Cost of Air and Water Pollution Control 1976-1985

AMERICAN REVOLUTION BICENTENNIAL 1776-1976

Section One
Agency Draft
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Section Three

THE ECONOMICS OF WATER POLLUTION CONTROL

Chapter 1
Summary

The economics of controlling water pollution encompasses both the expected benefits and the probable costs of control. The principal findings in the control cost area are summarized below; benefits of water pollution control are discussed in the next chapter of this section.

5. INDUSTRIAL CONTROL COSTS

Introduction

The extent of water pollution and the costs of treating it vary significantly among industries and among the firms within an industry; therefore, it is important to examine the structure, production methods, sources of pollution, effluent standards, and wastewater control technology for each industry. The following sections of this chapter briefly summarize the relevant characteristics of each industry and report the estimated annual abatement costs attributable to achieving full compliance with the 1977 (BPT) and 1983 (BAT) effluent standards.

MODELING AN INDUSTRY

The plants in an industry have various options by which to comply with the water pollution standards. In general they may:

1. Fully treat their effluents.
2. Pretreat their effluents and discharge to a municipal system.
3. Change their manufacturing process.

Table 24.
Pollution Control Costs as a Percentage of Alimon Scenario GNP

	1975	1977	1980	1983	1985
Air Stationary Source Costs					
Capital Costs	0.60%	0.47%	0.30%	0.18%	0.11%
O&M Costs	0.42%	0.37%	0.43%	0.38%	0.34%
Water Industrial Costs					
Capital Costs	0.26%	0.36%	0.52%	0.48%	0.06%
O&M Costs	0.02%	0.02%	0.23%	0.27%	0.52%
Water Municipal Costs					
Capital Costs	0.36%	0.39%	0.36%	0.07%	0.02%
O&M Costs	0.03%	0.05%	0.12%	0.11%	0.11%

ECONOMIC FORECASTING IN THE SEAS SYSTEM

Economic forecasting within the SEAS system takes place in a context which meshes the features of a traditional input-output (I/O) model and econometric model-building. The basic structural economic component of SEAS, INFORUM', is not a typical economic input-output model. It is, to a substantial degree, a combined econometric-I/O approach to economic forecasting.

$$\frac{i(1+i)^N}{(1+i)^N - 1}$$

Table 10.
General Projections of the Reference Scenarios (S1), 1975-1985

	Value In			Annual Percentage Change			
Statistics	1975	1985	1975-85	1975-77	1977-80	1980-83	1983-85
Population (Millions)	213.9	235.7	0.97	0.89	0.97	1.02	1.00
Labor Force (Millions)	93.8	107.7	1.40	1.71	1.62	1.25	0.96
Unemployment Rate (%)	8.4	4.4	-6.38	-8.07	-10.66	-3.04	-2.94
Disposable Income Per Capita (1975 $)	3,553	5,753	4.94	5.16	7.96	3.29	2.74
Gross National Product (Trillion 1975 $)	1.470	2.365	4.87	6.43	6.50	3.34	3.18
Personal Consumption Expenditure	.933	1.563	5.30	4.87	7.55	4.36	3.79
Investment	.222	.380	5.59	13.69	6.43	1.85	2.31
Government Expenditures	.307	.414	3.05	2.99	3.74	2.68	2.64
Federal	.117	.136	1.61	.71	.70	2.58	2.43

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Section One-OVERVIEW

$bACKOWLEDGEMENTS$R

Preparation of this combined air and water pollution control cost analysis was an extensive effort made possible only through coordination of the hard work of many different dedicated individuals. The final product is the result of expert analysts in EPA and the private sector. EPA personnel and contractor personnel responsible for various aspects of the report are listed below:

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$aExecutive Summary$R

This is the first Agency report to combine the national economic impact analyses required by the Clean Air Act (P.L. 91-604) and the Federal Water Pollution Control Act (P.L. 92-500) into a single, integrated study. The report is designed to facilitate comparison of the projected impacts of the two laws on a common basis, as well as to provide an estimate of their combined effect on the economy. It is presented in four sections: Overview, The Economics of Air Pollution Control, The Economics of Water Pollution Control and A Comprehensive Assessment of Pollution Control.

$bAGGREGATED ESTIMATES$R

The report indicates that if the nation's economy continues to recover and grow at official Federal forecast rates, the total cost to meet requirements of the laws will be about $480 billion over the decade beginning this year and ending in 1985. This amount represents the decade sum of annual debt retirement payments, plus operation and maintenance costs associated with a capital investment in plant and equipment of about $220 billion. The $480 billion (1975 dollars) comprises about two and one-half percent of the gross national product (GNP) summed over the same decade.

Pollution control expenditures are estimated to have a net positive effect on total national employment over the 1976-1985 decade. During the period 1976-1979, when pollution-control construction and capital equipment demands are at their highest, the increase in total employment is estimated to range between one and two percent per year. In subsequent years, the job requirements related to pollution control shift toward operation and maintenance activities, and the increase in total employment is estimated to decline to one-quarter of one percent by 1985. Beginning in 1984, with the economy assumed to be at full employment, growth in pollution control employment comes at the expense of labor in production activities.

Other investigations have indicated that premature closings of older industrial facilities due to pollution control requirements is probable in some cases, causing temporary, localized unemployment. Forecasting of this complex economic process, however, was not within the scope of this study.

In developing these projections, a national cost calculation procedure was employed which allows future cost estimates to be adjusted to conform with different forecasts of national economic growth, as indicated by GNP. This computer-based adjustment capability is useful because of the uncertainty and frequent changes associated with GNP forecasts. For example, the report examines estimated air and water pollution control costs for a more conservative growth forecast (called the "Low Productivity Scenario") in which the decade GNP is about 90 percent of the official "Reference Scenario." Another scenario, referred to as the "Energy Conservation Scenario," provides for a GNP equivalent to the Reference Scenario, but with a different mix of products due to the implementation of certain feasible energy conservation practices. Table 1 presents some summary indications of the impact of these different forecasts of the future. Although air and water pollution control costs change with the economic forecasts, the decade costs remain very close to two and one-half percent of the GNP.

$dTable 1.
Summary of Scenario Results

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Scenario	Decade GNP (Trillion 1975$)	Decade Pollution Control Cost[1] (% GNP)	1985 Energy Consumption (Quad. Btu's)	Net Residuals in 1985[2] (% of Reference) SO	Part	NO	HC	CO	BOD	SS	DS	Nut.
Reference	20.007	0.0	109.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
Reference Abatement	20.162	2.42	112.9	37.9	12.6	91.3	39.3	26.5	16.9	9.3	61.4	44.1
Reference Abatement with $7 B/yr Municipal Appropriation	20.195	2.60	113.2	38.0	12.7	91.6	39.3	26.5	14.5	7.9	61.4	27.4
Low Productivity	18.596	0.0	102.0	90.3	90.6	88.5	87.3	84.9	93.2	91.9	88.5	99.3
Low Productivity Abatement	18.849	2.53	105.7	34.1	11.3	81.5	35.1	23.0	15.7	8.7	54.3	43.8
Energy Conservation	20.062	0.0	95.7	89.9	93.9	91.8	86.3	86.8	99.3	99.4	96.7	99.9
Energy Conservation Abatement	20.201	2.41	99.6	34.6	11.9	84.5	34.8	24.4	16.9	9.2	58.6	44.2

1. See Tables 2, 4, 9, 12, 17, 21, and C-1, for composition of pollution control costs by year from 1976 through 1985.

2. Part = Particulates, SS = Suspended Solids, DS = Dissolved Solids, Nut. = Nutrients, SO = Sulfur Oxides, NO = Nitrogen Oxides.$R

The calculation procedure also provides for consistent estimation of the mass of pollutants discharged into the nation's air and water, based on the particular economic forecast and the particular set of pollution control measures assumed to be employed. This report expresses pollution control costs as increments occasioned by the passage and implementation of the two laws. For this purpose, it was assumed that without current Federal statutes, pollution control efforts would not have advanced beyond that practiced in 1971. Costs and pollutant discharges reported are thus incremental to those that would have occurred by maintaining 1971 levels of control throughout the 1976-1985 decade.

Table 1 presents the results from pairs of future forecasts or scenarios designed to demonstrate the impact of the Federal air and water quality statutes on pollution control costs and pollutant discharges under different economic forecast assumptions. Each pair contains estimates of control costs (as a percent of GNP) and pollutant discharges (as a percent of Reference Scenario forecasts for 1985) with and without the Federal controls. The costs without the controls are zero by definition. A third scenario is presented under the official Reference Case forecasts, in which the municipal wastewater treatment construction grant program is assumed to be augmented by $42 billion ($7 billion per year for six years) above current authorizations. Comparing the first two scenarios of the Reference Case, it is seen that, with Federal controls and official economic growth rates, the discharge of particulates into the air and suspended solids into the water in 1985 are estimated to be only 13 and 9 percent, respectively, of what probably would have occurred during that year in the absence of the controls.

The projected reductions in pollutant discharges are translated into improved ambient environmental quality, which is, in turn, recognized as pollution control benefits by society. Discussions in Sections Two and Three of the report describe the techniques which can be used to calculate various types of benefits on a monetary basis, with several examples from the recent literature. Some benefits, however, such as esthetic and other psychic categories, are not yet reliably quantifiable, even though subjectively they appear very important. This lack of information, plus the lack of sufficient data for calculating the more quantifiable benefits on a nationwide basis, make any total national benefit figures somewhat suspect. For these reasons, projected total national pollution control benefits are not expressed in dollar terms in this report.

Table 2 shows the estimated capital investment schedule for various air and water pollution control categories throughout the decade. These entries represent only the value of the capital plant and equipment purchased, and do not include any interest charges or operations and maintenance expenses. Table 3 presents the total cost calculation information. Total cost is defined as the sum of anualized capital costs plus operation and maintenance costs. Annualized capital costs are derived by amortizing capital investment at an interest rate of 10 percent over the life of the equipment. This can be thought of as repayment of a capital loan at 10 percent interest over the life of the capital plant and equipment. All investments are amortized at the same interest rate, so they can be compared on an equivalent basis. Both sets of costs are significant: the investment represents the value of plant and equipment that must be produced and delivered by the pollution control industry and related suppliers. The total cost is a close estimate of the actual costs which must be borne by the purchaser of the pollution control equipment and facilities.

Since pollution control equipment must be continually operated and maintained and periodically replaced, and new equipment must be purchased for new industrial or public service growth, total annual costs are continually increasing. The nation must be willing to accept these costs as a permanent, increasing part of the national budget if desired environmental quality is to be restored and maintained. Figure 1 shows how total annual costs grow from $27 billion to $64 billion over the decade.

$dTable 2.
Air and Water Pollution Control
Investments, 1976-1985
(Billions of 1975 $)

$t

	1976	1977	1978	1979	1980	1981	1982	1983	1984	1985	Decade Total
Air											
Stationary Sources	3.7	5.5	5.9	3.4	1.7	1.4	1.0	0.7	0.6	0.7	24.6
Mobile Sources	5.5	6.3	11.6	11.7	11.8	12.0	12.1	12.2	12.4	12.4	108.1
Transportation Controls	0.14	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.2
Totals	9.2	11.8	17.5	15.1	13.5	13.4	13.1	12.9	13.0	13.2	132.9
Water											
Industrial	5.1	7.3	4.8	6.8	7.8	7.2	6.8	5.4	1.4	1.7	54.3
Municipal	6.6	8.1	8.1	5.6	2.9	1.8	0.8	0.7	0.7	0.5	35.8
Totals	11.7	15.4	12.9	12.4	10.7	9.0	7.6	6.1	2.1	2.2	90.1
Combined Air and Water Total											223.0

Components may not sum to totals due to rounding.

Value approximately 0.003, or $3 million.$R

$dTable 3.
Total Cost of Air and Water
Pollution Control, 1976-1985
(Billions of 1975 $)

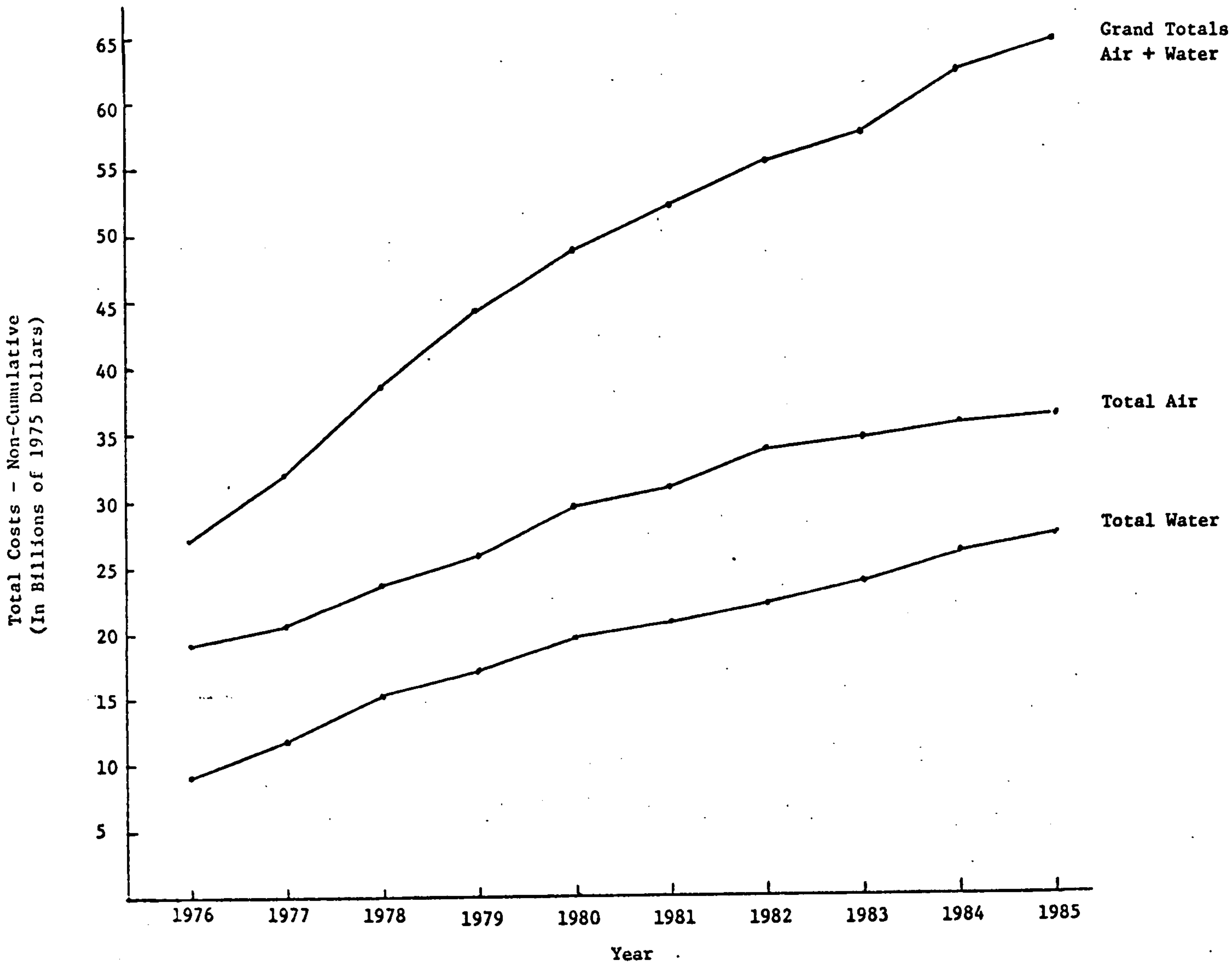
$t

	1976	1977	1978	1979	1980	1981	1982	1983	1984	1985	Decade Total
Air											
Stationary Source											
Annualized Capital	4.0	4.8	5.6	6.1	6.3	6.5	6.6	6.7	6.8	6.9	60.3
O&M	3.5	4.1	4.6	5.0	5.3	5.4	5.4	5.4	5.4	5.4	49.3
Totals	7.5	8.9	10.2	11.1	11.6	11.9	12.0	12.1	12.2	12.3	109.6
Mobile Source											
Annualized Capital	5.4	6.6	9.4	11.9	14.1	16.1	17.8	19.2	20.4	21.3	142.2
O&M	5.6	4.6	4.2	4.0	3.9	3.8	3.6	3.4	3.3	3.2	39.5
Totals	11.0	11.2	13.5	15.9	18.0	19.8	21.4	22.6	23.7	24.5	181.8
Transportation Control											
Annualized Capital	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02
O&M	(0.06)	(0.01)	(0.14)	(0.13)	(0.12)	(0.12)	(0.11)	(0.12)	(0.12)	(0.12)	(1.0)
Totals	(0.04)	(0.01)	(0.12)	(0.11)	(0.10)	(0.10)	(0.09)	(0.10)	(0.10)	(0.10)	(0.8)
Air Total											290.6
Water											
Industrial											
Annualized Capital	2.2	3.1	3.7	4.5	5.5	6.4	7.3	8.0	8.2	8.4	57.3
O&M	3.7	4.9	5.9	6.4	6.9	7.2	7.5	7.8	11.0	11.5	72.8
Totals	5.9	8.0	9.6	10.9	12.4	13.6	14.8	15.8	19.2	19.9	130.1
Municipal											
Annualized Capital	2.3	3.2	4.1	4.7	5.0	5.2	5.3	5.4	5.4	5.5	46.1
O&M	0.7	0.9	1.4	1.6	1.8	1.8	1.9	1.9	2.0	2.0	16.0
Totals	3.0	4.1	5.5	6.3	6.8	7.0	7.2	7.3	7.4	7.5	62.1
Water Total											192.2
Air & Water Total											482.8

Components may not sum to totals due to rounding.

Values in parentheses indicate savings due to improved fuel economy.sR

Figure 1.
Total Annual Expenditures for
Air and Water Pollution Control



$bUNCERTAINTIES$R

Whenever a new estimate of national pollution control costs is produced, there is a natural tendency to compare it with related estimates developed by other parties. Such efforts frequently show considerable discrepency between estimates for ostensibly the same cost categories. Such discrepencies are, in fact, to be expected, due to the vast number of conditions which must be specified to assure that even the category of cost analysis is identical between two different estimates. For example, costs reported for the "Animal Feedlots" category can contain estimates for any number of the following animal production businesses: beef cattle, dairy cattle, hogs, sheep, chickens, turkeys, etc.

Since most pollution control regulations are in terms of effluent or emission concentrations, assumptions must be made as to what type of technology will be generally applied by each industrial category to achieve effluent or emission requirements. ~~the required ambient quality~~. Estimates must then be made for the variation of capital and operation and maintenance costs with respect to age, size, and location of the many plants within the industrial category. This area is probably the greatest source of ~~difference~~ disagreement in the field of pollution control cost~~s~~ estimating.

