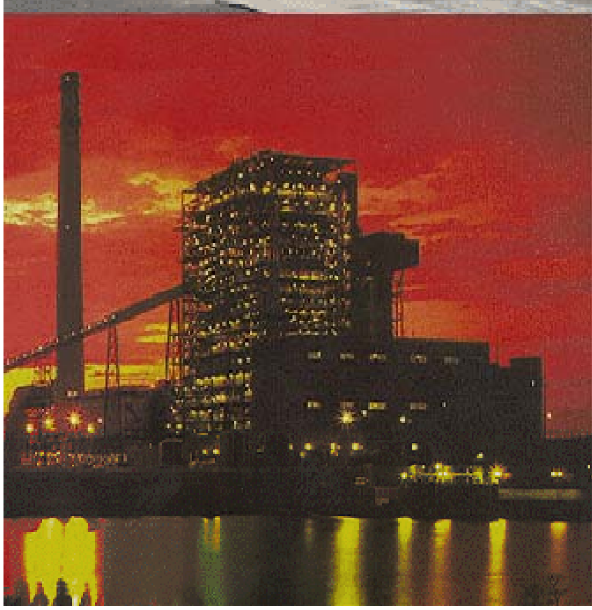

ENGINEERING AND ECONOMIC FACTORS AFFECTING THE INSTALLATION OF CONTROL TECHNOLOGIES FOR MULTIPOLLUTANT STRATEGIES

The information presented here reflects EPA's modeling of the Clear Skies Act of 2002. The Agency is in the process of updating this information to reflect modifications included in the Clear Skies Act of 2003. The revised information will be posted on the Agency's Clear Skies Web site (www.epa.gov/clearskies) as soon as possible.

FOREWORD

The U. S. Environmental Protection Agency is charged by Congress with protecting the Nation's land, air, and water resources. Under a mandate of national environmental laws, the Agency strives to formulate and implement actions leading to a compatible balance between human activities and the ability of natural systems to support and nurture life. To meet this mandate, EPA's research program is providing data and technical support for solving environmental problems today and building a science knowledge base necessary to manage our ecological resources wisely, understand how pollutants affect our health, and prevent or reduce environmental risks in the future.

The National Risk Management Research Laboratory is the Agency's center for investigation of technological and management approaches for reducing risks from threats to human health and the environment. The focus of the Laboratory's research program is on methods for the prevention and control of pollution to air, land, water, and subsurface resources, protection of water quality in public water systems; remediation of contaminated sites and groundwater; and prevention and control of indoor air pollution. The goal of this research effort is to catalyze development and implementation of innovative, cost-effective environmental technologies; develop scientific and engineering information needed by EPA to support regulatory and policy decisions; and provide technical support and information transfer to ensure effective implementation of environmental regulations and strategies.

This publication has been produced as part of the Laboratory's strategic long-term research plan. It is published and made available by EPA's Office of Research and Development to assist the user community and to link researchers with their clients.

E. Timothy Oppelt, Director
National Risk Management Research Laboratory

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Engineering and Economic Factors Affecting the Installation of Control Technologies for Multipollutant Strategies

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Executive Summary

This report evaluates the engineering and economic factors of installing air pollution control technologies to meet the requirements of multipollutant control strategies. The implementation timing and reduction stringency of such strategies affect the quantity of resources required to complete the control technology installations and the ability of markets to adjust and to provide more resources where needed. Using the Integrated Planning Model (IPM), the U.S. Environmental Protection Agency (EPA) estimated the number and size of facilities that need to install new emissions control equipment to meet the implementation dates and emission reductions set forth in the Clear Skies Act.

This study provides an estimate of the resources required for the installation of control technologies to obtain emission reductions of sulfur dioxide (SO_2), nitrogen oxides (NO_x), and mercury under the Clear Skies Act. More innovative control technologies and compliance alternatives requiring fewer resources than those considered for this study are likely to be developed with the implementation of the Clear Skies Act. Market based approaches reward firms for finding cost-effective measures that exceed emission reduction targets. For example, improved scrubber performance and the ability of some firms to switch to lower sulfur fuels under the Acid Rain Program were reasons the cost of that program were less than projected. The development of control technology alternatives to selective catalytic reduction (SCR) under the NO_X State Implementation Plan (SIP) Call is another example of how alternative solutions may require fewer resources than the projected approach. In addition to innovative technologies, the time allowed for installation of significant numbers of control technologies is an important factor to consider, especially for the near future. While it is expected that markets for the materials and labor used in the construction and operation of the control technologies will respond to increased demand, this response will not be instantaneous. It is likely that the strength of this market response will increase as time progresses. It is expected that the market would have sufficient time to respond to phase II of the program as the more stringent emission targets for phase II are set for 2018. Even though this analysis looks at the resource availability beyond 2010, these projections are of limited value as they do not take into account this market response. However, it is projected that there are sufficient resources available to complete the projected control technology installations for phase I by 2010. It should also be noted that decreasing the amount of time provided to install control technologies to meet a given strategy has the potential to affect the cost of compliance as this will accelerate their installation.

The control technologies considered by this report as candidates to be used for multipollutant control strategies include: limestone forced oxidation (LSFO) flue gas desulfurization (FGD) for the control of SO_2, SCR for the control of NO_X, and activated carbon injection (ACI) for the control of mercury.

Installation of LSFO presents a conservatively high estimate of anticipated resources and time to provide additional control of SO_2 emission, since LSFO systems commonly are more resource intensive than many other FGD technologies. Conservatively high assumptions were made for the time, labor, reagents, and steel needed to install FGD systems. For LSFO installation timing, it is expected that one system requires about 27 months of total effort for planning, engineering, installation, and startup, with connections occurring during normally scheduled outages. Multiple retrofits at one plant would take longer to install (e.g., approximately 36 months for the retrofit of three absorbers for six boilers). Limestone is the reagent used in LSFO to remove SO_2 from the flue gas stream. Steel is the major hardware component for FGD systems and is used primarily for the absorber, ductwork, and supports.

Other elements of FGD installations, such as construction equipment requirements, are typically modest, particularly given that systems are installed at the back end of the facility and close to the ground. More recently, improvements in technology have been implemented where space requirements were an issue for construction and accommodating the FGD system, including fewer and smaller absorbers and more efficient on-site use and treatment of wastes and byproducts.

SCR is currently the predominant technology to be used for NO_X control and is also the most demanding in terms of resources and time to install when compared to other NOx control technologies. It is expected that one SCR system requires about 21 months of total effort for planning, engineering, installation, and startup. Multiple SCR systems at one facility would take longer to install (e.g., approximately 35 months for seven SCRs). Ammonia and urea are the reagents used along with a catalyst to remove NO_X from the flue gas stream. Experience in installing SCRs for the NO_X SIP Call has shown that the SCR equipment can be installed on the facilities in the space provided. In some cases, some moving of equipment has been necessary. One of the primary pieces of specialized construction equipment that can be useful for SCR installations are tall, heavy-lift cranes, and these appear to be in adequate supply.

ACI was presumed to be the technology that would be used to reduce mercury where dedicated mercury controls were needed. Planning, engineering, installation, and start up of one ACI system is only about 15 months. Multiple ACI systems at any one facility are assumed to take longer to install (e.g., approximately 16 months for two ACI). ACI hardware is comprised of relatively common mechanical components and is largely made of steel. An ACI system requires much less in terms of steel, labor, or other resources to install than either FGD or SCR technology. Therefore, the impact of ACI hardware on resource demand is much less than that of FGD or SCR technologies for SO_2 or NO_X control, respectively.

The resources required for the installation of control technologies to achieve the emission reductions under the Clear Skies Act were estimated and compared to their current market availability. For the Clear Skies Act, control technology installations have been looked at for the periods between now and 2005, 2005 and 2010, 2010 and 2015, and 2015 and 2020. For the first period, it is assumed that all controls need to be installed in a 31-month period. This will provide a conservatively high estimate of the required resources because many of the necessary control installations have already begun. For the other five year-periods, it is conservatively estimated that all installations will be completed within three years. However, the estimates indicate that there is ample steel and general construction labor to support the installation of these technologies over these time periods. As noted above, projections beyond 2010 are of limited value as market conditions could change significantly between now and 2010 in response both to demand for resources for a multipollutant program and because of other market factors. Skilled labor requirements, specifically for boilermakers, were estimated and have the potential to be the more limiting resource requirement in phase I of the program. The demand for boilermaker labor due to the NO_X SIP Call over the next few years is likely to be limiting, but through the implementation of the Clear Skies Act, additional recruiting and training of new boilermakers would create a stronger market for skilled labor, ultimately increasing the supply.

With regards to reagents and other consumables, it is projected that there is sufficient supply of limestone for additional FGD systems. It is estimated that there is also enough SCR catalyst capacity to supply this market. Ammonia and urea supply is also plentiful, although it is expected that NO_X reduction will cause a moderate increase in U.S. demand. Bolstered by the fact that there is currently a worldwide excess capacity problem for suppliers of these globally traded commodity chemicals, it is projected that there will be an ample supply of ammonia and urea. U.S. demand for activated carbon is expected to slightly increase as a result of the Clear Skies Act. Activated carbon is traded on a global basis and there is currently substantial excess capacity that can readily provide for this increase in demand.

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List of Acronyms

AC	Activated carbon
ACI	Activated carbon injection
CAAA	Clean Air Act Amendments
DCS	Distributed control system
ESP	Electrostatic precipitator
FF	Fabric filter
FGD	Flue gas desulfurization
GW_e	Gigawatt (electric)
IPM	Integrated Planning Model
LSD	Lime spray dryer
LSFO	Limestone forced oxidation
MEL	Magnesium enhanced lime
MW_e	Megawatt (electric)
NAAQS	National Ambient Air Quality Standards
PJFF	Pulsejet fabric filter
PLC	Programmable logic controller
SCR	Selective catalytic reduction
SIP	State Implementation Plan
TVA	Tennessee Valley Authority

Chapter 1
Background

In response to continuing concerns about emissions from electric generating units, further reductions of emissions of multiple pollutants from electric power sector are being considered. Because the largest portion of emission reductions are expected to come from the coal-fired electricity-generating segment of the electric power sector, this report considers environmental improvement for coal-fired electricity generating power plants. Strategies enabling the control of multiple pollutants (multipollutant control strategies) from these plants have recently been receiving increased attention.

Currently, power plants are required to reduce emissions of nitrogen oxides (NO_X) and sulfur dioxide (SO_2). The revisions of the National Ambient Air Quality Standards (NAAQS) aimed at reducing haze may require electric utility sources to adopt additional control measures. In addition, the U.S. Environmental Protection Agency (EPA) has determined that the regulation of mercury emissions from coal-fired power plants is appropriate and necessary. Concurrently, legislation has been proposed in previous and current Congresses that would require simultaneous reductions of multiple emissions, and the Administration's National Energy Policy recommends the establishment of "mandatory reduction targets for emissions of three main pollutants: sulfur dioxide, nitrogen oxides, and mercury."

The administration's multipollutant proposal, a far reaching effort to decrease power plant emissions, was introduced as the Clear Skies Act in the U.S. House of Representatives on July 26, 2002 and in the U.S. Senate on July 28, 2002. This legislation is intended to reduce air pollution from electricity generators and improve air quality throughout the country. The Clear Skies Act is designed to decrease air pollution by 70 percent through an emission cap-and-trade program, using a proven, market-based approach that could save consumers millions of dollars. The Clear Skies Act calls for:

- Decreasing SO_2 emissions by 73 percent, from current emissions of 11 million tons to a cap of 4.5 million tons in 2010, and 3 million tons in 2018,
- Decreasing NOx emissions by 67 percent, from current emissions of 5 million tons to a cap of 2.1 million tons in 2008, and to 1.7 million tons in 2018, and
- Decreasing mercury emissions by 69 percent by implementing the first-ever national cap on mercury emissions. Emissions will be cut from current emissions of 48 tons to a cap of 26 tons in 2010, and 15 tons in 2018.

Therefore, it is timely to review the engineering and resource requirements of installing control technologies for multipollutant control strategies.

This report analyzes the resources required for installing and operating retrofit control technologies for achieving reductions in multiple pollutants from coal-fired power plants in the United States. It examines the control technology's hardware, reagents, availability of the needed construction equipment, time required to implement at plants with single and multiple installation requirements, and the availability of labor needed for installation. The control technologies considered in this report include limestone forced oxidation (LSFO) wet flue gas desulfurization (FGD), selective catalytic reduction (SCR), and activated carbon injection (ACI) for the control of SO_2, NO_X, and mercury, respectively.

The report is organized into eight chapters and one appendix. Chapter 1 provides general background information on emission control technologies. Chapter 2 analyzes the SO_2 control technology resource requirements by providing information on control technology's hardware and reagents, the construction equipment necessary to install a control technology, time required to implement this control technology at plants with single and multiple installation requirements, and the amount of labor needed to install the control technology. Chapters 3 and 4 review, in the same fashion, the resource requirements of installing NO_X and mercury control technology, respectively. Chapter 5 focuses on synergistic combinations of control retrofits on a single unit. Chapter 6 examines the availability of resources necessary for the installation of SO_2, NO_X, and mercury control retrofit technologies for the timing and emission reductions proposed under the Clear Skies Act. Conclusions are presented in Chapter 7 and references in Chapter 8. Appendix A is located at the end of this report. It provides implementation schedules for single and multiple control technology installations.

Chapter 2
SO_2 Control Technology Retrofits

In this chapter, the resource requirements to retrofit FGD systems to remove SO_2 are examined for existing coal-fired electric utility boilers. The FGD technology most commonly installed in the U.S. and worldwide is LSFO. Material, labor, and construction equipment resource estimates presented in this chapter are for LSFO systems and are a conservative estimate compared to less resource intensive magnesium enhanced lime (MEL) or lime spray dryer (LSD) technologies. Typically, MEL and LSD technologies rely upon increased reactivity of reagents with flue gas and require fewer resources for installation. Advances in FGD technology, design, materials, and expertise available for retrofit installations made over the last decade form a sharp contrast to earlier retrofit systems. Technology to remove SO_2 is anticipated to continue along current trends and rely heavily on wet FGD and other advanced technologies. This chapter examines the experience and issues for the retrofit installation of LSFO technology.

The chapter focuses on the resources needed for typical or normally constrained wet FGD, specifically LSFO, retrofit installations. Wet FGD retrofit technology generally provides a conservatively high estimate of most resources. However, it is likely that other SO_2 removal technologies, as well as upgrades or enhancements to existing FGD systems, will compete in the market under a multipollutant strategy. Upgrades to existing FGD systems would include a case-by-case examination of the absorber tower, flue gas inlet, absorber gas velocity, reagent preparation, upgrade pumps, and potential changes to some internals, the type of reagent, and to the chemical processes to increase performance. Scrubber upgrades were not considered in this analysis in order to provide a conservative estimate of the resource demand for a multipollutant strategy. This is because upgrades to existing retrofits will generally consume fewer resources than full retrofits regardless of the technology.

2.1 System Hardware

The wet FGD process operates by reacting SO_2 in the flue gas with a reagent in an absorber. FGD systems are typically positioned after the particulate control device. FGD retrofits are positioned downstream, typically at the back end of the facility, and are not intrusive to the boiler. Typical configuration is shown in Figure 2-1. At the typical unit, hot corrosive flue gases leaving the particulate control device (149– 182 ºC) are cooled, or quenched, before entering the main absorber device. Quenching cools and saturates the flue gas with absorber slurry. Quenching can occur in a prescrub area or more commonly an area integral to the absorber. After quenching, the less corrosive flue gases entering the absorber decrease to temperatures of 49 – 66 ºC with pH values between 5 and 6.5. Some higher efficiency boilers may have increased flue gas velocities and can result in corrosive flue gas "blow through" to the absorber. The chemical reactions that occur with the limestone reagent form a corrosive environment requiring many of the system components to be corrosion and abrasion resistant. The quenching area is typically a highly corrosive environment and the reagent slurries are highly abrasive. The handling and processing of the reagent, commonly limestone, is often done onsite, as is the treatment of the effluent as waste or processing into a saleable product (e.g., gypsum handling facility).

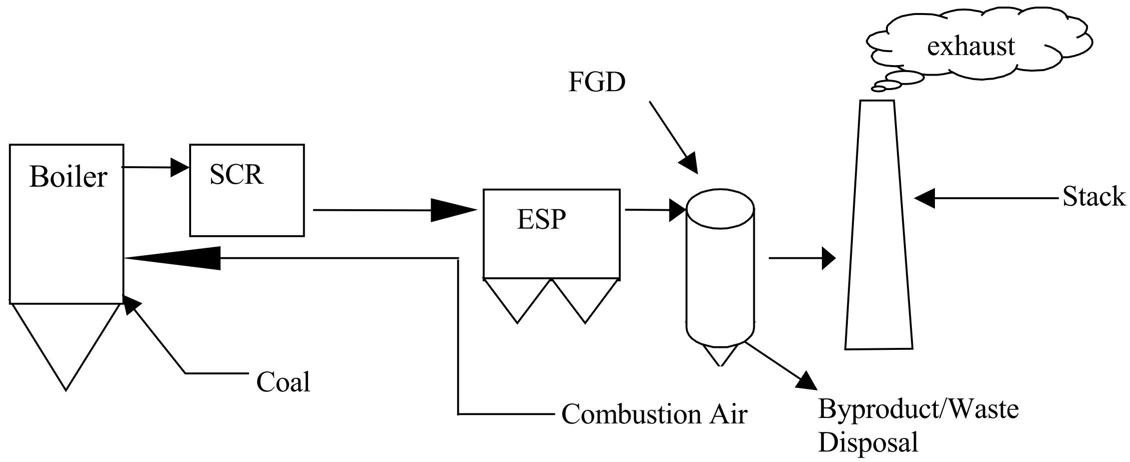

Figure 2-1. Gas path for coal-fired boiler with FGD.

The major systems and components of a wet FGD limestone reagent system include:

Reagent Feed

- Limestone conveying and crushing (e.g., ball mills) equipment
- Slurry preparation tank and reagent feed equipment

SO_2 Removal

- Absorber tower or reactor (tray optional)
- Absorber slurry recirculation/reaction tank and optional air sparger (forced oxidation operation)
- Mist eliminator wash system
- Slurry bleed
- Pipes, pumps, and valves
- Gas reheaters

Flue Gas Handling

- Ductwork
- Support steel
- Fans, blowers, and dampers

Waste/By-Product

- Dewatering system (settling tanks/vessels, hydrocyclones, and/or vacuum filters)
- Stacking equipment

Major wet FGD system components are shown in Figure 2-2. The hardware and equipment to support wet FGD technology involves five major systems. Two systems are primarily responsible for the direct scrubbing and handling of flue gases, and three systems are involved with delivery of reagents, processing of wastes (air, solids, and water), and the processing of wastes into saleable by-products. Typically, the greatest hardware requirements involve the systems for SO_2 removal, primarily the absorber vessel, and flue gas handling, particularly ductwork and support steel. Much of the equipment for these systems will be unique to the site and project requirements, although the equipment specifications may be repeated if multiple absorbers are involved. Typically an FGD retrofit can use an existing chimney or stack.

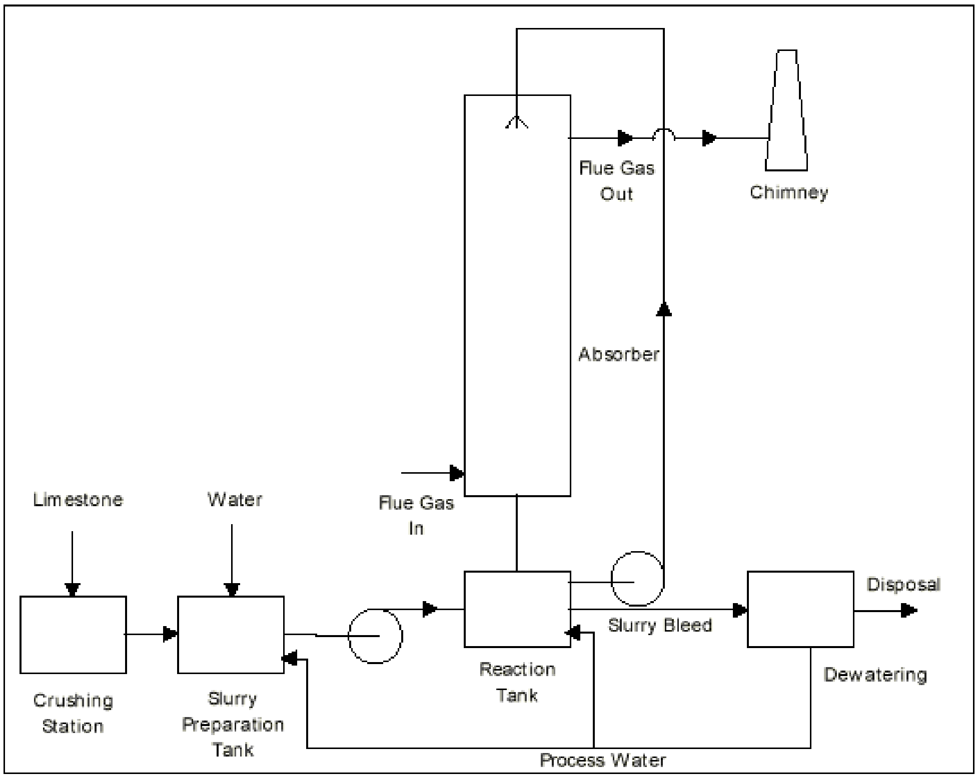

Figure 2-2. Major components of wet FGD.

The material used in the largest quantity for an FGD retrofit, aside from reagent, is steel. In general, the amount of structural steel for a typical FGD retrofit system is equal to or less than the steel requirements for a SCR retrofit of the same size.[1] The reduced requirement for structural steel is due to the FGD absorber usually being self-supporting, weighing less, and being installed closer to the ground. In contrast, a typical SCR installation is heavier, elevated, and adjacent to the boiler. The majority of structural steel in modern FGD installations is dedicated to ductwork and supports. Other steel may be needed to reinforce existing steel at a facility. In addition to structural steel, additional light, or gallery, steel may be used in the limestone preparation area and for the processing of waste or byproducts (e.g., buildings). Modern FGD systems are more attuned to the corrosive SO_2 scrubbing environment and therefore increasingly utilize fiberglass, rubber lined steel, and alloys in construction. In addition, because of existence of corrosive zones, preference is often given to the use of large-sized sheets that minimize welding.[2] Large-sized sheets are used to fabricate the absorber vessel, the ductwork, and supports. Particularly over the past decade, there has been greater availability of plate steel for FGD projects due to the global sourcing of carbon steel.

Total steel requirements for retrofitting a typical 500 mega Watt, electric (MW_e) FGD system are in the range of 1000 to 1125 tons of steel, or between 2.0 and 2.25 tons of steel per MW_e. This range assumes approximately 80 percent of the structural steel is for ductwork and supports and 20 percent is required for miscellaneous steel such as reagent conveying equipment, buildings, and solids handling systems. An assumption of 1125 tons of steel is a conservatively high estimate since 500 MW_e FGD retrofit installations have been completed with as little as 250 to 375 tons of steel, or 0.5 tons of steel per MW_e..[1,3] Often a single absorber will serve multiple boilers and reduce much of the steel that would be required if absorbers had been fed by individual boilers. Currently, the installed maximum single absorber capacity in the U.S. is 890 MW_e being fed by 2 boilers at Tampa Electric's Big Bend Station. It is likely that two 450 MW_e boiler units will use a common single absorber with commensurate reduction in required steel from efficiencies gained by common areas. For example, a 900 MW_e system is estimated to use approximately 2000 tons of steel, or about 2.2 tons of steel per MW_e, rather than a combined maximum of 2025 tons for a situation in which the boilers required separate absorbers.

