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Research Triangle Park, NC 27711

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Air

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ESCALATION INDEXES FOR AIR POLLUTION CONTROL COSTS

Acknowledgments

It has become customary for every author to state, solemnly: "This report/book/article, etc., never could have been written without the help of the following individuals..." Most of the time, we'd hope, these acknowledgments are sincere. But in other cases, they are motivated more by politeness or political expediency than by an honest need to thank those who should be thanked.

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Table of Contents

I. Introduction

This report documents the work accomplished during the second *Bernard J. Steigerwald Opportunity for Independent Study*, which occurred from April to October 1994.[a] This opportunity was used to develop a group of quarterly indexes for adjusting ("escalating") air pollution control equipment costs and total annual costs from one period to another. In all, 16 indexes were developed, one equipment cost index (ECI) and one total annual cost index (TACI) for each of eight control device categories. These indexes—collectively known as the Vatavuk Air Pollution Control Cost Indexes (VAPCCI)—can be used to escalate costs from the initial ("base") period (first quarter 1994) forward to any quarter. So far, final indexes have been calculated for the second, third, and fourth quarters of 1994; preliminary indexes, for first quarter 1995. Indexes will be computed for subsequent quarters as soon as the required input data become available.

These indexes are unique, as no others have been developed for such a wide array of control devices. The only indicators similar to the VAPCCI are two equipment *Producer Price Indexes* (PPI) compiled by the U.S. Department of Labor's Bureau of Labor Statistics. The latter will be described in this report, as well. But, first things first...

Why Do We Need the VAPCCI?

For that matter, we could ask, "Why do we need the Consumer Price Index, or the Producer Price Index, or any other cost/price index?" Cost/price indexes are needed for two reasons: (1) to record changes in costs or prices over time and (2) to escalate costs or prices from one date to another. The Consumer Price Indexes are good examples. Compiled monthly by the Bureau of Labor Statistics (BLS) since 1913, they have been used for decades throughout the public and private sectors to adjust prices and (with another BLS index, the *Employment Cost Index*) wages and salaries. Consequently, they are oft-quoted in the media and frequently cited in the literature.

Nonetheless, not even such indexes as the CPI perfectly reflect the marketplace. At best, they provide a cloudy mirror. The CPI are comprised of certain "mixes" of goods and services that may or may not correspond to the mix(es) for which prices are needed. *In other words, there is no substitute for current price information obtained from suppliers of those goods and*

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[a] A "final" report was completed in October 1994, but not peer-reviewed. This report incorporates peer review comments and index values updated through first quarter 1995.

services.

For instance, if we wanted to determine the price increase in widgets from 1947 to 1994, the most accurate way to do so would be for us to survey all the widget manufacturers and analyze the data they provided to come up with an average price increase. But suppose we didn't have the time or the resources to do that? We could get the data we need from the Producer Price Index for widgets. Alas, there is *no* such PPI. Instead, we could look up the Producer Price Index for *frobbits*, which (as everyone knows) is the category of devices that resembles widgets most closely. Now, the PPI for frobbits wouldn't give us the exact price history for widgets over this 47-year period, but it would provide a close approximation. What's more, it wouldn't take nearly as long to use this PPI as it would to survey all (or even a representative sample) of the dozens of widget manufacturers presently in business.

In this respect, air pollution control devices are no different from widgets. Ideally, we wouldn't need an index to track the change in air pollution control costs or to escalate them. We just could contact air pollution control equipment vendors for price information. Wouldn't that suffice? Unfortunately, it isn't easy to obtain price data from vendors. Vendors are usually busy preparing quotations for potential (read: *paying*) customers and have little time or interest to work up price quotes for those who would use them for (in their view) "academic" purposes. Even a vendor who would agree to provide quotes would almost always require a written request and, once he/she receives it, often take weeks to respond.[b] How much easier would it be to estimate the current cost via one of the VAPCCI, using this simple equation:

$$Cost_{new} = Cost_{old}\ (VAPCCI_{j,new}/VAPCCI_{j,old}) \qquad (1)$$

where: the subscript "j" denotes the VAPCCI for control device "j"

To illustrate, suppose that the 1988 equipment cost for a fabric filter (baghouse) were $100,000 and that we wanted to estimate how much this baghouse would cost in 1994. Further, suppose that the 1988 (old) and 1994 (new) values of the VAPCCI were 100 and 130, respectively. Then, the 1994 estimated equipment cost would be:

$$Cost_{new} = \$100{,}000\ (130/100) = \$130{,}000.$$

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[b] Or *months*, as we discovered when awaiting vendor replies for this project.

In other words, according to the VAPCCI for fabric filters, the cost of this baghouse would increase by an estimated 30% during this six-year period.[a] Clearly, this VAPCCI would provide a very quick and easy method for updating costs. Using this index would save analysts time and effort, especially if they needed to escalate costs over several different time periods.

Of course, if we did use one of the VAPCCI to escalate the costs, we would have to make sure that we were using the index *correctly*. That is, if an index were designed for escalating baghouse equipment costs, we certainly shouldn't use it to update costs of electricity, labor, materials, or other items that are needed to keep a baghouse system in operation. By the same token, if a VAPCCI were designed for escalating equipment costs of, say, a wet scrubber, it shouldn't be used to update incinerator, adsorber, or other equipment costs.

Why Can't We Use Other Equipment Cost Indexes?

Before developing the VAPCCI, this author used certain published price indexes to escalate control equipment costs. These have been the *Chemical Engineering Plant Index* (CEPI), computed by and published in *Chemical Engineering* magazine, and the *Marshall and Swift Equipment Cost Index* (M&SI), also published in *Chemical Engineering*. While better than most, overall, these indexes have not been adequate air pollution control cost indicators.[b]

Developed in 1963, the CEPI has been used mainly to escalate chemical process plant construction costs. It encompasses such process equipment as heat exchangers, pipes and fittings, pumps, and compressors.[1] While some of these items are used in control devices, most are *not*. Moreover, the CEPI does not cover such control device components as fabric filter bags and electrostatic precipitator collector plates.

Updated quarterly (like the VAPCCI), the M&SI compiles cost data on an industry category basis. The 47 industries covered include "electric power," "mining and milling," "refrigerating," and "process industries". The last encompasses such categories as cement, chemicals, clay, and rubber products. A separate

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[a] The operative word here is "estimated," as indexes are intended for *predicting* current costs. They are *not* meant to be substitutes for them.

[b] However, the CEPI can be used to escalate the costs of flue gas desulfurization (FGD) systems, Claus sulfur recovery plants, sulfuric acid plants, and other stand-alone chemical processes that are often used to control air pollution.

index is developed for each of these industries. Unfortunately, each index reflects the specific mix of equipment for that particular industry, as well as costs for other commodities, such as labor.[2] Undoubtedly, some of this equipment is control equipment. However, the contribution of control equipment to the total equipment cost in, say, the portland cement industry, would be relatively small. Changes in total cement industry equipment costs would overshadow any changes in the control costs incurred there. Thus, the M&SI is too broad-based to use in accurately tracking or escalating air pollution control costs.

Newer—and more applicable—indicators are the two Producer Price Indexes mentioned above, namely those for "fabric filters" and "mechanical collectors". Before discussing them, we should present some background on the PPI, as several of them are key inputs to the VAPCCI.

The Producer Price Indexes at a Glance

Calculated and published monthly by the Bureau of Labor Statistics, the PPI measure average changes in sales prices received by domestic commodity producers in all "stages of processing". The BLS presently tracks prices for about 3,200 commodities and processes 80,000 quotations each month. There are three primary systems of indexes within the PPI program: (1) stage-of-processing indexes; (2) indexes for the net output of industries and their products; and (3) commodity indexes.

Stage-of-processing indexes track price changes for products organized by "class of buyer" and "degree of fabrication". They are grouped into three major categories: "finished goods" (commodities that will not undergo further processing); "intermediate materials, supplies, and components" (commodities that have been processed but require further processing); and "crude materials for further processing" (products entering the market for the first time that have not been manufactured or fabricated and that are not sold directly to consumers). Each of these categories encompasses several subcategories, covering such products as foodstuffs, fuels, consumer goods, and capital equipment. Also, each stage-of-processing index has a reference base of 1982 = 100.

The second system of indexes includes the PPI for the net output of industries and their products. These industry price indexes are grouped according to the Standard Industrial Classification (SIC) and the Census product code extension of the SIC. They are also compatible with other economic time series organized by SIC codes, such as data on employment, wages, and productivity. Each index is classified according to a four-digit "industry code," followed by a two- to five-digit code number denoting the specific product class, product, and (in some cases) subproduct. Consider this example:

Industry: "Industrial and commercial fans and blowers and purification equipment" (3564)

Product class: "Dust collection and other air purification equipment for industrial gas cleaning systems" (3564-6)

Product: "Particulate emission collectors" (3564-651)

Subproduct: "Fabric filters" (3564-65113)

Thirdly, the PPI commodity indexes structure organizes products by similarity of end-use or material composition. These eight-digit indexes track commodity prices irrespective of the industries in which they are produced. Some of the commodity indexes correspond to the industry price indexes, the differences being in their reference bases and index levels. While most of the commodity indexes have a base of 1982 = 100, most of the industry indexes have different bases, each corresponding to the year and month that an index was introduced. (For instance, the reference date of the "Fabric filters" subproduct index is *June 1989*.) As a result, the absolute values of the indexes are different. Nevertheless, the *relative*, month-to-month changes in the respective commodity and industry price indexes are identical.

All three classes of indexes are published in the monthly BLS periodical *Producer Price Indexes*. For each index, the following information is listed: index name, code number, base (month-and-year), index values, and percent changes. The index values are provided for the current period, preceding period, and for the period four months previous. The percent changes are given to the current period both from the previous period and from the period twelve months before, as shown in Figure 1. Note that the percent changes are listed as "unadjusted". This means that the index values have not been "seasonally adjusted" to account for price movements resulting from normal weather patterns, regular production and marketing cycles, model change-overs, seasonal discounts, and holidays. However, to cost analysts, marketing specialists, purchasing agents, and similar professionals, the *unadjusted* index data are of primary interest, for these data are generally cited in escalating longterm contracts, such as purchasing agreements. For this reason, the VAPCCI have been based on the unadjusted PPI.

To supplement information in their *Producer Price Indexes* periodical, the BLS will, upon request, distribute computer printouts of the various PPI. (See Figure 2.) If the requester so desires, the printout can list the PPI from the initial reporting period to the latest month for which the PPI are available. In the case of the "Metals and metal products" commodity price indexes, the initial period was January 1926, so

Figure 1. Sample Producer Price Index Listings in *Producer Prices*

Table 5. Producer price indexes for the net output of selected industries and their products—Continued

Industry and product[1]	Industry code	Product code	Index base	Index July 1993[2]	Index Oct. 1993[2]	Index Nov. 1993[2]	Unadjusted percent change to Nov. 1993 from — Nov. 1992	Unadjusted percent change to Nov. 1993 from — Oct. 1993
Speed changers, industrial high-speed drives, and gears—Continued								
Secondary products and miscellaneous receipts		3566-SM						
Miscellaneous receipts		3566-M	07/84	138.4	138.4	138.4	4.7	0.0
Resales		3566-Z89	07/84	125.0	125.0	125.0	(3)	0
Secondary products		3566-S	12/83	138.1	143.9	143.5	12.1	-.3
Other secondary products		3566-SSS	12/83	149.7	161.7	160.8	23.6	-.6
Power transmission equipment, n.e.c.		3568-S	12/83	128.0	128.6	128.6	2.0	0
Industrial process furnaces and ovens	3567		06/81	146.1	147.4	147.5	1.9	.1
Primary products		3567-P	06/81	143.0	144.3	144.4	1.9	.1
Electric industrial furnaces, ovens, and kilns, excluding induction		3567-1	06/81	146.5	149.4	149.4	2.8	0
Electric furnaces		3567-11	12/86	116.0	119.0	119.0	3.5	0
Metal processing and heat treating (such as annealing, hardening, carburizing, etc.)		3567-118	12/86	116.5	122.3	122.3	5.1	0
Electric industrial ovens and kilns, including infrared		3567-19	12/86	122.1	122.4	122.3	.8	-.1
Fuel-fired industrial furnaces, ovens, and kilns		3567-2	06/81	137.4	138.2	(3)	(3)	(3)
Fuel-fired ovens and kilns		3567-29	12/86	(3)	(3)	(3)	(3)	(3)
Electrical heat. equip. for industrial use, n.e.c. (exc. soldering irons) and parts and attach		3567-5	06/81	150.4	151.3	151.5	2.2	.1
Industrial electric heating units and devices, except heating units for electric furnaces		3567-55						
All other industrial heating units and devices, incl. immersion heaters, compound pots, etc.		3567-559	06/81	169.1	169.1	169.1	1.7	0
Parts and attach. for ind. furn. and ovens, including electric heating units		3567-59	06/81	137.0	139.7	140.4	3.2	.5
Secondary products and miscellaneous receipts		3567-SM						
Secondary products		3567-S	06/81	166.1	166.8	167.5	2.5	.4
Other secondary products		3567-SSS	06/81	167.6	168.5	168.5	2.1	0
Power transmission equipment, n.e.c.	3568		12/84	128.3	128.8	128.7	2.3	-.1
Primary products		3568-P	12/84	126.9	127.3	127.3	2.4	0
Plain bearings and bushings, except automotive and aircraft		3568-1	12/84	116.5	117.8	117.0	1.8	-.7
Plain bearings and bushings, unmounted, machined, excluding carbon and graphite		3568-115	12/84	114.7	115.9	115.0	1.7	-.8
Power transmission equipment, except speed changers, drives, and gears, n.e.c.		3568-3	12/84	129.1	129.4	129.6	2.6	.2
Clutches		3568-3A	12/84	133.9	133.9	133.9	1.3	0
Friction type		3568-311	12/84	127.8	127.8	127.8	.7	0
All other clutches		3568-319	12/84	142.0	142.0	142.0	2.3	0
Flexible couplings		3568-3B	12/84	122 9	124.6	124.0	1.2	-.5
1-inch nominal bore and over, gear type		3568-321	12/84	93.2	93.7	93 7	-4.9	0
1-inch nominal bore and over, other than gear type		3568-322	12/84	141.9	144.8	143 6	4.3	-.8
Less than 1-inch nominal bore		3568-324	12/84	130.7	130.7	130.7	2.0	0
Chains for sprocket drives		3568-3C	12/84	120.8	120.9	120.9	2.5	0
ASA standard roller chain, 3-inch and under in pitch		3568-332	12/84	114.8	115.0	115.0	4.0	0
Other chains for sprocket drives		3568-335	12/84	125.9	125.9	125.9	1.0	0
Sprockets		3568-3D	12/84	122.8	124.5	(3)	(3)	(3)
Pulleys		3568-3E	12/84	119.4	118.9	118.9	6.4	0
Pulleys		3568-351	12/84	119.4	118.9	118.9	6.4	0
Sheaves		3568-3F	12/84	137.0	137.0	137.0	4.2	0
Single drive		3568-361	12/84	136.8	136.8	136.8	5.5	0
Other power transmission equipment, except aircraft, automobile, truck, and bus		3568-3G	06/89	113.7	113.7	114.2	2.9	.4
Ball joints, drive and flexible shafts, and drive shaft parts		3568-393	06/89	110.1	112.0	112.0	2 4	0
Mechanical valve operators and transmissions, excl. marine transmissions		3568-394	06/89	120 7	118.8	121.0	.7	1 9
All other mechanical power transmission equip., except aircraft, automobile, truck, and bus		3568-399	06/89	110 7	110 7	110 7	1 8	0
Secondary products and miscellaneous receipts		3568-SM						
Miscellaneous receipts		3568-M	02/85	130 1	130.1	130 1	1 5	0
Resales		3568-Z89	02/85	124 6	124.6	(3)	(3)	(3)
Secondary products		3568-S	12/84	135.8	136.8	136.8	2.0	0

