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Regulatory Impact Analysis for the National Emissions Standards for Hazardous Air Pollutants for Source Categories: Organic Hazardous Air Pollutants from the Synthetic Organic Chemical Manufacturing Industry and Seven Other Processes

DRAFT

EPA No. 450/3-92-009

REGULATORY IMPACT ANALYSIS

For The
National Emissions Standards for Hazardous Air Pollutants for Source Categories: Organic Hazardous Air Pollutants from the Synthetic Organic Chemical Manufacturing Industry and Seven Other Processes

Emission Standards Division

U.S. Environmental Protection Agency
Office of Air and Radiation
Office of Air Quality Planning and Standards
MD-13, Research Triangle Park, North Carolina 27711

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EXECUTIVE SUMMARY

The Environmental Protection Agency (EPA) plans to propose regulations to reduce air pollutant emissions from synthetic organic chemical manufacturing industry (SOCMI) facilities in eight source categories, and facilities in seven other equipment leak source categories. Both new and existing facilities that meet the Clean Air Act definition of major sources will be regulated under the authority of sections 112(c) and (d). This decision is based on evidence that SOCMI facilities release air pollutants that have adverse effects on both public health and welfare, and the need for additional control of air pollutants already covered by the Act before the 1990 Amendments.

Section 112(b) lists 189 hazardous air pollutants (HAP's). The proposed regulation will reduce the emissions of approximately 150 of the organic chemicals on the list. The proposed regulation requires sources to achieve emissions limits reflecting the application of the maximum achievable control technology (MACT).

The HON regulation covers five types of emission points: process vents, wastewater, transfer operations, storage vessels, and equipment leaks. The regulation is made up of two standards, one covering the first four emission points, and the second covering equipment leaks. The standard for the first four emission points was arrived at by the usual regulatory process, while the equipment leaks standard was developed by regulatory negotiation.

This regulation is unusual in that the regulation of the emissions occurring from production of an extremely large number of chemicals is being targeted at one time. Facilities in virtually every state shall be affected by the HON. In determining the regulatory options, the Agency evaluated methods of determining what technologies should be applied for particular types of emissions, what would be the minimum level of stringency for pollutant control, and strategies for obtaining control at the lowest cost (emission averaging).

The standards will require reductions of emissions of HAP's, which are a subset of VOC's (volatile organic compounds). The level of control provided by the regulatory options chosen ranges from no control for existing small storage tanks (i.e, storage tanks with less than 10,000 gallon capacity) to 95 percent control for new process vents. The total amount of emission reduction for HAP's will be 475,000 Mg (megagrams), and for all VOC's (including HAP's) approximately 980,000 Mg.

These standards, based on the regulatory options chosen, will cost the nation $182 million annually by the fifth year after all affected sources have complied with the regulation (i.e., 1997). The most stringent alternative, total industry control (TIC), if chosen would have cost the nation $359 million annually by 1997. The economic impacts for the regulatory options chosen are expected to be small. Price increases for a large majority (78 percent) of affected chemicals are expected to be under 2 percent, and decreases in production for a very large majority (91 percent) of affected chemicals are expected to be under 2 percent. Due to the flexible nature of the SOCMI, and the several process routes possible for production of most SOCMI chemicals, significant closures for SOCMI facilities are quite unlikely.

The regulatory alternatives under consideration will not affect a substantial number of small entities, so a Regulatory Flexibility Analysis is not required.

The absence of valuation and sufficient exposure-response information precludes a quantitative benefits analysis at this time.

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Acronyms, Definitions, and Conversions

Acronyms

BID	Background Information Document
CAA	Clean Air Act
CAAA	Clean Air Act Amendments of 1990
CPP	Chemical Production Processes
EPA	Environmental Protection Agency
HAP	Hazardous Air Pollutant
HON	Hazardous Organic NESHAP (NESHAP is defined below)
LDAR	Leak Detection and Repair
LEL	Lower Explosive Limit
MACT	Maximum Achievable Control Technology
NAAQS	National Ambient Air Quality Standards
NESHAP	National Emission Standards for Hazardous Air Pollutants
NPDES	National Pollutant Discharge Elimination System
OAQPS	Office of Air Quality Planning and Standards
OSHA	Occupational Safety and Health Administration
POTW	Publicly Owned Treatment Works
RACT	Reasonably Available Control Technology
RFA	Regulatory Flexibility Act; also Regulatory Flexibility Analysis
SIC	Standard Industrial Classification
SIP	State Implementation Plan
SOCMI	Synthetic Organic Chemical Manufacturing Industry

TLV	Threshold Limit Value
TRE	Total Resource Effectiveness
VOC	Volatile Organic Compound
VHAP	Volatile Hazardous Air Pollutant
VOHAP	Volatile Organic Hazardous Air Pollutant
VVHAP	Very Volatile Hazardous Air Pollutant

Chemical Symbols

CO_2	Carbon dioxide
CO	Carbon monoxide
HCl	Hydrochloric acid
NH_3	Ammonia
NO_x	Nitrogen oxide
O_3	Ozone
SO_2	Sulfur dioxide

Economic, Regulatory, and Scientific Terms

Annual Cost	Annualized capital plus annual operating costs
Area Source	Any emission source emitting less than 10 tons per year of a single HAP or 25 tons or more per year of two or more HAPs, unless EPA establishes a lesser quantity cutoff
bbl	One barrel; equal to 42 gallons
Btu	One British thermal unit
C/E	Cost effectiveness, which is the net present value of cost of emission control divided by the present value of emission reductions in megagrams (defined below)

Gg	One gigagram, or 1,000,000 kilograms
Gm	One *gram*
kw	One kilowatt, or 1,000 watts
lpm	One liter per minute
Major Source	Any emission source emitting 10 tons or more a year of a single HAP or 25 tons or more a year of two or more HAPs
Mg	One megagram, or 1,000 kilograms
MJ	One megajoule, or .949 Btu
MW	One megawatt, or .949 Btu per second
ppmv	parts per million by volume (air)
ppmw	parts per million in water
psia	Pounds per square inch absolute
112(b)	Section of Title III in the CAAA that requires the EPA to promulgate regulations establishing emission standards for new and existing sources of HAPs on the list of 189 HAPs in the title
scfm	One standard cubic foot per minute
Title I	The first title of the CAAA; this title classifies nonattainment areas, sets attainment schedules, and prescribes control measures for O_3, CO, PM-10, and for SO_x, NO_x, and Lead
Title III	The third title of the CAAA; this title lists the 189 HAPs to be controlled with MACT, as well as the control of major and area sources, incinerator air emissions, accidental releases, and special studies

TIC	Total Industry Control; the most stringent regulatory option for each source type

Units and Conversions

This report uses metric units, some of which may not be familiar to all readers. The EPA is required by Congress to use metric measurements. The following is a short guide to the units and their conversions.

Conversions

To Approximate	As	Multiply by
Mg (megagram)	Ton (2,000 lb)	1.1
scm (standard cubic meter)	scf(standard cubic foot)	35.3
MJ (megajoule)	Btu (British thermal unit)	949
MW (megawatt)	Btu/second	949
kg (kilogram)	lb (pound)	2.2

CHAPTER 1

BACKGROUND

1.1 Introduction

The NESHAP being proposed is commonly known as the hazardous organic NESHAP, or HON. The HON would regulate emissions of certain organic hazardous air pollutants from SOCMI process units. A SOCMI process unit is defined as a unit producing one or more of a list of SOCMI chemicals. A SOCMI process unit is only covered by the HON if it either 1) produces a HAP as a product, by-product, co-product, or intermediate; or 2) uses a HAP as a reactant or raw material to produce a SOCMI chemical. Seven non-SOCMI source categories would also be regulated under the proposed equipment leaks standard (see Section 2.1): styrene/butadiene rubber production; polybutadiene production; chlorine production; pesticide production; chlorinated hydrocarbon use; pharmaceutical production; and miscellaneous butadiene use.

1.2 Legal History

On November 15, 1990, the Clean Air Act was amended significantly. Section 112 was substantially revised at that time altering the basic framework for regulating emissions of toxic air pollutants from stationary sources.

Prior to the amendments passed in 1990, Section 112 required the Administrator to list air pollutants for which he intended to establish NESHAPs. Within 180 days after the listing of such air pollutants, regulations were to be proposed. Final regulations were to be issued in another 180 days. Thus, once the Administrator added a pollutant to the Section 112 list, a final NESHAP for that pollutant had to be issued within one year. The statute itself did not contain a list of hazardous air pollutants.

The amendments enacted in 1990 altered the preexisting scheme of Section 112 fundamentally. Instead of requiring the Administrator to determine which air pollutants ought to be listed and regulated as hazardous air pollutants, Congress provided a list of 189 hazardous air pollutants in the statute itself. EPA may revise that list only in conformance with clear statutory guidelines. The Agency is now required to develop a list of all categories and subcategories of sources emitting any of the listed pollutants, and develop technology-based standards to control such emissions. Thus, these standards are to be based on the sources of the emissions rather than being set pollutant by pollutant as in the past and are no longer to be risk based. Regulations for all source categories must be promulgated within

10 years of enactment of the amendments. Generally, assessment and control of any remaining unacceptable health risk is to occur 8 years after the technology-based standards are promulgated. However, for the HON the residual risk assessment is to be conducted 9 years after promulgation.

1.3 Retrospective on Section 111 and 112 Standards Affecting the SOCMI

The provisions of the proposed standards incorporate data, information, and experience gained by EPA through previous rulemaking efforts involving similar sources. Information on control technology applicability, performance, and cost were available from previous NSPS and NESHAP regulatory development efforts. This information was considered in selecting MACT and in developing the proposed standards.

Under the NSPS program, EPA has promulgated NSPS for SOCMI air oxidation and distillation process vents; SOCMI emissions from equipment leaks; petroleum refinery equipment leaks; and VOC emissions from volatile organic liquid storage vessels. Similarly, under the NESHAP program, regulations were promulgated for benzene storage tanks, transfer racks and wastewater emissions , and for vinyl chlorine and benzene equipment leaks. In the development of the HON, this previously collected array of information was carefully reconsidered in light of the provisions of the CAA of 1990. This technical information is presented in detail in the HON BID.

Each of these previous efforts regulates some sources or chemicals that would be subject to the HON, but none of them comprehensively regulate emissions of all of the organic HAP's emitted from new and existing SOCMI process units from all emission points. The HON would regulate all five of the emission points at each affected SOCMI source (see Section 2.1), and would regulate emissions of any of the listed organic HAP's. The first of the HON standards (Subpart G) was developed through usual regulatory procedures, and covers four of the five emission points. An analysis of various regulatory alternatives was conducted for this standard. The second, the equipment leaks NESHAPs (Subpart H), was developed through the regulatory negotiation process, and, as a result, a formal analysis of regulatory alternatives was not conducted.

The negotiators in this process originally were to develop standards for equipment leaks for 13 source categories that would be affected by standards already under development. The standards under development would have applied to only eight organic chemicals. However, during negotiation of the amendments to the CAA, EPA expanded the scope of the standards to include all SOCMI processes that produce or use as a reactant one of the 149 organics listed in the CAA list of 189 HAP's (55 FR

8984, March 9, 1990; 55 FR 14349, April 17, 1990). Petroleum refinery processes were not to be covered, however.

1.4 Executive Order 12291

The President issued Executive Order 12291 on February 17, 1981. It requires EPA to prepare regulatory impact analyses (RIAs) for all regulations having "major" impacts. An impact is considered "major" if the annual effect on the economy is $100 million or more, and/or may result in a "significant" increase in prices. The EPA considers the HON regulations to be major and thus is issuing this RIA.

Along with requiring an analysis of benefits and costs, E.O. 12291 specifies that EPA, to the extent allowed by the Clean Air Act and court orders, demonstrate 1) that the benefits of the HON regulations will outweigh the costs and 2) that the maximum level of net benefits will be reached. Chapter 8 describes the benefits in detail. As explained in that chapter, EPA cannot quantify some of the benefits. Thus, EPA cannot show quantitatively that the benefits of the regulations will outweigh the costs. Despite this problem of quantifying benefits, EPA has determined that CAA Sec. 112 requires issuance of the HON regulations at the stringency level described in Chapter 2. For more information, refer to Chapter 9 and the Federal Register preambles to the HON.

1.5 Guide to the References

Most of this RIA is a summary of research reports, analyses, correspondence, minutes of various meetings and hearings, policy directives, legal notices, laws, regulations, and other documents relating to the development of CAA Sec. 112 regulations for SOCMI (and certain non-SOCMI) facilities. The principal references are listed in the back of the chapter on the subject of interest to you. Consult these references, as well as the preambles that accompany proposal of the HON in the Federal Register, for more detailed information. References are held in public dockets and are available for inspection and copying-the latter may require a fee-during normal business hours. For more information on the docket, contact:

Air Docket (LE-131)
Room M-1500,
Waterside Mall
401 M Street, SW
Washington, DC 20460

Hours: 8:00 a.m. to 3:30 p.m.
Phone No.: (202) 382-7549

CHAPTER 2

THE PROPOSED HON EMISSION STANDARDS IN BRIEF

The HON is organized in three subparts. Subpart F provides a description of the applicability of the standards. Subparts G and H provide the control, monitoring, recordkeeping and reporting requirements for the standard.

2.1 Subpart F: Applicability of the HON

The HON would regulate certain components of new and existing major sources, as defined by Section 112(a), in the SOCMI and 7 non-SOCMI equipment leak source categories.

To define the SOCMI source category, Subpart F includes a list of organic HAP's and a list of approximately 400 synthetic organic chemicals produced by the SOCMI as commercial products. The "chemical manufacturing processes" used to produce these 400 chemicals can, but do not always, result in organic HAP emissions. Only those processes resulting in HAP emissions are subject to the standard.

As proposed, Subpart F defines "source" for the SOCMI source category as all process vents, storage vessels, transfer racks, wastewater streams, and equipment leaks in the organic HAP emitting chemical manufacturing processes that are subject to the HON. To be subject to the HON, a chemical manufacturing process must be used to produce one or more of the approximately 400 SOCMI chemicals listed in Subpart F, and have an organic HAP as either 1) a product, by-product, co-product, or intermediate; or 2) a raw material in the production of another SOCMI chemical product.

To be part of the same source, chemical manufacturing processes that are subject to the HON must also be located within a contiguous plant site under common control.

Subpart G will apply to the following kinds of emission points in SOCMI chemical manufacturing processes: process vents, wastewater operations, storage vessels and transfer operations.

Subpart H will apply to the equipment leaks in SOCMI and non-SOCMI chemical manufacturing processes. The following non-SOCMI equipment leak source categories are subject to Subpart H: styrene/butadiene rubber production; polybutadiene production; chlorine production; pesticide production; chlorinated hydrocarbon use; pharmaceutical production; and miscellaneous

butadiene use.

2.2 Subpart G: Provisions for Process Vents, Wastewater Operations, Storage Vessels and Transfer Operations

Subpart G of the proposed rule would require the owner or operator of a source to limit source-wide emissions of HAP's. Subpart G provides specific instructions for determining how much emissions must be reduced at each source. The required emissions reduction is determined by how much emissions would be reduced if a "reference control technology" were applied to all the "Group 1" emission points in the source.

The proposed standard specifies the reference control technology for each kind of point. Group 1 points are those points that meet the applicability criteria included in the control requirements for the proposed standard. The reference control technologies and applicability criteria for Group 1 points are specified in Subpart G of the standard as well as the definition list in the HON preamble.

The owner or operator of a source can use two methods to comply with the emissions reduction requirement. Either method can be used exclusively, or the two can be combined.

The first method is to apply the reference control technology, or an equivalent technology, to Group 1 emission points; thereby achieving some part of the required emission reduction at each Group 1 point that is controlled.

The second method is to average emissions from two or more emission points such that the overall required emission reduction is achieved. With the second method, emissions averaging, the owner or operator does not have to apply the reference control technology to each Group 1 point, as long as an equivalent or greater emissions reduction is achieved elsewhere in the source. The proposal provides specific procedures that must be followed to utilize emissions averaging as a means of compliance with the HON. These procedures are summarized in Section III.B.6 of this notice.

Although equipment leaks are included in the definition of source for the SOCMI source category, equipment leaks can not be included in the emissions averages because: 1) the equipment leaks standard has no fixed performance level; and 2) no method currently exists for determining the magnitude of allowable emissions to assign equipment leaks for purposes of emissions averaging. When this methodology is developed, EPA will consider allowing equipment leak emissions to be included in emissions averages.

2.3 Subpart H: Provisions for Equipment Leaks

The provisions in Subpart H of the proposed rule were developed using regulatory negotiation and represent an extension of existing equipment leak control techniques to the eight source categories regulated by today's proposal.

Subpart H proposes work practice requirements to reduce emissions from equipment leaks for equipment in volatile HAP service for 300 or more hours per year. To be in volatile HAP service is to be in contact with or containing fluid that is 5 percent or more HAP.

The following types of equipment are subject to the proposed standards in Subpart H: valves, pumps, connectors, compressors, pressure relief devices, open-ended lines, sampling connection systems, instrumentation systems, agitators, product accumulator vessels, and closed-vent systems and control devices.

CHAPTER 3

THE NEED FOR AND CONSEQUENCES OF REGULATORY ACTION

3.1 The Problems

One of the concerns about potential threats to human health and the environment from chemical manufacturing plants is air emissions of hazardous organics. Hazardous chemicals can also find their way into underground water supplies, and in the solid waste stream. Health risks from emissions of hazardous organics into the air include increases in cancer incidences and other toxic effects. This chapter discusses the need for and consequences of regulating of hazardous air emissions from chemical plants. Section 3.2.3 provides more detail on the health risks of these pollutants.

3.2 Need for Regulation

3.2.1 Market Failure

The U.S. Office of Management and Budget (OMB) directs regulatory agencies to demonstrate the need for a major rule.[1] The regulatory impact analysis must show that a market failure exists and that it cannot be resolved by measures other than Federal regulation. Market failures are categorized by OMB as *externalities*, *natural monopolies*, or *inadequate information*. The following paragraphs address the three categories of market failure. Chapter 5 discusses the regulatory options and makes a case for the necessity of a Federal regulation.

3.2.1.1 Air Pollution as an Externality

Air pollution is an example of a negative externality. This means that, in the absence of government regulation, the decisions of generators of air pollution do not fully reflect the costs associated with that pollution. For a chemical plant operator, air pollution from the plant is a product or by-product that can be disposed of cheaply by venting it to the atmosphere. Left to their own devices, many plant operators treat air as a free good and do not fully "internalize" the damage caused by emissions. This damage is born by society, and the receptors---the people who are the ones adversely affected by the pollution---are not able to collect compensation to offset their costs. They cannot collect compensation because the adverse effects, like increased risks of morbidity and mortality, are by and large, non-market goods, that is, goods that are not explicitly

and routinely traded in organized free markets.[a]

Consider an example. It may be somewhat unreal, but it illustrates why air pollution is a market externality. A young man estimates that over his remaining lifetime he has a risk of getting cancer of, let's say, 4 chances in 10. A new chemical plant is being constructed in his neighborhood, and he pessimistically calculates that the added pollution to his own environment will boost his odds of getting cancer to, say, 5 chances in 10. He walks up to the people owning the chemical plant and offers to "sell his exposure" to the plant's air pollution for a bargain basement price of just $5 a day. For his efforts he gets no more than a laugh. What's wrong? Most young men either would be unwilling to even consider such a transaction, or, if they were willing, they would not know enough about their futures and about the effects of the pollution to set such a precise price. Furthermore, even if they were willing and did have a price, they would not have any good way of coming to terms with the plant owners.[b] The plant owners would ordinarily not attempt such a transaction for many of the same reasons the young man would not attempt it. Given that the plant owners and the young man could accept such a transaction, if transactions costs were low enough and all others parties' concerns were negligible, a transaction which would internalize the air pollution externality could occur, as explained in Coase's theorem. However, it is unusual for this type of externality to be eliminated by this route.[c]

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[a] Litigation also is a possible route for collecting compensation. EPA recognizes that improving the legal system to facilitate environmental protection lawsuits, and the consequent reduction of negative externalities, may be as cost effective and equitable as regulation under the CAA. However, EPA has not explored this avenue for controlling hazardous organic air pollutant emissions.

[b] Again, litigation would be a possible route.

[c] An air pollution externality caused by a chemical plant outside of Port Arthur, Texas was dealt with by a market transaction. The company owning the plant purchased the homes of local residents who had complained about the pollution. However, this transaction only occurred after intense political activity instigated by the residents. See "How a Neighborhood Talked Fina Refinery Into Buying It Out," The Wall Street Journal, December 10, 1991. Other oil companies have also bought land around facilities (called "greenbelts") in order to preempt the creation of pollution externalities. However, this land buying preceded operations.

How would it help to force chemical plants either to compensate the people suffering the consequences of the pollution, or simply to reduce the pollution? Where there are negative externalities like air pollution, the market price of goods and services does not reflect the costs, borne by receptors of air pollution, generated in the course of producing the goods and services. Government regulation can be used to improve the situation. The NESHAPs will force chemical plant owners and operators to reduce the quantity hazardous organic air pollutants they emit. With the NESHAPs in effect, what chemical plant owners and operators must spend to produce chemicals will more closely approximate the full social costs of production. In the long run, chemical plants will be forced to increase prices of the products sold in order to cover total production costs. Thus, prices will rise, consumers accordingly will reduce their demand for chemical products, and hence less chemicals will be provided. The more the costs of pollution are internalized by the chemical plants, the greater the improvement in the way the market functions. If we could internalize all negative externalities---including, of course, those from chemical plants---society's allocation of resources would be improved.

3.2.1.2 Natural Monopoly

In some respects, chemical plants can tend toward "natural" monopolies. There are large economies of scale in chemical manufacturing; the heavy up-front capital needed to construct a plant acts as a barrier to entry. Due to the necessity for heavy up-front capital, most chemical market are oligopolies (i.e., dominated by a few firms). Thus, each firm in this type of market possesses more monopoly power than if each firm were operating in a more competitive market. The NESHAPs are not designed to address this circumstance, and will not reduce the tendency of chemical production markets toward monopoly or oligopoly.

3.2.1.3 Inadequate Information

The third category of potential market failure that sometimes is used to justify government regulation is inadequate information.

Some chemical manufacturing facilities can reduce costs by installing air pollution control devices, reducing leaks or recycling hazardous organic chemicals. Due to lack of information, some of these facilities do not install such systems. The NESHAPs would require the collection of information that may give a chemical plant owner enough data to make an informed decision on whether or not control devices are the best option.

3.2.2 Insufficient Political and Judicial Forces

There are a variety of reasons why many emission sources, in EPA's judgment, should be subject to reasonably uniform national standards. The principal reasons:

* Air pollution crosses jurisdictional lines.

* The people who breathe the air pollution travel freely, sometimes coming in contact with air pollution outside their home jurisdiction.

* Harmful effects of air pollution detract from the nation's health and welfare regardless of whether the air pollution and harmful effects are localized.

* Uniform national standards, unlike potentially piecemeal local standards, are not likely to create artificial incentives or artificial disincentives for economic development in any particular locality.

* One uniform set of requirements and procedures can reduce paperwork and frustration for firms that must comply with emission regulations across the country.

None of these reasons, by itself, provides overriding justification for Federal action in the case at hand. Collectively, however, the reasons argue against reliance on state and local action to control hazardous organic air emissions from chemical plants.

Citizens, as well as EPA, may sue state and local governments to force them to control hazardous organic air emissions from chemical plants. Litigation under both the CAA and RCRA is possible. However, EPA has not explored ways of improving the judicial route so that it might serve as a substitute for action under Section 111 of the CAA.

3.2.3 Harmful Effects of Hazardous Organic Air Emissions

Only health effects associated with hazardous organic air emissions are addressed in these NESHAPs. Direct exposure to air emissions can occur through inhalation, soil ingestion, the food chain, and dermal contact.

Out of the 189 hazardous air pollutants identified in the Clean Air Act Amendments, 149 chemicals are being regulated by the HON; however, of these 149, only 110 are regulated by Subpart G of the HON. Of these 110 chemicals, approximately one-third are carcinogens and approximately two-thirds are noncarcinogens. The EPA has devised a system, which was adapted from one developed by the International Agency for Research on

Cancer, for classifying chemicals based on the weight-of-evidence.[2] Three of the carcinogens, benzene, vinyl chloride, and bis(chloromethyl)ether, are classified as group A or known human carcinogens. This means that there is sufficient evidence to support that the chemical causes an increased risk of cancer in humans. One of these known human carcinogens, benzene, is a concern to the EPA because long term exposure to this chemical has been known to cause leukemia in humans. While this is the most well known effect, benzene exposure is also associated with aplastic anemia, multiple myeloma, lymphomas, pancytopenia, chromosomal breakages, and weakening of bone marrow (53 FR 28504; July 28, 1988).

Vinyl chloride is another known human carcinogen. Exposure to vinyl chloride has been known to cause angiosarcoma of the liver. It has also been associated with other forms of cancer as well as noncancerous effects. The noncancerous effects include liver damage and, potentially, chemical mutagenicity and teratogenicity (40 FR 59533; Dec. 24, 1975).

Most of the carcinogenic chemicals on the list are classified as group B or probable human carcinogens. This means that there is limited data on human carcinogenicity, but sufficient data on animal carcinogenicity to suggest possible increased human risks as well. Some examples of the twenty-five probable human carcinogens on the list are 1,3-butadiene, carbon tetrachloride, acetaldehyde, benzyl chloride, and tetrachloroethylene. In several rat studies, 1,3-butadiene caused several tumors on different organs (50 FR, pp. 41466-41468, Oct. 10, 1985). In addition, at high concentrations, it can cause coughing, fatigue, sleepiness, headache, giddiness, unconsciousness, respiratory paralysis, and death.[3] Carbon tetrachloride is known to cause cancer in animals and is thus suspected to cause cancer in humans. It may also increase stratospheric ozone depletion, which can cause a rise in the incidence of skin cancer and possibly various other effects (50 FR 32621; Aug. 13, 1985).

Twelve of the HON chemicals are considered to be group C or possible human carcinogens. A few of these are acrolein, vinylidene chloride, allyl chloride, and 1,1,2,2-tetrachloroethane. For these chemicals, there is either inadequate data or no data on human carcinogenicity, and there is limited data on animal carcinogenicity. Therefore, while cancer risk is possible, there is not sufficient evidence to support that these chemicals will cause increased cancer risks in humans.

The remaining 70 HON chemicals are noncarcinogens. Though they do not cause cancer, they are considered hazardous because of the other significant adverse health effects with which they are associated. Some examples of the noncarcinogens include

chloroprene, methyl chloroform, diethyl sulfate, methyl hydrazine, and triethylamine. One of these chemicals, chloroprene, causes various effects at different lengths of exposure. Possible effects from acute exposure range from vertigo and nausea at very short exposure periods to liver damage and death after a few hours. Subchronic toxicity effects observed in human studies include fatigue, pressure and chest pain, dermatitis and hair loss. Subchronic animal studies at higher concentrations and for longer periods of time revealed effects ranging from small increases in underdevelopment and behavioral effects to lung and liver tissue damage and death (50 FR 39632; Sept. 27, 1985).

Methyl chloroform is another noncarcinogen that is a concern to the EPA. Acute exposure to this chemical may result in small changes in perception, while subchronic effects of slight histological and biochemical alterations have been observed in mice livers. At high concentrations, liver necrosis has been reported.

The following table lists the HON chemicals by CAS number and their classification by their carcinogenic effect, if any.

