United States
Environmental Protection
Agency

Air and Energy Engineering
Research Laboratory
Research Triangle, NC, 27711

Research and Development

600/S2-88/013 Apr.1988

EPA

Project Summary

Assessment of SO_2 and NO_x Emission Control Technology in Europe

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This report is a compilation of information on the current status of abatement technology used to control major air pollutants, including sulfur dioxide (SO_2) and nitrogen oxides (NO_x) in Europe. It focuses on flue gas desulfurization (FGD), combustion modification (CM), and selective catalytic reduction (SCR) of NO_x. Information presented was gathered from utility company representatives and FGD, CM, and SCR process developers, as well as from the author's research. Current air pollution regulations in Europe, related problems, operational parameters of commercial FGD and SCR plants, FGD and SCR economics, and the author's evaluation of the processes are also described.

This Project Summary was developed by EPA's Air and Energy Engineering Research Laboratory, Research Triangle Park, NC, to announce key findings of the research project that is fully documented in a separate report of the same title (see Project Report ordering information at back).

Introduction

Updated details are presented of major FGD and denitrification (de-NO_x) installations in West Germany for coal-fired boilers. The status of technology in other European countries is also presented. The report provides an understanding of the principal types of control system designs that have been applied, outlines technological advancements that have been achieved, and reviews operating experience gained to date in expanded use of FGD and NO_x removal facilities in Europe in the 1980s. Significant differences from FGD service and practice in the U. S. and Japan are described, and specific information that may improve operation and reliability of new and retrofit FGD installations in the U.S. is offered. Principal topics include:

- A presentation of governmental emission control requirements in Europe for new and existing coal-fired sources.
- An overview of West German FGD and de-NO_x installations and purchase commitments, including details of generic processes applied, operating history and current performance, and trends and developments in technology utilization.
- Control of industrial boilers.
- Management of solid and liquid waste by-products
- Substantial activities in other European countries.

FGD Activity in West Germany

Recent acceleration of European activities for reduction of SO_2 and NO_x emissions is centered in the Federal Republic of Germany (West Germany). Great emphasis has been placed on extensive forest damage, considered to be tied to air pollution, which has occurred in some regions of the country. Effects on trees have been particularly severe in the area of North Rhine-Westphalia in central Germany, as well as Baden-Wuerttemberg in the southwest. In 1983 West Germany enacted a major national acid rain control directive

Table 1. *Federal SO_2 Control Requirements for West German Coal-Fired Boilers*

Size, MW(e)	*SO_2 Emission Limit, mg/Nm^3 (lb/10^6 Btu)*	*%Removal*	*Compliance Deadline*	*Approx. No. Boilers Existing*
Over 110	*400 (0.5, avg)*	*85*	*07/01/88*	*160*
35 to 110	*2,000 (2.5, avg)*	*60*	*04/01/93*	*370*
18 to 35	*2,000 (2.5, avg)*	*–*	*04/01/93*	*300*

for SO_2 (see Table 1), spawning a major program of FGD installation at both new and existing boilers, primarily on large coal-fired units. Boilers larger than 110 MW(e) have been required to add stack gas cleaning by 1988. Reduction of emissions from smaller boilers, 18 to 11OMW(e), is tied to a 1993 deadline. Requirements are the same for existing oil-fired boilers.

Emission limits for small existing industrial boilers [e.g., 1% sulfur fuel fired units larger than about 6,500 lb/hr steam generation, the equivalent of about 0.5 MW(e)], are addressed in new national legislation (TA Luft) of February 27, 1986. With many exceptions at present, it is specified that boilers emitting more than 5 kg SO_2/hr must limit emissions to 500 mg/Nm^3 (180 ppm).

Individual local (provincial) governments have the authority to impose more stringent requirements than those specified by the national laws. For example, in North Rhine-Westphalia (with nearly 50% of the electric power generation of the entire country, a large portion being fired with lignite) special requirements were placed on about 3,000 MW(e) of existing lignite fired boiler capacity in 1984 calling for an interim SO_2 emission reduction of 110,000 metric tons per year by 1987 (through temporary low-capital-cost dry-alkali injection means).

Table 2 shows the number and size of existing West German boilers, almost all firing low-medium sulfur fuel, generally bituminous coal or lignite, and indicates that more than 150 units are impacted by the 1988-deadlined SO_2-control requirements. Also affected are 7,400 MW(e) of new, coal-burning units under construction or expected to start up by about 1990.