Figure 2. Sample Producer Price Index Printout

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BUREAU OF LABOR STATISTICS

LABSTAT SERIES REPORT

SURVEY PC NOT SEASONALLY ADJUSTED

SERIES PCU34438111 Bare tube heat exchangers 8003

BEGIN DATE 80/03 END DATE 94/03 DATE OF LAST UPDATE 04/08/94

YR	JANUARY	FEBRUARY	MARCH	APRIL	MAY	JUNE	JULY	AUGUST	SEPTEMBER	OCTOBER	NOVEMBER	DECEMBER	ANNUAL
89	176.4	178.2	177.6	176.5	177.2	179.7	180.1	180.2	180.8	180.8	181.4	182.2	179.2
90	182.8	183.1	183.4	183.8	184.6	184.5	184.5	184.7	185 8	185.8	185 7	187.5	184 7
91	190.5	189.2	189.4	190.1	189.0	189.5	189.5	189.5	189.5	188.9	188 9	188.9	189.4
92	190.2	190.4	191.6	191.6	191.6	191.6	192.0	192.0	191 9	191 9	192.0	191.9 (3)	191.5 (3)
93	192.0 (3)	192.3 (3)	192.3 (3)	192.7	192.7	192.7	192.7	192.4	192.4	192.2	192.2	192.2	192.4
94	192.2	192 2	192.7										

SURVEY PC NOT SEASONALLY ADJUSTED

SERIES PCU34438115 Fin tube heat exchangers 8003

BEGIN DATE 80/03 END DATE 94/03 DATE OF LAST UPDATE 04/08/94

YR	JANUARY	FEBRUARY	MARCH	APRIL	MAY	JUNE	JULY	AUGUST	SEPTEMBER	OCTOBER	NOVEMBER	DECEMBER	ANNUAL
89	142.4	141.0	146.0	148.8	145.7	145.7	145.7	145.8	146.1	147.3	148.3	148.8	146 0
90	149.0	148.1	152.9	153.0	153.4	156.0	156.2	156.3	156.3	156 9	156 9	157.2	154.3
91	157.0	156.9	157.0	156.3	156.6	156.5	156.5	156.5	158.8	158.8	159.0	160.7	157.6
92	161.3	161.3	161.0	161.7	160.8	160.9	161.6	161.8	161 8	161.0	161 0	161.0 (3)	161.3 (3)
93	161.0 (3)	161.3 (3)	161.1 (3)	161.1	160.7	161.8	161.7	160.3	160.4	160.0	160.2	161.3	160.8
94	161.6	162.0	160.5										

- 3) PRELIMINARY DATA

that nearly 70 years of data are available. As Figure 2 indicates, a PPI printout lists both monthly and annual indexes. Each annual index is simply the arithmetic average of the 12 monthly indexes for the year in question. Also, for the most recent (usually three) months, the index values are listed as "preliminary". These index values are subject to revision by BLS one time, four months after being published as "preliminary," to reflect the availability of late reports and corrections by respondents. Finally, the letters "NA" mean that no index was reported for the month indicated.

The foregoing discussion on the PPI was taken from a BLS technical note, "Brief Explanation of Producer Price Indexes".[3] If the reader would like more background on the PPI, he/she should consult this reference or "Producer Prices," chapter 16 in the *BLS Handbook of Methods*.[4]

The PPI and Control Equipment Cost Escalation

Of the hundreds of PPI, only two have potential use for escalating air pollution control equipment costs. These are the "Fabric filters" and "Mechanical collectors" subproduct indexes, discussed above. Like the other PPI, each value reflects the average of data from at least two of three respondents in the BLS survey pool.[5] These respondents are control equipment manufacturers. Because these indexes were first compiled in June 1989, they are newer than most of the PPI. Figure 3 displays these PPI from their inception through July 1994.

Although it would seem that both PPI are ideally suited to adjusting control equipment costs, they have two shortcomings. First, neither index specifies such important facts as the sizes and designs of the control equipment to which the index applies. As we'll see in Section II of this report, these specifications are important to the formulation of an escalation index. Second, the "Mechanical collectors" index is of limited value, simply because mechanical collectors (cyclones) are rarely used as primary particulate control devices. Rather, mechanical collectors mainly are used upstream of fabric filters, electrostatic precipitators, or wet scrubbers to remove larger particles from the waste gas. Thus, they are auxiliary equipment, like screw conveyors, spray chambers, fans, ductwork, and the like.

Despite these weaknesses, these PPI—especially the "Fabric filters" index—are certainly more relevant to escalating control costs than are the Chemical Engineering Plant and Marshall & Swift Indexes. At the very least, they can be compared to the VAPCCI and, in some cases, augment them.

Figure 3. Historical Listings of "Fabric Filters" and "Mechanical Collectors" Producer Price Indexes[a]

SURVEY PC NOT SEASONALLY ADJUSTED
SERIES PCU3564#65113 Fabric filters 8906
BEGIN DATE 89/06 END DATE 94/03 DATE OF LAST UPDATE 04/08/94

YR	JANUARY	FEBRUARY	MARCH	APRIL	MAY	JUNE	JULY	AUGUST	SEPTEMBER	OCTOBER	NOVEMBER	DECEMBER	ANNUAL
89						100.0	100.2	101.0	101.0	101.0	102.6	102.6	NA
90	102.6	103.3	103.3	103.3	103.5	103.4	103.4	104.0	104.0	104.0	104.0	105.0	103.7
91	105.4	106.3	106.3	106.7	106.7	107.5	107.5	107.5	107.5	107.5	107.1	107.1	106.9
92	107.3	107.3	107.3	107.3	108.3	108.3	108.3	108.8	108.8	108.8	108.8	108.8	108.2
												(3)	(3)
93	108.8	108.8	105.8	106.0	107.3	107.3	107.2	107.5	107.5	107.5	107.8	107.5	107.4
				(3)	(3)	(3)	(3)						
94	109.1	109.1	109.1	109.2	109.1	109.1	110 1						

SURVEY PC NOT SEASONALLY ADJUSTED
SERIES PCU3564#65115 Mechanical collectors 8906
BEGIN DATE 89/06 END DATE 94/03 DATE OF LAST UPDATE 04/08/94

YR	JANUARY	FEBRUARY	MARCH	APRIL	MAY	JUNE	JULY	AUGUST	SEPTEMBER	OCTOBER	NOVEMBER	DECEMBER	ANNUAL
89						100.0	100.4	100.1	100.1	100.1	102.6	102.6	NA
90	102.6	102.6	103.0	103.0	103.0	103.0	103.0	106.1	106.1	106.1	106.1	106.1	104.2
91	106.4	108.0	108.0	110.0	110.0	110.0	110.0	110.0	110.0	110.0	110.0	110.0	109.3
92	110.0	110.0	110.0	110.0	110.0	110.0	110.0	110.0	110.0	110.0	110.0	110.0	110.0
				(3)	(3)	(3)	(3)						
94	111.8	111.8	111.8	111.8	111.8	111.8	111.8						

3) PRELIMINARY DATA

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[a] No values are shown for the "Mechanical Collectors" PPI for 1993, because no data were reported for that year.

The Rest of this Report

The next section of this report describes how the eight control device equipment cost indexes were developed and compares them to other published indexes. Also presented are "historical" index data for seven of these devices, which were obtained from control equipment vendors.

Section III presents the total annual cost indexes (TACI), which serve to supplement the corresponding equipment cost indexes. Also presented in this section is a mini-course in total annual cost estimating, covering cost terminology, input variables, and related topics. A detailed illustration of the TACI is also given.

The total annual cost spreadsheet programs are described in Section IV. These programs were written to facilitate the computation of the capital and annual cost "weighting factors" that were used, in turn, to develop the total annual cost indexes.

In Section V we talk about how the VAPCCI can best be distributed to known and potential users, mainly cost analysts and other technical personnel. These will include not only those in EPA and other control agencies, but also users in industry, academia, and other sectors.

Section VI discusses future work needed to update, refine, and expand these indexes. Estimates of resources (both in-house and contractual) for accomplishing this work also are given.

Appendix A tabulates the control equipment component price factors which were used in developing the equipment cost indexes. This is followed by a list of the references cited in the report.

II. Equipment Cost Indexes

The foundation of the VAPCCI are the control device equipment cost indexes (ECI). Each of the ECI allows the user to adjust equipment costs forward from the first quarter 1994 to any future quarter. Moreover, the ECI are key inputs to the total annual cost indexes (TACI), which will be discussed in Section III.

As stated in Section I, ECI have been developed for eight categories of control devices. These are as follows:

- ✓ Carbon adsorbers (fixed-bed regenerable)
- ✓ Catalytic incinerators (fixed-bed)
- ✓ Flares (elevated)
- ✓ Gas absorbers (packed column)
- ✓ Regenerative thermal oxidizers
- ✓ Refrigeration systems
- ✓ Thermal incinerators (recuperative)
- ✓ Wet scrubbers (particulate control)

Note that all but one of the devices control gases (primarily volatile organic compounds). The sole exception is the wet scrubbers category, which includes venturis, wet impingement scrubbers, and similar devices.

Before describing the various ECI in detail, we need to discuss the methodology that was employed to structure the indexes, develop survey forms, and collect and analyze the input data.

Structuring and Surveying

In structuring the ECI, we first selected the major categories of add-on control devices used in controlling air pollution from point sources. Why was the selection limited to add-ons? For one thing, despite the introduction of various process modifications—material substitutions, equipment changes, chemical injections, and the like—add-ons are still the most commonly used control methods and the methods with which technical personnel are most familiar. Secondly, due to time and resource constraints, we were unable to survey, let alone analyze the costs of, the dozens of process modifications, fugitive emission controls, and sundry other control technologies being used today. This is not to say that indexes should not be developed for these technologies. As we discuss in Section V, there is considerable merit for doing so eventually. Rather, we simply had to "draw the line" somewhere. And that line was drawn around the add-ons listed above.

Our next step was to develop a survey form to send to control equipment vendors. Because we wanted to compare past ("historical") price changes to future changes predicted by the ECI, we devised a survey form that requested both kinds of information. Also, because each type of control device has unique features, we crafted a different form for each of the eight categories. Figure 4 depicts an example, the survey form for flares. Part I of the form requests historical *list* prices by quarter from 1989 to 1994. Why did we select 1989 as the starting date? We did so because, according to a well-accepted cost engineering rule-of-thumb, costs should *not* be escalated over periods longer than five years. Note that the form asks for prices to be expressed relative to the price in first quarter 1989, which is arbitrarily set at 100.0. This not only made it easier for vendors to respond to the survey, but it also facilitated analysis of the results. Finally, prices were requested for *all* devices manufactured by the vendor surveyed. We did not ask for price history breakdowns according to different device sizes or designs.

Not so in Part II of the form. Notice that it requests data for three device sizes: "small," "medium," and "large". Because different control devices have differing applications, these sizes vary according to device type. Based on our experience, we chose three size *ranges* for each device—a small, a medium, and a large—to reflect the capacities typically installed. In Figure 4, for instance, the small size range corresponds to a flare tip diameter of < 12 inches, while the medium and large ranges correspond to 12 - 48 inches and > 48 inches, respectively.

For each size range, the form asks for price breakdowns ("percent of list price") according to device component. These are the primary components that make up the device. Some of these components, such as fans and instrumentation, are common to many devices, while others (e.g., flare burner tips) are found with only specific types. As explained below, these price breakdowns were used to compute the the equipment cost indexes.

The Survey Responses

Survey responses were simply averaged and tabulated. No effort was made to "weight" the data before averaging, as each response was given equal credence.

Historical price data: Some vendors reported annual, rather than quarterly prices. To make them compatible with other responses, we assigned the same price to each quarter of a given year. Also, a few vendors were unable or unwilling to report prices for one or more quarters during the five-year period. Rather than entering zeroes or other assumed numbers for these quarters, we just reported "no data" and did not average them with the other responses.

Figure 4. Example Vendor Survey Form

Part I. Historical Price Data

For each of the dates below, please indicate the overall list prices of your flares relative to the price in first quarter 1989. If your prices changed less (or more) often, please so indicate.

Year	Quarter	Relative Price
1989	First	100.0
	Second	
	Third	
	Fourth	
1990	First	
	Second	
	Third	
	Fourth	
1991	First	
	Second	
	Third	
	Fourth	
1992	First	
	Second	
	Third	
	Fourth	
1993	First	
	Second	
	Third	
	Fourth	
1994	First	
	Second	

Did your price changes vary according to equipment size, style, etc.? If so, please indicate the extent to which they varied.

Figure 4 (cont'd.)

Part II. Component Price Data

Please estimate how much (%) each of the following components has contributed to the total list price of your flares. Include labor, materials, and profit. If you cannot give an exact percentage for a component, please list a range.

Component	Percent of List Price		
	Small[a]	Medium[b]	Large[c]
Flare burner tip			
Pilot burners			
Flare tower (stack) & support			
Utility piping (from base)			
Liquid & gas seals			
Ladders & platforms			
Dampers & valves			
Knockout drum			
System fan			
Fan motor & drive			
Instrumentation & controls			
Other (specify)			
Totals:	100.0	100.0	100.0

[a] Flare tip diameter: < 12 inches.

