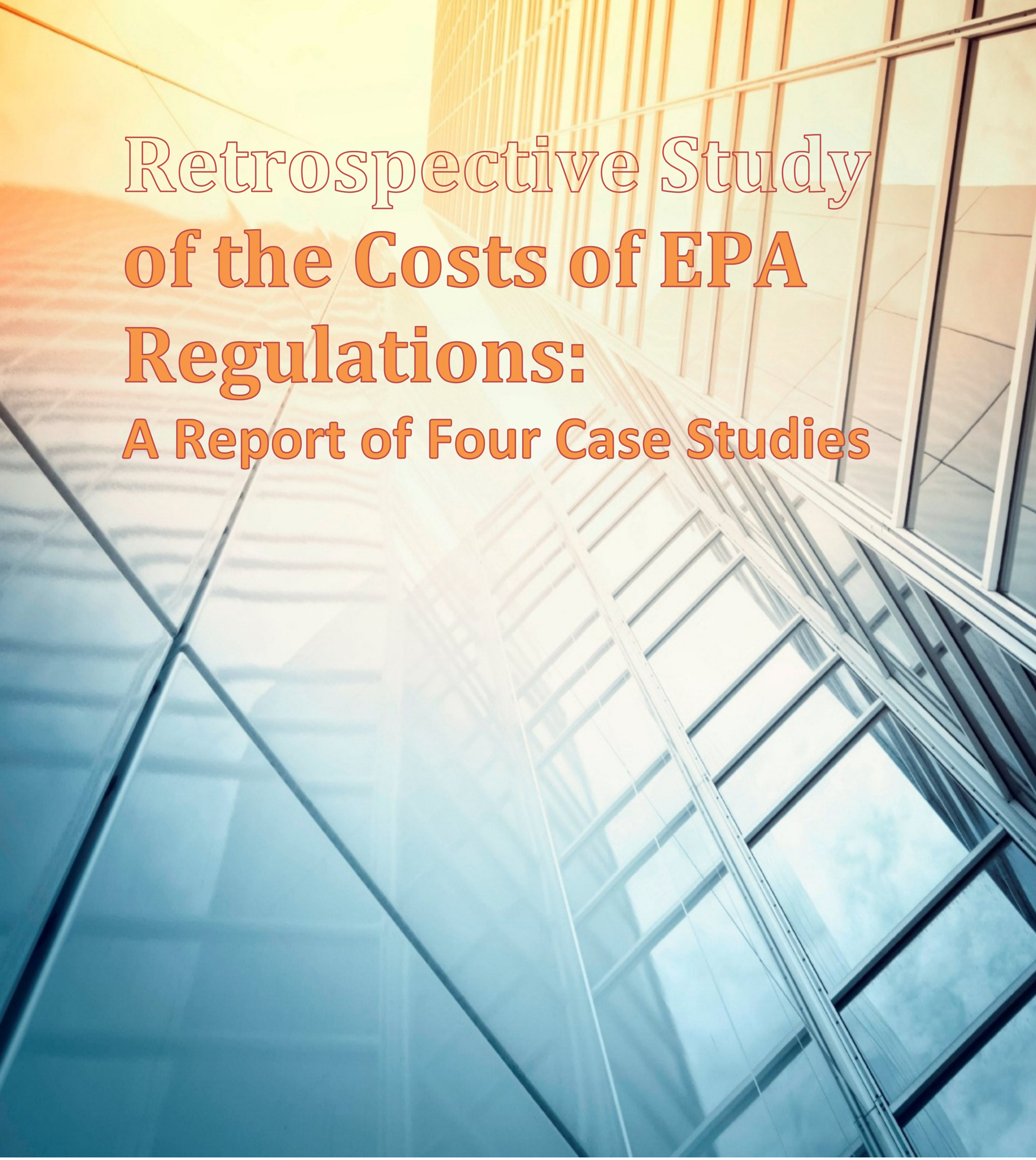

Retrospective Study of the Costs of EPA Regulations:

A Report of Four Case Studies

United States Environmental Protection Agency

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Preface

The Office of Management and Budget (OMB) has stressed the need for regulatory agencies to conduct retrospective analyses of their rules. In their draft 2014 Report to Congress on the Benefits and costs of federal regulation, OMB states: "Retrospective analysis, required by Executive Order 13563 and institutionalized by Executive Order 13610, can be an important way of increasing accuracy."[1] The Executive Orders instruct: "it is particularly important for agencies to conduct retrospective analyses of existing rules to examine whether they remain justified and whether they should be modified or streamlined in light of changed circumstances, including the rise of new technologies."[2]

Benefit-cost analyses (BCA) of environmental regulations most often involves integrating science from a wide array of disciplines. Engineering, fate and transport modeling, ecology, toxicology, epidemiology, exposure modeling, behavioral modeling and economic valuation methods are all needed to assess the benefits and costs of environmental regulations. All of these sciences have advanced dramatically in the last decade. With these advances, it is prudent for agencies to periodically assess whether regulations are still appropriate in their current form.

While new science and the need to quantify more previously unquantified benefits has driven benefits analysis, comparatively less work has been done examining how well EPA estimates the costs (or benefits) of regulation. The ex post cost studies that are available in the literature are often based on limited data and overlap in coverage – many of the same regulations appear in multiple publications. And while the literature posits a number of hypotheses for why one might expect ex ante and ex post cost estimates to differ, EPA's current judgment is that ex post analyses are too few in number to draw conclusions regarding general tendencies to under- or over-estimate costs in ex ante evaluations.

The National Center for Environmental Economics (NCEE) has launched an effort to evaluate the feasibility of augmenting the existing literature with additional ex post evaluations of costs. Researchers examining the relationship between ex ante and ex post cost generally used a case study approach. We do too. However, we develop a common conceptual framework for our ex post cost assessments. In this report we present the ex post assessments of five EPA regulations: 2001/2004 National Emission Standards for Hazardous Air Pollutants and Effluent Limitations Guidelines, Pretreatment Standards, and New Source Performance Standards on the Pulp and Paper industry; Critical Use Exemptions for Use of Methyl Bromide for Growing Open Field Fresh Strawberries in California for the 2006-2010 seasons; the 2001 National Primary Drinking Water Regulations for Arsenic; and the 1998 Locomotive Emission Standards. These case studies were developed with extensive support and input from staff in EPA program offices, economists in EPA's NCEE, and

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[1] U.S. Office of Management and Budget (OMB.) 2014. *Draft Report to Congress on the Benefits and Costs of Federal Regulations and Unfunded Mandates on State, Local, and Tribal Entities.* Page 3.

[2] E.O. 13610, "Identifying and Reducing Regulatory Burdens." FR 77(93), May 14, 2012. (available at: http://www.whitehouse.gov/sites/default/files/docs/microsites/omb/eo_13610_identifying_and_reducing_regulatory_burdens.pdf)

members of the Science Advisory Board – Environmental Economics Advisory Committee. They represent a first step by EPA in generating a larger body of evidence on key drivers of compliance costs.

The purpose of the case studies (and the case studies done by other researchers) is NOT to estimate ex post costs reliably. Rather, it is to see if sufficient information can be gathered to make a "weight of evidence" determination about whether ex ante cost estimates tend to be higher or lower than ex post cost estimates. We cannot emphasize this enough. The case studies in this report do not aim to estimate ex post costs of these EPA actions. Rather, we investigate the key drivers of compliance costs across regulations to see if informed judgments can be made on the general accuracy of ex ante estimates and what underlying factors contribute to differences (or similarities) between ex ante and ex post estimates.

If the case study approach is successful, there is much that can be learned from this effort. A careful assessment of ex post cost drivers could help identify systematic differences between ex post and ex ante compliance cost estimation and, ultimately, allow for improvements in the way in which ex ante analyses are done. For instance, if unanticipated changes in market conditions, energy prices, or available technologies regularly result in an over or underestimate of costs, EPA can invest in improving methods such as expanded uncertainty analysis that better capture these effects on costs ex ante. It is also possible that industry overstates the expected costs of compliance (EPA often has to rely on industry to supply it with otherwise unavailable information on expected compliance costs). Even if such specific differences between ex ante and ex post cost studies cannot be identified, a sizable set of retrospective analyses can offer broader insights, such as whether certain cost categories are particularly uncertain or how to better incorporate behavioral responses to regulation into ex ante analyses.