Table 3-1. HON Chemicals by Classification

CAS Number	Chemical Name	Classification*
71432	Benzene	A
542811	Bis(choromethyl)ether	A
75014	Vinyl chloride	A
107131	Acrylonitrile	B1
75218	Ethylene oxide	B1
50000	Formaldehyde	B1
75070	Acetaldehyde	B2
79107	Acrylic acid	B2
62533	Aniline	B2
98077	Benzotrichloride	B2
100447	Benzyl chloride	B2
75252	Bromoform	B2
106990	1,3-Butadiene	B2
56235	Carbon tetrachloride	B2
67663	Chloroform	B2
111444	Dichloroethyl ether	B2
542756	1,3-Dichloropropene	B2
77781	Dimethyl sulfate	B2
123911	1,4-Dioxane	B2
122667	1,2-Diphenylhydrazine	B2
106898	Epichlorohydrin	B2
106934	Ethylene dibromide	B2
107062	Ethylene dichloride	B2
118741	Hexachlorobenzene	B2
75092	Methylene chloride	B2
75569	Propylene oxide	B2
127184	Tetrachloroethylene	B2
79016	Trichloroethylene	B2
107028	Acrolein	C
107051	Allyl chloride	C
75343	Ethylidene dichloride	C
87683	Hexachlorobutadiene	C
67721	Hexachloroethane	C
78591	Isophorone	C
79345	1,1,2,2-Tetrachloroethane	C
79005	1,1,2-Trichloroethane	C
75354	Vinylidene chloride	C
60355	Acetamide	NC
75058	Acetonitrile	NC
98862	Acetophenone	NC
79061	Acrylamide	NC
90040	0-Anisidine	NC
92524	Biphenyl	NC

HON Chemicals by Classification (Continued)

CAS Number	Chemical Name	Classification*
105602	Caprolactum	NC
75150	Carbon disulfide	NC
79118	Chloroacetic acid	NC
532274	2-Chloroacetophenone	NC
108907	Chlorobenzene	NC
126998	Chloroprene	NC
1319773	Cresols/Cresylic acid (isomers and mixture)	NC
95487	o-Cresols/Cresylic acid (isomers and mixture)	NC
108394	m-Cresols/Cresylic acid (isomers and mixture)	NC
106445	p-Cresols/Cresylic acid (isomers and mixture)	NC
98828	Cumene	NC
106467	1,4-Dichlorobenzene	NC
111422	Diethanolamine	NC
121697	N,N-Dimethylaniline	NC
64675	Diethyl sulfate	NC
119937	3,3'-Dimethylbenzidine	NC
68122	N,N-Dimethylformamide	NC
57147	1,1-Dimethylhydrazine	NC
131113	Dimethyl phthalate	NC
51285	2,4-Dinitrophenol	NC
121142	2,4-Dinitrotoluene	NC
140885	Ethyl acrylate	NC
100414	Ethylbenzene	NC
75003	Ethyl chloride	NC
107211	Ethylene glycol	NC
0	Glycol ethers	NC
123319	Hydroquinone	NC
108316	Maleic anhydride	NC
67561	Methanol	NC
74839	Methyl bromide	NC
74873	Methyl chloride	NC
71556	Methyl chloroform	NC
78933	Methyl ethyl ketone	NC
60344	Methylhydrazine	NC
108101	Methyl isobutyl ketone	NC
624839	Methyl isocyanate	NC
80626	Methyl methacrylate	NC
1634044	Methyl tert-butyl ether	NC
101688	Methylenediphenyl diisocyanate (MDI)	NC

HON Chemicals by Classification (Continued)

CAS Number	Chemical Name	Classification*
101779	4,4-Methylenedianiline	NC
91203	Naphthalene	NC
98953	Nitrobenzene	NC
100027	4-Nitrophenol	NC
79469	4-Nitropropane	NC
108952	Phenol	NC
106503	p-Phenylenediamine	NC
75445	Phosgene	NC
85449	Phthalic anhydride	NC
0	Polycyclic organic matter	NC
57578	beta-propiolactone	NC
123386	Propionaldehyde	NC
78875	Propylene dichloride	NC
106514	Quinone	NC
100425	Styrene	NC
127184	Tetrachloroethylene	NC
108883	Toluene	NC
95807	2,4-Toluenediamine	NC
584849	2,4-Toluene diisocyanate	NC
95534	o-Toluidine	NC
120821	1,2,4-Trichlorobenzene	NC
95954	2,4,5-Trichlorophenol	NC
121448	Triethylamine	NC
540841	2,2,4-Trimethylpentane	NC
108054	Vinyl acetate	NC
1330207	Xylenes	NC
95476	o-Xylene	NC
108383	m-Xylene	NC
106423	p-Xylene	NC

*The carcinogens included in this list are chemicals which have been designated as group A, B1, B2, or C by IRIS, CRAVE verification, or a Health Assessment Document. NC stands for noncarcinogenic.

3.3 Consequences of Regulation

3.3.1 Consequences if EPA's Emission Reduction Objectives are Met

3.3.1.1 Allocation of Resources

There will be improved allocation of resources associated with chemical manufacturing. Specifically, more of the costs of the harmful effects of chemical production will be internalized by chemical plants. This, in turn, will affect consumers' decisions on whether, where, how, and how much chemicals to use. To the extent these newly-internalized costs are then passed along to the people who use the chemical products, and to the extent these people are free to buy as much or as little products as they wish, they will purchase less (relative to their purchases of other competing services). If this same process of internalizing negative externalities occurs throughout the entire chemical manufacturing industry, an economically optimal situation is approached. This is the situation when the marginal cost of resources devoted to chemical production equals the marginal value of the products to the people who are using the chemical products. There are many "ifs" in this chain of events. It is easy to cite situations where the air pollution control costs will not ripple through as suggested here and affect decisions by the consumers of chemical products. Nevertheless, in the aggregate and in the long run, the NESHAPs will move society toward this economically optimal situation.

3.3.1.2 Emissions Reductions and Air Quality

Under the proposed standard, it is estimated that emissions of hazardous air pollutants will be reduced by 475,000 megagrams annually by 1997 and emissions of VOC's (which includes HAP's) will be reduced by 986,000 megagrams annually by 1997. (For more information refer to Chapter 8.) Air quality will improve. (This analysis does not translate emission reductions into ambient air quality improvements.)

There will be a slight increase in emissions of carbon monoxide and nitrogen oxides resulting from the on-site combustion of fossil fuels as part of control device operations. These estimates are 1,570 megagrams per year of carbon monoxide and 15,700 megagrams per year of nitrogen oxides.

3.3.1.3 Costs and Benefits

The national annual cost of emission control will increase by about $182 million by 1997. Expected benefits include reduced risks for certain adverse health and welfare effects from lower levels of HAP's and VOC's emissions. (See Chapters 8 and 9.)

3.3.1.4 Energy Impacts

Increases in energy use were estimated for steam, natural gas, and electricity. These three types of energy were compared and totaled on a barrels of energy (BOE) basis. Under the standard, estimates for total energy use are 260 million kw-hr/yr (440,000 BOE/yr) of electricity, 6,650 billion Btu/yr (6.31 billion J/yr) of natural gas, and 5,300 billion Btu/yr (5.03 billion J/yr) of steam. This equates to 2.42 million BOE/yr (15.5 billion J/yr).

3.3.1.5 Solid Waste and Water Quality

Impacts for water pollution and solid waste were judged to be negligible and were not quantified. The required controls do not generate any solid waste. However, in time, as collection and control equipment is replaced, the components themselves may become part of the solid waste stream.

3.3.1.6 Technological Innovation

Section 112 of the CAA regulations serve to disseminate both pollution control and chemical manufacturing technology, and to stimulate further technological development. Chemical facility constructors have the freedom to seek the most economical way to comply with standards. The NESHAPs may promote the sharing of technology with other countries, and probably will open new directions of research in chemical manufacturing technology.

3.3.1.7 State Regulation and New Source Review

State regulatory programs will be strengthened. The NESHAPs will be delegated to the states for enforcement as part of their operating permitting programs if they are approved the EPA. Assuming states do not pull resources from other programs to handle their enlarged responsibilities, there will be a natural strengthening of state air pollution control staffs. Recognition that the NESHAPs are effectively reducing emissions will expedite the state process of reviewing applications for new chemical plants and issuing permits for their construction and operation. There will be less controversy involved. Finally, state regulations will be uniform, and the disadvantages of the piecemeal approach to emission regulation will be avoided.

3.3.1.8 Other Federal Programs

The effects of the NESHAPs on other Federal regulatory programs have not been thoroughly investigated. Under Title I there are CTGs (control technology guidelines) that specify levels of control for VOC's in nonattainment areas. Any NESHAP shall require control in attainment and nonattainment areas. While the baseline for the HON incorporates present CTGs, the

effect from new CTGs is not incorporated. There is possible overlap between these new CTGs and HON for facilities in nonattainment areas. The extent of this overlap has not been defined.

3.3.2 Consequences if EPA's Emission Reduction Objectives are not Met

The most obvious consequence of failure to meet EPA's emission reduction objectives would be emissions reductions and benefits that are not as large as EPA is projecting. However, costs are not likely to be as large either. Whether it is noncompliance from ignorance or error, or from willful intent, or simply slow compliance due to owners and/or operators exercising legal delays, poor compliance can save some facilities money. Unless states respond by pouring more resources into enforcement, then poor compliance could bring with it smaller aggregate nationwide control costs. EPA has not included an allowance for poor compliance in its estimates of emissions reductions. This is because poor compliance is unlikely.

If the emission control devices degraded rapidly over time or in some other way did not function as expected, there could be a misallocation of resources. This situation is very unlikely because the NESHAPs are based on demonstrated technology. Other ways the regulations could fail are conceivable.

References

1. U.S. Office of Management and Budget. Regulatory Impact Guidance, Appendix V of Regulatory Program of the United States Government, April 1, 1991 - - March 31, 1992.

2. U.S. Environmental Protection Agency. The Risk Assessment Guidelines of 1986, Office of Health and Environmental Assessment, Washington, D.C. August 1987.

3. Sittig, Marshall. Handbook of Toxic and Hazardous Chemicals and Carcinogens, Second Edition. New Jersey: Noyes Publication, 1985. pp. 153-154.

CHAPTER 4

CONTROL TECHNIQUES

The scope of the HON is broad. The control technology and techniques involved are extensive. Combustion technology, product recovery devices, steam strippers, and vapor recovery tanks are all part of the technology requirements for the HON, and LDAR will be used to control fugitive emissions. This chapter does not attempt to be comprehensive in explaining the technology and techniques used to control air toxics emissions under the HON; it does attempt to survey what technologies and techniques are being used and how effective they are.

4.1 Combustion Technology

Combustion control devices, unlike noncombustion control devices, alter the chemical structure of the VOC. Destruction of the VOC by combustion is complete if all VOC's are converted to CO_2 and water. Incomplete combustion results in some of the VOC remaining unaltered or being converted to other organic compounds such as aldehydes or acids. If chlorinated or sulfur-containing compounds are present in the mixture, the products of complete combustion include the acid components HCl or SO_2, respectively, in addition to water and carbon dioxide.

4.1.1 Incinerators

Incineration is one of the best known methods of industrial gas waste disposal. It is a method of ultimate disposal, that is, the constituents to be controlled in the waste gas stream are converted rather than collected. Provided proper engineering design is used, incineration can eliminate the desired organic chemicals in a gas stream safely and cleanly.

The heart of an incinerator is a combustion chamber in which the VOC-containing waste stream is burned. The temperature required for combustion is much higher than the temperature of the inlet gas, so energy is usually supplied to the incinerator to raise the waste gas temperature. This is accomplished by adding auxiliary fuel (usually natural gas).

The amount of auxiliary fuel required can be decreased and energy efficiency increased by providing heat exchange between the inlet stream and the effluent stream. The effluent stream containing the products of combustion, along with any inerts that may have been present in or added to the inlet stream, can be used to preheat the incoming waste stream, auxiliary air, or both via a "primary", or recuperative, heat exchanger.

Auxiliary air may be required for combustion if the requisite oxygen is not available in the inlet gas stream. Most industrial gases that contain VOC's are dilute mixtures of combustible gases in air. With air oxidation reactor and distillation processes, the waste gas stream is deficient in air.

Important in the design and operation of incinerators is the concentration of combustible gas in the waste gas stream. Having a large amount of excess air (i.e., in excess of the required stoichiometric amounts) may be costly, but any mixture within the flammability limits, on either the fuel-rich or fuel-lean side of the stoichiometric mixture is considered a fire hazard as a feed stream to the incinerator. Therefore, some waste gas streams are diluted with air before incineration, even though this requires more fuel in the incinerator.

There are two types of incinerators: thermal and catalytic. While much of what was discussed above applies to both, there are important differences in their design and operation.

4.1.1.1 Thermal Incinerators

As is true of other combustion control devices, thermal incinerators operate on the principle that any VOC heated to a high enough temperature in the presence of sufficient oxygen will be oxidized to CO_2 and water. The theoretical temperature for thermal oxidation depends on the properties of the VOC to be combusted. There is great variation in theoretical combustion temperatures between different VOC's.

There are three requirements that must be met for a thermal incinerator to be considered efficient: 1) a high enough combustion chamber to enable oxidation of the organic compounds to proceed rapidly to completion; 2) enough turbulence for good mixing of the hot combustion products from the burner, the combustion air, and the organic compounds; and 3) sufficient residence time for oxidation to reach completion.[1]

A typical thermal incinerator is a refractory-lined chamber containing a burner or set of burners at one end. Entering gases are mixed with the process vent streams and the inlet air in a premixing chamber. Then the stream of gases passes into the main combustion chamber. This chamber is designed to allow the mixture enough time at the required combustion temperature for complete oxidation (usually from 0.3 to 1.0 second). A heat recovery section is often added to increase energy efficiency.[2] Oftentimes inlet combustion air is preheated; if this occurs, insurance regulations require the VOC concentration must be maintained below 25 percent of the lower explosive limit (LEL) to minimize the possibility of explosions. Concentrations from 25 to 50 percent are permitted given continuous monitoring by LEL monitors.

monitors.

The required level of VOC control of the waste gas that must be achieved within the time it spends in the thermal combustion chamber dictates the reactor temperature. The shorter the residence time, the higher the reactor temperature must be. Once the unit is designed and built, the residence time is not easily changed, so that the required reaction temperature becomes a function of the particular gaseous species and the desired level of control. These required combustion reaction temperatures cannot be calculated a priori, although incinerator vendors can provide guidelines based on their extensive experience. Predictions of these temperatures are further complicated by the fact that most process vent streams are mixtures of compounds.[3]

Good mixing is also important, particularly in determining destruction efficiency. Even though it cannot be measured, mixing is a factor of equal or even greater importance than other parameters such as temperature. The most feasible and efficient way to improve the mixing in an incinerator is to adjust it after start-up.[4]

Other parameters affecting thermal incinerator performance are the heat content of the vent stream, the water content of the stream, and the amount of excess combustion air (the amount of air above the stoichiometric air needed for combustion). Combustion of a vent stream with a heat content less than 1.9 MJ/m^3 (52 BTU/scf) usually requires burning supplemental fuel to maintain the desired combustion temperature.

The maximum achievable VOC destruction efficiency decreases with decreasing inlet VOC concentration because combustion is slower at lower inlet concentrations. Therefore, a VOC weight percentage reduction based on the mass rate of VOC exiting the control device versus the mass rate of VOC entering the device is appropriate for vent streams with VOC concentrations above approximately 2,000 ppmv (which corresponds to 1,000 ppmv VOC in the incinerator inlet stream since air dilution is typically 1:1).[5]

4.1.1.1.1 Applicability

Thermal incinerators are technically feasible control devices for most vent streams. They are not recommended, however, for vent streams with potentially excessive fluctuations in flow rate (process upsets, for example), and for vent streams containing halogens. The former case would require a flare (see Section 4.2) and the latter case would require additional equipment such as acid gas scrubbers (see Section 4.1.3).

4.1.1.1.2 Types of Thermal Incinerators

The very simplest type of thermal incinerator is the direct flame incinerator, which is made up of only the combustion chamber. Energy recovery devices such as a waste gas preheater and a heat exchanger are not included with this type of incinerator.

A second type of thermal incinerator is the recuperative model. Recuperative incinerators use the exit (product) gas to preheat the incoming feed stream, combustion air, or both via a heat exchanger. These heat exchangers can recover up to 70 percent of the energy (or enthalpy) in the product gas. The two types of heat exchangers commonly used for this purpose and many others are plate-to-plate and shell-and-tube. Plate-to-plate exchangers can be built to achieve a variety of efficiencies and offer high efficiency energy recovery at lower cost than shell-and-tube designs. But when gas temperatures exceed 520 degrees Celsius, shell-and-tube exchangers usually have lower purchase costs than plate-to-plate designs. Moreover, shell-and-tube exchangers offer better long-term structural reliability than plate-to-plate units.[6]

Occasionally it is desired to recover some of the energy added by auxiliary fuel in the traditional thermal units (but not recovered in preheating the feed stream). Additional heat exchangers can be added to provide process heat in the form of low pressure steam or hot water for on-site application. The need for this higher level of energy recovery will be dependent upon the plant site. The additional heat exchanger is often provided by the incineration unit vendor.

A third type of thermal incinerator is the regenerative incinerator. This type of incinerator use direct contact heat exchangers constructed of a ceramic material that can tolerate the high temperatures needed to achieve ignition of the waste stream. The concept behind this incinerator type is that the traditional approach to energy recovery in thermal units still requires a significant amount of auxiliary fuel to be burned in the combustion chamber when waste gas heating values are too low to sustain the desired reaction temperature at the moderate preheat temperature employed. Under these conditions, additional fuel savings can be realized in units with more complete transfer of exit stream energy. Hence the regenerative incinerator.

In this type of incinerator, the inlet gas first passes through a hot ceramic bed thereby heating the steam to its ignition temperature. The hot gases then react and release energy in the combustion chamber and while passing through another ceramic bed, thereby heating it to the combustion chamber outlet temperature. The process flows are then switched, now

feeding the inlet stream to the hot bed. This cyclic process affords very high energy recovery (up to 95 percent).[7]

4.1.1.2 Catalytic Incinerators

A catalyst promotes oxidation of some VOC's at a lower temperature than that required for thermal incineration. The catalyst increases the rate of the chemical reaction without becoming permanently altered itself. Catalysts typically used for VOC incineration include platinum and palladium. These catalysts work well for most organic streams, but are not tolerant of compounds containing halogens such as chlorine and sulfur. Among the catalysts that have been developed that are effective in the presence of these halogens are chromia/alumina, cobalt oxide, and copper oxide/manganese oxide.[8] Inert substrates are coated with thin layers of these materials to provide maximum surface area for contact with the VOC in the vent stream. Compounds containing elements such as lead, arsenic, and phosphorus should, in general, be considered poisons for most oxidation catalysts. In addition, particulate matter, including dissolved minerals in aerosols, can rapidly blind (deactivate) the pores of catalysts and deactivate them over time. Because essentially all the active surface of the catalyst is contained in relatively small pores, the particulate matter need not be large to blind the catalyst.

For optimal operation, the volumetric gas flow rate and the concentration of combustibles (in this case, VOC's) should be constant. Large fluctuations in the flow rate will cause the conversion of the VOC's to fluctuate also. Changes in the concentration or type of organic compounds in the gas stream can also affect the overall conversion of the VOC contaminants. Most changes in flow rate, organic concentration, and chemical composition are generally the result of upsets in the manufacturing process generating the waste gas stream.

4.1.1.2.1 Applicability

Applicability of catalytic incinerators for control of VOC's is limited by the catalyst deactivation sensitivity to the characteristics of the inlet gas stream. The vent stream to be combusted should not contain materials that can poison the catalyst or deposit on and block the reactive sites on the catalyst surface. In addition, catalytic incinerators are unable to handle high inlet concentrations of VOC or very high flow rates. Catalytic incineration is generally useful for concentrations of 50 to 10,000 ppmv, if the total concentration is less than 25 percent of the LEL and for flow rates of less than 2,820 m^3/min (100,000 scfm).[9] Catalytic units are also typically used for vent streams with stable flow rates and concentrations (refer to Section 4.1.1.2).

4.1.1.2.2 Types of Catalytic Incinerators

One type of catalytic incinerator is fixed-bed. Fixed-bed incinerators themselves come in two varieties, depending on the type of catalyst used: the monolith and packed-bed. The monolith catalyst is the most widespread method of contacting the VOC-containing stream with the catalyst. In this scheme the catalyst is a porous solid block containing parallel, non-intersecting channels aligned in the direction of the gas flow. Monolith catalysts offer the advantages of minimal attrition due to thermal expansion/contraction during startup/shutdown and low overall pressure drop.

A second contacting scheme is a simple packed-bed in which catalyst particles are supported either in a tube or in shallow trays through which the gases pass. The tray type arrangement is the more common packed-bed scheme due to the use of pelletized catalysts. This tray arrangement is preferred because pelletized catalysts can handle inlet streams containing contaminants such as phosphorus or silicon.[10] The tube arrangement is not used widely due to its inherently high pressure drop compared to a monolith, and the breaking of catalyst particles due to thermal expansion when the confined catalyst bed is heated/cooled during startup/shutdown.

A third contacting pattern between the gas and catalyst is a fluid-bed. Fluid-beds have the advantage of very high mass transfer rates, although the overall pressure drop is somewhat higher than for a monolith. Fluid-beds also possess the advantage of high bed-side heat transfer compared to a normal gas heat transfer coefficient. This higher heat transfer rate to heat transfer tubes immersed in the bed allows higher heat release rates per unit volume of gas processed and therefore may allow waste gases with higher heating values to be processed without exceeding maximum permissible temperatures in the catalyst bed. The catalyst temperatures depend on the rate of reaction occurring at the catalyst surface and the rate of heat exchange between the catalyst and imbedded heat transfer surfaces.

In general, fluid-bed systems are more tolerant of particulates in the gas stream than fixed-bed or packed-bed systems. This results from the constant abrasion of the fluidized catalyst pellets, which helps remove these particulates from the exterior of the catalysts in a continuous manner.

4.1.2 Flares

Flaring is an open combustion process in which the oxygen necessary for combustion is provided by the air around the flame. The organic compounds to be combusted are piped to a remote,

usually elevated, location and burned in an open flame in the open air using a specially designed burner tip, auxiliary fuel, and sometimes steam or air to promote mixing for nearly complete (98 percent minimum) destruction of combustibles. Good combustion in a flare is governed by flame temperature, residence time of organic species in the combustion zone, turbulent mixing of the organic species to complete the oxidation reaction, and the amount of oxygen available for free radical formation. Combustion is complete if all combustibles (i.e., VOC's) are converted to CO^2 and water, while incomplete combustion results in some of the VOC's being unaltered or converted to other organic compounds such as aldehydes or acids.

Flares are generally categorized in two ways: 1) by the height of the flare tip (i.e., ground-level or elevated), and 2) by the method of enhancing mixing at the flare tip (i.e., steam-assisted, air-assisted, pressure-assisted, or unassisted). Elevating the flare can prevent potentially dangerous conditions at ground level where the open flame is located near a process unit. Further, the products of combustion can be dispersed above working areas to reduce the effects of noise, heat radiation, smoke, and objectionable odors.

In most flares, combustion occurs by means of a diffusion flame. A diffusion flame is one in which air diffuses across the boundary of the fuel/combustion product stream toward the center of the fuel flow, forming the envelope of a combustible gas mixture around a core of fuel gas. This mixture, on ignition, establishes a stable flame zone around the gas core above the burner tip. This inner gas core is heated by diffusion of hot combustion products from the flame zone.

Cracking can occur with the formation of small hot particles of carbon that give the flame its characteristic luminosity.[11] If there is an oxygen deficiency and if the carbon particles are cooled to below their ignition temperature, smoking occurs. In large diffusion flames, combustion product vortices can form around burning portions of the gas and shut off the supply of oxygen. This localized instability causes flame flickering, which can be accompanied by soot formation.

4.1.2.1 Applicability

Flares can be dedicated to almost any VOC stream, and can handle fluctuations in VOC concentration, flow rate, heating value, and inerts content. Flaring is appropriate for continuous, batch, and variable flow vent stream applications.

Some streams, such as those containing halogenated or sulfur-containing compounds, are usually not flared because they corrode the flare tip or cause formation of secondary pollutants

for complete combustion, have lower combustion temperatures that minimize cracking reactions, and are more resistant to cracking.

4.1.2.3.4 Pressure-Assisted Flares

This type of flare use vent stream pressure to promote mixing at the burner tip. If sufficient vent stream pressure is available, these flares can be applied to streams previously requiring steam or air assist for smokeless operation. Pressure-assisted flares generally have the burner arrangement at ground level, and consequently, must be located in a remote area of the plant where there is plenty of space available. They have multiple burner heads that are staged to operate based on the quantity of gas being released. The size, design, number, and group arrangement of the burner heads depend on the vent gas characteristics.

4.1.2.3.5 Enclosed Ground Flares

The burner heads of an enclosed flare are inside a shell that is insulated. This shell reduces noise, luminosity, and heat radiation and provides wind protection. A high nozzle pressure drop is usually adequate to provide the mixing necessary for smokeless operation and air or steam assist is not required. In this context, enclosed flares can be considered a special class of pressure-assisted or non-assisted flares. Enclosed flares are always at ground level.

Enclosed flares generally have less capacity than open flares and are used to combust continuous, constant flow vent streams; although reliable and efficient operation can be attained over a wide range of design capacity. Stable combustion can be obtained with lower heat content vent gases than is possible with open flare designs, probably due to their isolation from wind effects.[17]

4.1.3 Boilers and Process Heaters

4.1.3.1 Description of Boilers

Industrial boilers are combustion units that boil water to produce high and low pressure steam. Industrial boilers can also combust various vent streams containing VOC's, including vent streams from distillation operations, reactor processes, and other general operations.

The majority of industrial boilers used in the chemical industry are of watertube design, and over half of these boilers use natural gas as a fuel.[18] In a watertube boiler, hot combustion gases contact the outside of heat transfer tubes which contain hot water and steam. These tubes are interconnected by a

set of drums that collect and store the heated water and steam. Energy transfer from the hot flue gases to the water in the furnace watertube and drum system can be better than 85 percent efficient.[19] Additional energy can be recovered from the flue gas by preheating combustion air in an air preheater or by preheating incoming boiler feed water in an economizer unit.

When firing natural gas, forced- or natural-draft burners throughly mix the incoming fuel and combustion air. A VOC-containing vent stream can be added to this mixture or it can be fed into the boiler through a seperate burner. In general, burner design depends on the characteristics of the fuel-- either the combined VOC-containing vent stream and fuel or the vent stream alone (when a separate burner is used).

4.1.3.2 Description of Process Heaters

A process heater is similar to an industrial boiler in that heat liberated by the combustion of fuels is transferred by radiation and convection to fluids contained in tubular coils. It is different from an industrial boiler in that process heaters raise the temperature of process streams instead of producing high temperature steam. Process heaters are used in many chemical manufacturing operations to drive endothermic reactions. They are also used as feed preheaters and as reboilers for some distillation operations. The fuels used in process heaters include natural gas, refinery offgases, and various grades of fuel oil.

A typical process heater design consists of the burner(s), the firebox, and a row of tubular coils containing the process fluid. Most heaters also contain a convective section in which heat is recovered from hot combustion gases by convective heat transfer to the process fluid.

4.1.3.3 Efficiency of Boilers and Process Heaters

Average furnace temperature and residence time determine the combustion efficiency of boilers and process heaters, just as they do for incinerators. When a vent gas is injected as a fuel into the flame zone of a boiler or process heater, the required residence time is reduced because of the relatively high temperature and turbulence of the flame zone.

Residence time and temperature profiles in boilers and process heaters are determined by factors such as overall configuration, fuel type, heat input, and excess air level.[20] A mathematical model developed to estimate furnace residence time and temperature profiles for a variety of industrial boilers predicts mean furnace residence times ranging 0.25 to 0.83 second for natural gas-fired watertube boilers that range in size from

4.4 to 44 MW (15 to 150 x 10^6 Btu/hr).[21] Boilers with a 44-MW capacity or greater generally have residence times and operating temperatures that would ensure a 98 percent VOC destruction efficiency. The required temperatures for these size boilers are at least 1,200 degrees Celsius.

Firebox temperatures for process heaters can show wide variations depending on the application. Firebox temperatures can range from 400 degrees Celsius for preheaters and reboilers to 1,260 degrees Celsius for pyrolysis furnaces. Tests conducted by EPA on process heaters using a mixture of benzene offgas and natural gas showed greater than 98 percent destruction efficiency for C_1 to C_6 hydrocarbons.[22]

4.1.3.4 Applicability of Boilers and Process Heaters

Both of these devices are used throughout the chemical industry to provide steam and heat input essential to chemical processing. Most of these devices possess sufficient size to provide the necesary temperature and residence time for VOC destruction. Furthermore, boilers and process heaters have proved effective in destroying compounds that are difficult to combust, such as PCBs (polychlorinated biphenyls). Boilers and process heaters are thus effective in reducing VOC emissions from any vent streams that are certain not to reduce the performance or reliability of the boiler or process heater.

Ducting some vent streams to a boiler or process heater can present potential safety and operating problems. The varying flow rate and organic content of some vent streams can lead to explosive mixtures or flame instability within the furnace. In addition, vent streams with halogenated or sulfur-containing compounds are usually not combusted in boilers or process heaters due to the possibility of corrosion.

Boilers and process heaters are most applicable where the potential exists for heat recovery from the combustion of the vent stream. Vent streams with a high enough VOC concentration and high flow rate can provide enough equivalent heat value to act as a substitute for fuel that would otherwise be needed. Because boilers and process heaters cannot tolerate wide fluctuations or interruptions in the fuel supply, they are not widely used to reduce VOC emissions from batch operations or other noncontinuous vent streams.

4.2 Product Recovery Devices

4.2.1 Absorbers

In absorption, a soluble vapor is absorbed from its mixture with an inert gas by means of a liquid in which the solute gas is

more or less soluble. For any given solvent, solute, and operating conditions, there exists an equilibrium ratio of solute concentration in the gas mixture to solute concentration in the solvent. The driving force for mass transfer at a given point in an operating absorber is the difference between the concentration of solute in the gas and the equilibrium concentration of solute in the liquid.

Devices based on absorption principles include spray towers, venturi and wet impingement scrubbers, acid gas scrubbers, packed columns, and plate columns. Spray towers have the least effective mass transfer capability due to their high atomization pressure requirement, and are generally restricted to particulate matter removal and control of high-solubility gases such as SO_2 and NH_3 (ammonia).[23] Venturi scrubbers have a high degree of gas/liquid mixing and provide high particulate matter removal efficiency. They also require high pressure drops (i.e. high energy requirements) and have relatively short contact times. Their use is also restricted to high-solubility gases. Acid gas scrubbers are used with thermal incinerators to remove corrosive combustion products. Acid gas is formed upon the contact of halogenated or sulfur-containing VOCs with intense heat during incineration. This gas is quenched to lower its temperature and is then scrubbed in an absorber. In most cases, the type of absorber used is packed or plate columns, the two most commonly used absorbers for VOC control.

Packed towers are vertical columns containing inert packing, manufactured from materials such as porcelain, metal, or plastic, that provides the surface area for contact between the liquid and gas phases in the absorber. Packed towers are used mainly for corrosive materials and liquids with tendencies to foam or plug. They are less expensive than plate columns for small-scale or pilot plant operations where the column diameter is less than 0.6 m. They are also suitable where the use of plate columns would result in excessive pressure drops.

Plate columns contain a series of trays on which contact between the gas and liquid phases in a stepwise fashion. The liquid phase flows down tray to tray as the gas phase moves up through openings in the tray (usually perforations or bubble caps), passing through the liquid on the way.

The major design parameters for absorbing any substance are column diameter and height, system pressure drop, and required liquid flow rate. Deriving these parameters is accomplished by considering the solubility, viscosity, density, and concentration of the VOC in the inlet vent stream (all of which depend on column temperature); the total surface area provided by the packing material; and the mass flow rate of the gases to be treated.