Economic variables are another cause of discrepancies; dollar value deflators, interest rates, equipment lifetimes, wage rates, power and material costs, economic growth rates, capital availability, and other factors must all be estimated and projected into the future to produce an estimate of pollution control costs over a period of years.

In addition, the particular purpose of the estimates may not be exactly the same. The estimates in this report represent the expenditures which would probably be incurred if all parties met the regulations on schedule by installing an assumed particular type of equipment. The resulting forecasts are thus unrealistic to the extent that polluting activities fail to meet all requirements on schedule.

The Bureau of Economic Analysis (BEA) of the Department of Commerce conducts periodic surveys of industries to estimate actual pollution control expenditures. These estimates are nearly twice as high as EPA estimates in some categories, and only one-fifth as much in others. These differences can be attributed to variations in industry category definition, slower or faster equipment installation schedules, different judgements of the amount of industrial expenditures for process modification which can be properly attributed to pollution reduction, and the probable statistical errors in BEA's industrial questionnaire sampling process. Chapter 3 in this Section discusses the impact that process modification can have on pollution reduction and the difficulties involved in apportioning cost between pollution control and production cost accounts. A discussion of BEA estimates is presented in Section Four.

The closest parallel to the estimates in this report are the estimates for the cost of water pollution control recently prepared by the National Commission on Water Quality. The Commission's estimates involve the same effluent limitations, and many of the same economic assumptions and industrial category definitions. Some of the industrial category cost estimates compare very closely, but there are still categories which differ significantly. These differences are attributed primarily to (1) uncertainties in plant inventories in those industries characterized by large numbers of small plants, (2) differences in professional judgement on what process would most likely be applied to achieve the required effluent quality, (3) industrial growth rates and plant size trends over the decade, and (4) different assumptions about the current status of pollution control in the industries (capital-in-place).

To summarize, variations in estimates of national activities of this level of complexity are to be expected, but detailed examination of the data and calculation procedures can usually explain the reasons for the variations. The general economic assumptions used in this report are explicitly stated in Sections One and Four of the report, and industry descriptions and pollution control process descriptions are described in considerable detail in Sections Two and Three. Information in greater detail in support of the entire document is maintained on file in the Agency.

$bHIGHLIGHTS

Combined Effects$R

The five most severely impacted industrial categories based on the total control costs for both air and water pollution as a percentage of total output for the category are Fabricated Metals and Electroplating, Pulp and Paper, Leather Tanning, Iron and Steel, and Steam Electric Power, all having combined expenditures in excess of 4 percent of their total output. The high ranking of the first and third categories is due entirely to water pollution control expenditures. The other three show significant expenditures in both air and water pollution controls.

In terms of pollution control investment relative to total investment projected in the various sectors, the top five categories become Leather Tanning, Fabricated Metals and Electroplating, Canned and Frozen Foods, Pulp and Paper, and Grain Milling and Feed Mills. This parameter projects a more severe impact, with Leather Tanning being required to spend nearly 70 percent of its total decade investment on pollution control. The lowest of the five, Grain Milling and Feed Mills, is anticipated to spend over 15 percent of its total investment on pollution control, about 95 percent of which would be directed toward air pollution control. The percentages on which these impacts are based for the entire industrial community are shown in Table 4. Chapter 4 of Section Four (Tables 8 and 9) presents the actual values used to develop these percentages.

$dTable 4.
Ranking of Impacted Sectors by Total Abatement Expenditures
as Percentages of Investment and Output
(1976-1985)

$t

	Investment						Output					
	Air		Water		Both		Air		Water		Both	
	Rank	%	Rank	%	Rank	%	Rank	%	Rank	%	Rank	%
Fabricated Metals & Electroplating	-	-	2	22.11	2	22.11	-	-	1	5.30	1	5.30
Pulp & Paper	5	5.05	4	10.56	4	15.61	1	3.21	4	2.05	2	5.26
Leather Tanning	-	-	1	69.31	1	69.31	-	-	2	4.54	3	4.54
Iron & Steel	6	4.69	10	5.12	9	9.81	4	2.61	6	1.55	4	4.16
Steam Electric	2	6.28	13	4.23	7	10.51	2	3.16	9	0.93	5	4.09
Chemicals	10	0.99	5	9.64	6	10.71	9	0.64	3	3.34	6	3.98
Nonferrous Metals	3	5.98	22	0.79	14	6.77	3	2.70	14	0.37	7	3.07
Grain Milling, Feed Mills	1	14.49	20	0.81	5	15.31	6	1.75	21	0.10	8	1.86
Asbestos, Clay, Lime & Concrete	7	2.98	23	0.25	17	3.22	5	1.76	23	0.07	9	1.82
Canned & Frozen Food	-	-	3	15.69	3	15.69	-	-	5	1.78	10	1.78
Petroleum & Asphalt	4	5.37	11	4.87	8	10.24	7	1.28	13	0.39	11	1.67
Plastics & Synthetics	15	0.20	9	7.56	12	7.77	13	0.07	7	1.35	12	1.42
Machinery	20	0.04	8	7.67	13	7.72	18	0.02	8	1.07	13	1.09
Fertilizers	8	1.83	12	4.57	15	6.40	10	0.61	12	0.43	14	1.04
Furniture	9	1.36	-	-	21	1.36	8	0.88	-	-	15	0.88
Dairy	-	-	6	9.59	10	9.59	-	-	10	0.73	16	0.73
Transportation Equipment	18	0.10	14	3.45	16	3.55	16	0.55	11	0.67	17	0.73
Meat & Poultry	-	-	7	7.93	11	7.93	-	-	15	0.29	18	0.29
Beet & Cane Sugar	-	-	15	2.99	18	2.99	-	-	16	0.25	19	0.25
Lumber & Wood Products	-	-	21	0.80	24	0.80	-	-	17	0.24	20	0.24
Paints	12	0.54	-	-	26	0.54	11	0.21	-	-	21	0.21
Glass	-	-	18	1.21	22	1.21	-	-	18	0.19	22	0.19
Natural Gas	14	0.37	-	-	28	0.37	12	0.18	-	-	23	0.18
Builder's Paper	-	-	16	2.34	19	2.34	-	-	19	0.15	24	0.15
Rubber Products	-	-	19	1.09	23	1.09	-	-	20	0.13	25	0.13
Textiles	17	0.12	17	1.33	20	1.44	19	0.02	22	0.10	26	0.12
Wholesale & Retail (Grain Handling)	13	0.53	-	-	27	0.53	14	0.06	-	-	27	0.07
Mining	11	0.55	-	-	25	0.55	15	0.06	-	-	28	0.06
Printing	16	0.15	-	-	30	0.15	17	0.04	-	-	29	0.04
Agriculture	-	-	24	0.20	29	0.20	-	-	24	0.02	30	0.02
Services (Dry Cleaning)	19	0.04	-	-	31	0.04	20	0.01	-	-	31	0.01Rs

$bAir$R

By comparing total air pollution control costs to total industrial category output, the five most severely impacted categories are found to be Pulp and Paper, Steam Electric Power, Nonferrous Metals, Iron and Steel, and Asbestos, Clay, Lime and Concrete, all five having relative costs below 3 percent. Comparing air pollution control investment to total project investment in the categories, the most severely impacted industries become Grain Milling and Feed Mills, Steam Electric Power, Nonferrous Metals, Petroleum and Asphalt, and Pulp and Paper, their relative pollution control investments ranging between 5 and 15 percent. Table 4 presents these rankings for the entire industrial community.

Since it is now apparent that many stationary sources did not meet the 1975 target for installation of controls, it is no longer logical to assume that all sources meet all requirements according to specified schedules in the State Implementation Plans. Instead, it is now assumed that stationary controls will be installed according to a more realistic schedule as proposed in a 1975 EPA report on "The Economic Impact of Pollution Control: Macroeconomic and Industry Reports," wherein all sources are brought within compliance by 1981. This change shifts investments into later years in the decade as reported in Section Two.

Chapter 4 of Section Two discusses mobile source emission control costs. Costs in this category are significantly different than earlier estimates due to a variety of factors, including changes in standards, changes in lead-content phase-out schedules, changes in projected average age and weight of the automobile population, and other conditions related to the recent energy shortage problems.

In metropolitan areas where mobile emission control devices are not sufficient to guarantee achievement of ambient air quality standards, additional efforts are required, such as transportation control plans. An important factor in these plans is inspection and maintenance programs, wherein all vehicle owners are required to have periodic inspection and required maintenance for both engine performance and emission controls performance. Such maintenance, while costly, results in better gas mileage, which translates into an economic benefit to the owner. Estimates of fuel savings have been calculated in the analysis this time. Using assumed fuel cost projections, the inspection and maintenance programs actually result in a net economic benefit to the nation in addition to improving air quality.

Details of these estimates are shown at the end of Section Two.

$bWater$R

The five industrial categories most severely impacted by water pollution control regulations on a total cost basis are Fabricated Metals and Electroplating, Leather Tanning, Chemicals, Pulp and Paper, and Canned and Frozen Foods, their expenditures ranging between 1 and 5 percent of their output. On a relative investment basis, the ranking is Leather Tanning, Fabricated Metals and Electroplating, Canned and Frozen Foods, Pulp and Paper, and Chemicals, whose water pollution investments range from 9 to nearly 70 percent of total projected investments. The rankings for all water-using industrial categories are presented in Table 4.

Because of the recently completed municipal wastewater treatment Needs Survey, and the overriding constraints of the Construction Grant Program on the rate of expenditure for Municipal facilities, costs were not calculated based upon meeting requirements, but rather, consist of the $20.8 billion of Federal funds scheduled for outlay during the decade, required matching funds from local governments (25 percent of total investment), $600 million estimated to be spent irrespective of Federal grants, plus operation and maintenance (O&M), and finance charges associated with the aforementioned investments. Other Agency documents have discussed the need for a greater amount of Federal grant funds. Section Two, accordingly, includes an analysis of the impact of a potential augementation of the Construction Grant Program.

Because of the rapidly changing situation with regard to nonpoint source pollution from urban and rural stormwater run-off, and because control of this type of pollution is primarily dependent upon plans issuing from the P.L. 92-500 "208" planning process in late 1978, no estimate of the types or levels of these controls is currently available. Therefore, there are no estimates for costs of urban stormwater pollution nor agriçultural run-off pollution control in this report.

$BComprehensive Analysis$R

Section Four describes the analytical procedures used to develop pollution control cost forecasts on a year-by-year basis over the decade. By using the "input/output" national economic analysis technique of the Strategic Environmental

Assessment System, individual industrial category growth rates are derived which are totally consistent with the aggregate national GNP growth forecasts of each scenario. This approach eliminates the problem of obtaining individual growth rates from a number of different sources with varying accuracies and differing base assumptions. The projected growth rates are used in the cost analysis to provide an indication of the number of facilities subject to new source performance standards in both air and water pollution control.

The analysis of pollution control expenditures over the decade, as presented in this report, provides the Agency with a longer-range view of its programs and a better understanding of the interrelationships and time phasing of its many different pnograms. In addition, the ten-year forecast horizon should be sufficient to accommodate most delays in compliance and still provide stable estimates of total costs and related impacts. The assessment system also provides an estimate of the total amount of residuals discharged to air, water, and land disposal, rather than studying any single environmental medium in isolation. This allows for an analysis of potential secondary pollution caused by primary pollution control processes, a concept brought to the fore by the National Environmental Policy Act.

Finally, the existence of a routinized, fully documented set of data and calculation procedures provides for more defensible cost estimates, and quickly pinpoints particular problem areas whenever the aggregate cost estimates are challenged. Negotiation and resolution of these detailed areas of conjecture continually carries us toward improved estimates which should result in fewer and fewer areas of disagreement as the cost estimation exercise is reiterated.

$aChapter 1$R

$aIntroduction$R

$bPURPOSE$R

Standards for the control of air and water pollution have been developed to implement the requirements of the Clean Air Act (PL 91-604) and the Federal Water Pollution Control Act (PL 92-500). Under the provisions of Sections 312(a) and 516(b) of these acts, respectively, the Environmental Protection Agency (EPA) has the responsibility of submitting regular reports to Congress regarding the cost of pollution controls necessary to achieve the legislated standards.

Two series of six reports each have been previously submitted to Congress on the Economics of Clean Water and the Cost of Clean Air. The last submittals were a 1973 biannual report on water and a 1974 annual report on air. For 1975, the two reports have been combined into this single integrated report to provide a comprehensive assessment of both air and water pollution control.

$bSCOPE AND ASSUMPTIONS$R

This report presents the best available EPA estimates of the national costs of complying with the Clean Air Act and the Federal Water Pollution Control Act over the next decade, 1976-85. It begins with an overview section which presents a discussion of those issues common to the study of both air and water pollution control. The next two sections present the costs of pollution control for air and water, respectively, together with estimates of the reduction in environmental pollution effected by the controls. The fourth and final section presents an analysis of the economic impacts and tradeoffs associated with these costs. Particular emphasis is placed on illustrating how these impacts and tradeoffs might change under alternative sets of assumptions about future economic activity and energy conservation policies.

Included in the overview (Section One) is a presentation of the basic assumptions and general approach taken in the development of control costs and in the analysis of the consequent impacts of these costs. This is followed by a discussion of the concept of benefits as applied to the economic analysis of pollution control. Finally, the economic advantages of controlling pollution through process changes are presented. Five major industries are used as examples in this analysis: copper, aluminum, pulp and paper, petroleum refining, and inorganic chemicals.

Both Sections Two and Three begin with a brief summary followed by a discussion of the estimated types of damages resulting from pollution. In Section Two, the cost of controlling air pollution is presented in terms of government program expenditures, industry and utility control costs, and transportation control costs. Section Three, on the cost of controlling water pollution, also includes a presentation of government program expenditures, followed by municipal and industrial cost estimates.

A comparative analysis approach is taken in Section Four to examine the relative impact of pollution control under alternative futures or scenarios. Included in this presentation is an examination of the gains and losses experienced by consumers and by individual industries which spend and/or receive funds for pollution abatement.

Wherever possible, the national pollution abatement costs, the economic impacts and tradeoffs, and the associated environmental changes that have been estimated and presented in this report are those that would not have occurred without Federal legislation. Specifically, it is assumed that, in the absence of the two laws, the amount of pollution discharged per unit of production (or per person for sewage, per mile for vehicles) would have remained the same as in 1971. A pre-legislation baseline, defined in terms of 1971 pollution control technology levels, is thus established, and all costs, impacts, tradeoffs, and environmental changes are measured as differences from that baseline.

$bProblem Overview$R

Both the comprehensive assessment of pollution control and also the industry-by-industry estimates of pollution control expenditures and pollution reduction are presented at the national level. Although more detailed information is provided in many instances at state or local levels, or for typical sizes of industrial plants, this information is presented primarily to enhance an understanding of the bases established for the national aggregated estimates.

Estimating the control costs and the quantities of pollutants produced on a national basis is a complicated process. Not only are there a large number of pollution sources, but each source could emit a number of pollutants that can be controlled separately or jointly by several alternative control technologies. Conversely, each specific pollutant can be traced to a considerable number of different sources. The costs of control are most conveniently estimated by source, even though they will usually cover more than one pollutant for each source. On the other hand, levels of pollution are more easily examined by pollutant; these levels are estimated by aggregating emissions by pollutant across all sources of that pollutant.

A general overview of the relationships among sample sources, pollutants, effects, and control technologies is presented in Table 1. Discussions of these relationships are found for each industry affected by Federal pollution control legislation in Sections Two and Three of this report.

$dTable 1.
Overview of Sample Pollution Control Relationships

Medium	Source	Pollutant	Effects	Control Technology
Air	Automobiles	NOx, HC,CO	Smog, Lung Damage	Engine Modification, Catalysts
	Electric Utilities	SOx	Respiratory Problems	Scrubbers, Fuel Switching
		Particulates	Soiling, Reduced Visibility	Electrostatic Precipitators, Filters
	Industry			
	Sulfuric Acid	SOx	Respiratory Problems	Absorption
	Petroleum	HC	Smog	Floating Roof Tanks
	.	.	.	.
	.	.	.	.
	.	.	.	.
Water	Municipal Sewers	BOD	Dissolved Oxygen	Oxidation, Adsorption
		Suspended Solids	Materials, Fish Damage	Sedimentation, Filtration
		Pathogens	Infection	Disinfection
	Industry	BOD	Dissolved Oxygen	Oxidation, Adsorption
		Suspended Solids	Materials, Fish Damage	Sedimentation, Filtration
		Dissolved Solids	Materials Damage	Ion Exchange
		Acids	Materials Damage	Neutralization
		Toxics	Poisoning	Adsorption
		.	.	.
		.	.	
		.	.	
		.	.	

$bAssumptions$R

The Federal pollution control legislation ultimately requires industries, consumers (transportation vehicles), and municipalities to lessen or completely eliminate their discharges of pollutants into the nation's atmosphere and waterways. Hence, these pollution contributors must spend a portion of their money resources for pollution abatement regardless of the state of the economy. However, pollution control expenditures are not independent of the state of the economy because the level of economic activity affects the level of production, which in turn affects the amount of pollution generated by industries, consumers, and municipalities. Consequently, the forecasts of pollution control expenditures are based on corresponding forecasts of national economic activity.

Forecasts of pollution control expenditures must also be based upon explicit assumptions about the rate of compliance with pollution control legislation. The assumed timetables for installing pollution abatement equipment are given later in this Introduction as part of the compliance assumptions for this report. All cost estimates presented in this report are expressed in 1975 dollars unless otherwise noted. In addition, annual costs apply to calendar years unless specified differently.

$bEconomic Assumptions$R

A consistent set of economic assumptions is the basis for the cost estimates presented in this report. These assumptions were used to produce a "Reference Case" forecast of the U.S. economy and are summarized in Table 2. An alternative set of economic assumptions is presented in Section Four; the pollution control cost and pollutant discharge estimates corresponding to this alternative scenario enable us to evaluate possible variations from the Reference Case estimates introduced by different economic assumptions.

$bEnergy Assumptions$R

The energy assumptions for Reference Case pollution control forecasts are taken from the Federal Energy Administration's "Business as Usual" scenario in the November 1974 Project Independence Report where the import price for oil is $7 per barrel; they are summarized in Table 3.