In general, a better understanding of the chemical processes in an FGD system allows designers to maximize mass transfer in a minimum amount of space.[4] More efficient designs can also reduce the amount of steel needed for the absorber and ductwork. Other advanced design factors reduce steel requirements, including the virtual elimination of redundant absorbers, the ability to down-size absorbers without sacrificing performance (e.g., by increasing flue gas velocity, advanced placement of spray nozzles, enhancing limestone characteristics), and material changes including wallpapering with alloys and utilizing fiberglass.[5] A new generation of wet FGD systems, pioneered in the mid to late 1990's, improved mass transfer, which resulted in the usage of more compact absorbers that are estimated to require 50 percent less material, compared to an older generation of wet FGD systems.[5] In addition, typical MEL absorber units need less steel due to the use of smaller absorbers enabled by shorter residence time requirements than for LFSO systems. In this report, the estimate of typical LFSO FGD system hardware requirements provides a conservatively high estimate of installation resources compared to other SO_2 control technologies.

The majority of hardware required for FGD systems is commonly available. Storage tanks, nozzles, and piping for the reagent storage and delivery system are also common and therefore widely available. The major hardware for an FGD system includes the flue gas duct system, limestone storage (including loading and conveyer equipment), gypsum dewatering and wastewater treatment, gypsum storage, piping, valves, pumps and tanks, electricity supply, controls, instrumentation, pipe bridges and cable channels, and foundations and buildings as needed. FGD systems also include hardware such as inlet fans, dampers, absorber internals, recirculation pumps, and oxidation blowers that are commonly used in other large industries. Because this hardware is used extensively throughout industry, availability should not be an issue, except that supply of this type of equipment needs to be integrated into the overall project schedule so it does not cause bottlenecks. Early FGD systems were designed with separate quenching, or prescrubber, systems to cool the flue gas coming off the particulate control device. Modern systems take the hot flue gas directly into the absorber, where quenching occurs. Limestone and gypsum handling also includes milling, conveying, and wastewater treatment systems.

2.2 Reagents

Wet FGD systems require a continuous feed of reagent to remove SO_2. Generally, if pH of scrubbing liquor falls below a range of 5.0 to 6.0, additional reagent is required to maintain the reactivity of the absorbent. Limestone is the most commonly used reagent, with the quantity of its consumption depending primarily on coal sulfur levels. For example, even in the range of 3 percent to 4 percent coal sulfur levels, a 4 percent sulfur coal can increase consumption by about one-third.[6] It is not uncommon for modern FGD systems to achieve 97 percent utilization of limestone.[7] Generally, higher percent utilization equates to higher reactivity of the reagent, and, therefore, less reagent is needed to achieve a given level of SO_2 removal. The production of gypsum requires a minimum of 92 percent limestone utilization.

A 500 MW_e plant uses roughly 25-32 tons per hour of limestone. A coal with 4 percent sulfur, conservatively, will require 32 tons* of limestone per hour, or 0.064 tons per MW_e per hour. This estimate is based on an 85 percent load factor, 10,500 Btu/kWh, stoichiometry of 1.1 for limestone, SO_2 removal rate of 95 percent, and a minimum purity of 95 percent for $CaCO_3$. Any enhancement of the reagent (i.e., magnesium or buffering agents) will reduce the amount of limestone needed. MEL sorbent consumption for a 4 percent sulfur coal is approximately 17-18 tons per hour.[6] These estimates are conservatively high given that recent FGD systems are operating at near stoichiometric levels[8] and additives are commonly used to achieve higher SO_2 removal, particularly to enhance the performance of existing retrofits. Limestone stoichiometry is the number of moles of Ca added per mole of SO_2 removed. Typically the required stoichiometry of a wet FGD limestone system is in the range of 1.01 to 1.1, with 1.01 to 1.05 typical for modern wet FGD systems.[8] A stoichiometry of 1.03 is typical when the FGD process is producing gypsum by-product, while a stoichiometry of 1.05 is needed to produce waste suitable for a landfill. Grinding limestone to an ultrafine particle size improves dissolution rate of limestone in the slurry and can decrease the size requirement of the reaction tank.[8]

2.3 Construction Equipment

The construction equipment required for typical FGD installations is standard construction equipment – welders, excavation equipment, concrete pouring equipment, cranes, etc. Crane requirements for FGD technology retrofits are generally site specific, although these requirements are generally less demanding than requirements for SCR retrofits. Generally, FGD systems tend to be constructed closer to the ground compared to SCR technology retrofits. Lift at a site rarely exceeds 30 meters (100 feet) and 100 tons. The use of modular and fabricated absorbers shifts much of the construction off-site, reducing the need for specialized cranes and equipment. The usefulness and appropriateness of using cranes in an FGD installation is dependent on several factors, including the ability to physically place a crane on site or adjacent to the site (e.g., on a barge) and the use of modular construction of major FGD technology components. Prefabrication has been used since the early 1990's, notably on two large retrofit projects: the 1300 MW_e Zimmer Station and the 2600 MW_e Gavin station. Both facilities had limited lay-down area to perform the retrofit installation. In these two retrofits, the absorber modules were fabricated in two pieces, shipped by barge, and assembled on site. Often modular units can be transported via barges or trucks to the site for assembly. Component modularization and prefabrication off-site can reduce the amount of time cranes are needed on a site, as well as provide opportunities to reduce project schedules and construction costs and to concentrate jobs locally at the prefabrication facility.

2.4 Installation Time

Implementation of an SO_2 control technology at a plant involves several activities contingent upon each other. These activities may be grouped under the following phases of an implementation project: (1)

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* EPA cost modeling for wet scrubber installations estimate 29 tons of limestone required to achieve 95 percent SO_2 removal while burning a 4 percent sulfur coal.

conducting an engineering review of the facility and awarding a procurement contract; (2) obtaining a construction permit; (3) installing the control technology; and (4) obtaining an operating permit.

Modular construction can minimize field labor and construction time on a site by prefabricating at a shop and then transporting large sections, such as ductwork or absorber modules, by barge or truck. For example, the 550 MW_e boiler at Kansas City Power & Light Company's Hawthorne Generating Station required rebuild and NO_X, SO_2, and PM simultaneous control retrofits. To expedite placing the facility back into use, large sections were fabricated off site and transported by barge to the site. Shop fabrication has also been used outside of the U.S. For example, ten absorber modules handling a combined capacities of 2000 MW_e and 3000 MW_e at two facilities were installed during December 1995 (order placed) through March 2000. The ten absorbers were mostly installed sequentially with startup of the units staggered over 22 months. The 2000 MW_e FGD systems at the Taean facility in South Korea were fabricated off-site in three modules, shipped by barge, and then assembled on-site.

FGD installation plans and experience have been extensive in the U.S. and abroad. To date, there have been approximately 94 GW_e of scrubber capacity built on coal-fired power plants in the US. Over 200 GW_e of capacity has been built worldwide.

Exhibits A-1 and A-2 in Appendix A depict the timelines typical to complete a single absorber module and a three absorber-module installation of FGD, respectively. The three absorber-module installation assumes each absorber module can treat up to 900 MW_e of boiler capacity. Currently, approximately 900 MW_e of single absorber capacity has been successfully installed in the U.S. However, greater absorber capacities are being offered outside of the U.S.[9] While the sum of the time estimated to complete individual tasks generally exceeds the overall estimated installation time, the overall installation schedule accounts for overlap in these tasks. These timelines also indicate that completion of some of the activities is contingent upon completion of some other activities. In general, the FGD implementation schedule appears to be driven primarily by the pre-hookup construction activities. Multiple absorber installations will typically add a few months to the implementation schedule, particularly to connect additional absorbers during scheduled outages. Prefabrication of absorber modules can reduce the overall construction schedule. The major phases of the implementation schedule are discussed below.

Engineering Review

As shown in Exhibits A-1 and A-2 in Appendix A, in the first phase of technology implementation, an engineering review and assessment of the combustion unit is conducted to determine the preferred compliance alternative. During this phase, the specifications of the control technology are determined, and bids are requested from the vendors. After negotiating the bids, a contract for implementing the SO_2 control technology is awarded. The time necessary to complete this phase is approximately four months.

Construction Permit

Before the actual construction to install the technology can commence, the facility must receive a construction permit from the applicable State or local regulatory authority. The construction permit process requires that the facility prepare and submit the permit application to the applicable State or local regulatory agency. The State or local regulatory agency then reviews the application and issues a draft approval. This review and approval process is estimated to take about six months. The draft construction permit is then made available for public comment. After any necessary revisions, a final construction permit is issued. The estimated time to obtain the construction permit is approximately nine months[10] but can vary with State and local permitting procedures as well as other interests in the project.

Control Technology Installation

In the second phase, the control technology is installed. This installation includes designing, fabricating, and installing the control technology. In addition, compliance testing of the control technology is completed in this phase. Since FGD technology is not invasive to the boiler, most of the construction activities, such as earthwork, foundations, process electrical, and control tie-ins to existing items, can occur while the boiler is in operation. The time needed to complete this phase of an implementation project is about 23 months.

An important element of the overall control technology implementation is the time needed to connect, or hook up, the control technology equipment, particularly in relationship to the planned outage time for the unit. On average, it takes about four to seven weeks to connect FGD.[1, 3] For example, the Homer City and Centralia facility FGD retrofit connections were performed during the scheduled outages in approximately five weeks. Based on experience in Germany in response to a compliance directive, a significant quantity of SO_2 and NO_X control installations were performed within outage periods consisting of less than four weeks.[11] Electricity generating facilities often plan the connection to occur during planned outages to avoid additional downtime. Additional downtime leading to loss of a unit's availability to supply electricity is atypical for FGD technology installations.[3,12] Because peak electricity demand generally occurs during the summer months (May through September), typically control connections occur during months of other seasons, notably the spring or fall.[10] For example, FGD connections to the two Centralia units were performed outside of the peak electricity demand period. Sources located where peak demand does not occur during the summer months may be less time-constrained to connect the FGD controls. However, FGD connections for single and multiple systems can typically be performed during planned outage times. Multiple systems normally are installed in sequence and overlapping to maintain a high level of activity at the site. Installation of the control device hookup on a sequential basis usually involves an overlap of compliance testing of FGD system on one unit with hookup of an FGD system with the next unit. The total implementation time for sequential hookup for multiple systems is estimated at between 32 months for two absorber modules and 36 months for three absorber modules. Although not as common, multiple systems installed at a single facility can be performed simultaneously. Generally, scheduled outages will govern which method can be used for multiple FGD system installations.

Operating Permit

Facilities will also need to modify their Title V operating permit to incorporate the added control devices and the associated reduced emission limits. In some States, an interim air-operating permit may need to be obtained until the Title V permit is modified. The operating permit modification process consists of preparation and submission of the application to the applicable State or local regulatory agency. This process can occur simultaneously with the processing of the construction permit application.[10] The process of transitioning from the construction permit to the operating permit varies among States, but the application review process is estimated to take between 9 – 11 months. The Title V operating permit must also be made available for public comment. The Title V operating permit is then not made final until compliance testing on the control device is completed. Therefore, the total estimated time to modify the Title V operating permit is about 17 months, plus the additional time to complete compliance testing.

Based on the estimated time periods needed to complete each of the four phases described above, the estimated time period to complete the implementation of a single FGD installation is conservatively 27 months. For the Clear Skies Act, EPA's projections reflect that the majority of FGD installations will involve a single absorber unit installation per plant; however, the maximum projected number of scrubbers retrofitted at any facility is three absorber modules serving six boilers with a maximum of 2400

MW_e of boiler capacity. Changes in FGD technology and reliability have resulted in planning for smaller and fewer absorbers per retrofit installation. For example, the Zimmer and Gavin station FGD retrofits performed in the early 1990's both involve three absorbers on each 1300 MW_e unit. If these retrofits were being planned today, these stations' two 1300 MW_e units would likely require only two absorbers per unit rather than three.[6]

Average FGD installation times have commonly been within 24-27 months. For example, recent FGD retrofit systems installed at Homer City (September 2001) and Centralia (July 2001) were both completed within approximately 24 months.[13] Although these FGD system installations are considered typical, the Homer City FGD retrofit installation was performed during the same time frame as the installation of three SCR units. Both of these units provide more recent insight into the ability and scheduling to install FGD systems during a period of high demand for SCR installations.

One factor that can increase the time to install a scrubber is competition for resources with other emission control projects. During the first time period analyzed (through the end of 2005), EPA projects that a large number of SCR's will be installed to meet the requirements of the NO_X SIP Call. However, SCR installations designed to comply with the NO_X SIP Call are generally already into the installation process or, at a minimum, into the engineering phase of the project.[13] Furthermore, construction has already begun or been completed for 4 GW_e of the scrubbers that EPA projects will be built by 2005 under current regulatory requirements. Typically the overall engineering, fabrication, and construction resources would remain the same as the scenario analyzed above, with the exception that these resources are reallocated over an extended schedule. One estimate is that, as demand for installation resources increase for FGD and other air pollution control installations, planned FGD retrofit installations could be between 30 and 42 months[1] while another source estimates FGD installations at 36 months.[14] It should be noted, however, that some recent contracts have been signed to install scrubbers between now and 2005 that would be installed in less than 36 months. For instance, a contract to install a scrubber on a 500 MW_e unit at the Coleman Station in Kentucky is scheduled to be completed in early 2004 (approximately 24 months after the contract was announced, which is several months shorter than the installation schedule set forth in Exhibit A-1). This suggests that labor demands to install SCR's for the NO_X SIP Call may not lead to increased installation time for scrubbers.

Single-unit FGD installations have occurred in as little as 20-21 months[9], and multiple FGD systems have been installed within 36 months. In addition, owners of new, or "greenfield," power generation facilities often request 24 months for completion of these projects, including installation of the boiler, FGD system, and SCR. Primarily as a cost cutting option, more relaxed installation schedules of up to 36 months for a single FGD retrofit installation may be planned, but are not common. Despite changes in overall installation schedules, efficient utilization of labor and sequencing the installation during planned outages will continue to be planning issues. In summary, the total time needed to complete the design, installation, and testing at a typical 500 MW_e facility with one FGD unit is 27 months, 32 months at a facility with two boilers being served by a single absorber module, and approximately 36 months at a facility with three absorber modules (six boiler units). For the multiple installation of three absorber modules at one plant (six boiler units), an additional four months may be needed to schedule the outage for the FGD hookup outside of the high electricity demand months. Typically, multiple absorbers will be installed sequentially with some overlap to conserve and schedule continuous use of labor, as well as keep associated installation costs down.

2.5 Labor

The installation of an FGD system requires a significant amount of labor. Approximately 80 percent of the labor is for construction of the system, and 20 - 25 percent of the labor is for engineering and project management. The installation of the FGD control technologies may require the following types of labor:

- general construction workers for site preparation and storage facility installation;
- skilled metal workers for specialized hardware and/or other material assembly and construction;
- other skilled workers such as electricians, pipe fitters, millwrights, painters, and truck drivers; and
- unskilled labor to assist with hauling of materials and cleanup.

A typical turnkey 500 MW_e unit FGD system retrofit requires 380,000 man-hours, or approximately 200 person-years, of which 20 percent, or 72,000 man-hours, are dedicated to engineering and project management,[3] and roughly 40 percent of man-hours are for boilermakers.[14] The labor required to install an absorber vessel and ductwork is a major portion of the system installation man-hours. Generally, construction labor is proportional to the amount of steel used in the system. The greatest labor requirement occurs for FGD on a single unit (i.e., 500 MW_e), and additional efficiencies in incremental labor occur when scheduling multiple units at one facility, particularly when combining multiple boilers into a single absorber. In general, large numbers of boilermakers have been used in this industry; however, it is not expected that this demand will impact other industries. A more thorough discussion of boilermaker labor demand is given in Chapter 6.

There are some efficiencies that result when multiple systems are installed at one site. In engineering alone, there is a 10-15 percent savings in engineering and project management labor commonly realized when installing multiple units of similar design. In addition, other increases in project management and labor productivity and efficiencies in using resources and equipment can occur with multiple system installations on one site. While multiple systems on one site are common, the number of required systems to serve large MW_e of capacity has been decreasing. For example, in the past FGD systems for 2,600 MW_e stations included six absorbers; however, today these systems would likely be designed for four absorber systems, or approximately 650 MW_e of boiler capacity per absorber.[6] Using the methodology described for 900 MW_e of capacity, today a six-absorber system could serve as much as 5,400 MW_e of capacity, or more than double the capacity served in installations in the early 1990's.

A reasonable estimate of multiple FGD installations at one site includes 380,000 man-hours for the initial 500 MW_e of capacity (or 760 man-hours/MW_e) and an additional 500 man-hours per MW_e, up to a total of 900 MW_e, for any combination into a single common absorber. Therefore, a 900 MW_e system requires the initial 500 MW_e at 380,000 man-hours, and the second 400 MW_e at about 273,200, for a combined labor requirement of 653,200 man-hours, or approximately 300 person-years, or the equivalent of about 725 man-hours per MW_e. As another example, a 1400 MW_e system retrofit using 2 (700 MW_e) turnkey systems requires 700,000 man-hours, or only 500 man-hours per MW_e.[6] Generally, extending FGD installation schedules may reduce the number of persons on a job at one time but will not reduce the overall labor requirement.

While, it is likely that installation of multiple systems will benefit from economies of scale to reduce labor requirements, the range for man-hours per MW_e for multiple systems is bounded by 500 and 725 man-hours per MW_e. It is also clear that boiler capacities of at least 900 MW_e can be served by a common absorber, and a minimum 10 percent reduction in engineering and project management labor will result from multiple absorbers being installed at a single site. For example, procurement contracts only need to be negotiated once, and common site issues need only be addressed once. Therefore, 653,200 man-hours is a conservative estimate of labor required to install FGD at a 900 MW_e facility. Because no additional efficiencies in engineering and project management are assumed for larger installations, multiple 900 MW_e absorber systems each add another 653,200 man-hours. A 2,700 MW_e facility requires approximately 1,960,000 man-hours for the retrofit installation. This produces a conservatively high estimate bounding the uncertainties of labor and how many boilers or units will be combined into a single absorber.

The above estimates of labor are conservative particularly given efficiencies realized in recent retrofit installations. In many cases, portions of retrofit construction can be performed off-site, particularly with modular designs. For example, at the Gavin scrubber retrofit installation the absorber modules were fabricated at the vendor's shop and then shipped by barge to the site for hookup. To take advantage of off-site fabrication requires that a shop and facility are available and collocated with an adequate shipping and transport facilities (i.e. water accessible facility and a barge). When the requirements are met the fabrication has the potential to employ and retain a skilled work force as well as opportunity to save time and reduce field labor requirements.

Based upon the discussion from sections 2.1 through 2.5, the total resources needed for a single 500 MW_e FGD retrofit and multiple FGD retrofits are shown in Table 2-1.

2.6 Space Requirements

Generally 1-acre on-site will allow the installation of an FGD retrofit.[1] The need for additional space for support systems ranges from no additional space needed to 2.5 acres typical for up-front reagent processing and 1 acre for dewatering when reagent processing and dewatering operations are selected as part of the FGD system design. Space issues also include the positioning of the FGD after the particulate control device and before the stack. This area of the power unit is generally referred to as the "back end" – an area where there is typically ample space for retrofit installations.

The FGD retrofit on the Cinergy's Gibson Unit 4 is an example of an extremely space limited retrofit.[1] Gibson Unit 4 is a 668 MW_e inhibited oxidation limestone FGD retrofit designed for 92 percent SO_2 removal and completed in late 1994. In the case of this scrubber retrofit, the congestion at the site did not allow for a clean pick by a standard sized crane. With up-front planning, one module was raised by less conventional means (jacking construction), allowing for the second module to be constructed using more conventional methods. Because of the difficulty due to congestion of the site, this retrofit required additional time and labor, but worked within space constraints. This method of jacking construction has been used in other retrofits. The wet FGD retrofit at the Bailly Generating Station, Units 7 & 8, is an example where a full service system (single limestone absorber for combined 528 MW_e capacity, 2-4.5 percent sulfur coal, >95 percent SO_2 removal) was able to significantly reduce space requirements while also decreasing cost by about one-half and creating no new waste streams. Much of the success of this public/private project (DOE/operator and vendors) was due to a more compact and multi-functional (pre-quenching, absorption, and oxidation) absorber vessel that used a co-current flow design. As a result, the FGD system required only modest space requirements.[15] In most locations connection space is not a problem since there is usually adequate space behind the flue gas stack to perform the scrubber retrofit. If connection space is limited, additional ductwork may be necessary.

Table 2-1. Estimated Resources Needed for Single and Multiple FGD Retrofits.

	Units	One Boiler	Two Boilers	Six Boilers
Capacity Retrofit	MW_e	500		2,700[a]
Number of Absorber Modules		1	1	3
Heat Rate	Btu/kWh	10,500	10,500	10,500
Capacity Factor		85 percent	85 percent	85 percent
Percent Reduction		95 percent	95 percent	95 percent
Uncontrolled SO_2 [b]	lb/MMBtu	6.0	6.0	6.0
Uncontrolled SO_2 [c]	lb/MMBtu	8.0	8.0	8.0
Controlled SO_2 [b]	lb/MMBtu	0.30	0.30	0.30
Controlled SO_2 [c]	lb/MMBtu	0.40	0.40	0.40
SO_2 Reduced per year [b]	tons/yr	111,411	200,539	601,618
SO_2 Reduced per year [c]	tons/yr	148,548	267,386	802,158
Steel	tons	1,125	2,000	6,000
Labor				
Project Duration	months	27	32	36[d]
Engineering/Project Mgt.	man-hours	72,000	129,600	388,800
Construction	man-hours	308,000	523,600	1,570,800
Total Labor	man-hours	380,000	653,200	1,959,600
Total Labor	person years	200	300	900
Limestone Consumption[b]	tons/yr	125,250	225,450	676,350
Limestone Consumption[c]	tons/yr	255,000	459,000	1,377,000
MEL Limestone Equivalent[c]	tons/yr	142,560	256,608	769,824

[a] *Under the Clear Skies Act, EPA modeling projects that three plants with six boilers each will be retrofitted with FGD. The maximum capacity at any one of the three plants was 2,400 MW_e*

[b] *3 percent sulfur coal*

[c] *4 percent sulfur coal*

[d] *May require an additional four months to avoid scheduling outages for control hookup during peak electricity demand months.*

Often absorbers can be designed to accommodate site-specific requirements. Smaller absorbers, use of common absorbers for multiple boilers, and technology advances that supplant the need for redundant absorbers, have decreased the footprint needed for a modern FGD retrofit installation. Where space for the FGD installation is an issue, reducing the overall absorber size can be accomplished by using multiple absorber trays (within one absorber) and improving mass transfer with the use of a fan.[16] Improved absorption at higher velocities has contributed to smaller, more compact absorbers. For example, designers are continually improving absorber efficiencies by increasing absorber gas velocities in the range of 5 m/s (15 feet/s) and greater. Velocities of 6.1 m/s (20 feet/s) have been demonstrated.[8] By contrast, earlier systems' design capacities were based on absorber flue gas velocities of 3 m/s (10 feet/s). In addition to smaller absorbers, single absorbers commonly serve multiple boilers, reducing the overall footprint of the FGD retrofit. To date, a single absorber has been successfully installed to serve up to 900 MW_e of capacity in the U.S. while even larger absorber modules (i.e. 1000 MW_e and greater) are now being offered for purchase overseas.