[b] Flare tip diameter: 12 to 48 inches.

[c] Flare tip diameter: > 48 inches.

Component price data: There were some blanks in these responses as well. For example, a few vendors did not report data for one or more size categories, because they had not built units of these sizes. Here again, these blanks were reported as "no data" and omitted from the data averaging. While some vendors reported zeroes for the "Other" component, a few completed that line on the form. Most of the "Other" costs consisted of engineering, project management, startup, and the like. However, one vendor included "structural supports" in this category. Finally, some vendors indicated that the size categories on the survey form did not correspond to the sizes of the units they manufactured. Instead of reporting no data for these size ranges, they entered results, but noted that they applied to different sizes.

Results: Historical Price Data

We received enough vendor responses to present historical price data for seven control device categories. These results are shown in Tables 1 and 2. Note that, over this period, the prices of six of the seven device categories increased, by amounts ranging from 6.7% (catalytic incinerators) to 20.5% (thermal incinerators). The exception is the refrigeration systems category, whose prices *decreased* by 0.7%, relative to first quarter 1989 prices. The average change for the seven devices was +10.4%.

It is very difficult to account for these price changes, as many factors—the costs of raw materials, fabrication labor costs, and market forces—affect pricing. However, in two cases—catalytic incinerators and refrigeration systems—the changes can be at least partly explained. With catalytic incinerators, a drop in catalyst prices led vendors to lower their prices by approximately 7% between fourth quarter 1991 and first quarter 1992.[a] (See Table 1.) Although catalytic incinerator prices crept upward during the next two years, they did not return to the third quarter 1991 peak level of 107.1. Similarly, a design innovation marketed by a leading vendor of refrigeration systems prompted him to lower his prices in mid-1993.

How do these price changes compare to changes reflected by published indexes? In Table 3 are listed the Marshall and Swift (M&SI) and the Chemical Engineering Plant (CEPI) Indexes for 1989-1st quarter 1994. The values shown are the M&SI composite and the "Equipment" component of the CEPI. The CEPI/Equipment index values have been converted from monthly to quarterly figures by simply averaging the index values for the months of a

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[a] Telephone conversation between William M. Vatavuk (U.S. Environmental Protection Agency, Research Triangle Park, NC) and Darrell Bump (ABB Air Preheater, Wellsville, NY), August 1994.

Table 1. Control Device Equipment Relative Prices: 1989-94 (Catalytic Incinerators through Refrigeration Systems)

Year	Quarter	Relative Price (1st quarter 1989 = 100)			
		Catalytic Inciner.	Flares	Gas Absorbers	Refrig. Systems
1989	First	100.0	100.0	100.0	100.0
	Second	100.3	100.0	100.5	100.0
	Third	100.4	101.5	101.0	100.0
	Fourth	100.9	101.5	101.5	100.0
1990	First	102.7	104.0	103.4	103.3
	Second	103.0	104.0	103.8	103.3
	Third	103.8	110.0	104.2	103.3
	Fourth	104.2	110.0	104.6	105.5
1991	First	106.8	110.0	106.0	107.3
	Second	107.0	110.0	106.4	107.3
	Third	107.1	110.0	106.8	107.3
	Fourth	107.1	110.0	107.2	107.3
1992	First	100.2	113.0	107.6	109.6
	Second	100.2	113.0	108.0	109.6
	Third	100.2	113.0	108.4	109.6
	Fourth	100.2	113.0	108.9	109.6
1993	First	104.2	113.0	109.0	110.8
	Second	104.2	113.0	109.1	110.8
	Third	104.2	113.0	109.3	99.3
	Fourth	104.2	113.0	109.4	99.3
1994	First	106.7	113.5	112.2	99.3
Overall Change (%):		+ 6.7	+ 13.5	+ 12.1	- 0.7

Table 2. Control Device Equipment Relative Prices: 1989-94 (Regenerative Thermal Oxidizers through Wet Scrubbers)

Year	Quarter	Relative Price (1st quarter 1989 = 100)		
		Regenerative Thermal Oxidizers	Thermal Incinerators	Wet Scrubbers
1989	First	100.0	100.0	100.0
	Second	100.2	100.7	100.5
	Third	100.6	101.0	102.0
	Fourth	101.2	101.8	102.5
1990	First	101.6	106.9	102.9
	Second	103.9	108.1	103.3
	Third	104.3	108.2	103.7
	Fourth	104.6	109.3	104.1
1991	First	105.8	112.6	106.0
	Second	105.9	112.7	106.4
	Third	107.2	112.8	106.8
	Fourth	107.9	113.3	107.2
1992	First	108.0	115.3	107.6
	Second	108.1	115.6	108.0
	Third	109.3	115.7	109.4
	Fourth	109.6	115.8	109.8
1993	First	114.7	117.9	110.0
	Second	114.8	118.3	110.1
	Third	115.0	118.3	110.3
	Fourth	109.7	118.5	110.4
1994	First	108.9	120.5	112.1
Overall Change (%):		+ 8.9	+ 20.5	+ 12.1

Table 3. Marshall and Swift Equipment and Chemical Engineering Plant Indexes: 1989 - 1st Qtr.1994[6,7]

Year	Quarter	Index Value	
		M & S	CEPI/Equipment
1989	First	884.7	388.1
	Second	894.7	391.8
	Third	897.0	392.4
	Fourth	903.9	391.8
1990	First	905.8	388.9
	Second	912.2	391.3
	Third	917.9	393.6
	Fourth	924.5	395.1
1991	First	925.9	396.0
	Second	928.6	397.5
	Third	935.1	397.8
	Fourth	932.9	396.5
1992	First	932.9	394.7
	Second	943.5	393.1
	Third	949.7	390.2
	Fourth	946.1	390.8
1993	First	952.4	392.1
	Second	966.6	393.9
	Third	966.9	394.9
	Fourth	970.8	396.1
1994	First	980.3	400.4
Overall Change (%):		+ 10.8	+ 3.2

given quarter. Over this five-year period, the M&SI increased by 10.8%. This increase is higher than the price increases for three of the seven devices. More importantly, the M&SI increase is quite close to the average price increase, 10.4%. Good as this agreement is, the fact remains that the M&SI increase does *not* reflect the wide (-0.7 to +20.5%) range in the device price changes.

The "Equipment" component of the CEPI grew by a much smaller amount (3.2%) than did the M&SI. This change in the CEPI was much lower than the cost increases for seven of the eight devices, and higher than the change registered by the eighth (refrigeration systems, - 0.7%). Clearly, the CEPI was a poor barometer of control device price changes, at least during this five-year period.

What can we learn from these comparisons? *If these two indexes are representative, we can conclude that a published index* ***might*** *track the* ***average*** *price of control equipment reasonably well. However, because device price histories are so diverse, no published index alone can provide an acceptable indicator of the price changes for a given type of air pollution control equipment.*

Results: Component Price Data

As mentioned above, we received enough data from vendors to develop equipment cost indexes (ECI) for eight control device categories. These included the seven for which we have compiled historical price data plus carbon adsorbers. The averages of the reported component price percentages (factors) for these devices are listed in Appendix A. Here, we will focus on one of the categories—gas absorbers—as a "case study" and examine it in detail. We picked gas absorbers for three reasons: (1) they are widely used for gaseous emissions control, (2) they are complex devices with many components, and (3) by virtue of the *OAQPS Control Cost Manual*[8] chapter on gas absorbers, there is thorough, timely background material available for sizing and costing them. We will continue to focus on gas absorbers as we progress through this report.

First, consider the component price data, as shown in Table 4. Of the dozen components listed, the absorber column accounts for the largest fraction (0.17 to 0.257) of the equipment price for all three sizes. At approximately 0.11 and 0.10, the next largest contributors are the "instrumentation & controls" and the "system fan," respectively. The remainder of the price is more or less equally divided among the other nine components. Note, however, that these fractions vary among the small, medium, and large sizes. This is especially true for the "absorber column," "packing," and "other" components. Similar variations occur for the other seven device categories. (See Appendix A.)

Table 4. Average Reported Gas Absorber Component Price Factors

Component	Fraction of List Price		
	Small[a]	Medium[b]	Large[c]
Absorber column[d]	0.235	0.257	0.170
Packing	0.090	0.067	0.065
Platforms and ladders	0.040	0.043	0.065
Internal piping	0.060	0.050	0.065
Recirculation tank	0.085	0.100	0.080
Pumps	0.090	0.087	0.085
Dampers & valves	0.060	0.043	0.050
Mist eliminator	0.045	0.043	0.065
System fan	0.100	0.093	0.115
Fan motor & drive	0.070	0.053	0.070
Instrumentation & controls	0.110	0.107	0.110
Other[e]	0.015	0.057	0.060
Totals:	1.000	1.000	1.000

[a] Capacity: < 2,000 acfm. However, one vendor specified an upper limit of 10,000 acfm.

[b] Capacity: 2,000 - 40,000 acfm. However, one vendor specified a range of 10,000 - 40,000 acfm.

[c] Capacity: > 40,000 acfm.

[d] Including: gas inlet and outlet ports; liquid inlet port and outlet port/drain; liquid distributor/redistributor; sump space; and, as applicable, trays or packing support plates.

[e] Includes "engineering".

Constructing the Equipment Cost Indexes

The component price factors comprise one of the two sets of inputs needed to construct the equipment cost indexes (ECI). The second set are the appropriate Producer Price Indexes (PPI). As explained in Section I, the PPI are compiled and published monthly by the Bureau of Labor Statistics. Of the hundreds of PPI, certain ones correspond to the components comprising the control devices. How were the "right" PPI selected? First, we reviewed the lists of control device components and attempted to find matches among the PPI. For example, the "pumps" component, which pertains to gas absorbers and wet scrubbers, corresponds to PPI #3561-13, "Centrifugal pumps". We were able to find PPI for most of the components in this way. However, there were no published PPI for several components. For the latter, we used surrogates.

For instance, as a surrogate for the column component in the gas absorbers list, we used the PPI for "Laminated plastic plate, sheet, and profile shapes" (PPI # 3083-1). Our reasoning was that, as most absorber columns are fabricated of FRP (fiberglass-reinforced plastic), the price of these columns would follow changes in the price of laminated plastic plate. This is a reasonable assumption, given that absorber vendors typically fabricate their vessels, mist eliminators, recirculation tanks, and other major components, while they usually purchase their pumps, fans, piping, and other auxiliaries. Although there are exceptions, most control device vendors operate in such a fashion. That is, they fabricate the major equipment items, purchase the smaller components from other vendors, and assemble all of them into a finished control system.

Table 5, which lists the PPI and other data used to construct the gas absorbers ECI, reflects this reasoning. Notice that Table 5 also contains the various index values for the first and second quarters of 1994. In the case of the PPI, these values have been obtained by simply averaging the indexes for the months of each quarter. (However, the quarterly BLS Employment Cost Index values are listed as published.) Of the indexes listed, all have increased, except for "Centrifugal pumps," which dropped, and "Unsupported plastic profile shapes, rods, & tubes/polyethylene," which did not change.

The equipment cost index for gas absorbers was constructed by "marrying" the data in Tables 4 and 5, in the following manner. First, we selected special quantities—the *equipment cost weighting factors.* Each equipment cost weighting factor denotes the fraction of the total equipment cost that a given component contributes. Thus, *the equipment cost weighting factors are identical to the component price factors listed in Table 4 and Appendix A.* Referring again to Table 4, the weighting factors for the absorber column would be 0.235, 0.257,

Table 5. Indexes Used In Contructing the Gas Absorbers Equipment Cost Index

Component	Producer Price Index (number)	Index Value	
		First[a]	Second
Absorber column	Laminated plastic plate, sheet, and profile shapes (3083-1)	129.4	130.5
Packing	Unsupported plastic profile shapes, rods, & tubes/polypropylene (3082-105)	97.5	97.5
Platforms & ladders	Metal ladders, including ladder accessories (1089-0557)	98.0	98.8
Internal piping	Plastic pipe (3084)	109.2	106.5
Recirculation tank	(Same as absorber column)	129.4	130.5
Pumps	Centrifugal pumps (3561-13)	146.4	147.3
Dampers & valves	Air-conditioning ducts, including dust-collecting (3444-637)	125.7	127.1
Mist eliminator[b]	(Same as absorber column)	129.4	130.5
System fan	Centrifugal blowers & fans (3564-3)	130.4	130.0
Fan motor & drive	Universal motors, A.C.& D.C. (3621-12)	100.3	102.6
Instrumentation & controls	Process control instrumentation (1182)	139.2	139.9
Other (engineering)	Employment Cost Index (professional specialty & technical occupations)	124.6	125.3

[a] These are the index values for first and second quarter 1994.

[b] Mist eliminators are installed by a vendor and sold with the FRP columns. They also are fabricated from FRP. Other mist eliminator designs employ stainless steel and other materials and may be sold as stand-alone units. Prices of the latter would be escalated via PPI different from those shown in this table.

and 0.170, respectively, for the "small," "medium," and "large" units.

Next, we multiplied each weighting factor by the ratio of the PPI or Employment Cost Index for the most recent quarter by the corresponding index value for the base quarter (first quarter 1994). Based on the Table 5 data, this ratio for absorber columns would be 130.6/129.4 = 1.009, or a 0.9% increase. The products of the weighting factors and index ratio for absorber columns would be 0.237 (small), 0.259 (medium), and 0.172 (large).

Lastly, we summed these weighting factor-index ratio products and multiplied the sum by 100 to obtain the ECI for the period in question (second quarter 1994). For gas absorbers, the ECI were 100.51 (small), 100.53 (medium), and 100.48 (large). In this instance, the ECI values were quite close.

Tables 6 to 9 show the ECI for the eight control devices for second, third, and fourth quarter 1994 and first quarter 1995, respectively. Except for first quarter 1995 (which are preliminary), all the ECI's are final values. In each table are listed the ECI's for the "small," "medium," and "large" device size ranges, as well as the "averages" (arithmetic means) of these three. Also, to give an indication of how the ECI varies according to device size category, each table includes a column labeled "Range/Average x 100%". This column lists the ratio of the ECI range (highest - lowest) and the average ECI (minus 100, the baseline ECI), all times 100%. For example, in Table 9, the highest, lowest, and average ECI's for carbon adsorbers are 106.72, 104.87, and 106.02, respectively. The range/average (R/A) ratio is, therefore:

$$R/A\ ratio = [(106.72 - 104.87)/(106.02 - 100)] \times 100\%$$

$$= 30.7\%.$$

The next highest R/A ratio in Table 9 is 26.8% (wet scrubbers), though the others are somewhat lower, ranging from 1.5 to 9.0%. The R/A ratios in Tables 6 to 8 behave similarly. That is, one or two are large (> 20%), while the others are lower. There is no discernible pattern to this behavior, however. The ratios do not increase with time (i.e., the further we get from the first quarter 1994 baseline). Nor are the ratios consistently larger for some devices and smaller for others. The only conclusion that we can draw is that for most (i.e., 6 of the 8) devices in a given quarter the R/A ratios are relatively low—typically, < 20%. On the whole, this indicates a somewhat

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[c] This is *not* a Producer Price Index, although it also is compiled and published by the Bureau of Labor Statistics.