Furnaces larger than 110 MW(e) are fired almost exclusively with hard (bituminous) coal or lignite. The sulfur content of the hard coal is about 0.7-1.2% (in the future up to 1.5%); that of lower quality (ballast) coal, as high as 2.7% sulfur; and that of wet raw lignite, 0.3-1.2%.

In keeping with the 1988 target compliance date almost all utility units are now being retrofitted with scrubbers except for about 12,000 MW(e) of capacity to be retired by 1993 after no more than 30,000 additional hours of operation. More than 100 FGD installations, primarily commercial-gypsum-producing types comprising more then 35,000 MW(e), are being erected. About 50,000 MW(e) of FGD is expected to be in place by the early 1990s. FGD facilities already running are the result of a comparatively modest, provincial control program that began before 1983 and resulted in 20 FGD applications, almost all for slipstream single-module installations. Comparatively few boilers under 110 MW(e) have been retrofitted with FGD to date. In the absence of a percent removal stipulation in the 1983 law, boilers smaller than 35 MW(e) may be expected to typically rely on fuel modification/switching as needed to meet the specified 2,000 mg/Nm^3 (720 ppr SO_2 emission limit. Influenced by th new control activity in Germany, abo 2,000 MW(e) of usable-gypsum-pro ducing FGD systems are being installe in The Netherlands, and a major FG installation program is underway on utilit boilers in Austria.

In West Germany, SO_2 emissions of million metric tons per year, about 80 of which originate from utility an industrial boilers, are expected to b reduced by almost two-thirds by 198 The cost for these FGD installations ha been projected to be as much as 1 billion (10^9) German marks (DM). FG selection in Germany has reflected strong emphasis on the need to achiev high system availability (95%). As Japan, most of the installations of eac principal supplier are designed to emplo forced oxidation to yield a commerciall usable gypsum and to thus avoid th substantial cost and complexity alternative throwaway-waste manage ment in Europe.

However, 30 throwaway-waste FG systems of 9000 MW(e) capacity ar being installed, all at minemouth lignite fired plants where disposal of solid wast in the mine is anticipated. In mainlan Europe the use of throwaway-solid waste processes, including dry or sem dry scrubbing methods feasible for low sulfur fuel applications in Scandinav and the U.S., is curtailed by the prese lack of effective means of utilizin sulfite-containing FGD waste and adequate landfill disposal space.

Table 2. *Population of Existing West German Coal- and Oil-Fired Boilers*

Size, MW(e)	*Number*	*Aggregate MW(e)*	*Average MW(e)*
Above 300	*41*	*18,400*	*450*
135-300	*91*	*17,800*	*195*
75-135	*95*	*9,900*	*104*
30-75	*378*	*18,500*	*49*
9-30	*548*	*10,600*	*19*
Above 9 (Total)	*1153*	*75,200*	*-*

Gypsum-solids dewatering systems are comparatively simple, typically comprising primary dewatering by liquid cyclones, with final dewatering by centrifuge or horizontal vacuum filter. Due to transportation-economics some early installations in Germany use lime in lieu of limestone. However, as a universal energy conservation measure, all recent FGD commitments have been dedicated to the use of limestone reagent. Rotary regenerative heat exchangers are being commonly used to meet the mandatory 72°C (162°F) minimum stack temperature requirement without use of augmental energy for gas reheat.

Much like a frequent process design practice in the U.S. during the 1980s, the most typical FGD system that is currently being applied in Europe incorporates:

- Lime or limestone reagent use, preferably limestone.
- Spray tower absorber design, rubber-lined.
- In-situ forced oxidation facilities installed in the sump of the absorber without use of H_2SO_4 reagent for pH adjustment.
- Production of a throwaway or usable grade of gypsum.
- Single-loop systems that omit low-pH prescrubbing used extensively in Japan and in some early German installations for segregated removal of HCl and other minor raw-gas components.

Use of FGD in West Germany is comparatively recent, but as of the end of 1984, almost 3000 MW(e) of lime/limestone scrubbing systems were in operation, all of single-module slipstream design to meet requirements of pre-1983 legislation. These FGD system installations are reported to have provided acceptable reliability and performance. However, German electric utility specialists note that, with only partial scrubbing of plant flue gas, these earliest installations have not been subjected to typical full-scale electric-utility-industry operating conditions requiring high availability at sustained high/variable load. Additional FGD capacity of approximately 5000 MW(e) originating from the 1983 legislation has now come on line but is in an initial stage of operation without an extensive period of experience. Thus, Germany's massive FGD program is seen to be at too early a stage of implementation to show broadly demonstrated success or to thoroughly characterize performance and reliability of system designs that are being applied.