Executive Summary

While advancements in research on benefit and cost estimation methods and models is continually applied to EPA analyses of *new* regulations, there also is significant potential to learn from analysis of the benefits and costs of *past* regulations. New science and the desire to capture previously un-quantified benefits has driven periodic ex post reviews of how benefits analyses are conducted, but comparatively less work has been done retrospectively examining how well EPA estimates the costs of regulation. The literature posits a number of hypotheses for why one might expect ex ante and ex post cost estimates to differ, yet ex post cost case studies are too few in number and narrow in scope to lend strong support for one hypothesis over another. Existing case studies are often based on limited data and overlap in coverage, with many of the same regulations appearing in multiple publications.

For these reasons, EPA launched an effort to augment the existing literature with additional ex post evaluations of costs. Similar to previous studies, we examine the relationship between ex ante and ex post cost using a case study approach. However, unlike prior literature, we develop a common conceptual framework for our ex post cost assessments to more consistently investigate the key drivers of compliance costs across regulations to see if informed judgments can be made on the general accuracy of ex ante estimates and what underlying factors contribute to differences (or similarities) between ex ante and ex post estimates.

A careful assessment of ex post cost drivers may help identify systematic differences between ex post and ex ante compliance cost estimation and, ultimately, allow for improvements in the way in which ex ante analyses are done. For instance, if unanticipated changes in market conditions, energy prices, or available technologies regularly result in an over or underestimate of costs, EPA can invest in improving methods such as expanded uncertainty analysis that better capture these effects on costs ex ante.

After outlining the conceptual framework, this report applies it to four case studies that retrospectively examine the compliance costs of five EPA regulations. These five rules were not chosen randomly, but rather are chosen as pilot case studies to help us understand which methodologies are appropriate to measure ex post compliance costs for a range of rules. Given this purpose, the five rules cover various media, source categories, and types of regulations (e.g., performance standard versus prescriptive regulation). The five regulations evaluated in this report are: the 2001/2004 National Emission Standards for Hazardous Air Pollutants and Effluent Limitations Guidelines, Pretreatment Standards and New Source Performance Standards on the Pulp and Paper industry; Critical Use Exemptions for Use of Methyl Bromide for Growing Open Field Fresh Strawberries in California for the 2004-2008 seasons; the 2001 National Primary Drinking Water Regulations for Arsenic; and the 1998 Locomotive Emission Standards.

For each case study, we assessed whether it would be possible to collect sufficient ex post compliance cost information using only publicly-accessible data sources. In general, we found that while data for some necessary components are readily available, the cost information is generally lacking. The critical use exemption for methyl bromide use for California strawberries fared the best of the five with regard to the availability of cost information, and was designated as the case study that would be based on publicly-available data alone. For the remaining rules, we also consulted industry compliance experts to gather information on compliance strategies and ex post cost data.

While several of the case studies are suggestive of overestimation of costs ex ante, we do not consider the current evidence to be conclusive. First, they only represent a small subset of regulatory and other policy actions taken by EPA. Second, conducting ex post analysis has proven more challenging than anticipated. With regard to data, these challenges have included the inability to identify qualified industry experts that did not also work on the rule as well as limited access to industry data. Analytic challenges have included how to evaluate a highly heterogeneous industry with a limited set of information, how to form a reasonable counterfactual, and how to disentangle the costs of compliance from other factors, to name a few.

Chapter 1: Background

The Environmental Protection Agency (EPA) conducts benefit-cost analyses (BCA) for many of the new rules it proposes.[3] While there are a number of factors that can influence regulatory decisions (including environmental justice, statutory direction, enforceability of specific options, and uncertainty and precaution), the benefits and costs of regulatory options are important criteria. Furthermore, BCA informs stakeholders, policy makers, Congress, and the public of how society will be better off from an environmental regulation and how much it will cost. Given the prominent role of BCA, EPA strives to use the best available science, data and methods when conducting its analyses. While research on benefit and cost estimation methods and models is continually applied to EPA analyses of *new* regulations, there is significant potential to learn from additional analysis of the benefits and costs of *past* regulations. New science and the desire to capture previously un-quantified benefits has driven innovations in benefits analyses, but comparatively less work has been exploring how to improve cost estimation techniques.

A careful assessment of ex post cost drivers could help identify systematic differences between ex post and ex ante compliance cost estimation and, ultimately, allow for improvements in the way in which ex ante analyses are done. For instance, if unanticipated changes in market conditions, energy prices, or available technologies regularly result in an over or underestimate of costs, EPA can invest in improving methods such as expanded uncertainty analysis that better capture these effects on costs ex ante. It is also possible that industry overstates the expected costs of compliance (EPA often has to rely on industry to supply it with otherwise unavailable information on expected compliance costs).

Even if such specific differences between ex ante and ex post cost studies cannot be identified, a sizable set of retrospective analyses can offer broader insights, such as whether certain cost categories are particularly uncertain or potential ways to better incorporate behavioral responses to regulation into ex ante analyses.

Using a common conceptual framework described in more detail below, we examine the key components of the estimated cost (e.g., the number of regulated facilities, baseline definition, compliance strategies employed, capital costs) using a case study approach. The purpose of the case studies is not to estimate ex post costs at the same level of rigor employed in the original economic analyses, but rather to assess available information on the key drivers and make a "weight of evidence" determination about whether and how ex ante cost estimates differ from ex post cost estimates. When a substantial difference exists, we seek to understand the reasons for the discrepancy and to determine if there are any systematic reasons for the differences. Ultimately, the goal is to identify areas in which to improve EPA's ex ante cost estimation.

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[3] Since 1981, EPA has been required to conduct benefit cost analyses of all economically significant regulations (i.e., those that have an annual effect on the economy of$100 million or more, or meet other criteria).

While additional retrospective case studies are underway and still more are planned, this report summarizes the results of the first four case studies that examine five EPA regulations: the 2001/2004 National Emission Standards for Hazardous Air Pollutants and Effluent Limitations Guidelines, Pretreatment Standards, and New Source Performance Standards on the Pulp and Paper industry; Critical Use Exemptions for Use of Methyl Bromide for Growing Open Field Fresh Strawberries in California for the 2004-2008 seasons; the 2001 National Primary Drinking Water Regulations for Arsenic; and the 1998 Locomotive Emission Standards.

The remaining sections are organized as follows. Section I reviews the literature on the accuracy of a variety of ex ante regulatory cost estimates and discusses competing hypotheses about what causes a divergence between ex ante and ex post compliance costs. Section II describes our methodology: the conceptual framework we apply to structure each of the case studies, the rule selection process, and the ex post cost estimation strategies as well as potential sources of ex post cost data. Results from four case studies are presented in Sections III through VI. Section VII presents concludes.

1.1. Literature Review of Previous Retrospective Cost Studies

A number of researchers have reviewed ex ante estimates of the costs of environmental and other forms of regulation in light of ex post estimates of such costs. We focus here largely on survey articles that review a number of individual studies, each of which have attempted to compare ex ante to *ex post* cost estimates, and then try to draw out more general lessons concerning the accuracy of the ex ante estimates.[4] As these survey articles themselves may incorporate results from a dozen or more individual studies (although there is some overlap between survey articles in the original studies they include), we should emphasize that the overall literature is significantly larger than one might infer simply from counting the number of papers we cite. We begin with a brief overview of the types of regulations that have been examined retrospectively as well as the general findings with regard to the accuracy of ex ante cost estimates. We then discuss the main reasons why ex ante costs may be under or overestimated based on this literature.

---

[4] Simpson (2011) assesses the published literature on comparing ex ante and ex post costs and discusses the different treatment of costs across the studies. He also considers what we can infer from the findings of these studies, noting in particular that not all of the studies actually conduct a numeric comparison of the *ex ante* to *ex post* costs. Regrettably, for our purposes, Simpson finds only a relative handful of analyses considering the *total* (as opposed to unit) costs of regulations in the U.S. Thus, while he attempts a statistical analysis to test if *ex ante* estimates are biased, the limitations of his sample severely compromise the power of his test.