4.2.1.1 Absorber Efficiency

Control efficiencies for absorbers can vary widely depending on the solvent selected, design parameters, and operating practices. Solvents are chosen for high solubility for the specific VOC and include liquids such as water, mineral oils, kerosenes, nonvolatile hydrocarbon oils, and aqueous solutions of oxidizing agents, sodium carbonate, and sodium carbonate.[24] An increase in absorber size (i.e., contact surface area) or a decrease in the operating temperature can increase the VOC removal efficiency of the system for a given solvent and solute. It is sometimes possible to increase VOC removal efficiency by changing the solvent.

4.2.1.2 Applicability of Absorbers

The primary determinant of absorption applicability for controlling VOC emissions is the availability of a suitable solvent.[25] Water is a suitable solvent for absorption of organic chemicals with relatively high water solubilities (e.g., most alcohols, organic acids, aldehydes, glycols). For organic compounds with low water solubilities, other solvents (usually organic liquids with low vapor pressures) are used.

Other important factors influencing absorption applicability include absorptive capacity and strippability of VOC in the solvent. Absorptive capacity is a measure of the solubility of VOC in the solvent. The solubility limits the total quantity of VOC that could be absorbed in the system, while strippability describes the ease with which the VOC can be removed from the solvent. If strippability is low, then absorption is less viable as a VOC control technique.[26]

The concentration of VOC in the inlet vent stream also determines the applicability of absorption. Absorption is usually considered only when the VOC concentration is above 200 to 300 ppm.[27] Below these gas-phase concentrations, the rate of mass transfer of VOC to solvent is decreased enough to make reasonable designs infeasible.

4.2.2 Steam Stripping

Steam stripping can be used as initial treatment of a process wastewater stream to reduce the VOC loading of that steam before it is sent to the facility-wide wastewater treatment system. There are several components in a steam stripping system: a feed tank, heat exchanger, steam stripping column, condenser, overhead receiver, and a destruction device (if necessary).

4.2.2.1 Description

Steam stripping involves the fractional distillation of wastewater to remove VOC's. The basic operating principle of steam stripping is the direct transfer of heat through contact of steam with wastewater. This heat transfer vaporizes the more volatile organic compounds. The overhead vapor contains water and organic compounds, and it is condensed and separated to recover the organic fraction. Recovered organic compounds are either recycled for reuse in the process or incinerated in an on-site combustion device for heat recovery.

Steam stripper systems may be operated in batch or continuous mode. Batch steam strippers are more prevalent when the wastewater feed is generated by batch processes, when feed characteristics are highly variable, or when small volumes of wastewater are generated. They may also be used if wastewater contains relatively high concentrations of solids, resins, or tars. In batch stripping, wastewater is charged to the receiver, or pot, and brought to the boiling temperature of the mixture. Solids and other residues remaining in the bottom of the pot (hence the term "bottoms") at the completion of the batch are nonvolatile, heavy compounds that are removed for disposal. By varying the heat input and fraction of the initial charge boiled overhead, a batch stripper can be used to treat wastewater mixtures with widely varying characteristics.[28]

In contrast to batch strippers, continuous steam strippers are designed to treat wastewater streams with relatively consistent characteristics. Continuous strippers can have several stages and achieve greater efficiencies of VOC removal than batch strippers. Other advantages offered by continuous strippers include more consistent effluent quality, more automated operation, and lower annual operating costs.

Typically, wastewater steams continuously discharged from process equipment are usually consistent in composition. A continuous steam stripper system would thus be indicated for treating the wastewater. However, batch wastewater streams can also be controlled by continuous steam strippers by incorporating a feed tank with adequate residence time to provide a consistent outlet composition.

4.2.2.2 Collecting, Conditioning, and Recovery

The controlled sewer system or hard piping from the point of wastewater generation to the feed tank controls emissions before steam stripping. The feed tank collects and conditions the wastewater fed to the steam stripper. If the feed tank is adequately designed, a continuous steam stripper can treat wastewater generated by some batch processes. In these cases,

the feed tank serves as a buffer between the batch process and the continuous steam stripper. During periods of no wastewater flow from the batch process, wastewater stored in the feed tank is fed to the stripper at a relatively constant rate.

Often present in the feed tank are aqueous and organic phases. The feed tank provides the retention time necessary for these phases to separate. The organic phase is recycled to the process for recovery of organic compounds or disposed by incineration. The water phase is fed to the stripper to remove the soluble organic compounds. Solids are also separated in the stripper feed tank; the separation efficiency depends on the density of the solids dissolved in the process wastewater. The more dense solids, which settle to the bottom of the tank, are removed periodically from the feed tank and are usually landfilled or landfarmed.

After this conditioning of the wastewater, it is pumped through the feed/bottoms heat exchanger where it is preheated and then pumped into the steam stripping column. Steam is sparged into the stripper at the bottom of the column, and the wastewater feed enters at the top. The wastewater flowing down the column contacts the flowing countercurrently up the column. Both latent and sensible heat is transferred from the steam to the organic compounds in the wastewater, vaporizing them into the vapor stream. These constituents flow out the top of the column with any uncondensed steam.

The wastewater effluent leaving the bottom of the stripper is pumped through the feed/bottoms heat exchanger which heats the feed stream and cools the bottoms before discharge. After leaving the exchanger, the bottoms stream is usually either routed to an on-site wastewater treatment plant and discharged to an NPDES-permitted outfall, or sent to a publicly owned treatment works (POTW).

Recovery of both VOC's and water vapors from the gaseous overheads stream from the steam stripper is usually accomplished with a condenser. The condensed stream is fed to an overhead receiver, and the recovered VOC's are usually either pumped to storage and recycled to the process unit or combusted for their fuel value in an incinerator, boiler, or process heater (all discussed earlier in this chapter). If an aqueous phase is generated, it is returned to the feed tank and recycled through the steam stripper system.

4.2.2.3 Efficiency of Control

The degree of contact between the steam and the wastewater is the primary variable affecting the ability of a steam stripper to remove VOC's. In turn, this variable is affected by five factors: 1) column dimensions (height and diameter); 2) the

contacting media (packing or trays); and 3) operating parameters such as the steam-to-feed ratio, column temperature, and wastewater pH.

Control efficiency increases as column height increases since there is greater opportunity for contact between the steam and the wastewater. The column height is determined by the number of theoretical stages required to achieve the desired removal efficiency. The number of theoretical stages is a function of the equilibrium coefficient of the pollutants and the efficiency of mass transfer in the column, and this number can be computed by either the McCabe-Thiele graphical method or the Kremser analytical method.

The column diameter determines the required cross-sectional area for liquid and vapor flow through the column. The smaller the cross-sectional area, the higher the superficial gas velocity, which increase turbulence and mixing resulting in high column efficiencies. However, the column cross-sectional area must be sufficient to prevent flooding from excessive liquid loading or liquid entrainment. This area also affects the liquid retention time, with higher retention times resulting in higher efficiencies. These factors have to be weighed in selecting the column diameter and the design velocities.

The contacting media in the column also play an important role in determining the mass transfer efficiency. Packing or trays are used to provide contact between liquid and vapor phases. Packing provides for continuous contact while trays provide staged contact. Trays are usually more effective for wastewater containing dispersed solids because of the plugging and cleaning problems encountered with packing. Tray towers can also operate over a wider range of liquid flow rates than packed towers. Packed towers, on the other hand, are often more cost effective to install and operate when treating highly corrosive wastewater since corrosion resistant ceramic packing can be used. Also, the pressure drop through packed towers may be less than through tray towers.[29]

The steam-to-feed ratio required for high removal efficiencies is affected by the wastewater temperature as it enters the column. If the feed temperature is lower than the operating temperature at the top of the column, part of the steam is required to heat the feed. With good column design, sufficient steam flow is provided to heat the feed as well as volatilize the organic constituents. Any steam in excess of this flow rate helps carry VOC's out of the top of the column with the overheads stream. Also, increasing the steam-to-feed ratio will increase the ratio of the vapor to liquid flow through the column, which increases the stripping of VOC's into the vapor phase.

Two other influences on VOC removal are the column temperature and wastewater pH. Temperature influences the solubility and equilibrium coefficients of the organic compounds. pH has an effect on the vapor liquid equilibrium characteristics of VOC's. To ensure steam stripping is successful, columns are operated at pressures slightly exceeding atmospheric, and operating temperatures are usually slightly higher than the normal boiling point of water. Wastewater pH is controlled by adding caustic to the feed.[30]

4.2.2.4 Applicability

Steam stripping is most applicable to treating wastewaters with organic compounds that are highly volatile and have a low solubility in water. The VOC's that have low volatility tend not to volatilize and thus are not easily stripped out of the wastewater by the steam. Similarly, VOC's that are very soluble in water tend to remain in the wastewater and are not easily stripped by steam. Oil, grease, solids content and pH of wastewater also affect applicability. High oil, grease, and solids levels can cause operating problems for steam strippers, and extremes in pH may prove to be corrosive to equipment. Design or wastewater preconditioning techniques can be used to mitigate these problems.

4.2.3 Carbon Adsorbers

Adsorption is a mass-transfer operation involving interaction between gas- or liquid-phase components and solid-phase components. In this operation, certain components of a gas- or liquid-phase (or adsorbate) are transferred to the surface of a solid adsorbent. The transfer is accomplished by physical or chemical adsorption mechanisms. Physical adsorption takes place when intermolecular (van der Waals) forces attract and hold the gas molecules to the solid surface. Chemisorption occurs when a chemical bond forms between the gaseous- and solid-phase molecules. A physically adsorbed molecule can be removed readily from the adsorbent (under suitable temperature and pressure conditions); the removal of a chemisorbed component is much more difficult.

Most industrial adsorption systems use activated carbon as the adsorbent. Activated carbon effectively captures certain organic vapors by physical adsorption. The vapors can then be released for recovery by regenerating the adsorption bed with steam or nitrogen. Oxygenated adsorbents such as silica gels or diatomaceous earth exhibit a greater selectivity for capturing water vapor than organic gases compared to activated carbon. They thus are of little use for high-moisture vent streams characteristic of some VOC-containing vent streams.[31]

Among the factors influencing the design of a carbon adsorption system are the chemical characteristics of the VOC being recovered, the physical properties of the inlet stream (temperature, pressure, and volumetric flow rate), and the physical properties of the adsorbent. The mass of VOC that adheres to the adsorbent surface is directly proportional to the difference in VOC concentration between the gas phase and the solid surface. In addition, the quantity of VOC adsorbed depends on the adsorbent bed volume, the surface area of adsorbent available to capture VOC, and the rate of diffusion of VOC through the gas film at the gas- and solid-phase interface (the mass transfer coefficient). It should be noted that physical adsorption is an exothermic operation that is most efficient within a narrow range of temperature and pressure.[32]

4.2.3.1 Types of Adsorbers

There are five types of adsorption equipment used in gas collection: 1) fixed regenerable beds; 2) disposable/rechargeable cannisters; 3) traveling bed adsorbers; 4) fluid bed adsorbers; and 5) chromatographic baghouses. The fixed-bed type is the one most commonly used for control of VOC's,[33] so this section addresses this type only.

Fixed-bed units can be sized for controlling continuous, VOC-containing streams over a wide range of flow rates, ranging up to several thousand cubic meters per minute (100,000 scfm). VOC concentrations in streams that can be treated by fixed-bed units can range from several parts per billion by volume (ppbv) to 10,000 ppmv.

Fixed-bed adsorbers can be operated in two modes: intermittent or continuous. In intermittent mode, the adsorber removes VOC's for a specified time (called "the adsorption time"), which corresponds to the time during which the controlled source is emitting VOC's. In continuous mode, a regenerated carbon bed is always available for adsorption, so that the controlled source can operate continuously without shutting down. While continuous operation allows for more adsorption over the same period of time because it does not need to be shut down, more carbon must be provided. This is necessary since a bed for desorbing must be provided along with the adsorbing bed in order to recover the captured VOC from the carbon.[34]

4.2.3.2 Control Efficiency

Well designed and operated carbon adsorption systems can achieve control efficiencies of 95 to 99 percent for a variety of solvents including ketones such as methyl ethyl ketone and cyclohexanone. The VOC control efficiency depends on factors such as inlet vent stream characteristics (temperature, pressure,

and velocity), the physical properties of the compounds present in the vent stream, the physical properties of the adsorbent, and the condition of the regenerated carbon bed.

The adsorption capacity of the carbon and the resulting outlet concentration are dependent upon the temperature of the inlet vent stream. High vent stream temperatures increase the kinetic energy of the gas molecules, causing them to overcome van der Waals forces and release from the surface of the carbon. At vent stream temperatures above 38 degrees Celsius, both adsorption capacity and outlet concentration may be adversely affected.[35]

Increasing vent stream pressure improves VOC removal efficiency. Increased stream pressure results in higher VOC concentrations in the vapor phase and increased driving force for mass transfer to the carbon surface. Decreased stream pressure, on the other hand, is often used to regenerate carbon beds. Reduced pressure in the carbon bed effectively lowers the concentration of VOCs in the vapor phase, desorbing the VOCs from the carbon surface to the vapor phase.

Vent stream velocity entering the carbon bed must be quite low to allow time for diffusion and adsorption. Typical inlet vent stream velocities range from 15 to 30 meters per minute (50 to 100 feet per minute). If inlet VOC concentrations are low, as is expected in the SOCMI, the bed area required for the volume needed usually permits a velocity at the high end of this range.[36]

The required depth of the bed for a given compound is directly proportional to the carbon granule size and porosity and to the inlet vent stream velocity. For a given carbon type, bed depth must increase as the vent stream velocity increases. Generally, carbon adsorber bed depths range from 0.40 to 0.95 meter (1.5 to 3.0 feet).

The condition of the regenerated carbon bed will change with use. After repeated regeneration, the carbon bed loses activity, resulting in reduced VOC removal efficiency.

4.2.3.3 Applicability

Carbon adsorption cannot be used universally for distillation or process vent streams. It is not recommended under the following conditions, common with many VOC-containing vent streams: 1) high VOC concentrations, 2) very high or low molecular weight compounds, 3) mixtures of high and low boiling point VOC's, and 4) high moisture content.

Absorbing vent streams with VOC concentrations above 10,000 ppmv may result in excessive temperature rise in the carbon bed

due to the accumulated heat of adsorption resulting from the VOC loading. If flammable vapors are present, insurance company requirements may limit inlet concentrations to less than 25 percent of the LEL.[37]

The molecular weight of the compounds to be adsorbed should be in the range of 45 to 130 gm/gm-mole for effective adsorption. High molecular weight compounds that are characterized by low volatility are strongly adsorbed on carbon. The affinity of carbon for these compounds makes it difficult to remove them during regeneration of the carbon bed. Conversely, highly volative materials (i.e, molecular weight less than about 45 gm) do not adsorb readily on carbon, thus adsorption is not typically used for controlling streams containing such compounds.

Adsorption systems can be very effective with homogeneous vent streams but much less so with streams containing a mixture of light and heavy hydrocarbons. The lighter organic compounds tend to be displaced by the heavier compounds, greatly reducing system efficiency.

Humidity is not a factor in adsorption at adsorbate concentrations above 1,000 ppmv. Below this level, however, water vapor competes with VOC's in the vent stream for adsorption sites on the carbon surface. In these cases, vent stream humidity levels exceeding 50 percent (relative humidity) are not desirable.[38]

4.2.4 Condensers

Condensation is a separation technique in which one or more volatile components of a vapor mixture are separated from the remaining vapors through saturation followed by a phase change. The phase change from gas to liquid can be achieved in two ways: 1) by increasing the system pressure at a given temperature or 2) by lowering the temperature at a constant pressure. The latter method is the more common to achieve the specified phase change, and it alone is addressed here.

4.2.4.1 Description

The basic equipment includes a condenser, refrigeration unit(s), and auxiliary equipment such as a precooler, recovery/storage tank, pump/blower, and piping.

The two most commonly used condenser types are surface condensers and direct contact condensers.[39] In surface condensers, the coolant fluid does not contact the vent stream; heat transfer occurs through the tubes or plates in the condenser. As the vapor condenses, a film forms on the cooled surface and drains away to a collection tank for storage, reuse,

or disposal. Because the coolant from surface condensers does not contact the vapor stream, it is not contaminated and can be recycled in a closed loop. Surface condensers also allow for direct recovery of VOC's from the gas stream.

Most refrigerated surface condensers are the shell-and-tube type, which circulates the coolant fluid on the tube side. The VOC's condense on the outside of the tube (the shell side). Plate-type heat exchangers are also used as surface condensers in refrigerated systems. Plate condensers operate under the same principles as the shell-and-tube systems, for there is no contact between the coolant and vent stream), but the two streams are separated by thin, flat plates instead of cylindrical tubes.

In contrast to surface condensers, direct contact condensers cool the vapor stream by spraying a liquid at ambient or lower temperature directly into the vent stream. Spent coolant containing VOC's from direct contact condensers usually cannot be reused directly. Additionally, VOC's in the spent coolant cannot be recovered without further processing. The combined stream could present a potential waste disposal problem, depending upon the coolant and the specific VOC's.

A refrigeration unit generates the low-temperature medium necessary for heat transfer for recovery of VOC's. Typically in refrigerated condenser systems two kinds of refrigerants are used, primary and secondary. Primary refrigerants such as ammonia and chlorofluorocarbons (e.g., chlorodifluoromethane) are those that undergo a phase change from liquid to gas after absorbing heat. Secondary refrigerants, such as brine solutions, have higher boiling points and thus act only as heat carriers and remain in the liquid phase.

There are some applications that require auxilary equipment. If the vent stream contains water vapor or if the VOC has a high freezing point (e.g., benzene or toluene), ice or frozen hydrocarbons may form on the condenser tubes or plates. This will reduce the heat transfer efficiency of the condenser and thereby reduce the removal efficiency. Formation of ice will also increase the pressure drop across the condenser. In such cases, a precooler may be used to remove the moisture before the vent stream enters the condenser. Alternatively, ice can be melted during an intermittent heating cycle by circulating ambient temperature brine through the condenser or using radiant heating coils.

It is necessary in some cases to provide a recovery tank for temporary storage of condensed VOC before its reuse, reprocessing, or transfer to a large storage tank. Pumps and blowers are typically used to transfer liquid (e.g., coolant and recovered VOC) and gas streams, respectively, within the system.

4.2.4.2 Control Efficiency

The major parameters that affect the removal efficiency of refrigerated surface condensers designed to control air/VOC mixtures are: 1) Volumetric flow rate of the VOC-containing vent stream; 2) Inlet temperature of the vent stream; 3) Concentrations of the VOC's in the vent stream; 4) Absolute pressure of the vent stream; 5) Moisture content of the vent stream; and 6) properties of the VOC's in the vent stream, such as dew points, heats of condensation, heat capacities, and vapor pressures.[40]

Any operator of a condenser should remember that a condenser cannot lower the VOC concentration to levels below the saturation concentration at the coolant temperature. Removal efficiencies above 90 percent can be achieved with coolants such as chilled water, brine solutions, ammonia, or chlorofluorocarbons.

4.2.4.3 Applicability

Condensers are widely used as product recovery devices. They may be used to recover VOC's upstream of other control devices or they may be used alone for controlling vent streams containing relatively high VOC concentrations (usually greater than 5,000 ppmv). In these cases, the removal efficiencies of condensers can range widely, from 50 to 95 percent.

Since the temperature necessary for condensation depends on the properties and concentration of VOC's in the vent stream, streams having either low VOC concentrations or more volatile compounds require lower condensation temperatures. Also, depending on the type of condenser used, disposal of the spent coolant can be a problem. If cross-media impacts are a concern, surface condensers would be preferable to direct contact condensers.

Condensers used as emission control devices can process flow rates as high as about 57 m^3/min (120,000 scfm). Condensers for vent streams with greater volumetric flow rates and having high concentrations of noncondensibles will require significantly larger heat transfer areas.

4.2.5 Vapor Collection Systems for Loading Racks

When liquids are transferred into a transport vessel, vapors in the head space of that vessel can be lost to the atmosphere. The principal factors affecting emissions from transfer operations are the vapor pressure of the chemical being transferred. Other factors that influence emissions from transfer operations include the transfer rate and the purge rate of nitrogen (or other inert gas) through the vessel during

transfer.

The vapor pressure of the chemical being transferred has the greatest influence on emissions from transfer operations. For pure materials, the vapor pressure gives a measure of the amount of organic compound lost during transfer. The total potential emissions from any transfer is related to the void volume of the transport vessel and the concentration of the VOC in the head space.

The mode of transfer is also an important factor in determining emissions from transfer operations. Top splash loading creates the most emissions because it enhances the agitation of the liquid being transferred, creating a higher concentration of the compound in the vapor space. With alternate loading techniques, such as submerged fill or bottom loading, the organic liquid is loaded under the surface of the liquid, which reduces the amount of agitation and suppresses the generation of excess vapor in the head space of the transport vessel.

The rate of transfer has a more subtle influence on emissions; its greatest effect is on air quality. Transfer rate will dictate the short-term emission rate of the compound being transferred, thereby influencing exposure to the worker or public.

A nitrogen purge is used to reduce the potential for explosion of some chemicals in air or to keep some chemicals moisture-free. Using an inert gas purge increases the emission rate of VOC lost to the atmosphere because it creates a turnover rate of gas through the transport vessel, increasing the total volume of vapor discharged to the atmosphere.

Most vapor collection systems collect the vapors generated during transfer operations and transport them to either a recovery device for return to the process or a combustion device for destruction. In vapor balancing systems, vapors generated during transfer operations are returned directly to the storage facility for the material, and the system requires no additional controls.

4.2.5.1 Description of Vapor Collection Systems

Vapor collection systems consist of piping that captures and transports to a control device VOC's in the vapor space of transport vessels that are displaced when liquids are loaded. These systems may use existing piping normally used to transport liquids under pressure into the transport vessel or piping separate from that for transfer. Collection systems comprise very few pieces of equipment and minimal piping. The principal piece of equipment in a collection system is a vacuum pump or blower, used to induce the flow of vapors from the transport

vessel to the recovery or combustion system.

Blowers can also be used to remove vapors from the head space of the tank car as liquid is transferred into the tank car. Standard recovery techniques such as condensation or refrigeration/condensation systems, or combustion can be applied to the captured vapors.

Vapor balancing is another means of collecting vapors and reducing emissions from transfer operations. Vapor balancing is most commonly used where storage facilities are adjacent to the loading facility. In this collection system, an additional line is connected from the transport vessel to the storage tank to return any vapor in the transport vessel displaced by the liquid that is loaded to the vapor space of the storage vessel left by the transferred liquid. Since this is a direct volumetric change, there are no losses to the atmosphere.

4.2.5.2 Efficiency

The three factors affecting the efficiency of a vapor collection system are:

1) Operating pressure of the collection system;

2) Volume of piping between the loading arm and the transport vessel; and

3) The efficiency of the ultimate control device.

The first factor influences the efficiency of collection through the VOC concentration remaining in the line after transfer. The VOC concentration for systems operating at low pressures or under vacuum is decreased, thus lowering the total amount of VOC in the piping. This effectively reduces the amount of VOC lost to the atmosphere when disconnecting transfer lines. The opposite occurs for systems operating at higher pressures.

The second factor establishes the quantity of VOC not delivered to the transport vessel and not collected for treatment. Systems that minimize the piping between the transfer loading arm and the transport vessel are more efficient than those with larger piping connections, because there is less open piping to the atmosphere.

The third factor is the most important, for it affects the the overall efficiency of the collection system and the control system. In the SOCMI, collection systems are generally hard-piped between the transport vessel and the control system. Thus, there is no loss of efficiency, other than losses associated with connections and disconnections.

4.2.5.3 Applicability

Applicability of vapor collection systems depends on four factors:

1) Vapor pressure of the material;

2) Value of the product;

3) Physical layout of the facility; and

4) OSHA considerations.

Materials with vapor pressures greater than atmospheric are stored and loaded under pressure. Loading under pressure eliminates the losses associated with atmospheric transfer operations and limits losses to those associated with connections and disconnections.

For purely economic considerations, expensive products are candidates for more extensive collection and recovery systems. Further, it is unlikely that combustion techniques will be used to control emissions of products whose value is high enough to warrant recovery efforts.

The third factor, physical layout of the facility, is the most important. The shorter the distance between the vapor balancing system and the storage tank, the fewer meters of piping required, and the more affordable a vapor balancing system is. Because vapor balancing is a simple and cost effective control technique for transfer operations, it is often used in RACT (reasonably available control technology) requirements and has been used in many instances as a control measure to meet the emission requirements of many state air toxic regulations.

OSHA limitations on work place exposure to chemicals being transferred are additional considerations. Some chemical compounds being transferred are more toxic than others, and thus must be more tightly controlled. Highly toxic or carcinogenic compunds require stringent control measures such as transferring VOCs under vacuum, vapor compression, refrigeration, and combustion.

4.3 LDAR

Leak detection and repair programs have been required by the EPA for a number of years. They have been undertaken to reduce emissions due to leaking equipment. These emissions occur when process fluid (liquid or gaseous) is released through the sealing mechanisms of equipment in the chemical plant. This section discusses the sources of equipment leak emissions and control techniques that can be applied to reduce emissions from equipment

leaks, including the applicability of each control technique and its associated effectiveness in reducing emissions.

Many potential sources of equipment leak emissions exist in an organic chemical plant. The following sources are covered in this section: pumps, compressors, agitators, pressure relief devices, open-ended lines, sampling connections, process valves, connectors, instrumentation systems, and product accumulator vessels.

The techniques for reducing emissions from equipment leaks are as diverse as the types of sources. The three major categories for techniques are: 1) Equipment (modifications); 2) Closed vent systems; and 3) Work practices. The selection of a control technique and its effectiveness in reducing emissions depends on a number of factors including: 1) Type of equipment; 2) Equipment service (gas, light liquid, heavy liquid); 3) Process variables influencing equipment selection (temperature, pressure); 4) Process stream composition; and 5) Costs.

4.3.1 Equipment Description and Controls

4.3.1.1 Pumps

Pumps are used widely in the SOCMI for the movement of organic liquids.[41] Chemicals transferred by pump can leak at the point of contact between the moving shaft and the stationary casing. Consequently, all pumps require a seal at the point where the shaft penetrates the housing in order to isolate the pumped fluid from the environment.

4.3.1.1.1 Seals for Pumps

Two generic types of seals, packed and mechanical, are used on pumps. Packed seals can be used on both reciprocating and rotary action (centrifugal) pumps. A packed seal consists of a cavity (or "stuffing box") in the pump casing filled with packing material that is compressed with a packing gland to form a seal around the shaft. Coolant is required to remove the frictional heat between the packing and shaft. The necessary lubrication is provided by a coolant that flows between the packing and the shaft.[42] Deterioration of the packing can result in leakage of the process liquid.

Mechanical seals are limited in application to pumps with rotating shafts. There are single and double mechanical seals, with many variations to their basic design, but all have a lapped seal face between a stationary element and a rotating seal ring. In a single mechanical seal, the faces are held together by the pressure applied by a spring on the drive and by the pump

pressure transmitted through the pumped fluid on the pump end. An elastomer O-ring seals the rotating face to the shaft. The stationary face is sealed to the stuffing box with another elastomer O-ring or gasket.

For double mechanical seals, two seals are arranged back-to-back, in tandem, or face to face. In the back-to-back arrangement, a closed cavity is created between the two seals. A seal liquid, such as water or seal oil, is circulated through the cavity. This seal liquid is used to control the temperature in the stuffing box. For the seal to function properly, the pressure of the seal liquid must be greater than the operating pressure of the pump. In this manner, any leakage would occur across the seal faces into the process or the environment.

Double mechanical seals are used in many process applications, but there are some conditions for which their use is not indicated. Such conditions include service temperatures above 260 degrees Celsius, and pumps with reciprocating shaft motion. Further, double mechanical seals cannot be used where the process fluid contains slurries, polymeric, or undissolved solids.

4.3.1.1.2 Sealless Pumps

Another type of pump used in the SOCMI is the sealless pump. Sealless pumps are used primarily in processes where the pumped fluid is hazardous, highly toxic, or very expensive and where every effort must be made to prevent all possible leakage of the fluid. Canned-motor, diaphragm, and magnetic drive pumps are three common types of sealless pumps.

Canned-motor pumps have interconnected cavity housings, motor rotors, and pump casings. Because the process liquid is the bearing lubricant, abrasive solids in the process lines cannot be tolerated. Canned-motor pumps are widely used for handling organic solvents, organic heat transfer liquids, and light oils.

Diaphragm pumps contain a flexible diaphragm of metal, rubber, and plastic as the driving member. The primary advantage of this arrangement is the elimination of all packing and seals exposed to the process liquid provided the diaphragm's integrity is maintained. This is important when handling hazardous or toxic liquids. Emissions from diaphragm pumps can be large, however, if the diaphragm fails.

In magnetic-drive pumps, no seals contact the process fluid. An externally-mounted magnet coupled to the pump motor drives the impeller in the pump casing.

4.3.1.2 Compressors

Compressors move gas through a process unit in much the same way that pumps transport liquid. Compressors are typically driven with rotating or reciprocating shafts. Thus, the sealing mechanisms for compressors are similar to those for pumps, i.e., packed and mechanical seals. Emissions from this source type may be reduced by improving the seals' performance or by collecting and controlling the emissions from the seal. Emissions from mechanical contact seals depend on the type of seal or control device used and the frequency of seal failure.

Shaft seals for compressors are of several different types: labyrinth, restrictive carbon rings, mechanical contact, and liquid film. All of these seal types restrict leaks, although none of them completely eliminates leakage. Compressors can be equipped with ports in the seal area to evacuate collected gases, which could then be controlled.