Based on extensive economic assessments recently published, retrofit capital investment for a typical 350 MW(e) limestone scrubbing FGD installation is reported to be 80 million DM; i.e., 230 DM/kW. Annual cost with 6000 hr/yr of operation is 19.3 million DM including fixed cost of 14.8 million DM (representing 18.5% of the capital investment of 80 million DM). On a unit basis this annual cost equals 0.92 pfennig (Pfg)/kWh. Values are based on 1985 currency.*

NO_x Reduction in West Germany

After enactment of 1983 landmark SO_2 legislation, which imposed modest NO_x requirements, concern about NO_x as a contributor to forest damage substantially increased. Following a "technology forcing" provision of the 1983 law tied to state-of-the-art technical developments, a 1984 accord between federal and provincial environmental ministers in effect substantially reduced the 1983 limits for NO_x. At the same time it called for deadlines to be set by the individual provincial jurisdictions. The limit values legislated in 1983, and tightened by sanction of the national government in 1984, for coal-fired boilers are shown in Table 3. Existing coal-fired boilers (with future operation of unrestricted duration) as well as new boilers must limit NO_x emission to 200 mg/Nm^3, a level equivalent to about 100 ppm (volume). (An approximate equivalence between the four most common emission concentration measures is: 1 mg/Nm^3 = 0.487 ppm = 0.35 g/GJ = 0.000814 lb/10^6 Btu.) This stringent requirement is predicated on commercial experience in Japan indicating that selective catalytic reduction technology is effective, and the

*1 DM = U S $0 50, 1Pfg per kWh = 5 mills per kWh

Table 3. *NO_x Control Requirements for West German Coal-Fired Boilers*

Category	NO_x Emission Limit, mg NO_2/Nm^3* (ppm) (6% O_2 Basis, Dry Bottom: 5% O_2 Basis, Wet Bottom) 18 to 110		Over 110	
Size, MW(e)				
New Units, Dry Bottom:				
1983	800	(400)	800	(400)
1984	400	(200)	200	(100)
New Units, Wet Bottom (Slag-Tap):				
1983	1,800	(900)	1,800	(900)
1984	400	(200)	200	(100)
Existing Units, Dry Bottom:				
1983	1,300	(650)	1,300	(650)
1984	650	(325)	200	(100)
Existing Units, Wet Bottom (Slag-Tap):				
1983	2,000	(1,000)	2,000	(1,000)
1984	1,300	(650)	200	(100)

*200 mg/Nm^3 equals about 0.16 lb/10^6 Btu

Table 4. *Comparison of NO_x Emission Standards for Coal-Fired Utility Boilers*

	NO_x Emission Standard, mg NO_2/Nm^3 (6% O_2)
West Germany, New and Existing over 110 MW(e), (½ hr avg)	200*
U.S., New Sources	600-750
Japan, after 1987	410

*300 mg/Nm^3 for existing boilers.

judgment that it is demonstrated to be capable of reducing emissions to this low level. [NO_x limits, 1984 basis, for new oil-fired units are 150 mg/Nm^3 above 110 MW(e) and 300 mg/Nm^3 from 18 to 110 MW(e). For existing units of unspecified future lifetime the limits are 150 mg/Nm^3 above 110 MW(e) and 450 mg/Nm^3 from 18 to 110 MW(e).] Note, however, that (at the option of boiler owners, as decided by them in 1984) old boilers aggregating approximately 12,000 MW(e) capacity will be phased out (i.e., retired) no later than 1993 after no more than 30,000 additional hours of operation, during which they will be allowed to emit 650 mg NO_x/Nm^3 (about 325 ppm); for wet bottom units above 18 MW(e), 1,300 mg/Nm^3 will be allowed; and for oil-fired units, 450 mg/Nm^3. The state government of Baden-Wuerttemberg, the area of greatest forest-damage severity, was the first to impose prompt deadlines for the stringent 1984 NO_x emission limits. Dry bottom boilers, both new and existing, must comply by 1988; and wet (molten-ash) bottom boilers, by 1990. Similar deadlines have also been established by other state jurisdictions including North Rhine-Westphalia. It is expected that the retrofitting of NO_x removal systems on existing West German boilers larger than 110 MW(e) will be completed by 1990 resulting in an average 70% reduction in NO_x emissions.