1.1.1. Overview of the Survey Articles

Table 1.1 summarizes many of the studies described in this section with regard to the types of regulations reviewed and general findings of accuracy. Most of the underlying studies focus on U.S. regulations, with EPA regulations featured prominently. We omit retrospective studies of the Title IV SO2 cap-and trade

Table 1.1: Summary of Accuracy of Ex Ante Costs from Existing Studies[5]

Authors (Date of Publication)	Description	Accuracy of ex ante cost estimation
Putnam, Hayes, and Bartlett (1980)[6]	Compare US EPA and industry ex ante estimates of capital expenditures to actual expenditures for five EPA regulations promulgated from 1974-1977	In four of five cases, industry over-estimated costs. In three of five cases, EPA over-estimated costs
Jantzen (1989) and RIVM (2001) as reported in Oosterhuis et al. (2006)	Evaluate costs of compliance for 8 regulations associated with the first Dutch National Environmental Plan of 1988	Costs were overestimated ex ante for 5 regulations, but only one ex ante estimate was as much as 2x the ex post estimate; in aggregate ex ante was only 13% higher than ex post
Office of Technology Assessment (1995)[7]	Eight OSHA regulations promulgated from 1974-1989 in the chemical, service, and manufacturing industries	OSHA overestimated costs ex ante in every case. In two cases, costs may have been negative
Hodges (1997)	Compare industry ex ante estimates to ex post cost estimates for 12 US environmental and workplace safety regulations from the 1970s to 1990s	In every case evaluated, costs were overestimated ex ante; in 11 of 12 cases, ex ante estimates were more than double ex post costs
Harrington, Morgenstern, and Nelson (2000)	28 US regulations promulgated by EPA, OSHA, and other regional and international regulators (13 were EPA regulations)	Total costs overestimated for 14, underestimated for 3, and reasonably accurate (within +/- 25%) for 11 regulations; unit costs overestimated as often as underestimated. (For EPA regulations, 7 overestimated costs ex

[5] There are several studies of public programs and procurement that raise issues similar to those we consider. Boardman, et al. (1994) study the accuracy of *ex ante* cost estimates for a road-building project and find that costs were underestimated. Conventional wisdom has it that the costs of regulation tend to be overestimated. The direction of the bias is readily explained in both instances. In the road-building example private firms profit from public construction activities, and so would want to make such activities seem more attractive by understating costs. In the case of regulation, private firms bear the cost, and would thus have an incentive to exaggerate costs of compliance to make the regulation seem less desirable (in both the public works and the regulation cases public officials often must rely on private entities for cost estimates). Other studies of the accuracy of estimates of the costs and benefits of public programs include Dayton (1998) on HIV/AIDS intervention, Rideout and Omi (1995) on fuel reduction measures in public forests, Lindner and Jarrett (1978) on publicly sponsored research, LaFrance and Gorter (1985) on dairy price supports, and, very generally, Sappington and Stiglitz (1987) on privatization.

[6] Putnam, Hayes, and Bartlett (1980) also examined a sixth case of the effect of environmental regulations on new car prices but results were somewhat more ambiguous.

[7] In two cases, OTA suggests costs may actually have been negative -- i.e., in finding ways to reduce risks, producers may have identified processes that operate more efficiently. However, while environmental regulations may induce some firms to experiment with pollution reduction technologies they would not otherwise have tried, and some experimenting firms may be surprised to find in some instances that costs actually decline as a result, this does not mean that costs would, generally speaking, be *expected* to decline in response to tougher regulation. There may well be offsetting instances in which other firms try technologies that reduce pollution but, as expected, increase costs. Moreover, there are costs of experimentation, which are not always reported accurately.

Authors (Date of Publication)	Description	Accuracy of ex ante cost estimation
		ante, 2 underestimated, and 3 reasonably accurate.)
Anderson and Sherwood (2002)	11 vehicle emission and 6 fuel-quality US EPA regulations	In most cases ex ante estimates of induced price increases overestimated actual changes; EPA estimates tended to be more accurate than industry
Thompson et al. (2002)	US consumer safety regulation requiring air bags in automobiles	Cost estimated were reasonably accurate: ex ante exceeded ex post cost estimates by less than 5%
Grosse et al. (2005)	Evaluated the accuracy of 3 different ex ante studies of a US FDA regulation to fortify cereal grains with folic acid	Ex ante estimates overestimated costs by 3.5 to 9x actual costs
OMB (2005)[8]	47 US regulations initiated between 1976 and 1995 (18 EPA regulations)	Of 40 regulations for which data were available, 16 overestimated costs ex ante, 12 underestimated them, and 12 were reasonably accurate.
McLeod et al. (2006)	Eight UK regulations	Five overestimated costs ex ante, 2 underestimated, and one was reasonably accurate (within +/- 25%)
Oosterhuis et al (2006)[9]	Five EU environmental regulations	Costs were overestimated ex ante by a factor of two or more in 4 cases, and reasonably accurate in 1 case
Dale et al. (2009)	Used a hedonic regression approach to evaluate ex ante costs of US DOE energy efficiency regulations on consumer appliances	Ex ante estimates over estimated costs
National Research Council (NRC) (2012)	Evaluated EPA's estimates of costs for a proposed EPA water regulation to establish nutrient criteria	Inconclusive since ex post data were not yet available

[8] The OMB study was not completely independent of earlier work. For instance, results for nine of the studies in its sample were taken from Harrington, *et al*. 2000.

[9] Oosterhuis *et al*.(2006) actually consider six environmental directives, addressing large combustion plants, integrated pollution prevention and control, ozone control, ozone depleting substances packaging, and nitrates, but are unable to develop *ex ante* compliance cost estimation numbers for the packaging directive.

program from the table; the relatively large literature on this topic is instead summarized in Text Box 1. In a few cases, ex ante estimates of the cost of regulation are available from both the regulator and industry offering another point of comparison to ex post estimates. In general, ex ante cost estimates are more often found to overestimate than underestimate realized costs, and in cases where industry estimates are available it appears that the regulator is often more accurate in its assessments of costs ex ante.

While Table 1.1 may give the reader the impression that much work has already been done to evaluate the costs of regulation retrospectively, there are two reasons why this evidence is less compelling than it may appear. First, given both the paucity of ex post data on compliance costs and the large variation in methodology and scope of analysis, many of the predictions of over or under-estimation likely have large error bounds. Studies differ in the approaches they take to the estimation of ex ante costs, and the elements they include in such estimates. Some have considered only capital costs, others capital and operating costs. To the extent that the times at which costs are incurred differ across studies, differences in the discount rates their authors assume may have affected cost estimates. Moreover, analysts also have to apply their best judgment to distinguish costs that might be incurred in the course of business as usual from those that would need to be incurred to meet regulatory requirements. If, for example, the general trend in an industry is toward the availability of cleaner production technology over time, the cost associated with a regulation might best be measured as the incremental cost of accelerating capital replacement, rather than the total cost of a new capital investment.

Second, the collection of regulations for which any comparison of ex ante to ex post cost estimates has been performed is small and is unlikely to form a representative sample of the universe of environmental rules that have been promulgated. Many of the survey articles summarize the same sets of underlying studies, which means that there is substantial overlap. Within the regulations that have been analyzed, there is reason to believe that those for which unforeseen technological breakthroughs occurred might be overrepresented because they are often the most celebrated and visible regulations. For example, it came as a considerable surprise to many industry compliance experts that coal-fired power plants were able to substitute between coal types as easily as they were to meet emission limits under the SO2 cap-and trade program.[10] It was, then, natural to further investigate the divergence between *ex ante* and *ex post* estimates of the cost of regulation in this case (see Text Box 1). It is also likely that economists prefer to study regulations where regulated parties were given flexible options for compliance. Harrington et al. (2000) suggest that this is because more data are available for rules that establish markets, as prices are easily observed, and because “economists . . . have a proprietary interest in the performance of economic incentives.”

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[10] To give one example Joskow (1988) argued that electric utilities entered into long-term contracts with coal providers because the need for a specific grade of coal made for an obligate relationship between a mine and a plant. As it turned out, this relationship was not nearly as restrictive as had been thought in many cases.