Table 6. Control Device Equipment Cost Indexes: Second Quarter 1994

Control Device	Equipment Cost Index (First Quarter 1994 = 100)				
	Small	Medium	Large	Average[a]	Range/ Average x 100%[b]
Carbon adsorbers	100.95	101.21	101.28	101.15	28.7
Catalytic incinerators	100.96	100.89	100.86	100.90	11.1
Flares	100.69	100.74	100.76	100.73	9.6
Gas absorbers	100.51	100.53	100.48	100.51	9.8
Refrigeration systems	100.41	100.41	100.41	100.41	0
Regenerative thermal oxidizers	100.84	100.86	100.85	100.85	2.4
Thermal incinerators	100.76	100.77	100.76	100.76	1.3
Wet scrubbers	100.59	100.58	100.61	100.59	5.1

[a] Arithmetic averages of the three ECI values.

[b] Calculated as follows:
R/A = {(High Index-Low Index)/|Average index-100|} x 100%.

Table 7. Control Device Equipment Cost Indexes: Third Quarter 1994

Control Device	Equipment Cost Index (First Quarter 1994 = 100)				
	Small	Medium	Large	Average[a]	Range/ Average x 100%[b]
Carbon adsorbers	100.79	101.38	101.43	101.20	53.3
Catalytic incinerators	103.04	103.02	103.03	103.03	0.7
Flares	99.93	99.71	99.62	99.75	124.
Gas absorbers	100.90	100.94	100.96	100.93	6.5
Refrigeration systems	100.49	100.50	100.45	100.48	10.4
Regenerative thermal oxidizers	101.92	102.16	102.16	102.08	11.5
Thermal incinerators	101.81	101.86	101.82	101.83	2.7
Wet scrubbers	101.26	101.32	101.43	101.34	12.7

[a] Arithmetic averages of the three ECI values.

[b] Calculated as follows:
R/A = {(High Index-Low Index)/|Average index-100|} x 100%.

Table 8. Control Device Equipment Cost Indexes: Fourth Quarter 1994

Control Device	Equipment Cost Index (First Quarter 1994 = 100)				
	Small	Medium	Large	Average[a]	Range/ Average x 100%[b]
Carbon adsorbers	101.80	102.84	102.94	102.53	45.1
Catalytic incinerators	103.99	104.02	104.07	103.99	2.0
Flares	101.12	101.08	101.14	101.12	5.4
Gas absorbers	100.87	100.94	101.00	100.94	13.8
Refrigeration systems	100.83	100.85	100.84	100.84	2.4
Regenerative thermal oxidizers	102.04	102.38	102.35	102.26	15.0
Thermal incinerators	102.63	102.68	102.64	102.65	1.9
Wet scrubbers	101.96	102.18	102.33	102.15	17.2

[a] Arithmetic averages of the three ECI values.

[b] Calculated as follows:
R/A = {(High Index-Low Index)/|Average index-100|} x 100%.

Table 9. Control Device Equipment Cost Indexes: First Quarter 1995 (*Preliminary*)[a]

Control Device	Equipment Cost Index (First Quarter 1994 = 100)				
	Small	Medium	Large	Average[b]	Range/ Average x 100%[c]
Carbon adsorbers	104.87	106.48	106.72	106.02	30.7
Catalytic incinerators	105.35	105.45	105.47	105.42	2.2
Flares	105.53	105.45	105.45	105.48	1.5
Gas absorbers	103.62	103.85	103.66	103.71	6.2
Refrigeration systems	102.21	102.23	102.11	102.18	5.5
Regenerative thermal oxidizers	103.25	103.56	103.49	103.44	9.0
Thermal incinerators	104.06	104.07	104.00	104.04	1.7
Wet scrubbers	106.37	107.45	108.35	107.39	26.8

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[a] Because the PPI inputs to the ECI have been denoted as "unrevised" by the Bureau of Labor Statistics, these ECI values should be considered preliminary, as well. Final ECI values will be disseminated once the final first quarter 1995 PPI's become available.

[b] Arithmetic averages of the three ECI values.

[c] Calculated as follows:
$R/A = \{(\text{High Index-Low Index})/|\text{Average index-100}|\} \times 100\%$.

Finally, it is interesting to compare the ECI values with the Chemical Engineering (CEPI) and Marshall & Swift Indexes (M&SI). The CEPI and M&SI values for 1994 are listed below, along with the preliminary CEPI for first quarter 1995.

Date	**Index Value**			
	CEPI ("Equipment")		**M&SI (Composite)**	
1st Q '94	400.5	100.0	980.3	100.0
2nd Q '94	403.5	100.8	990.8	101.1
3rd Q '94	408.5	102.0	998.1	101.8
4th Q '94	415.1	103.6	1004.4	102.5
1st Q '95 (prelim.)	424.8	106.1	Unavail.	Unavail.

The right-hand column under each index lists the ratio of the index for each quarter and the first quarter 1994 index, times 100. We can directly compare these values to the ECI "averages" in Tables 6 to 9. Over these four quarters, the CEPI/Equipment ratios compare fairly well with the average ECI's, falling approximately in the upper-middle of the ranges. For the second quarter 1994 (Table 6), the CEPI exceeds four of the average ECI's and falls below the other four. In third quarter 1994, however, the CEPI is higher than six of the eight average ECI's (Table 7). In Table 8 (fourth quarter 1994), only one of the ECI (catalytic incinerators) exceeds the CEPI. Finally, Table 9 (first quarter 1995) shows the CEPI again to exceed the average ECI's of six of the eight devices. This agreement may be due, in part, to the fact that both the CEPI and the ECI's are based upon some of the same Producer Price Indexes (e.g., stainless steel).

The M&SI ratios, which have different bases, also agree fairly well with the ECI's in the second, third, and fourth quarters of 1994. Like the CEPI, the M&SI fall within the upper-middle of the ECI ranges. The M&SI exceed seven of the ECI in the second and third quarters, and five ECI in fourth quarter 1994. Again, because the M&SI was unavailable for first quarter 1995, no comparison could be made for that period.

Admittedly, the differences among the ECI and CEPI/M&SI are not large, absolutely or relatively. Keep in mind, however, that these comparisons are being made over just a single year (four quarters). Longer-term comparisons could produce larger discrepancies in some cases, smaller in others. For that reason, we should resist the temptation to brand the CEPI or M&SI as a "good" or "bad" surrogate for the ECI's, in general.

Reflections on the ECI

One might question how the ECI, being constructed from weighting factors and other published indexes, could accurately track control device equipment prices. Suppose, for instance, that the price of a thermal incinerator component—say, centrifugal fans—increases by 23% during a given quarter, while the prices of all other components do not change. Further suppose that this component makes up (a representative) 10% of the price of the incinerator. (See Appendix A.) Does this mean that the incinerator vendor would raise his prices by precisely 2.3% (10% of 23%) to recover his costs? Not necessarily. Depending on the current market, he could increase his prices by this amount, a different amount, or not at all. If the thermal incinerator market were especially "bearish," the vendor might choose to absorb part or all of this boost in fan prices. Conversely, if the demand for thermal incinerators were high, he might increase his prices by more than 2.3%. In such a case, an equipment cost index might provide less than an ideal escalator of incinerator price changes.

On the other hand, rarely do prices change for one component, and not for the others. As we saw in Table 5, some prices increase, others decrease, and still others stay unchanged. If a device is made of of several components, each with a unique price history as chronicled by a PPI or another index, there is a higher probability—a "central tendency," if you will—that such a weighted ECI would track price changes more closely than would another type of index. Interestingly, other published indexes are based on such a weighting scheme. For instance, as indicated above, the CEPI rests heavily upon a PPI foundation. And these indexes are widely used by analysts and cited in the literature.

What do equipment vendors think of the ECI methodology? Some insist that the ECI cannot accurately escalate price changes, for the reasons stated above. However, one wet scrubber manufacturer supports the ECI methodology. He wrote: "It should, therefore, be possible to arrive at historic market price data, if the official price indexes were applied for the main components of the system (manufactured stainless steel, motors, pumps, instruments, etc.) and the weighted percentages in your Table II be applied for each component."[9] Clearly, there is ample room for argument regarding the ECI.

Applying the Historical and Equipment Cost Indexes

How can the historical and equipment cost index data be used to escalate control device costs? Actually, they are quite easy to use, either separately or together, as the following example illustrates. Consider a gas absorber with a first quarter 1989 equipment cost of $100,000. What would its cost be, if escalated to (1) third quarter 1991 and (2) second quarter 1994 dollars, respectively?[a]

First, refer to Table 1, where a relative price of 106.8 is given. Because the original cost is in first quarter 1989 dollars, the base value is 100.0. After substituting these values into equation (1), we obtain:

Cost (3rd qtr.'91) = \$100,000 x (106.8/100.0) = \$106,800.

However, escalating the original cost to second quarter 1994 dollars requires two steps. First, escalate the equipment cost to first quarter 1994 dollars via the historical price data in Table 1. The corresponding index value is 112.2. Second, escalate this cost from first to second quarter 1994 using the ECI for gas absorbers, as given in Table 6. Here, we find the average index value of 100.51, where the base value is 100.0 (first quarter 1994). We can combine both steps into one, as follows:

Cost (2nd qtr.'94) = \$100,000 x (112.2/100.0) x (100.51/100.0)

= \$112,772 ≈ \$112,800.

In this calculation, note that the base value "100.0" appears twice. This happens because, for convenience, 100.0 was chosen as the base for both the historical and equipment cost indexes.

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[a] Escalation beyond second quarter 1994 would be ill-advised in this case, as costs should *not* be escalated over periods exceeding five years. (See previous discussion.) Instead, current prices for the equipment should be obtained from vendors or other equally reliable sources.

III. Total Annual Cost Indexes

Having developed escalation indexes for control device equipment costs, the next logical step is to devise similar indexes for the device total annual costs (TAC). However, there are several reasons why we should *not* do so. First of all, there is little need to escalate electricity, labor, and other direct annual ("O&M") costs, as current values for these costs are readily available from public and private sources.

Secondly, direct annual costs include a variety of components. The costs of these components typically exhibit vastly different escalation rates. For instance, the price of some fuels, such as natural gas, have fluctuated considerably over the years, when compared to, say, operating labor. No index could begin to track price changes in so many different components. Thirdly, unlike equipment costs, the prices of utilities, labor, and other direct annual costs may exhibit considerable regional variation. This would militate against using a single national index for tracking prices. Instead, regional indexes would be needed or, at least, adjustment factors to account for these variations.

Finally, the composition of the annual costs also varies according to the type of control device being costed. A thermal incinerator, for instance, would have the following direct annual costs: fuel (typically, natural gas), operating and supervisory labor, maintenance labor and materials, and electricity. Of these, the fuel cost would predominate. By contrast, the O&M cost for a carbon adsorber would cover labor, maintenance, and electricity, as well as steam, cooling water, and carbon replacement. To escalate these O&M costs, we would need to develop and use a different annual cost index for each type of control device. The effort required to do that might be better spent by obtaining current prices for the various O&M costs.

Despite all this, there may be cases where there is not enough time or information to collect current annual costs. To meet these needs, we have developed total annual cost indexes (TACI) to complement the equipment indexes presented in Section II. In this section, we will present a methodology for developing the TACI and apply this methodology to their creation. Nevertheless, *the TACI are to be used only when no other reliable annual cost data are available.*

Control Costs: A Refresher

First, let's review cost terminology. As Chapter 2 of the *Manual* explains, the total annual cost is comprised of three major elements:

$$TAC = DC + IC - RC \quad (2)$$

where: DC = sum of direct annual costs ($/year)
IC = sum of indirect annual costs ($/year)
RC = sum of recovery credits ($/year)

The table below shows the composition of these elements.

TAC Element	Costs/Credit Included
Direct Annual Costs (DC)	Labor (operating, supervisory)
	Maintenance (labor, materials)
	Utilities (electricity, etc.)
	Operating materials
	Replacement parts
	Waste treatment/disposal
Indirect Annual Costs (IC)	Overhead
	Capital recovery
	Taxes, insurance, admin. chgs.
Recovery Credits (RC)	Recovered materials

Most of the costs in this table are functions of one or more stream variables, facility parameters (e.g., annual operating hours), financial parameters (annual interest rate, etc.), and/or other costs, such as the total capital investment (TCI) of the control system. From a cost-escalating standpoint, the single most important parameter is the gas volumetric flowrate (ft^3/min), as it is the primary determinant of the control device size and, in turn, its equipment cost and total capital investment. Although other stream parameters can also be important—stream inlet temperature, waste gas heat content, pollutant loading, etc.—it is sufficient to focus on just the gas flowrate.

The second critical parameter is the operating factor (annual operating hours). All of the direct annual costs plus the recovery credits vary linearly with the operating factor. The overhead does as well, because it is factored from the total labor and maintenance cost.

Lastly, some costs—such as the operating, supervisory, and maintenance labor and maintenance materials—are *not* functions of any stream or facility parameters or the TCI, though they depend upon the operating factor. Rather, these costs are more or less constant, regardless of the system size. The table below lists the annual costs and the variables they primarily depend upon.

Main Determinant Variables of Annual Cost Elements

Annual Cost	Main Determining Variable(s)
Operating labor	Operating factor
Supervisory labor	Operating factor
Maintenance labor & materials	Operating factor
Utilities (electricity, etc.)	Gas flowrate, operating factor
Operating materials	Gas flowrate, operating factor
Waste treatment/disposal	Gas flowrate, operating factor
Replacement parts	Part cost, life, interest rate
Overhead	Total labor + maintenance cost
Taxes,insurance,administrative	Total capital investment
Capital recovery	Total capital investment
Recovery credits	Gas flowrate, operating factor

Note in this table that the "replacement parts" and all of the indirect costs except overhead depend on variables other than the gas flowrate or the operating factor. However, it can be shown that even these costs depend (albeit indirectly) on the gas flowrate, as well. The TCI, for instance, is normally calculated by multiplying a factor by the purchased equipment cost (PEC). But the PEC, in turn, is primarily a function of the gas flowrate. Moreover, the initial costs of parts—fabric filter bags, carbon adsorber carbon, etc.—are also functions of the gas flowrate. Again, the gas volumetric flowrate is the main variable of interest.

