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A National Analysis of Toxic Releases from Electric Power Plants

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ABSTRACT

As of 1998, electric utility companies burning coal or oil are required to report their annual releases of toxic chemicals to the Toxics Release Inventory (TRI), a national compilation of multi-media (air, water, land) releases of over 600 chemicals and chemical categories designated as toxic by the U.S. Environmental Protection Agency (EPA). TRI reports for 1998 must be filed with EPA by July 1, 1999, but results of the 1998 inventory not expected until mid-2000. To estimate the impact of utility emissions on TRI results, this paper uses historical data to estimate the magnitude of toxic releases for the electric utility sector relative to other industry groups in 1995. The analysis uses a public database of coal consumption for each coal-burning power plant in the United States to estimate reportable releases based on regional trace element coal characteristics and site-specific plant data. When aggregated to the national level, releases from the electric utility industry were found to exceed those of any of the manufacturing industries reporting to the TRI in 1995. These results suggest that the addition of power plants to the TRI could significantly change the rankings of chemicals, industries and facilities listed by EPA in its annual TRI report. Since the TRI gives only mass emissions without regard to the relative toxicity or risk from chemical releases there will be an increased need for risk communication programs to explain and interpret the new TRI results to the public.

INTRODUCTION

The Toxics Release Inventory (TRI) was established by Section 313 of the Emergency Planning and Community Right-to-Know Act (EPCRA) of 1986, and expanded by the Pollution Prevention Act of 1990. the law requires facilities in designated industry sectors to report annually the amounts of toxic chemicals released to the environment, along with information on waste management and pollution prevention activities. The TRI is a publicly available database established to provide U.S. communities with information on the presence and releases of toxic chemicals. Approximately 600 chemicals are included on the current TRI list. Published annually by EPA, and available on the World Wide Web, the TRI has become an important vehicle for identifying and quantifying the mass of chemicals released by industries and facilities at the local, state and national levels. However, the TRI provides no information on the relative toxicity or risks from the releases that are reported.

Since the TRI was established in 1986, the industries required to report toxic emissions included only the twenty major manufacturing industries identified by Standard Industrial Classification (SIC) codes 20-39. In May 1997, the U.S. Environmental Protection Agency (EPA) added seven new industry groups to the TRI, including oil- and coal-burning electric power plants (1). Affected facilities must report TRI emissions on an annual basis, beginning with 1998 emissions.

Reports for 1998 must be filed with EPA by July 1, 1999. Approximately one year is then needed for EPA to compile, analyze, and publish the results. Hence, the toxics inventory for 1998 is not expected to be available until mid-2000.

This paper develops preliminary state-level and national estimates of TRI emissions from the electric power sector in order to obtain some perspective on the importance of this sector relative to other reporting industries. Nationally, the chemicals industry (SIC 28) and the primary metals industry (SIC 33) have had the largest total releases, as seen in Table 1. By chemical, methanol, ammonia, and zinc compounds have been the TRI chemicals emitted in greatest quantity as shown in Table 2. The key question that motivates this paper is: how will the addition of the electric utility sector affect the magnitude and types of chemicals reported by the TRI, and the rankings of industry groups?

To address this question, we derive estimates of TRI emissions from coal-fired plants in the U.S. for the year 1995, the most recent year for which TRI data were available for other industry groups at the time this study was initiated. Since that time, TRI results for 1996 also have been released by EPA (2), but as seen in Tables 1 and 2 those results are similar to the inventory for 1995 (3). Details of our study methodology are presented following a brief review of the TRI and its requirements.

TRI REQUIREMENTS

Electric utility plants covered by TRI are in SIC codes 4911, 4931 and 4939. Any facility within a covered industry is required to report to TRI if it has the equivalent of ten or more full-time employees, and "manufactures" or "processes" more than 25,000 pounds of any listed toxic chemical during the reporting year, or "otherwise uses" more than 10,000 pounds of any listed chemical. A toxic chemical is considered to be manufactured if it is "produced, prepared, compounded, or imported," including coincidental manufacture as a byproduct or impurity. A chemical is considered to be processed if it is "prepared after manufacture for distribution in commerce." Finally, a chemical is considered to be otherwise used if its use does not fall under the categories of manufactured or processed (1).

Trace chemicals found in air and water intake streams are excluded from TRI reporting. The TRI also exempts toxic chemicals that appear in low concentrations in some types of products. The *de minimus* exemption applies only to "a listed toxic chemical in a mixture or trade name product received by the facility," and "a listed toxic chemical manufactured during a process where the toxic chemical remains in a mixture or trade name product distributed by the facility." Thus, a power plant which sells a byproduct such as flyash or gypsum containing TRI chemicals may be able to apply the *de minimus* exemption to that byproduct stream. If the concentration limit is not exceeded — as is typically the case for power plant byproducts — the quantity of chemicals in the byproduct would be exempt from TRI reporting.