Text Box 1.1 Title IV and the 1990 Clean Air Act Amendments

Title IV of the 1990 Clean Air Act Amendments (CAAA) called for large reductions in sulfur dioxide (SO_2) emissions by coal-fired electrical generating units (EGUs). The aim of Title IV was to cut aggregate annual SO_2 emission levels to approximately 9 million tons by 2010, roughly 50% of the recorded 1980 emission levels from EGUs. To help EGUs make these large SO_2 reductions, Title IV created a cap-and-trade program that established a cap on total SO_2 emissions, allocated allowances to EGUs equal to that cap, and permitted EGUs to freely trade these allowances or to bank them for future use.

Ex post analyses of the trading program tend to be some of the most analytically rigorous: boiler-level data on emissions, the price of permits and methods of compliance utilized allow for the use of sophisticated econometric evaluation techniques. Researchers studying the compliance costs for the first phase (1995-1999) of Title IV, which targeted the dirtiest 110 power plants, have shown that actual costs decreased substantially over time, particularly once the program began and data became available that documented how EGUs were responding to the regulation. Table 1 below provides a comparison of some of the Title IV's cost estimates. Rows that report *ex ante* estimates are shaded gray while rows reporting ex post costs remain unshaded. More recently, Chan et al. (2012) provide a summary of the vast ex-post literature focused on the trading program under Title IV.

Table 1 - Estimates of Compliance Costs for the SO_2 Program*

Author	*Annual Costs (Billions)*	*Marginal Costs per ton SO2*	*Average costs per ton of SO2*
Ex ante Studies			
ICF (1995)	$2.3	$532	$252
White et al. (1995)	1.4-2.9	543	286-334
GAO (1994)	2.2-3.3	n/a	230-374
Van Horn Consulting et al. (1993)	2.4-3.3	520	314-405
ICF (1990)	2.3-5.9	579-760	348-499
Ex post Studies			
Carlson et al. (2000)	$1.1	$291	$174
Ellerman et al. (2000)	1.4	350	137
Burtraw et al. (1998)	0.9	n/a	239
Goulder et al. (1997)	1.09	n/a	n/a
White (1997)	n/a	436	n/a

* Based on Table 2-1, Burtraw and Palmer (2004). n/a – not reported

Title IV proved less costly than originally estimated due to a number of factors, including unanticipated changes in the market for coal due to railroad deregulation, technological improvements and input price changes. The ability of facilities to "bank" SO_2 allowances allowed even greater flexibility in meeting the SO_2 cap, and also helped to contribute to additional reductions in actual compliance costs. Ex post cost estimates by Carlson et al. (2000) and Ellerman et al. (2000) take into consideration the discounted savings from banking. According to Ellerman et al., savings from banking are a relatively minor source of overall savings of Title IV, but are important in developing a picture of the program's overall effectiveness. Absent banking, some EGUs would have had to make larger pollution control investments and/or accelerated their investments in emission controls to be certain of meeting their emission targets. Because of banking, firms were able to "avoid the much larger losses associated with meeting fixed targets in an uncertain world" (Burtraw and Palmer 2004).

1.1.2. Why Ex Ante and Ex Post Cost Estimates May Differ

There are many reasons that potentially explain why ex post and ex ante cost estimates might diverge. The degree to which the studies included in Table 1.2 reflect on these reasons vary. They also vary with regard to the level of insight they provide on why ex ante and ex post cost estimates differ. With these caveats in mind, we briefly summarize potential reasons ex ante and ex post costs may differ. We are particularly concerned with factors that might lead to ex ante cost estimates being systematically too high (or too low), as opposed to those that would result in their being less accurate while still, on average, correct.

1.1.2.1. Strategic factors affecting ex ante costs

Much of the cost information used in regulatory analyses comes directly from industry (Hodges 1997; Harrington et al. 2000; Bailey et al. 2002). This is unavoidable since industry generally has the best information concerning expected compliance costs. It is not uncommon for EPA to solicit industry compliance cost data through surveys of individual firms or interactions with their trade organizations (Harrington et al. 2000). However, reliance on industry provided information leads to the possibility that compliance costs are either strategically over or understated by industry or by regulators when using this information to generate estimates.

A number of studies argue that regulated entities may overstate their costs of compliance (Hodges 1997, Bailey et al. 2002, MacLeod et al. 2006). Firms facing regulation might misrepresent their costs in a strategic attempt to influence regulator's actions and thwart what they see as onerous regulations by providing a signal that costs are prohibitive (see Bailey et al. (2002), and more generally, Sappington and Stiglitz (1987)).[11] *Ex ante* cost estimates are also typically based on the application of existing technologies, rather than relatively untested innovative approaches to inputs, abatement, and processes. While the best source for information about existing technologies is the people who use them, industry is likely to describe one or more plausible ways of complying rather than evaluate all alternatives before identifying those that are likely to minimize compliance costs. Harrington et al. (2000) also suggest that firms are more likely to describe "off-the-shelf" technologies in their cost estimates rather than examining opportunities for innovation.

Not all firms within an industry, or across different industries, have the same motivations, however. An alternate explanation may be that industry is providing conservative estimates given the numerous uncertainties associated with estimating compliance costs of regulations. For example, Oosterhuis, et al. (2006) note that, while "[t]here seems to be little evidence of industry knowingly providing biased cost estimates . . . in the face of uncertain future technological development, the affected industry will tend to come up with relatively high cost figures."

Industry interventions may also interact with process and timing issues to affect the accuracy of initial cost estimates. Proposed rules published in the *Federal Register* often receive a disproportionate number of comments, particularly of a technical nature, from the regulated industries and groups that support them

[11] Bailey, et al., (2002) make an interesting related observation: in addition to overstating costs, industry groups may also question the benefits of a proposed regulation.

highlighting specific issues. Environmental and public interest groups, in contrast, may submit fewer comments, which tend to be less specific—and therefore may be less useful to regulators for revising cost estimates. EPA's internal Action Development Process and the Administrative Procedures Act, which covers all Executive Branch agencies, require EPA to consider and respond to comments received in the open comment period and explain why cost estimates differ.

As a result of this asymmetric distribution of comments, final rules often prove less stringent than the versions initially proposed (Magat et al. 1986). Morgenstern and Landy (1997) find that industry interventions led to less stringent final standards in all twelve of the rules they considered. To the extent that Agency analyses were based on a version of a rule that was later made less stringent in response to industry comment, cost estimates may be higher than realized costs.

Environmental regulation might impose a restraint on the competition that can arise when some firms cannot operate as cleanly as others. Salop and Scheffman's (1983) depiction of "raising rivals' costs" could provide a rationale for why some firms would prefer regulation that would increase their own level of regulation because it would hurt others more.[12] Bailey et al. (2002) raise an interesting example of divergent incentives between the petroleum and the automobile industries. The former may oppose tighter regulation on fuels, whereas the latter might see the reformulation of fuel as a motivation for consumers to purchase new cars which perform better on the reformulated fuel.

A related concern may be that a regulatory agency may be less rigorous in estimating the costs of rules that appear likely to pass a benefit-cost test. Under such circumstances there may be reduced incentive for regulators to refine their cost estimates or to investigate alternative pathways to compliance, such as process changes or alternative technologies. Further, regulators might conservatively overstate costs in cases when affordability criteria must be met on the grounds that if a regulation is found to be affordable when stated costs are higher than expected, the regulation will be affordable using more refined estimates of costs as well. Harrington et al. (2000) noted that EPA provided upper bound cost estimates in their effluent guidelines program. It might also be counterproductive for regulators to strive to establish a more refined precise cost estimate, as the regulated industry might then feel compelled to protest, perhaps on the grounds that they do not want to see such cost estimates applied in subsequent rule-making.

In addition to the technologies regulators assume when predicting the costs of regulation, they also typically make assumptions concerning compliance and coverage. While it is common for regulators to assume full compliance with a proposed rule, actual compliance may be less-than-perfect. Although it is now dated, Putnam et al. (1980) found compliance rates of only 54 percent in the iron and steel industry and 83 percent in petroleum. MacLeod et al. (2006) cite imperfect compliance as one reason for finding costs overestimated in *ex ante* studies.

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[12] Maloney and McCormick (1982) argue that tighter OSHA regulation of cotton dust and EPA regulations to prevent significant deterioration near existing factories both had the effect of restricting new competition and enhancing the profits of incumbent firms that were well suited to avoid the impact of the regulations or exempted from meeting it. See Adler (1996) and Bailey et al. (2002) for other examples.