Table 2.
Reference Case Economic Assumptions
$t

Economic Assumption	Government Agency	Values
Population-Series E Projections (Millions of People)	Bureau of the Census	1975-213.9 1980-224.1 1985-235.7
Labor Force (Millions of People)	Bureau of Labor Statistics	1975- 93.8 1980-101.8 1985-107.7
Labor Productivity	Bureau of Labor Statistics	Varies by Industry
Gross National Product (Trillions of 1975 Dollars)	Ford/Council of Economic Advisors (1975-1980) Bureau of Labor Statistics (1980-1985)	1975-1.47 1976-1.57 1977-1.69 1978-1.81 1979-1.85 1980-1.99 1985-2.40
Forecast Time Period	EPA	Jan. 1, 1976 - Dec. 31, 1985
Unemployment Rate in 1985 (Full Employment Economy)	Bureau of Labor Statistics	4.5%
Nominal Interest Rates	Office of Management and Budget	Public - 10% Private - 10%
Federal Expenditures in 1980 and 1985 Excluding Transfers and Pollution Control Progress. (Millions of 1975 Dollars)	Department of Commerce, Bureau of Economic Analysis	1980 - $156,400 1985 - $173,400
Federal Expenditures for Pollution Control$R	EPA	

Table 3.
United States Total Gross Consumption of
Energy Resources (In Trillions of BTU's/Year)
(Business-as-Usual Without Conservation-$7/Bbl Oil)

$t

Fuel	1972	1977	1980	1985
Coal	12,495	16,854	18,074	19,888
Petroleum	32,966	37,813	41,595	47,918
Natural Gas	23,125	21,558	22,934	23,947
Nuclear Power	576	2,830	4,842	12,509
Other	2,946	3,543	4,014	4,797
TOTALS	72,108	82,598	91,459	109,059

Source: Project_Independence_Report, Federal Energy Administration, Appendix A1, p.37. November 1974.$R

$bAir Compliance Assumptions$R

EPA regulations and Federal legislation related to the Clean Air Act of 1970 apply different levels and modes of air pollution controls to these specific pollution source categories: mobile sources (transportation vehicles), existing stationary sources of air pollution, new stationary sources of air pollution, and sources of hazardous pollutants. The Clean Air Act and the cost estimates presented in this report are based on the principle that pollutant emissions will be brought under whatever level of control is necessary to achieve national ambient air quality standards. However, for many different reasons, many industries have not met the July 1, 1975, compliance date originally set for existing stationary sources. Similarly, the original dates and standards established for transportation vehicles have been changed. The specific assumptions for each source category are described below:

1. Mobile Sources (Transportation Vehicles). The emissions standards and the compliance schedule which must be met by mobile sources are presented in Section Two of this report (see Mobile Sources and State Transportation Control Plans). The assumed compliance dates reflect the delayed implementation of standards for reduced hydrocarbons and carbon monoxide emissions from light-duty vehicles from model year 1977 to model year 1978.

2. Stationary Sources (Existing). Stationary sources of air pollution (industrial plants, electric utilities) which existed at the time of passage of the Clean Air Act are regulated by approved State Implementation Plans (SIP's). The standards assumed for each industry and for utilities are given in the industry summaries in Section Two of the report. Most SIP's require compliance by July 1, 1975, but

achievement of this goal would imply a peaking of investment which did not occur in 1974 and 1975. Hence, except for sulfur dioxide control by electric utilities, all existing stationary sources are assumed to be moving toward full compliance at an extended expenditure rate, as given in the Summary for Section Two. A compliance date of January 1, 1981, is assumed for sulfur dioxide from utilities.

3. Stationary Sources (New). New sources of air pollution include new industrial plants built since the passage of the Clean Air Act and also existing plants which have made certain modifications in their facilities. These sources are assumed to comply with EPA New Source Performance Standards (NSPS) except where such standards have not yet been developed or where SIP standards are more stringent. In these latter two cases, SIP standards are assumed. New pollution sources are assumed to be in compliance with these standards when they go into operation. The exact standards being assumed are given in the appropriate sections in Section Two.

$bWater Compliance Assumptions$R

Unlike the Clean Air Act, the 1972 Amendments to the Federal Water Pollution Control Act prescribe full Federal regulation of water pollutant sources, except as redelegated to specified states. In addition to setting ambient water quality standards to be met by 1983, the act specifies the levels of control technology to be utilized by industrial and municipal pollution sources by July 1, 1977 and by July 1, 1983. EPA has defined these technologies for most major industrial pollution sources in effluent guidelines documents. It enforces the act through permit programs in 40 states, the remaining 10 having been delegated authority for state enforcement. The provisions of the act and the compliance assumptions for this report are enumerated below.

1. Industrial Sources.

   a. Industries discharging pollutants into the Nation's waters in 1972 will adopt the best practicable pollution control technology (BPT) by January 1, 1978, and the best available technology (BAT) by January 1, 1984. These dates have been pushed back six months from those specified in the act to allow the analysis for this report to be done on a calendar year basis.

b. Industries for which BPT and BAT are not defined in EPA guidelines are assumed to adopt control technologies similar to those of related industries covered by the guidelines. Specific control technology assumptions for water polluting industries investigated by this report are provided in Section Three.

c. Industries discharging their wastewater into municipal treatment plants must (and it is assumed they do) pretreat their effluents so that industrial pollutants do not interfere with plant operation and do not pass through the treatment process without adequate treatment. Pretreatment technology must be operating by January 1, 1978. Pretreatment is assumed to be unnecessary for those industries for which pretreatment guidelines have not been prepared.

d. All new sources of water pollution (usually plants constructed since 1974) are assumed to comply with EPA NSPS guidelines.

2. Municipal Sources.

Compliance with the Federal Water Pollution Control Act by all publicly-owned sewage treatment plants in existence on July 1, 1977, would require them to achieve a secondary treatment level for all effluents. Because of the current economic recession and the corresponding difficulty facing the municipalities in raising capital, treatment plants cannot be built at a fast enough rate to assure compliance with the act. Instead, it is assumed in this report that new plants will only be built as rapidly as permitted by Federal appropriations and state matching funds, which are proposed as shown in Table 4.

Table 4.
Direct Capital Outlays for Construction of
Publicly Owned Sewage Treatment Plants
(Federal, State, & Local)
(In Millions of 1973 Dollars)

	$t Fiscal Year	Calendar Year
1975	4,190	4,190
1976	4,182	4,190
Transition	1,260	N/A
1977	5,462	4,769
1978	6,212	5,691
1979	5,538	5,865
1980	3,925	5,017
1981	1,850	3,349
1982	1,100	1,829
1983	600	1,006
1984	600	662
1985	--	380

This "transition period" represents the months of July through September 1976; all subsequent Fiscal Years will run from October 1 through September 30 of the following year.$R

Section Three discusses in depth the relationship between these appropriated funds and the expenditures which would be necessary to comply with the act. It also considers the possibility of a $5 billion continuing appropriation after current appropriations expire.

These economic, energy, and compliance assumptions and other less quantifiable policy variables are further discussed in Section Four.

3. Elimination of Discharge.

Although Elimination Of Discharge (EOD) is specified as the goal of the Water Pollution Control Act, it is not currently required by regulations except for those industries where BAT is the same as EOD. Consequently, EOD is not assumed for the pollution control cost estimates appearing in this report.

$bPOLLUTION CONTROL COSTS: DEFINITIONS AND CALCULATIONS METHODS$R

The various costs presented in this report are described below, and the general approach used to estimate costs in each of three major categories is discussed. The three categories are direct costs, government program expenditures, and indirect costs.

$bDirect Costs$R

The expenditures associated with acquiring, owning, and operating the buildings and equipment needed to control pollution are direct costs. These costs are directly incurred by industries and municipalities to reduce pollutant levels; they include investment costs, operating and maintenance costs, and the costs incurred to borrow the necessary capital funds.

$bInvestment Costs$R

These costs include all expenditures for pollution control equipment and associated modifications or additions to buildings. They are the actual cash outlays used to purchase and install the equipment and to construct the buildings or building changes. In the case of municipal treatment plants, the cost of building the whole plant is a investment cost for pollution control. These costs do not include those charges made by a lending institution for borrowing the money, nor do they take into account the income tax writeoff benefits which accrue to an industry due to depreciation.

$bOperating and Maintenance$R

$b(O&M) Costs$R

The annual costs of operating and maintaining the pollution control equipment and plant include expenditures for:

1. Materials used by the equipment (e.g., chemicals)

2. Labor for maintenance and repairs

3. Energy

4. Materials for repairs

5. Overhead

6. Monitoring (labor)

7. Byproduct credits.

$bTotal Annual Costs$R

Total annual costs are those costs incurred each year by industry or government (municipalities) in owning and operating pollution control equipment and plants. They are the sum of the O&M costs for the year and the annualized capital costs for the year. Note that annualized capital costs are not the same as the investment costs discussed above. Annualized capital costs are derived by amortizing the initial investment over the life of the facility, and can be thought of so the annual amount needed to repay the loan with interest over a specific time period.

$bCosting Methodology$R

The direct costs of air and water pollution control are reported separately for each source and source category. For air pollution, the major source categories are: (1)Astationary sources, comprising industries, power utilities, and space heating; and (2)Amobile sources, namely, automobiles, trucks, and aircraft. The major source categories for water pollution are: (1)Apoint sources, which include municipalities, industries, and power utilities; and (2)Anonpoint sources, primarily run-off from urban areas and from mining and drilling operations, and agricultual crop production activities. Because nonpoint-source pollution control is a far more complex problem and an established regulatory procedure such as effluent permits is not yet developed and implemental costs for these sources could not be reliably estimated, and hence, are not reported in this document.

The details of calculating costs differ among the major source categories. In general, the procedure for each source is:

1. Examine the regulations to determine the emission or effluent standards to be met.

2. Select from the alternative technologies those pollution control methods that are likely to be employed.

3. Estimate the cost of using these methods for representative units (plants, vehicles, or run-off areas).

4. Multiply these unit estimates by the total number of such sources in the nation that are anticipated to require control in the appropriate year. Thus, for automobile emission controls, the cost of an individual

control system is multiplied by the total number of automobiles estimated to be sold in the appropriate year with that system.

This procedure, which is more complicated for industrial sources, is outlined below and is discussed more thoroughly in Section Four of this report:

1. Total industry production capacity is inventoried or estimated.

2. Unique production processes within the industry which emit differing levels of pollutants and/or require different control techniques are identified.

3. For each production process, the applicable abatement control technologies are identified and the percentage of plants using each technology is specified.

4. For each control technology associated with a given production process, the percentages of plants covered by different state implementation plans are estimated (for air control cost calculations only).

5. Usually from one to three typical plant sizes for each given implementation plan, control technology, and

production process combination within the industry are defined. (This combination is hereafter referred to as an industry segment.)

6. The capacity for the industry segment is allocated among the plant sizes, and capital and O&M costs are developed for a typical plant of each size in the segment, depending on the standard it must meet. (This depends in part on whether it is a new or existing plant).

7. The costs are applied to all plants of the same size within the segment; then costs for the different size classes are summed to obtain total capital and O&M costs for the segment. This is done for each segment of each production process within the industry. Control costs for the industry are obtained by totalling all the capital and O&M costs computed for the industry's segments.

The costs associated with building and operating municipal wastewater treatment plants for this report are directly related to the Federal appropriations and state matching funds available to build new plants. These costs have, however, been reported in five "Needs" categories. These categories relate to the Municipal Needs Survey (Final

Report to the Congress. "Cost Estimates for Construction of Publicly-Owned Wastewater Treatment Facilities", revised May 6, 1975) which was conducted in 1974 by EPA to determine the physical facilities needed by municipalities to adequately handle their sewage treatment problems; the categories are:

- Category I - Secondary Treatment Required.
- Category II - More stringent treatment required by water quality.
- Category IIIA - Correction of sewer infiltration/inflow.
  - IIIB - Major sewer rehabilitation.
- Category IVA - Collector sewers.
  - IVB - Interceptor sewers.
- Category V - Correction of combined sewer overflow.
  - VI - Treatment and/or control of stormwaters. Combined Sewers.

$bGOVERNMENT PROGRAM EXPENDITURES$R

Program costs which are incurred by governmental agencies in carrying out pollution control legislation include expenditures for planning, administration, enforcement, and research grants. These costs are incurred at all three levels of government: Federal, state, and local. The costs of constructing, operating, and maintaining control equipment owned by these governments are direct costs, and, as such, are included in the air and water program costs discussions in Sections Two and Three, respectively.

$bAir Program Costs$R

Government program costs for air pollution control have been estimated separately for Federal and non-Federal programs.

Federal programs involve two types of funds: grant funds, which are passed on to state and local governments; and in-house funds, which are expended by a Federal agency or by its contractors. Estimates of projected grant expenditures are obtained from the relevant agencies, primarily from EPA, which accounts for the vast majority (1973) of grant funds, and from the Appalachian Regional Commission and the

Department of Transportation, which account for most of the remainder. Estimates of projected in-house expenditures are based upon Fiscal Year 1974 outlays, Fiscal Year 1974-76 obligations, and forecasts of trends supplied by the relevant Federal agencies.

The basic procedure used for estimating program expenditures by state and local governments makes use of available data for 15 representative states. The estimated ratios of expenditures for various functional areas, such as enforcement and engineering, are first derived for these states and are then applied to all other states based on the similarity of industrialization, geography, population, and general air pollution control policies.

In general, sources of data for projecting government program costs for air pollution abatement beyond 1979 were not available. Instead, extrapolations were made from baseline data on the basis of several reports that provided forecasts of future government expenditures for specific program components.

$bWater Program Costs$R

The 10-year Federal water program expenditure projections are essentially the EPA's response to the Congressional Budget and Impoundment Act of 1974 (P.L. 93-344). The major assumptions underlying the 10-year projections are:

1. Future year estimates are a continuation of the budget year (Fiscal Year 1975) program level, except for statutory or other provisions which make the future year size of the program uncontrollable, and legislation or other provisions which clearly add a new component.

2. No new major legislative amendments will be made to the Federal Water Pollution Control Act.

As with the air program expenditures, Federal water program expenditures are divided into two general categories: Assistance Programs, which administer Federal grants: and Regulatory Programs, which include all other Federal administration and enforcement expenditures.

The 10-year state program expenditure projections are derived from the requirements under the 1972 Amendments of the states to issue permits, review construction grants, and monitor compliance. Permit costs are developed for each major category of activity. State agencies perform a variety of additional activities over and above those needed to comply with Federal requirements; the expenditures for these activities are not included here. In addition, there is no provision for program expenditures for nonpoint-source control activities.

$bIndirect Costs$R

Indirect costs are those experienced by government, business, or consumers as a result of having to bear the direct costs of pollution control. The added industrial costs for pollution control must either be passed on to the consumer in the form of increased prices or be absorbed by industry in reduced profits. Where investment requirements are high and profits are already low, some marginal plants might find it impossible to continue operation in the face of pollution control requirements. The resulting plant closures may thus result in local unemployment problems.

This report examines some of the indirect macroeconomic effects of pollution control at the national level. Thus, Section Four presents an analysis of the impact of control costs on aggregate production, investment, employment and other national accounts.

EPA's Office of Planning and Evaluation is currently engaged in a series of detailed economic impact analyses for six major industries: steel, electric utilities, non-ferrous metals, petroleum refining, chemicals, and pulp-and-paper. These studies, to be completed during Fiscal Year 1976, will cover the effects of current and proposed emission and effluent standards on prices, profits, production, productivity, plant closures, and employment for each industry, at both national and regional levels.

$bCOMPREHENSIVE ASSESSMENT$R

The primary reason for assessing the costs, benefits, and impacts of air and water pollution control resulting from Federal legislation and regulations in the same report is to make possible analysis of total impacts on the economy, including changes in the interrelationships among the various elements and sectors of the economy. Another consequence of the combined report is the capability of estimating the total pollution control costs for a single industry and their likely impact on that industry. For this report, a comprehensive, impact estimation and analysis system has been used to examine the comprehensive impacts of pollution control, at both national and industry levels. This system, the Strategic Environmental Assessment System (SEAS), is summarized in Section Four.

alternative assumptions about the future. A comparative analysis procedure is then used to assess the results. Scenario assumptions, scenario run results, and comparisons among scenarios are presented in Section Four.

As noted earlier, pollution control expenditures are not independent of the state of the economy. Similarly, the impact of these expenditures on the economy, the environment, and energy consumption depend on the initial assumptions made about the future in each of these areas. Hence, the objective in this report is not to predict exactly what the impacts of pollution control will be over the next 10 years, but rather to conditionally forecast their relative magnitude and interrelationships. The analysis focuses on how impacts vary as basic assumptions about future economic activity and energy policy are differentially changed.

The comparative analysis scheme used to assess the economic and environmental impacts of pollution control in this report takes into account that various experts may hold differing views about future U.S. economic growth, economic composition, and energy consumption. By exploring the impacts of a range of reasonable assumptions about the future, one is able, by this approach, to determine how sensitive the economy, the environment, and energy budgets are to alternative actions.

$bALTERNATIVE FUTURES$R

Assumptions for several alternative futures or scenarios are defined in Section Four of this report. These scenarios provide the basis for the comprehensive assessment of pollution control impacts on the economy and the environment also presented in Section Four. Although one forecast has been termed the Reference Case, it should not necessarily be interpreted as a prediction of the most realistic future. Rather, it is the benchmark or reference against which the comparative analysis was conducted. Assumptions for the Reference Case are essentially those enumerated earlier in this Introduction. They describe a high productivity/high growth-oriented economy where full employment is reached in the early 1980's.

Other alternative scenarios considered in Section Four are briefly described below.

1. The Low Productivity Scenarios. These scenarios are based on time series projections of labor productivity from 1952 to 1971 made by the developers of the INFORUM input-output model of the economy used in SEAS. They reflect a slowing down of productivity because of shifts toward service industries in the pattern of final demand, and because of a slowing down of the productivity increase rates in other industries. GNP estimates which correspond to these assumptions are shown in Table 5 compared with those for the Reference Case.

Table 5.
Comparison of GNP Estimates for Low Productivity and Reference Case Scenarios
(In Trillions of 1975 Dollars)

	Low Productivity GNP	Reference Case GNP
1975	1.53	1.47
1977	1.65	1.69
1980	1.84	1.99
1983	1.99	2.23
1985	2.08	2.40

2. The Energy Conservation Scenarios. These scenarios comprise a variation of the Reference Case in which energy consumption is reduced through selected conservation measures. It is based on the Federal Energy Administration's "Business-as-Usual with Conservation" scenario where the import price of oil is $11 per barrel. (See Appendix A1, page 46 of the November 1974 Project Independence Report_) The energy usage composition projected by Project Independence is not exactly matched because of differences in energy demand resulting from the redistribution of monetary savings to consumers.

Two scenarios are run and analyzed for each set of economic and energy-related assumptions. The first scenario in each case is used to develop a set of forecasts on the economy, industry output, environmental residuals, and energy budgets given no increase in pollution control beyond that present in 1971. The same parameters are then forecast in a second scenario, with pollution controls, costs, and equipment punchases superimposed on the original economic assumptions as necessary to comply with Federal legislation. This procedure results in six major scenarios:

Without Incremental With
Incremental Abatement Costs Abatement
Costs

Reference Case Scenario 1 Scenario 2 Low
Productivity Scenario 3 Scenario 4 Energy
Conservation Scenario 5 Scenario 6

The scenarios are then paried for a comparative analysis of relative impacts and tradeoffs in the following manner: (1,2) (1,3) (1,5) (2,4) (2,6) (3,4) (5,6). A subset of Scenario 2, which assumes a continuing appropriation of $5 billion a year for municipal sewage treatment facilities, is also compared with Scenarios 1 and 2. In addition to these analyses, which are presented in Section Four, Section One includes a study of the cost savings resulting from process change as compared with Scenario 2 control costs.