However, we must not forget that the labor, maintenance, utilities, and other direct annual costs also depend upon the unit costs for these expenditures (i.e., $/hour, $/kWhr, etc.). Although these unit costs vary from site to site, based on geography, industry, and other factors, they are not nearly as variable as the gas flowrate or the operating factor. The operating factor might range over an order of magnitude, while the gas flowrate may vary by a factor of 100 or more. Rarely do the unit costs exhibit such variability.

Because the various annual costs depend on the gas flowrate and/or the operating factor to different extents, the *proportion* that each cost contributes to the total annual cost will also depend on these two parameters. The costs of utilities, operating materials, waste treatment/disposal, and the recovery credits all vary linearly with both the gas flowrate and the operating factor. For instance, if either parameter increased by 50%, each of these costs would rise by 50%, assuming that all other parameters remained constant. On the other hand, a 50% increase in the gas flowrate might only cause a 25 to 30% jump in the total capital investment, as the TCI's dependence on the flowrate is weaker. By the same token, the capital recovery and taxes, insurance, and administrative costs—both of which are factored from the TCI—also would increase by 25 to 30%.

Total Annual Cost "Weighting Factors"

How does this discussion relate to the escalation of the total annual cost? First, it shows that the TAC cannot be escalated using a single index, as is the equipment cost (and, in turn, the TCI). We can use a single escalator with the TCI because, as we have shown in Section II, the price of a refrigeration system, wet scrubber, or other device increases (or decreases) by about the same percentage over a quarter regardless of the size of the unit. Not so with the TAC, because: (1) each of the costs comprising the TAC has an individual price history and (2) the *contribution* of each cost to the TAC will vary according to the gas flowrate and/or the operating factor.

To account for both the "cost mix" and the "cost contributions" we could derive complex equations that incorporate the gas flowrate, operating factor, and other parameters; calculate the TAC for any given set of parameters; and present a TAC escalation index for every flowrate from 1 to 1,000,000 ft^3/min. and operating factor from 8 to 8000 hours/year. But doing so would be not only cumbersome, but misleading, as it would imply that cost escalation is a very precise procedure, when, in reality, it is as much art as science. On the other hand, to present a single escalation index for the TAC would be equally misleading, as the TAC components do vary appreciably according to the gas flowrate and operating factor.

There is a middle ground, however. We can compute and present *six* TAC escalation indexes for each control device type—one each for "small," "medium," and "large" gas flowrates at both "low" and "high" operating factors. As we might expect, both the flowrate and operating factor ranges would vary according to the device. For instance, the gas flowrates used with thermal incinerators were 250 (small), 25,250 (medium), and 100,000 standard ft^3/minute (large). (Corresponding flowrates for gas absorbers were 1000, 22,300, and 80,000 actual ft^3/minute.) Also for each flowrate, cost indexes were calculated for 800 and 8,000 hours/year, the low and high operating factors for thermal incinerators. As was done with the equipment cost indexes, the TAC indexes for the small and medium cases were calculated using the midpoint of the size (flowrate) ranges, while for the large case, *twice* the lower end of the range was used.

In calculating the TACI, we used special quantities—the *TAC weighting factors*, which are analogous to the *equipment cost weighting factors* presented in Section II. Like their ECI counterparts, each TAC weighting factor denotes the fraction of the total annual cost that a given cost component contributes. If the natural gas cost for a thermal incinerator comprises 75.4% of the TAC at a given gas flowrate and operating factor, the natural gas weighting factor would be 0.754. However, for a different flowrate and/or operating factor, the weighting factor could be much different. Clearly, the weighting factors for the other annual costs also would change with changes in these two parameters.

How were the TAC weighting factors used in computing the TAC indexes? Before we answer that question, recall that each of the annual costs changes in a different way. That is, the price of electricity might increase by 4% in a given year, while the natural gas price might rise by 2%. And in certain situations, the price may actually *decline*.[a] As discussed in Section I, price changes are commonly reported in terms of indexes, of which the BLS Producer Price Indexes are among the most familiar.

Recall that each of the thousands of PPI's has a "base period" (month-and-year) for which the index value is arbitrarily set at "100". Prices in future periods are expressed relative to this base of 100. For example, if the "fabricated metals" PPI were, say, 107.3 for January 1994, the price in that month would be 7.3% higher (i.e., {[107.3/100]-1} x 100%) than it was in the base year and month. Now, as explained in Section II, it is often convenient to express price changes between two periods as the *ratio* of the indexes for the two periods of interest. This allows us to make price comparisons without knowing either the index base period or base value. If the "fabricated metals" PPI for November 1993 were 106.8, for example, the relative change in the index would have been 0.0047 ([107.3/106.8]-1), or 0.47%, between that month and January 1994. The following equation expresses the relationship between the indexes for the two periods and the base period index:

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[a] This is hardly unprecedented. During 1993, the U.S. Bureau of Labor Statistics reported price declines for several commodities, including fabricated steel plate, tranformers, and sodium hydroxide (caustic soda). The last registered a *23%* drop.

$$(I_{j2}/I_{jb})/(I_{j1}/I_{jb}) = I_{j2}/I_{j1} \qquad (3)$$

where: I_{j2} = cost "j" index value for period 2.

I_{j1} = cost "j" index value for period 1.

I_{jb} = cost "j" index value for base period.

Notice that I_{jb} cancels out in this equation, proving that the change in an index is independent of the base index.

Furthermore, we can show that the change in a total annual cost index, consisting of "n" cost components, can be expressed in terms of (1) the weighting factors and (2) the changes in the corresponding indexes of the component costs. That is:

$$TACI_f/TACI_i = \Sigma\ (W.F.)_j(I_{jf}/I_{ji}) \qquad (4)$$

$$= (W.F.)_1(I_{1f}/I_{1i}) + (W.F.)_2(I_{2f}/I_{2i}) + \ldots$$

where: TACI = total annual cost index for final (f) and initial (i) periods, respectively

W.F. = cost weighting factor for cost 1,2,...n

A TACI Illustration

To illustrate, again consider gas absorbers. Table 10 lists weighting factors for the "medium" capacity gas absorber (22,280 scfm) operated at the "high" operating factor (8,000 hours/year). These weighting factors were computed via the cost spreadsheet programs to be described in Section IV. Also shown in Table 10 are the Employment Cost Index and Producer Price Indexes for the respective total annual cost components corresponding to the first and second quarters of 1994, all obtained from the BLS.[a]

Note that five of the six costs increased during this three-month period, while one, "chemicals" (caustic soda) actually decreased. The index ratio for the "capital recovery; taxes, insurance, & administrative" component is actually the ratio of the equipment cost index for medium-capacity gas absorbers from Table 6. Because the base period for the ECI is first quarter 1994, the index value is 100.0. (See "Equipment Cost Index" discussion in Section II.) If we substitute these index ratios and corresponding weighting factors into equation 4, we obtain the total annual cost index ratio:

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[a] A quarterly index value is simply the arithmetic average of the monthly PPI's for that quarter.

Table 10. TACI Illustration: Gas Absorbers

Cost Component	Index Value		Index Ratio (I_{i2Q}/I_{i1Q})	Weight. Factor ($W.F._i$)
	1st Q '94	2nd Q '94		
Labor, maintenance, & overhead	120.2	121.2	1.008	0.101
Electricity	126.0	128.0	1.016	0.041
Water	126.0	128.0	1.016	0.002
Chemicals	92.9	83.0	0.893	0.723
Wastewater treatment	126.0	128.0	1.016	0.031
Capital recovery; taxes, insurance, & administrative	100.0	100.51	1.0051	0.102

$$TACI_{2Q}/TACI_{1Q} = (0.101)(1.008) + (0.041)(1.016) + (0.002)(1.016) + (0.723)(0.893) + (0.031)(1.016) + (0.102)(1.0051) = 0.9255$$

In other words, based on the component index ratios and weighting factors, the (predicted) *decrease* in the total annual cost index for this device would be 7.45%! Even though five of the six cost components increased—three (electricity, water, and wastewater treatment) by nearly 2% each—the total annual cost index dropped precipitously. Why? Simply because the chemicals cost—which comprised 72.3% of the TAC—fell, by nearly 11%. This decrease more than offsets the increases in the other components.

Suppose that, for expediency's sake, we had just *averaged* the changes in the cost components without first weighting them? (In effect, this would be assigning each component an equal weighting factor of 1/6 = 0.167.) How much would the TACI have changed then? We can get the answer simply by averaging the index ratios (column four in Table 10). The result would have been 0.9924—somewhat higher than the calculated result above. To say the least, the cost weighting factors are important to the escalation of total annual costs.

This example shows how sensitive the total annual cost (and TACI) can be to component unit prices. Normally, chemical prices do not change by so much over such a relatively short period. But during 1994, caustic soda (NaOH) prices have *not* been behaving normally. In fact, the NaOH market has been very unsettled and, consequently, hard to gauge. First, as the table above shows, the PPI for NaOH dropped from 92.9 to 83.0 from first to second quarter 1994, a 10.6% decrease.

However, the weekly *Chemical Marketing Reporter* (*CMR*), an oft-cited source of chemical prices, has been telling quite a different tale. A May 28, 1994, article entitled "Caustic Surge Leads to Potent Price Hike" reads: "Strong demand and a tighter-than-anticipated supply of caustic soda have led U.S. producers to push prices up even further...Spot prices for Gulf Coast caustic are pegged at $120 to $130 per ton...In January, caustic sold for $20 to $25 per ton...."[10] In other words, according to the *CMR*, caustic prices have *not* been dropping, as the BLS claims, but skyrocketing by factors of 5 to 6. But before we dismiss the BLS data, we should examine the price listing for NaOH in the *CMR*. For the week ending January 7, 1994, the *CMR* reported a price of $300 to $330/ton for "76% Na_2O, F.O.B. Gulf Coast". For the week ending January 14, the price remained the same—*and stayed the same for each and every week through the end of June (the end of the second quarter)*. Thus, if one did not read the *CMR* article, one might conclude that caustic prices were constant throughout both quarters of 1994.

With this kind of price confusion, it is no wonder that cost escalation—especially TAC escalation—is often uncertain. To quantify the uncertainty in this illustration, we twice reran the gas absorber total annual cost program to generate two new sets of TAC weighting factors. The first time we assumed no change to the NaOH price (i.e., we took the *CMR* price listing at face value). For the second rerun, we deleted the NaOH (chemicals) cost from the list of TAC components, assuming, in effect, that no caustic would be needed. The results for the gas absorber described above were as follows:

Gas Absorber TACI for Different NaOH Price Scenarios

NaOH Price Basis:	Total Annual Cost Index x 100
Producer Price Index	92.55
Chemical Marketing Reporter	100.26
No NaOH	100.92

These differences are significant, to be sure, and require no comment.

Keep in mind, of course, that these TACI values would pertain only to a medium-capacity gas absorber operating at 8,000 hours/year. As we will see in Section IV, the weighting factors and resulting TACI would be significantly different for gas absorbers of other capacities and operating factors.

TACI for All the Control Devices

Tables 11 to 14 list the total annual cost indexes for all eight control devices, pertaining to second, third, and fourth quarter 1994 and first quarter 1995, respectively. With the exception of the first quarter 1995 indexes (which are preliminary), all of the TACI are final values. For each device, the TACI are given for three sizes ("small," "medium," and "large") and two operating factors ("high" and "low"). The sizes are listed in Tables A-1 to A-8 of Appendix A. For all but three devices, the low and high operating factors are 800 and 8,000 hours/year, respectively. The exceptions are carbon adsorbers, flares, and refrigeration systems. Their operating factors are listed in a footnote in each of these tables.

As we might expect, the TACI vary noticeably among the three unit sizes and two operating factors. The differences, however, are larger for some devices than for others. This is especially true for gas absorbers. For example, for second quarter 1994, the TACI ranges from 91.65 (large unit, high operating factor) to 99.29 (small, low). Contrast these values with the third quarter

Table 11. Total Annual Cost Indexes: Second Quarter 1994

Control Device	Total Annual Cost Indexes (First Quarter 1994 = 100)					
	Small[a]		Medium		Large	
	Low O.F.[b]	High O.F.	Low O.F.	High O.F.	Low O.F.	High O.F.
Carbon adsorbers	100.98	100.95	101.38	100.84	101.47	100.73
Catalytic incinerators	100.86	100.74	100.65	100.01	100.56	99.79
Flares	100.02	99.51	99.40	98.84	99.15	98.68
Gas absorbers[c]	99.29	97.60	96.27	92.55	95.57	91.65
Refrigeration systems	100.49	100.63	100.59	100.56	100.51	100.71
Regenerative thermal oxidizers	100.84	100.85	100.78	101.09	100.87	101.02
Thermal incinerators	100.72	100.55	99.92	98.51	99.45	98.18
Wet scrubbers	100.76	100.83	100.84	101.05	100.90	101.24

[a] These capacities are listed in Tables A-1 through A-8 (Appendix A).

[b] Operating factors (O.F.) are 800 (low) and 8,000 (high) hours/year, with the following exceptions:

Carbon adsorbers—864, 8,640;
Flares—876, 8,640;
Refrigeration systems—520, 2,080.

[c] TACI are based on assumption of NaOH (chemicals) price based on PPI data. (See discussion above.)

Table 12. Total Annual Cost Indexes: Third Quarter 1994

Control Device	Total Annual Cost Indexes (First Quarter 1994 = 100)					
	Small[a]		Medium		Large	
	Low O.F.[b]	High O.F.	Low O.F.	High O.F.	Low O.F.	High O.F.
Carbon adsorbers	101.10	101.78	102.15	102.97	102.28	103.14
Catalytic incinerators	102.78	101.97	102.61	100.76	102.52	100.34
Flares	101.94	102.85	102.76	103.66	103.01	103.65
Gas absorbers[c]	103.49	105.77	106.64	112.08	108.00	113.22
Refrigeration systems	100.82	101.38	101.01	101.63	100.96	102.03
Regenerative thermal oxidizers	101.93	102.01	102.16	103.12	102.30	103.25
Thermal incinerators	101.70	101.24	99.67	96.04	98.61	95.19
Wet scrubbers	101.74	101.96	102.48	103.40	102.82	104.10

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[a] These capacities are listed in Tables A-1 through A-8 (Appendix A).

[b] Operating factors (O.F.) are 800 (low) and 8,000 (high) hours/year, with the following exceptions:

Carbon adsorbers—864, 8,640;
Flares—876, 8,640;
Refrigeration systems—520, 2,080.