A related consideration concerns the regulators' assumptions concerning baselines. EPA's *Guidelines for Preparing Economic Analyses* (2010) instruct analysts to compare the benefits and costs of regulations relative to a "baseline," which is defined as "a reference point that reflects the world without the regulation". Some authors have suggested, however, that regulatory agencies have their own strategic objectives which could, in theory, lead to incentives both to overstate the benefits and understate the costs of regulation (James 1998, Harrington et al. 2000, OMB 1998, Hahn 1996, MacLeod et al. 2006). Harrington et al. (2000) find that agencies may overstate the baselines relative to which subsequent costs under regulation are compared, but that the data do not support a purposeful underestimation of costs *per se*. Moreover, there may be limits to the ability of agencies to pursue cost underestimation. Industry groups with relatively concentrated membership and relatively closely aligned interests are likely to challenge unrealistically low estimates.

1.1.2.2. Technological innovation and unforeseen compliance options

As Bailey et al. (2002) write, "*Ex ante* estimates are forecasts and, like all forecasts, their accuracy will be limited due to uncertainty." There are a number of potential sources of uncertainty in cost analyses. Perhaps the most prominent is the prospect for the development of new technology to meet regulatory requirements. Almost all earlier literature surveys highlight that ex ante estimates of the cost of regulation do not carefully consider the role of innovation, or more broadly, the full range of options open to regulated entities in complying with tighter standards.

There is a vast literature on the "induced innovation hypothesis," and environmental regulations are listed as one factor among many that may induce innovation (see, in particular, Jaffe et al. (2003) for a survey of environmental regulation and innovation). When firms are forced to rethink production processes and become more efficient, the result may be both environmental improvement and competitive advantage (Porter 1991, Heinzerling and Ackerman 2002). While it is a recognized best practice to at least attempt to factor "learning curve" effects into estimates of the costs of regulation (EPA 2010),[13] analysts may not incorporate potential technological innovation into *ex ante* cost estimates. Even if they do include their best estimates of future technological improvements, there would still be random variation in how quickly or completely such improvements are realized.

Different assumptions concerning technological progress, requirements arising from regulations other than that under consideration in the analysis, and market conditions could all affect the estimated cost of regulations. For instance, when EPA estimated costs under its Enhanced Inspection and Maintenance program for automobiles, analysts assumed a high level of effectiveness of repairs and the incorporation of 56 million cars into the program. After implementation, however, it was determined that the repairs were

[13] These effects are due to compliance costs tending to decrease over time as regulated entities learn how to more easily comply with the regulation.

less effective at reducing emissions than EPA analysts assumed. Only four states actually implemented the program (Harrington et al 2000).

There are numerous cases where technological innovation following a new regulation was underestimated. In EPA's Chlorofluorocarbon (CFC) Rule, for example, the *ex post* costs of the CFC phase-out were 30 percent less than the *ex ante* estimates, even though an expedited phase-out occurred (Hodges 1997). Analysts estimating costs prior to the CFC phase-out's implementation did not account for process changes, reliance on blends of chemicals, and substitutes (e.g., existing hydrofluorocarbons or HFCs). While estimates suggested that substitutes would be unavailable for almost a decade, industrial efforts led to their availability after about two years (Hodges 1997; Harrington et al. 2000).[14] In this case, while the CFC rule was under development (for approximately two years), industry researched alternatives. After substitutes and new practices were identified, firms faced new costs, lower than those anticipated under *ex ante* estimates (Hammitt 2000, Harrington et al 2000).

As another example, cost estimates prior to the implementation of the Title IV of the 1990 CAAA failed to predict technological and process evolution that ended up lowering compliance costs considerably. Original estimates predicted compliance costs between $4 billion and $5 billion per year (Hodges 1997). In the *ex ante* analysis, scrubbers -- the SO_2 treatment technology -- were assumed to be less efficient than *ex post* studies show. Original estimates rested on assumptions that scrubbers were 85 percent reliable and removed between 80 and 85 percent of sulfur produced by an electric utility. In actuality, scrubbers have been more than 95 percent reliable and remove approximately 95 percent of total sulfur (Harrington et al 2000). Moreover, Popp (2003) concluded that Title IV, which was designed to provide incentives to install scrubbers with higher removal efficiencies, was successful in promoting the introduction of higher efficiency scrubbers into the market, thereby leading to lower operating costs. The *ex ante* analysis also did not account for fuel mixing—the blending of low and high sulfur coal—that lowered sulfur dioxide emissions (Harrington et al 2000). At the time of the estimates, blending fuels seemed impractical (Hodges 1997).

Finally, it makes sense to suppose that technological innovation is more likely to occur in response to regulations that affect a large number of facilities. Developing an improved technology is a fixed cost, and so investment in such technologies will be more attractive the greater the number of production units and cost savings over which it can be amortized.

1.1.2.3. Unanticipated exogenous changes

Even an analysis that might have proved to be reasonably accurate at the time it was prepared may be well wide of the mark by the time the rule actually enters into force. The EPA Action Development Process is often time-intensive. In 2006, the mean action development time for "significant" rules (those requiring

[14] CFC-12, used in refrigeration, was replaced with HFC-134a, an existing chemical used in automobile air conditioners starting back in 1991. Use of CFC-113 in foam-blowing applications has been replaced by HFC, a substitute; additionally, process changes and chemical blends were essential to decreased consumption of CFC-113 (Harrington *et al.* 2000).

benefit-cost analyses) was 1,088 days, or nearly three years.[15] Even if we confine our attention to the period between the proposal of a regulation and the publication of a final rule, Kerwin and Furlong (1992) found that 523 days elapse on average. Regulatory processes are also often subject to significant amendment and delay. Cost estimates based on early versions of a rule may no longer apply to the rule that eventually emerges (Putnam, *et al*., 1980, Morgenstern and Landy 1997, Harrington, *et al*., 2000; see also Oosterhuis, *et al*., 2006, who note a similar tendency in European regulation).[16]

Lower costs may arise from factors not directly tied to the regulation, but perhaps indirectly linked to it. In the case of the SO_2 rule, for example, changing market conditions affected the accuracy of *ex ante* cost estimates. Cost estimates did not anticipate the impacts of a deregulated railroad industry on the reduction of sulfur dioxide pollution. Deregulation of railroads allowed for low-cost shipping of low sulfur coals from the Powder River Basin in Wyoming to the East, decreasing eastern facilities' costs of consuming low sulfur coal. (Hodges 1997; but see also Busse and Keohane 2007, who argue that the two railroads serving the Powder River Basin retained some market power). This reduction in price of low-sulfur coal, coupled with low-cost technological improvements, reduced compliance costs by allowing EGUs in the East to lower SO_2 emissions by expanding their use of low-sulfur coal (Hodges 1997; Carlson et al. 2000; Harrington et al. 2000; Burtraw and Palmer 2004, Busse and Keohane 2007). This change in a related but separate market enabled electricity generators to alter production processes and fuel sources to achieve SO_2 reduction goals. While it cannot be proved that railroad deregulation was driven by heightened demand for Western coal under the CAAA, the benefits of railroad deregulation certainly increased with the increase in demand for low-sulfur coal.

1.2. Methodology

1.2.1 Conceptual Framework for Ex Post Cost Assessment

Developing a standardized framework provides a systematic way to identify the key components of compliance costs relevant to a regulation, to assess whether each of the components turned out to be larger or smaller than the ex ante estimates, and to understand the characteristics of the regulation that influenced the divergence. While the aim here is not to produce ex post cost estimates, or reproduce the ex ante estimates, using the same level of rigor employed in the RIAs, we hope to glean enough information on the drivers of compliance costs to make a weight of evidence determination on the direction of our ex ante

[15] See http://www.epa.gov/regstat/development_time_office2.html

[16] Other authors suggest that such delay may be part of the design of the regulatory process. Bailey, et al. (2002) describe the process of regulatory development in the European Union as a sort of extended negotiation between regulators and the firms they oversee, with each staking out negotiating positions from which they expect to be budged over time. This may, however, represent a distinction between European and US practice, the latter of which they characterize as "adversarial and legalistic."

estimates – were they likely too high, too low, or about right? – and to identify underlying factors that contributed to differences (or similarities) between ex ante and ex post costs.