The extremely stringent 200 mg/Nm^3 requirement for both new and existing coal-fired boilers larger than 110 MW(e) surpasses NO_x control requirements in all other nations including Japan (see Table 4). The West German NO_x stringency for boilers above 110 MW(e) is all the more remarkable, considering that most NO_x emissions are from mobile sources. (Note: additional regulations are being considered in West Germany that will require lead-free fuel and catalytic converters for gasoline-fueled autos.) Influenced by West Germany, significant NO_x control legislation has also passed or is pending in Austria, Switzerland, the Netherlands, Denmark, Sweden, and the European Economic Community (EEC). Table 5 shows the NO_x emission management objectives of governing officials of the EEC, revised in 1985 to call for emission rates throughout Europe after 1995 comparable to curren requirements in West Germany. Ne standards in Austria for coal-fire boilers above 110 MW(e) call for 15 mg/Nm^3 for new boilers, and comme cially developed CM for NO_x control ar expected to be routinely applie primarily on dry-bottom boilers However, the very substantial reductio that will be required is resulting i widespread application of SCR t essentially all German boilers larger tha 110 MW(e). Moreover, since it i necessary to sustain ample boile temperatures in wet bottom boiler sufficient to maintain bottom ash in molten state, only minor reduction in NC emission can be achieved by CM; an wet bottom boilers will require SC removal efficiencies as high as 90%.

New federal regulations issued o February 27, 1986, limit NO_x emission from industrial plants with an output c more than 5 kg NO_2/h, generally to limit of 500 mg/Nm^3. (As noted above the SO_2 emission limit for industri plants with an SO_2 output of more than kg/h has been set nominally at 50 mg/Nm^3.)

Table 5. *Effect of Amended European Community Directive*

		Emission Limits, mg NO_2/Nm^3		
		Coal	Oil	Gas
1983 Proposed Directive				
All Plants over 50 MW(e)*				
to 1995		800**	450	350
after 1995		400***	220	180
1985 Amended Directive				
to 1995:	over 50 MW(t)		450	350
	50-100 MW(t)	800**		
	100-300 MW(t)	800		
	over 300 MW(t)	650		
after 1995:	over 50 MW(t)		150	100
	50-100 MW(t)	400***		
	over 100 MW(t)	200		

* 100 MW(t) equals about 37 MW(e).
** 1300 mg/Nm^3 for slag-tap furnaces.
*** 800 mg/Nm^3 for slag-tap furnaces.

Table 6. *Draft SO_2 Emission Standards for Fuel Burning Plants in the Netherlands*

Fuel	New Installations	Existing Installations
Coal	Over 300 MW(t): 400 mg/m^3; 85% efficient FGD	Over 300 MW(t): 0.8% S; and for installations with an indefinite lifetime, the same as for new installations
	Under 300 MW(t): 700 mg/m^3	Under 300 MW(t): 1.2% S
Oil	Over 300 MW(t): 400 mg/m^3; 85% efficient FGD	Over 300 MW(t). 400 mg/m^3; 85% efficient FGD for installations with an indefinite lifetime. Other: 1,700 mg/m^3
	Under 300 MW(t). 1,700 mg/m^3	Under 300 MW(t). 1,700 mg/m^3
Gas	Refinery Gas: 35 mg/m^3	Refinery Gas: 35 mg/m^3 (1/1/1986)
	Oxygas: 35 mg/m^3	Oxygas: 35 mg/m^3 (1/1/1987)
	Blast Furnace Gas 200 mg/m^3	Blast Furnace Gas: 200 mg/m^3 (1/1/1987)
	Coke Oven Gas: 800 mg/m^3	Coke Oven Gas: 800 mg/m^3 (1/1/1987)

Other new NO_x limits as of February 1986 are

- Solids incineration, less than 50 MW(t); i.e., 18 MW(e)
  - -Wood 50 mg/Nm^3
  - -Fluidized Bed:
    - Above 20 MW(t) 300 mg/Nm^3
    - Other 500mg/Nm^3
- Oil incineration, less than 50 MW(t) 250 mg/Nm^3
- Gas incineration, less than 100 MW(t) 200 mg/Nm^3
- Gas engines
  - -Diesel
    - Above 3 MW(t) 2,000 mg/Nm^3
    - Below 3 MW(t) 4,000 mg/Nm^3
  - -Otto
    - Four-stroke 500 mg/Nm^3
    - Two-stroke 800 mg/Nm^3
- Gas Turbines
  - Above 60,000 Nm^3/h exhaust 300 mg/Nm^3
  - Below 60,000 Nm^3/h exhaust 350 mg/Nm^3