[c] TACI are based on assumption of NaOH (chemicals) price based on PPI data. (See discussion above.)

Table 13. Total Annual Cost Indexes: Fourth Quarter 1994

Control Device	Total Annual Cost Indexes (First Quarter 1994 = 100)					
	Small[a]		Medium		Large	
	Low O.F.[b]	High O.F.	Low O.F.	High O.F.	Low O.F.	High O.F.
Carbon adsorbers	101.99	102.06	103.58	102.96	103.48	102.88
Catalytic incinerators	103.43	101.99	103.31	100.14	103.19	99.45
Flares	101.83	102.05	102.14	102.36	102.17	102.29
Gas absorbers[c]	107.70	114.41	118.29	134.40	122.09	137.99
Refrigeration systems	100.99	101.27	101.03	101.00	100.90	101.04
Regenerative thermal oxidizers	102.04	102.03	102.25	102.28	102.32	102.13
Thermal incinerators	102.40	101.49	99.82	95.09	98.51	94.03
Wet scrubbers	101.92	101.91	101.96	101.79	102.01	101.84

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[a] These capacities are listed in Tables A-1 through A-8 (Appendix A).

[b] Operating factors (O.F.) are 800 (low) and 8,000 (high) hours/year, with the following exceptions:

Carbon adsorbers—864, 8,640;
Flares—876, 8,640;
Refrigeration systems—520, 2,080.

[c] TACI are based on assumption of NaOH (chemicals) price based on PPI data. (See discussion above.)

Table 14. Total Annual Cost Indexes: First Quarter 1995 (*Preliminary*)[a]

Control Device	Total Annual Cost Indexes (First Quarter 1994 = 100)					
	Small[b]		Medium		Large	
	Low O.F.[c]	High O.F.	Low O.F.	High O.F.	Low O.F.	High O.F.
Carbon adsorbers	104.69	103.50	106.76	103.93	107.09	103.94
Catalytic incinerators	104.70	102.87	104.36	100.71	104.11	99.88
Flares	102.21	100.29	100.67	98.98	100.05	98.75
Gas absorbers[d]	115.21	126.90	135.67	165.07	142.44	171.84
Refrigeration systems	102.26	102.35	102.32	102.10	102.09	102.04
Regenerative thermal oxidizers	103.23	103.21	103.40	103.26	103.43	103.05
Thermal incinerators	103.74	102.45	100.72	95.16	99.19	93.95
Wet scrubbers	103.93	102.83	104.85	102.78	105.34	102.87

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[a] Because the PPI inputs to the TACI have been denoted as "unrevised" by the Bureau of Labor Statistics, these TACI should be considered preliminary, as well. Final TACI will be disseminated once the final first quarter 1995 PPI's become available.

[b] These capacities are listed in Tables A-1 through A-8 (Appendix A).

[c] Operating factors (O.F.) are 800 (low) and 8,000 (high) hours/year, with the following exceptions:

Carbon adsorbers—864, 8,640;
Flares—876, 8,640;
Refrigeration systems—520, 2,080.

[d] TACI are based on assumption of NaOH (chemicals) price based on PPI data. (See discussion above.)

1994 TACI (Table 12). Here, the range is 103.49 (small unit, low operating factor) to 113.22 (large, high). This steep increase in the TACI—an increase that continues through the next two quarters—is almost solely due to the price of caustic soda, which, according to the Producer Price Index, jumped 110% from second quarter 1994 to first quarter 1995. Except for second quarter 1994, the gas absorbers TACI is seen to increase with increasing size and operating factor.

The indexes for the other devices do not increase as much as the gas absorbers TACI. Still, for two devices, patterns do emerge. For catalytic and thermal incinerators, the TACI generally decrease with increasing size and operating factor. This reflects the influence of the fuel (natural gas) cost contribution. As both the incinerator size and operating factor increase, the natural gas contribution to the total annual cost also increases. According to the BLS, the natural gas price steadily decreased from first quarter 1994 to first quarter 1995. The price drop during this twelve-month period was 8.9%. Accordingly, the TACI for the largest incinerators at the higher operating factor decreased. For example, the thermal incinerators low-end TACI dropped from 98.18 (second quarter 1994) to 93.95 (first quarter 1995). Conversely, the TACI for the smallest incinerators at the lower operating factor *increased*, reflecting the greater influence of the equipment cost. And the equipment costs grew during the past year, primarily because of increases in steel prices.

For the other five devices, the TACI exhibit no consistent pattern, although for some there are significant differences among sizes and operating factors. The TACI differences are largest for carbon adsorbers, flares, and wet scrubbers. This is especially noticeable for first quarter 1995 (Table 14). Here, the TACI ranges for carbon adsorbers, flares, and wet scrubbers are 3.6%, 3.5%, and 2.6%, respectively. Finally, the TACI for refrigeration systems and regenerative thermal oxidizers are essentially equal for all sizes and operating factors.

IV. Total Annual Cost Spreadsheet Programs

As we discussed in Section III, control costs depend upon a variety of emission stream, control device, and financial parameters. Often this dependency is quite complex, as in the sizing and costing of gas absorbers. Clearly, it would be cumbersome to make these calculations by hand, especially if costs were needed for a range of input parameters (e.g., waste gas flowrate). To make the calculation of the capital and annual costs and the TAC weighting factors easier, we developed 12 spreadsheet programs, one for each of the eight devices covered in this report, plus four others that we thought would be helpful to cost analysts. We wrote these programs in Eight-in-One™, a spreadsheet program that is compatible with Lotus 1-2-3™ (versions 1A and 2), is structured similarly, and utilizes many of the same commands. Each program yields itemized total capital investment and total annual costs and TAC weighting factors for a given set of input parameters. We wrote programs for the following control devices:

- Particulate emission controls:
  - ✓ Electrostatic precipitators
  - ✓ Fabric filters
  - ✓ Mechanical collectors (cyclones)
  - ✓ Venturi scrubbers[a]
  - ✓ Wet impingement scrubbers
- Gaseous emission controls:
  - ✓ Carbon adsorbers (fixed-bed regenerative)
  - ✓ Catalytic incinerators (fixed-bed)
  - ✓ Gas absorbers (packed-bed)
  - ✓ Flares
  - ✓ Refrigeration systems
  - ✓ Regenerative thermal oxidizers
  - ✓ Thermal incinerators (recuperative)

Most of the programs were based on design and cost data and procedures in the *OAQPS Control Cost Manual* (Fourth Edition, 1990) (*Manual*). The exceptions were the programs for mechanical collectors, venturi scrubbers, and wet impingement scrubbers. These three were based on information in *Estimating Costs of Air Pollution Control* (Lewis Publishers/CRC Press, 1990).[11] Those interested in obtaining copies of the programs may contact the author, William M. Vatavuk, at (919)-541-5309 (fax: 919/541-0839).

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[a] Basis of the "wet scrubbers" device discussed in Sections I to III of this report.

A sample printout of the gas absorbers program appears in Figure 5. Like the others, this program consists of six sections: (1)"Cost Reference Date," (2) "Input Parameters," (3) "Design Parameters," (4) "Capital Costs," (5) "Annual Cost Inputs," and (6) "Annual Costs". As the name implies, the "Cost Reference Date" section simply lists the date to which the costs in the program pertain. This date ranges from fourth quarter 1986 (fabric filters) to third quarter 1991 (gas absorbers). If the costs are updated, either directly or via the VAPCCI, this date would change.

The "Input Parameters" section contains technical data that *must be entered by the user.* The program needs these data to compute the design parameters, the costs, or both. Because these input parameters vary so much according to control device designs and applications, there are no "default" values for them. In other words, *the user must provide this information.*

Input parameters include such standard stream parameters as the waste gas volumetric flowrate, temperature, and pollutant loading—data that are common to all control devices. Another standard parameter, the control device "pressure drop," also may be a required input. Along with the gas flowrate, the pressure drop is used to calculate the control device fan horsepower requirement and, in turn, most (if not all) of the control system electricity requirement. In many cases, the user must provide the pressure drop. However, with other devices (e.g., thermal and catalytic incinerators) the pressure drop is calculated from one or more of the input parameters. With the latter devices, the pressure drop would *not* be an input parameter.

The input parameters section also lists data specific to a certain type of device. In the case of gas absorbers, the user must enter various solvent data (molecular weight, density, diffusivity, and viscosity) and packing parameters—data that can be found in Chapter 9 of the *Manual*.

The next section, "Design Parameters," lists data that are, for the most part, calculated by the program based on the input parameters. For gas absorbers, these include operating line data, pollutant-air equilibrium information, and such key absorber parameters as the absorption factor, column height, and pressure drop.

The "Capital Costs" section displays the control device equipment cost (itemized), the purchased equipment cost, and the total capital investment (TCI). No costs for auxiliary equipment (e.g., ductwork and fans), are included, although some "packaged" devices, such as thermal incinerators, come equipped with some auxiliaries. Both the purchased equipment cost (PEC) and TCI are "factored" from the total equipment cost (TEC), according to the procedure described in Chapter 2 of the *Manual*. The PEC is

Figure 5. Sample Printout of Gas Absorbers Cost Program

TOTAL ANNUAL COST SPREADSHEET PROGRAM--GAS ABSORBERS [1]
COST REFERENCE DATE: 3rd quarter 1991

INPUT PARAMETERS:

Stream parameters:

-- Inlet waste gas flowrate (acfm):	1000
-- Inlet waste gas temperature (oF):	100
-- Inlet waste gas pressure (atm.):	1
-- Pollutant in waste gas:	Hydrogen chloride (HCl)
-- Inlet gas poll. conc., yi (mole fraction):	0.001871
-- Pollutant removal efficiency (fraction):	0.99
-- Solvent:	Aqueous caustic soda
-- Inlet pollutant conc. in solvent:	0
-- Waste gas molecular weight (lb/lb-mole):	28.85
-- Solvent molecular weight (lb/lb-mole):	18
-- Inlet waste gas density (lb/ft3):	0.0706
-- Solvent density (lb/ft3):	62.4
-- Solvent specific gravity:	1
-- Waste gas viscosity @ inlet temp. (lb/ft-hr):	0.044
-- Solvent viscosity @ inlet temp. (lb/ft-hr):	2.16
-- Minimum wetting rate (ft2/hr):	1.3
-- Pollutant diffusivity in air (ft2/hr):	0.725
-- Pollutant diffusivity in solvent (ft2/hr):	1.020000e-04

Packing parameters:

-- Packing type:	2-in. ceramic Raschig rings
-- Packing factor, Fp:	65
-- Packing constant, alpha:	3.82
-- Packing constant, beta:	0.41
-- Packing constant, gamma:	0.45
-- Packing constant, phi:	0.0125
-- Packing constant, b:	0.22
-- Packing constant, c:	0.24
-- Packing constant, j:	0.17
-- Surface area-to-volume ratio, a (ft2/ft3):	28
-- Packing cost ($/ft3):	20

DESIGN PARAMETERS:

-- Material of construction (see list below):[2]	1
-- Inlet pollutant concentration (free basis):	1.874507e-03
-- Outlet pollutant concentration (free basis):	1.874507e-05
-- Out. eq. poll conc in solv., Xo* (op. line)	0.16
-- Theoretical operating line slope (Ls/Gs,min.)	0.0116
-- Ls/Gs adjustment factor:	1.5
-- Actual operating line slope (Ls/Gs, act.):	0.0174
-- Gas flowrate, Gs (free basis, lb-moles/hr):	146
-- Solvent flowrate, Ls (free basis, lb-mol/hr):	2.55
-- Gas flowrate, Gmol,i (lb-moles/hr):	147
-- Solvent flowrate, Lmol,i (lb-moles/hr):	2.55
-- Outlet actual pollutant conc. in solv., Xo:	0.1067
-- Gas poll. conc. in eq. w/Xo (Yo*):	1.000000e-04
-- Outlet solv. poll. conc. (mole fract. basis):	0.0964
-- Gas poll. conc., Yo* (mole fract. basis):	9.999000e-05
-- Outlet gas poll. conc., yo (mole fract.):	1.874472e-05
-- Slope of equilibrium line (m):	0.0010373962
-- Absorption factor (AF):	16.77
-- ABSCISSA (column diameter calculation):	3.650442e-04
-- ORDINATE (column diameter calculation):	0.2061
-- Superficial gas flowrate, Gsfr,i (lb/sec-ft2)	0.6779
-- Flooding factor, f:	0.7
-- Column cross-sectional area, A (ft2):	2.47
-- Superficial liquid flowrate (lb/hr-ft2):	18.54
-- Minimum liquid flowrate (lb/hr-ft2):	2271
-- Column diameter, D (ft2):	1.775
-- Number of transfer units, Ntu:	4.831
-- Gas film transfer coefficient, Hg (ft):	2.314
-- Liquid film transfer coefficient, Hl (ft):	1.064
-- Height of a transfer unit (ft):	2.377
-- Packing depth (ft):	11.483
-- Column total height (ft):	20.70

Figure 5. (cont'd.)

-- Column surface area (ft2):	120.4
-- Column gas pressure drop (in. w.c./ft packing	0.980
-- Column liquid pressure drop (ft of H2O):	60
-- Packing volume (ft3):	28.4

CAPITAL COSTS:

Equipment costs ($):	
-- Gas absorber	13,841
-- Packing	568
-- Total	14,409
Purchased Equipment Cost ($):	17,002
Total Capital Investment ($):	37,405

ANNUAL COST INPUTS:

Operating factor (hr/yr):	8000
Operating labor rate ($/hr):	15.64
Maintenance labor rate ($/hr):	17.20
Operating labor factor (hr/sh):	0
Maintenance labor factor (hr/sh):	0.5
Electricity price ($/kWhr):	0 0461
Caustic price ($/ton):	300
Solvent (water) price ($/1000 gal):	0.2
Wastewater trtmt cost ($/1000 gal):	3.8
Overhead rate (fraction):	0.6
Annual interest rate (fraction):	0.07
Control system life (years):	15
Capital recovery factor (system):	0.1098
Taxes, insurance, admin. factor:	0.04

ANNUAL COSTS:

Item	Cost ($/yr)	Wt. Factor	W.F.(cond.)
Operating labor	0	0.000	----
Supervisory labor	0	0.000	----
Maintenance labor	8,602	0.179	----
Maintenance materials	8,602	0.179	----
Electricity	761	0.016	----
Caustic	13,441	0.280	----
Solvent (water)	31	0.001	----
Wastewater treatment	586	0 012	----
Overhead	10,322	0.215	0.574
Taxes, insurance, administrative	1,496	0.031	----
Capital recovery	4,107	0.086	0.117
Total Annual Cost	47,948	1.000	1.000

Notes:
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[1] This program has been based on data and procedures in Chapter 9 of the OAQPS CONTROL COST MANUAL (4th edition).
[2] Enter one of the following: fiberglass-reinforced plastic (FRP)--'1'; 304 stainless steel--'1.4'; polypropylene--'0.95'; polyvinyl chloride (PVC)--'0 70'

figured at either **1.18** times the TEC if the control device cost *does not* include instrumentation and controls or **1.08** times the TEC if it *does*. The TCI is then factored from the PEC. The factor used depends on the type of control device and whether it is a packaged unit. For instance, the factor used with thermal and catalytic incinerators is either 1.25 (packaged units) or 1.61 (custom units). In Figure 5, the TCI factor is 2.20, a number that applies to all gas absorbers, because most of them are custom-built devices.