For most power plants, the most relevant set of TRI chemicals are those designated as manufactured or otherwise used (4). These categories are briefly reviewed below.

Manufacture During Combustion

The TRI rules consider the combustion process to "manufacture" new chemicals from the trace constituents in coal or oil used to generate power. Manufactured chemicals include not only the trace organics that may be found in some combustion flue gas streams, but also the metal oxides and other constituents present in flyash, bottom ash, stack emissions, and FGD wastes. Coincidental manufacturing is considered by EPA to have occurred any time a chemical substance in fuel is transformed into a different chemical compound within the power plant (1).

EPCRA Section 313 does not require affected sources to conduct any new measurement programs for purposes of TRI reporting. Since data are generally lacking on the specific chemical forms of metals in fuel and ash, EPA has stated that in the absence of better site-specific information, metals that take part in the combustion process may be assumed to convert completely into the lowest weight metal oxide per unit of the metal possible for each metal. An earlier paper (4) quantified the threshold for each TRI metal based on this criterion.

Other inorganic TRI chemicals that may be manufactured during combustion include hydrochloric acid (HCl), hydrogen fluoride (HF), and sulfuric acid (H_2SO_4). Gaseous HCl and HF are formed from chlorides and fluorides in coal, while sulfuric acid vapor is formed in the flue gas stream from the reaction of sulfur trioxide (SO_3) and water vapor. Although only the acid aerosol forms of HCl and H_2SO_4 are listed TRI substances, EPA has defined an aerosol to include gases and vapors as well as mixtures of gases and particles (1). Thus, HCl and H_2SO_4 emissions are reportable TRI release for most power plants.

Chemicals Otherwise Used

This category of TRI chemicals includes a variety of substances commonly used at power plants for water treatment, boiler cleaning, and other miscellaneous purposes. Chemical additives are used to control alkalinity, biofouling, deposition and corrosion in plant cooling and makeup water streams. Chemicals also are used to regenerate ion exchangers, treat and clean boiler tubes, remove suspended solids in clarifiers, and prevent freezing of coal piles in cold weather. It remains to be determined on a facility-by-facility basis, which, if any, "otherwise used" chemicals exceed 10,000 lbs/yr, making them reportable to TRI.

STUDY METHODOLOGY

This section summarizes the methods used in this paper to estimate chemical releases from power plants. The TRI provides substantial latitude in the methods that affected facilities may use to estimate toxic releases in the absence of site-specific data. Therefore, the "base case" approach used in this study assumes that sources will likely tend to utilize methods and assumptions which present their facility in the most favorable light in cases where there are reasonable uncertainties as to the "best" or most appropriate estimation method. Thus, our base case estimate attempts to reflect a utility point of view. Subsequently, we attempt to bound our estimates by developing an "upper bound" scenario that reflects alternative assumptions.

Data Sources and Assumptions

The following data sources and assumptions formed the basis for our analysis.

Coal Consumption and Power Plant Data

Power plant and fuel use data were taken from the 1995 Form 423 submitted by fossil-fuel burning power plants to the U.S. Federal Energy Regulatory Commission (FERC). The forms are submitted monthly and list the cost and quality of fossil fuels delivered to electric generating plants. The data are then merged into a large public database (5).

All coal-fired generating units with a gross capacity of 50 megawatts (MW) or more are considered in this study. Units smaller than 50 MW are excluded since FERC data do not clearly distinguish the amounts of different fuel used. Because each power plant can contain multiple units, the capacity of the individual units at a given facility are aggregated to determine exceedences of TRI thresholds. Figure 1 shows the distribution of the gross (nameplate) capacity for the 406 coal-burning plants modeled in this study. The gross capacity totaled 349 GW, of which 77 GW were equipped with flue gas desulfurization (FGD) systems.

Each unit reports the plant name, fuel source, fuel quantity, fuel quality and fuel cost on a monthly basis. The fuel source information includes the fuel type, fuel rank, county, state and supplier. The fuel quantity is reported for each fuel source. Finally, the fuel quality section reports the BTU content, sulfur content and ash content of the fuel on an as-received basis. Table 3 shows the subset of categories listed in FERC 423 data and used in this study. Table 4 shows the total coal consumption for 1995. For comparison, utility coal consumption for 1995 -1997 also is shown in Table 4, as reported by the U.S. Energy Information Administration (6). Net electricity generation from coal increases from 1653 BkWh in 1995 to 1789 BkWh in 1997 (6).