SO_2 and NO_x Activities in Other European Countries

The Netherlands

Under pending Dutch law, high-efficiency FGD is required for all coal-fired boilers larger than 300 MW(t). Large retrofitted FGD systems comprising approximately 2,720 MW(e) at four power plants are in operation or under construction, all designed for usable-gypsum production using wet limestone FGD for operation with 1.5% sulfur coal firing. A broad acid rain control regulation (Tables 6 and 7) modeled after current West German legislation is currently being considered, and in the interim has been used for SO_2 and NO_x emission control guidelines by licensing authorities.

The NO_x emission levels in the draft emission standards will, even for new boilers, enable the use of CM and low-NO_x burners to meet NO_x control objectives.

Three tangentially fired coal/natural gas boilers are under construction. The boiler volume is increased by 20-25% compared to the conventional design, and modified burners with overfire air will be applied. A 270 g/GJ (about 750 mg NO_2/Nm^3) emission limit is guaranteed by the boiler supplier over a broad range of coal analyses.

Ten existing oil/natural gas boilers will be equipped with gas turbines. Exhaust from the gas turbines will be used as boiler combustion air. Besides an increase in boiler efficiency, a considerable reduction of the NO_x emission is expected.

A demonstration of "in-furnace-reduction" is in preparation for a 185 MW(e) gas/oil-fired boiler. This is seen as an intermediate step toward application of this technology for new coal-fired boilers.

Table 7 *Draft NO_x Emission Standards for Fuel Burning Plants in the Netherlands*

Fuel	New Installations 1/1/1986	New Installations 1/1/1988	Existing Installations
Coal	Over 300 MW(t): 800 mg/m^3	400 mg/m^3	Over 300 MW(t): Pulverized fired: 1100-800 mg/m^3; Other: 1000 mg/m^3 (1/1/1989)
	Under 300 MW(t): 800 mg/m^3	500 mg/m^3	Under 300 MW(t): Not applicable
Oil	450 mg/m^3	300 mg/m^3	700/450 mg/m^3
Gas	350 mg/m^3	200 mg/m^3	500/350 mg/m^3

Finally, a fully government-funded demonstration of SCR technology for Dutch coal-fired power plant conditions is in progress. A 65 MW(e) unit is in operation. Design NO_x removal is 80%, with a maximum ammonia-leakage of 5 ppm. Technology is by the Japanese catalyst licensor, Mitsubishi.

Austria

Based on the requirements of the Ministry of Building and Construction stated in the Steam Boiler Emissions Law (DKEG), many FGD and de-NO_x projects are completed or underway. Through use of FGD, reductions in sulfur content of fuel oil and diesel oil, and switching from oil to natural gas fuel, annual SO_2 emissions were reduced between 1980 and 1985 from 354,000 to 180,500 metric tons. Winter season ground-level air monitoring in the center of four major cities, including Vienna, indicates that SO_2 concentration decreased from 30 to 60% during this period. Annual NO_x emissions, 65% of which are from mobile sources, remained about constant at 216,000 metric tons during this same period.

The national government drafted a technology-forcing amendment to DKEG in March 1986 (see Table 8), applicable to boilers over 10 MW(t) = 3.7 MW(e), calling for major retrofits to reduce SO_2 emissions from existing units over a 5-year period to levels already required for new boilers, and to reduce NO_x emissions over a 2-year period by use of primary (CM) measures. [Additionally, existing CO emissions must be reduced to 250 mg/Nm^3 (i.e., 200 ppm), and existing particulate emissions for boilers above 100 MW(t) must be reduced to 30 mg/Nm^3 (i.e., 0.025 lb/10^6 Btu heat input).] Note that the draft SO_2 emission limit for existing bituminous-coal-fired boilers larger than 300 MW(t), about equivalent to 110 MW(e), is 150 mg/Nm^3 (equivalent to 53 ppm), or 90% SO_2 removal, whichever is more stringent.

Approximately 2000 MW(e) of wet FGD is in operation or under construction, almost all usable-gypsum-producing lime/limestone installations, generally equipped with prescrubbers for segregated collection of HCl and residual particulate matter. Retrofit installations include two wet lime/limestone system totaling 370 MW(e) and one Wellman-Lord system with scrubber size equivalent to 163 MW(e).