In calculating the equipment cost for some devices, the program utilizes two powerful features of the Eight-In-One™ spreadsheet program. These features are the "IF...THEN" and "MAX" statements. Both have been employed in writing the Thermal Incinerators program, a sample of which is shown in Figure 6. First, note that the "primary heat recovery" must be entered as an input parameter. In this case, the primary heat recovery is 0.70 (70%). Under the "Equipment Costs" portion of the "Capital Costs" section, there are four lines for the incinerator cost, one each for primary heat recoveries of 0, 35, 50, and 70%. A different line is needed for each heat recovery because the incinerator equipment cost increases with increasing heat recovery. (For more information on this, consult Chapter 3 of the *Manual*.) Note that only the 70% line contains a cost, while each of the others shows "0". To accomplish this, each equipment cost cell was given a formula, such as:

"IF(D11=0.70,21342*D24^0.2500,0)".

Translation: "If the primary heat recovery equals 70%, the incinerator equipment cost equals 21,342 times the total gas flowrate (D24) raised to the 0.2500 power. If the heat recovery equals some other value, the cost equals 0." The formulas for the other three cells were written similarly.

One might ask, "If there are four values for the incinerator equipment cost—one number and three zeroes—how will the program know which to use to compute the purchased equipment cost?" To solve this problem, we entered the following formula in the PEC cell:

"1.08*MAX(D30:D33)".

Translation: "The PEC equals 1.08 times the *maximum value* entered in cells D30 through D33." This feature allows the program to ignore the cells containing zeroes.

The fourth section, "Annual Cost Inputs," lists nearly all of the parameters needed for the program to calculate the various annual costs. As with the "Input Parameters" discussed above, *the user must provide all of these inputs* (i.e., there are no

Figure 6. Sample Printout for Thermal Incinerators Cost Program

TOTAL ANNUAL COST SPREADSHEET PROGRAM--THERMAL INCINERATORS

COST REFERENCE DATE: April 1988

INPUT PARAMETERS

-- Gas flowrate (scfm):	25250
-- Reference temperature (oF):	77
-- Inlet gas temperature (oF):	100
-- Inlet gas density (lb/scf):	0.0739
-- Primary heat recovery (fraction):	0.70
-- Waste gas heat content (BTU/scf):	4.18
-- Waste gas heat content (BTU/lb):	56.56
-- Gas heat capacity (BTU/lb-oF):	0.255
-- Combustion temperature (oF):	1600
-- Preheat temperature (oF):	1150
-- Fuel heat of combustion (BTU/lb):	21502
-- Fuel density (lb/ft3):	0.0408

DESIGN PARAMETERS

-- Auxiliary Fuel Reqrmnt (lb/min):	8.608
(scfm):	211.0
-- Total Gas Flowrate (scfm):	25461

CAPITAL COSTS

Equipment Costs ($):	
-- Incinerator:	
@ 0 % heat recovery:	0
@ 35 % heat recovery:	0
@ 50 % heat recovery:	0
@ 70 % heat recovery:	269,590
-- Other (auxiliary equipment, etc.)	0
Total Equipment Cost:	269,590
Purchased Equipment Cost ($):	318,116
Total Capital Investment ($):	512,167

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ANNUAL COST INPUTS

Operating factor (hr/yr):	8000
Operating labor rate ($/hr):	12.96
Maintenance labor rate ($/hr):	14.26
Operating labor factor (hr/sh):	0.5
Maintenance labor factor (hr/sh):	0.5
Electricity price ($/kwh):	0.059
Natural gas price ($/mscf):	3.3
Annual interest rate (fraction):	0.07
Control system life (years):	10
Capital recovery factor:	0.1424
Taxes, insurance, admin. factor:	0.04
Pressure drop (in. w.c.):	19.0

ANNUAL COSTS

Item	Cost ($/yr)	Wt. Factor	W.F.(cond
Operating labor	6,480	0.013	----
Supervisory labor	972	0.002	----
Maintenance labor	7,128	0.014	----
Maintenance materials	7,128	0.014	----
Natural gas	334,177	0.659	----
Electricity	44,528	0.088	----
Overhead	13,025	0.026	0.0
Taxes, insurance, administrative	20,487	0.040	----
Capital recovery	72,921	0.144	0.1
Total Annual Cost	506,846	1.000	1.0

default values). Nevertheless, typical values for the parameters are given in the *Manual* chapter covering the device in question.

The first, and probably most important, annual cost input is the "operating factor"—the hours per year the control device operates. As discussed previously, it can range from less than 800 to more than 8000 hours/year, depending upon the emission source that the device controls. This parameter determines all of the operating and maintenance costs—labor, utilities, materials, and waste disposal. The operating and maintenance labor rates also depend on the source and its location. However, according to guidance given in the *Manual*, the program computes the maintenance labor rate by factoring it from the operating labor rate (i.e., the maintenance rate is 10% higher than the operating) and computes the maintenance materials cost at 100% of the maintenance labor cost.

The operating and maintenance labor factors—both given in hours/shift—vary according to device type, as some equipment (such as scrubbers) typically requires more operator attention and maintenance than others (e.g., incinerators). As a rule, the smaller devices require less attention than the larger, a fact that has been incorporated into these programs. For instance, the operating and maintenance labor factors for thermal and catalytic incinerators are each 0.5 hours/shift, *except for* devices treating gas flowrates less than 20,000 standard cubic feet per minute (scfm). The utility prices—electricity, natural gas, process and cooling water, steam, etc.—are self-explanatory. However, as with the other annual cost inputs, the user should be careful that they reflect the units shown on the spreadsheet. The natural gas price, for example, must be expressed in "$/thousand standard cubic feet," not "$/million BTU".

The "annual interest rate" and "control system life" are the two required inputs to the "capital recovery factor" (CRF). When the CRF is multiplied by the total capital investment (TCI), the capital recovery cost results. In accordance with Office of Management and Budget guidance, the annual interest rate should be 7%. However, the user can vary this parameter to determine its effect on the total annual cost. The control system life typically varies from 10 years (scrubbers, gas absorbers, and carbon adsorbers) to 20 years (ESPs, fabric filters, and mechanical collectors). But, there may be situations when the system life falls outside this range.

The CRF is computed according to the standard formula:

$$CRF = i(1+i)^n/[(1+i)^n-1] \qquad (5)$$

where: i = annual interest rate (decimal) n = control system life (years)

Finally, the "taxes, insurance, admin. [administration] factor" is set at 4% of the total capital investment, consistent with *Manual* guidance, although the user may vary this parameter if he/she desires.

The "Annual Costs" are displayed in the next section of the program. Appropriately, each cost is given in "dollars/year". The "operating labor" and "maintenance labor" costs are each computed from the operating factor, operating/maintenance labor rate, and operating labor factor—all of which are "Annual Cost Inputs". However, the "supervisory labor" is factored at 15% of the operating labor cost. The 15% supervisory labor factor and the overhead factor (60% of the sum of all labor and maintenance materials costs) are embedded in the program calculation formulas, rather than being listed as annual cost inputs. However, as both factors are standard *Manual* values contained in Chapter 2, there is little incentive to vary them.

The utilities costs—natural gas, electricity, water, steam, etc.—are calculated via the appropriate input parameters, design parameters, and/or annual cost inputs. The equations the program uses to compute these costs are very similar, if not identical, to those in the *Manual*. However, whenever the program calculates a negative utility parameter (e.g., natural gas usage for a regenerative thermal oxidizer), the annual cost for this item is set at zero.

For certain devices—namely, carbon adsorbers, catalytic incinerators, and fabric filters—there are also annual costs for replacement parts—carbon, catalyst, and filter bags, respectively. These costs are calculated by multiplying the part cost (*plus* taxes and freight and the part replacement labor cost) by a capital recovery factor that accounts for the interest rate and the part expected life. The last two costs—"taxes, insurance, administrative" and "capital recovery"—are obtained by multiplying the total capital investment by the "taxes, insurance, admin. [administrative] factor" and the "capital recovery factor," respectively. Whenever there are replacement parts costs, the capital recovery cost is factored from the total capital investment *less* the cost of the replacement parts, the applicable sales and freight taxes, and the cost of installing the parts in the device. (See Chapter 2 of the *Manual* for more guidance on this.)

When applicable, "Recovery credits" are deducted from the total annual costs for carbon adsorbers and refrigerated condensers. A credit can be quite significant, especially if the recovered product has a high value. In some cases, it actually can exceed the sum of the annual costs.

Note that the annual cost section includes two more columns: "Wt. factor [Weighting factor]" and "W.F. (cond.) [Weighting Factor, condensed]". The first of these lists the fractional contribution that each annual cost makes to the total annual cost (*without* recovery credits). These fractions range from 0 to greater than 0.97, depending on the various inputs. As discussed in Section III, the weighting factors are used in computing the Total Annual Cost Indexes (TACI).

Lastly, the "Weighting Factor [condensed]" column lists two numbers, each of which has been devised to streamline the calculation of the TAC indexes. The first "condensation" is the sum of all the labor-related weighting factors: operating, supervisory, and maintenance labor; maintenance materials; and overhead. The second number combines the "taxes, insurance, administrative" and "capital recovery" costs. Both condensations appear in the weighting factor tables.

V. Distributing the Indexes

Because so many cost analysts would benefit from using both the equipment and total annual cost indexes it seems only right that the indexes be disseminated as widely as possible. With this in mind, we have devised a strategy for distributing the "Vatavuk Air Pollution Control Cost Indexes" (VAPCCI). The strategy has two elements: intra-governmental dissemination and public domain distribution. This section discusses both elements, in terms of what is planned—and what has been done—to implement them.

Intra-governmental dissemination: This element includes all practical means for informing EPA, State/local, and EPA contractor users about the indexes and supporting information (such as the TAC spreadsheet programs). The best means for making such distribution is through the Emission Standards Division's Control Technology Center (CTC). The CTC has the capability of informing literally thousands of potential users via its computer bulletin board, newsletter (*CTC News*), and other communication tools. After announcing the availability of the indexes, the CTC then can mail hard copies of this report and/or computer diskettes containing the various indexes to requesters. In addition, the CTC's Technology Transfer Network (TTN) can be used to electronically disseminate the indexes and supporting information. Finally, via its "Hotline," the CTC can answer questions about the VAPCCI or refer callers to someone who can. In these respects the CTC is a "triple threat" information bank.

Within OAQPS, we already have informed potential users about the VAPCCI via the LAN. This notification generated some interest. Based on this response, we gave a seminar (December 1994) to present the VAPCCI and TAC spreadsheets, and demonstrate the use of both. As our contractors usually make more control cost calculations than we do, we invited them also.[a]

Public domain distribution: As the name implies, this element of the strategy entails distributing the VAPCCI to all users, especially those outside the regulatory sector. The most efficient way to do this is through technical publication.

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[a] This seminar on the VAPCCI was an addendum to a series of 12 control cost lectures this author presented to OAQPS personnel (primarily ESD) and ESD contractors from April 1991 to January 1993. Each of these lectures focused on a particular type of control device (e.g., fabric filters) and provided instruction on how to size and cost that device. The instruction closely followed the data and procedures presented in the applicable chapter(s) of the *OAQPS Control Cost Manual*.

Several technical journals are potential outlets for the VAPCCI. The four journals we considered were:

✓ *Chemical Engineering (CE)*

✓ *Environmental Engineering World (EEW)*

✓ *Journal of Air and Waste Management (JAWMA)*

✓ *Pollution Engineering*

Published by McGraw-Hill, *CE* is a high-circulation (70,000) and readership (300,000-plus) magazine that, for over six decades, has been dedicated to informing technical and management personnel about developments in the chemical process industries. In recent years, *CE* has devoted more coverage to environmental issues. (For instance, the March 1995 issue contained a feature report on the HON MACT.) During the past fifteen years, this author has had 25 articles published in *Chemical Engineering*.

Environmental Engineering World, also published by McGraw-Hill, is a recent "spin-off" from *Chemical Engineering* magazine. Suzanne Shelley, the editor of *EEW*, has committed to publish both a feature article about the VAPCCI and the indexes as they are updated. She also has arranged to have the article and indexes published in *CE*. When this is done, the indexes will reach the readership of both magazines, i.e., those who are working in the chemical processing and environmental control fields—just the kinds of professionals that would benefit from using the VAPCCI.

The *JAWMA* is another periodical to which we have contributed. This monthly periodical has been the unofficial (if not the official) organ of the air pollution control field for decades, both inside and outside government. The VAPCCI should fit *JAWMA*'s format well, and be well received by its readers.

Another monthly, *Pollution Engineering* is much like *EEW*, in terms of format, content, and targeted audience. Older than *EEW*, *PE* has been published since the early 1970's. The VAPCCI would fit its format just as well as it would *EEW*'s.

Other periodicals are possible outlets for the VAPCCI. Two are *Environment* and *Environmental Progress*. The former, published 10 times a year, typically publishes articles related to environmental science and policy, though not very many on control equipment usage, design, and cost.

The latter, *Environmental Progress* publishes practical articles related to air, water, and solid waste pollution control. It is one of several periodicals distributed by the American Institute of Chemical Engineers to AIChE members. However, with a quarterly publication schedule, *EP* would not give the VAPCCI nearly as much exposure as *CE, EEW, JAWMA*, or *PE*.

We should keep in mind, however, that publication of the VAPCCI would not necessarily be limited to one or more periodicals. As these indicies were developed on EPA time using EPA resources, *they are technically in the public domain*. Hence, no publisher or other entity can copyright the contents of the VAPCCI. In other words, the VAPCCI can be published in several periodicals simultaneously.