$aChapter 2$R

$aThe Benefits of$R

$aPollution Control Programs$R

Pollution control legislation has traditionally favored rigid standards, either to control the discharge of pollutants into air and water or to maintain ambient quality levels. While it was not possible to base such legislation on an analytical estimation of the full benefits that would result, its enactment reflected the judgement that the overall benefits to society were great enough to justify the necessary costs. Federal legislation also recognized the need for more elaborate and more accurate assessment of the costs and benefits of such programs, both for their implementation and for future consideration of additional legislation.

The purposes of such an assessment transcend the emphasis often given to the techniques for quantifying benefits and their numerical results, important though they may be. The purpose of cost-benefit analysis is to provide the type of information on the value of public investments that the market system provides on the value of private investments. However, public investments usually have many objectives in addition to those easily measured in dollars and cents.

Still, the process of logical and systematic scrutiny that is inherent in the accepted methods of cost-benefit analysis can contribute greatly to society's ability to improve its well-being by allocating more efficiently its limited resources.

Thus, a major purpose of this discussion and assessment of the national benefits of air and water pollution control is the achievement of a more precise understanding of the nature, sources, and approximate magnitude of such benefits. Such an understanding, when shared by legislators, program managers, and the public, may well be of greater value than the numerical results themselves.

$bDEFINITION OF BENEFITS$R

Benefits of controlling air and water pollution derive from the reduction of damages caused by air and water pollution. The measurement of benefits is performed in terms of the damages that would otherwise be incurred. A basic concept in benefit evaluation is willingness to pay, which can be defined as the highest price that individuals would be willing to pay to obtain the improvement in air or water quality resulting from a given pollution control program. Benefits are evaluated whenever possible in monetary terms because it provides a common measure of all the types of benefits and costs. The corresponding economic damages result in out-of-pocket losses caused by increasing the costs of using air and water, by decreasing the level of use of the resource, and by increasing costs of avoiding or repairing the effects of pollution.

Many types of benefits are not amenable to quantification in monetary terms because of their nature and the state of the art of available measurement methods. This is the case with "psychic" damages, so labeled because they relate to the pleasure or displeasure associated with the use of the air and water in our environment. Psychic damages include decrease or loss of pleasure from the use of air or water that has become polluted, and the increased experience of displeasure, pain, and anxiety, as well as the so-called option, preservation, and vicarious values experienced by non-users.

Option values arise because people are willing to pay to ensure the availability of clean air and water, even if they are uncertain when or how they would actually use it. Preservation values arise in a similar fashion, when people are willing to pay for the preservation of a resource, even when they are certain that they will never use it directly. Both preservation and option values are frequently associated with a unique environmental resource, for which no substitute exists. Preservation value can also be associated with risk aversion, in which a value is placed on the reduction in the probability of the loss of an environmental resource through extinction of a species or collapse of an ecological system.

Finally, the term vicarious satisfaction has been used to describe the motivation of people who are willing to pay to provide benefits for their fellow citizens rather than for themselves, and bequest value describes the similar benefit derived by individuals preserving an environmental resource for future generations. Although all these psychic values and the corresponding damages caused by pollution are currently not easily measured, they apparently account for a significant portion of the total value of pollution control to society.

In general, estimation of benefits resulting from alternative pollution control programs calls for four steps:

- Estimate the amounts of pollutants produced by projected economic activity.

Estimate the remaining discharge of pollutants to the environment after imposition of specified control measures.

- Estimate the ambient air or water quality that results from the diffusion and assimilation of pollutants by the environment.

- Estimate the nature and magnitude of resultant reduced damages and the corresponding benefits.

The first two steps involve the projection of a suitable economic scenario and evaluation of the cost-effectiveness of various administrative and technological pollution controls. The third step requires the use of complex models of the diffusion and assimilation of specific pollutants. The last step relies on the development and interpretation of dose-effect factors or damage functions, which are discussed in the next section.

Finally to the extent that they were developed for specific cases, estimates must eventually be aggregated over the pollutant/effect combinations, geographic regions, and time periods of interest.

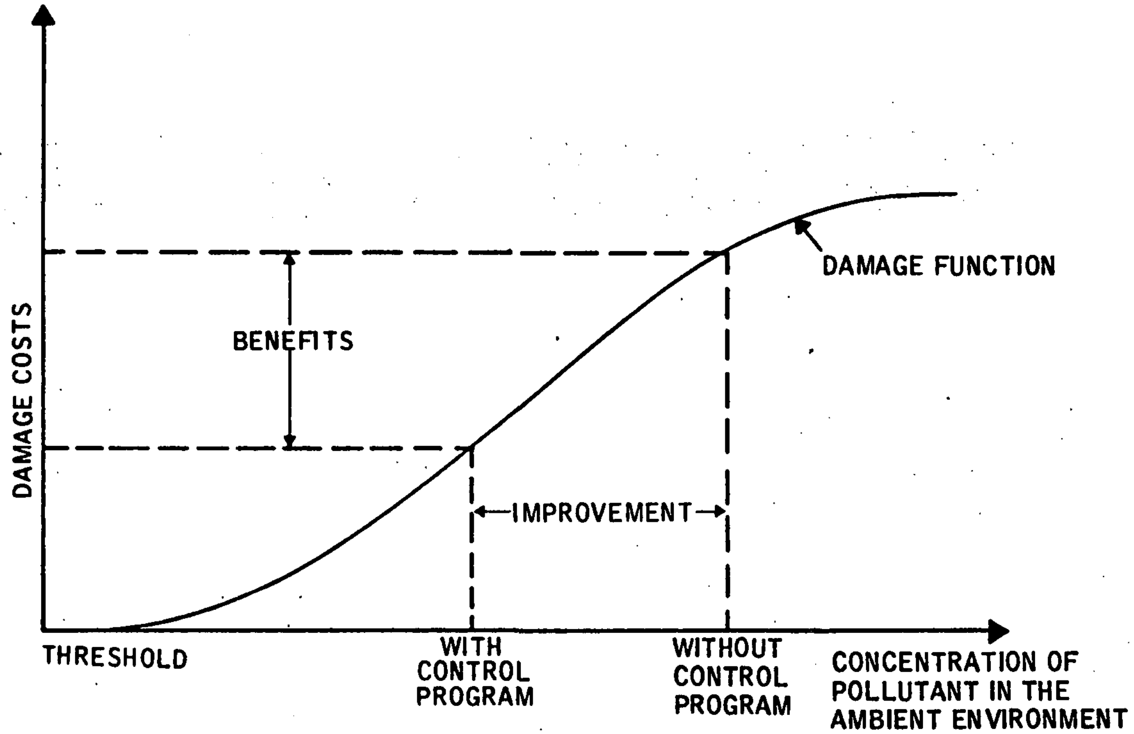
$bPHYSICAL AND ECONOMIC$R

$bDAMAGE FUNCTIONS$R

A damage function is the quantitative expression of a relationship between exposure to specific pollutants and the type and extent of the associated effect on a target population. Exposure is typically measured in terms of ambient concentration levels and their duration, and it may be expressed as "dosage" or "dose". The former is the integral of the function defining the relationship between time and ambient level to which the subject has been exposed. Dose, on the other hand, represents that portion of the dosage that has been instrumental in producing the observed effect (e.g., the amount of pollutants actually inhaled in the case of health effects of air pollution).

The effect can become manifest in a number of ways and can be expressed in either physical and biological or economic terms. If the effect is physical or biological, the resultant relationship is known as a physical or biological damage function, or a dose-effect function. On the other hand, an economic damage function is expressed in monetary terms. Economic damage functions can be developed by assigning dollar values to the effects of a physical or biological damage function, or by direct correlation of economic damages with ambient pollutant levels. A representative economic damage function, showing the benefits corresponding to a given improvement in environmental quality, is presented in Figure 1.

Figure 1.
Damage Function



The S-shaped damage function is rather characteristic of the relationships between pollutant exposure and resultant effect. The lower portion of the curve suggests that, up to certain pollutant ambient values, known as threshold levels, there are no measurable damages, while the upper portion indicates that there is a saturation level (e.g., death of the target population), beyond which increased pollutant levels do not produce additional damages. Between these segments is a range where damages are roughly proportional to the concentration of pollutants.

In reporting a damage function, one must specify the pollutant, the dose rate, the effect, and the target population, or the population at risk. Dose rate, or the rate at which ambient concentration varies with time, has a major influence on the nature and severity of the resultant effect. Long-term exposure to relatively low concentrations of air pollutants may result in manifestations of chronic disease, characterized by extended duration of development, delayed detection, and long prevalence. On the other hand, short-term exposure to high concentration levels may produce acute symptoms characterized by quick response and ready detection. Characterization of the population at risk is considered in more detail in subsequent paragraphs of this discussion.

The two principal techniques for analyzing the relationship between exposure and effect indices necessary to construct a damage function are known as multivariate regression and nonparametric or distribution-free estimation. Multivariate regression is by far the favored technique because it provides a rapid indication of the degree of association between a large number of independent and dependent variables and is readily programmable for computer operation. However, its validity is heavily contingent on a fairly precise a priori definition of the relationship between each independent and dependent variable, and on precise measurement of the independent variables. Thus, this technique is especially vulnerable to the poor precision in measurement and reporting of air pollution levels for a given segment of population. Nonparametric estimating is free of these assumptions, but it calls for laborious data reduction for each of the many pairs of independent and dependent variables, and expert judgement to guide each step of the process. Moreover, this technique requires sufficient data for each independent variable to isolate and remove the influence of likely interfering factors.

The data required to construct damage functions can be obtained by the following approaches:

- Epidemiological or field studies and observations
- Toxicological or laboratory investigations
- Market studies
- Delphi method
- Public opinion surveys
- Legislative decisions
- Litigation surveys.

The first two approaches are attuned to physical damage functions, while the remaining ones are directed toward derivation of economic relationships.

The first approach involves the comparative examination of the effects of pollutants on large segments of population exposed to different levels of pollution in order to deduce the nature and magnitude of the likely effect. Field studies and observations represent the same approach to assessment of effects on animals, vegetation, and materials, and they are characterized by similar analytical techniques and concerns. Toxicological studies involve deliberate administration of controlled doses of pollutants to animal subjects, followed by observation of the resulting effects. Laboratory studies represent essentially the same approach for determining effects of pollutants on plants and materials.

Two considerations need to be noted about epidemiological and field studies. First, it is very important to remove or control the influence of factors other than pollution that may be responsible for the different effects observed. In the case of health effects, for example, these include physiological, genetic, and other characteristics of the population under observation, such as age, sex, race, family medical history, occupational exposure, medical care, state of health, and nutrition. When these characteristics cannot be factored out, it is frequently assumed that their distribution is sufficiently uniform in the populations under observation that the basic results are not affected significantly. Secondly, epidemiological and field studies and observations can only indicate an association between exposure to pollution and the observed effect, though the impact of an association can be strengthened considerably through evidence of consistency and specificity of the relationship. A causal relationship can be demonstrated, or made plausible by toxicological and laboratory studies, or by the construction of a plausible connective mechanism.

Market studies, such as those investigating differences in property value or income, employ prices or wages as an indication of the values affected by pollution, and their usefulness has been demonstrated in a number of cases. This approach is heavily dependent on the investigator's ability to identify and isolate the many other factors that affect the value of property, or other indicators used. In the Delphi method, the knowledge of a diverse group of experts is pooled for the task of quantifying variables that are either intangible or shrouded in uncertainty. This method provides an efficient way to obtain subjective, but informed, judgements. Thus, in a recent project, the California Air Resources Board under EPA sponsorship constructed a number of dose-response functions based on expert opinions submitted by a group of clinicians and other health effects researchers.

Surveys of public opinion focus on estimating indivudal preferences and demands. Such surveys have been particularly helpful in understanding how attitudes about pollution are formed and affected by changes in environmental quality. They can also provide an indication of what people may be willing to pay for enhancement of environmental quality, or perhaps, what their preference might be for the reduced risk of experiencing certain adverse effects. Surveys of legislative decisions or litigation awards can also provide some insight into the perceived value of pollution abatement.

$bPOPULATION AT RISK$R

In the past, it was customary to assess the severity of air pollution in terms of point-source emissions, and later, in terms of ambient concentrations. These indicators reflected the progression in the state of the art from visual assessment of smoke plumes to increasing availability of air quality monitoring stations and associated data processing capabilities. However, the real significance of air pollution lies in its physical, economic, and social impact on the affected population.

Beyond this, characterization of the population at risk in terms of its potential susceptibility to various levels of air pollution can provide useful indications for allocation of resources and setting of priorities in air pollution abatement. For example, a higher clean-up priority could be assigned to an area containing a large population of older people or those exposed to high occupational pollution than to another area with a smaller population of relatively healthy people not otherwise exposed to harmful pollutants. This procedure can be refined further through control of specific pollutants.

Since the importance of characterizing the population at risk to various levels of air pollutants became recognized, there have been several attempts to obtain such a characterization through crude regional estimates. The first comprehensive, national assessment was only recently completed. The major assumptions and findings of this study are summarized here.

The specific objective of the population at risk study was to calculate the number of people in selected demographic and socioeconomic classes who are exposed to various levels of several air pollutants. This was accomplished in six steps:

- Select air quality indices
- Select population indices
- Select air quality and population coverage units
- Obtain and process air quality data
- Obtain and process census data
- Calculate population at risk.

The pollutants selected were total suspended particulates, sulfur dioxide, nitrogen dioxide, carbon monoxide, and photochemical oxidants. The air quality indices were expressed in terms of the relationships of pollutant ambient levels to their corresponding short-and long-term primary standards. They were divided into four classes: 0-75 percent, 75-100 percent, 100-125 percent, and above 125 percent of the corresponding primary standard. In the case of short-term standards, the 90th and 99th percentiles of the observed values were found to be more useful indicators than the maximum values.

Human susceptibility and resultant response to toxicological and physical stress produced by air pollutants is determined somewhat by certain intrinsic traits, such as age, race, sex, and general health, as well as by such extrinsic characteristics as employment, income, educational level, and general environmental conditions. The population classes selected for our study are listed below:

$t

- Age:
  - Under 19 years
  - 20-64 years
  - 65 years and over
- Race:
  - White
  - Negro
  - Other
- Employment:
  - Manufacturing
  - Other
- Family income:
  - Under $5,000
  - $5,000-$24,999
  - $25,000 and over$R

Although population information from the U.S. Bureau of the Census is available for the entire country, air quality data, stored in EPA's National Aerometric Data Bank, are not. The gaps occur in the form of specific pollutants, the short-term or long-term values, or missing stations. Consequently, this study dealt with 241 standard metropolitan statistical areas (SMSAs), which cover 68.6 percent of the population and 11.0 percent of the land area of the United States. Pollutant ambient levels in these areas were derived by plotting isopleths (equal concentration contours) between air quality monitoring stations and by superimposing this display over maps of the SMSAs. The year of coverage for air quality data was 1973, though the population information was based on the 1970 U.S. census.

Finally, the population at risk was computed within each pollutant and population class, and aggregated to state, regional, and national levels. The results are displayed in tables of population versus air quality classes for different combinations of pollutants and geographic locations. The national aggregations for all five pollutants are presented in Tables 1 through 5.

The study concluded that the exposure of the U.S. population surveyed to short-term particulate, short and long-term sulfur dioxide, and short-term carbon monoxide levels was within the respective permissible primary air quality standards. On the other hand, significant portions of the population surveyed were exposed to excessive long-term particulate (31 percent), long-term nitrogen dioxide (24 percent), and short-term oxidant (58 percent) levels.

Table 1.

Population Characterized by Socioeconomic and Demographic Factors Exposed to Total Suspend Particulates

(1,000 persons)

Area: United States

Air Pollutant: Total Suspended Particulates

Air Quality Index: Short Term - 90th percentile of 24 hour data
Long Term - Annual geometric mean

Population Characteristics	Air Quality Level Classes - $\mu g/m^3$									
	Short Term					Long Term				
	< 200	201-260	261-320	321-450	> 451	< 60	61-75	76-90	91-120	> 121
A. General										
Age: 0-19	47,859	2,004	471	142	105	19,889	10,631	7,054	4,640	2,758
20-64	68,487	2,717	631	205	139	28,434	16,684	8,350	6,802	4,006
65 and over	11,644	462	116	44	19	4,442	2,874	1,650	1,195	670
Race: White	110,532	4,261	904	325	214	47,564	25,309	13,763	10,385	6,443
Negro	14,836	859	301	58	47	4,537	4,553	3,005	1,992	808
All other	1,672	63	13	8	2	664	327	286	260	184
B. Economic										
Annual family income: (thousands of families)										
$0-$4,999	5,271	265	66	22	13	1,768	1,313	812	621	324
$5,000-$24,999	25,093	963	224	68	52	10,644	6,027	3,220	2,187	1,644
$25,000 and over	1,876	50	8	3	1	954	408	196	141	111
C. Labor Force										
Percentage in manufacturing	25.4%	26.6%	28.5%	24.8%	19.1%	26.2%	25.1%	27.2%	26.9%	24.0%
D. Total Population	127,990	5,183	1,218	391	263	52,765	30,189	17,054	12,637	7,435

Table 2.
Population Characterized by Socioeconomic and Demographic Factors Exposed to Sulfur Dioxide
(1,000 persons)

Area: United States

Air Pollutant: Sulfur Dioxide

Air Quality Index: Short Term - 90th percentile of 24 hour data
Long Term - Annual arithmetic mean

Population Characteristics	Air Quality Level Classes - $\mu g/m^3$							
	Short Term				Long Term			
	< 280	281-365	366-420	> 420	< 60	61-80	81-100	> 100
A. General								
Age: 0-19	49,283	62	2		37,403	399	167	1
20-64	70,412	93	3		53,534	566	214	1
65 and over	12,174	19	1		8,887	118	29	0
Race: White	113,073	161	3		83,921	928	393	2
Negro	16,032	12	3		13,133	145	15	0
All other	1,755	1	0		1,760	10	2	0
B. Economic								
Annual family income: (thousands of families)								
\$0-\$4,999	5,457	6	1		4,057	43	13	0
\$5,000-\$24,999	25,848	37	1		18,394	205	80	0
\$25,000 and over	1,932	2	0		1,554	14	5	0
C. Labor Force								
Percentage in manufacturing	25.4%	43.0%	14.5%		25.2%	23.7%	26.2%	38.9%
D. Total Population	131,869	174	6		99,824	1,083	410	2

Table 3.
Population Characterized by Socioeconomic and Demographic Factors
Exposed to Carbon Monoxide
(1,000 persons)