Coal-fired units aggregating 1500 MW(e) have been retrofitted with CM including overfire air and low-NO_x burners under the impetus of DKEG to reduce NO_x emissions. Based on use of technology by licensees Babcock Hitachi and Mitsubishi, retrofit SCR installations designed for 200 mg/NO_2/Nm^3 outlet emission were installed in 1986 on three bituminous-coal-fired units aggregating 925 MW(e). Additional SCR of 800 MW(e) capacity, primarily by retrofit, is scheduled for later application (1987 to 1990 initial start-up) in oil- and gas-fired service. In 1985, SCR pilot plant operations using technology of licensees comparative tests of ceramic vs. plate catalysts for retrofit application in a 330 MW(e) installation scheduled for initial operation in 1987.

Sweden

Sweden, severely impacted by acid precipitation for many years, has taken major steps to reduce its substantial emissions. Approximately 20,000 lakes and 90,000 km (56,000 miles) of water courses are affected by acidification due to the discharge of SO_2 and NO_x. Groundwater, land, and forests have also been affected. At the same time, between 80 and 90% of sulfurous precipitation in Sweden comes from foreign sources. As a result of a national program, annual SO_2 emissions in Sweden have decreased by more than 65% from a peak value of close to 1 million metric tons in the early 1970s. Sweden aims for a reduction by 1995 to an annual SO_2 emission inventory of about 175,000 metric tons or less, a level 65% less than that in 1980. The annual NO_x emission inventory peaked at about 325,000 metric tons in 1980. This amount is expected to decrease in the next 10 years due to the introduction of stricter exhaust emission control requirements on motor vehicles as well as measures to restrict NO_x emissions from stationary sources. The aim of the government is to reduce NO_x emissions by 1995 to a level 30% less than the 1980 peak.

Principal restrictions on new and existing emissions include a 1% limit on oil sulfur content and the equivalent maximum SO_2 emission, 0.24 g S/MJ (240 g S/GJ), equivalent to 1400 mg SO_2/Nm^3, for use of other fuels.

A 0.2-0.17 g S/MJ (570-970 mg SO_2/Nm^3) emission-limit guideline applies to new or modified emission sources smaller than 400 annual metric tons sulfur (e.g., industrial boilers, district heating, and cogeneration plants), the magnitude of the emission limit varying with geographic location and other factors. Several 20-40 MW(t) circulating fluidized/bed boilers utilize limestone addition for SO_2 emission control when firing coal.

An emission-limit guideline of 0.05-0.1 g S/MJ (i.e., 290-580 mg SO_2/Nm^3), equivalent to 0.23 lb SO_2/10^6 Btu heat input, applies to emission sources larger than 400 annual metric tons sulfur. This has led to installation of dry-scrubbing FGD for six district steam-heating plants. As of 1982 two new 500 MW(e) coal-fired units were anticipated to be in operation by 1992 (together with 15 to 25 new coal-fired district heating plants in the size range 150 to 600 MW(t), a few of which are already in operation with dry-scrubbing FGD). It is now expected that, when a new large coal-fired unit has to be built (to compensate for the expected permanent shutdown of nuclear power plants as dictated by national referendum), government authorities will require an emission limit both for SO_2 and NO_x at least as low as that which applies in West Germany at that time.

By the end of 1986, an aggregate of 1280 MW(t) [i.e., about 470 MW(e)] of dry-scrubbing FGD was in operation in low-sulfur coal service at the six heating plants noted above. Design removal efficiencies are generally in the range of 70 to 80% to achieve a 0.1 g S/MJ (570 mg SO_2/m^3) limit value. Most of these installations include an electrostatic precipitator precollector, which will help ensure a maximum potential for utilization of the FGD solid waste. FGD operations at two of the plants began in 1982 and 1983 and have been quite good.

In about 1985, concern for NO_x emissions substantially increased, and the government proposed an NO_x emission limit of 0.1 g NO_2/MJ (100 g/GJ), equivalent to 285 mg NO_2/m^3 (about 140 ppm), for large existing or new boilers. Implementation of these emission regulations for NO_x is still being studied. Also the "bubble concept" is being considered whereby emission limits would be tied to the combined emissions of SO_2 and NO_x.