In addition to publishing the VAPCCI in journals, we plan to send the indexes to certain control equipment vendors periodically, to solicit their comments. The vendors solicited will be those who responded positively to our surveys. We are mainly interested in seeing how well the VAPCCI—especially the equipment cost indexes—predict their price changes. If there are large enough differences between the real and predicted price changes, we can adjust the VAPCCI accordingly. This solicitation would not only provide a "reality check" on the VAPCCI, but also serve to publicize the indexes and encourage their use.

VI. Future Work

Unlike some projects that are complete once the final reports are written, this one will *never* be finished. Although we have devised equipment and total annual cost indexes for eight air pollution control devices, our work is far from being complete. For one thing, the indexes will have to be—and have been—updated quarterly. This updating process requires us to obtain current Producer Price Indexes, as well as inputs from other sources (e.g., the Department of Energy). These inputs must be keyed into the VAPCCI programs to generate the updated indexes. Finally, the updated indexes have to be disseminated to users, periodicals, and other outlets.

The future work will not be limited to just updating the VAPCCI. Based on feedback from vendors and other reviewers, the indexes may have to be revised. These revisions may entail something as easy as changing some of the index weighting factors. But, under certain circumstances we may have to restructure one or more of the indexes. Feedback from equipment vendors and other users, as well as data gleaned from further research, may point out areas where an index is deficient. As a result, we may have to make major changes, such as adding or deleting several components of the index. Though time- and resource-consumptive, such revisions will be necessary to maintain the integrity of the VAPCCI. (We do not anticipate that such major changes will be required often, however.)

Thirdly, we expect to expand the coverage of the VAPCCI to include additional control devices. Although those included at present cover most of the major control device categories, several others eventually should be added. These are the other particulate devices (fabric filters and electrostatic precipitators, mainly[a]), the several NO_x controls (selective and nonselective catalytic reduction, combustion modifications, steam and water injection, etc.), the many flue gas desulfurization (FGD) processes, and the fugitive emission controls, such as wet dust suppression.

All of this begs the question: "Who's going to do this work, and how much in-house time and contractual resources will be needed to accomplish it?" Although this author is not the *only* person who could update, refine, and expand the VAPCCI, he is the most likely candidate for the job. Besides which, the author's main responsibility is the maintainance and improvement of the

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[a] We had planned to include these two devices in this report, but were unable to obtain the requisite data from vendors.

quality of OAQPS control cost estimation. Hence, this work would fit his job description very nicely.

The in-house time and contractual resources required will depend on the type of VAPCCI work being done (i.e., updating, refining, or expanding). These requirements (figured on an annual basis) are listed in the table below. Obviously, these estimates are quite approximate, as the number of tasks (let alone their complexity) is still unknown.

Annual Time and Resources Needed for VAPCCI Tasks

VAPCCI Task	In-House Time (person-year)[a]	Contractor Resources (hours)
1. Updating[b]	0.14	None
2. Refinement[c]	0.02	None
3. Expansion[d]	0.04	240 - 400
Totals:	0.20	240 - 400

Notes:

[a] One person-year = 1800 hours/year = 225 days/year.

[b] Assumes that each of eight indexes will have to be updated four times per year (quarterly), with each index update requiring approximately one person-day.

[c] Assumes that one index will need a major refinement annually, with each refinement requiring approximately five person-days.

[d] Assumes that two new indexes will be developed annually, with each development requiring approximately ten person-days of in-house time and 240 to 400 (6 to 10 weeks) of contractor time.

* * *

In all, approximately two-tenths person and 240 to 400 hours of contractor time would be needed to update, refine, and expand the VAPCCI. Because this author has spent six months full-time developing the VAPCCI (and approximately one more month updating the indexes and revising this report), it is not too difficult to estimate the in-house time needed to accomplish these maintenance and development tasks. Estimating the contractual resources (task 3) is another matter, however. Not knowing which contractor(s) would be retained for developing new indexes, the capability of the staff assigned to the project, and other factors, it is difficult to provide a single hours/year estimate. Thus, a range has been listed. As note "d" indicates, this range reflects 6 to 10 weeks of contractor time.

Note that no contractor resources have been given for tasks 1 (updating) and 2 (refinement). Although one or both of these tasks could be assigned to contractors, they probably could be done more efficiently in-house. The procedures for updating the VAPCCI are easy to learn and use and are, therefore, amenable to in-house performance. (Interestingly, for several years the Chemical Engineering Plant Index was updated by clerical personnel at *Chemical Engineering* magazine.) Refining an index is a more complex undertaking, as it requires knowledge of how the index was developed, along with thorough knowledge of the control device and its components.

Clearly, index development demands technical expertise. However, it also requires a lot of data-gathering and analysis—the kinds of tasks that contractors are often better-equipped to handle than are in-house staff. In-house time will also be needed for task 3, for such jobs as writing the work assignment, monitoring the contractor's performance, and using the contractor's findings to devise the final index. In other words, the contractor would perform only part of the index development task. The rest would be done in-house.

Finally, no time has been allotted in the above table for "information service"—answering questions about the VAPCCI, sending copies of this report and computer diskettes, and related chores. As explained above, the latter tasks can be handled effectively by the Control Technology Center. Nevertheless, this author can best handle the "Q&A" work. As no one can predict how many calls we will get regarding the VAPCCI, we cannot estimate the resources needed to address them. In any event, we should hope to get *many*, for phone calls are an excellent barometer of how well we've distributed the VAPCCI and how much they are being used.

Appendix A. Control Device Component Price Data

The tables in this appendix list the averages of the reported component price factors for each of the eight control devices covered in this report. These factors were used in developing the equipment cost indexes (ECI) described in Section II.

Table A-1. Carbon Adsorber Component Price Data

Component	Fraction of List Price		
	Small[a]	Medium[b]	Large[c]
Adsorber vessels	0.180	0.240	0.250
Carbon	0.030	0.120	0.130
Condenser	0.040	0.040	0.030
Internal piping	0.170	0.130	0.140
Decanter	0.020	0.010	0.010
Pump (recovered organics)	0.020	0.010	0.010
Receiver	0.020	0.010	0.010
Distillation column	0.000	0.000	0.000
Air prefilters	0.020	0.040	0.040
Dampers & valves	0.060	0.070	0.080
System & cooldown fans	0.010	0.010	**0.010**
Fan motors & drives	0.040	0.040	0.050
Instrumentation & controls	0.210	0.150	0.140
Other (specify)[d]	0.180	0.130	0.100
Totals:	1.000	1.000	1.000

[a] Capacity: < 1,000 acfm.

[b] Capacity: 1,000 - 50,000 acfm.

[c] Capacity: > 50,000 acfm.

[d] Other includes "indirects" (engineering, primarily).

Table A-2. Catalytic Incinerator Component Price Factors

Component	Fraction of List Price		
	Small[a]	Medium[b]	Large[c]
Catalyst	0.225	0.265	0.295
Catalyst chamber	0.095	0.105	0.105
Preheat chamber	0.065	0.090	0.090
Filter/mixer (gas flow distribution)	0.060	0.015	0.010
Recuperative heat exchanger	0.180	0.255	0.270
Flow control dampers	0.015	0.005	0.005
System fan	0.070	0.075	0.075
System fan motor & drive	0.045	0.045	0.045
Stack	0.070	0.035	0.035
Instrumentation & controls	0.110	0.045	0.040
Other (specify)[d]	0.065	0.065	0.030
Totals:	1.000	1.000	1.000

[a] Capacity: < 2,000 acfm.

[b] Capacity: 2,000 - 50,000 acfm.

[c] Capacity: > 50,000 acfm.

[d] Includes "engineering and startup".

Table A-3. Flare Component Price Factors

Component	Fraction of List Price		
	Small[a]	Medium[b]	Large[c]
Flare burner tip	0.175	0.125	0.095
Pilot burners	0.120	0.075	0.035
Flare tower (stack) & support	0.315	0.390	0.425
Utility piping (from base)	0.040	0.055	0.070
Liquid & gas seals	0.065	0.080	0.080
Ladders & platforms	0.040	0.080	0.105
Dampers & valves	0.025	0.020	0.015
Knockout drum	0.065	0.070	0.085
System fan	0.020	0.020	**0.020**
Fan motor & drive	0.010	0.010	0.010
Instrumentation & controls	0.125	0.075	0.060
Other (specify)	0.000	0.000	0.000
Totals:	1.000	1.000	1.000

[a] Flare tip diameter: < 12 inches.

[b] Flare tip diameter: 12 to 48 inches.

[c] Flare tip diameter: > 48 inches.

Table A-4. Gas Absorber Component Price Data

Component	Fraction of List Price		
	Small[a]	Medium[b]	Large[c]
Absorber column[d]	0.235	0.257	0.170
Packing	0.090	0.067	0.065
Platforms and ladders	0.040	0.043	0.065
Internal piping	0.060	0.050	0.065
Recirculation tank	0.085	0.100	0.080
Pumps	0.090	0.087	0.085
Dampers & valves	0.060	0.043	0.050
Mist eliminator	0.045	0.043	0.065
System fan	0.100	0.093	0.115
Fan motor & drive	0.070	0.053	0.070
Instrumentation & controls	0.110	0.107	0.110
Other[e]	0.015	0.057	0.060
Totals:	1.000	1.000	1.000

[a] Capacity: < 2,000 acfm. However, one vendor specified an upper limit of 10,000 acfm.

[b] Capacity: 2,000 - 40,000 acfm. However, one vendor specified a range of 10,000 - 40,000 acfm.

[c] Capacity: > 40,000 acfm.

[d] Including: gas inlet and outlet ports; liquid inlet port and outlet port/drain; liquid distributor/redistributor; sump space; and, as applicable, trays or packing support plates.

[e] Includes "engineering".

Table A-5. Refrigeration System Component Price Data

Component	Percent of List Price		
	Small[a]	Medium[b]	Large[c]
Refrigeration unit	0.230	0.215	0.260
Precooler	0.050	0.050	0.050
VOC condenser(s)	0.165	0.165	0.175
VOC storage/recovery tank(s)	0.025	0.035	0.045
Internal piping	0.085	0.085	0.075
Pumps	0.025	0.025	0.035
Dampers & valves	0.030	0.030	0.045
System fan	0.040	0.045	**0.000**
Fan motor & drive	0.050	0.050	0.000
Instrumentation & controls	0.225	0.225	0.250
Other (specify)[d]	0.075	0.075	0.065
Totals:	1.000	1.000	1.000

[a] Capacity: < 10 tons.

[b] Capacity: 10 to 100 tons.

[c] Capacity: > 100 tons.

[d] Other includes "structural".

Table A-6. Regenerative Thermal Oxidizer Component Price Data

Component	Fraction of List Price		
	Small[a]	Medium[b]	Large[c]
Combustion chambers	0.110	0.115	0.100
Burners	0.035	0.025	0.020
Heat collection material (e.g., ceramic packing)	0.115	0.075	0.065
Insulation	0.100	0.100	0.100
Flow control dampers	0.115	0.175	0.200
System fan	0.200	0.200	0.215
System fan motor & drive	0.125	0.100	0.110
Instrumentation & controls	0.175	0.150	0.135
Other (specify)[d]	0.025	0.060	0.055
Totals:	1.000	1.000	1.000

[a] Capacity: < 5,000 acfm.

[b] Capacity: 5,000 - 100,000 acfm.

[c] Capacity: > 100,000 acfm.

[d] Other includes "engineering, startup, project management, and purchasing manhours".

Table A-7. Thermal Incinerator Component Price Data

Component	Fraction of List Price		
	Small[a]	Medium[b]	Large[c]
Combustion chamber	0.100	0.100	0.100
Burner(s)	0.050	0.050	0.050
Insulation	0.100	0.090	0.080
Recuperative heat exchanger	0.350	0.350	0.390
Flow control dampers	0.080	0.100	0.100
System fan	0.100	0.100	0.100
System fan motor & drive	0.050	0.050	0.050
Stack	0.040	0.030	0.030
Instrumentation & controls	0.080	0.080	0.070
Other (specify)[d]	0.050	0.050	0.030
Totals:	1.000	1.000	1.000

[a] Capacity: < 500 acfm.

[b] Capacity: 500 - 50,000 acfm.

[c] Capacity: > 50,000 acfm.

[d] Other includes "support legs".

Table A-8. Wet Scrubber Component Price Data

Component	Fraction of List Price		
	Small[a]	Medium[b]	Large[c]
Contacting unit (e.g., venturi)	0.110	0.120	0.105
Liquid-gas separator	0.045	0.097	0.165
Mist eliminator	0.045	0.043	0.065
Internal piping	0.065	0.073	0.065
Lining (e.g., rubber)	0.040	0.027	0.040
Recirculation liquid pump	0.125	0.107	0.085
Recirculation tank	0.160	0.143	0.075
Flow control dampers	0.040	0.037	0.055
System fan	0.125	0.110	**0.115**
System fan motor & drive	0.070	0.053	0.070
Instrumentation & controls	0.135	0.120	0.100
Other (specify)[d]	0.040	0.070	0.060
Totals:	1.000	1.000	1.000

[a] Capacity: < 1,000 acfm. (However, one vendor specified 10,000 acfm as the upper end of this size range.)

[b] Capacity: 1,000 - 50,000 acfm. (However, one vendor specified a size range of 10,000 - 50,000 acfm.)

[c] Capacity: > 50,000 acfm.

[d] Other includes "engineering".

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15. SUPPLEMENTARY NOTES

16. ABSTRACT This report documents the work accomplished during the FY 1993-94 "Bernard J. Steigerwald Opportunity for Independent Study". It discusses why and how air pollution control cost indexes were developed and presents index values for several periods (quarters). These indexes are used to adjust ("escalate") control equipment and total annual costs from one quarter to another. In all, 16 indexes were developed and are presented herein, one Equipment Cost Index (ECI) and one Total Annual Cost Index (TACI) for each of eight control device categories. These indexes——collectively known as the Vatavuk Air Pollution Control Cost Indexes——can be used to escalate costs from the initial (base) period (first quarter 1994) to any quarter thereafter. In this report, final ECI and TACI are given for the second, third, and fourth quarters of 1994; and preliminary indexes, for first quarter 1995.

17. KEY WORDS AND DOCUMENT ANALYSIS

a. DESCRIPTORS	b. IDENTIFIERS/OPEN ENDED TERMS	c. COSATI Field/Group
Stationary emission sources Costs Control techniques Carbon adsorbers Catalytic incinerators Flares Gas absorbers Regenerative oxidizers Refrigeration systems Thermal incinerators Venturi scrubbers	Cost estimation Cost escalation Escalation indexes Equipment costs Annual costs (direct, indirect) "Add-on" controls	

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