Space for an FGD installation may also include areas for reagent processing and treatment of the waste or byproduct. Complete limestone processing (delivery, crushing, slurry preparation, reagent feed equipment, etc.) requires as much as 2 to 3 acres; however, this space is a one-time requirement and does not increase with increasing FGD capacity being served. Conservatively, when on-site reagent processing is selected, an additional 2.5 acres for an entire facility will be sufficient. While limestone processing can be performed at the facility, purchased powdered limestone is an option that also reduces or eliminates the requirement for on-site reagent preparation and other equipment, as well as the space these processes would occupy. Ultra-fine limestone has been demonstrated as an optional enhancement over typical limestone reagent feed.[17] In areas where the ability to deliver limestone on a continuous basis during winter months may be limited, storage of limestone may be needed. For example, a 30-day supply of limestone to feed a 500 MW_e FGD system (95 percent control efficiency, 85 percent capacity, 4 percent sulfur coal) will require approximately 40 by 40 m (120 by 120 foot) storage area to handle approximately 23,000 tons of limestone.

Traditionally, FGD systems have produced a solid waste product that can be sent to a landfill, or an increasingly attractive alternative is to treat the byproduct for the manufacture and sale of gypsum. If dewatering is required, typically 1-acre will be needed for an entire facility regardless of the amount of FGD capacity being served. One approach to improving sorbent utilization is recycling the spent sorbent for multiple exposure to the SO_2 in the flue gas. The result is less unreacted sorbent and smaller quantities of end product.[18] Improved performance and alternative reagents are becoming common. By the mid-1990's, at least one FGD vendor was supplying a system that took advantage of a water treatment system's precipitated calcium and magnesium carbonates that produced a high quality, fine calcium and magnesium carbonate FGD reagent. In addition to reducing the facility's dependence on limestone, this process also reduced equipment required for limestone handling and milling.[4]

More efficient use of water in modern systems has almost completely removed the need for dewatering and containment ponds. Typically, purge streams are used if the wastewater contains high levels of chlorides. However, usually water is either evaporated from the system or remains in the by-product or waste. Techniques for wastewater minimization or elimination are commonly available. For example, many FGD systems repeatedly cycle the cooling tower blow-down before being treated in the wastewater system. As a result, the wastewater has a high solids content as well as high alkalinity for improved performance. Since large amounts of water are evaporated during this cycling, this method also benefits from reduced effluent that requires treatment by a wastewater system.[16]

While water treatment of FGD effluent was once a concern, contemporary FGD systems are much more effective in limiting production of waste water and can achieve zero, or near-zero, wastewater discharge.[9] Many of the wastewater advances being used outside of the U.S., including conserving blowdown in the absorber vessel primarily for chloride control, are now being used or considered in the U.S. For example, the 446 MW_e Hunter Unit 3 (operated by PacifiCorp) installed a wet FGD limestone reagent system in 1983; and, by use of mechanical draft cooling towers, the plant is zero-discharge for waste water. The FGD system operates at 0.12 lb SO_2/MMBtu and is designed for 90 percent SO_2 removal. An additional example of zero wastewater discharge is the 446 MW_e Craig Units 1 & 2 (installed 1980) that are designed for 85 percent SO_2 removal and also employ limestone reagent and mechanical draft cooling towers.

Chapter 3
NO_x Control Technology Retrofits

In this chapter, retrofit of SCR will be assessed for coal-fired electric utility boilers that would be affected by a multipollutant regulation. SCR is the NO_X control technology that is expected to have the greatest impact on future utility boiler NO_X emissions and is the most difficult NO_X control technology to install. It is, therefore, the most important NO_X control technology to understand from both a NO_X reduction and resource requirement perspective.

3.1 System Hardware

The SCR process operates by reacting ammonia with NO_X in the exhaust gas in the presence of a catalyst at temperatures of around 315 to 370 ºC. For most applications, this temperature range makes it necessary to locate the SCR reactor adjacent to the boiler – immediately after the boiler and before the air preheater as shown in Figure 3-1. An infrequently used alternative approach is to locate the SCR after the FGD. This approach, however, increases operating costs, as it requires additional heating of the gas. By locating the SCR reactor as in Figure 3-1, it is often necessary to install the catalyst reactor in an elevated location, which may result in a structure hundreds of feet tall. Figure 3-2 shows the configuration of the SCR that was retrofit onto AES Somerset Station, a 675 MW_e boiler already equipped with an electrostatic precipitator (ESP) and wet FGD system. In this common installation, the SCR reactor is installed on structural steel that elevates it above existing ductwork and the ESP (designated "precipitator" in the Figure 3-2). In the lower right corner of Figure 3-2, an image of a person provides a perspective of the size of the SCR installation.

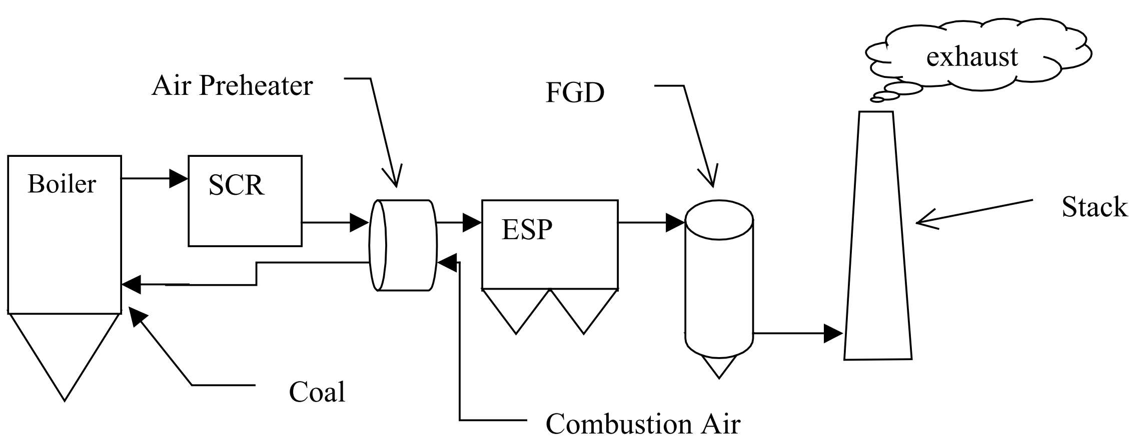

Figure 3-1. Gas path for coal-fired boiler with SCR, ESP, and FGD.

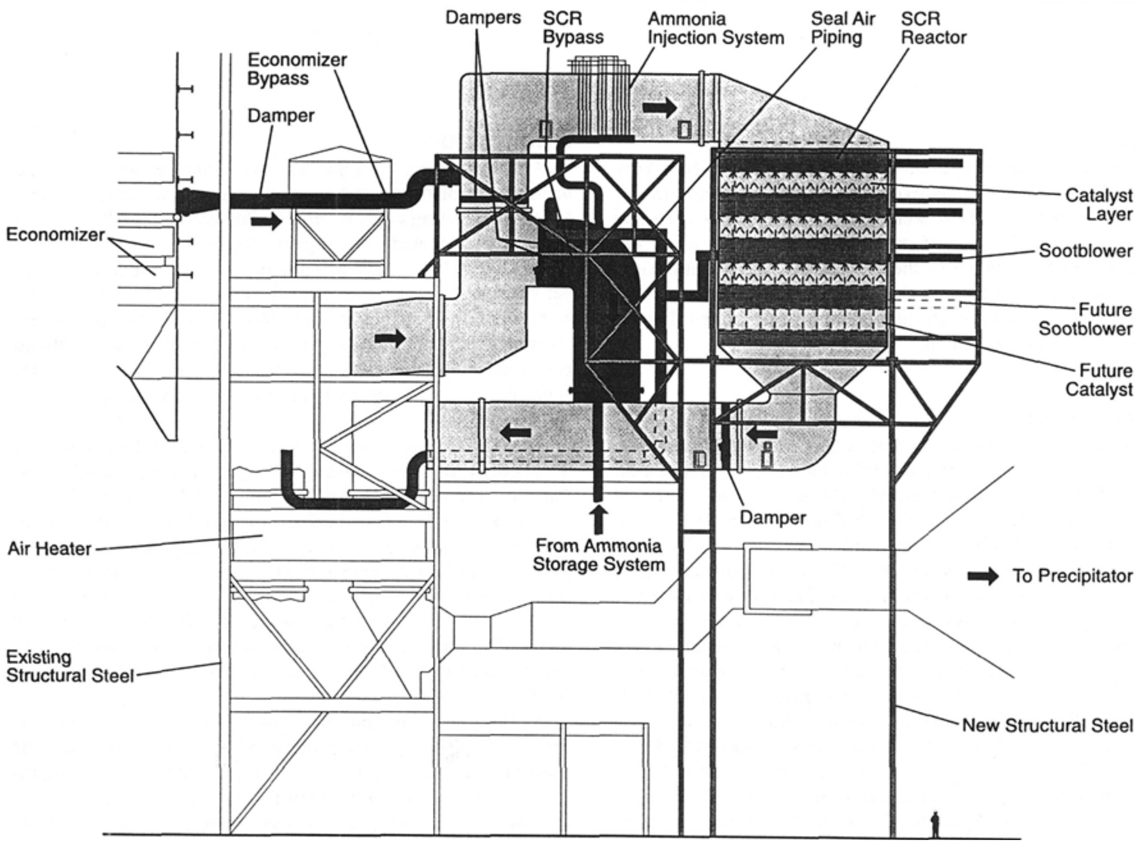

Figure 3-2. SCR installation at 675 MW_e AES Somerset Station.[19]

The SCR system reduces NO_X through a reaction of ammonia and NO_X in the presence of oxygen and a catalyst at temperatures around 315 to 370 °C (600 to 700 ºF). The products of this reaction are water vapor and nitrogen. The catalyst is mounted inside an expanded section of ductwork and is configured for the gas to pass through it as in Figure 3-2.

The major components of an SCR system include:

- Ammonia or urea storage
- Ammonia vaporization system (if aqueous ammonia is used)
- Urea to ammonia converter (if urea is used)
- Ammonia or urea metering and controls
- Dilution air blowers
- Ammonia injection grid
- Catalyst
- Catalyst reactor, ductwork and support steel
- Catalyst cleaning devices (soot blowers, sonic horns, etc)
- Instrumentation

Except for the catalyst, most of the material/equipment used to assemble an SCR system is either standard mechanical and electrical components (pumps, blowers, valves, piping, heaters, pressure vessels, temperature and pressure sensors, etc.) or is largely manufactured for other power plant applications and has been adopted for use in SCR systems (cleaning devices such as soot blowers or sonic horns, gas analyzers, etc.). The catalyst, however, is a specialized product designed specifically for this purpose.

The catalyst is typically a ceramic material that, in most cases, is either extruded into a ceramic honeycomb structure or is coated onto plates, as shown in Figure 3-3. The catalyst is assembled into modules at the factory. The modules are shipped to the site and installed into the SCR reactor in layers. Each layer of catalyst is comprised of several individual modules that are installed side-by-side.

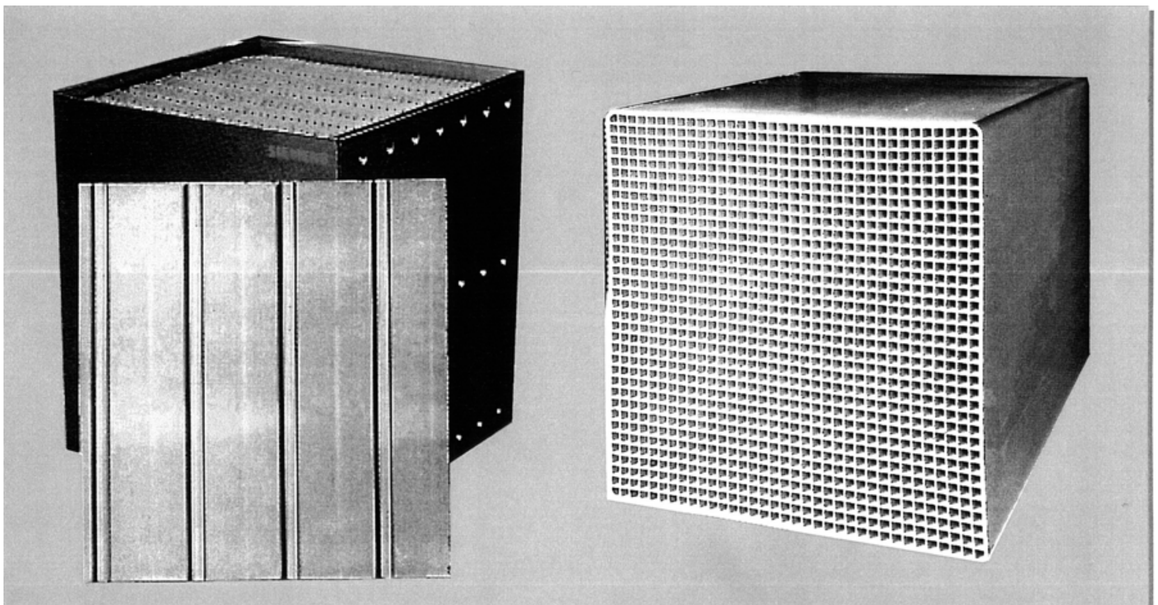
The catalysts used for selective catalytic reduction are mainly parallel-flow catalysts, of which there are two types, plates or extruded.

Figure 3-3. Plate and honeycomb catalyst.[20]

The material used in the largest quantity, aside from a catalyst or reagent, is steel. The amount of steel required for an SCR in the range of 300-500 MW_e is about 800 to 1200 tons,[20] or about 2.4 to 2.6 tons per MW_e. About 4,000 tons of steel is necessary for retrofit of two 900 MW_e units (1,800 MW_e total),[20] or about 2.2 tons per MW_e. The steel used for an SCR includes large structural members, plates, and sheets. These steel pieces are used to fabricate the catalyst reactor, the ductwork, and the support steel. There is typically less of a requirement for corrosive resistant alloys for an SCR installation when compared to a scrubber installation. Steel is also needed for boiler modifications. In this case, large pieces of steam piping or other large steel boiler components may need to be replaced. The catalyst reactor is often fabricated on-site. Sections of the catalyst reactor and ductwork may be fabricated off-site and shipped in pieces to the site for final assembly, or they may be fabricated on-site into subassemblies and lifted into place during erection.

If more than one boiler at a facility is to be retrofit with SCR, then some, but not all, equipment can be made common. For example, it may be possible, and is probably preferable, to have a common ammonia or urea storage facility. Reagent storage is probably the only major equipment item that lends itself to sharing between adjacent boilers. Therefore, there is some gained efficiency in the use of equipment at a site with multiple units. However, this gain in efficiency is generally small compared to the total project. The major synergy will be in construction equipment and in labor, as will be discussed in Sections 3.3 and 3.5, respectively.

3.2 Catalyst and Reagents

An SCR system requires an initial and ongoing supply of catalyst. It also requires reagent. The reagent can be ammonia or urea. Most facilities to date have used ammonia; however, urea is becoming an increasingly popular reagent due to its inherent safety and the recent availability of systems to convert urea to ammonia on-site.

Catalyst

The amount of catalyst required for an SCR system is directly proportional to the capacity (or gas flowrate) of the facility, if all other variables are equal. The actual amount of catalyst for any specific plant depends upon several parameters; in particular, the amount per MW_e (measured in m^3 per MW_e) for a given level of reduction and lifetime will fall within a general range. Therefore, it is possible to make an estimate of how much catalyst would be necessary to retrofit a particular facility or a large number of facilities if the total capacity is known. It is assumed that most SCR systems to be retrofit onto electric utility boilers will be designed for about 90 percent reduction. For most boilers, this level of reduction may initially require about 0.90 to 1.3 m^3 of catalyst for each MW_e of coal-fired boiler capacity.[18,21,22] For example, a 500 MW_e plant would be expected to have about 450 to 650 m^3 of catalyst. The amount of catalyst for a particular situation will vary somewhat depending on the catalyst supplier and the difficulty of the application. At the 675 MW_e AES Somerset Boiler, 90 percent NO_X reduction was achieved with SCR using 897 m^3 of plate catalyst,[19] or about 1.33 m^3 per MW_e. This unit fires 2.5 percent sulfur coal. At each of the 745 and 755 MW_e Montour Units 1&2, 671 m^3 of ceramic catalyst were used,[22] or about 0.89 m^3 per MW_e. This unit fires 1.5 percent sulfur coal that can have arsenic levels as high as 100 ppm (limestone injection is used to reduce gaseous arsenic concentration in the furnace). The amount of catalyst will tend to be lower in situations that are less challenging, such as with lower sulfur coals or situations expected to have lower gaseous arsenic concentration (gaseous arsenic is a catalyst poison that originates in the coal; it will reduce the lifetime of the SCR catalyst). Hence, less than 0.90 m^3 per MW_e may be sufficient in some cases.

The catalyst is typically loaded in three or more layers. This permits replacement of sections of the catalyst as activity is reduced. The advantage of this approach is that it permits lower overall catalyst usage over the economic lifetime of the plant. Normally, room for an extra layer is provided, so a fourth layer can be added, if necessary. At the first catalyst addition (typically, after about 24,000 operating hours), the fourth layer will be filled or half filled. Once the SCR reactor is full, layers of catalyst are replaced after catalyst activity drops to a minimum level. At the first catalyst replacement, new catalyst will replace the original first layer; at the next catalyst replacement, new catalyst will replace the original second layer, and so on. EPA modeling projections conservatively assumed that one layer of catalyst is replaced for every 15,000 – 20,000 hours of operation for coal-fired units. Therefore, after the initial installation, there is a need to replace roughly one fourth of the total catalyst reactor volume every 24- 32 months or so – or conservatively about $^1/_8$ of the installed volume should be replaced each year for the coal-fired installations.

The catalyst may also be regenerated rather than replaced.[23] This will reduce the amount of new catalyst that must be purchased. However, due to the limited experience with this method, it will be assumed that the catalyst is replaced according to the catalyst management plan.

Reagents

The amount of reagent consumed in the SCR process is directly proportional to the amount of NO_X reduced. Although ammonia is the chemical that actually participates in the chemical reaction, some suppliers have developed equipment to convert urea to ammonia on-site. According to one supplier of urea-to-ammonia converters, each mole of urea within the conversion system is converted to two moles of ammonia.[24] For example, reducing one pound of NO_X will require roughly 0.176 kg of ammonia or about 0.312 kg of urea. This includes a ½ percent increase in reagent demand due to ammonia slip and a five percent increase to account for a small amount of nitrogen dioxide (NO_2) in the flue gas.

Therefore, for any given plant size, the amount of catalyst and reagent consumption can be estimated. For a 500 MW_e plant reducing NO_X from 0.50 lb/MMBtu to 0.05 lb/MMBtu and 85 percent capacity factor (this is conservatively high for most coal boilers), approximately 3,400 tons/yr of ammonia (anhydrous equivalent) or about 6,100 tons/yr of urea (as 100 percent urea) would be needed. The same 500 MW_e plant would have around 450-650 m^3 of catalyst with roughly 120-160 m^3 replaced about every three years. This is, if a third of the initial catalyst loading must be replaced, on average, every 15,000 to 20,000 operating hours, then 0.015 to 0.0289 cubic meters per MW_e per 1000 hours must be replaced.

3.3 Construction Equipment

Construction equipment needed for installation of an SCR includes standard construction equipment – welders, excavation equipment, concrete pouring equipment, cranes, etc. In some cases, installers may use tall-span heavy-lift cranes. These cranes are capable of lifting heavy loads, as much as 100 tons or more, several hundred feet. The advantage of this crane type is realized when lifting assembled sections of catalyst reactor or other large pieces high off the ground. If lower capacity cranes are used, smaller pieces must be lifted, which means that less pre-fabrication is possible and more assembly must be done in place. Less pre-fabrication could lengthen the necessary boiler outage somewhat. Although the availability of the largest cranes is reported to about 60 or more, about 12 new cranes can be supplied every six months.[25] It has been reported that, in some cases, it has been necessary to go further away from the plant to source cranes with adequate lift and reach capacity. In other cases, engineers found that by changing the design/fabrication method to meet the available crane, the project could be managed with lower capacity cranes (lifting smaller pieces).[26,27] If more than one boiler is retrofit at one facility, then the crane can be used for both boilers, saving cost and time when compared to boilers retrofit separately. It is important to note that in many cases the erection method is not limited by the available crane, but is limited by the access to the plant (For example, can large sections be delivered by barge, rail, or roadway?) and by the available lay-down area for material and construction equipment on site. At many facilities, there is inadequate area to prefabricate large sections. In some instances, transportation routes to the facility do not permit transporting large, pre-assembled equipment to the site. In such cases, it will not be possible to do much pre-assembly, and a smaller, less expensive crane may be adequate. As a result, the type of crane that is best for a particular SCR installation frequently is not the largest crane available. The crane selected for a project will be determined as part of an overall construction plan developed to optimize all of the available resources – labor, material, and equipment - for a particular project.

The need to lift material to high elevations is a result of the location of the SCR – often above existing ductwork and adjacent to existing equipment. Figure 3-2 provided one good example of this. It may be necessary to move existing equipment, such as the air preheater, in order to accommodate the addition of the SCR reactor. As a result, every retrofit is a custom fit. However, engineers have been very innovative when installing these systems, even on facilities that apparently had little room available for the SCR. Hence, the physical size of the technology has not been limiting.

3.4 Installation Time

Implementation of a NO_X control technology at a plant involves several activities contingent upon each other. These activities may be grouped under the following phases of an implementation project: (1) conducting an engineering review of the facility and awarding a procurement contract; (2) obtaining a construction permit; (3) installing the control technology; and (4) obtaining an operating permit.

Exhibit A-3 in Appendix A depicts the timeline expected for completing a single unit installation of SCR. Completion of some of the activities is contingent upon completion of some other activities. For example, construction activities cannot commence until a construction permit is obtained. In general, the SCR implementation timeline appears to be driven primarily by the engineering activities (i.e., design, fabrication, and construction).

Engineering Review

As shown in Exhibit A-3 in Appendix A, an engineering review and assessment of the combustion unit is conducted in the first phase of technology implementation to determine the preferred compliance alternative. During this phase, the specifications of the control technology are determined, and bids are requested from the vendors. After negotiating the bids, a contract for implementing the NO_X control technology is awarded. The time necessary to complete this phase is approximately four months for SCR.

Construction Permit

Before the actual construction to install the technology can commence, the facility must receive a construction permit from the applicable state or local regulatory authority. The construction permit process requires that the facility prepare and submit the permit application to the applicable state or local regulatory agency. The state or local regulatory agency then reviews the application and issues a draft approval. This review and approval process is estimated to take about six months. The draft construction permit is then made available for public comment. After any necessary revisions, a final construction permit is issued. The actual time needed will depend on the size and complexity of the project and the local procedures for issuing a permit. Exhibit A-3 in Appendix A shows that nine months are allowed for the construction permit. This is expected to be ample time. In one case, only about 4-5 months were needed for obtaining the construction permit,[26] and only six months were needed to obtain the construction permit for retrofit of two 900 MW_e boilers in another case.[21] Shorter periods for construction permit authorization would allow earlier commencement of construction activities and could potentially shorten the overall schedule.

Control Technology Installation

In the second phase, the control technology is installed. This installation includes designing, fabricating, and installing the control technology. In addition, compliance testing of the control technology is also completed in this phase. Most of the construction activities, such as earthwork, foundations, process electrical and control tie-ins to existing items, can occur while the boiler is in operation. The time needed to complete this phase of an implementation project is about 17 months for SCR.