A buffer or barrier fluid may be used with these mechanical seals to form a buffer between the compressed gas and the environment, similar to barrier fluids in pumps. This system requires a clean, external gas supply that is compatible with the gas being compressed. Barrier gas can become contaminated and must be disposed of properly, for example by venting to a control device. Compressors can also be equipped with liquid film seals. This seal is formed by a film of oil between the rotating shaft and stationary gland.

4.3.1.3 Agitators

Agitators are used in the SOCMI to stir or blend chemicals. As with pumps and compressors, emissions from agitators can occur at the interface of a moving shaft and a stationary casing. Emissions from this source type may be reduced by improving the seal or by collecting and controlling emissions. There are four seal arrangements commonly used with agitators: packed seals, mechanical seals, hydraulic seals, and lip seals. Packed seals for agitators are similar in design and application to the packed seals for pumps (refer to Section 4.3.1.1).

While mechanical seals are more costly than other seal arrangements, they provide better leakage rate reduction. Also, the maintenance frequency of properly installed and maintained mechanical seals is one-half to one-fourth that of packed seals.[43] Mechanical seals can be designed specifically for high pressure applications (i.e., greater than 1,140 kPa or 165 psia).[44] As with packed seals, the mechanical seals for agitators are similar to the design and application of mechanical seals for pumps.

The hydraulic seal is the simplest and least-used agitator

shaft seal. In this type of seal, an annular cup attached to the process vessel contains a liquid that contacts an inverted cup attached to the rotating agitator shaft. The primary advantage of this seal is that it is a noncontact seal. However, this seal is limited to low temperatures and pressures and can only handle very small fluctuations. Process chemicals may contaminate the seal liquid and then be released into the atmosphere as equipment leak emissions.

Lip seals, which are relatively inexpensive and easy to install, can be used on a top-entering agitator as a dust or vapor seal. Once the seal has been installed, the agitator shaft rotates in continuous contact with the lip seal. Emissions can be released through this seal when it wears excessively or when the operating pressure surpasses the pressure limitation of the seal.

4.3.1.4 Pressure Relief Devices

Insurance, safety, and engineering codes require that pressure relief devices or systems be used in applications where the process pressure may exceed the maximum allowable working pressure of the process equipment. Pressure relief devices include rupture disks and safety/relief valves. The most common pressure relief device is a spring-loaded valve designed to open when the operating pressure of a piece of process equipment exceeds a set pressure. Equipment leak emissions from spring-loaded relief valves may be caused by failure of the valve seat or valve stem, improper reseating after overpressure relief, or process operation near the relief valve set pressure which may cause the relief valve to frequently open and close or "simmer."

Rupture disks are designed to burst at overpressure to allow the process gas to vent directly to the atmosphere. Rupture disks allow no emissions as long as the integrity of the disk is maintained. They must be replaced after each pressure relief episode to restore the process to an operating pressure condition. Although rupture disks can be used alone, they are sometimes installed upstream of a relief valve to prevent emissions through the relief valve stem.

Combinations of rupture disks and relief valves require certain design constraints and criteria to avoid potential safety hazards. For example, appropriate piping changes must be made to prevent disk fragments from lodging in damaging the relief valve when relieving overpressure. A block valve upstream of the rupture disk can be used to isolate the rupture disk/relief valve combination and permit in-service replacement of the disk after it bursts. Otherwise, emissions could result through the relief valve.

4.3.1.5 Open-Ended Lines

Emissions from open-ended lines are caused by leakage through the seat of an upstream valve in the open-ended line. Emissions that occur through the stem and gland of the valve are not considered "open-ended" emissions and are addressed in the section on process valves. Emissions from open-ended lines can be controlled by installing a cap, plug, flange, or second valve to the open end. Control efficiency of these control measures is assumed to be 100 percent.

4.3.1.6 Sampling Connections

Emissions from sampling connections occur as a result of purging the sampling line to obtain a representative sample of the process fluid. These emissions can be reduced by using a closed loop sampling system or disposing of the purged process fluid in a control device. The closed loop sampling system is designed to return the purged fluid to the process at a point of lower pressure. Closed loop sampling is assumed to be 100 percent effective for controlling emissions from a sample purge. This purged fluid could also be directed to a control device such as an incinerator, in which case the control efficiency would depend on the efficiency of the incinerator in removing the VOC.

4.3.1.7 Process Valves

Valves are the most common and numerous process equipment type found in the chemical industry.[45] There are many designs for valves, and most of the designs contain a valve stem which operates to restrict or allow fluid flow. Typically, the stem is sealed by a packing gland or O-ring to prevent leakage of process fluid to the atmosphere. Emissions from valves occur at the stem or gland area of the valve body when the packing or O-ring in the valve fails.

4.3.1.7.1 Seals for Valves

Valves that require the stem to move in and out or turn must utilize a packing gland. A variety of packing materials are suitable for conventional packing glands. The most common packing materials are the various types of braided asbestos that contain lubricants; other packing materials include graphite, graphite-impregnated fibers, and tetrafluorethylene. The choice of packing material depends on the valve application and configuration.[46] Conventional packing glands can be used over a wide range of operating temperatures.

4.3.1.7.2 Sealless Valves

Emissions from process valves can be eliminated if the valve

stem can be isolated from the process fluid. There are two types of sealless valves available: diaphragm valves and sealed bellows valves.

Diaphragm valves isolate the valve stem from the process fluid using a flexible elastomer or metal diaphragm. The position of the diaphragm is regulated by a plunger, which is controlled by the stem. Depending on the diaphragm material, this type of valve can be used at temperatures as high as 205 degrees Celsius and in strong acid service. If the diaphragm fails, the valve can become a relatively larger source of emissions.[47] In addition, use at temperatures beyond the operating limits of the material tends to damage or destroy the diaphragm.

Sealed bellows valves are another alternative leakless design. In this valve type, metal bellows are welded to the bonnet and disk of the valve, thereby isolating the stem from the process. These valves can be designed to withstand high temperatures and pressures and can provide leak-free service at operating conditions beyond the limits of diaphragm valves. However, they are usually dedicated to highly toxic services and the nuclear industry.

The control effectiveness of both diaphragm and sealed bellows valves is essentially 100 percent, although a failure of the diaphragm or bellows could cause temporary emissions much larger than those from other types of valves.

4.3.1.8 Connectors

Connectors are flanges, threaded fittings, and other fittings used to join sections of piping and equipment. They are used wherever pipe or other equipment (such as vessels, pumps, valves, and heat exchangers) require isolation or removal.

Flanges are bolted, gasket-sealed connectors. Normally, flanges are used for pipes with diameters of 50 mm or greater and are classified by pressure rating and face type. The primary cause of flange leakage are poor installation and thermal stress, which results in the deformation of the seal between the flange faces.[48]

Threaded fittings are made by cutting threads into the outside end of one piece (male) and the inside end of another piece (female). These male and female parts are then screwed together like a nut and bolt. Threaded fittings are normally used to connect piping and equipment having diameters of 50 mm or less. Seals for these fittings are made by coating the male threads with a sealant before joining it to the female piece. Emissions from threaded fittings can occur as the sealant ages

and eventually cracks. Leakage can also occur as the result of poor assembly or application of the sealant, and thermal stress of the piping and fittings.

Emissions from connectors can be controlled by regularly scheduled maintenance. Potential emissions can be reduced by replacing the gasket or sealant materials. If connectors are not required for process modification or periodic equipment removal, emissions from connectors can be eliminated by welding the connectors together.

4.3.1.9 Instrumentation Systems

An instrumentation system is a group of equipment components used to condition and convey a sample of process fluid to analyzers and instruments for the purpose of determining process operating conditions (e.g., composition, pressure, and flow rate). Valves and connectors are the predominant types of equipment used in instrumentation systems, although other equipment may be included. Emissions resulting from the components in the instrumentation system are controlled as they are for the same component in the process system.[49]

4.3.2 Closed Vent Systems

Emissions from equipment leaks may be controlled by installed a closed vent system around the leaking equipment and venting the emissions to a control device. This method of control is only applicable to certain equipment types, i.e., pumps, compressors, agitators, pressure relief valves, and product accumulator vessels. Because of the many valves, connectors, and open-ended lines typically found in chemical facilities it is not practical to use this technique for reducing emissions from all of these potential sources for an entire process unit. However, a closed vent system can be used to control emissions from a limited number of components, which could be enclosed and maintained under negative pressure and vented to a control device.

4.3.3 Work Practices

LDAR methods are used to identify equipment components that are emitting significant amounts of VOC and to reduce these emissions. The emission reduction potential for LDAR as a control technique is highly variable and depends on several factors, the most important of which are the frequency of monitoring and the techniques used to identify leaks. Repair of leaking components is required only when the equipment leak emissions reach a set level--the leak detection level. A low leak definition will initiate repair at lower levels, resulting

in a lower overall emission rate.

4.3.3.1 Leak Detection Methods

Leak detection methods include individual component surveys, area (walk-through) surveys, and fixed point monitors. Individual component surveys form a part of the other methods.

4.3.3.1.1 Individual Component Survey

Each source of equipment leak emissions (pump, valve, compressor, etc.) can be checked for VOC leakage by visual, audible, olfactory, soap bubble, or instrument techniques. Visual methods are good for locating liquid leaks. A visible leak does not necessarily indicate VOC emissions, however, because the leaking material may be non-VOC. High-pressure leaks may be detected by the sound of escaping vapors, and leaks of odorous materials may be detected by smell.

Soap spraying on equipment components can be used to survey individual components in certain applications. If the soap solution forms bubbles or blows away, a leak is indicated, and vice versa. Disadvantages of this method are that 1) it does not distinguish leaks of hazardous VOC's from nonhazardous VOC's; 2) it is only semiquantitative, since it requires the observer to determine subjectively the rate of leakage based on the behavior of the soap bubbles; and 3) it is limited to sources with temperatures below 100 degrees Celsius, because the water in the soap solution will evaporate at temperatures above this figure. This method is also not suited for moving shafts on pumps or compressors, because the motion of the shaft may interfere with the motion of the bubbles caused by a leak.

The best method for identifying leaks of VOC from components is using a portable hydrocarbon detection instrument. Air close to the potential leak site is sampled and analyzed by a sampling traverse ("monitoring") over the entire are where leaks may occur. The concentration of hydrocarbons in the sampled air is displayed on the instrument meter and is a rough indicator of the VOC emission rate from the component. If the concentration is higher than a specified figure ("action level"), then the leaking component is marked for repair.

4.3.3.1.2 Area Survey

An area or walk-through survey requires the use of a portable hydrocarbon detector and a strip chart recorder. The procedure involves carrying the instrument within one meter of the upwind and downwind sides of process equipment. The instrument is then used for an individual component survey in a suspected leak area. The efficiency of this method for locating leaks is not well established. Problems with this method include

the fact that leaks from overhead valves or relief valves will not be detected, and the possibility of leaks from adjacent units and adverse meteorological conditions affecting the results of the walk-through survey. Thus, the area survey is best for locating only large leaks at small expense.

4.3.3.1.3 Fixed point monitors

This method consists of placing several automatic hydrocarbon sampling and analysis instruments at various locations in the process unit. If elevated hydrocarbon concentrations are detected, a leaking component is indicated. Identifying the specific leaking component requires an individual component survey. The efficiency of fixed point monitoring is not well established, but fixed point monitoring of VOC's is not as effective as a complete individual component survey.[50] Fixed-point monitors are expensive, multiple units may be required, and the portable instrument is also needed to locate the particular leaking component. Calibration and maintenance costs may be high. Fixed-point monitors are used successfully to detect emissions of hazardous or toxic substances, and can provide an increased detection efficiency by selecting a particular compound as the sampling criterion.

4.3.3.2 Repair Methods

This section describes repair methods for possible equipment emission sources in a chemical plant. These are not intended to be complete repair procedures.

Many pumps have in-line or parallel spares that can be used while the leaking pump is being repaired. Leaks from packed seals may be reduced by tightening the packing gland. With mechanical seals, the pump must be dismantled to repair or replace the leaking seal. Dismantling pumps can result in spillage of some process fluid. If the seal leak is small, evaporative emissions of VOC from such spillage may be greater than the continued leak from the seal. Precautions must be taken to prevent or reduce these emissions.

Leakage from compressors with packed seals may be reduced by tightening the packing gland, as described for pumps. Repair of compressors with mechanical seals requires the compressor be removed from service. Since compressors usually do not have spares, immediate repair may not be practical or possible without a process unit shutdown.

Agitators, like pumps and compressors, can leak VOC's at the point where the shaft penetrates the casing, and seals are required to minimize fugitive emissions. Leaks from packed seals may be reduced by the repair procedure described for pumps, while

repair of other types of seals require the agitator to be out of service. In this latter case, process shutdown or isolation of the particular agitator being repaired is required.

Leaking repair valves usually must be removed for repair. To remove the relief valve without shutting down the process, a block valve may be required upstream of the relief valve. A spare relief valve should be attached while the faultly valve is repaired and tested.

A rupture disk can be installed upstream from a pressure relief valve to eliminate leaks until an overpressure release occurs. Once a release occurs, the rupture disk must be replaced to prevent further leaks. A block valve is required to isolate the rupture disk for replacement.

Most valves have a packing gland that can be tightened while in service. Although this procedure should decrease the emissions from the valve, it can actually increase the emission rate if the packing is old and brittle or has been over-tightened. Some types of valves have no means of in-service repair and must be isolated from the process and removed for repair and replacement. Most control valves have a manual bypass loop that allows them to be isolated and removed. Most block valves cannot be isolated easily, although temporary changes in process operation may allow isolation in some cases.

In some cases, leaks from connectors can be reduced by replacing the connector gaskets, but most connectors cannot be isolated to permit gasket replacement. Tightening of connector bolts also may reduce emissions from connectors. Where connectors are not required for process modification or periodic equipment removal, emissions from connectors can be eliminated by welding them.

4.4 Internal Floating Roofs

Internal floating roofs are commonly used in the chemical manufacturing industry to control emissions of chemicals from storage tanks. As the name implies, it is a roof inside a tank that floats on the surface of the stored liquid.

The presence of a floating roof (or deck) inside a fixed roof tank significantly reduces the surface area of exposed liquid. It serves as a physical barrier between the volatile organic liquid and the air that enters the tank through vents.

Because evaporation is the primary emission mechanism associated with storage tanks, emissions from floating roof tanks as well as fixed roof tanks vary with the vapor pressure of the stores liquid. Thus, the control efficiency of retrofitting a fixed roof tank with an internal floating deck depends on the

material being stored.

Other factors affecting emissions, and therefore control efficiency, are tank size, number of turnovers, and the type of deck and seal system selected. Installing an internal floating roof can reduce emissions by 61 to 98 percent.[51] The relative effectiveness of one internal floating roof design over another is a function of how well the deck can be sealed. Probably the most typical internal floating roof design is the noncontact, bolted, aluminum internal floating roof with a single vapor-mounted wiper seal and uncontrolled fittings.

4.4.1 Types of Losses and How They are Controlled

Loss of VOC's from internal floating roof tanks occurs in one of four ways:

1) Through the annular rim space around the perimeter of the floating roof (seal losses),

2) Through the openings in the deck required for various types of fittings (fitting losses),

3) Through the nonwelded seams formed when joining sections of the deck material (deck seam losses), and

4) Through evaporation of liquid left on the tank wall following withdrawal of liquid from the tank (withdrawal loss).[52]

4.4.1.1 Control of Seal Losses

Internal floating roof seal losses can be minimized by employing liquid-mounted primary seals instead of vapor-mounted seals and/or by employing secondary wiper seals in addition to primary seals.

Available emissions test data suggest that the location of the seal (i.e., vapor- or liquid-mounted) and the presence of a secondary seal are the major factors affecting seal losses. A liquid-mounted primary seal has a lower emissions rate, and thus a higher control efficiency, than a vapor-mounted seal. A secondary seal, with either a liquid- or a vapor-mounted primary seal, provides an additional level of control.

The type of seal used plays a less significant role in determining the emissions rate.[53] The type of seal is important

only to the extent that the seal must be suitable for the particular application. For instance, an elastomeric wiper seal is commonly employed as a vapor-mounted primary seal or as a secondary seal for an internal floating roof. Because of its shape, this seal is not suitable for use as a liquid-mounted primary seal. Resilient foam seals, on the other hand, can be used as both liquid- and vapor-mounted seals.

4.4.1.2 Control of Fitting Losses

There are numerous fittings that penetrate or are attached to an internal floating roof. Among them are access hatches, column wells, roof legs, sample pipes, ladder wells, vacuum breakers, and automatic gauge float wells. Fitting losses occur when VOCs leak around these fittings. Fitting losses can be controlled with gasketing and sealing techniques or by the substitution of fittings that are designed to leak less.

The effectiveness of fitting controls at reducing the overall emission rate is a function of the number of fittings of each type employed on a given tank. For example, if using controlled fittings reduces total fitting loss by 36 percent, and if fitting losses are about 35 percent of the total emissions from a typical internal floating roof tank, then the controlled fittings reduce the overall emissions by (.36*.35)= .126, or 12.6 percent over a similar tank without fitting controls. The usual increase in control efficiency achieved by installing controlled fittings ranges from 0.5 to 1.0 percent.[54]

4.4.1.3 Control of Deck Seam Losses

Deck seam losses are inherent in a number of floating roof types including internal floating roofs. Any roof constructed of sheets or panels fastened by mechanical fasteners (e.g., bolts) is expected to have deck seam losses. Deck seam losses are considered to be a function of the length of the seams and not the type of mechanical fastener or the position of the deck relative to the liquid surface. This is a conclusion drawn from a 1986 study on two roof types with significantly different mechanical fasteners and differences in the amount of contact with the liquid surface.[55]

Deck seam losses are controlled by selecting a roof type with vapor-tight deck seams. The welded deck seams on steel pan roofs are vapor tight. Fiberglass lapped seams of a glass fiber reinforced polyester roof may be vapor tight as long as there is negligible permeability of the liquid through the seam lapping materials. Some manufacturers provide gaskets for bolted metal deck seams.

Selecting a welded roof (rather than a bolted roof) will

eliminate deck seam losses. For a typical internal roof that has primary seals, secondary seals, and controlled fittings already, eliminating deck seam losses will raise the control efficiency as much as 1.5 percent.[56]

4.4.2 Applicability

The applicability of any storage tank improvement in order to reduce VOC emissions is dependent upon the characteristics of the particular VOC. Since floating decks are often constructed primarily of aluminum, they may not be applicable to tanks storing halogenated compounds, pesticides, or other compounds that are incompatible with aluminum. Contact between these compounds and an aluminum deck could corrode the deck and cause product contamination.

In addition, vapor pressures may affect the selection of tank improvements as an applicable control technology. For chemicals with very low vapor pressure, fixed roof tank emissions will already be so low that installing an internal floating roof may not significantly reduce emissions further. For chemicals with vapor pressures up to 65 kPa (9.4 psia), emission reductions of 95 percent and above are achievable with this technology. Above this vapor pressure, achievable emission reduction starts to decrease with increasing vapor pressure. Thus, an internal floating roof may not be indicated for chemicals with relatively high vapor pressures.

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CHAPTER 5

REGULATORY OPTIONS

5.1 Introduction

This chapter is devoted to briefly explain the decision process for choosing a regulatory option. The rationale for regulation vs. no regulation will be discussed as well as a MACT floor analysis, cost effectiveness, and economic incentives.

5.2 No Additional EPA Regulation

5.2.1 Judicial System

In the absence of governmental regulation, market systems fail to make the generators of pollution pay for the costs associated with that pollution. For an individual firm, pollution is an apparently unusable by-product that can be disposed of cheaply by venting it to the atmosphere. However, in the atmosphere pollution causes real costs to others. The fact that producers, consumers, and others whose activities result in air pollution do not bear the full costs of their actions leads to a divergence between private costs and social costs. This divergence is considered a market failure since it results in a misallocation of society's resources. Too many resources are devoted to the polluting activity when polluters do not bear the full cost of their actions.

Also, if there was no regulation, the previous regulations would be relied upon as the basis for making judicial decisions regarding excess emissions.

5.2.2 State and Local Action

The Clean Air Act requires each state to develop and implement measures to attain and maintain EPA's standards. Each state assembles these measures in a document called the State Implementation Plan (SIP). SIPs must be approved by the EPA, and the EPA is empowered to compel revision of plans it believes are inadequate. The EPA may assume enforcement authority over air pollution control programs any state fails to implement. The standards will become parts of each state's SIP, and enforcement authority will be delegated to the states. If the EPA were not to promulgate the standards, states would be responsible for making case-by case MACT decisions under Section 112 (g) and (j) whenever there is a major modification or when the date for MACT promulgation has passed without action on EPA's part.

The EPA believes that reliance on state and local action is not a viable substitute for the standards. This belief holds even if the EPA were to step up research and technology transfer programs to assist state and local governments.

5.3 EPA Regulation

5.3.1 Categories, Emission Points, and Floors

The EPA source category list identifies source categories for which NESHAP's are to be established. This list implements Section 112 (c) of the Act and reflects the EPA's determination that listed source categories include major sources of hazardous air pollutants. The source category list includes SOCMI chemical production as well as the seven non-SOCMI equipment leak source categories.

The SOCMI is a segment of the chemical manufacturing industry that includes the production of many high-volume organic chemicals. The products of SOCMI production processes are derived from approximately 10 petrochemical feedstocks. Of the hundreds of organic chemicals that are produced by the SOCMi, some are final products and some are the feedstocks for production of other chemicals or synthetic products. For example, large quantities of SOCMI products are used in the production of plastics, fibers, surfactants, pharmaceuticals, synthetic rubber, dyes, and pesticides. Production of these end products is not considered to be part of SOCMI production.

In the source category list, EPA identified the SOCMI with a list of chemical products whose production is believed to involve emissions of organic HAP's. This list of chemicals was identified from the literature describing SOCMI production processes, reactants, and products. A chemical was listed if organic HAP's could be used as reactants or produced in the production of the SOCMI chemical. The EPA recognizes that these chemical products can be produced using other reaction sequences and that not all plants producing the listed chemicals use a process that involves organic HAP emissions. Thus, the standard will only apply to those chemical production processes from which organic HAP's can be emitted.

The equipment leak standard would apply to the SOCMI and to processes within seven other non-SOCMI source categories: styrene/butadiene rubber production; polybutadiene production; chlorine production; pesticide production; chlorinated hydrocarbon use; pharmaceutical production; and miscellaneous butadiene use.

For this SOCMI component of the regulation, the EPA is proposing to define source as all the process vents, storage vessels, transfer operations, wastewater collection and treatment

operations, and equipment leaks in the subject industrial processes used to manufacture synthetic organic chemicals that are located in a single facility covering a contiguous area under common control.

As the entire production process is contained within a single source that is part of one source category, a single floor, as defined in Section 112 (d)(3), is applicable to the entire operation.[1] The five kinds of emission points as stated above are process vents, storage vessels, transfer operations, wastewater collection and treatment operations, and equipment leaks.

Though equipment leaks are included in the definition of source, they cannot be included in emissions averaging because there is no method that currently exists for determining the magnitude of allowable emissions to assign equipment leaks for purposes of emissions averaging. When methods are developed to assign allowable emission levels to particular leak points, the EPA will consider revising the HON to allow the inclusion of equipment leaks in emissions averages.

In order to develop the MACT standards, the floor must be established for the source category. This is due to the fact that the Act specifies that the standard be at least as stringent as the floor. Since there were no readily available data to determine the floor for the source as a whole, each kind of emission point was examined to determine the floor. Controls that comprise the best 12 percent of performance for existing sources determine the existing source floor. For new sources, the best controlled similar source is used to determine the floor. For SOCMI, what distinguishes a well-controlled facility is not only the type of control equipment used, but also the number of emission points that are controlled. The EPA used existing Federal and State regulations to determine current control levels on the emission points. Using this process to establish a floor for the part of the source regulated by Subpart G ensures that the control level of the standard will be equivalent to the emission control level on the best controlled 12 percent of SOCMI facilities.

For Subpart H, the negotiating committee agreed that the requirements of the negotiated standards constitute MACT for equipment leaks. The standards for equipment leaks were determined under the regulatory negotiation process. The committee that negotiated the equipment leak rule considered the many factors and uncertainties associated with regulating equipment leaks at a wide variety of chemical plants and developed an acceptably balanced approach. The negotiators weighted the need to be flexible, the technical uncertainties, the requirement for MACT standards, and the data limitations. At

the final negotiating session, the committee members conceptually resolved all outstanding major issues and over the following several months reached final agreement on the draft regulation and preamble.

All committee members agreed to support the standard providing that EPA proposes and promulgates a regulation and preamble with the same substance and effect as what was contained in the final agreement. Consequently, there were no regulatory options evaluated under the HON rule.

5.3.2 Development of MACT and the Regulatory Alternatives

The SOCMI standards potentially represents the greatest emissions reduction likely to be achieved by any air toxics source category being regulated under Title III. As such, regulating this industry represents a significant first step toward fulfilling the mandate of Title III to reduce emissions of toxic air pollution to the greatest feasible extent. In addition, SOCMI facilities tend to be large individual emitters of toxic air pollutants, which are generally suspected to pose potential health hazards at the local level (i.e. close to individual sources).

The EPA recognizes that the 110 HAP's regulated by Subpart G of the HON represent a wide range of toxicities associated with a variety of potential toxic effects at a variety of exposure levels. However, Title III does not contemplate quantifying the specific health and environmental risks associated with different chemicals in MACT standard setting. While MACT decisions are thus not risk-based, and risk information specific to the SOCMI industry has not been developed, the EPA nevertheless recognizes clear public interest in reducing toxic emissions from the SOCMI industry as much as is feasible, based upon the potential for health and environmental benefits from toxic emissions reduction of this magnitude.

Aside from the general goal of maximum feasible emissions reduction, the EPA has endeavored to structure this first major MACT rule to incorporate several other goals: overall administrative simplicity, allowing flexibility in implementation (in order to reduce costs), encouraging pollution prevention and source reduction, and enforceability. Some goals reinforce each other (e.g. ensuring flexibility and encouraging pollution prevention). Where different goals may tend toward opposing outcomes (e.g. flexibility vs. enforceability), the EPA has striven to find workable resolution of issues, and will be requesting comment on our proposed solutions.

The EPA has devised a standard for sources in this category that permits compliance either by applying reference technology

(MACT or an approved alternative) to all points specified by the standard, or alternatively by using emissions averaging, including Pollution Prevention/ Early Reduction credits.

Once the floor level of control was established, as required by the Act, the EPA considered the floor level of control for every kind of emission point and the options for control requirements beyond the floor. Bearing in mind all relevant statutory criteria, the EPA considered the magnitude of the emissions reduction to be obtained at a plant, the relative costs of different levels of controls and the general characteristics of this source category compared to other sources of hazardous air pollution when considering control requirements.

The alternative options were structured for each emission point. The same technology was used for each alternative but different parameters of emission points were generated which would result in a broader coverage as alternatives became more stringent.

5.3.3 Description of MACT and the Regulatory Alternatives

The options and floors chosen for each source are as follows: (See Tables 1 and 2 for details)

Process Vents

Using the TRE calculations, the EPA determined that the existing source floor level of control for process vents is equivalent to a cost effectiveness value of $1,500. The new source floor level of control is a TRE based cost effectiveness value of $11,000. The proposed standard would require combustion with 98 percent control efficiency for existing and new source process vents with TRE cost effectiveness values of less than $5,000 and $11,000, respectively.

Storage Vessels

For purposes of selecting control requirements, storage vessels were divided by capacity as follows: 10,000 to 20,000 gallons (small); 20,000 to 40,000 gallons (medium); and greater than 40,000 gallons (large). These size divisions are commonly used in regulations for storage vessels. The existing source floor level of control is a vapor pressure of 13.1 kPa (1.9 psia) for both large and medium storage vessels. The floor analysis for small storage vessels indicates that less than 12 percent of all small vessels are controlled to the efficiency of the reference control, and thus there is no floor control for existing source small storage vessels. The new source floor level of control is a vapor pressure of 13.1 kPa (1.9 psia) for small and medium storage vessels.

The control requirements for storage vessels apply to

existing source medium and large storage vessels storing liquids of vapor pressures more than 13.1 kPa (1.9 psia) and 5.2 kPa (0.7 psia), respectively. The proposed applicability criterion for new source small and medium storage vessels is storage of liquids with vapor pressures greater than 13.1 kPa (1.9 psia). There is no proposed control requirement for existing source small storage vessels. The proposed applicability criterion for new source large vessels is vapor pressures above 0.7 kPa (0.1 psia). The control requirements are the same for new and existing source vessels in the medium and large size divisions.

Transfer Operations

The existing and new source floor levels of control for transfer operations are a vapor pressure and throughput combination of 10.3 kPa (1.5 psia) and 643.5 m^3/yr (0.17 million gal/yr), respectively.

Wastewater Streams

The floor level of control for new source wastewater streams is 10 ppmw for very volatile HAP's (VVHAP). The control requirements for new source wastewater streams are to be applied to those streams with 10 ppmw VVHAP and 1000 ppmw volatile HAP. The applicability criteria for control of existing source wastewater streams are 10 lpm flow and 1000 ppmw volatile HAP. There is no floor for existing wastewater streams.

Equipment Leaks

The regulation would apply to both existing and new process units. It categorizes the regulated processes into five groups and uses a staggered implementation scheme, requiring some process units to comply 6 months after promulgation, while others would have to comply as late as 18 months after promulgation.

The regulation applies to those pieces of equipment currently regulated in the existing equipment-leak rules, including all valves, pumps, compressors, pressure relief devices, open-ended valves or lines, connectors, closed-vent systems and control devices, sampling connection systems, and product accumulator vessels.