Oil-Fired Plants

Although oil-fired power plants are covered by the TRI, they are omitted in the present study since a scoping analysis indicated that their contribution to total national releases is relatively small. Oil plants accounted for only 2% of 1995 generation, compared to 55% for coal. Furthermore, the low levels of chemical impurities in fuel oils, coupled with relatively small plant sizes and low average capacity factors, means that most of the oil-fired plants in the FERC database will not exceed TRI reporting thresholds. To the extent that some oil-fired plants do contribute to the TRI inventory (principally HCl, H_2SO_4 and nickel compounds), the current estimates for coal plants may be viewed as a lower-bound for the utility sector as whole.

Trace Element Concentrations and Emission Factors

In addition to plant-level data on annual coal consumption and sulfur content, the trace element concentration of coals burned is required to calculate TRI thresholds and chemical releases. This study employs trace element concentration data compiled by Radian International for EPRI (7). The data reflect information from a literature survey plus field tests by EPRI (8), the U.S. Department of Energy (9) and others. Table 5 shows the median values for the chemical concentrations in coal averaged across the six supply regions used in this study (Table 6). These data reflect coals actually used by utilities as opposed to coal in the ground. Because chemical concentrations are given on a dry basis, coal moisture content (Table 6) also must be specified to calculate chemical releases for TRI.

Trace Element Partitioning Data

The partitioning of trace chemicals between air and solids was estimated using data in the PISCES

Model (10), a mass and energy balance model used previously to identify and quantify TRI chemical releases for a representative coal-fired power plant (4). The data sources used to estimate air emissions (7-9) include much of the same data used to develop trace species emission factors published by EPA (11). A more detailed breakdown, however, is used to estimate partitioning for different power plant configurations based on the actual dataset.

Organics and Otherwise Used Chemicals

This study does not consider any chemicals that are "otherwise used" since such amounts are highly site-specific and not easily estimated. A previous case study (4) further suggests these amounts are likely to be small relative to the amounts "coincidentally manufactured" in the combustion process. That same study found that any trace organics formed during combustion were at least two orders of magnitude below threshold limits for listed TRI chemicals. Hence, the present study considered only inorganic chemicals in coal.

Boiler Type

Because of limited boiler configuration data in FERC 423, all boilers are assumed to be pulverized coal-fired units for the purpose of determining the fraction of trace chemicals collected in bottom ash. Since this study reports only the total ash-related releases (bottom ash plus flyash), this assumption has a negligible impact on results. Other potential influences of boiler type, such as effects on SO_3 formation, are discussed later in the paper.

Particulate Collector Performance

Because of site-specific data limitations on particulate collector type and emission rates, an electrostatic precipitator (ESP) is assumed for all power plants, and all particulate emission rates are assumed to be below the 1979 New Source Performance Standard (NSPS) of 0.03 lb/MBtu. This assumption determines the ESP trace chemical partitioning (removal efficiency) data obtained from the PISCES Model for each coal rank. Median values are used for all plant-level estimates, as is the case with EPA emission factors.

Sulfuric Acid Aerosol

One of the most poorly understood aspects of power plant toxic releases is the magnitude of H_2SO_4 vapor and aerosol formed and removed within power plant systems. Since sulfuric acid aerosol is not listed by EPA as a hazardous air pollutant (HAP), none of the recent field sampling programs conducted by EPRI (8) or DOE (9) included H_2SO_4 emissions in their testing. Nor do utilities commonly measure H_2SO_4 emission rates or removal efficiencies. The existing technical literature and data on this subject displays a very large uncertainty, ranging up to two orders of magnitude in emission estimates. Under these circumstances, the base case assumption in this paper is intended to reflect a reasonable estimate of H_2SO_4 emissions that utilities might be expected to use as the basis for TRI reporting. Table 7 summarizes these assumptions, which are based on a widely-circulated paper by Southern Company Services (12). The effect of alternative assumptions is discussed later in the paper.

FGD System Performance

Where the presence of a flue gas desulfurization (FGD) system is indicated in FERC 423, a wet lime/limestone system is assumed. The median value of TRI chemical concentrations in lime and limestone reagent are used as additional process inputs. The median value of trace chemical

removal efficiency across an FGD system (based on all fuel ranks) is obtained from the PISCES Model (10).