An important element of the overall control technology implementation is the time needed to connect, or hook up, the control technology equipment to the combustion unit because the boiler typically must be shut down for this period. SCR connection can occur in a three to five week outage period.[28] In some cases longer outages are needed. When Babcock & Wilcox retrofitted the 675 MW_e AES Somerset boiler, the outage began on May 14, and the boiler was returned to service on June 26 – about a six-week outage.[19] One major SCR system supplier in the U.S. stated that they would want in the range of one to two months of boiler down time and have never required more than two months.[27] Difficulty is increased as the extent of boiler modifications necessary to fit the SCR into the facility is increased. A German SCR system supplier installed SCR on a significant portion of the German capacity within outage periods consisting of less than four weeks.[11] Based upon outages in this time range for SCR connection, electricity-generating facilities would normally be able to plan the SCR connection to occur during planned outages to avoid additional downtime. Some facility owners have been innovative in their construction plans to minimize down time. At the Tennessee Valley Authority's (TVA's) 700 MW_e Paradise Unit 2, it was necessary to demolish the existing ESP with the unit on line. TVA installed a construction bypass to send gas from the air preheater outlet directly to the FGD, while the ESP was being demolished and the SCR reactor erected in its place.[11] However, in more difficult retrofits, down time might be impacted in a significant way. In some cases it may be desirable to plan a brief outage in advance of the hook-up to install structural steel through sleeves placed in existing equipment, such as the ESP, or to relocate existing equipment that would otherwise interfere with erection of the SCR. This permits erection of the catalyst reactor above existing equipment while the unit is on line.[26] However, because an SCR project is expected to extend close to two years (see Exhibits A-3 and A-4 in Appendix A), it should be possible to incorporate this work into planned outages, which would have occurred regardless of whether an SCR was to be installed.

Operating Permit

Facilities will also need to modify their Title V operating permit to incorporate the added control devices and the associated reduced emission limits. In some states, an interim air-operating permit may need to be obtained until the Title V permit is modified. The operating permit modification process consists of preparation and submission of the application to the applicable state or local regulatory agency. As shown in Exhibit A-3 in Appendix A, this process can occur simultaneously with the processing of the construction permit application. The process of transitioning from the construction permit to the operating permit varies among states and appears to be somewhat unclear due to the infancy of the Title V operating permit process. Nonetheless, based on discussions with several states, the application review process is estimated to take approximately 9-11 months. The Title V operating permit must also be made available for public comment. Following public comment, the Title V operating permit is not made final until compliance testing on the control device is completed. Therefore, the total estimated time to modify the Title V operating permit is about 17 months, plus the additional time to complete compliance testing.[10]

Based on the estimated time periods needed to complete each of the four phases described above, the estimated time period to complete the implementation of SCR on one combustion unit is about 21 months. This time period is shown in Exhibit A-3 in Appendix A. However, depending upon the specifics of the project, the time needed could vary by a couple of months. For example, at AES Somerset station, the time to complete the retrofit from the point of contract award was nine months.[19] Assuming four months of work prior to contract award, a total elapsed time of 13 months would have been necessary to retrofit this 675 MW_e boiler. Another facility, Reliant Energy's Keystone plant, has two 900 MW_e, 8-corner, T-fired combustion engineering units that burn approx 1.5 percent sulfur bituminous coal. Reliant intends to reduce the NO_X from a baseline of 0.40 lb/MMBtu to 0.04 lb/MMBtu. The permit to construct was received in approximately six months. The time from placing the order to completion of commissioning activities is 46 weeks for both units. However, preliminary engineering was accomplished earlier. Even if preliminary engineering and contract negotiation took as long as six to eight months, the total time for completing two 900 MW_e units would be about 17 to 19 months.[21] For the New Madrid plant, units 1 & 2 (600 MW_e each), the specifications were released to turnkey contractors in February 1998, the project specification was released in March 1998, the contract was awarded on June 26, 1998, and the first unit was in operation by February 2000. In this project, an option for a second unit was available (and was exercised), and air preheaters were replaced.[29] Therefore, 21 months should be a reasonable, and in some cases a conservative estimate of the total time necessary to retrofit a single utility boiler.

Under the Clear Skies Act, EPA does not expect that SCR will be implemented at every facility. For those plants where EPA projects SCR retrofits will occur, EPA's projections reflect that these facilities will typically have 1 to 4 boilers retrofit per site. However, for one facility, seven SCR retrofits are projected to be installed by 2020. Exhibit A-4 in Appendix A examines a schedule for retrofitting a facility with multiple (seven) SCR retrofits. This examines the installation of the control device hook-up on a sequential basis. Installation is staggered by two to three months between sequential units to enable more efficient utilization of manpower and project management than if multiple units were connected at one time. This approach also assures that at least about 83 percent of the plant capacity is available at any given time (only one boiler is shut down), and during most of the time there is no impact to the plant availability at all. This approach requires a total time of 35 months for seven SCR retrofits. An alternative approach might be to schedule outages to avoid any outage during high electricity demand periods. This might extend the total elapsed time by about four months. However, because there is a substantial amount of work that can be accomplished with the boiler on line, the additional time would be much less than the number of high electricity demand months that are accommodated by this approach. Another alternative approach would involve retrofit of more than one unit at a time during low-demand periods and avoiding any outage during high demand periods. This alternative could result in a faster project completion, but would have less even labor utilization, which is an important cost-benefit tradeoff.[30]

In summary, the total time needed to complete the design, installation, and testing at a facility with one SCR unit is about 21 months; at a facility with multiple SCR (seven) units, total time is approximately 35 months. Based on these timelines, it is estimated, in principal, that the NO_X controls needed to comply with a multipollutant strategy can be met provided that: (1) an adequate supply of materials and labor is available, and (2) the control technology implementation process begins at least about 35 months prior to the date controls must be in place. However, ideally, longer than 35 months would allow for all of the retrofits to occur over a period of several years so that facility owners can properly plan outages and suppliers can properly plan for resource availability.

3.5 Labor

The installation of an SCR system requires a significant amount of labor. Most of the labor is necessary for the construction of the facility. However, engineering and project management labor are also needed for the project. The total construction labor for an SCR system of 500 MW_e is in the range of 333,000 to 350,000 man-hours.[22,27] Typically, approximately 40-50 percent of the labor is for boilermakers.[31] However, the percent of labor for boilermakers will vary from one project to another, with 40-50 percent being an average for several projects.[32] Some projects require a higher degree of boiler integration and less erected steel and, therefore, have a higher percentage of boilermaker labor. Other projects require extensive steel erection with less boiler integration and will, therefore, have a lower percentage of boilermakers versus other trades. For a 500 MW_e plant, the construction labor would be about 340,000 man-hours, of this roughly 136,000-170,000 man-hours would be boilermaker activity. Engineering and project management are about 5 percent of the total cost, while construction is about 50 percent of the total cost.[19] If labor rates for engineering and project management is 50 - 100 percent greater than construction labor, then about 17,000 to about 28,000 man-hours of engineering and project management are needed for the project. Total labor man-hours of construction and engineering labor are then about 365,000 man-hours for a single 500 MW_e unit.

Construction man-hours are approximately proportional to the tons of steel fabricated. As noted earlier, the material needed for multiple boiler installations is generally not reduced significantly over the projects if they were installed separately. However, if more than one system is installed at a site, some significant efficiencies result.

When there are multiple units retrofit at one site only, one mobilization is needed for all of the boilers, only one construction supervisor is required, and equipment is more efficiently used. As a result, 15-20 percent efficiencies can be realized from these activities and can be planned into the project.[22] Long-term projects, such as retrofits of more than one unit at one site, also lend themselves to additional efficiencies from learning curves. Learning curves result from productivity improvements over the duration of the project. Productivity measures the actual man-hours used versus those planned. A productivity value over 100 indicates that fewer man-hours are needed to accomplish the goal than expected. A labor productivity value of 110 means that 10 percent more work was accomplished for the level of labor expended than if a productivity value of 100 was achieved. There are examples of productivity improvements of 9 to 19 percent during the project due to additional efficiencies gained from learning curves.[30] If only 10 percent or less improved efficiency results from planned reduced labor and from productivity improvements that occur after the project commences, the labor for each additional 500 MW_e plant might be reduced from 340,000 man-hours to about 310,000 man-hours, or about 2,170,000 construction man-hours for seven 500 MW_e units at one plant.

For a site with multiple units, the total engineering and project management man-hours are likely to be significantly less than the total if each unit were addressed separately. This is because there will be many common site issues that need to be addressed and engineered only once. Procurement contracts need to be negotiated only once, and only one project management team is needed over the duration of the contract. However, it is difficult to say how much engineering will be reduced, because adjacent units may be very similar or very different. One approximation is to make total engineering, project management, and testing proportional to the project duration. Thus, a seven-unit facility would require about 42,000 man-hours of engineering and project management.

Based upon the discussion from sections 3.1 through 3.5, the total resources needed for a single 500 MW_e plant and a site with seven 500 MW_e plants is shown on Table 3-1.

Table 3-1. Estimated Resources Needed for Single and Multiple SCR Retrofits

	Units	One Boiler	Seven Boilers
Capacity Retrofit	MW_e	500	3,500[a]
Heat Rate	Btu/kWh	10,500	10,500
Capacity Factor		85 percent	85 percent
Percent Reduction		90 percent	90 percent
Uncontrolled NO_x	lb/MMBtu	0.50	0.5
Controlled NO_x	lb/MMBtu	0.05	0.05
NO_x Reduced/yr	tons/yr	8,796	61,572
Steel	tons	1,250	8,750
Catalyst - initial fill	m^3	450	3,150
Time between fills	operating hours	15,000	15,000
Catalyst - replacement allowance	m^3/yr	55	385
Ammonia Skids	units	1	7
Ammonia Storage	units	1,250	8,750
Labor			
Project Duration	months	21	35[b]
Engineering/Proj. Mgt.	man-hours	25,000	42,000
Construction	man-hours	340,000	2,170,000
Total Labor	man-hours	365,000	2,212,000
Ammonia Consumption (equivalent Anhydrous)	tons/yr	3,400	23,000
Urea Equivalent	tons/yr	6,100	42,700

[a] *Under the Clear Skies Act, EPA modeling projects that the plant with the maximum number of SCR retrofits is one plant with seven boilers and a capacity of 2,400 MW_e.*
[b] *May require an additional four months to avoid scheduling outages for control hookup during peak electricity demand months.*

3.6 Space Requirements

An SCR system for a coal-fired boiler may have a negligible impact on the footprint of the boiler. This is because the SCR is frequently installed in an elevated position near the boiler and well off of the ground. The choice of installing the SCR reactor near the ground level or elevated well above ground level depends upon which configuration is viewed as most cost effective while considering installation cost and operating cost. Locating the SCR in an elevated location near the boiler economizer and air preheater is frequently done to minimize the length of ductwork (with the associated pressure loss) and because no additional real estate is necessary for the SCR reactor. When this type of installation is performed, the SCR reactor is installed atop a steel structure that must be erected above existing equipment, such as the electrostatic precipitator. This is an approach that is frequently used because engineers have developed cost effective methods to install the SCR reactor while addressing potential interferences from existing equipment. Section 3.4 of this document discussed how brief outages, in advance of the outage to connect the SCR, were taken to address interferences and permit SCR reactor construction with the unit on line. In some cases, however, the preferred approach has been to locate the SCR reactor on the ground near the boiler and to route the ductwork to and from the SCR reactor. This is the approach that was taken on the retrofit of PSNH Merrimack Unit 2, the first retrofit of a coal-fired boiler in the United States. In this case there was a large amount of space near the boiler to permit this approach. Regardless of where the SCR reactor is located, ductwork from the economizer outlet to the SCR reactor and back to the air preheater inlet must be accommodated. In cases where space for this ductwork was extremely limited, the air preheater was relocated. However, relocation of the air preheater(s) usually is not necessary. Only a few installations have required the relocation of the air preheater.

The other item that must be located is the reagent storage system. This usually does not take up as much room as the SCR reactor itself. However, the storage and unloading system must be located near rail or truck access to permit delivery of reagent. In some cases, long piping is run from the storage and unloading area to the SCR reactor. In these cases, the piping may be insulated and heat traced to prevent condensation of the ammonia vapor.

Chapter 4
Mercury Control Technology Retrofits

Under a multipollutant control scenario, mercury emissions would be controlled from coal-fired power plants by equipment that reduces emissions of other pollutants (e.g., scrubbers and SCR) and the use of sorbent injection. Other methods are being investigated (such as oxidation and scrubbing technologies), which utilize ozone, barrier discharge, and catalyst and/or chemical additives in combination with existing technologies. To the extent that other technologies are developed, these would provide more options for compliance, so their introduction would serve to reduce issues related to resource requirements of installing controls. Similarly, with regard to sorbent injection, sorbents other than activated carbon (AC) may ultimately prove to be superior for this application in terms of cost or collection efficiency performance and may reduce the likely demand for ACI from what is projected here. Nevertheless, all of the sorbent-based approaches use similar hardware to inject sorbent as ACI. Therefore, the assumption of ACI as a control method will provide a fairly representative indication of the demand for hardware and construction resources regardless of which sorbents are used in the market. The assumption of ACI as a mercury control method will be more conservative with regard to sorbent consumption since it will assume that all of the facilities installing sorbent injection for mercury control require AC.

4.1 System Hardware

The AC is typically injected at the lowest temperature available that is upstream of a particle-collecting device because experience has found that mercury collection is most efficient at lower temperatures. On a boiler equipped with an ESP or a fabric filter (FF) for particle collection, the configuration would look as in Figure 4-1. Collection of mercury is somewhat more efficient when a FF is used for particle collection because of the higher gas-sorbent contact in the filter cake. Another approach is to have injection downstream of an ESP, which would collect most of the coal fly ash, and upstream of a fabric filter (FF), which would mostly capture sorbent. This approach is shown in Figure 4-2. The advantages of this approach are that greater mercury capture occurs because of the additional mercury capture that can occur on the FF filter cake; and, because the ash is largely separated from the sorbent, more efficient sorbent utilization is possible through sorbent recycling. This approach could be implemented through addition of a Pulse Jet Fabric Filter (PJFF) when ACI is installed.

The ACI System consists of the following components, as shown in the simplified schematic of Figure 4-3:

- A silo for storing the sorbent
- A metering system for metering the amount of sorbent injected into the ductwork – typically a rotary metering valve
- A pneumatic or mechanical conveying system for moving the sorbent to the injection location
- An injection system for dispersing and distributing the sorbent in the boiler ductwork. For many facilities, injection of sorbent will occur after the air preheater and upstream of the ESP or FF. This injection system is principally made from piping that may split off to manifolds for injecting in multiple locations. Special nozzles or other hardware are generally not required.

- A blower to provide a carrying medium
- Associated piping for the blower and the distribution system
- A humidification system may be used in some cases to reduce temperature and improve mercury capture. The humidification system will typically consist of water spray injectors (possibly air atomized) located upstream of the ACI injectors, a grid for the spray injectors, and a water supply system that will include pumping and metering systems.
- A control system that may utilize a programmable logic controller (PLC) or may be accommodated by the plant distributed control system (DCS)

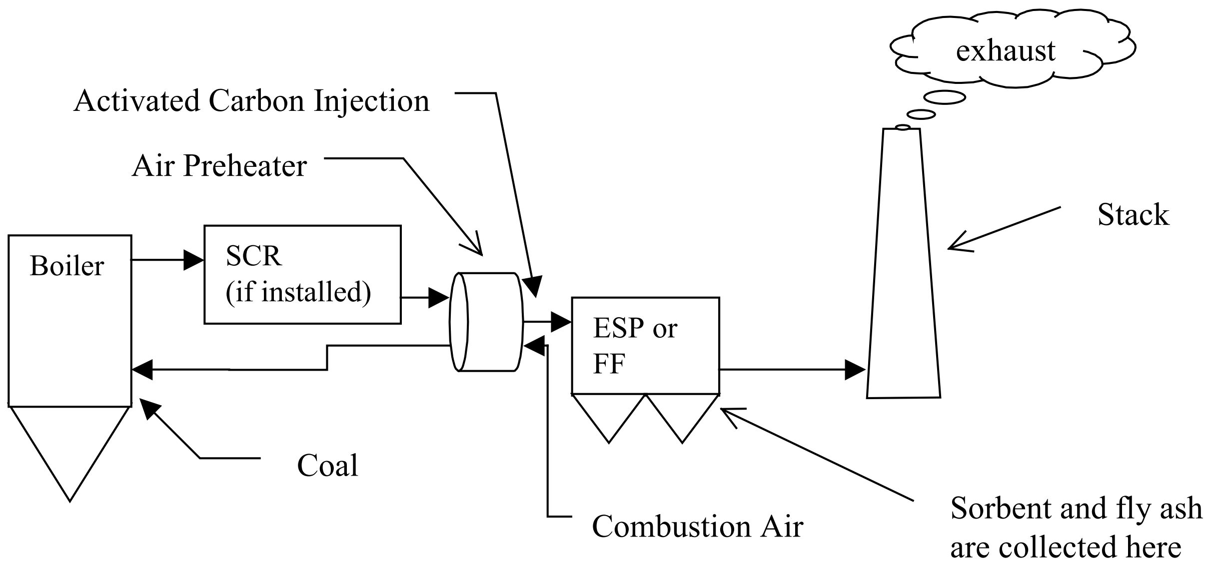

Figure 4-1. Gas path for coal-fired boiler with SCR, ACI, and ESP.

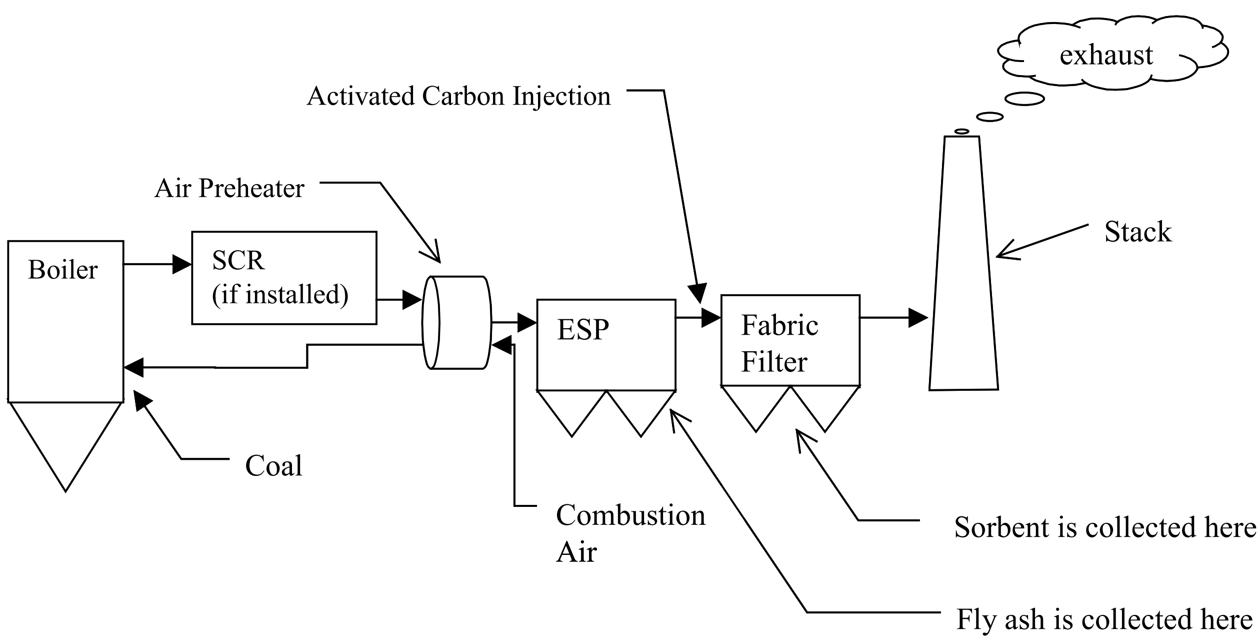

Figure 4-2. Gas path for coal-fired boiler with SCR, ACI, ESP, and FF.

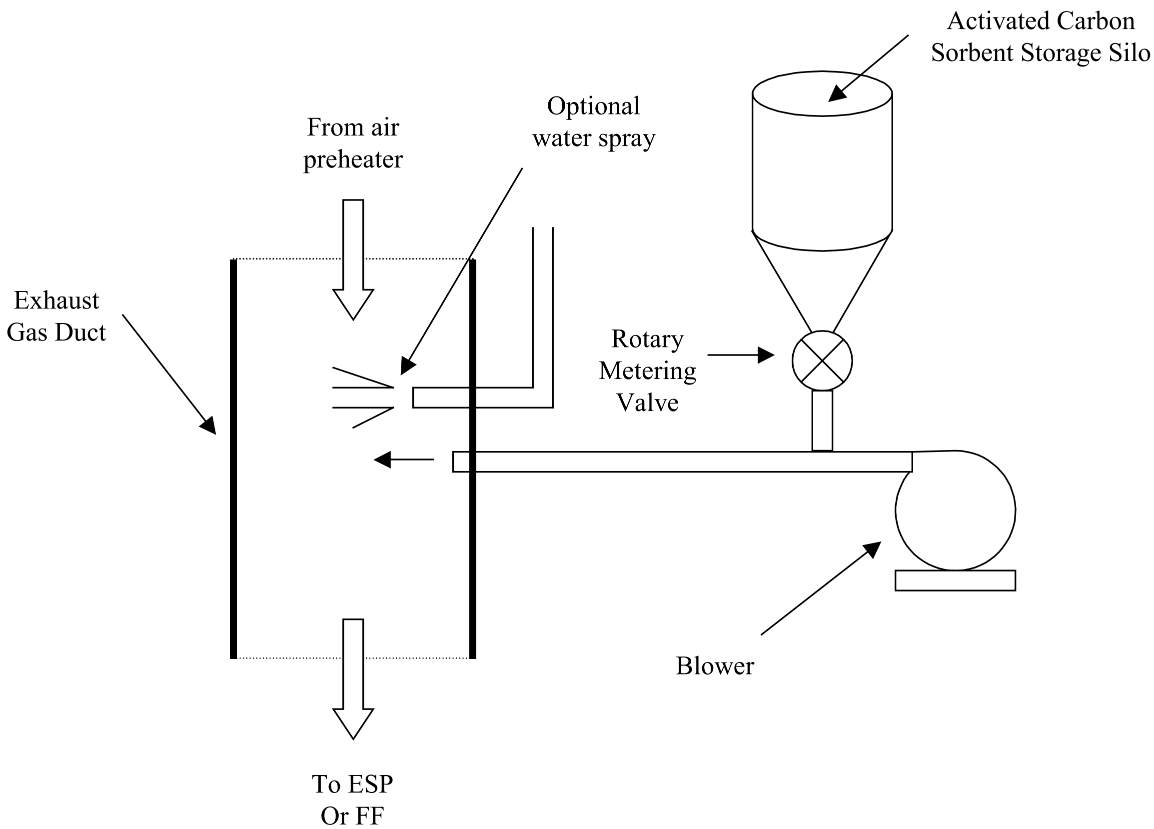

Figure 4-3. Simplified schematic of ACI system.

Regardless of boiler size, an ACI system will require the same equipment. The principal differences will be the size of the sorbent storage silo, the size of the metering and conveying system, and the size and number of injectors for the sorbent injection system.

There are also several other combinations that may be used, including combinations of ACI with spray dryer and FF and combinations of ACI with FGD.[32] The various combinations will be discussed further in Section 4.2. In each of these combinations, the actual equipment associated with the ACI system is similar. The particular combination of equipment chosen for mercury reduction at a particular facility is largely determined by the existing equipment and conditions at the facility. However, most facilities are currently equipped with ESPs, and some are equipped with FFs. Thus, the most likely scenario for application of ACI is in a configuration with ESP or FF.