Area: United States

Air Pollutant: Carbon Monoxide

Air Quality Index: Short Term - 99th percentile of one hour data

Population Characteristics	Air Quality Level Classes - $\mu g/m^3$			
	< 30	31-40	41-50	> 51
A. General				
Age: 0-19	37,356	246	242	191
20-64	54,394	420	407	292
65 and over	9,217	88	89	60
Race: White	86,944	606	509	452
Negro	12,257	127	183	47
All other	1,766	21	46	44
B. Economic				
Annual family income: (thousands of families)				
$0-$4,999	4,536	33	42	32
$5,000-$24,999	19,788	149	137	84
$25,000 and over	1,610	13	6	3
C. Labor Force				
Percentage in manufacturing	24.7%	13.9%	25.0%	31.7%
D. Total Population	100,967	754	738	543

Table 4.
Population Characterized by Socioeconomic and Demographic Factors Exposed to Nitrogen Dioxide
(1,000 persons)

Area: United States

Air Pollutant: Nitrogen Dioxide

Air Quality Index: Long Term - Annual arithmetic mean

Population Characteristics	Air Quality Level Classes - $\mu g/m^3$			
	< 80	81-100	101-125	>125
A. General				
Age: 0-19	6,268	1,697	2,223	220
20-64	9,034	2,470	3,374	460
65 and over	1,421	472	554	90
Race: White	15,024	3,649	5,364	535
Negro	1,195	966	577	183
All other	504	24	210	52
B. Economic				
Annual family income: (thousands of families)				
$0-$4,999	659	193	243	35
$5,000-$24,999	3,302	905	1,100	139
$25,000 and over	226	63	104	21
C. Labor Force				
Percentage in manufacturing	23.1%	30.1%	26.9%	27.0%
D. Total Population	16,723	4,639	6,151	770

Table 5.
Population Characterized by Socioeconomic and Demographic Factors
Exposed to Oxidants
(1,000 persons) $s

Area: United States

Air Pollutant: Oxidants

Air Quality Index: Short Term - 99th percentile of one hour data

Population Characteristics	Air Quality Level Classes - $\mu g/m^3$			
	< 120	121-160	161-200	> 200
A. General				
Age: 0-19	11,262	6,011	11,326	10,726
20-64	15,900	7,128	16,945	15,306
65 and over	2,630	1,205	3,061	2,424
Race: White	24,909	11,690	26,378	25,008
Negro	4,149	1,576	4,540	2,889
All other	734	178	413	560
B. Economic				
Annual family income: (thousands of families)				
$0-$4,999	1,116	561	1,357	1,073
$5,000-$24,999	5,911	2,592	6,074	5,616
$25,000 and over	458	167	530	421
C. Labor Force				
Percentage in manufacturing	24.0%	21.2%	22.0%	21.3%
D. Total Population	29,792	13,444	31,333	28,455

$bPROBLEMS OF MEASUREMENT$R

Assessment of benefits of pollution control is beset by a number of major difficulties that have a profound effect on the accuracy and reliability of the benefit estimates. Some of these difficulties can be largely overcome with the aid of available ancillary information, while others require the expenditure of much additional effort. Still others must be dealt with by indirect estimation and other imprecise techniques. The more important problem areas may be listed as follows:

- Collection of reliable ambient quality data
- Selection of exposure indices and identification of synergistic effects
- Selection of representative populations
- Measurement of effects
- Establishment of causal relationships
- Presentation of non-quantifiable information
- Regional, demographic, and temporal extrapolation
- Consistent classification of damages
- Double-counting and omission of damages
- Assessment of damage reductions.

Collection of sufficient air and water ambient quality data requires a very large number of measuring stations and a commitment to measurement and data handling well in excess of the present level, because the problem concerns numerous point and nonpoint sources of pollutants discharging at irregular intervals into air and water. Consequently, the available data seldom reflect hourly, or even diurnal variations that may be important.

Collection of useful data on damages and their proper attribution to exposure to specific levels of various pollutants suffers from several handicaps. One is the problem of selecting the proper exposure index for each pollutant in terms of level, duration, and presence of other pollutants, or influence of meteorological and hydrological factors. Another is the need to select sample populations that are representative of the population at large in terms of susceptibility to detectable levels of damage. In the case of health effects, this involves segregation based on demographic and socioeconomic makeup of the population at risk.

A third difficulty lies in measuring the resultant effects. This is especially problematic in the case of psychic damages, such as those associated with health, recreation, aesthetics, option, and preservation values. Such damages are not adequately assigned costs by the market system because they are aspects of environmental use that are not owned privately or exchanged. Thus, estimation of the corresponding benefits requires development of proxy or surrogate measures.

The fourth and most formidable problem involves identifying and documenting a causal relationship between exposure to a given dose and production of a specific effect and deriving the corresponding damage function. The existing literature contains estimates for only a few discrete points on the many damage functions of interest. In order to produce national benefit estimates, it is frequently necessary to make major assumptions about the shape of the damage curve on the basis of these few points.

Most studies leading to the evaluation of damages resulting from exposure to various pollutants address a specific geographic area, population, and time frame. Extension to the national level and a more recent time frame requires extrapolations of ambient levels, population at risk, personal income, and increases in costs of resultant damages due to inflation. The classification of damages, for which the data are collected, is often dictated by availability of sources and analytical expediency, rather than a uniform and self-consistent framework. Consequently, different studies evaluate damages that are not necessarily additive or even comparable, and any effort to reconcile or aggregate the results of such studies must apply careful interpretive techniques to prevent gross overlaps or omissions of damage estimates. Moreover, in aggregating such fractional results, it is not currently possible to reflect the potential impacts of changes in one pollutant or one region on the damages caused by other pollutants or in other regions, nor has it been possible to reflect the impact of the general adjustments the economy would make to pollution control programs and the resulting reduction in damages.

Finally, with effective abatement, the estimate of benefits associated with a given level of pollution control can be expressed in terms of the corresponding reduction of damages. This step, in turn, requires the definition of a quantitative relationship between reduced emissions and resultant ambient levels, as well as between these improved ambient levels and reduced damages. Development of pollutant transport and dispersion models describing the first set of relationships has been only partly successful because of the many ill-defined variables involved. Thus, it is commonly assumed that the fractional decrease in ambient levels is essentially proportional to the fractional reduction of emissions. The second set of relationships is defined by the damage functions discussed earlier. The unit damages obtained from a damage curve are converted to total damages through multiplication by the number of units at risk and the cost-per-unit damage, as appropriate.

Thus, assessment of benefits associated with a given level of pollution control is still most assuredly an art, which permits divergent interpretation of available data that may lead to widely differing results.

For this reason, although certain studies on air and water pollution damages are cited in Section Two and Three, national aggregate damage estimates are not presented in this report.

$aChapter 3

Pollution Control Cost Reduction

Through Process Change$R

$bINTRODUCTION$R

Opportunities for air and water abatement cost reduction through process change were identified for 40 industries. Five industries were examined in detail: copper, aluminum, pulp and paper, petroleum, and inorganic chemicals. Using Reference Case abatement costs developed in Sections II and III as a baseline, the extent of reduction achieveable through specific process change candidates in each industry was determined. The relative savings in accumulated capital expenditures through 1985 in the five industries are: 14.5 percent, 9.6 percent, 10.1 percent, 12.0 percent, and 2.5 percent. The analogous savings in annualized costs for 1985 are: 35.0 percent, 11.0 percent, 28.5 percent, 24.0 percent, and 25.0 percent. When these savings are assessed in terms of their applicability to opportunities in the other 35 industries, the total capital and annualized cost reductions for all 40 industries relative to reference case abatement costs are estimated to be (in million dollars and percentage reductions): $197, (-1.2 percent) and $211, (-9.9 percent).

$bImpact of Process Change Upon
the Cost of a Clean Environment$R

Pollution control legislation and associated effluent guidelines require that industry attain specific levels of pollutant control. The mechanism for achieving these levels is left to the discretion of each industry. The simple approach is to add treatment steps to the process at the points of waste emission, which are termed end-of-pipe control. The costs associated with these end-of-pipe (EOP) steps furnish an economic motive for waste-reduction process changes. If a net abatement cost reduction can be achieved through process change relative to that process or a competing process employing end-of-pipe treatment, an incentive for process change exists. This concept is evidenced in the generic types of process change in the more advanced standards (BAT, BPT, NSPS). For example, process changes designed to reduce water requirements, permit greater water reuse, and minimize leaks and spills are included in the compliance strategies recommended in the EPA effluent guideline development documents; considerable evidence exists to indicate such potential. Exemplary plants in many industries do operate at much higher efficiencies than the corresponding typical plants, and plant modernizations have been able to substantially improve abatement efficiency at a reasonable cost. In this discussion, emphasis is placed upon assessing the cost reductions achievable through process changes other than those not included in the Reference Case of Section Four.

A number of important distinctions must be made. There are important differences between what can be achieved in a new plant as compared with the upgrading of an existing facility. In some instances, it is less costly to abandon an existing facility and build a new one than it is to convert the older facility. In such a case, nearly all capital associated with the abandoned plant must be forfeited. When conversion of the existing facility is reasonable, the capability to do so may be unevenly spread across the industry. The larger firms have both greater technological capability and financial reserves than the smaller firms. Thus, even a technologically-feasible retrofit process change may have considerable economic impact.

Such economic considerations are well known. They are restated here to emphasize their importance in assessing process change as a method of reducing end-of-pipe treatment requirements. A final general comment of this type pertains to tax considerations. If a tax benefit is granted EOP-type investment and not those related to process change, there is an incentive to pursue the former course.

This discussion identifies the type of savings that may be achieved through process change. The estimates made are intended to be indicative rather than exact; i.e., the analysis objective is to establish reasonable bounds between which the impact of process change can be evaluated. The reference cases for comparison are the industry costs established in Sections Two and Three of this report. The measure of the economic benefit from the process change is the extent to which the pollution control savings relative to the Reference Case exceed the costs incurred in the process change. The industry-wide savings are derived by identifying the extent of industry acceptance of the designated process change.

$bEffect of Environmental Standards
on the Rate of
Process Change$R

In considering the effect of environmental regulations on industry's acceptance of process change, it must be remembered that this relationship takes place within the framework of industry's overall investment decisions. Most industries have a tacitly expressed, minimum acceptable rate of return. Below this level, investment is not believed to enhance a company's financial position, and other considerations, such as liquidity, may predominate. Whether or not sufficiently lucrative opportunities exist often depends on the investment climate, which in turn may be heavily influenced by interest rates, current market behavior, etc. Even under favorable investment conditions, corporations have limited capital resources. Consequently, they must select among investment options, seeking the opportunity most likely to bring a high, reliable return on venture capital.

Comparison of investment opportunities is conducted on the basis of comparative profitability. A piece of equipment, like a furnace, will process a given product throughput over a specified lifetime. The value of this production, based on projected prices, is compared against the capital outlays required to build and operate the unit; ancillary costs and benefits must be included in this comparison. An existing furnace has an established set of operating specifications: energy requirements, recovery efficiency, etc. If the challenging process can reduce energy needs, the operating savings that result are included in the profitability comparison.

In addition, an attempt should be made to assess the "venture risk" involved in the investment; an example is a shoe manufacturer's investment in a line of ski boots. The investor understands that an unseasonally warm winter might cut his sales prospects in half. This estimate of risk is taken into account in determining the desirable rate of return. Venture risk similarly applies to the introduction of new processes, where the firm takes a risk that the process will not live up to expectations.

In a highly competitive market, the costs associated with end-of-pipe control may be so high that firms cannot pass them on as higher prices without losing competitiveness. These plants must either develop alternative control strategies that can be implemented at an acceptable level of cost, or close their doors. In these cases, in-plant controls can truly be said to be environmentally inspired.

However, environmental regulations can also indirectly affect investment decisions by altering the profitability of certain options. Existing facilities will have additional capital and operating costs associated with end-of-pipe treatment of its wastes, assuming compliance with environmental standards. In-plant changes that reduce treatment costs will be treated like any other benefit in profitability calculations.

Abatement costs can affect the process trends that would have developed in the absence of environmental considerations in a variety of ways. The additional cost can tip the scales in favor of a project that was formerly less profitable. Alternatively, it can further improve the profitability of an already preferred investment opportunity, thereby accelerating its rate of acceptance by the industry. It is important to realize that in both these events the environmental regulations are only one of several motivating factors; the abatement savings are not usually sufficient to justify investment unless other advantages are gained as well. This fact becomes relevant when allocating the portion of cost savings attributed to the environmental regulations.

On the other hand, environmental investments do involve one special circumstance that vitally increases their importance. Traditional decisions on an investment, such as capacity expansion, offer a firm three choices: expansion using proven technology, expansion using a challenging process, or no expansion. By law, abatement decisions do not permit the third path of inaction to be taken; either an alternative abatement strategy must be found, or the present plant abated through end-of-pipe methods. Furthermore, expenditures on equipment with the sole function of control yield no direct economic return to the corporations. Consequently, firms may be receptive to strategies that can attain abatement objectives while in some way improving the processing efficiency of the plant.

Before proceeding, two cases should be noted in which environmental regulations do not affect general process trends. The first case is where little difference exists between the abatement costs for the two processes. If a relatively new process is only marginally more profitable after subtracting venture risk than the established technology, most companies will retain the proven profit-maker. This is important in the present discussion because the time frame in which alternatives to EOP treatment can be undertaken is very short. In the second case, a process that has to pay much higher abatement costs may remain more profitable than its competitor. In this case, the "dirtier" process will continue to be substituted for the "cleaner" process. This process change will have the effect of increasing total industry abatement costs.

$bTypes of Process Change$R

A survey was conducted within 29 polluting industries to identify those process changes that have significant pollution treatment implications. Three major categories of process change were found: material changes, process modification, and process substitutions. An additional and important type of change exists that, while not associated with a specific process, affects the control costs for each process. These are plant-wide changes, such as housekeeping, coordinated water usage by a set of processes to achieve a net reduction in water usage, etc. In the following discussion, plant-wide changes are addressed in terms of their effect on individual processes.

$cMATERIAL CHANGES$R

Material changes include modifying the nature or quality of raw materials employed or adjusting the specifications of the product produced. For example, use of natural Trona as a source of sodium carbonate obviates the large quantities of waste generated by Solvay process synthesis of sodium carbonate from salt and limestone. Likewise, use of rutile rather than ilmenite in the production of titanium dioxide significantly reduces waste quantities. Alternatively, synthetic rutile can be generated by pretreatment of ilmenite. Recycled or secondary material inputs are also important. For example, increased aluminum recycling circumvents the waste produced during bauxite processing. An example of a product specification change is the incorporation of a portion of process waste sludge in paper products not requiring high brightness.

Often, material changes are made on the basis of economic considerations related to materials availability. For example, domestic bauxite is of lower quality than bauxite imported from Jamaica, Surinam, or Australia; hence, the majority of bauxite consumed in the United States each year is imported. However, if the countries of origin are able to establish a higher bauxite price, the domestic alternative will appear more desirable. Such a change in material input will affect the nature and increase the quantity of wastes generated. Another example relates to the use of rutile in titanium dioxide production, as already discussed. Rutile, possessing a higher titania content, is predominantly imported from Australia, while large quantities of ilmenite ore exist in the United States. An adjustment could be made in the event rutile became either hard to obtain or highly priced. Again, the nature of the waste stream would change.

Crude oil quality also varies with its point of geographic origin. For example, Middle Eastern crudes have a higher sulfur content than domestic crudes, and the percentage usage of the former is increasing. Meanwhile, restrictions on the sulfur content of fuel oil for consumer use require that the refinery, which is now dealing with additional sulfur in its primary raw materials, reduce the sulfur content in its final product. This change in product specifications directly affects the amount of processing required, and, hence, the pollution-control related costs.

Environmental considerations are only one of the factors impinging upon the selection of raw material type. Nevertheless, the nature of the raw material utilized can have a direct effect upon the costs of pollution abatement.

$cPROCESS MODIFICATIONS$R

Three types of process modification were identified: revised process operation, byproduct recovery, and process-specific waste treatment.

1. Revised Process Operation. This category includes those process modifications made in an effort to improve process economics. The principal attribute is that in some way the efficency of the central reaction is improved, i.e., greater quantities of the desired products and lower quantities of pollution are generated per unit of input material. This may be accomplished by changing the temperature or pressure of

the reaction, extending or shortening the residence time, improving reactant mixing, introducing a more stable catalyst, increasing recycle quantities, reducing water use, or invoking real-time computer control. In some cases, optimal process operation when pollution control is required will differ from that when such control is not required. Usually, a complex linear programming scheme is required to balance the many factors involved in identifying the optimal performance, and this determination is strongly affected by the character of the input materials, as previously discussed.

2. Byproduct Recovery. The recovery of a salable material from the process waste stream is an obvious and often mentioned method of simultaneously reducing the waste load and at least partially compensating for the costs involved. However, the opportunity to profitably sell such recovered materials is sometimes elusive. An extreme example is the recovery of sulfur and its various compounds as pollution control. The marketplace may be unable to accommodate the quantities of sulfur to be made available. Hence, extraction of sulfur from the air and water waste stream could merely serve to transform the sulfur into a more readily-controlled solid waste. Attempts are underway to

expand the market for sulfur compounds by identifying new applications, but there may be limits to the amount of market expansion possible.

In many cases, recovered material can be put to profitable use. Frequently, the application is an in-plant use of the recovered material to perform a function that previously required a purchased input, (e.g., heat and fiber reuse in the paper industry). In addition, industrial complexes are beginning to cooperate in using each others waste streams when a desired attribute is present.

3. Process-Specific Treatment. This process modification is the treatment of process waste prior to merging it with the waste streams of other processes for end-of-pipe treatment. In general, the process waste must have some specific attribute that necessitates a unique treatment step; otherwise, the economies of scale associated with end-of-pipe treatment prevail.

Process Substitution. Process substitution is differentiated from process modification in that a fundamental change is made to the central reaction step. For example, going from the mercury cell to the diaphragm cell in chlorine production and from the open-hearth to the basic-oxygen furnace in steel production are process substitutions. For comparison, changing the reaction conditions, enlarging the reactor, or adding ancillary process equipment are process modifications.

Process substitutions are an extremely important process change category in terms of their effect upon pollution control requirements. A recent study of solid waste generation showed that for 17 of the 34 largest producers of process solid waste among industrial chemicals, a process substitution was underway or had already taken place. In each case, the amount of solid waste generated was reduced. As process efficiencies are improved, the yield of the main product goes up and the quantity of waste generated correspondingly goes down. In addition, the remaining wastes tended to be easier to treat. Usually, wastes associated with the raw materials can be segregated with comparative ease. The ones produced during the principal reaction, however, are generally closely associated with the main product, and hence, are more difficult to separate.