Solid Waste Management

Power plants use either wet or dry ash handling systems to manage solid wastes. For plants using wet systems, some of the trace substances in the collected solids is transferred to the sluice water, and some of that amount may be released to the environment via the plant water treatment system. Because of data limitations, TRI water releases are difficult to quantify, though limited case studies suggest they are a small percentage of the total in collected solids (4). In the absence of systematic data to characterize the solid waste handling and wastewater treatment practices at all U.S. power plants, the present study simply reports the air and total releases, recognizing that the difference is predominantly a disposal to land. Land releases may occur either on-site of off-site. The TRI considers any type of landfill disposal to be a release.

Exempt from TRI reporting, as discussed earlier, are chemicals contained in power plant byproducts distributed in commerce. These quantities are estimated based on national average percentages for 1995 (13), as summarized in Table 8.

Calculation Procedure

Figure 2 shows a schematic of the procedures used to estimate TRI releases. The following sections summarize the major steps.

Aggregate Unit Data

FERC 423 data for the individual units in the 1995 database were first aggregated to the plant level. The number of units per power plant varied from 1 to 14. Most plants used coal suppliers from multiple regions. Coal supply regions were determined by linking the reported state of origin to one of the six supply regions listed in Table 6. To obtain bulk properties such as average sulfur content, the reported FERC 423 values for individual coals were averaged for each coal rank in proportion to the quantity supplied.

TRI Threshold Determination

The aggregate data for each facility included the total annual coal use and the relative percentages of coal from each supply region. These percentages were applied to the trace element coal concentrations for each coal supply region and coal rank to determine the total quantity of trace chemicals manufactured during combustion. This is the principal quantity determining whether the TRI threshold is exceeded. For plants with FGD systems, the trace chemicals in the FGD reagent also were assumed to undergo coincidental manufacture. The TRI threshold test was applied to each trace chemical. If the threshold was exceeded, the total plant releases were calculated as described in the next subsection.

Calculations of Reportable Releases

The partitioning of each trace chemical between air and solids was calculated for each plant using the empirically determined removal efficiencies across the boiler, ESP and FGD system, as described earlier. The calculations also accounted for exemptions for TRI chemicals in byproducts that are distributed in commerce. Reportable releases thus excluded the Table 8 percentages of trace metal in collected solids. In the absence of more detailed information, the national average

percentages were applied to each plant. The final results were then aggregated to the state and national levels.

STUDY RESULTS

Table 9 summarizes the total estimated releases of reportable TRI chemicals for 1995. Hydrochloric acid aerosol (as defined by EPA) is the major TRI chemical produced by electric power plants, accounting for 56% of the total releases nationally. Land and water releases (most of which is landfilled solids) amount to 25% of the national total. Overall, 17 TRI chemicals exceed the reporting threshold at one or more facilities. The thresholds for cadmium, mercury and silver were not exceeded anywhere.

Comparing the national power plant totals in Table 9 to the manufacturing industry totals in Table 1 shows that total 1995 releases from power plants would have exceeded those of the chemicals industry by 17 percent. Power plant air releases are comparable in quantity to the chemicals, primary metals and paper industries combined. Total power plant releases are broken down by state in Figure 3. Ohio has the largest total releases, which are slightly in excess of 100 million pounds per year (Mpy). Six states have total releases of 50 to 75 Mpy, and six more have releases between 25 and 50 Mpy. The top ten states comprise 63% of the total 1995 releases from coal-fired power plants.

The five states with the largest actual releases reported to TRI in 1995 are shown in Table 10. The second column shows the effect on the ranking of adding the electric utility industry. Ohio, Pennsylvania and Indiana move up in this ranking as a result of power plant releases. In 17 states, a power plant would have been named by EPA (14) as having the largest total release in the state.

Finally, a comparison between Table 9 and Table 2 shows that hydrochloric acid aerosol would have replaced methanol as the largest chemical release nationally in 1995 had utilities been a listed industry. Barium compounds and sulfuric acid aerosol would have been listed among the top ten chemical releases nationally as a result of power plant discharges.

Uncertainty Analysis

There is substantial uncertainty in any estimate of toxic releases from power plants. At the facility level, uncertainties arise whenever trace species fuel concentrations are determined from published estimates rather than site-specific data. Across the U.S., the concentration of trace elements in coal can vary by two orders of magnitude or more (4). Even where site-specific fuel data are available, the use of published emission factors to calculate air releases has roughly an order of magnitude uncertainty when applied to a specific facility (8). And even when site-specific measurements are available (which is not typically the case), the uncertainty interval for the usually small number of data point is extremely broad (15).