Most existing facilities have ESPs for particle emission control and do not have any SO_2 removal technology. Therefore, injection of sorbent, and possibly water for humidification, will most often be performed downstream of the air preheater and upstream of the electrostatic precipitator, where the gas temperature is typically in the range of 280-300 ºF. In this part of the boiler ductwork, there are no water wall tubes. Therefore, the mechanical interface between the ACI system and the boiler is through the duct walls, and high-pressure boiler tubing will not be affected by the retrofit of ACI.

Some companies offer other sorbent-based methods for reduction of mercury emissions; however, the equipment used is very similar in scope to the equipment used for ACI.[32]

The majority of the equipment used for an ACI system is produced from standard mechanical or electrical hardware that is sold for a wide range of purposes. The total amount of steel is relatively small in comparison to an SCR or an FGD for a 500 MW_e plant.[27] The estimated steel requirement for a 500 MW_e ACI system is indicated in Table 4-1.[33] Since the largest item contributing to the steel requirement is the storage silo, it will be assumed that the total steel requirement is proportional to the capacity of the unit, as the storage requirement would be proportional to the capacity. For multiple units at one site, all but the silo would certainly need to be duplicated. It is possible that there might be one large silo serving several units with more than one feed off of it, or, that individual silos may be needed. In any event, the synergies in reducing total steel requirement over what would be needed for individual units is expected to be small.

Table 4-1. Estimated Steel Requirement for 500 MW_e ACI System[33]

Item	Estimated Weight (lbs)
1" Sch. 40 Pipe, 1500 ft	4,000
2" steel tubing 1500 ft	4,500
Misc Structural Support Steel	5,000
Process Equipment (mostly steel)	15,000
Storage Silo	320,000
Total	350,000 lbs (175 tons)

4.2 Reagent

AC is assumed to be the principal reagent used to absorb the mercury in the exhaust gases. Most of the information on the AC injection requirements for a coal-fired power plant is from pilot studies and demonstrations of ACI technology. Table 4-2 shows AC injection rates estimated from the data provided a comprehensive assessment of ACI under a range of scenarios.[34] For example, to achieve 80 percent mercury reduction from a low sulfur bituminous coal using an ACI system with humidification will require a treatment rate of about 8 lb/million acf (MMacf).[34] If a pulsejet FF (PJFF) is used downstream, the sorbent injection rate can be reduced to about 4.6 lb/MMacf. If the facility fires high sulfur coal and is equipped with FGD, then the estimated sorbent rate is between 6.1 lb/MMacf to 2.0 lb/MMacf, without and with a PJFF, respectively. For a high sulfur coal application, humidification would not be performed due to risk of acid condensation. Table 4-2 summarizes estimated injection rates for a 500 MW_e boiler under various scenarios.[34] As shown, the injection rates vary substantially based upon the circumstances.

Because combination of SCR and FGD are expected to have high mercury removal due to the SCR and FGD systems, those facilities that are so equipped are not expected to add ACI systems.

There are really no synergies in consumption if multiple ACI units are installed at one site. Therefore, the total AC consumption at a plant will be roughly proportional to the total plant capacity equipped with ACI.

Table 4-2. Estimated AC Injection Rates for a 500 MW_e Boiler[34]

Example	Hg reduction, percent	Coal	Sulfur, percent	Existing Controls[a]	Additional Equipment[b]	Injection Ratio, lb/MMacf[34]	Est. AC rate for 500 MW_e plant	
							lb/hr	tons/yr [c]
1	80	Bit.	0.6	ESP	SI, WI	8.03	815	3,036
2	80	Bit.	0.6	ESP	SI, WI, PJFF	4.63	470	1,751
3	80	Bit.	3	ESP, FGD	SI	6.14	624	2,321
4	80	Bit.	3	ESP, FGD	SI, PJFF	2.00	203	756
5	80	Subbit.	0.5	ESP	SI, WI	9.00	914	3,403
6	80	Subbit.	0.5	ESP	SI, WI, PJFF	0.17	17	64
7	80	Subbit.	0.5	FF	SI, WI	0.73	74	276

[a] *ESP = electrostatic precipitator; FGD = flue gas desulfurization; FF = fabric filter; SCR = selective catalytic reduction*

[b] *SI = sorbent injection; WI = water injection; PJFF = pulsejet fabric filter*

[c] *Tons/yr estimated at 85 percent capacity factor (lb/hr * 8760 * 0.85/2000)*

4.3 Construction Equipment

Construction equipment needed for installation of an ACI system includes standard construction equipment – welders, excavation equipment, concrete pouring equipment, cranes, etc. Since an ACI system is much smaller and uses substantially less steel than an SCR or FGD system, cranes and other lifting equipment can be of low to moderate lifting capacity. Blowers, the sorbent storage silo, and other equipment will be mounted on concrete pads or foundations. In most cases, the sorbent storage silo will be field erected; however, for some facilities that require less sorbent, a smaller, prefabricated silo may be installed. Steel erection and minor excavation and concrete work is necessary for an ACI system, and this work should not require any more than very common construction equipment. Piping for sorbent transport will typically be welded steel and can be erected in the field in many cases. It should not be necessary to relocate any existing boiler equipment to install an ACI system. Therefore, the construction effort and need for equipment is relatively modest compared to the more involved SCR and FGD projects.

4.4 Installation Time

Implementation of a control technology at a plant involves several activities contingent upon each other. These activities may be grouped under the following phases of an implementation project: (1) conducting an engineering review of the facility and awarding a procurement contract; (2) obtaining a construction permit; (3) installing the control technology; and (4) obtaining an operating permit.

Exhibit A-5 in Appendix A depicts the timeline expected for completing a single unit installation of ACI. Completion of some of the activities is contingent upon completion of other activities. For example, construction activities cannot commence until a construction permit is obtained. In general, the ACI implementation timeline appears to be driven primarily by the engineering activities (i.e., design, fabrication, and construction).

Engineering Review

As shown in Exhibit A-5 in Appendix A, in the first phase of technology implementation, an engineering review and assessment of the combustion unit, is conducted to determine the preferred compliance alternative. During this phase, the specifications of the control technology are determined and bids are requested from the vendors. After negotiating the bids, a contract for implementing the control technology is awarded. The time necessary to complete this phase is approximately four months.

Control Technology Installation

In the second phase, the control technology is installed. This installation includes designing, fabricating, and installing the control technology. In addition, compliance testing of the control technology is also completed in this phase. Most of the construction activities, such as earthwork, foundations, process electrical and control tie-ins to existing items, can occur while the boiler is in operation. The time needed to complete this phase of an implementation project is expected to be less than three months.[33]

An important element of the overall control technology implementation is the time needed to connect, or hook up, the control technology equipment to the combustion unit. As a result of the minimal mechanical interface between the sorbent injection system and the boiler, retrofit of an ACI system will typically require a fairly short outage - one week or less.[33,34] This brief outage is necessary to install injection hardware and to make any control system connections that may be necessary between the ACI control and the boiler control. Other equipment associated with the ACI system can be installed with the boiler on line, as it does not require any interfacing with the boiler and should not require moving any essential boiler equipment.

It should be possible to complete a project in less than 4 months from receipt of order.[34] If construction and operating permits are included in the analysis, the project is likely to take longer than would be necessary only for engineering, supply, installation, and startup of the ACI system. This is because the permitting activities might become the time-limiting steps. In some localities, it is possible that the permitting activities will not be the limiting steps. In this case, a faster execution is possible than shown on Exhibit A-5 in Appendix A.

Operating Permit

Facilities will also need to modify their Title V operating permit to incorporate the added control devices and the associated reduced emission limits. In some states, an interim air-operating permit may need to be obtained until the Title V permit is modified. The operating permit modification process consists of preparation and submission of the application to the appropriate state or local regulatory agency. As shown in Exhibit A-5 in Appendix A, this process can occur simultaneously with the processing of the construction permit application. The process of transitioning from the construction permit to the operating permit varies among states and appears to be somewhat unclear due to the infancy of the Title V operating permit process. Nonetheless, based on discussions with several states, the application review process is estimated to take approximately 38 weeks (9-10 months). The Title V operating permit must also be made available for public comment and is not made final until compliance testing on the control device is completed. Therefore, the total estimated time to modify the Title V operating permit is about 12 months, plus the additional time to complete compliance testing.[10]

Based on the estimated time periods needed to complete each of the four phases described above, the estimated time period to complete the implementation of ACI on one combustion unit is about 15 months, as shown in Exhibit A-5 in Appendix A. Since the permitting process limits the timeline, a faster permitting process will shorten the time necessary to install ACI on a single unit.

Under the Clear Skies Act, EPA does not expect that ACI will be implemented at many facilities due to the co-benefit of mercury removal from other control technologies. For those plants where EPA projects ACI retrofits will occur, EPA's projections reflect that these facilities will either have 1 to 2 boilers retrofit per site. Exhibit A-6 in Appendix A examines a schedule for retrofitting a facility with multiple (two) ACI retrofits. This examines the installation of the control device hook-up on a sequential basis. Installation is staggered by one month between sequential units to enable more efficient utilization of manpower and project management than if multiple units were connected at one time. This approach requires a total time of 16 months.

In summary, the total time needed to complete the design, installation, and testing at a facility with one ACI unit is about 15 months, at a facility with two ACI units is approximately 16 months. Based on these timelines, it is estimated that, in principle, the mercury controls needed to comply with a multipollutant strategy can be met provided that (1) an adequate supply of materials and labor is available and (2) the control technology implementation process begins at least 16 months prior to the date controls must be in place. However, ideally, longer than 16 months would allow retrofits to occur over a period of several years so that facility owners can properly plan outages and suppliers can properly plan for resource availability. Erection of a PJFF would typically take 16 to 20 months from award of contract to start up.[35] If 4 months is added for pre-contract effort and 1-2 months is provided for start up and commissioning, the total project duration would be anywhere from about 21 months to 26 months. However, EPA's modeling under the Clear Skies Act projects that the units installing ACI will not be installing PJFFs.[36]

4.5 Labor

The man-hours of labor estimated to be required for supply of an ACI system are listed in Table 4-3, which includes a breakdown of man-hours by task.[33] Craft labor for installation is also indicated.

Table 4-3. Estimated Man-hours for Supply of an ACI System for a 500 MW_e 0.6% S Bituminous Coal Boiler with ESP (Example 1 from Table 4-4)[33]

Task	Man-hours
Off-Site Engineering and On-Site Testing	1,600
Installation, except silo (ironworkers, pipe fitters, electricians)	1,200
Erection of Silo (ironworkers, pipe fitters)	2,000
Total Man-hours*	4,800

**Estimated time for engineering, design, equipment procurement, and assembly is 6 months.*

In summary, a 500 MW_e boiler firing eastern bituminous coal with 0.6 percent sulfur, an ESP, and no SCR or FGD, is estimated to provide the performance and require the resources listed in the first column of Table 4-4, and estimates of performance and resources needed for other types of fuels and boiler configurations are shown in the other columns. A boiler firing subbituminous coal and with only an ESP for particle collection and pollution control will require the most activated carbon consumption and the most steel for the ACI system. Table 4-5 shows the estimated performance and resources needed for a single and multiple (two) ACI retrofit on a 500 MW_e boiler firing subbituminous coal and equipped with an ESP. As shown, as long as at least 16 months are provided for installation of ACI control technology, then there should be sufficient time for the technology to be installed. If a facility owner chose to install a Pulse-Jet Fabric Filter (PJFF) in addition to the ACI system for the purpose of improving sorbent utilization, the project time would necessarily be lengthened beyond this 16-month period to allow for the installation of the PJFF. As stated in section 4.4, the total duration for a PJFF retrofit is estimated to be anywhere from about 21 months to 26 months, including pre-contract effort and start up and commissioning. Since the Clear Skies Act provides much more than 26 months of notice for any mercury control regulation, there should be adequate time for compliance even if some facilities install PJFFs.

Table 4-4. Estimated Performance and Resources Needed for Single ACI Retrofit

	Units	Example 1	Example 2	Example 3	Example 4	Example 5	Example 6	Example 7
Fuel	coal type	Bit.	Bit.	Bit.	Bit.	Sub.	Sub.	Sub.
Sulfur	percent	0.6	0.6	3	3	0.5	0.5	0.5
Existing Controls		ESP	ESP	ESP, FGD	ESP, FGD	ESP	ESP	FF
Additional Controls		SI, WI	SI, WI, PJFF	SI	SI, PJFF	SI, WI	SI, WI, PJFF	SI, WI
Boiler Heat Rate	Btu/kWh	10,500	10,500	10,500	10,500	10,500	10,500	10,500
Fuel Heat Value	Btu/lb	12,500	12,500	12,500	12,500	8,500	8,500	8,500
Total MW_e	MW_e	500	500	500	500	500	500	500
Units		1	1	1	1	1	1	1
Total Heat Input	MMBtu/h	5,250	5,250	5,250	5,250	5,250	5,250	5,250
Plant Capacity Factor		85%	85%	85%	85%	85%	85%	85%
Coal Flowrate	tons/h	210	210	210	210	309	309	309
Coal Mercury Content	mg/kg	0.1	0.1	0.1	0.1	0.1	0.1	0.1
Uncontrolled Mercury	lb/h	0.042	0.042	0.042	0.042	0.062	0.062	0.062
Uncontrolled Mercury	gm/hr	19	19	19	19	28	28	28
Full Load AC Injection Rate	lb/MMacf	8.03	4.63	6.14	2.00	9.00	0.17	0.73
AC Injection Ratio	lb AC/lb Hg	19,416	11,195	14,846	4,836	14,798	280	1,200
Full Load AC Injection Rate	lb/h	815	470	624	203	914	17	74
Annual AC Required	tons/yr	3,036	1,751	2,321	756	3,403	64	276
Hg Control Level		80%	80%	80%	80%	80%	80%	80%
Controlled Hg	g/h	3.8	3.8	3.8	3.8	5.6	5.6	5.6
Annual Controlled Hg Emissions	lbs	50	50	50	50	74	74	74
Steel	tons	183	112	143	57	203	19	30
Labor	man-hours	4,800	3,954	4,330	3,298	5,043	2,842	2,982

Note: Annual consumption values are estimated using 85 percent capacity factor. Hourly consumption values are at full load. Steel and Labor do not include steel and labor for a PJFF, if added.

Table 4-5. Estimated Performance and Resources Needed for Single and Multiple ACI Retrofits (using Example 5 from Table 4.4)

Number of Boilers	**Units**	**1**	**2**
Existing Controls		ESP	ESP
Boiler Heat Rate	Btu/kWh	10,500	10,500
Fuel Heat Value	Btu/lb	8,500	8,500
Total MW_e	MW_e	500	1,000[a]
Total Heat Input	MMBtu/h	5,250	10,500
Plant Capacity Factor	%	85	85
Coal Flowrate	tons/h	309	618
Coal Mercury Content	mg/kg	0.1	0.1
Uncontrolled Mercury	lb/h	0.062	0.124
Uncontrolled Mercury	g/h	28	56
Performance			
Full Load AC injection rate	lb/MMacf	9.00	9.00
AC Injection Ratio	lb AC/lb Hg	14,798	14,798
Full Load AC injection rate	lb/h	914	1828
Annual AC required	tons/yr	3,403	6,806
Hg control Level	%	80	80
Controlled Hg	gm/h	5.6	11.2
Annual Controlled Hg Emissions	lbs	74	148
Resources			
Steel	tons	203	Up to 391
Labor	man-hours	5,153	Up to 7,505
Project Duration	months	15	16

[a] *EPA modeling projects that the plant with the maximum number of ACI retrofits is one plant with two boilers and a total capacity of 900 MW_e.*

Note: Annual consumption values are estimated using 85 percent capacity factor. Hourly consumption values are at full load.

4.6 Space Requirements

Most of the equipment and piping associated with a sorbent injection system is fairly small and can be easily accommodated on any facility. The only piece of equipment that could potentially be a challenge to locate on site is the sorbent storage silo, the other equipment largely being piping and a blower. The storage silo is, by far, the largest part of the ACI system. It is estimated that a storage silo that is sized for 15 days of AC storage at full load for a 500 MW_e plant firing bituminous coal and with only an ESP would be about 10.7 m in diameter and about 26.7 m high.[33] This sized piece of equipment, while large, should be readily accommodated on most sites large enough for a 500 MW_e boiler. For boilers with fabric filters, the size of the silo would be less because of the lower sorbent injection rate. Some facility operators may choose to install a PJFF in order to reduce sorbent consumption and to segregate carbon from the ash. In this case, more space would be needed for the PJFF. The dimensions for a PJFF on a 500 MW_e plant would be roughly 62 feet wide x 92 feet long x 90 feet high.[35]

Chapter 5
Synergies of Combinations of Control Retrofits on a Single Unit

This chapter will explore the combination of these technologies and how deployment of more than one technology at a unit could potentially result in improved resource utilization. It is assumed that the ACI, FGD, and SCR would not be necessary at a single unit because of the high mercury removal efficiencies expected through combination of FGD and SCR. Hence, the synergies of combining all three technologies were not explored.

5.1 SCR and FGD (Scrubber) Installations

In some cases, facility owners may choose to retrofit their plants with both SCR and FGD technology to achieve both NO_X and SO_2 reduction. Combination of SCR and FGD will also result in significant reduction of mercury emissions, thereby mitigating the need for the addition of ACI. However, both SCR and FGD are very capital-intensive projects, which require a substantial level of material and construction. Therefore, it is worthwhile to consider if both SCR and FGD installations can be combined efficiently.

An SCR project involves retrofitting in the boiler and its immediate area. Therefore, an SCR retrofit project may require relocation of equipment in the boiler area. An FGD system is installed farther downstream in the plant, after the ESP. Occasionally, it is necessary to install a new smoke stack, and it may be necessary to add more fan capacity. However, an additional smoke stack is normally unnecessary. The FGD connection with the facility is generally less difficult than with SCR because it does not require modification of the boiler, just connection to ductwork in the vicinity of the stack. As a result, the construction activities would normally be in different locations at the plant, reducing the interference between the two projects. The SCR might be the limiting item on the boiler outage because of its more complex connection. In any event, the tie-in of the SCR and the FGD systems could be done in the same outage, and it has been confirmed that the installation of SCR and scrubber could be performed simultaneously without interference.[37] Therefore, installing these at the same time on a boiler is preferable to doing them separately as they may be able to use the same outage, and project efficiencies result from a single mobilization, a single construction manager, and sharing of large construction equipment for the two projects. At Kansas City Power and Light's Hawthorn Power Station, Unit 5 was replaced (excluding turbine) in under 22 months. This included the boiler, an SCR, and an LSD/FF.[38] Although, in this case the equipment did not have to be erected adjacent to an operating boiler, the erection included demolishing and erecting a complete boiler island and demolishing the existing electrostatic precipitator. Hence, this was a very complex project that was completed approximately within the time frame estimated and shown in Exhibit A-7 in Appendix A.

5.2 Mercury Control Technology and Scrubber Installations

As noted in Chapter 4, ACI entails a much smaller construction project than either an FGD or an SCR. Moreover, the ACI is located in a different part of the plant than FGD or SCR and activated carbon injection occurs in the ductwork between the air preheater and the ESP or FF. One benefit of combining these two projects is that the ACI hookup can be completed during the outage for the scrubber hookup, since the installation effort necessary for the FGD will far outweigh that of the ACI system. A second benefit is better planning of material storage and handling equipment. Both FGD and ACI require a substantial amount of material (limestone and AC, respectively) and associated storage and handling facilities. Installing both technologies at the same time will permit better planning of material storage and equipment locations, thereby avoiding interference. Other benefits, such as a single mobilization, a single construction manager, and sharing of large construction equipment for the two projects exist, but they are not expected to make a significant difference due to the difference in size between the portions of the combined FGD and ACI project. Therefore, as shown in Exhibit A-8 in Appendix A, the schedule for a combined FGD and ACI project is expected to be the same as the schedule of an FGD project.

5.3 Mercury Control Technology and SCR Installation

As noted in Chapter 4, ACI entails a much smaller construction project than either an FGD or an SCR. The primary benefit of combining these two projects is that the ACI hookup can be completed during the outage for the SCR hookup, since the installation effort necessary for the SCR will far outweigh the ACI system. Other benefits, such as a single mobilization, a single construction manager, and sharing of large construction equipment for the two projects exist, but they are not expected to make a significant difference due to the difference in size between the SCR and ACI portions of the combined project. Therefore, as shown in Exhibit A-9 in Appendix A, the schedule for a combined SCR and ACI project is expected to be the same as the schedule of an SCR project.

Chapter 6
System Resource Availability

Having assessed the resource requirements for individual or multiple retrofits of control technologies, this chapter will assess the resource availability in the United States for retrofit of control technologies for the Clear Skies Act. This analysis considers the current availability of resources for the construction of control technologies and does not consider any potential increase in production of resources due to the demand created by the Clear Skies Act. Because this effect will be more pronounced in the period following 2010 and because other market factors may also change over time, the longer term projections are of less value than those out to 2010. EPA has made preliminary estimates of the retrofits of each technology that would result from the Clear Skies Act. Tables 6-1a, b, and c list the expected total MW_e of facilities that would be equipped with SCR, FGD, or ACI after response to a multipollutant rule. It is important to note that the "Current Air Quality Rule Retrofit MW_e" row of the table includes only the projected retrofits under the current air quality rules. The control technology retrofits estimated to result from the Clear Skies Act, including the retrofits from current air quality rules, is listed in the "Multipollutant & Current Retrofits MW_e" row of the tables. The "Cumulative Total" MW_e shown in Table 6-1 includes facilities that currently are equipped with the technology or are expected to be equipped with the technology as a result of current air quality rules, such as SCRs resulting from the NO_X SIP Call as well as the projected retrofits under the Clear Skies Act. EPA estimated that up to 72 GW_e of SCR would result from the NO_X SIP Call and an additional 13 GW_e from individual state multipollutant rules with approximately 14 GW_e currently installed. However, facilities are responding to the NO_X SIP Call at this time and it is uncertain exactly how many facilities will ultimately be equipped with SCR in 2004 when the NO_X SIP Call deadline arrives.

EPA projections estimate that it would be cost effective for 32,000 MW_e of FGD retrofits to be installed under the Clear Skies Act by 2005 even though the first phase of the SO_2 cap is not in effect until 2010. These retrofits would be early installations that sources initiate due to the economic benefits of banking SO_2 allowances. It is estimated that there are about 4,000 MW_e of FGD capacity being constructed or just recently completed. Based on availability of resources, particularly labor, it is projected that an additional 6,000 MW_e of FGD capacity could be built for a total of 10,000 MW_e by 2005. Because the FGD estimate based on availability of resources is much less than the amount of FGD capacity that would be cost effective to build, EPA ran model sensitivities constraining the amount of scrubber capacity that could be installed by 2005 at 10,000 MW_e. This estimate for the potential number of FGD retrofits considers the resource and labor requirements of the simultaneous installation of SCRs, which is further discussed under the labor section (6.2) of this chapter. The 22,000 MW_e difference, between the number of FGDs which would be cost effective to build and the estimated number based on resources, would be pushed back a few years to be completed by 2010. Therefore, the 53,000 MW_e of FGD retrofits projected to be built by 2010 for Clear Skies and current requirements remains the same under both scenarios. It is likely that additional FGD retrofits could be completed by 2005, but there would be the potential for an increase in the cost of construction due to decreased implementation time.

A typical unit size of 500 MW_e was selected for each technology. In previous sections, capacity factors of 85 percent were assumed. In reality, coal-fired facilities, on average, have lower capacity factors. For example, in 1999, 39.8 percent of 786 GW_e of generating capacity in the U.S., or 313 MW_e, was coal fueled. In that same year, coal-fired U.S. plants produced about 51 percent of 3,691 billion kWh, or

1,882 billion kWh.[39] This corresponds to a capacity factor of 68.7 percent (Data is from Energy Information Administration Web Site; Capacity Factor is total MW_e-h produced divided by the total MW_e-h that would be produced if the plant were run at full capacity for 8,760 h in the year). As a result, assuming a capacity factor of 85 percent will result in a much more conservative (high) estimate of resources needed than is likely to be the case.