$bCOSTING METHODOLOGY$R

The Industry Survey analysis, which appears later in this discussion, disclosed a number of promising process change opportunities. These opportunities were evaluated to determine the extent to which such process changes can be expected to reduce pollution control costs relative to the Reference Case, primarily an end-of-pipe approach. To do this, five representative industries were selected that together illustrate the various modes of process change. Specific process change candidates, ranging from the modification of a single processing step to replacement of an entire process, were examined. For each challenging and defending process, total unit costs (process + end-of-pipe) were calculated. The capital requirements and annualized costs of the changed operation were compared with costs developed for the Reference Case discussed in Section Four.

$bCosting at the Unit Level$R

A new process may be related to existing operations in one of three ways:

1. It can be basically interchangeable with part of the existing plant, with potential for both retrofit and new plant applications. (Examples: Continuous and batch digesters, oxygen paper processes, flash and reverberatory furnaces.)

2. It can be basically incompatible with in-place facilities and represent an alternative for new capacity only. (Examples: Hydrometallurgy, dry forming of paper.)

3. It can be basically additive in nature, with no unit serving a comparable function in the present process scheme. (Examples: Byproduct recovery units, spill containment systems.)

Each of these relationships calls for a different type of comparison of basic process costs. Table 1 diagrammatically represents the basis for comparison in each of these situations.

Table 1.
Nature of Process Cost Comparisons

$t

			Relevant Cost Parameters		
			Old Process	vs.	New Process
1.	Interchangeable Processes	Retrofit Application	O&M		Capital, O&M
		New Plant Application	Capital, O&M		Capital, O&M
2.	Alternative Processes		Capital, O&M		Capital, O&M
3.	Additive Processes		None		Capital, O&M$R

Values for capital, operating and maintenance (O&M) and annualized costs were obtained from available engineering cost estimates. Capital costs represent the installed costs of process equipment; this figure includes actual component costs plus expenditures for engineering plans, site preparation, and construction of necessary auxiliary facilities. Startup costs and penalties for plant shut-down time have not been included, because these values tend to be very plant specific. The operating and maintenance category includes: materials, taxes and insurance, direct and indirect labor, and maintenance. Annualized costs are defined as O&M costs + depreciation on capital investment (calculated at 10 percent of the unpaid principal per year and normalized over the capital lifetime.) All costs are developed for specific plant configurations, or model plants. Where competing units exhibit different economies of scale, more than one model size was used.

Sources of process cost estimates included technical journals, EPA economic impact studies, and other government publications, such as Bureau of Mines Information Circulars. The available materials frequently had to be converted to a form applicable to cost comparison at the unit level. In some cases, simplifying assumptions were employed. For example:

- Operating and maintenance figures are frequently available only at the plant level. In these instances, allocations between processes were constructed on the basis of information contained in the source literature. In the copper industry, for example, operating costs were provided for a typical smelter. For some of the operating expense items, such as electric power, chemicals, etc., the significant in-plant users were delineated; costs could therefore be attributed to those specific sources. For materials where detailed information was not available, and for general expenditures (labor costs, maintenance), costs were distributed according to the fraction of total capital investment represented by each unit process.

For some units, estimates of capital and O&M requirements are simply not available. This is particularly true for old defending process technologies, like the open-hearth steel furnace, where the last new unit of its type was built many years ago. Cost estimates for these processes were related directly to estimates obtained for challenging processes. The comparison between hydrotreating and drying and sweetening, included in the representative industry evaluation of petroleum refining, is a case in point. Operating costs for drying and sweetening can be expected to be lower than those attributed to a hydrotreating unit, due to the large hydrogen requirements of the latter process. Where operational differences could be clearly indicated in this manner, costs were estimated in accordance with these deviations; otherwise, costs were presumed to be roughly comparable.

$bEnd-of-Pipe Costs$R

The reference case for abatement costs is the set of costs provided for each industrial sector in Sections Two and Three of this report. These estimates were developed for current and projected plant inventories using treatment cost curves which are included in Appendix F. This material was supplemented by information obtained from EPA development documents, technical and trade journals, and other recent studies on the costs of pollution control. To make this data base responsive to the specific needs of the process change investigation, methods had to be devised for the allocation of reference case costs between specific unit processes, and the translation of waste load reductions possible through process change into a revised estimate of end-of-pipe costs.

$cALLOCATION OF REFERENCE CASE COSTS$R

Much of the information concerning abatement costs has been developed only at the plant level, while process changes frequently affect a single phase of the production process. Where this dichotomy exists, some technique for apportioning treatment costs among the processes within a plant is necessary. The demands on this allocation method increase with the complexity of the control problem.

In the simplest case, each piece of pollution control equipment in the treatment scheme can be associated with the abatement of a particular pollutant generated at a single source within the plant; e.g., a baghouse for control of particulates from process A, and a wet scrubber for control of sulfuroxide from process B. In this instance, the only information required for cost allocation is the breakdown of total abatement costs into the expenditures required for each control component.

More often, however, a pollutant is generated at a number of sources within a plant. In the case of copper smelting, sulfur oxide off-gases are produced in various proportions during each of the major processing steps (roasting, furnacing, or conversion). Some, or all, of these streams may be combined and sent to the same treatment sequence. If a control device handles wastes from several plant sources, some portion of the related costs of control should be assigned to each of these process sources on the basis of the fraction of total pollutant loading each contributes. To calculate these fractions, emissions factors that establish a general ratio between pollution and output must be obtained for each relevant process. These factors, when multiplied by the model plant unit capacity, provide an estimate of plant waste loads. If roasting is found to contribute 55 percent of plant sulfur oxides, it is presumed that it can be assigned 55 percent of the reference case costs incurred in controlling that waste stream by means of a scrubber, acid plant, etc. This assumed one-to-one correspondence is not entirely accurate, due to the fact that wastes classified in the same general pollutant category (TSS, particulates) can have widely-divergent strengths and treatabilities. Nonetheless, the relationship is a generally accepted rule of thumb which has been employed in other recent abatement cost studies.

In a single plant, many different types of pollutants are generated, and must be controlled by the same abatement facilities. Ideally, some portion of the total costs should be allocated to each of the pollutants removed by the treatment system. Formulas of this type have been developed for the inorganic and organic chemicals industry. There were serious limitations, however, in the application of this type of analysis to the representative industry examples. Detailed breakdowns of model plant waste loads to the subprocess level are only available for a limited number of pollutants. Similarly, references on waste reductions resulting from process changes often confined their discussion to one or two major parameters. Consequently, it was frequently necessary to designate one pollutant as the dominant concern of industry abatement standards. In the petroleum industry, for example, BOD removal was concluded to be the compelling force behind BPT standards; costs for installation of the required biological treatment systems were therefore allocated between the various in-plant sources of that pollutant.

$cWASTE REDUCTIONS AND REVISED ABATEMENT COSTS$R

The relationship between the reduction in waste load and the reduction in treatment costs is not proportional. A 10 percent dimunition of plant wastes might result in a 5, 8, or even 12 percent savings on control expenditures, depending on factors like the economies of scale involved, the degree to which control systems are modular, etc. Two approaches were utilized to determine the cost reduction associated with a given level of waste reduction. Where information estimating this relationship was provided in the literature, this material was employed. An example of this type of information is the study by McGovern on waste reduction in the petroleum industry. In the absence of specific analysis, end-of-pipe cost savings were measured by moving down the treatment cost curves which are included in Appendix F, to a facility size consistent with the waste load reduction achieved. The difference between this revised value and reference case costs represents the savings. After the revised level of end-of-pipe expenditures is determined, allocation of these costs among unit processes is again undertaken in the manner outlined above.

The example of substituting hydrotreating for drying and sweetening can be used as an illustration of these two procedures. A model plant configuration was chosen which included drying and sweetening. Using BOD as a surrogate indicator, the contribution of this process to the total refinery waste burden was 45 percent. This fraction was then applied to the estimated total for plant end-cf-pipe expenditures, to determine the costs attributable to drying and sweetening. For the same plant, waste loads were recalculated, utilizing lower polluting hydrotreating processes in place of drying and sweetening. The resulting reduction in waste (42 percent) was converted into its equivalent effect on end-of-pipe costs (23 percent), using materials generated by the McGovern study. The percentage of new total BOD coming from hydrotreating was calculated, with this fraction applied to the revised cost estimate.

$bEconomic and Environmental
Motivations for Process Change
and the Allocation of Cost Effects$R

In addition to indicating the substitution potential of new processing concepts and the pollution control cost savings resulting from their implementation, the unit cost comparisons can serve as a basis for speculation about the motivating force behind a process change decision. In some cases, e.g., spill containment in the paper industry, process changes are adopted that provide no economic return on investment, the only benefit being a reduction in end-of-pipe costs. Changes of this type can truly be said to be environmentally inspired. Therefore, the costs for installing and operating the containment system should be charged to pollution control. Conversely, some concepts, like the Bayer-Alcoa aluminum process, have processing advantages that are sufficient to insure their adoption before end-of-pipe savings are taken into account. An approximate line of demarcation beyond which process changes are economically motivated is an industry's minimum acceptable rate of return. Since pollution control savings are incidental to the decision maker in cases providing greater rates of return, it is inappropriate to attribute these costs to pollution control.

In between these two clear cases lies a substantial gray area. Recovery and sale of byproduct H2S and NH3 in a large petroleum refinery results in a return of about 3.6 percent a year; this profit margin would not in itself be sufficient to justify the investment. However, when environmental savings are included and the revised treatment system is contrasted with a pure end-of-pipe approach, the process becomes very desirable. It would be logical to charge only part of the process change costs to pollution control.

This concept, although important to recognize, can not be accurately implemented given the present data base. Minimum acceptable rates of return vary by several percentage points among companies in the same industry. A more detailed analysis of industry is required to delineate these variances. Similarly, there is a degree of inaccuracy in the estimations of process cost effects. Even a slight error can negate the accuracy of a carefully-constructed allocation algorithm. Since only a few of the changes examined in the representative industry studies lay in this gray area, none of the savings in basic process costs stemming from process change were included in the estimates of control cost reductions. It should be emphasized, however, that the resulting estimates represent the lower boundary of possible savings.

$bCosting at the Industry Level$R

Even though a particular process change may be shown to be economically profitable on the basis of the unit level comparison, the opportunities for its application may not be fully exploited. It is necessary to establish the industry context into which process change variables are introduced because certain characteristics of the industry environment will constrain or encourage adoption of new process ideas. Table 2 presents a partial representative list of elements in the contextual picture that were examined for their possible influence on the rate of penetration. These limiting factors can be physical or financial, and not all of these factors are applicable to each industry considered in the representative evaluations.

$dTable 2.
Some Factors Affecting Process Change Potential

	Factor Considered	Reason for Consideration
1.	Industry growth rate	Taken together, these estimations measure the amount of new capacity being built. If the process change being considered is an option for new plants only, the possibilities for penetration are highly controlled by these variables.
2.	Rate of plant obsolescence/ replacement	
3.	Availability of input materials (Ex. - higher grade ores, low sulfur fuels, rutile)	External (outside the industry) market conditions frequently constrain the ability of the industry to employ particular options. This is especially true of raw material changes and byproduct recovery and sale.
4.	Availability of markets for recovered byproducts.	
5.	Industry attitude toward process change	The historical receptiveness of the industry to new process ideas is a general indicator of the time frame required for the industry to implement new methods on a large scale.
6.	Size distribution of plants	The profitability of process change is frequently linked to economies of scale.
7.	In-place end-of-pipe abatement facilities	For a plant with an already installed treatment system capable of meeting environmental standards, the utility of installing process change measures designed to reduce waste load is greatly diminished.
8.	Availability of capital	If a particular process change requires a large initial capital investment, its application may be restricted to those firms with higher profit margins and favorable liquidity position.$s

Because the possibilities for process substitution in a given industry are dependent on the complex interactions of several variables, a scenario approach was utilized to indicate the range of possible results. Two basic scenarios were defined: a maximum, and a best-guess estimate of process change penetration. In the aluminum industry, for example, the best-guess market share for the Alcoa smelting process in 1985 is 8 percent of primary aluminum capacity; if maximum penetration is assumed, the share increases to 12 percent. The difference between these scenarios is the assumption of price or other constraints on the availability of bauxite and energy inputs. In some cases, the maximum and best-guess penetrations are equivalent.

For each alternative, pollution control costs as modified by process change were calculated and compared against the reference case estimates. To aggregate costs to the industry level, a size distribution of existing and future plants was estimated. The cost studies in Sections Two and Three of this report assign existing facilities in the plant inventory to various size classes. For future growth, plant capacities were developed from information on known expansion plans and extrapolation of recent size trends.

$bINDUSTRY SURVEY$R

This section summarizes the results of an industry survey to identify those process change opportunities having implications for pollution control costs. Each industry considered in the cost studies of Sections Two and Three in this report were assessed to determine the answers to two questions: Is the industry a significant contributor to air and water pollution, and are there opportunities for process change that can reduce the total cost of abatement? By comparing estimates of current industry effluent levels with corresponding national totals, a general measure of significance was developed. If an industry contributed more than 1 percent of the national total for any major pollutant parameter, it was considered to be a significant polluter. In the case of air emissions, this analysis was supplemented by comparing industry abatement costs to total abatement expenditures. Additionally, sectors were judged significant if they were responsible for highly toxic emissions (mercury, asbestos, etc.) that pose special abatement problems.

If the answer to the first questions was affirmative, the industry was further investigated for process change potential. Trade journals and other magazines, EPA development documents, previous Cost of Clean Air and Water reports, and other reports on the subject of industrial pollution control formed the base from which the survey results were developed. A process change was considered a viable alternative only if it had at least been tested at the pilot plant level.

The results of the industry survey are summarized in Table 3, with additional information provided in the industry profiles presented in Appendix F of this report. All process changes discussed in these profiles have been classified according to the type of process change involved, the media affected, and whether or not the change was included as part of the reference case abatement strategy. This material is presented in Table 1A of Appendix F.

Table 3.
Summary of Survey Results
$t

Industry Category	Significant Polluter?	Pollution Reduction Potential Through Process Change?
Fossil Fuels Group		
Coal Cleaning	---	---
Natural Gas Processing	---	---
Petroleum Refining	A,W	W
Steam Electric Power	A,W	A
Foods Group		
Feedlots	W	W
Meat Products Processing	W	W
Dairy Products Processing	W	W
Seafood Processing	W	No
Canned & Frozen Fruits and Vegetables	W	W
Feed Mills	A	No
Grain Handling	A	No
Beet Sugar	W	No
Cane Sugar	W	No
Fertilizer/ Phosphates	---	---
Construction Materials Group		
Cement	A	No
Lime	---	---
Asphalt	A	No
Asbestos	A,W	No
Insulation Fiberglass	---	---
Metals Group		
Aluminum	A,W	A,W$R

Table 3. (Continued)
Summary of Survey Results
$t

Industry Category	Significant Polluter?	$tPollution Reduction Potential Through Process Change?
Metals Group (con't)		
Copper	A	A
Iron and Steel	A,W	A,W
Lead	A	No
Zinc	---	---
Other Non-Ferrous Metals	A,W	No
Electroplating	W	W
Chemicals Group		
Inorganic Chemicals	A,W	W
Organic Chemicals	W	No
Miscellaneous Chemicals	---	---
Plastics & Synthetics	W	No
Consumer Product Inputs Group		
Timber Products Processing	---	---
Pulp & Paper Mills	A,W	W
Builders Paper and Board Mills	---	---
Textiles	W	W
Soaps and Detergents	---	---
Leather Tanning	W	No
Glass	---	---
Rubber	---	---
Consumer and Government Services		

Table 3. (Continued)
Summary of Survey Results

$t

Dry Cleaning	A	A
Municipal		
Solid Waste		
Disposal	A	A
Sewage Systems	---	---

Key: A-Air; W-Water.

Sectors are listed if they either pay more than 1% of total national abatement expenditures , or generate more than 1% of the national total of particulates, hydrocarbons, SO2, NOX, BOD, COD, TSS, or oils and greases.

Sectors generating highly toxic emissions.

Sectors found to be nonsignificant polluters were not investigated further.$R

For several reasons, process ideas now being considered will not exert the same degree of influence over an industry's future planning. Some processes, though promising in theory, may encounter operational difficulties that substantially reduce currently anticipated economic benefits; other changes may be restricted in application to plants of a certain type, size, or age. Therefore, twenty-two "candidates" for further study were selected from the initial list of opportunities as best prospects for implementation within the time frame and at a level where they could seriously influence the abatement cost outlook for an industry. These changes are categories by type of process change and by industrial sector in Table 4.

$dTable 4, Sheet 1 of 3.
Process Change Opportunities by Industry and Type Change
A. Materials Changes

	Raw Materials		Pretreatment		Product Specification	
Industry	Old Process	New Process	Old Process	New Process	Old Process	New Process
Municipal Refuse Disposal						
Paper					High Brightness	Lower Brightness
Industrial Chemicals	Salt/Lime Ilmenite	Trona Rutile	Ilmenite	Synthetic Rutile		
Paints	Solvent Base	Powder Base				
Petroleum Refining					Downstream Control	Low Sulfur Fuel Oil
Iron and Steel			Released Fines	Pellet Agglomeration		
Copper	Sulfide Ores	Oxide Ores				
Aluminum	Bauxite High Grade Bauxite	Recycled Aluminum Low Grade Bauxite				
Electric Utilities			Stack Gas Scrubbing	Fuel Desulfurization		
Dry Cleaning						

Table 4. Sheet 2 of 3.
Process Change Opportunities by Industry and Type Change
B. Process Modifications

Industry	Byproduct Recovery: Old Process	Byproduct Recovery: New Process	Revised Process Operations: Old Process	Revised Process Operations: New Process
Municipal Refuse Disposal				
Paper	Disposal	Sawdust for Pulping Fiber/Chem/Heat	Batch Digesting	Continuous Digesting
Industrial Chemicals				
Paints				
Petroleum Refining	Disposal	Sulfur/NH3	Barometric Condensers in Vac. Distillation	Surface Condensers
Iron and Steel				
Copper		Sulfuric Acid	Reverberatory Furnace	Flash/Electric Furnace/Hydrometallurgy
Aluminum				
Electroplating	Disposal	Chemicals Recycling		
Electric Utilities				
Dry Cleaning				
Textiles	Disposal	Recovery of grease from wool scouring/PVA Reclamation/Latex Recovery		Counterflow Washing
Fruits & Vegetables	Disposal	Solids Recovery	Once Through	Water Recycle

Table 4. Sheet 3 of 3.
Process Change Opportunities by Industry and Type Change
C. Process Substitutions

Industry	Old Process	New Process
Municipal Refuse Disposal	Incineration	Landfills/Minefills
Paper	Kraft Process Wet Forming	Dry Forming
Industrial Chemicals	C12: Mercury Cell Na2CO3: Solvay Process TiO2: Sulfate Process	Diaphragm Cell Trona Process, Chloride Process
Paints	Solvent Suspension	Electrostatic Suspension
Petroleum Refining	Catalytic Cracking	Hydrotreating, Hydrocracking
Iron and Steel	Open-Hearth/Electric-Arc Blast Furnace	Basic-Oxygen Furnace, Direct Reduction
Copper		
Aluminum	Hall Process Bayer-Hall Process	Alcoa Process, Monochloride Process
Electroplating		
Electric Utilities		
Dry Cleaning	Petroleum Solvents	Synthetic Solvents
Textiles		
Fruits & Vegetables	Mechanical Peeling	Dry Caustic Peeling$s

At this point, five industries were selected for in-depth study: copper, aluminum, pulp and paper, petroleum refining, and inorganic chemicals. These industries were chosen because they were industries in which two or more process changes are concurrently being considered, and collectively, they contained examples of all the major types of process change. Additionally, it was felt that the data base of process change information in these areas was rich enough to permit detailed analysis. Short summaries of these representative evaluations are provided in the next section. The full text containing the bulk of the assumptions, calculations, and documentation that form the basis for these conclusions is presented in Appendix F.