Some commercial experience in NO_x reductions through CM has been gained at some coal-fired plants in Sweden. Three 120 MW(t) coal-fired boilers that began operation in 1982 have comparatively large furnaces with tangential firing and overfire air injection. The NO_x emission is comparatively low, 0.14 g NO_2/MJ (400 mg/m^3). The extra cost is about 6 Swedish kroner/kW(t); i.e., 16 kronor/kW(e). Similar performance has been reported at other new pulverized-

Table 8. *Proposed SO_2 and NO_x Emission Standards for Boilers in Austria*

MW(t)	SO_2 Standard (90% Removal or mg/m³, below) Lignite	Bituminous	NO_x Standard (mg NO_2/m³)
10-50	1200	400	400
50-100	500	200	300
100-150	350	200	300
150-300	350	200	300
over 300	300	150	150

coal-fired plants. Some retrofitted facilities include low-NO_x burners. The emissions of NO_x are in those cases 0.2-0.28 g NO_2/MJ (570-800 mg/m³). Information about costs and operating experience is not yet available.

Denmark

Electric utilities, over an 11-year period, have converted to 95% use of coal fuel overall. Four thousand MW(e) of an overall generating capacity of 8,000 MW(e) will be equipped with 12 FGD systems by 1995. One 350 MW(e) dry-scrubbing FGD system under construction will achieve 92% SO_2 removal in typical low-sulfur coal service. Planning for reduction of NO_x emission inventory is underway.

Norway

Because of the wide abundance of hydroelectric power, there are presently no fossil-fueled power plants in Norway. It is possible that one or two 600 MW(e) gas-fired power plants will be built within about 10 years. Virtually sulfur-free gas from the North Sea will be used, and no FGD will thus be required.

FGD has been installed on industrial sources such as aluminum smelters, industrial oil-fired boilers, an ilmenite prereduction furnace, and tail gas from Claus sulfur plants. A large FGD system is currently being supplied to an oil refinery catalytic cracking unit. Nearly all of the FGD systems are Flakt-Hydro seawater scrubbers aggregating the equivalent of 1430 MW(e) scrubber capacity. The control requirements for such large sources are set case-by-case in accordance with local requirements. SO_2 emissions from small industrial boilers, which are located in urban areas, are limited by burning low sulfur (1.2%) oil.

Finland

Furnace limestone injection tests have been carried out, beginning in 1984, leading to a 1986, full-scale, 250 MW(e) installation on low-sulfur bituminous coal service with limestone injected at the superheating level to avoid furnace slagging. It is equipped with a 125 MW(e) capacity, direct-contact, flue-gas humidifier that boosts SO_2 removal in gas it treats to 80%.

France

Due to the strong orientation toward nuclear power development in France, SO_2/NO_x emission reduction efforts are understood to be principally directed toward decreased fossil fuel usage.

In 1985, a parliamentary panel headed by Minister Valroff published a report presenting a proposed action plan for "acid rain" control. Elements of this plan tied to SO_2 and NO_x control consist of:

- In conjunction with a French government objective to gain a 50% reduction in the 1980 SO_2 emission inventory by 1990, which objective had already been reached in 1985, an SO_2 emission levy of 130 francs per metric ton of SO_2 is proposed, applicable to combustion sources larger than 50 MW(t) and to non-combustion sources greater than 2,500 metric tons of SO_2 per year, to help fund investments aimed at SO_2 emission reduction as well as related process development studies. Special emphasis for such funding goes to fluidized-bed combustion and to other processes allowing desulfurization.
- Implementation of "special protection zone" and "alarm zone" systems for specific areas, particularly the city of Strasbourg.
- Limiting of sulfur content of diesel fuel and distillate heating oil to 0.2% in conjunction with such a Europe-wide measure to be adopted by the EEC.
- Studies of forest dieback.
- A speed limitation on motor vehicles in conjunction with actions by the EEC.

Additional related recommendations include:

- A substantial action plan for reduction of hydrocarbon emissions to curb ozone formation considered to be of significance in forest dieback.
- Flue gas treating for urban waste incineration to collect HCl.

Belgium

Like France, Belgium emphasizes use of nuclear power However, although specific national laws requiring FGD do not presently exist, it is expected that a planned 600 MW(e) coal-fired boiler and an existing 300 MW(e) boiler being converted from blast furnace gas to coal will be required to have FGD at efficiency levels comparable to such system installations in West Germany

Switzerland

National SO_2 regulations are in place similar to those in West Germany, but there are no existing coal- or oil-fired boilers of substantial size.

In Switzerland, as in West Germany, the spreading decay of the forests is believed to demonstrate unequivocally that atmospheric pollution in that country has reached proportions which seriously threaten the environment and, hence, human health.