In estimating the resources necessary to put new control technology capacity in place (labor, steel, etc.), the "Multipollutant & Current Rule Retrofits MW_e" values of Tables 6-1a, b and c are of greatest interest. For estimating the consumables necessary for the technologies, such as limestone, ammonia, catalyst, or activated carbon, the "Cumulative Total MW_e" value is most important. The multipollutant and total MW_e of control technology retrofits are given for 2005, 2010, 2015, and 2020. To provide a conservative estimate of required resources, the following analysis looks at implementing the retrofits for 2005 in 31 months prior to 2005 and retrofits for 2010, 2015, and 2020 three years prior to each five-year period. For example, it estimates the resource requirements from the period between 2005 and 2010 over three years prior to 2010 instead of five years. Thirty-one months was used for 2005, because the analysis for 2005 was based on the projected number of retrofits needed by 2005, less the amount of capacity installed by May 2002. It should also be noted that most of the retrofits needed by 2005 are being installed to meet existing requirements under the NO_X SIP Call or other regulatory requirements as opposed to the requirements of a multipollutant program such as the Clear Skies Act.

Table 6-1a. FGD Retrofits

Scrubbers	2005	2010	2015	2020
Existing Scrubbers (MW_e)	94,000[a]			
Current Air Quality Rule Retrofits (MW_e)	6,000	2,000	7,000	1,000
Multipollutant & Current Rule Retrofits (MW_e)[b]	10,000[c]	43,000	29,000	36,000
Cumulative Total Scrubbers (MW_e)	104,000	147,000	176,000	212,000
Incremental Number Scrubbers	21	87	84	100 (292)[d]
Average Size Unit (MW_e)	476	494	345	360 (404)[e]
Maximum Number of Units at One Plant	2	5	6	6
Number of Plants with 6 Boilers Retrofitted[f]	0	0	1 (1)	2 (3)
Number of Plants with 5 Boilers Retrofitted[f]	0	3 (3)	1 (4)	0 (4)
Number of Plants with 4 Boilers Retrofitted[f]	0	3 (3)	2 (5)	5 (10)
Number of Plants with 3 Boilers Retrofitted[f]	0	6 (6)	8 (14)	9 (23)
Number of Plants with 2 Boilers Retrofitted[f]	6	16 (22)	11 (33)	10 (43)
Number of Plants with 1 Boiler Retrofitted[f]	9	10 (19)	19 (38)	21 (59)

a - 94,000 MW_e of scrubbers currently installed

b – includes the retrofits from multipollutant strategy as well as the projected retrofits due to current regulations

c – IPM results reflect that it would be cost-effective to install 32,000 MW_e, but based on resource availability it is estimated that 10,000 MW_e can be built

d - 292 is the total number of projected units to be retrofitted with scrubbers from present to 2020

e - 404 is the average size retrofit of the 292 units to be retrofitted with scrubbers (does not include the current 94 GW_e)

f - number in parentheses represents cumulative number of plants with "x" boilers retrofitted from present to given year

Table 6-1b. SCR Retrofits

SCR	2005	2010	2015	2020
Incremental Annual NO_x Reductions (1000 tons)	717	1,572	20	364
Total Annual NO_x Reduced (1000 tons)	717	2,289	2,309	2,673
Current Air Quality Rule Retrofits (MW_e)	85,000	6,000	3,000	6,000
Multipollutant & Current Rule Retrofits (MW_e)[b]	85,000[g]	65,000	3,000	40,000
Cumulative Total SCR from Present-to-date (MW_e)	85,000	137,000	140,000	180,000
Incremental Number SCR	162	156	18	119 (455)[h]
Average Size Unit (MW_e)	525	416	167	336 (413)[i]
Maximum Number of Units at One Plant	5	6	6	7
Number of Plants with 7 SCR Retrofits[f]	0	0	0	1 (1)
Number of Plants with 6 SCR Retrofits[f]	0	2	0 (2)	1 (3)
Number of Plants with 5 SCR Retrofits[f]	4	2 (6)	0 (6)	0 (6)
Number of Plants with 4 SCR Retrofits[f]	7	9 (16)	2 (18)	5 (23)
Number of Plants with 3 SCR Retrofits[f]	15	5 (20)	1 (21)	9 (30)
Number of Plants with 2 SCR Retrofits[f]	24	17 (51)	1 (52)	22 (74)
Number of Plants with 1 SCR Retrofits[f]	33	29 (62)	5 (67)	15 (82)

g – up to 72 GW_e of SCR to be installed for NO_X SIP Call with 14 GW_e of the total 85 GW_e already installed, 13 GW_e of installations projected for individual state multipollutant rules

h - 467 is the number of total SCRs installed from present to 2020 (includes NO_X SIP Call retrofits); 455 is the number of total SCRs installed from 2005 to 2020

i- 413 is the average size retrofit of the 467 projected SCRs (includes NO_X SIP Call retrofits)

Table 6-1c. ACI Retrofits

ACI	2005	2010	2015	2020
Current Air Quality Rule Retrofits (MW_e)	0	0	0	0
Multipollutant & Current Rule Retrofits (MW_e)[b]	0	0	1,000	300
Cumulative Total ACI from Present-to-date (MW_e)	0	0	1,000	1300
Incremental Number ACI	0	0	2	1 (3)[j]
Average Size Unit (MW_e)	0	0	500	300 (433)[k]
Maximum Number of Units at One Plant	0	0	2	2
Number of Plants with 2 ACI Retrofits[f]	0	0	1	0 (1)
Number of Plants with 1 ACI Retrofit	0	0	0	1

j - 3 is the number of total ACI installed from present to 2020

k - 433 is the average size retrofit of the 3 projected ACIs retrofits

6.1 System Hardware

The hardware items such as steel, piping, nozzles, pumps, soot blowers, fans, tower packing, and related equipment required for a typical SCR, FGD, or ACI systems installation are used in large industries such as construction, chemical production, auto production, and power production. Consequently, installation of these technologies on many coal-fired utility boilers is not expected to result in severe changes in demand for the hardware items listed.

From Chapter 2, roughly 1,125 tons of steel is needed for a 500 MW_e FGD system, which is about 2.25 tons per MW_e. This is conservatively high since there are some significant synergies possible when there are multiple units on site. In particular, two boilers with 900 MW_e of capacity require approximately 2.1 tons per MW_e. From Chapter 3, an SCR for a coal-fired utility boiler requires roughly 2.5 tons of steel per MW_e for the typical size. From Chapter 4, a 500 MW_e facility will need about 175 tons of steel to install an ACI system, or about 0.35 tons per MW_e. Estimated steel requirements for the projected retrofit MW_e are shown in Table 6-2 assuming that the retrofits occur over 31 months prior to 2005 and over three years prior to 2010, 2015, and 2020. For retrofits starting in 2005 facility owners are likely to have more than three years to complete this work as many of these retrofits have already begun. These time periods were chosen to show that even under short periods of time, no significant impact to U.S. steel supply is expected.

Census Bureau data on U.S. steel shipments in 2000 was approximately 108,703,000 tons, and imported steel was 30,993,000 tons for a total demand of about 140 million tons. An assumed growth rate of US steel demand was chosen at 3 percent, a typical number for growth in GDP. For each increment of time, the impact to US steel demand was less than one tenth of one percent. Even if there were no growth in the US steel production and imports from 2000 out to 2020, the amount of steel needed to complete the retrofits for the Clear Skies Act would still be less than one tenth of one percent of US production including imports.

Similarly, available supplies of piping, nozzles, pumps, soot blowers, fans, and other related standard component necessary for SCR, FGD or ACI installations are not expected to present constraints on the ability of facilities to install the technology. SCR catalyst is the only specialized piece of equipment that is needed. Catalyst is discussed in Section 6.4.

Table 6-2. Estimated Steel Required for Multipollutant Initiative

Year	2005	2010	2015	2020
FGD Steel Requirement, tons per year	9,000	32,000	22,000	27,000
SCR Steel Requirement, tons per year	69,000	54,000	3,000	33,000
ACI Steel Requirement, tons per year	0	0	120	40
Total Steel Requirement, tons per year	78,000	86,000	25,120	60,040
US Steel Demand (with 3% annual growth)	162,000,000	188,000,000	218,000,000	253,000,000
Percent of Total US Steel Demand	0.048	0.046	0.012	0.024

Note: Assumes that all retrofits occur over 31 month period prior to 2005 and a 3-year period prior to 2010, 2015, and 2020. Steel demand was determined from the "Multipollutant and Current Rule Retrofits MW_e" row of Table 6-1a,b,c. These estimates include the retrofits due to the NO_X SIP Call, current rules, and state rules. The steel demand for SCR was adjusted from 85 GW_e of demand in 2005 to 71 GW_e to account for 14 GW_e of SCR, which have been completed by May 2002.

6.2 Labor

The installation of the SCR, FGD, and ACI control technologies will require the following types of labor:

- general construction workers for site preparation and storage facility installation;
- skilled metal workers for specialized metal and/or other material assembly and construction;
- other skilled workers such as boilermakers, electricians, pipe fitters, painters, and truck drivers; and
- unskilled labor to assist with hauling of materials, placing of catalyst elements, and clean up.

From Chapter 2, it takes roughly 760 man-hours of labor per MW_e of FGD built. Chapter 3 showed that about 700 man-hours of labor per MW_e are required for an SCR system on a coal-fired boiler, and Chapter 4 showed that roughly 10 man-hours of labor are needed per MW_e for an ACI system. Using these factors and the expected retrofits, the labor requirement for SCR, FGD, and ACI retrofits can be determined and are shown in Table 6-3. These estimates do not take into account any synergies or efficiencies realized from retrofitting multiple units on a site, as are described in Section 2.5 and 3.5, or from a combination of technologies, as described in Chapter 5. Roughly 50 percent of an SCR project man-hours and 40 percent of an FGD project man-hours are for boilermakers.[40] There is little data on ACI breakdown of labor; however, a conservative level of 50 percent is assumed. Using these rates and assuming the above mentioned construction periods, it is possible to estimate the number of fully employed laborers and boilermakers. The results are shown in Table 6-3. The actual annual requirement for labor would be less if the estimated number of retrofit installations were evenly distributed over the full five-year increment of time instead of the conservative three-year increment.

Table 6-3. Estimated Annual Construction and Boilermaker Labor Required for Clear Skies Act (man-years)

Year	2005	2010	2015	2020
FGD Labor	1,425	5,225	3,525	4,375
FGD Boilermakers	575	2,100	1,425	1,750
SCR Labor	9,250	7,300	325	4,475
SCR Boilermakers	4,625	3,650	175	2,250
ACI Labor	0	0	2	2
	0			
ACI Boilermakers		0	1	1
Total Labor	10,675	12,525	3,852	8,852
Total Boilermakers	5,200	5,750	1,601	4,001

Note: Assumes that all retrofits for 2005 occur over thirty-one months prior to 2005 and over a three-year period for each five-year increment after 2005 through 2020. SCR labor and boilermaker demand were adjusted from 85 GW_e of demand in 2005 to 71 GW_e to account for 14 GW_e of SCR which have been completed by May 2002.

Figure 6-1 shows a summary of construction worker labor available in the United States. The data shows steady growth in construction industry employment at the national level during the 1992 to 2000 period. Employment in the construction sector grew by 49.1 percent (4.1 percent annualized) over the period compared to 21.7 percent (2.0 percent annualized) for the economy as a whole. The unemployment rate of 6.4 percent in 2000 compares to 4.0 percent for the whole economy.[41]

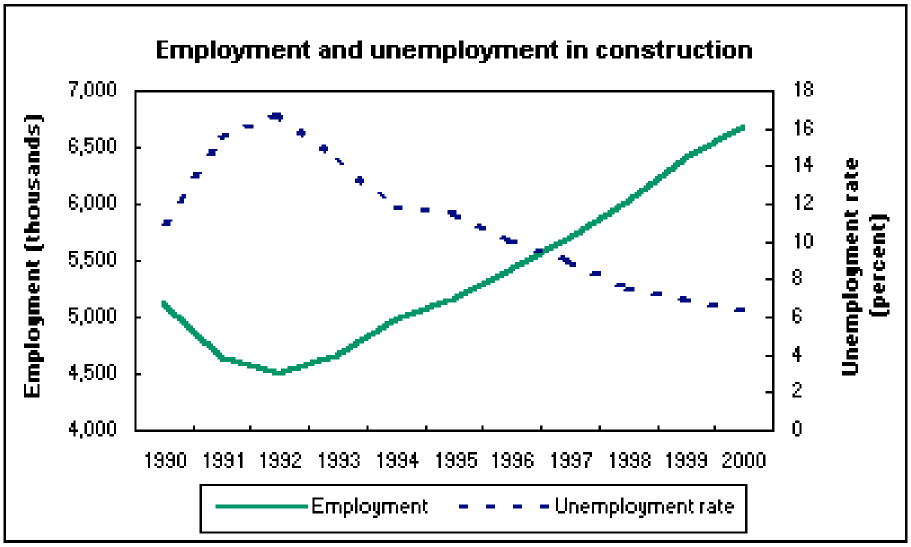

Figure 6-1. U.S. construction employment and unemployment (Source: Bureau of Labor Statistics).

The available construction labor in the United States, about 6.7 million, will provide a large labor pool for the trades that are not unique to the power industry, such as iron and steel workers, pipe fitters, and electricians. In other words, that the estimated demand of under 20,000 full-time workers represents only about 0.3 percent of the current total labor pool.

Boilermakers are a skilled labor source that is fairly unique to utility work. Sixty percent of the demand for boilermakers in the construction division is from the utility industry.[31] Other industries requiring boilermaker labor include refinery (13 percent), chemical (6 percent), paper (7 percent), and metals (6 percent). These are the industries where boilers and high-energy vessels are most likely to be found. Retrofit of equipment on utility boilers often requires a significant number of boilermakers due to the integration that is needed with the boiler that often requires modification of steam piping or other boiler equipment. Also, in response to the increase in demand for boilermakers over the last few years, their ranks have increased from 15,444 active members in 1998 to 17,587* members in 2000 - an annualized growth rate of 6.7 percent.[31] Employment level also increased during this time from 69.8 percent to 81.8 percent (employment level is equal to the total man-hours worked in the year divided by total active members time 2080 h/yr). During much of the 1990's the number of active boilermakers had been declining due to very low employment levels resulting from very low activity in the utility power plant construction business.[30] Therefore, the increased activity of the last few years has been a welcome change to boilermakers.

Several sources have mentioned that the availability of boilermakers has been tight for the SCR projects underway for the NO_X SIP Call.[42, 43] However, where shortages have been experienced in manning SCR construction projects with adequate numbers of boilermakers, manpower planning had been done with short notice.[44] Many boilermakers travel to work sites that are out of their local area. A large project may require mobilization of several hundred boilermakers to a site, which will frequently require pulling

* It is assumed that this number is for journeyman boilermakers and does not include persons in apprenticeship programs.

members from other parts of the country. In the current, competitive environment for utilities, power plant owners are reluctant to provide much advance notice of when outages will occur. Therefore, in some cases contractors must find manpower on very short notice. The boilermaker's union (The International Brotherhood of Boilermakers, Iron Ship Builders, Blacksmiths, Forgers and Helpers) attempts to provide the necessary manpower to the contractors. However, with very short notice, it is sometimes difficult to move the manpower to the site in the short time desired. Nevertheless, the union has been successful in providing sufficient manpower to the project sites where they have had adequate advance notice.[44] Therefore, although there is little slack in the availability of boilermakers, better coordination may have avoided the labor shortage problems.

It is worthwhile to consider the expected future state of the supply of boilermakers. The total number of members in the boilermaker's construction division is currently about 24,000 journeymen and apprentices.[44] The union has about 4000 members in Canada. These numbers are up from the 1990's when a severe drought of work for boilermakers caused many boilermakers to seek other lines of work. Due to the current workload, the boilermaker ranks are growing. However, the average age of the work force is about 48. Because of the aging workforce and because of the anticipated demand for work at power plants, the union has made it an objective to have at least 28,000 members in the construction division by 2005, or at least a 5.3 percent annual growth rate. The boilermaker's union is working to recruit new members into their apprenticeship programs, which takes four years to complete. Also, skilled workers from other trades may choose to work as a boilermaker, so a shorter apprenticeship may be possible, depending upon the experience and skill level of the individual. For example, iron and steelworkers who had been boilermakers in the past could move back into boilermaker work very quickly. Since, boilermakers earn somewhat more than ironworkers,[42] it is reasonable to expect that with increased job stability in the boilermaker trade, some ironworkers might choose to move to the boilermaker trade for the higher pay, especially if they had worked as boilermakers in the past. The iron and steelworkers union has 150,000 members.[45] Even without prior boilermaker experience, some of these iron and steelworkers could choose to move to boilermakers with much less than a full four-year training requirement because of their knowledge and skill level. In addition, the boilermaker's shipbuilding division has about 30,000 members[45] who, depending upon industry conditions, could move over to the construction division quickly.

As noted earlier, the number of boilermakers dropped quickly during the 1990s when little work was available. Conversely, increasing demand for boilermakers that would result from a multipollutant rule should stimulate more workers to enter the trade. The overall employment outlook for boilermakers should be quite good, considering the work created by a multipollutant initiative and the work on new power plants that is projected over the next 20 years. As stated in the National Energy Policy (May 2001):

> *Over the next 20 years, the United States will need 1300 to 1900 new power plants. Electricity demand is expected to increase at a rate of 1.8 percent per year over the next 20 years, creating the need for 393,000 MW_e of generating capacity. At a 1.5 percent growth rate that number is reduced by between 60,000 to 66,000 MW_e to about 330,000 MW_e of new generating capacity.*

A large quantity of new generating capacity, consisting mostly of gas combined cycle units, has been built within the last several years. Since 1998, close to 200 GW_e of new capacity have been built or is currently under construction with an even larger quantity being proposed. This excess in capacity is projected to create an overall reserve margin greater than 25 percent in the US over the next few years. By comparison, this is a significant increase in the reserve margin since it dipped below 10 percent in the late 1990's. As the demand in electricity grows, the need for new generating capacity will not be felt until the excess capacity is worked off. Assuming new capacity will be needed when the reserve margin approaches 15 percent, it is expected to push back the need for additional capacity beyond 2005 and in some regions as late as 2010.

Due to the installation of SCR units for the NO_X SIP Call, a significant percentage of the boilermakers who are currently working in the utility industry would be needed to complete those retrofits by 2004. Integrated Planning Model (IPM) projections indicate that it would be cost effective to install 32 GW_e of scrubbers by 2005 in addition to the projected SCR installations; however, boilermaker labor is not expected to be sufficient to meet this demand even if their numbers grow at the projected 5.3 percent annual growth rate. Figure 6.2 shows the boilermaker labor requirements out to 2010 assuming 32 GW_e of scrubbers and 85 GW_e of SCR installations are installed by 2005 and compares the demand to the supply of labor.

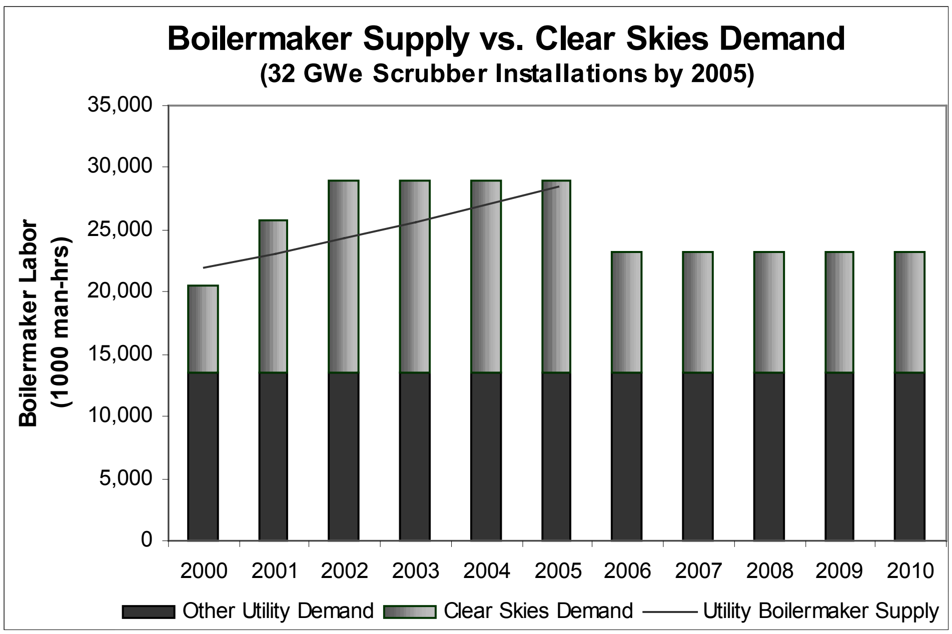

Figure 6-2. Boilermaker demand under Clear Skies Act (32 GW_e of FGD installations).

Assuming that the boilermaker membership grows at a 5.3 percent growth rate out to 2005, it is estimated that there will be sufficient new boilermaker labor to complete approximately 10 GW_e of scrubber retrofits by 2005. Considering that 4 GW_e of scrubber capacity is either being built or recently constructed, it is conservatively assumed than an additional 6 GW_e could be completed by 2005. This estimate of 10 GW_e of scrubber retrofits by 2005 was determined from the difference between the boilermaker labor hours available from the boilermaker membership working in the electric utility industry and the labor hours needed to complete control technology retrofits and other electric utility projects. This estimate is supported by the number of orders of FGDs for 2001 and projected orders through 2002 by the electric utility industry, which totals over 11 GW_e[46], and over 13 GW_e of announced scrubbers which are scheduled to start up by 2005. Orders for scrubbers, such as the recent order for the Coleman Station in Kentucky, are continuing to be received in spite of the concerns raised about the availability of boilermaker labor during the simultaneous installation of SCRs for the NO_X SIP Call. The other electric utility projects that boilermakers work on include such projects as routine maintenance at operating plants and new plant construction, which account for approximately 13,500,000 man-hours of boilermaker labor per year.[30] Figure 6-3 compares the available boilermaker labor to the demand from the electric utility industry which includes the retrofits from the Clear Skies Act.

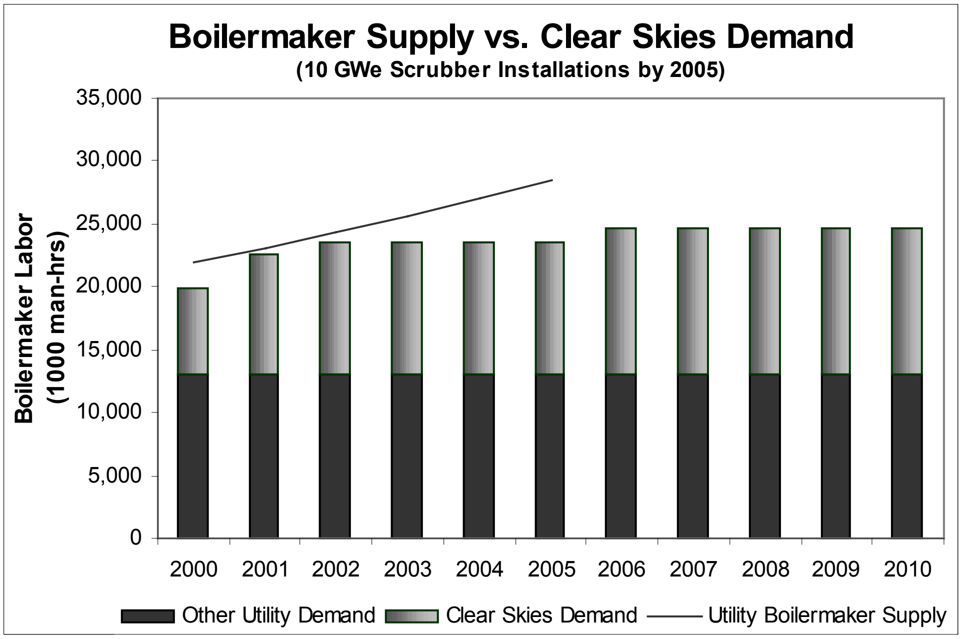

Figure 6-3. Boilermaker demand under Clear Skies Act (10 GW_e of FGD installations).