The degree to which an ex post evaluation of the costs of regulation is able to determine the accuracy of the initial assessment by EPA will vary by rule. We focus the ex post evaluation on costs that – if incorrect - could fundamentally alter the findings of the ex ante cost assessment. The scope of the ex post analysis is informed by a brief review of the ex ante cost assessment to identify:

- T*he main drivers of costs ex ante:* If these drivers were misidentified, ex ante cost estimates might be flawed.
- *The main sources of uncertainty in estimating costs ex ante:* The less that was known with certainty, the less accurate we would expect cost estimates to be.
- *Unanticipated exogenous changes that occurred after completion of the ex ante analysis that have significant implications for the costs of the rule:* If the "state of the world" changed in unpredicted, or perhaps unpredictable, ways, estimates would again be less accurate.

Sources of uncertainty are often rule specific but may include: lack of knowledge about who is in the regulated universe; lack of knowledge about the effectiveness of certain types of control technologies or processes in reducing pollutants; lack of information about the costs of relatively untried control technologies or processes; behavioral responses by industry or consumers to changing rules or incentives, including the possibility of non-compliance (NRC 2012). In general, we maintain a timeline for implementation consistent with ex ante assumptions. However, in some cases there is uncertainty as to when regulated entities begin to undertake investment to comply with the rule. Thus, baseline assumptions may themselves be a source of uncertainty.[17]

Exogenous changes are often difficult to anticipate ex ante but may have significant implications for the cost of meeting rule requirements. Examples include unrelated changes in market demand, higher than expected oil prices, industry wide changes in manufacturing processes (unrelated to the rule), and other regulations, legal or political decisions that occurred concurrent with or after the ex ante assessment took place but affected rule implementation.

Using the information gleaned from the scoping exercise, we proceed to an ex post assessment of costs. For each regulation analyzed, we evaluate likely drivers of identified differences between ex ante and ex post cost estimates using a broad categorization of cost components consistent with EPA's *Guidelines for Preparing Economic Analyses* (2010). Table 1.2 summarizes the key components of the cost analysis and the main questions we pose as part of the ex post assessment.

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[17] OMB defines the baseline as "the best assessment of the way the world would look absent the proposed action" (OMB 2003).

Table 1.2: Summary of Conceptual Framework to Guide Ex Post Cost Assessment -

Cost Component	Assessment Questions Posed
Regulated Universe	What types of entities are required to comply with the rule? How many entities of each type are required to comply?
Baseline	To what extent are these technologies already in use prior to the rule?
Methods of Compliance	What types of technologies or methods are used to comply? How often are these compliance strategies used?
Direct Compliance Costs	What are the initial or one-time compliance costs (fixed or variable components)? What are the ongoing compliance costs (operation and maintenance)?
Indirect Compliance Costs	What are the indirect compliance costs (e.g., quality trade-offs)?
Opportunity Costs	Are there other major opportunity costs associated with the rule (for instance, in related markets)?

To evaluate unit compliance costs, we combine information about direct costs per unit of abatement (*direct compliance costs*) associated with each identified method of compliance (*methods of compliance*) plus any additional indirect compliance costs per unit of abatement (*indirect compliance costs*). When possible, we also offer an assessment of total compliance costs. To do this, we need to understand whether EPA correctly identified who has to comply (*regulated universe*), netting out any facilities already in compliance (*baseline*). While ideally we would measure the social cost of regulation (i.e., the sum of all opportunity costs incurred), most ex ante regulatory analyses only quantify compliance costs. As such, the first five components of the conceptual framework in Table 1.2 focus on the basic components for quantifying compliance costs. The final component (*opportunity costs*) leaves open the possibility of broader ex post evaluation of social cost when possible.

For each case study, we provide a summary of our assessment by cost component in one table to make it easy to understand how the ex ante and ex post costs compare and to aid the reader in making comparisons across case studies (Table 1.3). Table 1.3 includes some sub-categorization of the main cost components to mirror the assessment questions posed in Table 1.2. However, while we strive for consistency across the case studies, sub-categories are sometimes modified to reflect unique aspects of a particular rule.

Table 1.3: Generic "Summary of Findings" Table -

Components of Cost Estimate			Source of Ex Post Information	Assessment (Compared to Ex Ante)
Regulated Universe	Types of Entities			
	Number of Entities			
Baseline				
Methods of Compliance	Types			
	Usage			
Compliance Costs	Direct, One-Time	Fixed Cost		
		Variable Cost		
	Direct, On-Going	Operating		
		Maintenance		
	Indirect			
Opportunity Costs				
Per Unit Costs				
TOTAL COSTS				

1.2.2. Selection of Rules

To select the five rules for the case studies presented in this report, we first assembled an inventory of all EPA regulations coded in the Agency's Rule and Policy Information and Development System (RAPIDS) database as "economically significant" and promulgated since January 1995. RAPIDS is the Agency's tracking database for regulatory and significant non-regulatory actions.[18] Typically, these are actions that will involve notice and comment rulemaking, or are major work products that require significant cross-Agency collaboration. "Economically significant" rules are those anticipated to have an annual effect on the costs or benefits associated with the rule of $100 million or more as stated in Executive Order 12866.[19] We focus on recent regulations because rules promulgated decades ago will likely have been overridden by new regulations, making it more difficult to isolate the compliance strategies and costs associated with the old

[18] In February 2012, ADP TRACKER replaced RAPIDS as the system EPA uses to track its Action Development Process (ADP).

[19] Regulatory impact analyses are unlikely to be performed if the annual effect is predicted to be less than $100 million.

rule. Furthermore, the lessons learned from examining older regulations may be less relevant going forward due to advancements in benefit-cost analysis methodologies that have been adopted since that time.

The RAPIDS search generated a list of 111 entries. We reviewed the list and gathered preliminary information on each rule (e.g., compliance dates) to determine which rules could feasibly be studied. We discarded any duplicate entries and rules that were:

- not yet implemented
- remanded by the courts
- consisting of minor amendments to existing rules
- noted to be "Other significant action" but not meeting $100 million benefit-cost criteria for E.O.12866, or
- difficult to analyze (e.g. multi-sector nature of NAAQS).

To that list, we added effluent limitation guidelines, a category of rules that routinely undergoes OMB review for which detailed cost analyses are produced. The resulting eligible inventory (shown in Table 1.4) consists of 42 rules promulgated between 1995 and 2005. We circulated this list to EPA program offices for their feedback to ensure that there were no inadvertent omissions or rules that should not be included. The list does not include chemical actions as these are not tracked in the RAPIDS database.

Five rules were selected to serve as pilot studies to inform which methodologies are most appropriate to measure ex post compliance costs for a range of rules. The five rules analyzed in this report are:

- National Primary Drinking Water Regulation for Arsenic (2001)
- Integrated NESHAP and Effluent Guidelines for Pulp and Paper – known as the Cluster Rule (1998)
- NESHAP: Chemical Recovery Combustion Sources at Kraft, Soda, Sulfite and Stand-Alone Semichemical Pulp Mills (2001)
- Locomotive Emission Standards (1998)
- Methyl Bromide Critical Use Nomination for Preplant Soil Use for Strawberries Grown for Fruit in Open Fields on Plastic Tarps (2004 – 2008)

These rules were not chosen randomly, but rather were chosen to cover various media, source categories, and types of regulations (e.g., performance standard versus prescriptive regulation). Four of the rules were taken from the master list shown in Table 1.4 and described above. The critical use exemption nomination of a fumigant was identified separately by the Office of Pesticides Program (OPP) as a good candidate for study.[20] Because the two NESHAPs for the Pulp Mills were so closely related, we opted to combine the two rules into one case study and that case study is part of this report. Future case studies will be chosen using stratified random sampling (see Chapter 6).

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[20] We also selected the NSPS for Nitrogen Oxide Emissions but decided to postpone the analysis in a subsequent report.