Aggregation of site-specific estimates to the state and national levels, as in this study, reduces the overall uncertainty since some of the site-specific uncertainties offset each other. This offsetting effect may not be symmetrical, however. For example, coal concentration data and emission factor estimates often are reported as median values of a positively skewed distribution (e.g., a lognormal distribution). While this gives a reasonable estimate of the most probable value for an

individual facility, the sum of such estimates across a population of facilities systematically underestimates the true total if the underlying distribution is positively skewed.

While a rigorous evaluation of uncertainties is not currently feasible, we attempt to bound the TRI estimates in Table 9 by examining the sensitivity of those results to key assumptions affecting the largest releases.

Results for HCl and HF

HCl aerosol, as defined by EPA, is the dominant release from power plants. Releases of HF are roughly an order of magnitude smaller, but represent the third largest air release. The magnitude of both of these releases is governed mainly by the chloride and fluoride concentrations in coal. It is unclear how utilities will estimate those values in the absence of site-specific data. To the extent the median regional values used in this study are representative of the values employed, the Table 9 totals would accurately reflect expected HCl and HF releases (which incorporate the efficient removal of HCl and HF in FGD systems). The use of a more detailed distribution function for Cl and F coal concentrations — as might be obtained from detailed site-specific data — would result in higher releases than shown in Table 9 (for the same median value) because of the positive skewness discussed above. A bounding estimate of HCl and HF releases, however, is most easily obtained using the EPA emissions factors provided in the utility industry TRI guidance document (16). Those factors reflect much higher as-fired coal concentrations for Cl and F (924 ppmw and 109 ppmw, respectively) than used in this study. Use of the EPA factors would double the estimates in Table 9, allowing for the same HCl and HF removal efficiencies used in the base case.

Results for Sulfuric Acid

The large uncertainty in H_2SO_4 aerosol releases stems from uncertainty in the fraction of fuel sulfur converted to SO_3 and subsequently released as H_2SO_4 (produced in the flue gas train). SO_3 production levels are known to depend upon plant parameters such as boiler type and excess oxygen levels, while emission levels (as H_2SO_4) depend also upon coal ash composition, air preheater design, and air pollution control equipment. Measurement methods also may affect reported results. In the absence of systematic and reliable data on actual H_2SO_4 stack emission, TRI estimates must rely on the range of data available in the literature. As discussed earlier, the values in Table 7 were based primarily upon a recent study by Hardman, et al (12), which is being used by the Edison Electric Institute (EEI) in its guidance for electric utility companies. Other studies, however, report SO_3 emissions as high as 2-3% of total sulfur. Nonetheless, we believe it unlikely that average H_2SO_4 emissions reported to TRI will exceed the EPA emission factor estimate of 0.7% sulfur as SO_3 (17), which is several times higher than the values in Table 7. Thus, our bounding case uses the EPA emission factor, along with a slightly lower SO_3 removal efficiency for FGD systems (50%, as recommended in (12), vs. 65% in the base case). These assumptions yield a national estimate of H_2SO_4 releases that is twice the Table 9 value.

Results for Trace Metals

The base case estimate for trace metal air releases in Table 9 assumed that all coal-fired power plants in 1995 were equipped with ESPs that met or exceeded the 1979 NSPS of 0.03 lbs/MBtu for total particulate matter. Since older plants may have less stringent emission standards, a second case was run using the median value of PISCES Model trace element partition factors for all plants emitting less than 0.1 lb/MBtu total particulates (the 1971 NSPS value). This increased

the combined trace metal air emissions of the 14 elements in Table 9 by 10 percent when applied to all U.S. power plants. A more complete measure of uncertainty also should consider the variability of trace element concentrations within each coal supply region. The positive skewness of such distributions would again tend to raise the estimate of total national releases of trace metal compounds. While a detailed analysis was not performed in this study, we estimate an increase of roughly 20 to 30 percent based on previous case studies (4, 15).

Summary of Results

Table 11 summarizes the range of TRI estimates for 1995 encompassed by the base case (Table 9) and the upper bound estimates discussed above. Depending on the methods and data used by utilities to estimate TRI emissions, national totals for coal-fired plants conceivably could be lower than our base case estimates; but we believe it unlikely that national totals would exceed our upper bound estimates, which are a factor of two higher than the base case. As noted earlier, these estimates do not include oil-fired power plants, nor small coal-fired boilers less than 50 MW in size. Any reportable releases from such facilities would increase the totals shown in Tables 9 and 11.