Since boilermakers earn more money than most other craft trades[42] and the demand for boilermakers should be steady and increasing, it is reasonable to expect that the growth in boilermaker numbers experienced these last few years should continue for many more years. To assess the impact of this, it was assumed that the boilermakers in the U.S. continued to grow at the 5.3 percent pace that the International Brotherhood of Boilermakers, Iron Ship Builders, Blacksmiths, Forgers, and Helpers has set as a minimum growth target. Based upon the estimates of Table 6-3 and the assumed growth rates, the annual boilermaker demand created by the Clean Skies Act can be estimated and is shown in Table 6-4. Table 6-4 was derived considering that 14 GW_e of SCRs have already been installed for the NO_X SIP Call, so the remaining 71 GW_e of SCR and 10 GW_e of scrubber installations were considered for 2005. According to Table 6-4, if the retrofit of the FGD, SCR, and ACI systems for 2005 occur over thirty-one months prior to 2005 and over a three-year period for each five-year increment after 2005 to 2020, the maximum demand would be about 23 percent of the journeyman boilermakers or about 19 percent for journeymen and apprentices combined.

Considering only the boilermakers who are currently in demand by the utility industry, the demand would be about 38 percent of the journeyman boilermakers or about 31 percent for journeymen and apprentices combined. These percentages of demand are expected to be experienced prior to 2010, but with growth in the boilermaker numbers out to 2010, the percent of boilermakers affected drops off. The number of boilermakers in demand for retrofit installations under the Clear Skies Act is spread fairly evenly out to 2010 when the demand begins to decrease. However, there may still be significant demand for boilermakers after 2010 from other power plant construction programs.

Table 6-4. Estimated Annual Boilermaker Demand Created by the Clear Skies Act

Year	2000	2005	2010	2015	2020
Boilermaker demand from Multipollutant Proposal		5,200	5,750	1,601	4,001
Considering Journeymen from all Industries					
Boilermaker Journeymen (persons 5.3% annual growth)	17,587	22,775	29,475	38,160	49,403
Boilermaker Journeymen (persons 6.7% annual growth)	17,587	24,325	33,638	45,015	62,256
Boilermaker Apprentice and Journeymen (persons 5.3% growth)	24,000	28,000	36,249	46,929	60,755
Demand (% of Journeymen @ 5.3% annual growth)		22.8	19.5	4.2	8.1
Demand (% of Journeymen @ 6.7% annual growth)		21.4	17.1	3.6	6.4
Demand (% of apprentice & journeymen @ 5.3% growth)		18.6	15.9	3.4	6.6
Considering Journeymen currently active in Utility Industry (60 percent of total)					
Boilermaker Journeymen (persons 5.3% annual growth)	10,552	13,661	17,685	22,896	29,642
Boilermaker Journeymen (persons 6.7% annual growth)	10,552	14,594	20,183	27,009	37,353
Boilermaker Apprentice and Journeymen (persons 5.3% growth)		16,800	21,749	28,157	36,453
Demand (% of Journeymen @ 5.3% annual growth)		38.1	32.5	6.9	13.5
Demand (% of Journeymen @ 6.7% annual growth)		35.6	28.4	5.9	10.7
Demand (% of Apprentice and Journeymen @ 5.3% growth)		31.0	26.4	5.7	11.0

Note 1: A 5.3 and 6.7 percent growth rate in boilermaker journeymen and apprentices is assumed over the period. In reality, this growth rate would probably drop off some time after 2010 unless there were other demand-generating events. The maximum growth rate assumes the boilermaker membership meets the union goal of 28,000 in 2005 from 2002 levels of 24,000 and then grows at 5.3 percent thereafter.

Note 2: It is conservatively assumed that all construction for retrofits by 2005 occur over thirty-one months prior to 2005 and over a three-year period for each five year increment after 2005 through 2020. SCR labor and boilermaker demand were adjusted from 85 GW_e of demand in 2005 to 71 GW_e to account for 14 GW_e of SCR which have been completed by May 2002.

The actual impact on the demand for boilermakers could be lower for several reasons. Due to the longer increments of time that the Clear Skies Act provides facility owners to comply than was assumed in this analysis, installation of these technologies will extend over more than three years, spreading out the demand. As stated earlier, this analysis does not consider any of the synergies or efficiencies that have been demonstrated to occur on multiple unit retrofits or multiple-technology retrofits. The boilermaker population has been growing at a faster rate– 6.7 percent annually – in recent years than the union's minimum target of 5.3 percent that was assumed. Therefore, the number of boilermakers may actually grow more quickly than what was assumed. This analysis also neglects overtime, which would reduce the demand for workers somewhat.

6.3 Construction Equipment

Most of the construction equipment necessary for the installation of SCR, FGD, and ACI technology is standard construction equipment that is used for most construction activities. The piece of equipment that is not standard that may be needed for SCRs and possibly for FGD systems is a tall-span heavy-lift crane. These cranes are necessary to lift heavy pieces (sometimes over 100 tons) several hundred feet and are not needed for all projects. When the largest piece to be lifted is determined from the construction plan, the necessary crane can be determined. In some cases, the available crane or the crane pricing may limit the largest piece to be lifted, and the construction plan may be modified to accommodate a smaller crane by lifting smaller pieces. In many instances, the best crane for the job is not the largest because the large cranes are very expensive to rent (one size up could double or triple the monthly charges for renting the crane[30]). As a result, it may be more cost effective overall to use a smaller crane and lift smaller pieces. This may lengthen the installation time slightly, but it will reduce crane rental fees. Therefore, an economic trade off must be assessed for each project.

As discussed in Section 3.3, utility engineers reported that while installing SCRs for the NO_X SIP Call, crane availability has been an issue that can be accommodated with proper planning. The construction plan could be modified to employ the available or most cost-effective crane. Therefore, sufficient supply of construction equipment is expected to be available for installing air pollution control equipment.

6.4 Reagents

The major groups of reagents considered in this Section include limestone for FGD systems, SCR catalyst, Ammonia/Urea, and AC for ACI systems.

Limestone for FGD Systems

Limestone is used for a wide range of purposes in the United States. Overall limestone usage increased 22 percent over the four years from 1995 to 1999 (annualized growth of 5.1 percent). Table 6-5 shows the production of crushed limestone sold or used by U.S. producers.

Table 6-5. Crushed Limestone Sold or Used By U.S. Producers

Year	Total Use (thousand tons)
1999	1,080,000
1998	1,050,000
1997	1,010,000
1996	956,000
1995	884,000

Source: U.S. Geological Survey, Minerals Yearbook, Volume I. Metals and Minerals, Crushed Stone, 1995 - 1999. http://minerals.usgs.gov/minerals/pubs/commodity/stone_crushed/index.html

As noted in Chapter Two, 500 MW_e plant firing 4.0 percent sulfur coal and equipped with LSFO FGD technology will use about 32 tons per hour of limestone, or about 240,000 tons/yr (about 0.064 tons/MWh), and limestone consumption for MEL technology would be less.[6] Using an LSFO consumption rate is conservatively high, and Table 6-6 shows expected consumption rates if all projected FGD retrofits were LSFO technology and operated at 85 percent capacity factor. The row "Multipollutant & Current Rule FGD Limestone Consumption (tons)" provides an estimate of the limestone consumption for the projected retrofits due to the multipollutant strategy and current air quality rules. The row "Cumulative FGD Limestone Consumption (tons)" provides an estimate of the limestone consumption for the cumulative total number of FGD installations, which includes 94 GW_e of current installations. As shown, the impact to total U.S. production for the multipollutant strategy remains less than 2 percent out to 2020 while the overall demand from all installed FGD remains less than 4 percent out to 2020.

Table 6-6. Estimated FGD Limestone Consumption and U.S. Production

Year	2005	2010	2015	2020
Multipollutant & Current Rule FGD Limestone Consumption (tons)	4,800,000	25,300,000	39,100,000	56,200,000
Cumulative FGD Limestone Consumption (tons)	49,600,000	70,100,000	84,900,000	101,000,000
Estimated U.S. Production (tons; 5.1% growth)	1,455,600,000	1,866,600,000	2,393,700,000	3,069,600,000
Multipollutant & Current Rule Percent of Limestone Production	0.33	1.36	1.63	1.83
Cumulative Percent of Limestone Production	3.41	3.76	3.55	3.29

SCR Catalyst

SCR catalyst is a critical part of the SCR system that is manufactured on a worldwide basis by some of the largest companies in the world. Manufacturing is largely in the United States, Europe, and Japan, and the worldwide capacity is used to support worldwide sales. The current and planned capacity of SCR catalyst supply available to the U.S. market for coal-fired boilers is nearly 90,000 m^3/yr. Table 6-7 shows the results of a survey of major suppliers of SCR catalyst to coal-fired boilers. The suppliers provided EPA their current capacity and the capacity that will be on line in the year 2002. The estimated capacity of other suppliers of catalyst to coal-fired boilers that could not be reached in time for this study is listed also. Suppliers that have offered catalyst for coal applications in the past but currently focus strictly on gas and oil -fired applications were not included. However, it is recognized that these companies could shift their product mix if the market conditions justified it, so the capacity value shown could be quickly increased if manufacturers simply changed product focus.

The current capacity was originally built overseas to meet overseas demand or was subsequently built to meet U.S. demand for catalyst spurred by the NO_X SIP Call and the build up of gas turbine power plants in the U.S. Except for a moderate demand for replacement catalyst, much of this capacity will be available after 2004 because these large demand peaks will have mostly passed. Because most of the companies that supply catalyst are divisions of very large companies with the resources to rapidly expand their manufacturing capacity to meet increases in market demand, it is reasonable to assume that this manufacturing capacity could be expanded if the market demand justified it. In fact, recent capacity expansions provide strong evidence of this.

Table 6-7. SCR Catalyst Capacity For Coal-fired Boilers

Capacity type	Capacity Value
Current Confirmed Capacity	55,300 m^3/yr
New Capacity Coming On Line	22,000 m^3/yr
Total Confirmed Capacity	77,300 m^3/yr
Additional Estimated Capacity	10,000 m^3/yr
Total Estimated Capacity*	87,300 m^3/yr*

**This only includes catalyst manufacturers who currently supply catalyst for coal-fired applications. Significant additional capacity is available from suppliers that may have offered catalyst for coal applications in the past, but currently focus on gas and oil -fired applications and could potentially shift capacity to a coal product.*

Currently, the equivalent of approximately 100 GW_e of coal, oil, and gas-fired capacity worldwide utilizes SCR technology. At these worldwide installations, the volume of SCR catalyst in use is estimated to be approximately 55,000 to 95,000 m^3.[10] Assuming that one-twelfth of the current catalyst is replaced each year on average, the annual demand for replacement SCR catalyst is approximately 5,000 to 8,000 m^3/yr. Note that the estimate for the current annual demand is quite conservative since the catalyst replacement rate on oil- and gas-fired combustion units is likely to be less frequent than one-twelfth of the catalyst per year. By 2005, an additional 85 GW_e of coal-fired SCR capacity is expected to be on line in response to the NO_X SIP Call and recently promulgated State rules (this includes anticipated SCR retrofits under the state rules for Missouri, Connecticut, and Texas). Assuming conservatively that one-eighth of the catalyst is replaced each year on average for coal-fired units, the annual demand for replacement SCR catalyst would increase by 12,600 m^3/yr by 2005. Adding the current annual replacement demand from worldwide installations to the projected annual replacement demand under the Clear Skies Act would yield a total of 17,600 - 20,600 m^3/yr demand for replacement catalyst by 2005.[10]

The estimated annual demand for catalyst from the Clear Skies Act, which consists of the demand due to new installations and annual replacement is shown in Table 6-8. The highest catalyst demand will occur by 2010. From Table 6-7, the estimated capacity of catalyst supply is 87,300 m^3/yr. Considering the initial fill demand of 26,000 m^3/yr from 65 GW_e of SCR installations and replacement demand of 22,300 m^3/yr from 150 GW_e of cumulative SCR installations plus the worldwide catalyst replacement demand of between 5,000 and 8,000 m^3/yr, the annual excess capacity is estimated to be 31,000 to 34,000 m^3/yr. A more conservative approach to determining if there is sufficient catalyst supply to meet the demand from the Clear Skies Act is demonstrated in Figure 6-4. It compares the current cumulative production capacity for SCR catalyst to the cumulative annual demand for SCR catalyst from the total SCR installations in 2005 and 2010. This approach assumes that the annual production of catalyst continues at the current level of 87,300 m^3/yr and starts accumulating in May 2002. If all SCR systems were loaded with catalyst in just a one year period prior to 2005 and 2010 instead of spreading out the loading over several years, there would be sufficient accumulated supply to meet the increased demand.

Table 6-8. Estimated Annual SCR Catalyst Demand resulting from Clear Skies Act and NO_X SIP Call

Year	2005	2010	2015	2020
Catalyst for new installations [a], m^3/yr	33,000	26,000	1,200	16,000
Replacement catalyst [b], m^3/yr	12,600	22,300	22,800	28,700
Total catalyst, m^3/yr	45,600	48,300	24,000	44,700

[a] *It is assumed that installations by 2005 occur over 31 months prior to 2005 and over a three-year period prior to 2010, 2015, and 2020. SCR catalyst demand was adjusted from 85 GW_e of demand in 2005 to 71 GW_e to account for 14 GW_e of SCR which have been completed by May 2002.*

[b] *The replacement catalyst was estimated based on the projected number of SCR installations given in Table 6-1b and does not include the catalyst replacement demand from current 100 GW_e of worldwide SCR installations.*

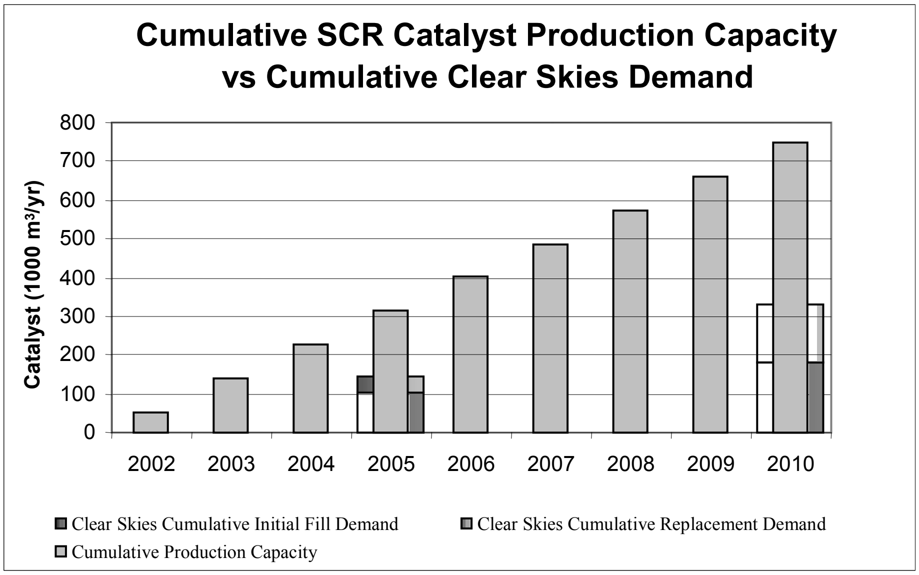

Figure 6-4. Cumulative SCR catalyst demand compared to cumulative production capacity.

Utility power plants are already installing SCR catalyst for the purpose of NO_X SIP Call compliance in 2004. As shown in Figure 6-4, the cumulative demand from the Clear Skies Act plus the worldwide demand can be met with the total cumulative confirmed capacity. Consequently, adequate capacity of SCR catalyst supply is available to satisfy the demand that may result from the projected installations. Of course, as demonstrated by the catalyst suppliers, if more capacity was desirable to satisfy the market, it could be added given sufficient lead time for the construction of the catalyst production facility.

The ability to retrofit a large number of SCR systems over a short period of time was exemplified in Germany during the late 1980s. Figure 6-5 shows the number of systems installed over an eight-year period, with most of these systems (97 of 137) installed during two consecutive years (1989-1990). This pattern of installations exhibits that the catalyst market demonstrated the ability to respond to the surge in demand resulting from a dramatic increase in SCR installations.

Ammonia and Urea

The installation and operation of SCR systems is not expected to be constrained by the future availability of ammonia or urea. The production of anhydrous ammonia in the U.S. in 2000 was approximately 17,400,000 tons (equivalent anhydrous) with apparent consumption of 22,000,000 tons and about 4,600,000 met through net imports, as shown in a 2001 edition of U.S. Geological Survey Minerals Commodity Summaries. Ammonia demand is directly proportional to the tons of NO_X reduced. The increased ammonia demand from a multipollutant rule is estimated to increase to about 1,040,000 tons per year by 2020. This 4 percent increase in demand over a nearly 20-year period can easily be met. Moreover, the U.S. and worldwide ammonia business is struggling because of slumping domestic demand and increased global capacity for the product and other nitrogen fertilizers derived from it, such as urea. Nevertheless, more capacity is scheduled to come on in the U.S. during the near future. In addition, 1.2 million tons of capacity is being built in Trinidad and Venezuela. Algeria and the former Soviet Union have also added significant capacity. Another problem is the withdrawal of China as an importer of ammonia. China traditionally bought 3 to 6 million tons of urea annually (which is produced from ammonia), but in 1996, the country launched a drive to become self-sufficient in urea, a move that has displaced 1.9 to 3.7 million tons of ammonia.[47] Based on these estimates, the ability to supply of ammonia will continue to exceed its demand, even with the additional demand from newly installed SCR systems.

SCR systems can also use urea as a reagent, and it is becoming preferred to ammonia in many cases because of its safety. Urea is a commonly available chemical with approximately 11,760,000 tons of domestic annual production capacity.[48] For SCR purposes, this adds effectively another 6.7 million tons of ammonia annually available as SCR reagent.* Additionally, U.S. urea manufacturers and distributors routinely trade within a 130,000,000 tons worldwide annual production capacity.[10] Based on total world urea trade, increased demand due to a multipollutant regulation would be well under 2 percent of world trade if all SCRs used urea rather than ammonia. And, like ammonia, the urea market is currently experiencing an oversupply situation. Urea prices have fallen precipitously since China, formerly a major buyer, decided to strive for self-sufficiency. From 1994 to 1997, China opened nine new urea plants and raised its domestic production by 50 percent. U.S. producers knew China would bring on the new, more-efficient plants, but they did not expect that country to continue running its smaller, less-efficient ones.[48] Thus, it is expected that this worldwide supply will provide additional flexibility in meeting any significant increases in demand. Since urea production is performed on a worldwide basis, plants producing urea would be able to expand their capacity if needed. Based on these considerations, adequate urea supply is expected to be available for the SCR systems.

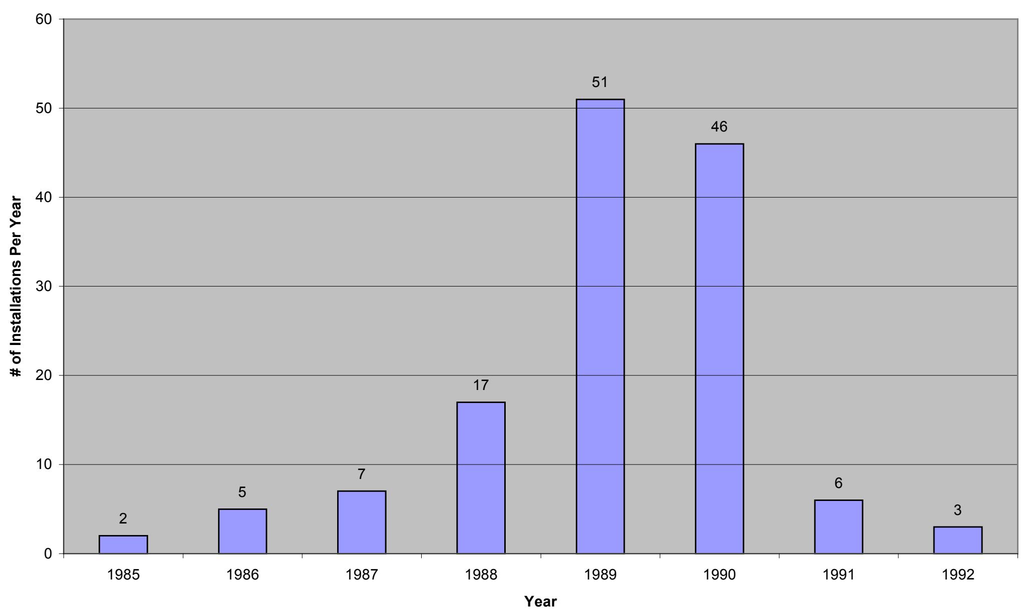

Figure 6-5. SCR Installations on coal-fired plants in Germany.[11]

* It takes about 1.76 lbs of urea to make one lb of ammonia reagent in a urea to ammonia conversion.

AC for ACI Systems

AC is produced in the United States and abroad for filtration and other manufacturing purposes. Total AC usage in the United States was 182,887 tons/yr in 2000, as given in the U.S. Census Bureau Summary Current Industrial Reports for the Inorganic Chemical Industry. Capacity in the U.S. is equal to 465 million pounds/yr, or 233,000 tons.[49] Both of these numbers include both granular and powdered carbon, powdered being preferable to granular for ACI applications. U.S. demand is projected to grow to 454 million pounds, or about 227,000 tons, in 2004.[49] However, large underutilized capacity overseas will provide a ready supply of potential imports, which will tend to limit price increases for most grades.[49] The competition from Chinese and South-East Asian producers remains strong.[50] Chinese exports quadrupled from 53,230 tons in 1995 to 224,331 tons in 1997, with the average product cost dropping by 16 percent to 660/ton. Therefore, growth in demand experienced in the 1990's has not been reflected in the value of the market due to over-capacity and the continued rise in Asian exports. AC producers are concentrating increasingly on the Asia-Pacific region to exploit growing markets and take advantage of lower production costs; reported capacity expansions of over 15,000 tons/yr are all planned for Asia-Pacific and Russia.[50]

According to Norit, the largest supplier of AC for air pollution control purposes, there is currently adequate excess capacity to accommodate significant growth in the demand (tens of millions of pounds/yr, or roughly tens of thousands of tons/yr).[51] However, depending upon how much growth occurs as a result of regulation, additional capacity may be necessary. It would take 2-3 years to add a plant; and this would only be done after a regulation was put in place, the technical advantages of ACI for mercury removal were proven relative to other approaches, and a clear time-line for compliance was mandated.[51] Therefore, even if a multipollutant strategy implementation causes a large increase in demand for AC, provided that the timing of compliance was clear and far enough in the future, adequate supply of AC should be assured.