Table 1.4. Final EPA Regulations Eligible for Retrospective Study -

	Title	Program Office	Year
1	Final Effluent Limitations Guidelines and Standards for the Coastal Subcategory of the Oil and Gas Extraction Point Source Category (RIN 2040–AB72)	OW	1996
2	Pharmaceutical Manufacturing Category Effluent Limitations Guidelines, Pretreatment Standards, and New Source Performance Standards (RIN 2040-AA13)	OW	1998
3	National Primary Drinking Water Regulations: Stage I Disinfectant/Disinfection By-Products Rule (RIN:2040-AB82SAN:2772; Tier:1; Stage:COMPLETED)	OW	1998
4	National Primary Drinking Water Regulations: Interim Enhanced Surface Water Treatment Rule (RIN:2040-AC91SAN:2304; Tier:N/A; Stage:COMPLETED)	OW	1998
5	NPDES Comprehensive Storm Water Phase II Regulations (RIN:2040-AC82SAN:3785; Tier:3; Stage:COMPLETED)	OW	1999
6	Effluent Limitations Guidelines, Pretreatment Standards, and New Source Performance Standards for the Landfills Point Source Category (RIN 2040-AC23)	OW	2000
7	Effluent Limitations Guidelines, Pretreatment Standards, and New Source Performance Standards for the Commercial Hazardous Waste Combustor Subcategory of the Waste Combustors Point Source Category (RIN 2040-AC23)	OW	2000
8	Effluent Limitations Guidelines, Pretreatment Standards, and New Source Performance Standards for the Transportation Equipment Cleaning Point Source Category (RIN 2040-AB98)	OW	2000
9	Effluent Limitations Guidelines, Pretreatment Standards, and New Source Performance Standards for the Centralized Waste Treatment Point Source Category (RIN 2040-AB78)	OW	2000
10	Effluent Limitations Guidelines and New Source Performance Standards for the Oil and Gas Extraction Point Source Category (RIN 2040-AD14)	OW	2001
11	National Primary Drinking Water Regulations: Arsenic and Clarifications to Compliance and New Source Contaminant Monitoring (RIN:2040-AB75SAN:2807; Tier:2; Stage:COMPLETED)	OW	2001
12	Coal Mining Point Source Category; Amendments to Effluent Limitations Guidelines and New Source Performance Standards (RIN 2040-AD24)	OW	2002
13	Effluent Limitations Guidelines, Pretreatment Standards, and New Source Performance Standards for the Iron and Steel Manufacturing Point Source Category (RIN 2040–AC90)	OW	2002
14	Effluent Limitations Guidelines and New Source Performance Standards for the Metal Products and Machinery Point Source Category (RIN 2040-AB79)	OW	2003
15	Effluent Limitations Guidelines and New Source Performance Standards for the Concentrated Aquatic Animal Production Point Source Category (RIN 2040-AD55)	OW	2004
16	Effluent Limitations Guidelines and New Source Performance Standards for the Meat and Poultry Products Point Source Category (RIN 2040-AD56)	OW	2004
17	Land Disposal Restrictions - Phase III: Decharacterized Wastewaters, Carbamate Wastes, and Spent Aluminum Potliners (RIN:2050-AD38SAN:3365; Tier:1; Stage:COMPLETED)	OSWER	1996

	Title	Program Office	Year
18	Risk Management Program for Chemical Accidental Release Prevention (RIN:2050-AD26SAN:2979; Tier:N/A; Stage:COMPLETED)	OSWER	1996
19	Land Disposal Restrictions - Phase IV: Treatment Standards for Metal Wastes and Mineral Processing wastes; Mineral Processing Secondary Materials and Bevill Exclusion Issues (RIN:2050-AE05SAN:3366; Tier:2; Stage:COMPLETED)	OSWER	1998
20	PCBs; Polychlorinated Biphenyls (PCBs) Disposal Amendments (RIN:2070-AD04SAN:2878; Tier:2; Stage:COMPLETED)	OPPTS	1998
21	Lead; Identification of Dangerous Levels of Lead Pursuant to TSCA Section 403 (RIN:2070-AC63SAN:3243; Tier:1; Stage:COMPLETED)	OPPTS	2001
22	TRI; Reporting Threshold Amendment for Certain Persistent and Bioaccumulative Toxic Chemicals (PBTs) (RIN:2070-AD09SAN:3880; Tier:1; Stage:COMPLETED)	OEI	1999
23	Emission Standards for Marine Tank Vessel Loading Operations (RIN:2060-AD02SAN:3104; Tier:N/A; Stage:COMPLETED)	OAR	1995
24	NSPS: Municipal Waste Combustion--Phase II and Phase III (Large Units) (RIN:2060-AD00SAN:2916; Tier:1; Stage:COMPLETED)	OAR	1995
25	NSPS: Municipal Solid Waste Landfills Amendments (RIN:2060-AC42SAN:2535; Tier:3; Stage:COMPLETED)	OAR	1996
26	Regulation of Fuel and Fuel Additives: Certification Requirements for Deposit Control Additives (RIN:2060-AG06SAN:3597; Tier:2; Stage:COMPLETED)	OAR	1996
27	Control of Emissions of Air Pollution: Emission Standards for Gasoline Spark-Ignition and Diesel Compression-Ignition Marine Engines (RIN:2060-AE54SAN:3350; Tier:N/A; Stage:COMPLETED)	OAR	1996
28	Federal Test Procedure for Emissions From Motor Vehicles and Motor Vehicle Engines; Review (RIN:2060-AE27SAN:3323; Tier:N/A; Stage:COMPLETED)	OAR	1996
29	Acid Rain Program: Nitrogen Oxides Control Regulation (RIN:2060-AD45SAN:2888; Tier:N/A; Stage:COMPLETED)	OAR	1996
30	Acid Rain Program: Phase II Nitrogen Oxides Reduction Program (RIN:2060-AF48SAN:3575; Tier:3; Stage:COMPLETED)	OAR	1996
31	Hospital/Medical/Infectious Waste Incinerators (RIN:2060-AC62SAN:2719; Tier:N/A)	OAR	1997
32	Control of Emissions of Air Pollution From Nonroad Diesel Engines (RIN:2060-AF76SAN:3645; Tier:1; Stage:COMPLETED)	OAR	1997
33	Compliance Assurance Monitoring Rule (Previously Enhanced Monitoring Rule) (RIN:2060-AD18SAN:2942; Tier:1; Stage:COMPLETED)	OAR	1997
34	Integrated NESHAP and Effluent Guidelines: Pulp and Paper (RIN:2060-AD03SAN:3105; Tier:1; Stage:COMPLETED)	OAR	1998
35	Locomotive Emission Standards (RIN:2060-AD33SAN:2961; Tier:2; Stage:COMPLETED)	OAR	1998
36	NSPS: Municipal Solid Waste Landfills Amendments (RIN:2060-AI09SAN:4150; Tier:3; Stage:COMPLETED)	OAR	1998

	Title	Program Office	Year
37	NSPS: Nitrogen Oxide Emissions From Fossil-Fuel Fired Steam Generating Units--Revision (RIN:2060-AE56SAN:3352; Tier:2; Stage:COMPLETED)	OAR	1998
38	Control of Emissions of Air Pollution From Nonroad Diesel Engines (RIN:2060-AF76SAN:3645; Tier:1; Stage:COMPLETED)	OAR	1998
39	Control of Emissions from Nonroad Diesel Engines (RIN:2060-AH50SAN:4014; Tier:1; Stage:COMPLETED)	OAR	1998
40	Finding of Significant Contribution and Rulemaking for Certain States in the Ozone Transport Assessment Group (OTAG) Region for Purposes of Reducing Regional Transport of Ozone (RIN:2060-AH10SAN:3945; Tier:2; Stage:COMPLETED)	OAR	1998
41	NESHAP: Source Categories: (SOCMI) and Other Processes Subject to Negotiated Regulation for Equipment Leaks (HON) (RIN:2060-AC19SAN:2363; Tier:N/A; Stage:COMPLETED)	OAR	1999
42	Tier II Light-Duty Vehicle and Light-Duty Truck Emission Standards and Gasoline Sulfur Standards (RIN:2060-AI23SAN:4211; Tier:1; Stage:COMPLETED)	OAR	2000

1.2.3. Strategies for Ex Post Data Collection

Various methodologies exist for collecting the information needed to conduct the ex post assessments, ranging from using publicly available data sources, reaching out to industry compliance experts, conducting site visits to facilities, and/or to administering a comprehensive industry survey such as the Pollution Abatement Costs and Expenditures (PACE) survey (see Text Box 1.2.[21] For each case study, we assessed whether it would be possible to collect sufficient ex post compliance cost information using only publicly-accessible data sources. For example, in the case of the 1998 Locomotive Rule, we assessed whether there are any databases from which we could determine the number of locomotives in operation (based on data of original manufacture or remanufacture) to compare with EPA's ex ante estimate. Similarly, we explored the availability of public data on the control mechanisms used for each locomotive to come into compliance with the rule requirements and the cost of such mechanisms.