$bREPRESENTATIVE INDUSTRY EVALUATIONS

Copper$R

The main environmental problem facing the copper industry is the control of sulfur dioxide contained in the off-gases from reverberatory furnaces used in primary smelting operations. Because of the very weak concentration of these gases (usually less than 1 percent sulfur dioxide by volume), they cannot be treated effectively through conversion into sulfuric acid. The costs of abatement are consequently very substantial; expenditures on control measures in a recent year, for example, represented 22 percent of total capital investment. As a result, U.S. producers have greatly increased their interest in processing innovations that have the potential to reduce the industry's control burden. Research efforts have been directed in support of three main process alternatives: flash furnaces, electric furnaces, and hydrometallurgical smelting. The first American commercial scale example of each technology has either been installed within the past 5 years or is currently under construction.

$cPROCESS CHANGES$R

Flash smelting is a commercially proven technology that has been employed extensively in Europe and Japan for over a decade. Off-gases from the furnace attain sulfur dioxide concentrations of 10-14 percent and can be easily handled by an acid plant. By combining treatment of all plant emissions in a single facility, a 1,500-ton of concentrates per day smelter can achieve an estimated 11 percent reduction in capital requirements, and a 27.2 percent reduction in the annualized costs of pollution control. Although process costs for the flash furnace are somewhat higher due to additional slag processing requirements. overall unit costs figure to be 10-20 percent less than those estimated for a reverberatory furnace of comparable size. On this basis, it is projected that up to 50 percent of new pyrometallurgical capacity requirements in 1975-80, and 75 percent in 1981-85, will be supplied by flash smelters. If recently proposed new source performance standards are promulgated which would specify more stringent and much more costly controls on reverberatory furnaces, the rate of penetration by the challenging technology will be further accelerated.

Electric furnaces claim a dual advantage over their reverberatory counterparts; they increase the sulfur dioxide concentration of off-gases by eliminating combustion gases within the furnace, and they exhibit a higher thermal efficiency. Two existing U.S. smelters have already made the switch to this technology as part of their abatement strategy. The smelting site must be close to a source of cheap electric power if the process is to be economically competitive. This fact alone will seriously restrict application of this technology in some of the remote and arid Western mining areas. In addition, industry spokesmen have frequently expressed doubts about the operating reliability of electric furnaces. Consequently, the option is viewed as a less preferred alternative, with its substitution possibilities limited to areas where the cost of power is low enough to override other concerns.

Two hydrometallurgical smelting techniques, the Arbiter and Cy-Met processes, are in advanced stages of development. Major questions affecting evaluation of the substitution potential of these concepts concern the time frame in which successful scale-up can occur, and the extent to which current process cost estimates will accurately represent commercial scale results. If the operating economics achieved during pilot plant operations can be maintained, hydrometallurgy can reduce annual process costs by up to 25 percent; in addition, pollution control costs are practically zero, requiring only some form of storage or disposal for the sulfate solid waste which is produced. Even after successful scale-up, substitution will proceed slowly; hydrometallurgy will constitute no more than 4 percent total primary capacity by 1980, and 12 percent by 1985.

In addition to these basic process changes, it is necessary to assess the market opportunities for sale of the byproduct sulfuric acid generated during the control process. If there are profitable opportunities present, some of the estimated costs of pollution control can be defrayed: contrarily, if no opportunities exist, the costs of neutralization and disposal of the byproduct should be counted as an additional abatement expense. Competition for markets will be very strong, and smelter acids face one major disadvantage by being far from their primary users. However, smelters can take advantage of opportunities within the industry to use H2SO4 as a leaching agent to extract copper from oxide ores and mine tailings; they can also increase their marketability by selling acid at a price well below the going market rate. Based on these parameters, four possible price/market opportunity scenarios were examined. In the combination of circumstances deemed most likely to occur, it was assumed that 12 of the primary smelters with acid plants will be able to sell their acid at an average price well below market rate, resulting in revenue of over $30 million per year.

$bIndustry Effects$R

The overall reduction in pollution control costs resulting from implementation of the process changes discussed above is summarized in Table 5. The bulk of the savings attained through 1980 is the result of byproduct acid sales; the major increase in savings estimated for 1985 is attributable to greater application of flash and hydrometallurgical smelting technologies.

Table 5.
Copper Industry -- Abatement Cost Reduction Through Process Change

(In Millions of 1975 Dollars)
$t

	Reference Case Abatement Costs		Revised Abatement Costs (with Process Change)	
	1980	1985	1980	1985
Cumulative Investment (from 1972)	1,405.1	1,433.8	1,292.6 (-8.0%)	1,174.2 (-18.1%)
Annual Costs	420.1	423.4	354.6 (-15.6%)	311.2 (-26.5%)

From Scenario 2 - air control costs only.$R

$bAluminum$R

The two pollutants of primary concern to the aluminum industry are red mud from the refining of bauxite, and fluorides from the reduction of alumina to aluminum. Red mud is usually impounded in an evaporation pond, and it is thus possible to achieve zero discharge. Fluoride is associated with the Hall reduction process and is about 70 percent controlled to date. Existing facilities may have to install expensive secondary roof scrubbers to achieve the proposed standards of 90 percent capture.

A new source performance standard of 95.5 percent removal is achievable by the Alcoa Dry Scrubbing Process but used in conjunction with vertical stud soderberg aluminum reduction cells. Other types of cells will require expensive secondary scrubbers. Thus, pollution control factors are prompting consideration of alternative technologies.

$cPROCESS CHANGES$R

Three process substitutions may have an effect on pollution control costs in the aluminum industry. The most direct factor would be an increase in the capacity to recycle scrap aluminum. Substitution of the Bayer-Alcoa process for the Bayer-Hall would decrease the unit pollution control costs from primary smelting by 73 percent. Non-electrolytic processes, like the Monochloride process would probably increase the unit cost of pollution control by 13 percent. Such a technology might be considered in the future because of energy and bauxite constraints.

$cINDUSTRY-WIDE COST REDUCTION$R

The penetration of new technologies is related to the growth rate of the industry, which in turn is related to the industry's pollution control cost. The absence of constraints on raw material availability or pollution output tends to preserve the present technology. Moderately-constrained growth tends to encourage the search for less-costly alternatives. Three scenarios based on these growth-penetration assumptions are presented in Appendix F. However, for purposes of comparison, a 7 percent growth scenario with moderate penetration of recycling and the Bayer-Alcoa process is presented here.

The costs resulting from a Bayer-Hall/Bayer-Alcoa/recycling mix of 77 percent/1 percent/22 percent in 1980 and 68 percent/ 8 percent/24 percent mix in 1985 are shown in Table 6; note the lower capital and annualized operating figures for the process change case. The large increase in savings from 2 percent in 1980 to 11.3 percent in 1985 is due to the increased coverage of recycling and the Bayer-Alcoa process. Other scenarios with different growth and technology coverage assumptions can be found in Appendix F.

Table 6.
Aluminum Industry Abatement Cost Reduction Through Process Change
(In Millions of 1975 Dollars)
$t

	Reference Case Abatement Cost		Revised Abatement Cost (with process change)	
	1980	1985	1980	1985
Cumulative Investment (from 1972)	2,357.4	2,431.4	2,314.9 (-1.8%)	2,197.9 (-9.6%)
Annual Costs	787.5	728.6	716.6 (-9.0%)	663.0 (-9.0%)

From Scenario 2 : air and water control costs.$R

$bPulp and Paper Industry$R

The paper industry discharged 2.47 billion gallons of water in 1972, even though it was recycled over three times during processing. About 60 percent of that water was used in direct process contact, higher than any other industrial activity. This leads to a discharge of about 2.2 million tons per year each of BOD and of suspended solids. The industry spent 30 percent of its capital investment, the largest percentage of any manufacturing industry, in an effort to meet pollution control standards.

$cPROCESS CHANGES$R

The pulp and paper industry has several short-term and several long-term water pollution control savings opportunities through process change. In the short-term (1975-1980), process modifications and product specifications changes can have a significant effect. Process modifications designed to contain spills, recover fiber, process chemical and energy have some savings involved. They range from a 20 percent savings per ton to a 65 percent savings per ton where applicable. The increased use of lower brightness papers can result in a 67 percent saving in pollution control costs where applicable. Unfortunately, the applicability of these changes is limited to moderately old plants and the industrial tissue market, so that the overall savings potential is decreased.

The long-term (1980-1985) process substitutions of oxygen processes and dry forming, appear to have a substantial effect on the cost of pollution control. , The use of oxygen for bleaching, waste treatment, and process liquor recovery result in a 53 percent savings in water pollution control costs. Dry forming of paper eliminates water pollution control costs where applicable. These process substitutions appear to have a wide range of applicability, but are limited to new capacity implementation.

$cINDUSTRY-WIDE COST REDUCTION$R

If it is assumed that 30 percent existing capacity and all of the new capacity before 1980 will take advantage of the near-term savings, and that 50 percent of new capacity after 1980 will take advantage of the long-term savings, the paper industry can achieve the aggregate water pollution control costs savings shown in Table 7.

Table 7.
Abatement Cost Reduction Through Process Change
Pulp and Paper Industry, Water Pollution Costs
(In Millions of 1975 Dollars)
$t

	Reference Case Abatement Cost		Revised Abatement Cost (with process change)	
	1980	1985	1980	1985
Cumulative Investment (from 1972)	2,869.9	5,905.5	2,656.7 (-7.4%)	5,055.1 (-14.4%)
Annualized Cost (by year)	606.0	1,386.9	499.3 (-17.6%)	1,006.9 (-27.4%)

From Scenario 2 - water control costs only.$R

$bPetroleum Refining$R

The petroleum industry has made a number of in-plant improvements in the past designed to improve water effluent characteristics and increase water reuse and recycle rates. These efforts have been fruitful, with the water reuse ratio in the industry almost doubling in the last 20 years; nonetheless, refineries face substantial future outlays for pollution control systems. In-plant process changes designed to minimize end-of-pipe treatment requirements are likely to be a major part of the overall abatement strategy selected.

$cPROCESS CHANGES$R

Many proposed changes affect operations at the subprocess level, and can achieve substantial reductions in plant waste loadings for a fairly small initial capital outlay. An example of this type of process modification is the recovery of phenols produced during catalytic cracking. Removal of this pollutant can reduce total plant BOD by 7 percent and end of pipe costs by 5 percent. Additionally, there are economic advantages arising from the recovery of free oils entrained in the wastewaters from the cracker. Analysis of the effects of installing such a unit in three model refinery configurations . indicates that this change could be profitable for a group of refineries comprising 65 percent of current total capacity.

Recovery of byproduct sulphur and ammonia from refinery sour waters has been a widely practiced technique in recent years, and is recommended in the EPA Development Document as part of BPT abatement strategy. Analysis in this section of the study focused on estimation of the cost-offsetting benefits achievable through sales of recovered materials. Available process cost data on typical stripping and recovery facilities demonstrates a potential for returns on investment of up to 20 percent per year, provided that all byproduct can be sold. For both sulphur and ammonia, a detailed analysis (refer to Appendix F) was made of market conditions; and an assessment given of the competitive opportunities available to refinery producers. Results of this investigation indicated that sales of the ammonia and sulphur generated at current production levels could translate into revenues of $62 and $50 million, respectively, provided that maximum sour water recovery was practiced using dual stage stripping techniques. In addition, maximum processing resulted in 45 percent reductions in typical refinery BOD loadings, with a corresponding pollution control savings of 25 percent.

Greater use of hydrocracking has often been suggested as a way to reduce air and water pollution problems resulting from catalytic cracking operations. Although hydrocracking units offer greater operational flexibility and increased product yields in addition to reducing pollution problems, industry adoption of the process since its development in the 1960's has been very cautious. The major obstacle to implementation has been the higher costs associated with the challengining processes; this gap has recently widened due to sharp increases in hydrocracking input prices. As a result, a great deal of effort has been funneled into modification and improvement of the defending process. Major developments include use of new catalysts requiring less frequent regeneration, and the installation of carbon monoxide waste heat boilers. These recent events indicate a resurgence of expansion to catalytic cracking, with a resulting increase in end-of-pipe requirements and costs.

The use of hydroprocessing techniques has been rapidly increasing over the past decade, growing at an average of 8 percent per year. The addition of hydro-desulfurization steps to refinery operations reduces the waste burden of sulphur, nitrogen, and metals requiring end-of-pipe treatment, and concentrates these constitutents in sour water streams which can be readily processed for byproduct recovery. In other areas of refinery, hydrotreating processing can replace older, dirtier processes like acid treating, or drying and sweetening. Although the impetus for greater use of the processes is still strong, there are definite limitations on further extension of these processes in refineries which have already exhausted their inplant hydrogen surplus, since hydrogen production facilities are an expensive capital cost item. Further penetration by this process is likely to occur at a slower rate.

$cINDUSTRY-WIDE COST EFFECTS$R

It was very difficult to quantify the pollution cost savings possible in the petroleum refining sector. If all process changes discussed in this chapter were implemented in a specific refinery, waste load reductions of up to 60 percent could be achieved. There are many limitations restricting the substitution possibilities which exist; and, given the diverse structure of the industry, it was hard to determine the number of plants that were actually constrained. Nonetheless, it is believed that these various concepts could be introduced at a level sufficient to reduce average waste loadings of BOD by 20 percent. This corresponds to about 12 percent reduction in end-of-pipe capital and O&M costs. Additional revenue is added from byproduct recovery. These estimates are summarized in Table 8.

Table 8.
Petroleum Refining-Abatement Cost Reduction Through Process Change
(In Millions of 1975 Dollars)
$t

	Reference Case Abatement Costs		Revised Abatement Costs (with process change)	
	1980	1985	1980	1985
Cumulative Investment (from 1972)	938.8	1,898.5	826.1 (-12.0%)	1,557.1 (-12.0%)
Annual Costs	204.8	412.4	128.4 (-37.3%)	274.6 (-33.4%)

From Scenario 2 - water control costs only.$R

$bInorganic Chemicals$R

Chemical and allied products rank first in industrial water consumption, with inorganics accounting for over one-fifth of this use. The vast majority (72.3 percent) of water intake by inorganic chemicals is for cooling, with only 11.1 percent used as process water. The principal wastes are inorganic salts including chlorides, sulfates, carbonates, etc; Other significant wastes include ore tailings and metals, such as chromium, mercury, lead and iron. In EPA's evaluation of water-borne pollution from 25 major inorganics, over 99 percent of the waste load was attributed to five products: sodium chloride (38.3 percent), sodium carbonate (35.6 percent), titanium dioxide (17.1 percent), and the coproducts chlorine/ sodium hydroxide (8.5 percent). Each of these large waste products was evaluated for process change potential.

$cSODIUM CHLORIDE$R

Sodium chloride waste is usually deep-welled or stored, and does not pose a difficult water pollution problem.

$cSODIUM CARBONATE$R

There are two manufacturing processes for sodium carbonate (or soda ash). The older Solvay process synthesizes sodium carbonate from salt and limestone, with ammonia serving as a chemical intermediary. Approximately 1.5 kilograms of dissolved solid wastes are generated per kilogram of product. The dissolved solids are about two-thirds calcium chloride, with the remainder mainly unreacted salt. The solids have slight market value and are usually discharged into surrounding water bodies. In contrast, the newer process utilizes natural ore, called Trona, or lake brines containing burkeite. Neither of these alternatives generates a troublesome waste, since ore tailings and brine wastes can be returned to the mine or lake.

The Solvay process has been steadily losing ground. No Solvay plants have been built since 1935. From 1960 to 1972 Solvay plan participation in soda ash production declined from 85 percent to 58 percent. The one advantage still held by the Solvay plants is geographic location. The Trona and lake brine deposits are concetrated in Wyoming and California, whereas market concentrations lie in the East. As a result, the natural ores have only gradually displaced the Solvay plants; pollution control requirements promise to speed this displacement. Partially due to such considerations, two Solvay plants closed between 1972 and 1974, further reducing process participation to 46 percent. The extent of Solvay process participation is the principal factor determining the aggregate water pollution control cost for sodium carbonate production. The anticipated closing of two of the smaller plants by 1977 will cut Solvay capacity by one-quarter, and reduce abatement capital and annualized costs by 28 percent (BPT and BAT costs are the same for this product).

Another important consideration is whether to recover a portion of the waste calcium chloride for byproduct sale. Assuming there is a sufficient market, recovery and sale of 20 percent of the calcium chloride would lead to an 81 percent reduction in annualized costs, but would necessitate a 206 percent increase in capital requirements.

$cTITANIUM DIOXIDE$R

There is competition both among processes and raw materials for the production of titanium dioxide. The older, sulfate process utilizes a more abundant, less pure ore, called ilmenite. Until recently, the newer chloride process has been restricted to the use of the purer rutile ore. Since the reserve of the latter is quite limited, 20 to 25 years at present consumption rates, raw material costs have played a large role in process selection. In spite of the rutile constraint, process efficiencies achieved with the chloride process have enabled it to increase its production share to 46 percent since its introduction in the mid-1950's. No new sulfate plants have been built since 1956.

Recent sharp increases in rutile and chlorine prices have tended to slow the encroachment of the chloride process. However, environmental considerations are lending a new competitive edge to the chloride process. The sulfate process generates 4 to 5 times the amount of waste per kilogram as compared with only 1.2 times for the chloride process. A significant aspect of the difference in waste load is the use of a purer raw material by the chloride process. The sulfate waste is mainly spent sulfuric acid and ferrous sulfate (copperas). The waste from the chloride process is primarily ferric chloride.

Abatement capital requirements for the chloride process are only 56 percent of those for the sulfate process for BPT, and 65 percent for BAT. Similarly, annualized costs for the chloride process are 40 percent of those for the sulfate process for BPT, and 59 percent for BAT.