These standards are estimated to reduce emissions by about 60-70 percent and after control, leak frequencies (i.e. the percentage of equipment components within a process unit that leak) would be approximately 5 percent.

The standard only applies to equipment containing or contacting process materials that are five percent VHAP or greater. In certain chemical plants, particularly those with batch processes that produce a number of different products, some equipment is used in VHAP service only occasionally. In such cases, implementation of the standard could be difficult and

cases, implementation of the standard could be difficult and would achieve very little emission reduction. For these situations, equipment that is operated in VHAP service for 300 h/yr is exempt.

The HON will establish a control requirement for each kind of emission point regulated by Subparts G and H. To facilitate emissions averaging, the standard will also establish an allowable emissions level for the emission points regulated by Subpart G at each source. The allowable emissions level will be equal to the sum of the emissions from each point in the source excluding equipment leaks, after the required controls have been applied. As such, the allowable emissions level is set for a given mix of emission points, and the emissions limit will change as the number of each kind of emission point in the source changes.

Both Group 1 and 2 emission points as defined in Subpart G must be included in the calculation of the source's allowable emissions level. However, emission points associated with equipment that is no longer operational are not to be included in the calculation of the emissions limit because these points are not subject to the standard. Though the form of the standard established in Subpart G of the HON is an allowable emissions level, the EPA does not anticipate that any owner or operator will actually calculate emissions estimates for every point in order to comply with the standard. Actual emissions estimates will only be required for those emission points that are included in emissions averages. For emission points that are not included in emissions averages, compliance will be determined on a point by point basis. For these points, the use of an appropriate and well maintained control serves as a surrogate for an emissions estimate in determining compliance with the allowable emissions level.[2]

Table 5-1

Regulatory Options

Process Vents

- Existing - C/E $\leq$ $2,000/Mg
- New - C/E $\leq$ $11,000/Mg

Transfer Operations

- Existing and New - Control for racks with vapor pressure $\geq$ 10.3 kPa (1.5 psia) and throughput > 643.5 m^3/yr (0.17 million gallons/yr)

Wastewater Operations

- Existing - > 10 liter/min and > 1000 ppmw total VOHAP
- New
  - Control for VVHAP > 10 ppmw and > 1000 ppmw total VOHAP

Storage Vessels

- Small Tanks
  - Existing - no control
  - New - control for vapor pressure > 13.1 kPa (1.9 psia)
- Medium Tanks
  - Existing - control for vapor pressure > 13.1 kPa (1.9 psia)
  - New - same as existing
- Large Tanks
  - Existing - control for vapor pressure > 5.2 kPa (0.75 psia)
  - New - control for vapor pressure > 0.7 kPa (0.1 psia)

Table 5-2

Floor Elements

Process Vents

- Existing - control vents with cost effectiveness of < $1500/Mg
- New - No control required

Wastewater Operations

- Existing - No control required
- New - control for streams > 10 ppmw VVHAP

Transfer Operations

- Existing - control for racks loading liquid HAP's with vapor pressure > 10.3 kPa (1.5 psia) and throughput > 643.5 m^3/yr (0.17 million gallons per year)
- New - same as existing

Storage Vessels

- Small Tanks
  - Existing - no control required
  - New - control for tanks storing HAP's with vapor pressure > 13.1 kPa (1.9 psia)
- Medium Tanks
  - Existing - control for tanks storing HAP's with vapor pressure > 13.1 kPa (1.9 psia)
  - New - same as existing
- Large Tanks
  - Existing - control for tanks storing HAP's with vapor pressure > 13.1 kPa (1.9 psia)
  - New - control for tanks storing HAP's with vapor pressure > 5.2 kPa (0.75 psia)

5.3.4 Role of Cost Effectiveness

EPA has often used cost effectiveness (C/E) analysis as a guide for selecting among regulatory alternatives. Regulatory alternatives can sometimes be ranked based on stringency of control. All else equal, alternatives yielding the same level of control but higher average C/E (usually control cost per ton of pollutant reduced) could be eliminated from consideration. Incremental C/E can then be calculated for each step up the stringency ranking. The selection of a regulatory alternative could then be made by selecting the most stringent alternative below some agreed upon C/E cutoff. The level of such a C/E cutoff would generally depend on the pollutant being controlled and other factors.

However, since the HON regulation is to be a MACT standard, the role of C/E analysis for selecting a regulatory alternative for this regulation is somewhat limited. A MACT floor level of control stringency is required regardless the C/E at this control level. At stringency levels beyond the MACT floor, cost effectiveness can be legally considered, and EPA believes cost-effectiveness of controls is a primary consideration for stringency levels beyond the MACT floor.

5.3.5 Economic Incentives: Subsidies, Fees, and Marketable Permits

Economic incentive strategies, when designed properly, act to harness the marketplace to work for the environment. Such strategies influence, rather than dictate producer and consumer behavior, in order to achieve environmental goals. They make environmental protection of economic interest to producers and consumers. When feasible, properly designed systems can be employed to achieve any environmental goal at the least cost to society.

Several types or categories of economic incentive strategies exist. One broad category of incentive programs is based of the use of fees or subsidies. Fee programs establish and collect a fee on emissions, providing a direct economic incentive for emitters to decrease emissions to the point where the cost of abating emissions equals the fee.[3] Similarly, subsidy programs provide a direct incentive for emitters to decrease emissions by providing subsidy payments for emission reductions beyond some baseline.

A second broad category of economic incentive strategies is based on the concept of emissions trading. A wide range of variations in emissions trading programs exist. The common idea in such programs is to allow sources with low abatement cost

abatement cost alternatives so that the cost of meeting a given total level of abatement is minimized.

There are two important constraints regarding the workability of economic incentive programs. The first constraint concerns the problem of emissions monitoring. Without an effective emissions monitoring system it is not possible to charge fees or use other economic incentive strategies. Only the traditional "command and control" approach of requiring employment of specific control technologies is feasible in this circumstance.

The second problem constraining the potential value of economic incentive strategies is legal. Various legal restrictions imposed by the CAAA limit the applicability of economic incentive strategies to reduce air pollution.

Legal constraints imposed by Title III of the Act severely limit the usefulness of economic incentive strategies for reducing HAP emissions. Title III requires the implementation of MACT. Thus sources have little or no choice as to the type or level of control they implement except perhaps if going beyond the MACT floor control level. As a limited economic incentive, it may the be possible to impose, for example, and emissions fee on residual emissions after the MACT technology is employed to encourage additional control.

Hence the applicability of economic incentive programs for the HON regulation is very limited. However, limited emissions at the facility level may be feasible and legal given that each facility is considered an emissions source. This emissions averaging strategy allows facilities to trade emission reductions across emission points so as to minimize control costs for any given facility level emission reduction requirement. Thus, to this extent, an economic incentive strategy may be implemented for the HON regulation.

The analysis of control costs (Chapter 6) does not incorporate emission averaging. It is recognized that if facilities were to use this strategy their costs of control should fall. Thus, the costs calculated are an overestimate. It also should be noted that the economic impacts and benefits analyses (Chapters 7 and 8) are only for the TIC option due to data paucities. These analyses are therefore overestimates of the impacts and benefits of the regulation. The control costs calculated in Chapter 6 do, however, include data for the MACT floor and more stringent options up to TIC for each emission point.

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CHAPTER 6

CONTROL COST AND COST EFFECTIVENESS

Due to the unavailability of complete information upon which to base emission and control impacts to the desired degree of accuracy for all chemicals, estimates were developed in the following manner. As much information gathering and analysis as possible was completed for those chemical production processes (CPP) used in the manufacture of SOCMI chemicals.[1] Emissions and control impacts were then estimated for each CPP involved in the manufacture of those chemicals for which complete information was available.[2] For those chemicals with incomplete information, generic estimates of emissions and control impacts were developed.

Section 6.1 of this chapter presents and discusses the cost and cost effectiveness for controlling each of the five HON emissions source types. Section 6.2 presents the method for and results of estimating the cumulative control cost of producing SOCMI chemicals. Section 6.3 addresses control costs in light of the regulatory alternatives, and Section 6.4 presents the estimated national costs of the HON.

6.1 Cost Impacts of Control Technologies

In developing facility level and national costs for the HON, source emission models and appropriate control technologies were paired with the CPP units in the HON database. Control impacts were determined for each modeled emission source at a process unit that was required to implement additional control.

The costs, emission reductions, and cost effectiveness on a model plant basis, are shown in Tables 6-1 through 6-5. Table 6-1 shows the annualized costs, emission reductions, and cost effectiveness for controlling 12 model process vent streams. These model vent streams were selected to illustrate a range of impacts as well as a range of production processes and control

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[1] For a detailed explanation of the methodology used to assess emission and control impacts, refer to Volume 1A, Chapter 4 of the HON BID.

[2] The chemicals for which sufficient information was found account for more than 90 percent of total SOCMI production capacity.

technologies.[3] For this analysis it was assumed that each production process would be equipped with a dedicated combustion device. Some cost savings would be achieved at larger facilities if a common combustion device was used to control multiple production process vent streams. As shown, the annualized costs range from $8 to $2,630,000.

Tables 6-2 and 6-3 show annualized costs, emission reductions, and cost effectiveness for controlling equipment leaks for 6 model units. The model units represent combinations of numbers of equipment components and existing control levels.[4] The recovery credit values are determined by multiplying VOC emission reductions by the average chemical price of $1,590/Mg. Table 6-2 presents annualized costs, emission reduction, and cost effectiveness when quarterly valve monitoring is required. Quarterly monitoring is required if less than 2 percent of all valves are leaking at or above a leak definition of 500 ppmv. Table 6-3 presents annualized costs, emission reduction, and cost effectiveness when monthly valve monitoring is required. Monthly monitoring is required if more than 2 percent of all valves are leaking at or above a leak definition of 500 ppmv. The costs range from a savings of $246,539 to a net cost of $390.

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[3] For a detailed explanation of the development and use of model process vent streams see Volume 1C, Chapter 2 of the HON BID. The model streams are subsets of all the process vent streams in the database.

[4] For a detailed explanation of the development and use of equipment leak model units see Volume 1C, Chapter 6 of the HON BID.

Table 6-1. Annualized Control Cost Estimates

Model Vent Number	Total Annualized Cost ($/yr)	Total HAP/VOC Emission Reductions (Mg/yr)	Cost Effectiveness ($/Mg)[a]	VOC Emission Reductions (Mg VOC/yr)	Cost Effectivenss ($/Mg VOC)[a]
1	1310	79.4	16.5	79.5	16.5
2	1100000	2710	407	7380	150
3	152000	759	200	758	200
4	2630000	5980	439	5980	439
5	8.33	6.76	1.23	8.10	1.03
6	56400	6.23	9060	12.0	4720
7	46100	3.32	13900	3.32	13900
8	46000	0.136	337000	0.136	337000
9	65800	90.4	728	116	568
10	45800	13.4	3420	17.1	2670
11	109000	14.7	7400	18.8	5770
12	45500	0.331	138000	0.424	107000

[a]Cost Effectiveness ($/Mg) = Total Annual Cost ($/yr) ÷ Total HAP/VOC Emission Reduction (Mg/yr)

Table 6-2. Cost Effectiveness For Model Units (Quarterly Valve Monitoring)

	Unit A	Unit B	Unit C	Unit D	Unit E	Unit F
Total annual cost ($/yr)	(26,639)[a]	(108,882)	(246,539)	(6,021)	(27,037)	(76,844)
Emission reductions (Mg VOC/yr)	36.47	149.19	306.11	21.39	92.57	187.98
Average HAP/VOC ratio	0.78	0.78	0.78	0.78	0.78	0.78
Emission reductions (Mg HAP/yr)	28.45	116.37	238.77	16.68	72.20	146.62
Cost effectiveness ($/Mg VOC)	(730)	(730)	(810)	(280)	(290)	(410)
Cost effectiveness ($/Mg HAP)	(940)	(940)	(1,030)	(360)	(370)	(520)

[a]Parentheses indicate negative values (i.e., savings).

Table 6-3. Cost Effectiveness For Model Units (Monthly Valve Monitoring)

	Unit A	Unit B	Unit C	Unit D	Unit E	Unit F
Total annualized cost ($/yr)	(14,099)[a]	(65,171)	(154,369)	6,519	16,675	15,327
Emission reductions (Mg VOC/yr)	36.47	149.19	306.11	21.39	92.57	187.98
Average HAP/VOC ratio	0.78	0.78	0.78	0.78	0.78	0.78
Emission reductions (Mg HAP/yr)	28.45	116.37	238.77	16.68	72.20	146.62
Cost effectiveness ($/Mg VOC)	(390)	(440)	(500)	300	180	80
Cost effectiveness ($/Mg HAP)	(500)	(560)	(650)	390	230	100

[a]Parentheses indicate negative values (i.e., savings).

Table 6-4 summarizes the annualized costs, emission reductions, and cost effectiveness for controlling each of 17 model storage tank farms.[5] The costs depend on the emission rate of the storage vessel and the specific control device used. For this analysis it was assumed that each individual tank would be equipped with a dedicated control device. However, some cost savings could be achieved at larger facilities if, for instance, a single condenser serves all the tanks in one farm. The product recovery credit shown is the value in dollars per year of the recovered product. It is calculated by multiplying the emission reduction by the unit price of the individual chemical. The total annualized costs for the model tank farms range from a savings of $280,000 to a net cost of $556,000.

Table 6-5 summarizes the annualized cost, emission reductions and cost effectiveness for controlling 18 model waste water streams with steam strippers. A total of 84 model wastewater streams were created from various combinations of flow rate, VOHAP concentration, and strippability.[6] Although impact estimates were made based on specific stream characteristics of all 84 streams, a subset of 18 examples were selected from the 84 model streams to illustrate the potential cost and environmental impacts. These 18 were selected to provide a manageable number of examples while still illustrating the full range of impacts. For calculating treatment costs, it was assumed that facilities would combine wastewater streams for treatment whenever technically feasible. Accordingly, steam strippers were sized and costed for combined wastewater feed rates of 50 and 500 liters per minute (lpm). As shown in table 6-5, the annualized costs per facility range from $121,000 to $418,000.

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[5] For a detailed explanation of the development and use of model storage tank farm farms see Volume 1C, Chapter 4 of the HON BID.

[6] For a detailed explanation of the development and use of model wastewater streams see Volume 1C, Chapter 5 of the HON BID.

Table 6-4. Annualized Control Cost Estimates for Example Model Tank Farms

Model Tank Farm Number	Control Technology[a]	Annual Cost Without Product Recovery Credit ($/yr)	Product Recovery Credit ($/yr)	Total Annual Cost ($/yr)[b]	Total HAP/VOC Emission Reductions (Mg/yr)	Cost Effectiveness ($/Mg)[c]
1	Condenser	111,513	1,298	110,215	1.03	107,000
2	Condenser	57,283	4,490	52,793	3.74	14,110
3	Install floating roof	7,907	5,590	2,317	2.23	1,040
4	Install floating roof	7,907	19,676	(11,769)	16.4	(720)
5	Install floating roof	39,483	93,442	(53,959)	37.2	(1,450)
6	Install floating roof	39,483	73,848	(34,365)	151	(210)
7	Install floating roof	151,117	37,749	113,368	51.7	2,190
8	Install floating roof	151,117	431,283	(280,166)	172	(1,630)
9	Condenser	167,967	577	167,390	2.55	65,640
10	Condenser	139,737	23,274	116,463	44.5	2,620
11	Condenser	558,758	2,422	556,336	8.74	63,650
12	Condenser	554,657	7,130	547,527	32.0	17,110
13	Condenser	350,715	11,279	339,436	57.5	5,900

Model Tank Farm Number	Control Technology[a]	Annual Cost Without Product Recovery Credit ($/yr)	Product Recovery Credit ($/yr)	Total Annual Cost ($/yr)[b]	Total HAP/VOC Emission Reductions (Mg/yr)	Cost Effectiveness ($/Mg)[c]
14	Upgrade floating roof	6,630	1,152	5,478	1.31	4,180
15	Upgrade floating roof	6,630	7,944	(1,315)	6.62	(200)
16	Upgrade floating roof	37,436	10,249	27,187	34.2	790
17	Upgrade floating roof	19,966	31,555	(11,589)	26.3	(440)

[a]Each storage tank has a dedicated control device. Thus, the costs for Model 11 represent the costs of seven condensers, one for each tank.

[b]Total Annual Cost = (Annual Cost w/o Recovery Credit) - (Recovery Credit).

[c]Cost Effectiveness ($/Mg) = Total Annual Cost ($/yr) ÷ Total HAP/VOC Emission Reductions (Mg/yr).

Table 6-5. Cost Effectiveness of Wastewater Model Streams

Model Stream	Total Annual Facility Cost ($/yr)	Total Annual Stream Cost ($/yr)	Uncontrolled HAP Emissions (Mg/yr)	HAP Emission Reductions (Mg/yr)	Cost Effectiveness ($/Mg)
4	121,000	24,200	0.02	<0.01	2,400,000
5	121,000	24,200	0.41	0.02	1,200,000
6	121,000	24,200	8.3	0.41	59,000
46	121,000	24,200	0.02	0.01	2,400,000
47	121,000	24,200	0.41	0.29	83,000
48	121,000	24,200	8.3	5.8	4,200
67	121,000	24,200	0.02	0.02	1,200,000
68	121,000	24,200	0.41	0.41	59,000
69	121,000	24,200	8.3	8.1	3,000
19	418,000	83,600	0.17	0.01	8,400,000
20	418,000	83,600	4.1	0.21	400,000
21	418,000	83,600	82.8	4.1	20,000
61	418,000	83,600	0.17	0.12	700,000
62	418,000	83,600	4.1	2.9	29,000
63	418,000	83,600	82.8	58.0	1,400
82	418,000	83,600	0.17	0.16	500,000
83	418,000	83,600	4.1	4.1	20,000
84	418,000	83,600	82.8	81.1	1,000

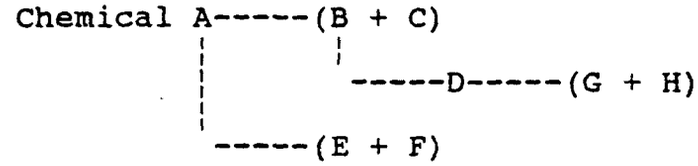
Table 6-6 shows the annualized cost, emission reduction and cost effectiveness for controlling 20 model transfer operations.[7] The costs depend on the transfer rate for a given loading rack and the combustion device selected for control. For this analysis a single control device was assumed to service the entire facility. The annualized costs of the control systems for model transfer racks range from $9,630 to $84,400.

6.2 Cumulative Control Cost Analysis

In addition to addressing the cost of the HON on a facility level, the HON economic impact analysis requires an estimate of the potential impact of the HON on SOCMI chemical prices. To better facilitate this assessment, an analysis of the potential cumulative control cost associated with each chemical's production was performed. The basis for this analysis was chemical use trees developed specifically for the HON.

A chemical tree conveys the production relationship between chemicals, indicating the possible precursor evolution of a SOCMI chemical. For instance, the tree in Figure 6-1 depicts the relationship between chemical A and its precursors. Chemical A can be produced by either combining chemicals B and C, or combining chemicals E and F. Chemical B can be produced from chemical D, and D by combining chemicals G and H.

Figure 6-1 Hypothetical Chemical Tree



[7] For a detailed explanation of the development and use of model transfer loading operations see Volume 1C, Chapter 3 of the HON BID.

Table 6-6. Annual Control Cost Estimates[a]

Model Rack Number	Total Annualized Cost ($/yr)	Total HAP/VOC Emission Reduction (Mg/yr)	Cost Effectiveness ($/Mg)[b]
1	9,630	$3.56 * 10^{-6}$	$2.70 * 10^{9}$
2	63,800	$6.32 * 10^{-4}$	$1.01 * 10^{8}$
3	9,650	$1.42 * 10^{-4}$	$6.81 * 10^{7}$
4	66,000	$3.08 * 10^{-2}$	$2.14 * 10^{6}$
5	10,600	$9.19 * 10^{-2}$	$1.16 * 10^{5}$
6	84,400	3.39	$2.49 * 10^{4}$
7	22,600	$9.63 * 10^{-1}$	$2.35 * 10^{4}$
8	25,900	1.67	$1.55 * 10^{4}$
9	39,000	6.39	$6.11 * 10^{3}$
10	28,100	5.65	$4.98 * 10^{3}$
11	6,870	$2.34 * 10^{-6}$	$2.93 * 10^{9}$
12	63,800	$6.32 * 10^{-4}$	$1.01 * 10^{8}$
13	10,100	$2.96 * 10^{-4}$	$3.42 * 10^{7}$
14	15,600	$9.72 * 10^{-4}$	$1.61 * 10^{7}$
15	63,800	$2.08 * 10^{-1}$	$3.06 * 10^{5}$
16	16,800	$2.11 * 10^{-1}$	$7.97 * 10^{4}$
17	14,300	$8.55 * 10^{-1}$	$1.68 * 10^{4}$
18	74,300	4.46	$1.67 * 10^{4}$
19	67,200	4.22	$1.59 * 10^{4}$
20	38,400	19.3	$1.99 * 10^{3}$

[a]Each transfer rack has a dedicated control device.

[b]Cost Effectiveness ($/Mg) = Total Annual Cost ($/yr) ÷ Total HAP/VOC Emission Reduction (Mg/yr).

6.2.1 Building Chemical Trees

Chemical trees are formed by linking together individual CPPs. A CPP is identified by its chemical inputs and outputs. The chemical output of one process is matched to the chemical input of another to form a chain. Additional processes that match are linked to the chain to form the tree. The HON trees begin with a "root" chemical and identify all the chemicals that can be used to produce the root chemical. Each root chemical can be associated with a producer, and the cost of controlling the process that makes each precursor chemical can be introduced into the tree framework.

6.2.2 Cumulative Control Cost Methodology

Cumulative control cost refers to the price increase for the root chemical that is necessary to recover HON compliance cost, given that the root chemical and its precursor chemicals incur additional production costs as a result of regulation. In simple form, the cumulative cost of controlling a root chemical is the sum of all control costs for each link in the root chemical's production chain. Because the market relationships between production process links are not fully characterized by a chemical tree, each link is assumed to denote an imaginary common marketplace where output chemicals of one process are sold as inputs to another process. One limitation of the cumulative control cost methodology is that market quantity adjustments are not considered. There are hundreds, possibly thousands, of market interactions that would have to be characterized in order to incorporate the chemical production quantity changes that result from the HON into the analysis, and this was not deemed feasible. Therefore, the chemical trees cumulative control cost analysis only addresses for each chemical the probable price increase necessary to recover the HON compliance cost when all other variables are held constant.[8]

Another limitation already alluded to is that the chemical trees represent possible market interactions, not actual interactions. Not all process links in the chemical trees are technically or economically viable. Without an indepth investigation of individual circumstances, an interaction determination cannot be made with certainty.

6.2.3 Cumulative Control Cost Results

The cumulative control cost analysis was performed for the HON options representing total industry control (TIC). This analysis, therefore, represents an upper-bound, or worst-case cost impact scenario. Table 6-7 shows the results of the

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[8] For a summary of the indepth economic impact analysis of the representative HON chemicals, refer to Volume 1A, Chapter 6 of the HON BID, or Chapter 7 in this document.

cumulative control cost analysis for the TIC options. The average percentage cost increase for all HON chemical products appears prohibitively high due to the extremely low cost effectiveness of controlling some small (less than 1.00 Gg/yr) production process units. Of course, many of these units would be unaffected by options less stringent than TIC. The chemical percent price increase necessary to recover HON compliance costs is relatively insignificant for chemicals whose annual production exceeds 1 Gg.

6.3 Costs and Regulatory Options

Tables 6-8 through 6-19 present the total annual cost, emission reductions, and cost effectiveness for the control options considered for each source type (with the exception of equipment leaks which is governed by a negotiated regulation). It is important to note that the information in these tables pertains only to those CPPs for which sufficient information was available. Recall from this chapter's introduction that these CPPs account for over 90 percent of total SOCMI production. Tables 6-8 and 6-9 present the control options for existing and new process vents. Tables 6-10 and 6-11 present the control options for existing and new wastewater sources. Tables 6-12 and 6-13 present the control options for existing and new transfer operations. Tables 6-14 and 6-15 present the control options for existing and new 10,000 to 20,000 gallon storage vessels. Tables 6-16 and 6-17 present the control options for existing and new 20,000 to 40,000 gallon storage vessels. Tables 6-18 to 6-19 present the control options for existing and new storage vessels with greater than 40,000 gallon capacity.

6.4 National Costs

6.4.1 Monitoring, Recordkeeping, and Reporting Costs

The national costs of monitoring, recordkeeping, and reporting from compliance with the HON were calculated. Estimates of hours per item (i.e., a required action), frequency of required action per year, and number of respondents used in the cost calculations were prepared in consultation with people who routinely work with or consult major chemical firms or have considerable experience with such firms. These costs are shown in Table 6-20.

To compute the costs associated with the burden estimates, a wage rate of $32 per hour (in 1990 dollars) was assumed. This assumption was based on 85 percent of the labor accomplished by technical personnel (typically by an engineer with a wage rate of $33 per hour), 10 percent by a manager (at $49 per hour), and 5 percent clerical (at $15 per hour). All of the wage rates include an additional 110 percent for overhead. Costs were annualized assuming an expected remaining life for affected

facilities of 15 years from HON promulgation (officially November 1992), and using an interest rate of 10 percent.

The annualization of costs took into account the different starting points for compliance requirements. For example, facilities must develop implementation plans for monitoring, recordkeeping, and recording by 12 or 18 months before the compliance date. The starting point for annualizing these costs is taken as November 1993, a choice that employs the conservative assumption that facilities will develop implementation plans by the earliest possible time.[9]

Compliance requirements vary in terms of frequency, and are taken into account in the annualization of costs. Performance tests to demonstrate compliance with the control device requirements are required once. Compliance requirements also include monitoring of operating parameters of control devices and records of work practice and other inspections. These activities must be reported semiannually. The compliance requirements that must be met only once are annualized over the time from the year in which they are to take place to the expected end of facility life (November 2007).

6.4.2 Summary

Table 6-21 shows the national annual control cost and average cost effectiveness for the options currently proposed for the HON. These costs include costs for monitoring, recordkeeping, and reporting. The national annual control cost and cost effectiveness are estimated for the fifth year following proposal. The fifth year is used to approximate the date by which all affected sources will have complied with the regulation. The total annual control cost is estimated to be $182 million.

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[9]For more information, refer to the memorandum from Larry Sorrels, U.S. EPA/OAQPS, to Troy Hillier, U.S. OMB, dated October 7, 1992.

Table 6-7. Cumulative Control Cost Analysis Results For Total Industry Control (TIC) Options

Chem. Production (Gg/yr)	% of HON Chem.	Percent of Total HON Production	Average Cumul. Cost Increase ($/kg)	Median Cumul. Cost Increase ($/kg)	Average Percent Cost Increase	Median % Cost Increase
> 0	100	100.00	19.85	0.016	1,158	1.12
> 1	87	99.99	0.069	0.014	3.74	0.94
> 5	79	99.89	0.066	0.012	3.55	0.85
> 10	66	99.41	0.020	0.009	1.35	0.71

Table 6-8. Control Options For Process Vents
Existing Sources

Option[a]	Emission Reduct. (Mg HAP per yr)	Percent HAP Reduct.[b]	Annual Cost ($1000)	Avg. Cost Effective-ness ($/Mg)	Incremental Cost Effective-ness ($/Mg)
1	231,980	93	51,032	220	
2	233,556	93	53,882	231	1,808
3	235,115	94	57,701	245	2,450
4	236,186	94	61,868	262	3,891
5	236,790	94	65,406	276	5,858
6	237,047	95	67,601	285	8,546
7	237,401	95	73,198	308	15,800
8	237,601	95	92,614	390	97,153

[a]Option 1 - (MACT floor) control vents with cost effectiveness < $1,500/Mg.

Option 2- control vents with cost effectiveness < $2,000/Mg. This was the regulatory option chosen.

Option 3- control vents with cost effectiveness < $3,000/Mg.

Option 4- control vents with cost effectiveness < $5,000/Mg.

Option 5- control vents with cost effectiveness < $7,500/Mg.

Option 6- control vents with cost effectiveness <$10,000/Mg.

Option 7- control vents with cost effectiveness <$28,000/Mg.

Option 8- control all vents with any HAP's (i.e., TIC).

[b]Baseline emissions are 250,664 Mg/yr of HAP.

Table 6-9. Control Options For Process Vents
New Sources

Option[a]	Emission Reduct. (Mg HAP per yr)	Percent HAP Reduct.[b]	Annual Cost ($1000)	Avg. Cost Effective-ness ($/Mg)	Incremental Cost Effective-ness ($/Mg)
1	45,046	95	15,206	338	
2	45,106	95	16,199	359	16,550
3	45,132	95	17,745	393	59,452
4	45,144	95	20,203	448	205,528

[a]Option 1- (MACT floor) control vents with cost effectiveness <$11,000/Mg. This was the regulatory option chosen.

Option 2- control vents with cost effectiveness <$28,000/Mg.

Option 3- control vents with cost effectiveness <$100,000/Mg.

Option 4- control all vents with any HAP's.

[b]Baseline emissions are 47,626 Mg/yr of HAP.

Table 6-10. Control Options For Wastewater Existing Sources

Option[a]	Emission Reduct. (Mg HAP per yr)	Percent HAP Reduct.[b]	Annual Cost ($1000)	Avg. Cost Effective-ness ($/Mg)	Incremental Cost Effective-ness ($/Mg)
1	82,100	73	23,900	291	
2	82,200	73	24,500	298	5,126
3	82,800	74	25,700	310	1,968
4	85,300	76	34,300	402	3,500
5	85,700	77	37,900	442	7,644
6	85,800	77	38,900	453	19,890
7	85,700	77	37,900	442	15,002

[a]MACT floor is no control.