A detailed overall survey of the nature/effect of emissions of atmospheric pollutants in Switzerland (including the decay of forests) regarding the main harmful substances – SO_2, NO_x, and hydrocarbons (HC) – is being prepared. There has been a considerable increase in air pollution in Switzerland since the 1950s. Although SO_2 emissions have declined since the beginning of the 1970s, NO_x and HC emissions have continued their upward trend. Dendrochronological analyses indicate that the proportion of trees showing growth disorders has constantly risen since the 1950s, and forestry experts believe that, to protect the forests, air pollution should be brought down to its 1950-1960 level. The Swiss Federal

Council has adopted a series of measures seeking to accomplish this.

Italy

In conjunction with extensive coal energy development in Italy, major FGD activity is foreseen by U.S. system suppliers. A new, cooperative, coal-logistics-related activity by the government of Italy and the U.S. Department of Energy (DOE) examines the present and future fuel requirements of Italian utilities and industries and the capability of meeting the requirements with U.S. coal. The U.S. DOE said that Italy is converting many of its older power stations to coal and building new power plants. Because of that, Italy could double its current steam coal consumption by the 1990s. Currently, the U.S. supplies about 9 million annual metric tons of coal to Italy, which is about 40% of the coal used in that country. While metallurgical coal use will remain relatively constant, steam coal demand is expected to increase sharply.

The government-owned national power company, ENEL, is building 10 MW(e) Wellman-Lord, limestone-gypsum, and ammonia-scrubbing demonstration FGD systems in Sardinia for service in high-sulfur bituminous coal. A bromine-liquor based regenerative FGD pilot plant will also be installed in Sardinia for operation in 1988 or 1989.

ENEL is reported to have recently announced planning and strategy for use of wet FGD in coal-fired boiler service and use of modified burners for NO_x emission control.

Spain

In conjunction with the new membership of Spain in the EEC, new stringent regulations for environmental protection are expected to take effect in a few years. Current SO_2 and NO_x control-related technical development activity in that country includes:

- Assessment in a Basque regional-government sponsored study of local dolomite and limestone sources for potential use in wet and/or dry FGD.
- Coal study work to coordinate FGD process selection with characteristics of indigenous fuel.

Current tolerant national regulations limit SO_2 emissions from boilers to the level of 3,000 mg/Nm^3 for oil-firing, 2,400 mg/Nm^3 for bituminous or anthracite, and 9,000 mg/Nm^3 for lignite, and there is no significant experience with FGD. Of the boiler supply, 20% is solid fuel.

United Kingdom

In 1986, British authorities licensed a new/large, high-sulfur-coal-fired unit in North Yorkshire without requiring SO_2 emission control.

However, two positive developments are reported:

- The UK-government-owned national power company, CEGB, in actively investigating the construction of two new coal-fired power plants within the next few years, is fully expected to utilize SO_2 controls.
- The national government's Department of Trade and Industry recently commissioned a comprehensive study of available treatment processes for SO_2 and NO_x control, a report on which was issued in 1987.

Reduced NO_x emissions in firing of oil and gas have become a major objective. The latest requirements are for 100 ppm NO_x on oil and 50 ppm NO_x on gas, with a total particulates limit of 115 mg/Nm^3. In newest jet-atomizing fuel-burner designs, particulate levels of 50 mg/Nm^3 are being achieved while maintaining efficient oxygen levels, with NO_x levels approximately 150 ppm on oil and 80 ppm on gas for most radiant burners in standard configuration. By adding discrete external flue gas recirculation (FGR) to the burner, these NO_x levels can be brought down to and below the latest requirements, but extra ductwork and fans are required for conveying the flue gas. For this reason burners to achieve FGR internally by means of education, thereby eliminating extra hardware, are being developed. The development of staged fuel or air burners is being avoided since it is felt that this would compromise overall combustion performance of liquid and gaseous fuel burners.

Turkey

Three small limestone FGD systems are being installed in Turkey.

Other Countries

Planning of FGD systems on very large SO_2 emission sources in the German Democratic Republic (East Germany) and Czechoslovakia has begun.

A Wellman-Lord FGD system has been purchased for a power plant in East Berlin.

In Yugoslavia, investigations are underway at two coal-fired power plants to determine the cost of installing FGD.

☆U.S.Government Printing Office: 1988 — 548-158/67114

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The complete report, entitled "Assessment of SO_2 and NO_x Emission Control Technology in Europe," (Order No. PB 88-168 992/AS; Cost: $14.95, subject to change) will be available only from:
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