Byproduct recovery is an important aspect of the pollution control opportunities for titanium dioxide. Ferric chloride from the chloride process is already being recovered and sold for water treatment by some companies, and can alternatively be converted to chlorine for recycling and to iron oxide for sale. Sulfate process waste acid can either be recovered and recycled or converted to gypsum, and then sold. Acid recovery and recycle in the sulfate process alone enables a 22.4 percent reduction in the total titanium dioxide accumulated capital expenditures for abatement through 1985, and a 23.2 percent reduction in annualized abatement costs in 1985.

$cCHLORINE$R

Environmental considerations have acted to reverse an ongoing shift among process alternatives for chlorine production. Worldwide usage of the mercury cell electrolysis process for chlorine substantially exceeds that of the competing diaphragm cell; in the United States, the latter has always been predominant. Nevertheless, mercury cell participation in U.S. chlorine manufacture had been on the rise, increasing from 4.3 percent of production in 1946 to 28.6 percent in 1968. At that point, concern regarding mercury emissions to the environment surfaced. Since then, some existing plants have converted from mercury cells to diaphragm cells, and little new mercury cell capacity is being added. By 1973, mercury cell participation had declined to 24.6.

The wastes from the mercury and diaphragm cells are similar: brine impurities, unreacted salt, weak caustic, waste sulfuric acid, sodium hydrochlorate and sodium bicarbonate. However, the mercury cell waste also contains a limited quantity of mercury. The need for strict control of the mercury content causes significant abatement cost differences between the two cell-types. The diaphragm cell abatement capital requirements for BPT and BAT are only 13 percent and 36.4 percent, respectively, of those for the mercury cell. Likewise, the annualized capital cost comparison is 25.7 percent and 44.9 percent for BPT and BAT. As a result, the ongoing shift from the mercury cell, if no new mercury cell plants are built, will reduce the accumulated capital expenditures through 1985 by 16.4 percent, relative to the reference case, and 1985 annualized costs for pollution control by 12.8 percent. It should be noted that a great deal of developmental work is underway to bring mercury cell control costs into line with those of the diaphragm cell.

$cINDUSTRY-WIDE COST REDUCTION$R

The industry-wide implications of the process change opportunities for the four chemicals, sodium carbonate, titanium dioxide, and chlorine/caustic, are presented in Table 9. The four chemicals account for more than half the abatement capital and annualized cost requirements for the entire industry. Presuming other chemicals have similar process change opportunities, a 38.1 percent reduction in abatement annualized costs in 1980 can be achieved and a 25.0 percent reduction in 1985. A slight (2.5 percent) reduction can be made in cumulative capital expenditures.

Table 9.
Inorganic Chemicals Abatement Cost Reduction
Through Process Change
(In Millions of 1975 Dollars)
$t

	Reference Case Abatement Cost		Revised Abatement Cost (with process change)	
	1980	1985	1980	1985
Cumulative Investment (from 1972)	419.4	727.4	419.3 (0%)	709.2 (-2.5%)
Annual Costs Cost (by year)	166.7	219.0	103.2 (-38.1%)	164.3 (-25.0%)

From Scenario 2 - water control costs only.

·The revised abatement costs were scaled from the costs determined for sodium carbonate, titanium dioxide, and chlorine. These three chemicals account for between 50% and 70% of the Reference Case values for capital and annualized costs.$R

$bGENERALIZATIONS

Range of Pollution
Control Savings$R

The range of pollution control savings through process modifications varies among industry and category types of process change. This variation is to be expected if one considers the specific implementation limits on any given process change. Financial, technical, and physical constraints to process change vary considerably between industries and within each industry. The highly-specific nature of process changes and the varied nature of the industrial climate in which they are imbedded inhibits generalization.

Substantial savings have been demonstrated in the representative industry studies. These savings vary considerably from industry to industry as shown in Table 10. On the capital side, they range from a savings of 2.5 percent in inorganics to 14.5 percent in copper. The annualized savings are somewhat larger than capital savings, ranging from 11 percent in the aluminum industry to 30 percent in the petroleum industry. The advantages accrued through process change within the representative industry studies may serve as an indication of the range of potential savings in a similar situation in another industry. It is worthwhile to emphasize the approximative nature of the following generalizations; they are made to facilitate estimation of the overall effects of process change, and they do not represent precise assessments of the situation in a given industry.

$dTable 10.
Abatement Cost Impact of Process Change - 1985
(% Change from Reference Case: Cumulative Capital/Annualized Cost)

Process Change	Industry (Media)	Copper (Air)	Aluminum (Air/Water)	Pulp & Paper (Water)	Petroleum (Water)	Inorganics (Water)
· Materials Change		--	-3.2/-3.3	-0.1/-0.3	--	-2.2/-2.1
Raw Materials		--	Recycling	--	--	Trona (Na2CO3) Rutile (TiO2)
Product Specification		--	--	Reduced brightness	--	--
· Process Modification		0/-21.8	--	-5.0/-21.5	-7.0/-25.0	+13.9/-9.9
Revised Operations		--	--	Spill Containment	Phenol Recycle	--
Byproduct Recovery		Sulfuric Acid	--	Fiber/Chem/Heat	Sulfur/Ammon	Calcium chloride (Na2CO3) Sulfuric acid (TiO2)
· Process Substitution		-14.5/-13.1	-6.3/-7.7	-5.0/-7.0	-5.0/-5.0	-14.2/-13.0
		Hydro-metallurgy/ flash furnace/ electric furnace	Alcoa	Oxygen processing	Hydrotreating	Chloride process (TiO2)
			Monochloride	Dry Forming	Hydrocracking	Diaphragm Cell (Cl2)
Industry Totals		-14.5/-34.9	-9.5/-11.0	-10.1/-28.8	-12.0/-30.0	-2.5/-25.0

Mean 9.72/25.9$s

$bVariations Within
Process Change Types$R

The variation across industries within a process change category is quite pronounced.

$cMATERIALS CHANGES$R

The least variation and least sizable savings appears in the Materials Change category. Paper specification changes are limited to a 0.1 percent savings in total industry capital, and a 0.3 percent savings in industry annualized costs because of limited market acceptability. Sodium carbonate and titanium dioxide raw material changes account for a capital/annualized cost savings of 2.4 percent/2.1 percent, respectively because of low profit margins (low change incentive). Increased aluminum recycling (scrap as a raw material) results in a 3.2 percent and 3.3 percent savings in capital and annualized costs, respectively. These relatively low savings are due primarily to supply constraints on consumer scrap and the quality limitations of secondary aluminum which limit recycling penetration.

In considering other industry material change opportunities, metallic ores provide varied cases of pollution control cost impact. Oxide ores of copper may be leached using acid from the acid plant at a copper smelter. For such process change, an overall decrease in pollution control on the order of 2 percent for the whole industry might be expected. In contrast, the substitution of lower grade bauxite or alunite in aluminum production as higher grade ores become expensive will probably increase total industry pollution control costs by about 2 percent. Ilmenite processed to synthetic rutile (Inorganics) may cause a slightly increased (1 percent) pollution control cost. Product specification changes toward low-sulfur-petroleum-derived products will also tend to increase the cost of the cleanup in the petroleum industry.

$cPROCESS MODIFICATIONS$R

Opportunities for both revised process operations and byproduct recovery were evaluated in the five industry studies. There were two examples of revised operations examined quantitatively: spill containment (paper) and phenol recycle (petroleum refining). Both examples affected process efficiency primarily by reducing the waste load and water use associated with process operations, while their effects on product yields are negligible. These changes can be usually implemented for small capital outlays, but their savings potential is small as well, in the range of 2 to 5 percent of capital and annualized abatement costs. Other changes of this type likely to achieve similar savings include: the use of counterflow washing in textile manufacturing, the increased recycling of water used in the processing of fruits and vegetables, and the installation of surface condensers in petroleum refinery vacuum stills.

Other operational modifications may have a greater effect on product yield. Improvement of the catalysts used in the cracking of petroleum, for example, increases product yield by 13 percent while simultaneously reducing process wastes. Changes of this type seem likely to achieve somewhat greater control cost savings than those modifications discussed above, if only because the increased economic benefits will make the change attractive to a greater portion of the industry.

Byproduct recovery opportunities were found to exist in four of the five industries studied. Estimated savings in annualized abatement costs from application of these recovery processes range from 9.9 percent to 23 percent. The savings in capital costs, on the other hand, are very slight, and in the case of acid recovery during titanium dioxide manufacture (organic chemicals), addition of byproduct processes substantially increases total capital requirements.

Byproduct options can be divided into two basic categories: those products which are reused within the recovering plant, and those products which are sold in the competitive marketplace. Examples in the first category include the recovery of heat, fiber, chemicals (paper, and sulfuric acid (inorganic chemicals). These byproducts reduce the need for virgin input materials in the process. The savings potential of such measures is primarily dependent on whether the material recovered is a significant operating expense item for the plant. The latter category is represented in the industry evaluations by the recovery of sulfuric acid (copper), sulfur and ammonia (petroleum refining), and calcium chloride (inorganic chemicals). Market considerations are the controlling factor in the determination of the cost savings achievable through implementation of these processes. Primary questions that are of concern: Whether the supply-demand situation can accommodate the new influx of supply, or whether contrarily, market opportunities are limited; and whether byproduct producers can increase their market share by selling their goods at prices below the prevailing market prices. A third factor restricting savings potential can be a low unit-price for the recovered material.

Based on the factors discussed above, estimates have been made of the savings potential of byproduct recovery in other surveyed industries. In the first category, recycle of the chemicals used in electroplating should reduce plant materials costs substantially, with annual savings in the 16 to 23 percent range possible. In contrast, three byproduct recovery operations in the textile industry (PVA reclamation, latex recovery, and caustic recovery) will affect materials requirements only for specific segments of the industry; consequently, overall savings can be expected to fall in the lower 10 to 15 percent range. In the second category, demand for whey (dairy products) and recovered solids to be used in animal feeds (fruits and vegetables) is fairly weak; possibilities for market expansion seem to be limited. Producers of byproduct sawdust (timber product processing) and fly ash (electric utilities) were in similar circumstances a few years ago; however, both industries have extended their market opportunities by finding various new applications for their products. In addition, all of these examples are products with very low unit prices. Consequently, it is projected that recovery of whey and solids can achieve savings somewhat below those encountered in the industry evaluations, or about 6 to 9 percent of annual costs, while use of sawdust and fly ash can achieve 10 to 15 percent savings. For all cases, no capital savings were assumed.

$cPROCESS SUBSTITUTIONS$R

As with other process change opportunities, the abatement savings achievable through process substitution are limited by the applicability range of the change and the rate of substitution. Process substitutions are usually introduced during capacity expansions, rather than as retrofit conversions. Thus they are related to the rates of industry growth and equipment obsolesence. Applicability range means the fraction of industry able to incorporate a change, the impact on overall costs of any single change, and the number of complementary or competitive changes; the effect of the number of opportunities is reflected in Table 10. Two process changes were identified as already underway in the copper and inorganic chemicals industries--their capital and annualized cost savings fell between 13.0 and 14.5 percent. In the other three industries, only one process change was found to be significant; the resulting capital and annualized cost savings fell between 5.0 and 7.7 percent.

It is useful to consider how process substitution possibilities in other industries relate to those in the five representative industries. The displacement of incineration by landfill or minefill in the disposal of municipal waste is a process substitution affecting air emissions. The high cost of incineration equipment is countered by the high land cost in most urban settings. In addition, a great deal of effort is underway to incorporate the recovery of metallic and thermal resource values in municipal waste during the incineration step. Likewise, new techniques of sanitary landfill are being developed that facilitate subsequent productive use of that land. Overall, some displacement of incineration by landfill is envisioned, leading to abatement costs in the 5.0 to 7.7 percent range. Another process substitution is the displacement of solvent-based paints by electrostatically-suspended paints. This substitution is occurring rapidly, motivated both by environmental considerations and concern regarding future shortfalls in solvent supply. The abatement cost savings should lie in the high range shown in Table 10 between 13.0 and 14.5 percent. A similar type of process substitution is the displacement of petroleum solvents by syntehtic solvents in the drycleaning industry. Here the opportunities are more limited, leading to possible abatement cost savings in the 5 to 7.7 percent range. A final example is the substitution of the basic-oxygen furnace for the open-hearth furnace in the iron and steel industry. This substitution has been underway for some time; it is estimated that the remaining possibilities for process substitution will only permit an abatement cost savings of approximately 2 percent.

$cSUMMARY$R

The greatest opportunities for abatement cost savings, as reflected in reduced annualized costs, lie in the area of process modifications. In the copper, pulp and paper, and petroleum industries, process modifications can lead to annualized cost reductions of more than 20 percent, and in the inorganic chemicals industry the potential savings are 10 percent. Process substitution offers the second largest opportunity for abatement cost savings. In both the copper and the inorganics industries, two significant process substitutions were identified that lead to abatement cost reductions of 13 percent for eacy industry. In the aluminum, pulp and paper, and petroleum industries, single process changes were identified that lead to a range of annualized cost reductions of 5.0 to 7.7 percent for the three industries. The process change opportunities that lead to the least abatement cost reduction are those associated with materials changes; the range in annualized cost reductions is 0.3 to 3.3 percent. This apparently reflects a high degree of optimization in the section of the raw materials now being used.

Table 11 presents the estimate savings potential of process change through comparison with the Reference Case estimates of abatement cost requirements. In addition to the results from the five industries surveyed in-depth, other known process change opportunities with readily-quantifiable cost effects were incorporated in the comparison. This latter group includes greater use of recycling in the metals-producing sectors, application of subprocess modifications to textile manufacturing, and changes in consumer demand patterns for paper products. Where process change trends that are primarily or partially inspired by environmental concern have been included in the reference case economic forecast (e.g., hydrometallurgical smelting of copper or the Bayer-Alcoa process), adjustments have been made to the baseline cost estimates. Where process changes are an integral part of the Reference Case control strategy, as in the case of waste heat boilers for petroleum refinery carbon monoxide control, these values have not been adjusted because of the absence of a costed-out alternating strategy. The results indicate that savings of almost $2 billion in capital expenditures and $1 billion in annual costs can be attained by 1985 through application of process change in these industries. In addition, it should be recognized that the technologies considered do not fully exhaust the possibilities within the surveyed industries. These industries represent 15.8 percent of total capital expenditures on abatement by industrial point sources (excluding mobile sources of in emissions, municipal water treatment and waste incineration, etc.), and 14.2 percent of total annual costs.

$dTable 11 Sheet 1 of 2.
Abatement Cost Comparison:
End-Of-Pipe Controls vs. Combined EDP/Process Change Strategies

Air Pollution Control Costs - 1980

Industry	Cumulative Investment 1972-1980 (Reference Case)	Cumulative Investment 1972-1980 (Revised Value)	% Change	Annual Costs 1980 (Reference Case)	Annual Costs 1980 Revised Value)	% Change
Aluminum	2,265.1	2,142.8	-5.4%	734.2	420.1	-4.7%
Copper	1,405.1	1,292.6	-8.0%	420.1	354.6	-18.1%
Inorganic Chemicals			NOT CONSIDERED			
Lead	81.1	79.4	-2.1%	19.2	18.8	-1.8%
Petroleum Refining	1,003.0	1,003.0	0%	230.3	230.3	0%
Pulp & Paper	2,891.0	2,590.3	-10.4%	807.6	720.4	-10.8%
Textiles			NEGLIGIBLE			
Zinc	77.4	74.4	3.9%	31.2	30.0	-3.9%
Totals	7,722.7	7,182.5	-6.9%	2,242.6	2,026.6	-10.0%

Reference case value adjusted to reflect effects of process change.
Reference case value includes process change effects that cannot be estimated.

Water Pollution Control Costs - 1980

Industry	Cumulative Investment 1972-1980 (Reference Case)	Cumulative Investment 1972-1980 (Revised Value)	% Change	Annual Costs 1980 (Reference Case)	Annual Costs 1980 (Revised Value)	% Change
Aluminum	92.3	89.9	-2.6%	53.3	51.5	-3.4%
Copper	27.7	27.9	+.8%	18.6	19.0	+1.9%
Inorganic Chemicals	419.3	419.3	0%	166.7	103.2	-38.1%
Lead	5.6	5.4	-2.8%	5.9	5.7	-2.8%
Petroleum Refining	938.8	826.1	-12.0%	204.8	128.4	-35.4%
Pulp & Paper	2,869.9	2,056.7	-7.4%	606.0	499.3	-17.6%
Textiles	302.2	274.7	-9.1%	65.8	59.8	-9.1%
Zinc	16.5	15.7	-4.6%	6.0	5.7	-5.2%
Totals	4,616.7	3,715.5	-7.2%	1,127.1	872.6	-21.6%

Reference case value adjusted to reflect effects of process change.

Table 11 Sheet 2 of 2.
Abatement of Cost Comparison:
End-Of-Pipe Controls vs. Combined EDP/Process Change Strategies

Air Pollution Control Costs - 1985

Industry	Cumulative Investment 1972-1985 (Reference Case)	Cumulative Investment 1972-1985 (Revised Value)	% Change	Annual Costs 1985 (Reference Case)	Annual Costs 1985 (Revised Value)	% Change
Aluminum	2,281.8	2,010.3	-11.9%	660.3	600.2	-9.1%
Copper	1,433.8	1,210.1	-15.6%	425.5	312.1	-26.5%
Inorganic Chemicals			NOT CONSIDERED			
Lead	84.2	79.4	-5.7%	20.3	19.3	-4.8%
Petroleum Refining	1,099.5	1,099.5	0%	251.7	251.7	0%
Pulp & Paper	3,147.5	2,672.2	-15.1%	423.5	772.0	-16.4%
Textiles			NEGLIGIBLE			
Zinc	83.9	78.7	-6.2%	39.4	36.8	-6.5%
Totals	8,130.7	7,150.2	-11.7%	2,320.7	1,992.7	-15.6%

Reference case value adjusted to reflect effects of process change.
Reference case value includes process change effects that cannot be estimated.

Water Pollution Control Costs - 1985

Industry	Cumulative Investment 1972-1985 (Reference Case)	Cumulative Investment 1972-1985 (Revised Value)	% Change	Annual Costs 1985 (Reference Case)	Annual Costs 1985 Revised Value)	% Change
Aluminum	149.3	138.8	-7.0%	68.3	63.4	-7.2%
Copper	33.4	34.0	+1.9%	25.6	26.1	+1.8%
Inorganic Chemicals	727.4	709.2	-2.5%	219.0	164.3	-25.0%
Lead	6.4	5.9	-7.6%	5.5	5.1	-7.6%
Petroleum Refining	1,899.0	1,557.1	-12.0%	412.4	274.6	-33.4%
Pulp & Paper	5,905.5	5,055.1	-14.4%	1,386.9	1,006.9	-27.4%
Textiles	461.5	414.4	-10.2%	91.3	82.0	-10.2%
Zinc	20.8	19.3	-7.2%	14.3	13.3	-7.2%
Totals	9,203.3	7,933.8	-11.9%	2,223.3	1,635.7	-25.6%

Reference case value adjusted to reflect effects of process change.$s

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