Option 1 - control streams > 10 lpm and > 1000 ppmw volatile HAP's. This was the regulatory option chosen.

Option 2- control streams > 5 lpm and > 1000 ppmw volatile HAP's.

Option 3- control streams > 5 lpm and > 800 ppmw volatile HAP's.

Option 4- control streams > 2 lpm and > 500 ppmw volative HAP's.

Option 5- control streams > 1 lpm and > 200 ppmw volative HAP's.

Option 6- control streams > 1 lpm and > 100 ppmw volative HAP's.

Option 7- control all streams with any HAP's (i.e., TIC).

[b]Baseline emissions are 111,984 Mg/yr of HAP.

Table 6-11. Control Options For Wastewater New Sources

Option[a]	Emission Reduct. (Mg HAP per yr)	Percent HAP Reduct.[b]	Annual Cost ($1000)	Avg. Cost Effective-ness ($/Mg)	Incremental Cost Effective-ness ($/Mg)
1	17,790	64	6,400	360	
2	24,170	87	16,500	685	1,595
3	24,270	88	17,200	710	6,990
4	24,595	89	33,700	1,370	49,980

[a]Option 1 - (MACT floor) control streams > 10 lpm and > 1000 ppmv volatile HAP's. This was the regulatory option chosen.

Option 2- control streams > 1 lpm and > 10 ppmw highly volatile HAP's; other streams > 1 lpm and > 800 ppmw volatile HAP's.

Option 3- control streams > 1 lpm and > 10 ppmw highly volatile HAP's; other streams > 1 lpm and > 500 ppmw volatile HAP's.

Option 4- control streams > 1 lpm and > 10 ppmw highly volatile HAP's; other streams > 1 lpm and > 200 ppmw volatile HAP's.

Option 5- control all streams with any HAP's (i.e., TIC).

[b]Baseline emissions are 21,277 Mg/yr of HAP.

Table 6-12. Control Options For Transfer Existing Sources

Option[a]	Emission Reduct. (Mg HAP per yr)	Percent HAP Reduct.[b]	Annual Cost ($1000)	Avg. Cost Effective-ness ($/Mg)	Incremental Cost Effective-ness ($/Mg)
1	360	65	3,128	8,690	
2	424	77	6,521	15,416	53,860

[a]Option 1 - (MACT floor) control racks loading liquid HAP's with vapor pressure > 10.3 kPa (1.5 psia) and throughput > 643.5 m^3/yr (0.17 million gallons per year). This was the regulatory option chosen.

Option 2- control all racks loading liquid HAP's (i.e., TIC).

[b]Baseline emissions are 551 Mg HAP/yr.

Table 6-13. Control Options For Transfer Operations New Sources

Option[a]	Emission Reduct. (Mg HAP per yr)	Percent HAP Reduct.[b]	Annual Cost ($1000)	Avg. Cost Effective-ness ($/Mg)	Incremental Cost Effective-ness ($/Mg)
1	68	65	594	8,690	
2	81	77	1,239	15,420	53,860

[a]Option 1 - (MACT floor) control racks loading liquid HAP's with vapor pressure > 10.3 kPa (1.5 psia) and throughput > 643.5 m^3/yr (0.17 million gallons per year). This was the regulatory option chosen.

Option 2- control all racks loading liquid HAP's (i.e., TIC).

[b]Baseline emissions are 105 Mg HAP/yr.

Table 6-14. Control Options For Storage Vessels: Existing Sources 10,000 to 20,000 Gallon Capacity

Option[a]	Emission Reduct. (Mg HAP per yr)	Percent HAP Reduct.[b]	Annual Cost ($1000)	Avg. Cost Effective-ness ($/Mg)	Incremental Cost Effective-ness ($/Mg)
1	53	14	318	6,000	
2	322	85	7,736	23,950	27,474
3	359	95	18,949	52,780	311,500

[a]MACT floor is no control. The MACT floor was the regulatory option chosen.

Option 1 - control tanks storing HAP's with vapor pressure > 60.1 kPa (11.1 psia).

Option 2- control tanks storing HAP's with vapor pressure > 13.1 kPa (1.9 psia).

Option 3- control all tanks storing HAP's (i.e., TIC).

[b]Baseline emissions are 379 Mg/yr of HAP.

Table 6-21. National Control Cost Impacts In The Fifth Year[a]

Emission Source Type and Other Cost Categories	Total Capital Cost (10^6 $)	Total Annual Cost (10^6 $)	Average HAP Cost Effectiveness ($/Mg HAP)[b]	Average VOC Cost Effectiveness ($/Mg VOC)
Equipment Leaks	110	(1)	(20)	(10)
Process Vents	92	75	260	160
Storage Vessels	49	19	3,400	3,400
Wastewater Collection and Treatment	86	35	280	80
Transfer Operations	10	5	10,000	10,000
Monitoring, Recordkeeping and Reporting	N/A	48	N/C	N/C
Total	347	182	280	140

[a]Existing emission points account for 84 percent of the total. Emission points constructed or modified in the first five years account for the additional 16 percent.

[b]Average cost effectiveness values are determined by dividing total annual costs by total annual emission reduction.

N/A = Not Available

N/C = Not Calculated

CHAPTER 7

ECONOMIC IMPACT ANALYSIS

7.1 Industry Profile

7.1.1 Introduction

It is necessary to define the affected industry before beginning an economic analysis.[1] In the subsections below, a brief synopsis of the U.S. synthetic organic chemicals industry is presented. The purpose of the profile is to identify factors and trends likely to influence the nature and magnitude of the economic impacts of the HON, which will involve the regulation of approximately 450 synthetic organic chemicals. Due to the large number and diversity of chemicals that will be regulated under the HON, the scope of the profile is broad. Recent trends (up to 1989) in the synthetic organic chemicals industry are covered. Topics covered include industry structure, production trends, supply, demand, end uses, foreign trade, pricing, and profitability.

It should be noted that the U.S. International Trade Commission defines synthetic organic chemicals to include intermediate and end-use organic chemicals.[2] For this report, however, the synthetic organic chemicals industry will be taken to include all organic chemicals. This definition reflects the interdependence of organic chemicals in processes. This is also consistent with definitions EPA has used in previous studies.

Upon examination of the synthetic organic chemicals industry, one characteristic that is quickly evident is its diversity. More than 7,000 chemicals are produced by this industry for varied uses such as packaging, consumer products, automotive products, housing and construction, pharmaceuticals, and agriculture.[3] And in all, there are nearly 1,500 firms in the U.S. that produce chemicals and similar products.[4]

Complexity is also a characteristic of the synthetic organic chemicals industry. Many synthetic organic chemicals are produced as coproducts of other chemicals, and can be produced by more than one process. With more than one process route possible, process substitution can occur given price changes and technical considerations. Some chemical industries have the ability to switch between different types of feedstocks. One example is the U.S. petrochemical industry. Two-thirds of its capacity has the capability to switch back and forth between heavy liquids (e.g. petroleum)-based feedstocks and natural gas liquids-based feedstocks.[5] Due to the interdependence of many synthetic organic chemicals, many producers of synthetic organic chemicals are horizontally and/or vertically integrated.

The degree of both types of integration increased in the late 1980s. It came in the form of acquisitions, spin-offs, plant closings, and early retirement and layoff programs. An example of this is the styrene-butadiene industry, which in 1984 had 13 firms operating 24 plants. By 1989, the same industry contained five firms operating six plants.[7] Takeovers have decreased due to high levels of debt among chemical companies and the demise of the junk bond market.

Most plants producing synthetic organic chemicals are located in five states: Texas, Louisiana, New Jersey, Ohio, and Illinois, with Texas containing the most plants. Plant capacities for this industry vary widely, from under 500 kg per year to over 2,000 Gg.[8] Generally speaking, basic and intermediate chemicals are produced in larger volumes than end-use chemicals, which means that plants producing basic and intermediate chemicals normally have larger capacities than end-use chemical plants.

Included among selected Census data for eight four-digit SIC categories that can be considered to comprise the synthetic organic chemical industry (see Table 7-1)[9] is data giving an indication of the incidence of small facilities in the industry. In every category but SIC 2824 (Manmade Organic Fibers, except Cellulosic), establishments with fewer than 20 employees account for one-third or more of all establishments. The highest proportion is in SIC 2833 (Medicinal Chemicals and Botanical Products), in which 62.7 percent of all establishments have fewer than 20 employees. SIC 2824 has the highest incidence of establishments with 100 or more employees, at 72.2 percent. Table 5 shows the value distribution of shipments by establishment size. Due to their small size, establishments with less than 20 employees account in all cases for a lower share of the total value of shipments than of the total number of establishments. In every four-digit code other than SIC 2891 (Adhesives and Sealants), establishments with 100 or more employees contribute more than 50 percent of total value of shipments, ranging up to 99.1 percent for SIC 2824. The highest contribution to total value of shipments by establishments with fewer than 20 employees is 15.3 percent in SIC 2891.

7.1.2 Production, Shipments, and Capacity Utilization

From production and sales data compiled by the U.S. International Trade Commission (ITC) in 1987 and 1988 for synthetic organic chemicals and their raw materials (basic organics), there is presented information for 13 major categories of synthetic organic chemicals--based principally on end use--and two categories of basic organics. Total production of organic chemicals in 1988 was 387,659 pounds (176,209 kilograms). It should be noted, however, that the ITC data reflect duplication because production and sales of some chemicals are measured at

more than one stage of the manufacturing process. For example, intermediates will be double-counted if production and sales of the finished chemicals in which they are consumed are also reported. Nevertheless, the data give a good indication of the comparative sizes of the various different major categories of synthetic organic chemicals. In each category, quantity sold is less than quantity produced because a portion of output is consumed captively. This is particularly true in categories such as "primary products from petroleum and natural gas" and "cyclic intermediates"-- where the products are generally intended for further processing downstream. Due to some definitional changes, the data for 1987 and 1988 are not strictly comparable.[10]

As for the whole chemical industry, including allied products -- SIC 28 -- increased by 2 percent from 1989 to 1990.[11] This followed higher increases of 2.9 percent in 1989 and 5.4 percent in 1988. Output of industrial organic chemicals, however, fell 2 percent from 1989 to 1990, a sharp departure from the increase of 5.9 percent occurring from 1988 to 1989. While production in SIC 28 has closely followed total manufacturing output since 1985, output in SIC 28 has increased only 20 percent since 1980, total manufacturing output has increased by 39 percent in the same period. There was an overall increase of 8 percent in production of plastics from 1989 to 1990, a reversal from the decrease of 2 percent recorded from 1988 to 1989. This increase partially explains the increase in output in 1990 of two important plastics feedstocks: ethylene and propylene. In 1990, ethylene production increased by 7 percent, and propylene production by 8 percent.

An examination of selected SIC groupings that include synthetic organic chemicals reveals that the value of shipments in SIC 28 was $274.5 billion in 1989.[12] In the SICs defined by the Commerce Department to represent the petrochemicals industry, value of shipments was $123.6 billion, about one-half of which was contributed by SICs 2865 and 2869. Because of an increase in the price level, growth in constant-dollar value of shipments has been less than growth in current-dollar value of shipments. Constant-dollar value of shipments is usually a good proxy for the physical volume of shipments. An increase in the constant-dollar value of shipments from 1988 to 1989, despite a decline in production, is most likely due to draw downs in inventories, causing shipments to exceed production. It also is partially explained by a change in product mix, particularly an increase in the average quality of shipments, which would be reflected in an increase in shipment value, but not a price adjustment.

Table 7-1

SIC Codes for the SOCMI

SIC Code	Industry
2821	Plastics Materials, Synthetic Resins, and Nonvulcanizable Rubber
2822	Synthetic Rubber
2824	Manmade Organic Fibers, Except Cellulosic
2833	Medicinal Chemicals and Botanical Products
2843	Surface Active Agents, Finishing Agents, Sulfonated Oils, and Assistants
2865	Cyclic Organic Crudes and Intermediates, and Organic Dyes and Pigments
2869	Industrial Organic Chemicals, N.E.C.
2891	Adhesives and Sealants

Average capacity utilization in the chemical industry increased to a peak in January, 1989 of 89.3 percent, its highest level since 1951.[13] Production of some chemicals, particularly plastics, were running at nearly 100 percent of capacity. By the end of the year, however, capacity utilization dropped to 87.0 percent.[14]

7.1.3 Demand and End-use Markets

Demand for synthetic organic chemicals leveled off in 1990 after a continuous increase from the mid- to late- 1980s. Weak markets for automotive products and housing were to blame. Production of motor vehicles declined 4 percent in 1989 to the lowest level since 1983.[15] In the first five months of 1990, motor vehicle output was down 20 percent from the same period in 1989. In addition, new housing starts in 1989 were at the lowest level since 1982, falling 7 percent from 1988.[16] The decrease in domestic demand was offset only partially by strong export demand. Demand in 1989 did not decline as much as production, however, since demand was met by a reduction in inventory. An inventory build-up in the previous year in anticipation of supply shortages was relieved by the end of 1989,[17] and it has been predicted that "production of synthetics should better than match final demand in 1990."[18]

The demand for two groups of chemicals, polymers and specialty chemicals, have outpaced demand for chemicals as a whole in the 1980s. The reasons for the high demand for polymers was the stronger consumer markets in synthetic products used as end products.[19] There was growth in the amount of polymers used in packaging for consumer products, and the use of polymers in housing and consumption. They also achieved some of their growth in the 1980s by replacing such natural materials as wood, metals, glass, and paper. Reasons for the increased demand for specialty chemicals include increasing use of specialty polymers, refinery chemicals, adhesives, water treatment chemicals, lubricant additives, and industrial coatings.

There is an unpublished demand elasticity estimate for chemicals and allied products of -0.7 to -0.9, which is cited in a U.S. International Trade Commission document in April 1983.[20] According to this estimate, the demand for chemicals is in general relatively inelastic. This is consistent with the notion that most chemicals are producer goods that are needed as inputs by other producers -- both other producers in the chemical industry (it is true that the largest market for chemicals is the chemical industry itself) and producers in other industries. It should be noted that the elasticity of demand for chemicals must be evaluated on a case-by-case basis. Demand could be relatively elastic if a substitute is readily available at comparable cost. For example, synthetic materials face competition from such natural materials as wood, metals, paper, and glass. Another

example comes from a trade journal article. In reference to the surfactants business, the article states that "intermediates producers don't always have the luxury of passing cost hikes along to customers ... because of the pressures of potential substitutions ..."[21]

7.1.4 Foreign Trade

The chemical industry is the leading export industry in the U.S. Exports in SIC 28, Chemicals and Allied Products, amounted to $38.0 billion in 1989, and the trade balance was +14.8 billion dollars. The trade surplus for SIC 28 has increased 54.7 percent since 1987, based on impressive export growth of 42.4 percent that exceeded import growth of 35.6 percent. In 1989, the only two four-digit SIC codes within SIC 28 with trade deficits were SIC 2843, Surface Active Agents (-$10 million), and SIC 2833, Medicinals and Botanicals ($-886 million).[22] The major reasons for the improvement in the balance of trade are the decline in the value of the dollar, which made U.S.-produced chemicals less expensive relative to foreign chemicals; and cost-cutting by U.S. industry in the early 1980s, which improved the competitiveness of the industry.[23]

Plastics, resins and organic chemicals lead the way in U.S. foreign trade statistics, accounting for 54 percent of all exports and 55 percent of the total trade surplus. The U.S. also accounts for 13.2 percent of world exports and 7.6 percent of world imports. The U.S. ranks second behind Germany in three major measures of world trade: exports, imports, and the balance of trade.

7.1.5 Pricing

Prices of chemicals and related products recorded their biggest gains in 1988 and 1989 since 1981.[24] The 5.8 percent increase in 1989 masks a decline in prices that began in the middle of the year, however. The Producer Price Index (computed by the U.S. Department of Labor) peaked in April and May of 1989, and by December had fallen 3.1 percent. Still, prices were 7.2 percent higher than in January, 1988. The decline in prices in the second half of 1989 can be attributed to lower demand and capacity increases. The fall in prices was most pronounced for organic chemicals and plastics materials.[25]

The price decreases in the second half of 1989 occurred despite increases in labor and raw materials costs. This suggests that it may not be possible to recover cost increases by increasing prices if demand conditions do not permit. In general, it is likely that producers of end-use chemicals have more pricing flexibility than producers of basic and intermediate chemicals. It should be noted, however, that this does not mean end-use chemical producers have sufficient pricing flexibility to

recover cost increases for production inputs to a great extent. Basic and intermediate chemicals are essentially commodity products, produced to standard specifications with little or no product differentiation. There are usually a large number of producers as well. For example, in the U.S., basic chemicals are produced on average by 25 different producers.[26] These two factors could inhibit pricing flexibility. End-use chemicals are generally produced in smaller volumes and produced to perform a specific function and are more differentiated than basic and intermediate chemicals. Consequently, their producers are likely to have some pricing discretion.

7.1.6 Financial Profile

Profitability in the U.S. chemical industry turned down during the middle of 1989, but the year was still a profitable one for U.S. chemical companies. Thirty companies sampled in 1989 had an average after-tax profit margin of 8.6 percent, a higher margin than in any other year in the 1980s except 1988.[27]

Total capital spending in 1990 was $20.54 billion, up 11.2 percent from the year before. The average annual rate of increase from 1980 to 1989 was 6.4 percent. Capital spending is forecast to reach $21.63 billion for 1991.

From a sample of 19 chemical companies with sales over $1 billion in 1989, Chemical & Engineering News calculated that the median ratio of long-term debt to total capitalization (or long-term debt plus equity) in 1989 was 32.6 percent, the median ratio of capital spending to sales was 9.0 percent, and the median ratio of R&D spending to sales was 2.7 percent.[28] In comparison with a sample of 17 chemical companies with sales below $1 billion, the companies in the former sample tend to devote a greater portion of their budgets to capital spending and R&D spending. Also, large companies are more highly leveraged. The average ratio of debt to total capitalization in SIC 28 (mentioned above) in 1989 was 33.5 percent, the highest figure in that decade. This is lower, however, than the average ratio for all manufacturing, 37.2 percent.[29] The major reason for the increase in the ratio is that many acquisitions were financed by debt.

7.2 Studies of Twenty Selected Chemicals

7.2.1 Selection Rationale

For purposes of analyzing the SOCMI, chemical trees have been constructed for chemical compounds regulated by the HON, which identify the various routes by which a particular chemical is produced. (See Chapter 6 for a discussion of chemical trees.) Of these approximately 450 chemicals, 20 have been chosen for detailed analysis, all of which are subject to HON controls.

Selecting chemicals for analysis is an important process, geared towards adequately representing the SOCMI.

Relevant data for the SOCMI are, in general, limited. Accurate judgements of economic impacts hinge on the ability to assemble comprehensive profiles, detailing key market characteristics for each chemical, including pricing and output and trends, market structure variables, and overseas competition. Thus, the first factor governing sample selection is the availability of information. One of the implications of this limitation is that information is available primarily for those chemicals which are commercially important. These chemicals tend to have large production volumes. Therefore, from the outset the sample is biased towards large-volume chemicals.

An initial list of potential candidates was formed based on a preliminary search of available market information. This search resulted in an inventory of approximately 60 compounds subject to HON regulations. From this initial list, more complete literature searches were performed.[30]

Once precursory information files were assembled for this subset of synthetic organic chemicals, rankings were assigned so that the list could be paired down. Three factors were considered central as determinants of rank. (1) Compliance cost distribution -- efforts were made to cover regulated chemicals from the low end to the high end of the compliance-cost spectrum. (2) Production volume distribution -- in order to accurately represent the SOCMI, the range of production levels in the industry as a whole should, ideally, be mirrored in the selected chemicals. (3) Feedstocks -- synthetic organic chemicals are produced from eight basic feedstock chemicals. Each of these eight feedstocks, should, ideally, be represented.

7.2.1.1 HON Compliance Costs

Compliance costs were calculated for model plants in the SOCMI.[31] In some instances, chemical manufacturers are already in compliance, and are not subject to controls. In other cases, cost increases can be in excess of 100 percent of market price. Since costs vary widely, an attempt was made to cover the gamut of costs. In addition, a particular effort was made to ensure coverage of chemicals with relatively high compliance costs. Biasing the selection in favor of high cost chemicals is justifiable, since these are the chemicals where impacts are likely to be most severe.

7.2.1.2 Volume of Production

The volume of production is calculated for each of the compounds. Annual output levels range from less than ten

kilograms to greater than six billion kilograms. It is apparent that qualitative differences exist between chemical production, and are to some extent reflected in different levels of production. Styrene, for example, is the ninth largest synthetic organic chemical manufactured in the United States, with 1989 production in excess of 3.5 billion kilograms. Its market characteristics are likely to be different than those of hydroquinone, a specialty chemical with two U.S. manufacturers, and a 1989 output level of 10.9 million kilograms. For example, hydroquinone producers are apt to possess more pricing discretion than styrene producers, due to less competition and more specialized end-uses. On the other hand, styrene producers, because of their large size, are liable to realize economies of scale in unit compliance costs. It follows that economic impacts resulting from HON controls are likely to be different as well. Thus, when ranking chemicals, attention is paid to adequate coverage of the scope of production volumes in the SOCMI.

7.2.1.3 Basic Feedstock Chemicals

Synthetic organic chemicals are ultimately derived from eight basic feedstock chemicals, which serve as the building blocks for the SOCMI. They are: benzene, toluene, xylenes, methylene, naphthalene, ethylene, propylene, and butylenes. Each feedstock has different supply and demand conditions, as well as qualitative and quantitative differences in emissions. Thus, economic impacts will vary among chemicals derived from different feedstocks. Accordingly, consideration was paid to covering the range of feedstocks.

7.2.1.4 Selected Chemicals

Given the preceding factors, final selections were made based on the additional consideration of breadth of available market data. Chemical compounds which presented easy access to comprehensive information were given precedence, so as to convey up-to-date and accurate profiles and impacts. The sample of chemicals chosen, and their respective chapters in the economic impact analysis, is presented in Table 7-2.

7.2.2 Methodology for Selected Studies

This section presents a broad overview of the methodology employed for assessing the impact of HON controls. For a more detailed discussion the reader is directed to Appendix A of the HON Economic Impact Analysis.

An industry profile was assembled for each of the chemicals chosen for analysis. The purpose of the industry profile is to detail historical, current, and future market characteristics. 8Profiles introduce the chemicals, discuss and analyze supply and

demand conditions, and summarize and forecast trends into the mid-1990's.

This information forms the basis for the economic impact analysis.

7.2.2.1 The Model

A traditional supply and demand model, assuming a downward-sloping demand curve, is employed to evaluate the impact of HON controls. A demand curve with an exponential form is utilized:

$$Q = aP^{e}, \qquad (1)$$

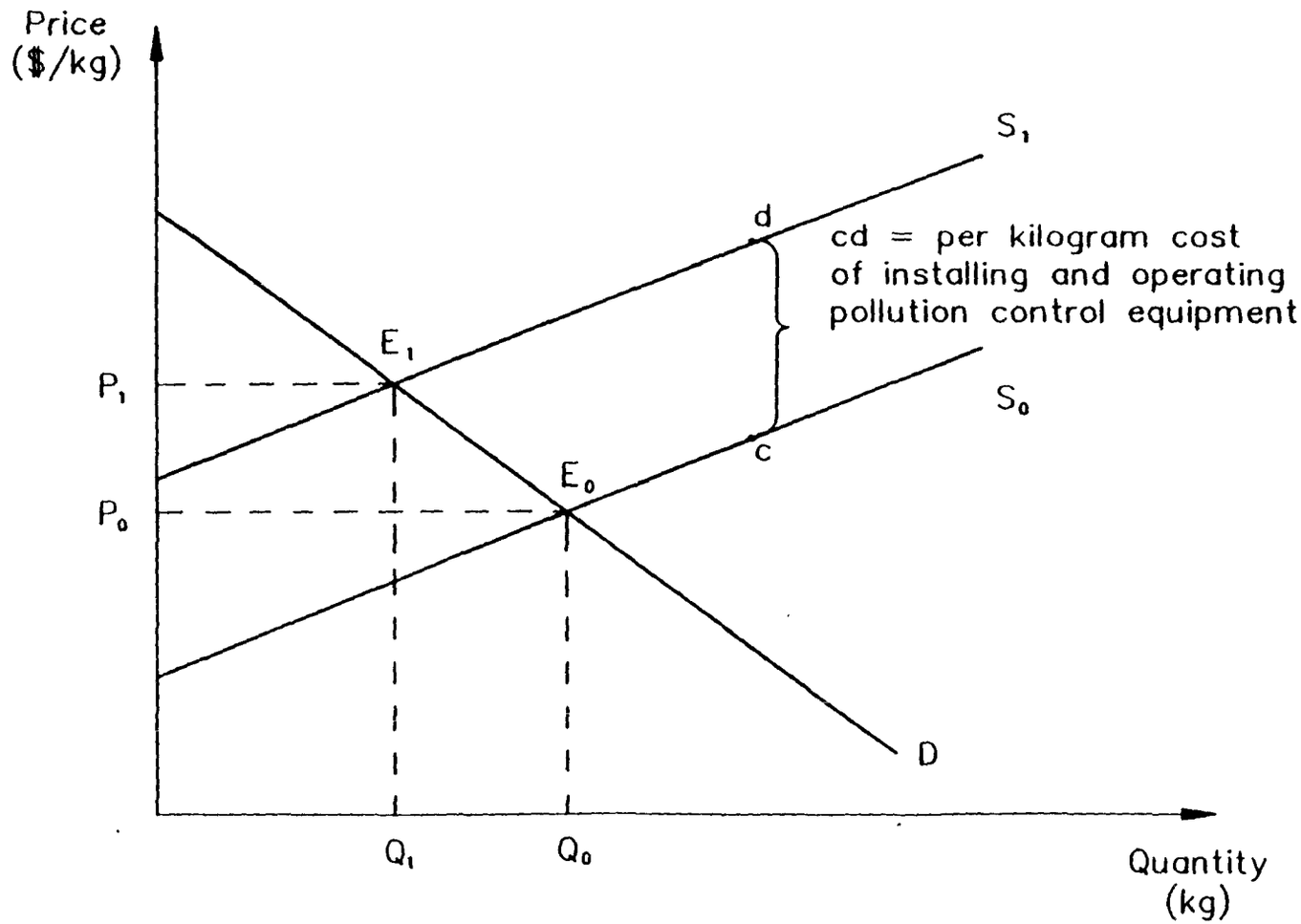
where P (market price in dollars) and Q (quantity in kilograms) are variables, and a and e are parameters, with e = price elasticity of demand.

A comparative statics approach is applied, comparing the equilibrium price and quantity before and after the assessment of control costs. Figure 7-1 illustrates the influence of control costs on chemical markets in the short run. The initial equilibrium point is at P_0 and Q_0. This point represents the baseline, which is where the market is situated at the time the regulation takes effect. Basically, the installation of pollution control equipment causes an increase in the cost of production, represented by a leftward shift of the industry supply curve, from S_0 to S_1. The vertical distance cd is equal to the annualized per-kilogram cost of installing and operating pollution control equipment. As shown, HON controls result in a market clearing price P_1 which is higher than in the baseline, and a market clearing quantity Q_1 which is lower than in the baseline.

Table 7-2. Sample Of Twenty SOCMI Chemicals

Chapter Number	Chemical
1	Butadiene
2	Polybutadiene
3	Styrene-Butadiene Rubber
4	Ethylene Dichloride
5	Ethylene Oxide
6	Cyclohexylamine
7	Hydroquinone
8	Ethylene Glycol
9	Styrene
10	Formaldehyde
11	Acetone
12	Chloroform
13	Triethylene Glycol
14	Bisphenol-A
15	Terephthalic Acid
16	Propylene Glycol
17	Methyl-Tertiary Butyl Ether
18	Phthalic Anhydride
19	Benzoic-Acid
20	Acrylonitrile

FIGURE 7-1. MARKET EFFECTS OF INSTALLING POLLUTION CONTROL EQUIPMENT



7.2.2.2 Compliance Costs

Compliance costs have been provided for the total industry control option. TIC costs represent are the maximum HON control costs that an industry will incur.

Calculating HON compliance costs (CC) per unit of output essentially involves four steps. (1) Fixed and variable CC are identified for each emissions source in each facility. Fixed costs are constant over all levels of output of a process, and usually entail plant and equipment. Variable costs will vary as the rate of output changes. (2) Last Link and raw material CC are accumulated. In this analysis, last-link CC are those costs (fixed and variable) which are attributed to only the last step in the process chain. Raw-material CC are those costs (fixed and variable) that have accumulated in all steps prior to the last-link. (3) As the equilibrium analysis discussed above takes place at the market or industry level, a meaningful notion of average industry CC is developed. Since different facilities have different CC, it seems reasonable to "weight" these different costs by the share of total industry output that they are attributable to. Industry CC (ICC) can be written:

$$ICC = \sum_{j=1}^{J} [CC_j (\frac{Q_j}{Q})], \qquad (2)$$

where there are J facilities, CC_j is the compliance cost of facility j, Q_j is output of facility j, Q is total industry output, $0 \leq Q_j/Q \leq 1$, and Q_j/Q are the weights, which sum to 1. (4) Overall industry CC is divided by total industry output to get the per-unit industry CC.

In some cases, chemicals are produced by more than one process, and cost differentials between processes are of interest. Calculating CC for each process is done in the same way as for each facility.

7.2.2.3 Pricing

Chemical prices have been provided, and are used in the baseline. Impacts are assessed using the 1989 average realized price. A brief examination of pricing is presented in each chapter for the chemicals that are analyzed. If the baseline price is lower than the 1989 price, the impacts based on the higher price will be understated.