DISCUSSION AND CONCLUSIONS

The results of this study showed that the addition of the electric utility industry to the TRI would have significantly altered the national picture of major toxic releases and their sources for the year 1995. The electric utility industry was found to have the largest on-site and total releases nationally, with hydrochloric acid aerosol replacing methanol as the TRI chemical released in greatest quantity. Power plant releases also added to, and often dominated, the inventories of sulfuric acid aerosol, hydrogen fluoride and various metal compounds, especially barium. In many states and communities, a local power plant would have been named by EPA as the largest emitter of toxic pollutants, rather than a local industrial plant. Nationally, there is at least a factor of two uncertainty in the magnitude of total power plant releases, depending upon the estimation methods employed.

Since 1995, electric power plants have continued to reduce their sulfur emission rates, and have added some new FGD capacity which lowers releases of HCl and other TRI chemicals. Nonetheless, in view of the continued growth in coal use for power generation (see Table 4), the qualitative results found for 1995 are likely to also apply to the 1998 TRI, which will report the first true estimates of power plant toxic releases.

Since the TRI lists only the mass of chemical releases, and is silent on issues of toxicity or community risk, the anticipated focus on the magnitude of power plant releases will require a concerted effort on the part of electric utilities — as well as EPA — to explain and interpret the new inventory numbers to the public. Indeed, a major criticism of the TRI is that the mass numbers reported are not necessarily indicative of environmental concerns. In the case of power plant releases, for example, the quantities of metal compounds in flyash and bottom ash, which are labeled as “toxics” by the TRI, have been found previously by EPA to be “non-hazardous” under the National Resources Conservation and Recovery Act (RCRA). Similarly, the HCl and HF releases, which dominate the power plant inventory, were found by EPA to pose “no exceedance of the health benchmarks” for inhalation exposure in a recent assessment of health risks from

hazardous air pollutants (18). That same study did not even consider sulfuric acid aerosol since it is not listed by EPA as a hazardous air pollutant (though it is labeled as "toxic" under TRI).

This potentially confusing and conflicting set of labels, perceptions and concerns regarding power plant releases undoubtedly will become prominent when EPA reports the 1998 TRI results sometime in mid-2000. Thus, various types of risk communication activities are likely to be the most immediate consequence of the new TRI reporting requirements for electric utilities. In this regard, the use of toxicity weighting factors (19) and screening risk assessments (20) are among the tools that can be helpful. In the near to longer term, the TRI also is likely to stimulate efforts to better quantify major power plant releases, and to reduce overall emissions consistent with the pollution prevention objectives of TRI and the industry capability to respond.

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Table 1. Largest Total Releases by Industry in 1995-96 (millions of pounds per year)

SIC	Industry	1995 Releases Air[a]	1995 Releases Total[b]	1996 Releases Air[c]	1996 Releases Total[b]
28	Chemicals	407	844	392	785
33	Primary Metals	138	524	145	565
26	Paper	213	238	204	228
30	Plastics	112	127	105	116
37	Transportation Equipment	109	121	103	111
All Industries		**1,562**	**2,531**	**1,452**	**2,434**

[a]From Ref. (3), Table 4-10. Figures include both fugitive and stack emissions.
[b]From Ref. (2), Table 4-6. Figures include both on-site and off-site releases to air, water and land.
[c]From Ref. (2), Table 4-2. Figures include both fugitive and stack emissions.

Table 2. Largest Total Releases by Chemical in 1995-96 (millions of pounds per year)

Chemical	1995 Releases Air[a]	1995 Releases Total[b]	1996 Releases Air[c]	1996 Releases Total[b]
Methanol	210	255	206	241
Ammonia	157	195[d]	155	193
Zinc compounds	5	189	6	207
Toluene	145	147	125	127
Nitrate compounds	<1	145[d]	<1	164
All Chemicals	**1,562**	**2,531**	**1,452**	**2,434**

[a]From Ref. (3), Table 4-19. Figures include both fugitive and stack emissions.
[b]From Ref. (2), Table 3-9. Figures include both on-site and off-site releases to air, water and land.
[c]From Ref. (2), Table 2-9. Figures include both fugitive and stack emissions.
[d]From Ref. (3), Table 4-34.

Table 3. 1995 FERC Form 423 Data Used in This Study

Category	Comments
Plant Name	Used to sum over all units and determine plant totals
Date	Summed over all dates to determine yearly quantities
Fuel Type & Rank	Only coal-burning plants > 50 MW included
Fuel Source Location	Used to determine the coal supply region
Fuel Quantity	Annual quantity from each supply region used
Fuel Characteristics	BTU and sulfur content

Table 4. Summary of Power Plant Coal Consumption (million tons/yr)

	FERC 423 Database[a]	DOE/EIA Annual Energy Review[b]		
Coal Rank	**1995 Totals**	**1995**	**1996**	**1997**
Bituminous	419			
Subbituminous	330			
Lignite	75			
Total	**823**	**829**	**875**	**899**

[a]From Ref (5).
[b]From Ref (6).