EPA estimated that, of the total 1,300 MW_e to be retrofit by 2020 with ACI, all of that capacity would have existing fabric filters.[36] As mentioned before, EPA's modeling indicates that none of the total MW_e of ACI retrofits will include a PJFF.[36] AC usage nationally for mercury control from power plants should be roughly proportional to the total MW_e of coal-fired facilities that are equipped with the technology (this assumes an average capacity factor of 85 percent and other assumptions of Tables 4-4 and 4-5). Table 6-9 shows the results of this analysis. Based upon this analysis, it is possible that existing excess capacity in AC production could adequately address the increased demand for AC. And, even if ACI is more broadly used than anticipated by EPA (more than 1,300 MW_e), it is clear that with at least 2-3 years of preparation time to build more production capacity the AC industry can accommodate any additional demand.

Table 6-9. Projected AC Demand Due to Multipollutant Initiative (MW_e values for retrofit are based on EPA's estimates from IPM)

Year	2005	2010	2015	2020
ESP + ACI, tons per year*	0	0	0	0
FF + ACI, tons per year	0	0	550	720
Total, tons per year	0	0	550	720

**Operation Resources, projected annual activated carbon demand*

6.5 Creation of Jobs under Clear Skies Act due to Control Technology Installations

The Clear Skies Act is expected to create jobs for those directly involved in the retrofit of facilities. These have been estimated in Section 6.2 of this document. In addition to the jobs that are directly created by this activity, jobs will be created indirectly as a result of the economic activity that is stimulated by additional discretionary income workers will have. Workers that are directly employed on these clean air projects will purchase consumer goods and services, which will stimulate additional economic activity. To account for these indirect effects of economic activity, economists use economic multipliers that are related to worker's marginal propensity to consume. Economic multipliers of 2 to 3 are often used.[52] Using the lower multiplier of 2 and the total labor estimates of Table 6-3, 25,000 additional jobs may be created through indirect economic activity (2 times the peak direct labor level of 12,500 workers indicated in Table 6-3). This effect does not consider the additional job-gain potential from U.S.-based equipment suppliers that export to other countries the clean-air technology know-how they will gain from these clean-air programs.

Chapter 7
Conclusions

This report evaluated the resources necessary to comply with the Clear Skies Act for which EPA estimated, by using the IPM, the number, and size of facilities that will have to install new hardware. The control technologies considered by this report as candidates to be used for this multipollutant control strategy include:

- LSFO for the control of SO_2;
- SCR for the control of NO_X; and
- ACI for the control of mercury.

Based upon the IPM-generated information from EPA and the characteristics of the technologies listed above, the total resources needed to comply with the multipollutant control strategy were estimated and compared to the available resources. The availability of resources was based on their current market demand and does not reflect the increased production capacity that a multipollutant strategy may create. It is likely that the market for materials, labor, construction equipment, and other resources used in the construction and operation of air pollution control technologies would respond by increasing production to meet demand where needed.

Installation of wet FGD, specifically LSFO, presents a conservatively high estimate of anticipated resources and time to provide additional control of SO_2 emissions. LSFO systems commonly are more resource intensive than many other FGD technologies. Conservatively high assumptions were made for the time, labor, reagents, and steel needed to install FGD systems. Although FGD installations are time and labor intensive, they are typically planned and installed within normally scheduled outages. It is expected that one FGD system requires about 27 months of total effort for planning, engineering, installation and startup. Modern FGD systems typically use fewer and smaller absorbers and increasingly control greater amounts of generating capacity using common absorbers fed by multiple boilers. Under the Clear Skies Act, three absorber systems for six boilers are anticipated to handle 2,400 MW_e of capacity. The estimate of labor includes planning and engineering, general labor, and skilled boilermakers. Construction of absorbers off-site is one way that projects can control project resources, schedules, and labor.

Steel is the major hardware component for FGD systems. Structural steel is used primarily for the absorber, ductwork, and supports, and secondarily in miscellaneous components including reinforcement of existing structures at a facility. FGD systems are installed on the back end of a facility, are usually built close to the ground, and do not require the amounts of structural steel generally associated with elevated installations such as SCR. By comparison, the conservative estimate of the amount of steel required for a full FGD system is less than or equal to that required for an SCR retrofit. Corrosion and abrasion resistant materials are increasingly being applied with success in modern FGD systems to improve reliability and long-term performance. The total demand for additional FGD installations will be modest and is expected to be well within the anticipated steel capacity, even with demands from other applications.

Construction equipment requirements for FGD installations are typically modest, particularly given that systems are installed at the back end of the facility and close to the ground. However, experience has indicated that project planning can surmount even difficult situations (e.g., prefabrication and jacking up components). Experience has also shown that specific site issues, while often a planning challenge, have not prevented installations of FGD systems. More recently, space requirements for construction and accommodating the FGD system have been addressed with the implementation of improvements in technology, including fewer and smaller absorbers and more efficient on-site use and treatment of wastes and byproducts.

Limestone was used as an estimate of reagent for FGD systems. Experience indicates that the quantity of limestone is conservatively high compared to other enhanced reagents such as fine-ground limestone and MEL. Even with the assumption that all new FGD capacity will require limestone, the amount of limestone needed as a reagent is projected to be within availability of supply.

SCR is the technology that will primarily be used for NO_X control. Since it is also the most demanding in terms of resources needed for installation, it was assumed to be the only technology used for NO_X control. SCR systems are primarily made from steel, standard mechanical hardware, and catalyst. Conservatively high assumptions were made for steel, catalyst, reagents, and the labor and equipment necessary to install the systems projected by the IPM that result from a multipollutant control strategy. The amount of ammonia or urea reagent needed can be estimated with good confidence as constituting a small portion of available supply.

Experience in installing SCRs for the NO_X SIP Call has shown that the SCR equipment can be installed on the facilities in the space provided. In some cases, moving of equipment has been necessary, but this has not proved to be limiting. The only specialized construction equipment that can be useful for SCR installations are tall, heavy-lift cranes. These appear to be in adequate supply and are not essential, since the erection plan can be modified to accommodate the use of smaller cranes, which are frequently more economical. The only specialized labor necessary for SCR installations are members of the boilermakers trade, and estimates of boilermaker demand were made. It is expected that one SCR system requires about 21 months of total effort for planning, engineering, installation, and start-up. Experience has shown that many installations have been completed in much shorter times. Therefore, 21 months appears to be somewhat conservative.

ACI was presumed to be the technology that would be used to reduce mercury where dedicated mercury controls were needed because the hardware is representative of most sorbent injection technologies. Also, other sorbent-based approaches in development may prove in time to be preferable to ACI, making the use of ACI only a conservative assumption. ACI hardware is comprised of relatively common mechanical components and is largely made of steel. An ACI system requires much less in terms of steel, labor, or other resources to install than either FGD or SCR technology. Therefore, the impact of ACI hardware on resource demand is much less than that of FGD or SCR technologies for SO_2 or NO_X control, respectively. The only piece of equipment of any consequence in terms of size is the storage silo, and this piece of equipment is not so large as to pose a problem with regard to location for most facilities. Planning, engineering, installation, and start-up of an ACI system is only about 15 months and could be done in much less time if administrative matters, such as permitting, occur more quickly than assumed. Figures for consumption of AC were based on prior, peer-reviewed EPA work, and conservative operating conditions were assumed.

In summary, this study found that the expected demand for resources resulting from a multipollutant control strategy could be met. However, the market is expected to adjust to changes in both the demand for resources under a multipollutant program and other market factors. For this reason, the longer term projections are of less value than those for the 2005 and 2010 time period. Table 7-1 shows a summary of resource demand and its effect on current supply. In Table 7-1 the Supply Basis may be current U.S. demand, capacity available to U.S. users, or other basis as appropriate and described in the table notes. For all resources needed for installation, it is assumed that these resources are required over a 31-month period prior to 2005 and a three-year period prior to 2010, 2015, and 2020. This is a very conservative assumption because the most complex FGD installations will require three years while the actual available time to complete the projected retrofits for each period, except prior to 2005, is five years.

As shown in Table 7-1, there is ample steel and general construction labor to support the installation of these technologies, assuming a 31-month period of installation prior to 2005 and a three-year installation prior to 2010, 2015, and 2020. Moreover, the demand assumptions do not consider any efficiencies that can be achieved at multiple unit installations or installations of multiple technologies at a site. As discussed in this document, these efficiencies can reduce steel requirement somewhat and labor needs substantially. Demand for boilermaker labor is significant when compared to the boilermaker labor supply basis. However, most boilermakers (60 percent) work in the electric power industry, so it should not be surprising that the percentage is high. It should also be considered that the value in this table assumes conservatively high proportion of boilermaker labor and that the boilermaker trade grows at its minimum target rate of 5.3 percent. In fact, the boilermaker trade has been growing at about 6.7 percent annually in recent years due to the improving employment prospects for boilermakers.

There is also ample SCR catalyst capacity to supply this market. SCR catalyst manufacturing is almost entirely dedicated to power generating applications. Thus, it should not be surprising that demand for initial fill and periodic replacement catalyst should account for a significant portion of the supply basis. Moreover, the U.S. market for catalyst is currently larger than all of the other national markets combined. With regard to reagents and other consumables, clearly there is ample supply of limestone for additional FGD systems, especially in light of conservatively high assumptions that were used to make these estimates. Ammonia and urea supply is also plentiful, although it is expected that NO_X reduction will cause a modest increase in U.S. demand. In fact, there is currently a worldwide excess capacity problem for suppliers of these commodity chemicals that are traded globally. Although U.S. demand for activated carbon is expected to increase by a small amount as a result of a multipollutant strategy, activated carbon is traded on a global basis, and there is currently substantial excess capacity that can readily provide for this increase in demand. Suppliers have also indicated that new plants could be brought on line within 3 years, if needed, to satisfy increased demand. Additionally, there are other technologies under development that potentially could reduce activated carbon demand from what is estimated here.

Table 7-1. Estimated Resources Needed for Installation and Operation of Technologies

Installation Resources				
Retrofits	**Before 2005**	**2005 - 2010**	**2010 - 2015**	**2015 - 2020**
Annual Labor Requirement, man-yrs	10,675*	12,525	3,852	8,852
Percent of current construction labor	0.19*	0.19	0.06	0.14
Annual Boilermaker Requirement, man-yrs	5,200*	5,750	1,601	4,001
Percent of minimum target level	22.8*	19.5	4.2	8.1
Annual Steel Requirement, tons	78,000*	86,000	25,120	60,040
Percent of current steel production	0.048*	0.046	0.012	0.024
Operation Resources	**in 2005**	**in 2010**	**in 2015**	**in 2020**
Annual Limestone (all FGD), tons	49,600,000	70,100,000	83,900,000	101,000,000
Annual Limestone (excluding existing FGD), tons	4,800,000	25,300,000	39,100,000	56,200,000
Percent of estimated limestone demand (all FGD)	3.41	3.76	3.55	3.29
Percent of estimated limestone (excluding existing FGD)	0.33	1.35	1.63	1.83
Annual Catalyst, New and Replacement, m^3	45,600*	48,300	24,000	44,700
Percent of current catalyst production	52*	55	27	51
Annual Ammonia, tons/yr	280,000	890,000	900,000	1,040,000
Percent of current U.S. NH_3 and urea demand	0.92	2.95	2.97	3.44
Annual Activated Carbon, tons	0	0	550	720
Percent of current U.S. AC demand	0.00	0.00	0.24	0.31

** Resource demand from SCR was adjusted from 85 GW_e of demand in 2005 to 71 GW_e to account for 14 GW_e of SCR which have been completed by May 2002.*

Chapter 8
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Appendix A

Implementation Schedules for Control Technology Installations

Legend:
Major Task – Dark Gray
Subtask – Light Gray
Key Completion Point – Black

Exhibit A-1: Single FGD	**Months**																										
	1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**	**16**	**17**	**18**	**19**	**20**	**21**	**22**	**23**	**24**	**25**	**26**	**27**
Facility Engineering Review and Award of Contract																											
Engineering Assessment of Technologies																											
Develop and Send Request for Bids																											
Receive, Review and Negotiate Bids																											
Award Contract to Technology Provider																											
Control Technology Installation																											
Engineering Fabrication Delivery																											
Construction: Pre Hookup																											
Construction: Control Device Hookup (Eqmt outage)																											
Control Technology Testing																											
Construction Permit																											
Permit Application - Preparation and Submission																											
Construction Permit - State Review and Draft Proposal																											
Construction Permit - Public Comment																											
Construction Permit - Approval (final)																											
Title V Operating Permit Modification																											
Title V Permit Application Preparation and Submission																											
Title V Permit Application - State Review																											
Title V Permit Application - Public Comment																											
Initial Compliance Stack Testing																											
Receipt of Title V Operating Permit																											

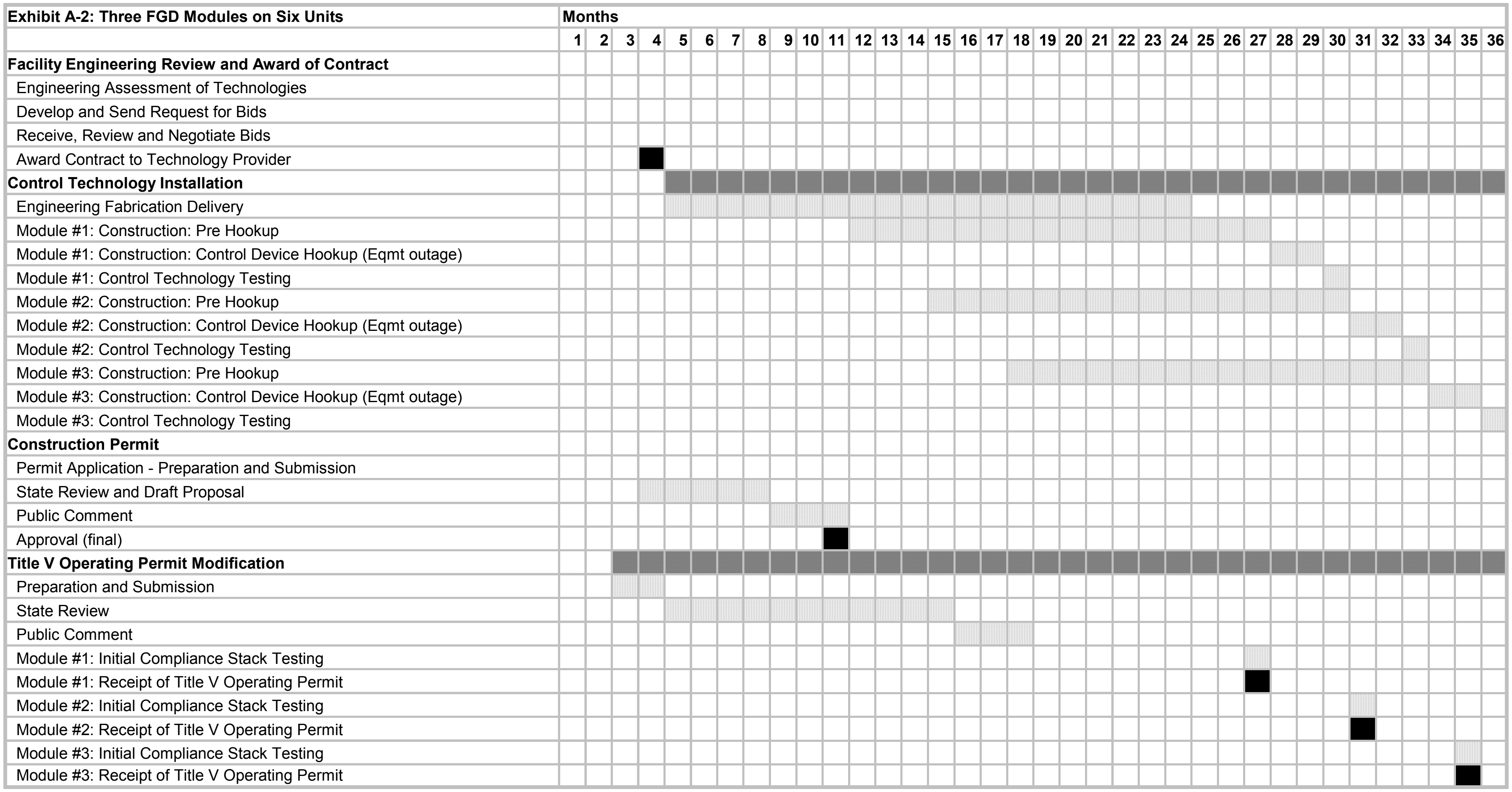
Exhibit A-2: Three FGD Modules on Six Units
Months
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25 26 27 28 29 30 31 32 33 34 35 36
Facility Engineering Review and Award of Contract
Engineering Assessment of Technologies
Develop and Send Request for Bids
Receive, Review and Negotiate Bids
Award Contract to Technology Provider
Control Technology Installation
Engineering Fabrication Delivery
Module #1: Construction: Pre Hookup
Module #1: Construction: Control Device Hookup (Eqmt outage)
Module #1: Control Technology Testing
Module #2: Construction: Pre Hookup
Module #2: Construction: Control Device Hookup (Eqmt outage)
Module #2: Control Technology Testing
Module #3: Construction: Pre Hookup
Module #3: Construction: Control Device Hookup (Eqmt outage)
Module #3: Control Technology Testing
Construction Permit
Permit Application - Preparation and Submission
State Review and Draft Proposal
Public Comment
Approval (final)
Title V Operating Permit Modification
Preparation and Submission
State Review
Public Comment
Module #1: Initial Compliance Stack Testing
Module #1: Receipt of Title V Operating Permit
Module #2: Initial Compliance Stack Testing
Module #2: Receipt of Title V Operating Permit
Module #3: Initial Compliance Stack Testing
Module #3: Receipt of Title V Operating Permit

Exhibit A-3: Single SCR	Months																				
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21
Facility Engineering Review and Award of Contract																					
Engineering Assessment of Technologies																					
Develop and Send Request for Bids																					
Receive, Review and Negotiate Bids																					
Award Contract to Technology Provider																					
Control Technology Installation																					
Engineering Fabrication Delivery																					
Construction: Pre Hookup																					
Construction: Control Device Hookup (Eqmt outage)																					
Control Technology Testing																					
Construction Permit																					
Permit Application - Preparation and Submission																					
State Review and Draft Proposal																					
Public Comment																					
Approval (final)																					
Title V Operating Permit Modification																					
Preparation and Submission																					
State Review																					
Public Comment																					
Initial Compliance Stack Testing																					
Receipt of Title V Operating Permit																					

Exhibit A-4: Seven SCRs (pg 1 of 2)	Months																																		
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35
Facility Engineering Review and Award of Contract																																			
Engineering Assessment of Technologies																																			
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Receive, Review and Negotiate Bids																																			
Award Contract to Technology Provider																																			
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Unit #1: Construction: Control Device Hookup (Eqmt outage)																																			
Unit #1: Control Technology Testing																																			
Unit #2: Construction: Pre Hookup																																			
Unit #2: Construction: Control Device Hookup (Eqmt outage)																																			
Unit #2: Control Technology Testing																																			
Unit #3: Construction: Pre Hookup																																			
Unit #3: Construction: Control Device Hookup (Eqmt outage)																																			
Unit #3: Control Technology Testing																																			
Unit #4: Construction: Pre Hookup																																			
Unit #4: Construction: Control Device Hookup (Eqmt outage)																																			
Unit #4: Control Technology Testing																																			
Unit #5: Construction: Pre Hookup																																			
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Unit #6: Construction: Pre Hookup																																			
Unit #6: Construction: Control Device Hookup (Eqmt outage)																																			
Unit #6: Control Technology Testing																																			
Unit #7: Construction: Pre Hookup																																			
Unit #7: Construction: Control Device Hookup (Eqmt outage)																																			
Unit #7: Control Technology Testing																																			

Exhibit A-4: Seven SCRs (pg 2 of 2)	Months																																		
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35
Construction Permit																																			
Permit Application - Preparation and Submission																																			
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Unit #5 Initial Compliance Stack Testing																																			
Unit #5 Receipt of Title V Operating Permit																																			
Unit #6 Initial Compliance Stack Testing																																			
Unit #6 Receipt of Title V Operating Permit																																			
Unit #7 Initial Compliance Stack Testing																																			
Unit #7 Receipt of Title V Operating Permit																																			

Exhibit A-5: Single ACI	Months														
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
Facility Engineering Review and Award of Contract															
Engineering Assessment of Technologies															
Develop and Send Request for Bids															
Receive, Review and Negotiate Bids															
Award Contract to Technology Provider															
Control Technology Installation															
Engineering Fabrication Delivery															
Construction: Pre Hookup															
Construction: Control Device Hookup (Eqmt outage)															
Control Technology Testing															
Construction Permit															
Permit Application - Preparation and Submission															
State Review and Draft Proposal															
Public Comment															
Approval (final)															
Title V Operating Permit Modification															
Preparation and Submission															
State Review															
Public Comment															
Initial Compliance Stack Testing															
Receipt of Title V Operating Permit															

Exhibit A-6: Two ACIs					**Months**											
	1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**	**16**
Facility Engineering Review and Award of Contract																
Engineering Assessment of Technologies																
Develop and Send Request for Bids																
Receive, Review and Negotiate Bids																
Award Contract to Technology Provider																
Control Technology Installation																
Engineering Fabrication Delivery																
Unit #1: Construction: Pre Hookup																
Unit #1: Construction: Control Device Hookup (Eqmt outage)																
Unit #1: Control Technology Testing																
Unit #2: Construction: Pre Hookup																
Unit #2: Construction: Control Device Hookup (Eqmt outage)																
Unit #2: Control Technology Testing																
Construction Permit																
Permit Application - Preparation and Submission																
State Review and Draft Proposal																
Public Comment																
Approval (final)																
Title V Operating Permit Modification																
Preparation and Submission																
State Review																
Public Comment																
Unit #1 Initial Compliance Stack Testing																
Unit #1 Receipt of Title V Operating Permit																
Unit #2 Initial Compliance Stack Testing																
Unit #2 Receipt of Title V Operating Permit																

Exhibit A-7: Single FGD and SCR						Months																					
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27
Facility Engineering Review and Award of Contract																											
Engineering Assessment of Technologies																											
Develop and Send Request for Bids																											
Receive, Review and Negotiate Bids																											
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Control Technology Installation																											
Engineering Fabrication Delivery																											
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Construction: Control Device Hookup (Eqmt outage)																											
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State Review																											
Public Comment																											
Initial Compliance Stack Testing																											
Receipt of Title V Operating Permit																											

Exhibit A-8: Single FGD and ACI						Months																					
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27
Facility Engineering Review and Award of Contract																											
Engineering Assessment of Technologies																											
Develop and Send Request for Bids																											
Receive, Review and Negotiate Bids																											
Award Contract to Technology Provider																											
Control Technology Installation																											
Engineering Fabrication Delivery																											
Construction: Pre Hookup																											
Construction: Control Device Hookup (Eqmt outage)																											
Control Technology Testing																											
Construction Permit																											
Permit Application - Preparation and Submission																											
State Review and Draft Proposal																											
Public Comment																											
Approval (final)																											
Title V Operating Permit Modification																											
Preparation and Submission																											
State Review																											
Public Comment																											
Initial Compliance Stack Testing																											
Receipt of Title V Operating Permit																											

Exhibit A-9: Single SCR and ACI	Months																				
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21
Facility Engineering Review and Award of Contract																					
Engineering Assessment of Technologies																					
Develop and Send Request for Bids																					
Receive, Review and Negotiate Bids																					
Award Contract to Technology Provider																					
Control Technology Installation																					
Engineering Fabrication Delivery																					
Construction: Pre Hookup																					
Construction: Control Device Hookup (Eqmt outage)																					
Control Technology Testing																					
Construction Permit																					
Permit Application - Preparation and Submission																					
State Review and Draft Proposal																					
Public Comment																					
Approval (final)																					
Title V Operating Permit Modification																					
Preparation and Submission																					
State Review																					
Public Comment																					
Initial Compliance Stack Testing																					
Receipt of Title V Operating Permit																					