7.2.2.4 Elasticities

The concept of elasticity is a general one, measuring the sensitivity of a dependent variable to a change in an independent variable, holding other variables constant. Elasticity coefficients (e) are broadly categorized into three ranges: (1) $0 < e < -1$ is considered inelastic; (2) $e = -1$ is unit elastic; and (3) $-1 < e < -\infty$ is elastic ($\infty \rightarrow$ infinity). The price elasticity of demand measures the percentage change in quantity demanded resulting from a percentage change in price. This is refferred to here as the demand elasticity. In this analysis, chemicals are factors of production. Demand for factors of production are said to be derived, i.e., the need for factors derives from the demand for the products which are produced by the factors. The major determinants of demand elasticity for factors are concisely defined by Alfred Marshall, and are known as Marshall's rules. Two of them are relevant to this analysis.[32] In the case of two factors,[33] the demand elasticity varies directly with the following:

-The demand elasticity for the product the factor produces. For example, the easy availability of close substitutes for styrene-butadiene rubber (i.e. relatively elastic demand) in the manufacture of automobile tires will flatten the demand curve for the factor butadiene, making demand more price elastic.

-The share of the factor in the cost of production. If a factor comprises a substantial share of the cost of production, an increase in its price contributes markedly to an increase in the product price. Hence, the proclivity for substitution.

In general, demand for factors tends to be inelastic in the short-run. This is due to the fact that firms are "locked into" a technology process, and speedy substitution is difficult.

The import elasticity of supply measures the percentage change in the quantity of imports supplied resulting from a percentage change in domestic price. The import elasticity of supply is referred to as the import elasticity.

Demand elasticities for each chemical are estimated on the basis of available substitutes for each chemical, substitutes for end-uses, and the cost share comprised by the chemical. No quantitative estimate of import elasticities is undertaken. If imports appear to be significant, the ability of domestic producers to raise prices without considerable loss in output will be hindered.

7.2.2.5 Estimating Market Adjustments

Once cost, price, and elasticity data are quantified, price and quantity adjustments can be estimated. Of particular interest is the maximum percentage price increase necessary to fully recover compliance costs. On a per-unit basis, the maximum percentage price increase is the annualized cumulative compliance cost per kilogram divided by revenue per kilogram (revenue per kilogram = price).

Quantity adjustments are calculated by solving the demand equation (equation 1) for the percentage change in quantity, given the baseline price and the estimated demand elasticity.

Impacts on total revenue (TR) and employment in the chemical industry are estimated as well.

7.2.2.6 Market Structure

Market structure has important implications for the size of the price increase that will occur as a result of HON controls. If the market is perfectly competitive, and a long-run horizontal market supply curve is assumed, the imposition of HON controls will shift up the supply curve from S_0 to S_1 by the amount of the per-unit compliance cost, as shown in Figure 7-2. Thus, the price increase is exactly equal to the cost increase, and firms do not absorb any of the cost increase. However, if the market is characterized by pure monopoly, some costs are absorbed. The demand curve faced by a pure monopolist is the same as the market demand curve, because the monopolist is the only producer. Since price is a declining function of output for the monopolist, the marginal revenue curve lies below the demand curve. Increasing output by one unit leads to a lower price not only for the one additional unit, but for all of the other units as well. A profit-maximizing monopolist prices its product on the demand curve vertically above where marginal revenue (MR) is equal to marginal cost. An upward shift of the monopolist's marginal cost (MC) curve resulting from HON controls is illustrated in Figure 7-3. Since the marginal revenue curve has a steeper slope than the demand curve, the price increase resulting from compliance costs is less than in the competitive case. The monopolist, therefore, absorbs some of the cost increase associated with HON compliance.

In actuality, the market structure probably lies somewhere between the two extremes of perfect competition and pure monopoly. In general, it can be said that if a market structure is not perfectly competitive, firms in the industry will absorb some portion of compliance costs, and raise prices less than they would in the perfectly competitive case.

FIGURE 7–2. MARKET EFFECTS OF HON CONTROLS ON A PERFECTLY COMPETITIVE MARKET

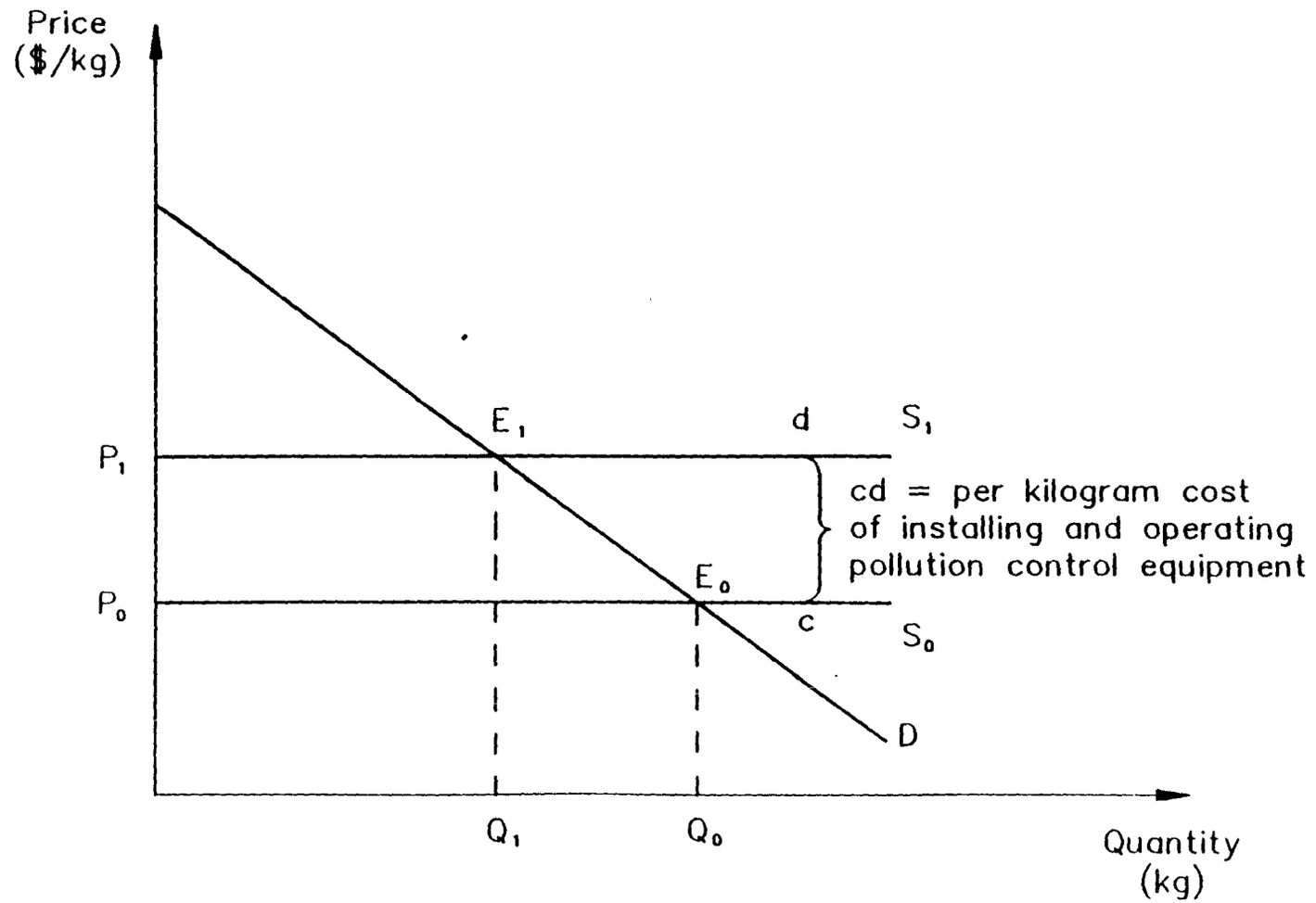
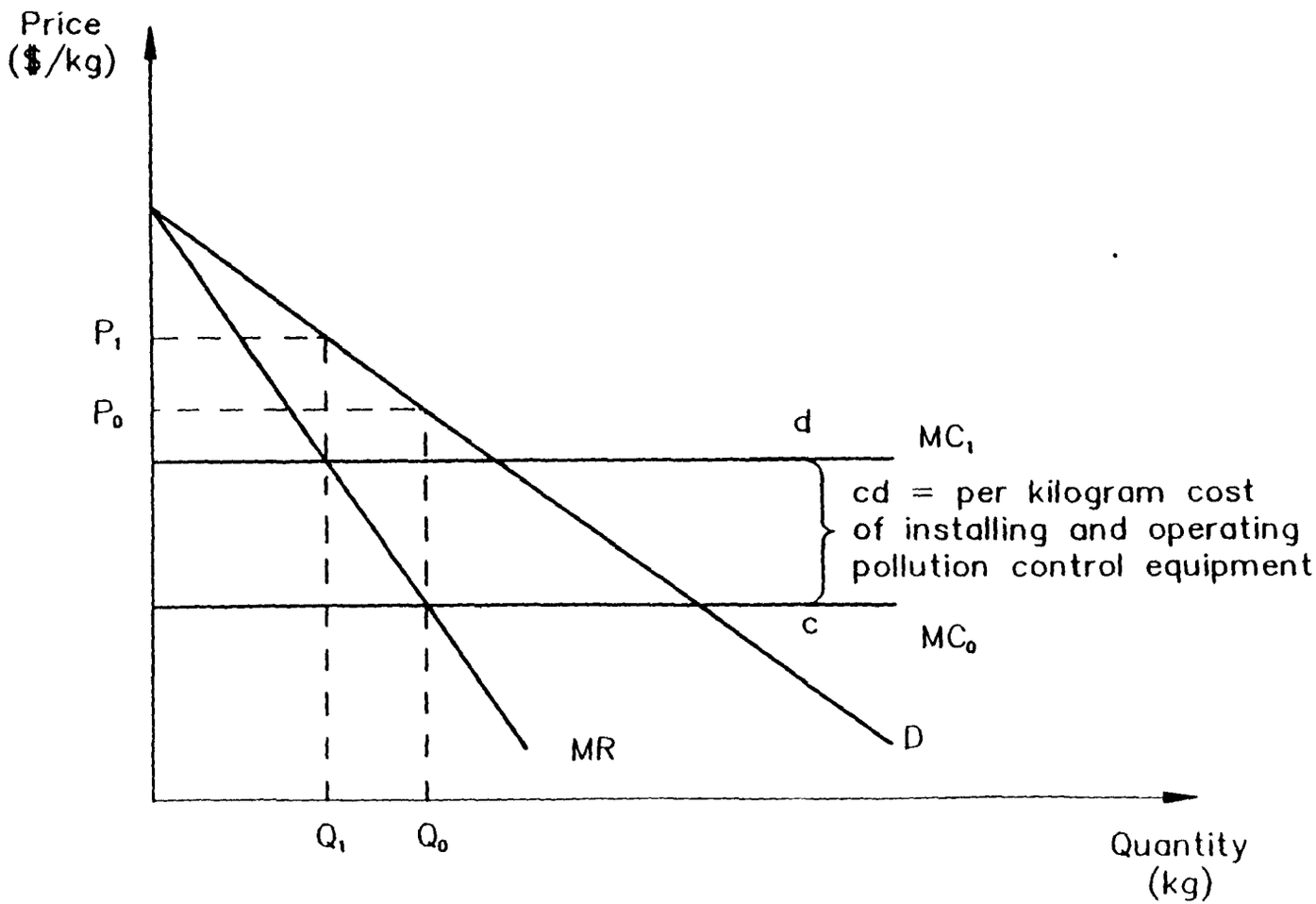


FIGURE 7–3. MARKET EFFECTS OF HON CONTROLS ON A PURE MONOPOLY



The extent of market power is based on the following factors:

- The number of firms: the larger the number of firms, the smaller the magnitude of market power, other things being equal.

- The importance of foreign competition: if a chemical is produced by overseas competitors, pricing discretion by domestic manufacturers is hindered, and market power is lessened.

- Vertical integration: for the majority of chemicals, data on captive consumption are available. Captive consumption suggests vertical integration, and enhances market power. In some cases, additional market information is available on vertical integration.

- Market concentration: two measures of market concentration are computed. (1) The four-firm concentration ratio measures the sum of the market shares of the top four firms in the industry. Studies have shown an upsurge in profitability as four firm concentration ratios exceed from 45 percent to 59 percent.[34] (2) The Herfindahl-Hirschman index (HHI) estimates industry concentration by emphasizing the firms with the largest market shares, and is estimated in the following way:

$$HHI = \sum_{t=1}^{T} S_t^2 \times 10,000 \qquad (3)$$

where there are T firms, S^t is the market share of the t^{th} firm. The HHI places the greatest weight on the largest firms by squaring the market shares. When the industry is a pure monopoly, the HHI = 10,000. If, on the other hand, 100 firms each control one percent of sales, then the HHI would be 100. Thus, the HHI declines as the number of firms in the industry rises or the firms become more unifrom in size. The Justice Department uses HHI to evaluate mergers, ignoring mergers where the resulting HHI is less than 1800. For this study, an HHI in excess of 1800 is regarded as an indication of significant market power.

The market structure section in the economic impact analysis utilizes these four factors to determine the extent of market power in the industry, and the influence of this power on the impact of HON controls.

7.2.3 Results of Studies

The economic impacts of HON controls on the SOCMI derive from three possible outcomes; the closure of a facility, a reduction in the level of output of a facility, and the substitution of one process for another. When discussing process substitution, the reference is to the substitution of less costly methods of producing chemical inputs. For example, a process might be altered if a chemical can be produced with raw materials that are not subject to the HON, thus realizing a cost advantage over the existing process.

Table 7-3 summarizes the market adjustments of the sample. The changes in the level of output are based on the upper bound of the estimated price elasticity of demand, which forecasts the maximum decline in output. It should be noted that the change in price is an increase, and the change in output is a decrease.

Table 7-4 summarizes the likelihood of closure and process substitution for the sample. Closure is possible for 30 percent of the sample. In only one case is closure probable. Process substitution is possible for 20 percent of the sample, and probable for one chemical.

It should be noted that the closure forecasts are extreme cases. Given the dynamic and flexible nature of the SOCMI, it is likely that the majority of these closures can be avoided. Also, since the majority of parent companies are very large, there appears to be the ability to sustain control costs without shutting down.

Table 7-3. Summary of Market Adjustments

Chemical Name (CAS Number)	Total Industry Control	
	% Δ Price[a]	% Δ Quantity[b]
Butadiene (106990)	0.97	(0.96)
Styrene-butadiene rubber (00043)	0.28	(0.28)
Polybutadiene (00045)	0.31	(0.31)
Ethylene Dichloride (107062)	1.24	(0.82)
Ethylene Oxide (75218)	0.65	(0.22)
Cyclohexylamine (108918)	2.01	(1.33)
Hydroquinone (123319)	0.97	(0.96)
Ethylene Glycol (107211)	0.94	(0.63)
Styrene (100425)	0.49	(0.48)
Formaldehyde (50000)	2.81	(1.84)
Acetone (67641)	1.07	(0.71)
Chloroform (67663)	2.87	(0.96)
Triethylene Glycol (112276)	0.55	(0.37)
Bisphenol-A (80057)	0.91	(0.61)
Terephthalic Acid (100210)	1.85	(1.22)
Propylene Glycol (57556)	0.75	(0.74)
Methyl tert-butyl Ether (1634044)	0.31	(0.10)
Phthalic Anhydride (85449)	4.84	(3.12)
Benzoic Acid (65850)		
Facility 1A	0.91	(0.90)
Facility 2A	1.45	(1.42)
Facility 3A	4.13	(3.96)
Acrylonitrile (107131)	0.92	(0.61)

[a]The percentage price increase is based on the production-weighted average compliance cost. (See Chapter 2 of the Economic Impact Analysis for methodology).

[b]The percentage change in quantity is based on the most elastic estimate of demand elasticity, which forecasts the higher percentage change in quantity.

Δ = Change in

Table 7-4. Likelihood Of Closure And Process Substitution Under TIC

Chemical Name	Likelihood Of Closure	Likelihood Of Process Subst.
Butadiene	Possible	Unlikely
Styrene-butadiene rubber	Unlikely	N.A.
Polybutadiene	Unlikely	N.A.
Ethylene Dichloride	Possible	N.A.
Ethylene Oxide	Unlikely	N.A.
Cyclohexylamine	Unlikely	Possible
Hydroquinone	Unlikely	Unlikely
Ethylene Glycol	Possible	N.A.
Styrene	Possible	Possible
Formaldehyde	Probable	Probable
Acetone	Possible	Possible
Chloroform	Possible	Unlikely
Triethylene Glycol	Unlikely	Unlikely
Bisphenol-A	Unlikely	N.A.
Terephthalic Acid	Possible	Unlikely
Propylene Glycol	Unlikely	N.A.
Methyl tert-butyl Ether	Unlikely	Unlikely
Phthalic Anhydride	Possible	Possible
Benzoic Acid	Unlikely	N.A.
Acrylonitrile	Unlikely	N.A.

N.A. - not applicable, since only one process is used.

7.3 Distribution of Cumulative Costs

This section examines the distribution of HON control costs. Costs have been compiled by the size of the cost as well as the volume of production. The reader is reminded that the low volume chemicals are not represented in the sample. Thus, comparisons of the sample HON control costs and the population HON control costs will be based only on those chemicals with annual production greater than 10 million kilograms. This includes 19 chemicals from the sample, and 330 chemicals from the population.

Table 7-5 presents the distribution of compliance costs under the TIC options. For the range of cost increases less than 2 percent, the correlation is the strongest. Sixty-eight percent of the population is included in this range, as compared with 85 percent of the sample. The cost range of 3 to 5 percent, which includes 23 percent of the population and only 10 percent of the sample is less strong. For costs greater than 5 percent, 17.6 percent of the population is included, and 5 percent of the sample is included. Of note is the fact that four categories are not represented in the sample. These four categories make up 10.8 percent of the population.

7.4 Implications for the Rest of the Affected Chemical Industry

Table 7-6 categorizes the sample chemicals in three ranges of percentage cost increase, and compares this to the number andpercentage of the population of chemicals that fall within the same range. Comparisons are based on the TIC option. The cost ranges are classified as low, intermediate, and high; less than 2 percent, 2 to 5 percent, and greater than 5 percent, respectively. If the sample is representative of the population, it follows that the results of the economic impact analyses can be extended to the rest of the affected chemical industry.

7.4.1 Low Cost Impacts

The low cost range includes 80 percent of the sample and 68 percent of the population. Since this range represents the majority, it is useful to try and extend the results of these impacts to the population. For the low cost chemicals in the sample, maximum quantity adjustments range from .10 percent to 1.22 percent of industry output. For six of these chemicals, the decline in output is less than 5 percent of the smallest size firm. For two others, it is less than 20 percent. In six cases, closure is possible, and in one, closure is probable.

Three of the low-cost chemicals are produced by more than one production process. For two of these, the cost differential is large enough to predict possible process changes.

One qualification is necessary: of those chemicals in the low cost range of the population, 21.8 percent have annual production of less than 10 million kilograms. All of the chemicals in the sample exceed this level of production for the low cost range. Thus, little can be said about the low volume chemicals in the population.

7.4.2 Intermediate Cost Impacts

The intermediate cost range includes 20 percent of the sample, and 14.5 percent of the population. Maximum quantity adjustments range from .96 percent to 3.96 percent of industry output. The decline in output ranges from 3.1 percent to 25 percent of the smallest size facility for the sample. Closure is possible for chloroform and phthalic anhydride, and unlikely for the other two chemicals. One important condition which mitigates against closure is that several chemicals are produced in the majority of facilities in this cost range. Chloroform facilities average nine chemicals each, which makes closure difficult to predict even though the decline in output is significant.

Two out of four of the intermediate-cost chemicals are produced by more than one process. In each case, the cost differential is large enough to predict process changes.

It is important to note that, of those chemicals in the intermediate cost range of the population, 38 percent have annual productions of less than 10 million kilograms. All of the sample chemicals in this range exceed this level of production. Thus, little can be said about the low volume chemicals in the population.

7.4.3 High Cost Chemicals

No chemicals in the sample are high-cost, and so no conclusions can be drawn for this range.

Table 7-5. Distribution of HON Chemicals By Percentage Cost Increase And Annual Production (10^6 kg): TIC Option

% Change In Cost[a]	The Population Chemicals Number	% Of Total	Distribution By Annual Production (10^6 kg) <1	1-5	5-10	>10
Less than 1.00	237	48.4%	20	9	10	198
1.00 - 2.00	96	19.6%	0	1	20	75
2.00-3.00	48	9.8%	0	0	13	35
3.00-4.00	16	3.3%	0	3	6	7
4.00-5.00	7	1.4%	0	3	2	2
5.00-7.00	11	2.2%	0	3	4	4
7.00-10.00	19	3.9%	3	8	4	4
Greater than 10.00	56	11.5%	41	6	4	5
Total	490	100.0%	64	33	63	330
% Of Total	100%		13.1%	6.7%	12.9%	67.3%

% Change In Cost[a]	The Sample Chemicals Number	% Of Total	Distribution By Annual Production (10^6 kg) <1	1-5	5-10	>10
Less than 1.00	11	55%	0	0	0	11
1.00 - 2.00	6	30%	0	0	1	5
2.00-3.00	2	10%	0	0	0	2
3.00-4.00	0	0%	0	0	0	0
4.00-5.00	0	0%	0	0	0	0
5.00-7.00	0	0%	0	0	0	0
7.00-10.00	1	5%	0	0	0	1
Greater than 10.00	0	0%	0	0	0	0
Total	20	100%	0	0	1	19
% Of Total	100%		0%	0%	5%	95%

[a]Cost increase based on control costs at the 50th percentile of industry output.

Table 7-6. Summary of HON Control Costs For Sample Chemicals And Percentage of Total HON Chemicals In The Same Cost Range[a]

Cost Range/ Chemical Name	Percentage Cost Increase Total Industry Control	Number (Percentage) Of Total HON Chemicals In Same Range
High Cost: Over 5 Percent		86 (17.5%)
None		
Intermediate Cost: 2 to 5 Percent		71 (14.5%)
Phthalic Anhydride	4.84%	
Benzoic Acid 3	4.13%	
Chloroform	2.87%	
Formaldehyde	2.81%	
Cyclohexylamine	2.01%	
Low Cost: Below 2 Percent		333 (68%)
Terephthalic Acid	1.85%	
Benzoic Acid 2	1.45%	
Ethylene Dichloride	1.24%	
Acetone	1.07%	
Butadiene	0.97%	
Hydroquinone	0.96%	
Ethylene Glycol	0.94%	
Acrylonitrile	0.92%	
Bisphenol-A	0.91%	
Benzoic Acid 1	0.91%	
Propylene Glycol	0.75%	
Ethylene Oxide	0.65%	
Triethylene Glycol	0.55%	
Styrene	0.49%	
Polybutadiene	0.31%	
Methyl tert-Butyl Ether	0.31%	
Styrene-butadiene rubber	0.28%	

[a]The range of percentage cost increases is based on total industry control costs.

7.5 Small Business Impacts

The RFA (Public Law (96-354, September 19, 1980) requires Federal agencies to give special consideration to the impact of regulation on small businesses.

The RFA specifies that a regulatory flexibility analysis must be prepared if a proposed regulation will have (1) a significant economic impact on (2) a substantial number of (3) small entities. (It should be noted that new RFA guidance was provided on April 9, 1992; however, the SAN for the HON was filed before the date, thus leaving the HON subject to the old RFA guidance). Regulatory impacts are considered significant if:

- Annual compliance costs increase total costs of production by more than 5 percent,
- Annual compliance costs exceed 10 percent of profits for small entities,
- Capital cost of compliance represent a significant portion of capital available to small entities,
- The requirements of the regulation are likely to result in closures of small entities.

A "substantial number" of small entities is generally considered to be more than 20 percent of the small entities in the affected industry.

A first step in determining small business impacts is assigning an appropriate definition for what constitutes a small entity in the SOCMI. The Small Business Administration (SBA) defines small businesses in the chemical industry as having employment from under 500 to under 1,000, depending on the SIC.[35]

There is reason to believe that this employment cut-off is too high. Firms in the SOCMI tend to be capital-intensive, and large amounts of revenue are generated with a limited labor force. The 1987 census of manufacturers provides data on employment and revenue for the affected SIC categories. From this data, is estimated that each employee, on average, accounts for $367,000 in total sales. Using this relation, an average firm with 500 employees will generate sales of $183.5 million. This doesn't seem "small." A company employing 100 will generate sales of $36.7 million, which might be considered small. Therefore, it is offered here that an appropriate employment cut-off for a small business in the SOCMI is 100.

Table 7-7 lists 1990 sales and employment figures for those companies in the SOCMI which produce the 20 chemicals selected for the HON analysis. This is a comprehensive list of sample chemical producers, totaling 66 companies. Data was compiled from a collection of 1991 annual reports, the 1991 Million Dollar

Directory, and Standard and Poor's Register of Corporations, Directors, and Executives.

As shown, 2 of the 66 companies falls below the 100 employee cut-off. One of these -- Diamond-Shamrock -- has 1990 sales in excess of $1 billion, and so cannot be considered a small entity. Spurlock, however, does indeed appear to be small given our definition. Thus, given this sample, only one firm in 66, or 1.5 percent, of the SOCMI can be classified as small. Thus, even if this firm experiences significant impacts, it seems difficult to argue that only one firm is a substantial number.

The 1988 Handbook of Small Business Data, which provides information on the nature of businesses which typify different SIC categories, supports this assertion. Each of the SIC categories affected by the HON are listed as "Large-Business-Dominated." This classification is based on the more conservative definition of small entities that the SBA uses. Thus, it is argued here that a substantial number of small entities will not be impacted, and that an RFA is therefore unnecessary.

Table 7-7. 1990 Sales And Employment of Selected SOCMI Members

Company	Sales (10^6)	Number of Employees
Air Products	2,895	14,000
Allied Signal	12,343	105,800
American Cyanamid	4,574	32,012
American Petrofina	3,978	3,997
American Synthetic Rubber Corp.	93	311
American Synpol	N.A.	2,600
AMOCO	31,581	54,524
ARCO	18,808	27,300
Ashland Oil, Inc.	8,994	33,400
Atlantic Richfield	1,590	26,600
BASF	4,023	133,759
B.F. Goodrich	2,470	11,892
Borden	7,633	46,300
British Petroleum	33,039 (£ mil.)	118,050
BTL Specialty Resins Corp.	64	200
Champlin Refining	974	800
Chevron	41,540	54,208
Citgo	4,940	3,300
Conoco	12,330	19,000
Copolymer Rubber and Chemical	250	710
Deltech	20	200
Diamond-Shamrock	1,118	84
Dow	19,773	62,100
DuPont	40,028	
Eastman-Kodak	18,908	134,450
Exxon	115,794	104,000
Firestone	3,867	53,500

Company	Sales (10^6)	Number of Employees
Formosa Plastics	625	1,700
GE	55,300	292,000
General Tire	1,300	9,600
Georgia Gulf	1,110	1,350
Georgia Pacific	12,665	63,000
Goodyear	11,273	107,671
Hanlin Group	1,110	1,350
Hercules	3,200	19,867
Hill Petroleum	4	1,070
Hoechst Celanese	1,500	2,400
Kalama	N.A.	N.A.
Koppers	426	1,900
Marathon (USX)	20,659	51,523
Mobil	64,472	67,300
Monsanto	8,995	41,081
Mt. Vernon Phenol[a]	56,279	292,043
Occidental Petroleum	1,500	12,500
Olin	25,300	15,400
Oxy Petrochemicals	322	1,320
P.D. Glycol	26	185
Pfizer	6,406	42,500
Phillips Petroleum	12,500	21,800
Polysar	643	1,200
PPG	5,820	35,500
Quantum	2,656	N.A.
Questra (Rhone-Poulenc Data)	2,278	91,571
Rexene	553	1,300
Shell Oil	24,460	
Spurlock	11	41
Stepan Co.	346	1,150

Company	Sales (10^6)	Number of Employees
Sterling Chemical	581	926
Sun Co.	13,270	20,926
Texaco	41,822	39,000
Texas Olefins	300	300
Union Carbide	8,740	45,000
Velsicol	100	500
Vista Chemicals	779	1,750
Vulcan Materials	1,080	6,250

[a]Joint venture of General Electric, Champlin Petroleum, and JLM Industries.

7.6 Control Device Manufacturing Industry

The EPA is proposing a three year compliance period commencing in November 1992 for the Synthetic Organic Chemicals Manufacturing Industry (SOCMI) to comply with regulations mandated by the Clean Air Act Amendments of 1990. SOCMI has expressed concern that its member companies may be unable to meet a three year compliance period because of delays in permitting, limitations in the available engineering resources and the ability of the control device manufacturing industry to supply the equipment. The third of these concerns, the ability of the control device industry to supply the controls in time to meet the compliance deadline was investigated.

The investigation was made by telephoning a limited number of leading emission control device manufacturers. The major supply limitation is not fabrication capacity but the availability of design engineers for customized versus off-the-shelf systems.

This analysis was performed as if the HON standard represented the only demand for the control systems.* The demands of other industries that were not considered, such as coatings, that will also require emission control devices make the results overstate the availability of controls. However the results also understate the availability of controls because of the ability of about half of the member firms of the SOCMI to provide their own detailed engineering and design for control devices which can then be fabricated in local shops, because some waste minimization via process modification will occur, because the industry can shift from a control which may be in short supply to one which may be more available, because long delivery times may force a trend towards standardization and because EPA's early reduction program will stretch out the time for control procurement for those firms which take advantage of it.

For the reasons discussed in the preceding paragraph definitive conclusions were difficult to reach. At the least the results indicate that delivery times for the control devices will lengthen as a result of the demand anticipated as a result of the forthcoming regulations. The results as they pertain to each emission source are discussed in the following paragraphs.