Table 5. Mass Concentrations of Trace Chemicals in Coal[a] (ppmw, dry basis)

Chemical	Bit	Sub	Lig
Antimony	1.0	0.57	0.74
Arsenic	10.0	5.9	8.5
Barium	94.5	196.	220.
Beryllium	1.3	0.5	1.9
Cadmium	0.53	0.83	0.1
Chloride	750.	195.	140.
Chromium	18.6	5.0	9.3
Cobalt	6.4	2.0	3.7
Copper	21.	9.3	10.5
Fluoride	69.	44.	79.
Lead	8.1	7.8	6.2
Manganese	22.4	35.5	74.
Mercury	0.12	0.10	0.22
Molybdenum	2.1	1.7	3.0
Nickel	16.1	9.5	5.9
Selenium	3.2	0.9	1.3
Silver	0.2	0.16	0.1
Thallium	1.6	2.0	0.5
Zinc	22.0	8.7	7.8

[a]From Refs (7, 10). Values for each coal rank are the median values across the six coal supply regions listed in Table 6.

Table 6. Coal Moisture Content by Region and Coal Rank (median value)

Coal Supply Region	Coal Rank	Moisture (wt%)
Eastern	Bit	5.2
East & North Interior	Bit	7.7
Northern Great Plains	Sub	28.5
	Lig	36.5
Western Interior	Lig	35.0
Rocky Mountain	Bit	10.5
	Sub	9.0
Gulf Coast	Lig	33.9

Table 7. Assumptions for Sulfuric Acid Emissions

Coal Type	wt% SO_x as SO_3[a]
Base Case[b]	
Western bituminous	0.05
All other bituminous	0.4
PRB subbituminous	0.01
All other sub.	0.1
All lignite	0.1
Bounding Case[c]	
All coals	0.7

[a]All SO_3 is assumed to convert to H_2SO_4.
[b]Based on Ref (12). FGD assumed to remove 65% of values shown (Ref 10).
[c]From Ref (17). FGD assumed to remove 50% of values shown (Ref 12).

Table 8. Use In Commerce of Coal Combustion Byproducts in 1995

Byproduct	% of Total Produced[a]
Bottom Ash	33.3
Fly Ash	25.0
FGD Material	7.4

[a]From Ref (13)

Table 9. Base Case Estimates of Total Power Plant Releases for 1995 (millions of pounds)[a]

TRI Chemical	Air	Total
Hydrochloric acid	553.5	553.5
Barium compounds	< 0.4	142.3
Sulfuric acid	129.6	129.6
Hydrogen fluoride	55.4	55.4
Manganese compounds	0.2	29.3
Zinc compounds	0.2	19.2
Copper compounds	0.1	12.2
Nickel compounds	0.1	11.7
Chromium compounds	< 0.1	9.9
Lead compounds	< 0.1	6.8
Arsenic compounds	< 0.2	6.0
Molybdenum trioxide	< 0.1	4.7
Cobalt compounds	< 0.1	3.6
Antimony compounds	< 0.1	1.5
Selenium compounds	0.3	0.7
Thallium compounds	< 0.1	0.4
Beryllium compounds	< 0.1	0.3
Total	**740.**	**987.**

[a]Figures for metal compounds refer to weight of elemental metal. Totals Include on-site and off-site releases.

Table 10. Largest Total Releases by State in 1995

Rank	Actual 1995[a]	Actual 1995 + Utilities
1	Texas	Texas
2	Louisiana	Ohio
3	Ohio	Pennsylvania
4	Pennsylvania	Louisiana
5	Illinois	Indiana

[a]From Ref (2), Table 3-3.

Table 11. Uncertainty Estimates for Total 1995 Releases from Coal-Fired Power Plants (millions of pounds)

Substance	Air Releases		Total Releases	
	Base[a]	Bound[b]	Base[a]	Bound[b]
HCl aerosol	553	1147	553	1147
H_2SO_4 aerosol	130	287	130	287
Hydrogen fluoride	55	135	55	135
Metal compounds	< 2	2	249	311
Total	**740**	**1541**	**987**	**1880**

[a]Base case estimates from Table 9.
[b]Upper bound estimate (see text for assumptions).