Process Vents. The proposed control device for non-halogenated emissions from process vents is a flare.

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*EPA is in the process of procuring an existing study that shows demand for control systems from other industries and will provide another source of capacity data.

Flares are also the proposed control device for emissions from transfers of non-halogenated chemicals. The results indicate that flare manufacturers will require 1.7 years to fill the combined demand. Non-halogenated process vent emissions can also be controlled by incineration in the plant boiler or by an absorber. Absorbers, which are applicable to both halogenated and non-halogenated emissions, are readily available if the chemical manufacturer can supply the engineering design. Transfer operations emissions can be controlled by vapor balancing, adsorbers and refrigerated condensers and use of these controls can be expected to free-up flare manufacturing capacity for other sources. Incinerators with stack scrubbers are proposed for halogenated process vent emissions, and the results indicate capacity is adequate to fill the need.

Transfer operations. The proposed control device for non-halogenated emissions is a flare, which, as noted above, is also proposed for non-halogenated process vent emissions. The combined demand is estimated to be filled in 1.7 years. In addition, transfer operations can be controlled by vapor balancing, refrigerated condensers or adsorbers, use of which will ease the demand for flares. Incinerators with stack scrubbers are proposed for halogenated transfer operation emissions and manufacturing capacity appears adequate.

Storage Tanks. Internal floating roofs are the proposed control device for non-halogenated storage tank emissions. The survey indicates that 3.3 years will be required to fill the demand. Refrigerated vent condensers and adsorbers can also be used to control storage tanks emissions. Even with these additions the supply will be tight.

Refrigerated condensers and adsorbers are proposed for halogenated emissions from storage tanks. If refrigerated vent condensers were applied exclusively for halogenated storage tank emissions, the estimated demand would be filled in 1.6 years, but some systems will be applied elsewhere (e.g. for non-halogenated storage tank emissions as mentioned above), reducing availability. In-house or consultant design and engineering with local shop fabrication of adsorbers or condensers could be used to augment the supply.

Wastewater Streams. Steam strippers are the principal control system. Compared to the demand, the supply of wastewater steam strippers is extremely limited; it is estimated that over 1,500 years will be required to fill the anticipated need if the supply comes from only commercial venders. However, steam strippers are readily designed in-house or by consultants and can easily be fabricated by local shops. Other means, specific to the VOC, process and plant can also be expected to be used to destroy or remove VOCs in wastewater.

Equipment Leaks. This source was not investigated because of the myriad number of pieces of process equipment such as valves and pumps that may have to be replaced were assumed to be inadequate supply.

7.7 Conclusions

Price and quantity adjustments have been calculated for 20 select compounds which will be regulated by the HON. The majority of price increases -- 78 percent -- are below 2 percent. 91 percent of reductions in output are below 2 percent. In general, impacts on the selected compounds are small. Since the selection does not adequately represent the population of controlled compounds, the same cannot be said for all controlled compounds. Nevertheless, given the cost increases from Table 7-6, it is safe to say that impacts for the SOCMI are, in general, small.

Given the dynamic and flexible nature of the SOCMI, as well as the oligopolistic market structure, closure in the majority of cases is unlikely.

The notable impacts of the HON will be the stimulation of a shift to already existing chemical production processes, the ushering in of processes which were previously uncompetitive, or stimulation of research and development into new production processes. It is likely that each of these will take place in response to HON controls.

Small business impacts appear to be negligible.

In conclusion, the SOCMI is a dynamic industry which responds quickly to changes in the economic environment. Increasing costs driven by the HON will serve to reinforce moves to lower-cost production processes, plants engineered for flexibility in feedstock choice, and facilities capable of producing a variety of chemical substitutes depending on costs and market demand.

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CHAPTER 8

BENEFITS

8.1 Introduction

This chapter discusses the potential benefits associated with air toxics regulation under the HON regulation. Various limitations prevent a formal, quantitative benefits analysis. A formal benefits assessment requires analysis of the full pollutant path, tracing from the change in emissions to atmospheric dispersion through population exposure, effective dose, physical effect manifestation considering mitigating and averting behavior, and ultimately to economic valuation. Ideally, this analysis should be conducted for each of the air toxic chemicals regulated under the HON. Lack of information on an individual chemical basis, such as the quantity and location of emissions and chemical-specific physical effect and exposure data, as well as a significant time requirement preclude such a detailed benefit analysis.

Because of the above limitations, a qualitative analysis of the potential benefit categories is given that identifies the direct use and non-use benefits of the regulation. The physical effect categories that are associated with HON emission reductions include health and welfare responses that have been documented for HAPs, ozone, and particulate matter. Furthermore, option value, existence value, and bequest value are potential benefits creditable to this rule making.

The HON rule regulates 149 of the 189 hazardous air pollutants listed in Section 112(b). A general understanding of the physical and chemical nature of these compounds, including their potential toxicity and environmental fate, makes possible the categorization of physical effects from HAP emissions. Hazardous air pollutant emissions may occur in both gaseous and particulate form. Of the gaseous HAPs, the majority are volatile organic compounds (VOCs), which are precursors in the formation of ozone. The VOC HAPs may also condense or react to form particulate matter. HAPs may enter terrestrial and aquatic ecosystems through atmospheric deposition. HAPs can be deposited on vegetation and soil through wet or dry deposition. HAPs may also enter the aquatic environment from the atmosphere via 1) gas exchange between surface water and the ambient air, 2) wet or dry deposition of particulate HAPs and particles to which HAPs adsorb, and 3) wet or dry deposition to watersheds with subsequent leaching or runoff to waterbodies.[1]

Human exposure to HAPs may occur directly through inhalation or indirectly through ingestion of food or water contaminated by HAPs or through dermal exposure. In general, the reduction of

HAP emissions resulting from promulgation and implementation of the HON will reduce human and environmental exposure to these pollutants and thus, reduce potential health and welfare effects. This chapter provides a general discussion of the various components of total benefits that may be gained from a reduction in HAPs through the HON rule. Figure 8-1 lists the range of potential physical health and welfare effects categories that may be associated with HAP emissions and also with ambient concentrations of ozone and particulate matter secondarily formed by VOC HAPs.

Figure 8-1. **POTENTIAL PHYSICAL EFFECTS CATEGORIES FOR HON**

Categories may be applicable for hazardous air pollutants and ozone and PM secondarily formed by VOC HAPs.

Human Health Effects

Mortality Due to Chronic Exposure
Mortality Due to Acute Exposure
Morbidity Due to Chronic Exposure
Morbidity Due to Acute Exposure

Human Welfare Effects

Worker Productivity Losses
Odors

Non-Human Biological Effects

Agriculture
Forestry
Recreational/Commercial Fishing
Ecosystem

Soiling and Materials Damage

Residential/Commercial/Industrial Facilities
Miscellaneous Materials

Climate and Visibility Effects

Local Visibility
Non-local Visibility
Climate
Visibility at Parks
Transportation Safety

8.2 Hazardous Air Pollutant Benefits

8.2.1 Health Benefits of Reduction in Hazardous Air Pollutants

The HON will regulate 149 of the 189 air toxics listed under Title III. Exposure to ambient concentrations of these pollutants may result in a variety of adverse health effects considering both cancer and noncancer endpoints. In an effort to better understand the "big picture" of hazardous air pollutant exposures, EPA undertook broad studies in the 1980s to evaluate the releases of these pollutants and the relative implication of the resulting exposures to human health.

The first study assessed the magnitude and nature of potential cancer risks associated with exposure to hazardous air pollutants. Originally conducted in 1985[2] and updated in 1990[3], the work broadly assessed long-term exposures to HAPs and estimated potential cancer risks associated with these pollutants. Without chemical and site specific exposure and risk assessment, it is not possible to estimate the excess expected cancer cases attributable to HON emission sources.

A second EPA study[4] assessed ambient concentrations of HAPs in relation to their potential to elicit adverse noncancer effects. This project utilized several approaches to characterizing potential noncancer risks including review of case reports, evaluation of State, local and Federal agencies' experiences, and review of available health and exposure data. Although the magnitude of noncancer risks could not be estimated, the broad implications of this study indicated that areas of concern may be the following: short-term as well as long-term exposures, multiple chemical exposures, and the combined impact of an individual chemical emitted from multiple sources in the same geographic area. The major health endpoints of concern in this study were respiratory effects, developmental and reproductive toxicity, and neurotoxicity.

In general, noncancer health effects can be grouped into the following broad categories[5]:

- Genotoxicity - a broad term that usually refers to a chemical that has the ability to damage DNA or the chromosomes.
- Developmental toxicity - adverse effects on a developing organism that may result from exposure prior to conception (either parent), during prenatal development, or postnatally to the time of sexual maturation. Adverse developmental effects may be detected at any point in the life span of the organism. Major manifestations of developmental toxicity include:

death of the developing organism; induction of structural abnormalities; altered growth; and functional deficiency.

- o Reproductive toxicity - harmful effects on fertility, gestation, or offspring, caused by exposure of either parent to a substance.
- o Systemic toxicity - affects a portion of the body other than the site of entry.
- o Irritant - causes irritation of eyes, skin, and respiratory tract.

Exposure to HAPs may occur directly through inhalation as well as indirectly through oral or dermal exposure to food or water contaminated through deposition of HAPs. The Lake Michigan Fish-Eating Study provides evidence of adverse health effects due to indirect exposure to HAPs. Atmospheric deposition of HAPs into the Great Lakes is a major cause of the deteriorated water quality of this aquatic system. High concentrations of toxics have been observed in a number of commercial and recreational fish species. The Lake Michigan Fish-Eating Study revealed that the total amount of fish consumed by mothers in all years prior to conception and the amount of PCBs measured in umbilical cord serum is associated with decreased visual recognition memory--a measure of neurological development--in offspring. There is also evidence of developmental effects such as reduced birth weight and smaller head and skull circumference when compared to controls.[6]

Exposures related to routine emissions of HAPs may be acute (isolated or repeated events) or continuous in nature. Most commonly, populations are exposed to more than one pollutant at a given time. Consideration must be given to potential additive, synergistic, or antagonistic effects resulting from exposures to chemical mixtures. Adverse effects resulting from these exposures may be reversible or irreversible depending upon the magnitude of the exposure and the mechanism of action eliciting the effect. A wide range of responses may be seen from mild irritation to mortality.

For the 149 HAPs covered under the HON, evidence on the potential toxicity of the pollutants varies tremendously. Given sufficient exposure conditions, all of these pollutants have the potential to elicit adverse health or environmental effects in the exposed populations. It can be expected that emission reductions achieved through the HON regulation will decrease the incidence of adverse health effects.

8.2.2 Welfare Benefits of Reduction in Hazardous Air Pollutants

Environmental Impacts

Emissions of hazardous air pollutants may also bring about adverse, non-human biological effects such as ecosystem and recreational and commercial fishery impacts. Atmospheric deposition of toxics is believed to significantly contribute to the presence of hazardous compounds in the environment. The presence of toxic compounds in relatively pristine areas and around large point sources such as smelters provides a strong linkage between long and short-range transport of HAPs and the bioaccumulation of these compounds in terrestrial and aquatic systems. For example, atmospheric loading is estimated to account for approximately 80 - 90% of all pollutant inputs to the upper Great Lakes, an area considered relatively pristine and with few major sources of toxics. Similarly, short-range atmospheric deposition is thought to be responsible for 90 - 99% of lead inputs to the mid-lower Chesapeake Bay.[7]

Hazardous air pollutants may be directly harmful to organisms due to their presence in the ambient air. For example, experts believe that major declines in the lichen flora of urban and industrial areas worldwide are caused by atmospherically-derived metals and gaseous phytotoxicants.[8]

Atmospheric deposition of HAPs directly to land may affect terrestrial ecosytems. For example, there is documented evidence of terrestrial ecosystem impacts such as plant toxicity, changes in species composition, bioaccumulation, and inhibition of enzyme activity due primarily to atmospherically-derived metals . These effects may result in the loss of sensitive species and declines in ecosystem productivity.[9] Specifically, there is evidence of impacts on mammal populations near to and downstream of a mining-smelting complex in northern Idaho. Population declines in mink, muskrat, and other small mammals are believed to be due to the direct toxicity of atmospherically-derived metals as well as secondary effects on cover and food supply.[10]

Atmospheric deposition of HAPs also contributes to adverse aquatic ecosystem effects. Much of the documentation on the aquatic impacts of HAPs has focused on the Great Lakes. Many of the HAPs deposited to the Great Lakes are persistent toxics that, through the process of biomagnification, tend to accumulate in toxic concentrations in the tissues of species high on the food chain. This not only has adverse implications for individual wildlife species and ecosystems as a whole, but also the humans who may ingest contaminated fish and waterfowl. The Great Lakes is the largest freshwater fishery in the world. In 1985, more than 4 million people fished in the Great Lakes basin.[11] Recreational and commercial fishing is estimated to be worth $4.2 billion annually.[12] High tissue contaminant levels, however, have forced the closure of some commercial fisheries and the issuance of fish advisories for some recreational fish species. Therefore, atmospheric deposition of HAPs to the Great Lakes may

impose significant costs to the area's recreational and commercial fishing industries.

Toxic pollutants in the Great Lakes ecosystem are believed to be responsible for a number of specific problems in organisms at the top of the Great Lakes food web such as the following[13]:

- o reproductive problems and population decline
- o metabolic changes
- o birth deformities
- o hormonal changes
- o tumors
- o generational effects
- o behavioral changes.

Additionally, large increases (outside normal variation for vertebrate species) in the populations of cormorants and ring-billed gull indicate the occurrence of fundamental changes in the balance of the Great Lakes ecosystem.[14] Experts believe that these ecosystem changes are indirectly due to the presence of toxic compounds in the Great Lakes ecosystem.

The extent to which other ecosystems outside of the Great Lakes are adversely impacted by hazardous air pollutants is not yet known, although toxics loading appears significant. For example, loadings to the Chesapeake Bay are at least as high or higher than loadings to the Great Lakes on a per unit area basis. Because there is a proportionally larger watershed around the Chesapeake Bay than the Great Lakes, there is greater potential for indirect loading of HAP's into the Chesapeake Bay. In general, HAP emission reductions achieved through the HON should reduce the associated adverse environmental impacts.

Additional Welfare Effects

There is evidence of materials damage that may occur as a result of emissions of hazardous air pollutants. Acidic compounds may corrode or decay metals, stone, and automotive finishes.[15] Additionally, odor threshold concentrations have been reported for a number of hazardous air pollutants.[16] However, without site specific air quality modeling, it is not known the extent to which ambient concentrations of these air toxic compounds exceed the odor threshold level.

8.3 Ozone Benefits

8.3.1 Health Benefits of Reduction in Ambient Ozone Concentration

Ozone benefits may be attributable to this regulation as ozone is a product of VOC and nitrogen oxide emissions reacting

in the presence of sunlight. VOCs are a major pollutant for those sources/processes that will be regulated under HON. Consequently, reductions in the emissions of VOCs will also lead to reductions in the types of health and welfare impacts that are associated with elevated concentrations of ozone.

Approximately 47.7 million people live in nonattainment areas (classified as marginal, moderate, serious, severe and extreme) that contain a HON process unit and are potentially exposed to ozone levels above the standard. VOC emissions from HON process units therefore may contribute to some degree to the adverse health effects experienced by exposed individuals in those nonattainment areas. Furthermore, it is estimated that approximately 57% of the VOC reductions achieved by the HON may occur in ozone nonattainment areas.

There are sensitive subpopulations that are more at risk of adverse health effects from elevated ozone concentrations. These groups include people with the following conditions[17]:

- chronic bronchitis (3.5 percent of US population);
- asthma (3.5 - 5 percent of US population);
- allergies (7 percent of US population);
- emphysema (1 percent of US population);
- any individual exercising heavily during ozone exposure. Heavy exercise increases breathing frequency and depth of breathing resulting in a larger ozone dose to lungs and deeper penetration of ozone to the most sensitive lung tissue.

The health effects associated with increased ambient ozone concentrations have been well documented in EPA's recent review of the ozone standard and presented in the Office of Air Quality Planning and Standards Staff Paper on ozone. The major ozone health effects of concern to health scientists are the following[18]:

- Alterations in Pulmonary Function - modifications in such pulmonary measurements as forced expiratory volume, total lung capacity, and breathing frequency;
- Symptomatic Effects - eye, nose and throat irritation, chest discomfort, cough, headache, chest pain on deep inspiration, chest tightness, wheezing, lassitude, malaise and nausea;
- Exercise Performance - reduced workload and performance;
- Bronchial Reactivity - increased sensitivity of airway to agents such as histamines with subsequent initiation of an inflammatory response;

- o Aggravation of Existing Respiratory Disease - aggravation of existing asthma, chronic bronchitis or emphysema conditions;
- o Morphological Effects - occurrence of lesions in lung tissue of exposed animals;
- o Altered Host Defense System - alteration of host defense system rendering sensitivity to respiratory infection;
- o Extrapulmonary Effects - blood enzyme, central nervous system, liver, endocrine, cardiovascular, reproductive and teratological effects.

8.3.2 Welfare Benefits from Reduction in Ambient Ozone Concentration

Elevated concentrations of ambient ozone are also associated with adverse welfare (non-health) impacts. The welfare effects of concern are the following[19]:

- o decreased worker productivity;
- o crop damage resulting in yield losses and undesirable quality effects[20];
- o forest damage manifested as growth retardation or foliar injury;
- o materials damage of elastomers, textile fibers, dyes, and paints.

Reduction of VOCs through the HON regulation is another mechanism - in addition to Title I and II control measures - by which the ambient ozone concentration may be reduced and in turn reduce the incidence of the adverse health and welfare effects discussed above.

8.4 Particulate Matter Benefits

In addition to acting as precursors to ozone formation, VOC emissions may also condense or react to generate secondarily-formed aerosols, elevating ambient concentrations of particulate matter (PM). Based on available conversion factors, approximately 1 to 2 percent of VOC emissions condense or react to form secondary particulate matter. The 986,000 Mg of VOC emissions reduction under the HON will therefore cause a reduction of 9860 Mg to 19,720 Mg of secondary PM formation. These particles are respirable and contribute to impairment of visibility.

PM-related health effects include chronic and acute morbidity and mortality. PM-related welfare impacts encompass soiling and materials damage and climate and visibility effect.[21] Therefore by reducing VOC emissions, decreases in the adverse

health and welfare effects associated with elevated PM concentrations may be achieved.

8.5 Additional Benefits

There are additional benefits that may be attributable to the HON regulation above and beyond the direct use value as represented by the health and welfare benefits associated with HAP reductions as discussed above. Theoretical analysis of the value of non-market environmental amenities (i.e. air quality, visibility) or disamenities (i.e. Superfund sites, nuclear power plants) has led to the decomposition of willingness to pay into several components. One important distinction relevant to the HON that is made in the literature is that some portion of the value one places on air toxics reductions is related to one's own exposure to air toxics while some portion of the value may not be related to one's own exposure to air toxics. Use values are the values associated with an individual's desire to avoid his or her own exposure to an environmental risk, or in the case of the HON, toxic air pollutants. Non-use values are values an individual may have for lowering the concentration of toxic air pollution or level of risk *unrelated to his or her own exposure*. Non-use values may be related to the desire that a clean environment be available for the use of others now and in the future, or may be related to the desire to know that the resource is being preserved for its own sake, regardless of human use.

Several different categories of use and non-use values have been developed and rigorously defined in the literature.[22] These include:

- Option price. Option price is a measure of total value that reflects uncertainty regarding future use of a resource. It equals the expected value of current and future use plus a risk premium, which may be positive, negative, or zero. The risk premium is related to uncertainty regarding desired future use and its sign (positive or negative) depends on whether the individual prefers to err toward preserving the resource (reduced-toxic atmosphere) that may not be wanted for use in the future, or toward losing the resource that may be wanted for use in the future. The risk premium associated with option price is referred to as option value.

- Bequest value. This is the component of non-use value that is related to the use of the resource by others now and in the future. This value is typically thought of as altruistic in nature. Bequest value may be more significant to the HON regulation when considering the value an individual may have to reduce the risk of air

pollutant exposure to others (outside of one's family and friends) now living rather than future generations.

- o Existence value. This is the component of non-use value that is related to preservation of the resource for its own sake, even if there is no human use of the resource. In practice, bequest and existence values are difficult to distinguish and are often together referred to as existence value. In the case of the HON regulation, existence value would incorporate an individual's willingness to pay for the preservation of a reduced-toxic atmosphere.

These value categories may apply to changes in the quality of a resource. Freeman explicitly included this in his analysis.[23] With air emissions under the HON regulation, the issue is typically the concentration of air emissions to which people are exposed, not whether or not any emissions exist at all. These value categories may also be components of the total use and non-use values of a reduction in ambient ozone and PM concentrations that may also be achieved through the HON.

Option price differs from use value because it is an ex ante measure rather than an ex post measure of value related to exposure. As the ex ante measure, option price is the appropriate measure for analysis of proposed regulatory decisions that may affect the availability or quality of a resource. Option price may differ from use value due to differences between expected and actual use of the resource as well as due to any risk premium.

8.6 Conclusion

Because of various limitations, the benefits associated with the HON regulation have not been monetized. However, there are health and welfare improvements that could be gained through a reduction in air pollutants regulated under HON that have been qualitatively discussed. In summary, air toxic reductions may reduce mortality and morbidity from exposure directly to HAP's and secondary PM. Similarly, VOC reductions in ozone nonattainment areas will decrease ambient concentrations of ozone and therefore reduce morbidity effects. Because approximately 47.7 million people reside in ozone nonattainment areas with at least one HON process unit, any decrease in ambient ozone concentrations as a result of HON control will directly benefit these individuals. In fact, it is estimated that approximately 57% of the VOC reductions achieved by the HON will occur in ozone nonattainment areas. Human welfare benefits from HON control may include improvements in worker productivity and a decrease in odors.

The HON regulation may also result in beneficial biological effects such as agricultural crop yield increases, and beneficial forestry, fishing, and ecosystem impacts. A decrease in soiling and materials damage is another potential benefit of this rulemaking. Climate and visibility may also be improved through decreases in secondary PM associated with HAP reductions.

Finally, potential benefits from the HON regulation may also include existence value, bequest value, and components of option price.

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CHAPTER 9

BENEFIT-COST ANALYSIS

9.1 Introduction

This chapter provides an illustration of the economic efficiency framework for evaluating regulatory options under the proposed HON rulemaking. Unfortunately data paucities and time constraints preclude a formal quantification of the allocative efficiency aspects of this rule.

This chapter also identifies the overlap of the HON rulemaking with VOC emission reduction requirements for ozone nonattainment areas. The complementarity of these regulatory requirements may result in control cost savings in these areas.

9.2 Economic Efficiency Considerations

The adoption and implementation of air toxics regulations is not free. There is a reallocation of society's resources to address the negative spillover of air pollution. In the course of internalizing the air pollution externality, the cost of reducing emissions through the HON rulemaking is reflected in the production, distribution, and consumption of synthetic organic chemicals. This additional cost is in contrast to the improvement in society's well being from a cleaner environment and concomitant reductions in adverse health effects and other risks.

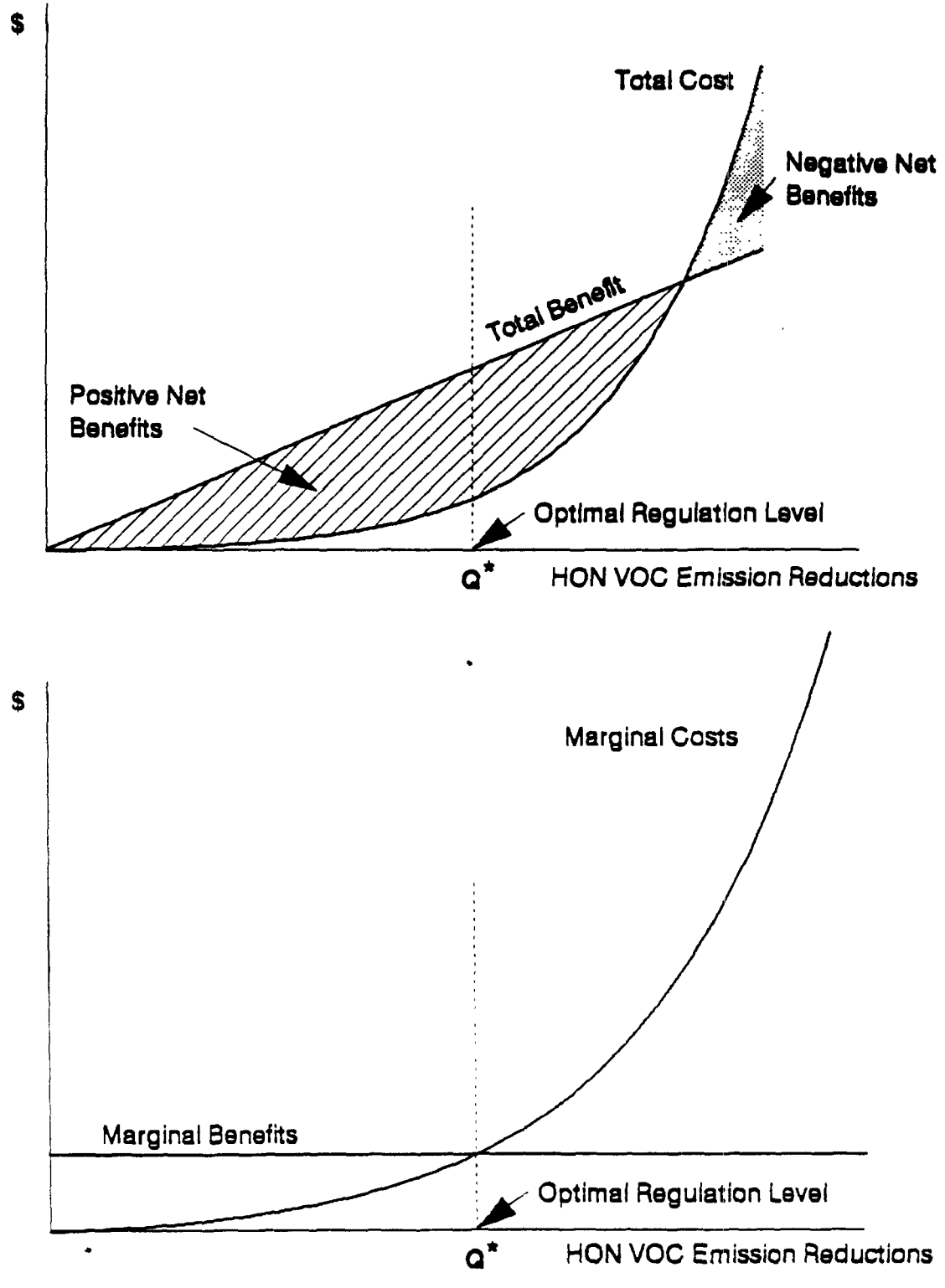
As displayed in Figure 9.1, the existence of a regulation to internalize the air pollution externality does not guarantee an allocatively efficient outcome. An allocatively efficient regulation maximizes the net benefits to society. In a mathematical sense, allocative efficiency requires that the marginal benefits of the rule be equal to the marginal cost and that marginal costs are rising at a rate greater than marginal benefits.

Because of the inability to compare in a quantitative sense both the benefits and the costs of the regulatory alternatives, the economic efficiency aspects of this rule cannot be assessed.

9.3 Cost-Effectiveness of HON VOC Emission Reductions in Ozone Nonattainment Areas

Environmental quality enhancement programs are not always independent of one another. In the course of accomplishing the objectives of Title III through the HON requirements, the regulation also reduces emissions of ozone precursors (VOC's) in ozone nonattainment areas. In the year 1995, HON VOC emission reductions for the most stringent regulatory option (TIC) are

Figure 9.1 Optimal Regulation and Net Benefit Levels



estimated to be 56 percent of the total VOC emission reductions required in nonattainment areas (classified as marginal, moderate, serious, severe, and extreme) for the ozone NAAQS.

Some of the VOC emission reductions for ozone nonattainment areas are achieved through nondiscretionary control measures. Some of these control measures include VOC emission reduction requirements based on new control techniques guidelines documents. One of the source categories for these new documents is the SOCMI. Consequently, there is some overlap between the HON VOC emission reductions and those reductions from nondiscretionary control requirements for ozone nonattainment areas.

There are additional VOC emission reductions from the HON rulemaking that will occur in moderate, serious, severe and extreme ozone nonattainment areas. Further emission reductions are required in these areas; however, the means of achieving these additional VOC emission reductions is discretionary. Consequently, the prudent regulatory authority may use the additional VOC emission reductions from the HON rules to replace the emission reductions from high cost discretionary controls. This replacement may result in a "savings" or avoided cost of the discretionary controls that are replaced by HON controls.

For example, the average cost of the HON VOC emission reductions for total industry control in nonattainment areas is estimated at $1,061 per Mg. The average cost of discretionary controls in the moderate, serious, severe, and extreme nonattainment areas is estimated to be $4,540 per Mg.[1] If a megagram of HON VOC emission reductions replaced a $4,540 discretionary control measure megagram, the savings would be $3,479. This is a potential control cost savings of nearly 77 percent.

The exact amount of savings resulting from the HON rule cannot be calculated due to uncertainties regarding the potential overlap of emission reductions resulting from rules derived from the control techniques guidelines documents for SOCMI sources and the HON rulemaking.

9.4 Conclusion

The economic efficiency aspects of HON regulatory options cannot be assessed because of the inability to quantify the benefits associated with the rule.

There is overlap between the emission reductions and environmental quality enhancement objectives of the nonattainment and air toxics titles of the Clean Air Act. This overlap may

result in a potential cost savings in selected ozone nonattainment areas.