Figure 1. Size Distribution of Coal-Fired Power Plants Modeled in this Study (Source=1995 FERC 423 Data)

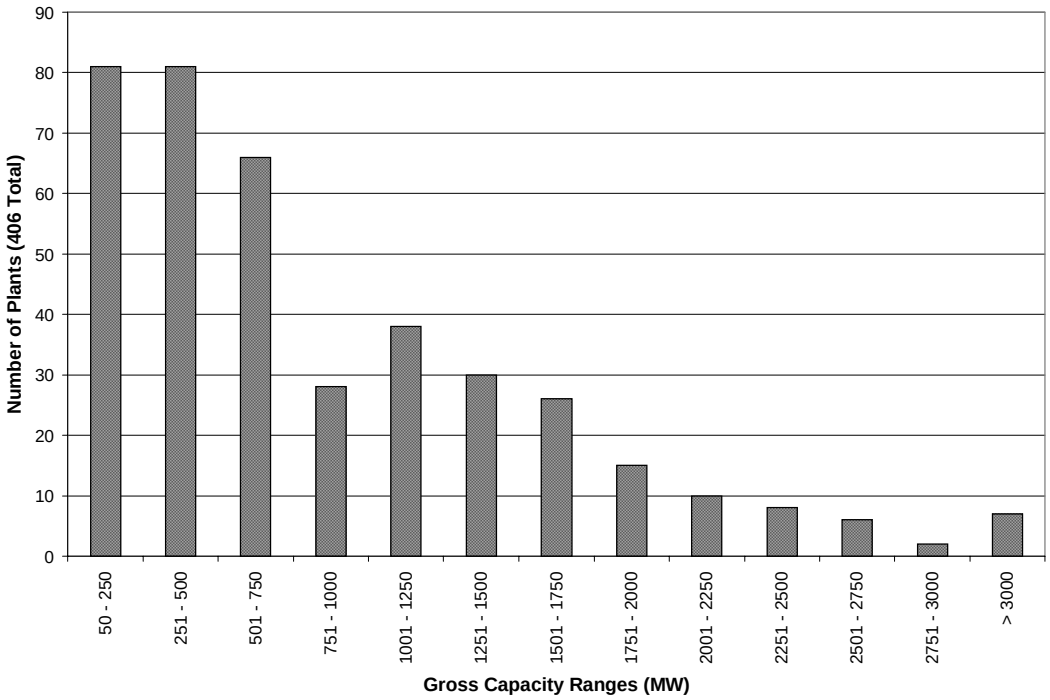

Figure 2. Schematic of Study Methodology

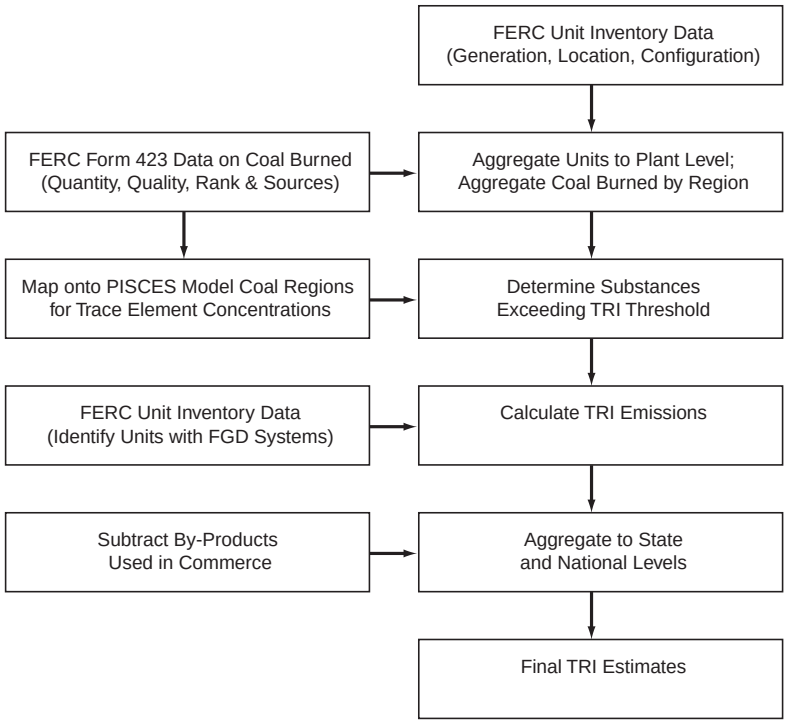

Figure 3. Base Case Estimates of TRI Releases from Coal-Fired Power Plants for 1995