In general, we found that while data for some necessary components are readily available, cost information is generally lacking. The critical use exemption for methyl bromide use for California strawberries fared the best of the five with regard to the availability of cost information, and was designated as the case study that would be based on publically available data alone.[22] We also explored the applicability and usefulness of the other methodologies for each rule to help inform analysis of future rules for this project.

[21] In the future it may be possible to collect ex post cost data for a particular rule by targeting the affected regulated entities directly using the PACE survey – this hinges on the PACE survey once again becoming an annual survey. The PACE survey has not been conducted since 2005 and has not been conducted annually since 1994.

[22] Ultimately, publicly available data were used to augment other sources for the Arsenic rule and the MACT II rule.

For four rules –the combined Cluster Rule and MACT II, Arsenic rule, and Locomotive rule - we consulted - industry compliance experts with contractor assistance to gather information on compliance strategies and ex post cost data. The process used to identify appropriate industry compliance experts with sufficient knowledge about the ex post regulatory compliance costs of the selected rules consisted of several steps. For each rule, we began by examining the rulemaking docket, the primary source for the initial set of potential industry compliance experts. This set includes organizations that supplied data and information during the original rulemaking and/or commented on it during the comment period. The initial set of potential industry compliance experts was circulated to relevant EPA staff for review. In some instances, the relevant program office was able to suggest additional potential industry compliance experts. We also allowed for identification of industry compliance experts through discussions with other entities or targeted internet searches. In some cases, for example, independent associations suggested appropriate engineering compliance assistance firms. We approached the following types of organizations during the information collection process for a given rule: engineering compliance assistance firms, compliance technology vendors, compliance assistance firms or consultants, independent associations of entities affected by regulations, independent information publishers, state regulatory agencies, and EPA contractors who supported the rule.[23]

Screening and securing commitment from the identified experts to participate in our study required considerable effort. In most instances, it took at least 2 to 3 rounds of phone calls to reach an individual within each organization who would be able to provide relevant feedback. Even after finalizing information provision agreements with the experts, weekly email and phone reminders were sometimes necessary to ensure their timely participation. To aid in the conversations with the experts, we developed a pilot questionnaire about each rule based on our review of EPA's ex ante cost estimation methodology. This questionnaire was also circulated to relevant EPA staff for comment and feedback. Each expert was also asked to provide documentation for any calculations he or she made to answer the cost questions during the interview. Summaries of the outreach effort for particular rules are described within each case study below together with the questionnaires.

[23] Any information provided for the RCS by contractors who helped EPA develop the rule was extensively documented.

Text Box 1.2. Pollution Abatement Costs and Expenditures Survey (PACE) -

The PACE survey was conducted annually between 1973 and 1994 (with the exception of 1987), but was discontinued after 1994 by the U.S. Census Bureau for budgetary reasons. Recognizing the need for this type of data, EPA provided the necessary financial and technical support to enable the Census Bureau to conduct additional surveys and collect PACE data for 1999 and 2005, but limitations on resources and other priorities have limited more recent data collection to these two years.

The PACE survey is the only comprehensive publicly available source of pollution abatement (operating) costs and (capital) expenditures spending for the U.S. manufacturing sector. The PACE survey collects establishment-level information on pollution abatement capital expenditures and operating costs associated with compliance with local, state, and federal regulations, as well as voluntary or market-driven pollution abatement activities. The PACE survey intends to capture only *incremental* costs of pollution abatement. The pollution abatement capital expenditures and operating costs are disaggregated into four "activity" categories: treatment, recycling, disposal, and pollution prevention, and by three types of media: air emissions, water discharges, and solid waste. Total pollution abatement operating cost are separated into five cost categories: (1) salaries, wages, and benefits; (2) energy costs; (3) materials and supplies; (4) contract work, leasing, and other purchased services; and (5) depreciation.

While EPA uses the PACE data to estimate the aggregate costs of its regulations, the data collected by the PACE survey contains information that could be useful in estimating the ex post cost of specific EPA regulations on the manufacturing sector in several ways. First, if EPA regulates an entire industry, EPA could approximate the incremental cost of a regulation by comparing pollution abatement costs for the entire industry before and after a regulation becomes effective. Second, if EPA knows which manufacturing facilities need to comply with a new regulation, EPA could estimate the incremental cost of the regulation using the establishment-level data at the US Census Bureau. Finally, if the PACE survey were to become an annual survey once again, EPA could use it to estimate the incremental cost of a new or more stringent regulation by developing a very specific set of questions that would only be sent to manufacturing facilities that EPA believed to be covered by the rule. Also since EPA would have the ability to collect cost data for several years before and after the regulation became effective it would provide more information on how pollution abatement costs change over time. This would also allow EPA to estimate how regulations induce technological change and affect employment.

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Chapter 2: Cluster Rule and MACT II Rule

Cynthia Morgan, Carl Pasurka and Ron Shadbegian

On April 15, 1998, U.S. Environmental Protection Agency (EPA) published new National Emission Standards for Hazardous Air Pollutants from the Pulp and Paper Industry (subpart S) as well as Effluent Limitations Guidelines, Pretreatment Standards, and New Source Performance Standards: Pulp, Paper, and Paperboard Point Source Category. Because the promulgated rule integrated air and water rulemakings, the combined standards and guidelines became known as the "Cluster Rule." The Cluster Rule, EPA's first integrated, multi-media regulation, set limits to reduce releases of toxic (e.g., dioxin, furans, chloroform) and nonconventional (e.g., adsorbable organic halides, chemical oxygen demand) pollutants to both air and water from the pulp and paper industry. According to EPA , 155 of the 565 pulp, paper and paperboard mills in the U.S. needed to comply with the new maximum achievable control technology (MACT I and III) standards for hazardous air pollutants. Of those 155 mills, 96 mills were also required to comply with either a new set of best available technology (BAT) economically achievable effluent guidelines or pretreatment standards for existing sources (PSES) (see U.S. EPA 1997b, p. 4-5).[24] Most requirements of the Cluster Rule became effective April, 2001.

Later, on January 12, 2001, EPA published the MACT II (combustion sources) rule to regulate chemical recovery combustion sources in the pulp and paper industry. This rule, which had to be met by January 12, 2004, established standards for sources annually emitting at least 10 tons of a hazardous air pollutant (HAP) or 25 tons of total HAPs. At rule proposal, it was anticipated that 149 of the mills subject to MACT I would also be subject to MACT II (see U.S. EPA 1998a, p. 18579). By the time of the promulgation of the final rule, EPA (2001b, Appendix B) identified 133 mills that would be subject to MACT II. A provision of the MACT II that improved the efficiency of the regulation for existing sources was a "bubble compliance alternative" allowing mills to reduce emissions at any unit as long as the mill-specific bubble limit was achieved.

In this paper, we compare EPA's ex ante cost analyses of the Cluster and MACT II rules to an ex post assessment of costs. This is not an evaluation of how well EPA conducted its ex ante analyses at the time of the rulemaking. Instead we attempt to gather enough information on the key drivers of compliance costs to make an informed *judgment* as to whether ex post costs are higher or lower than the estimates of ex ante

[24] U.S. EPA (1997b, p. 2-6) summarizes the mill subcategories (i.e., pulping processes) subject to the air and water provisions of the Cluster Rule. According to the U.S. EPA (1997b, p. 1-3), the technological basis for PSES is "… the same as the basis for the BAT limitations …, with the exception of biological treatment." Hence, in this paper we often refer to the effluent limitation guidelines (ELGs) of the Cluster Rule as BAT.

costs for these rules. This allows us to observe whether actual costs diverged from ex ante costs and, if so, what factors caused this divergence (e.g., changing market conditions, technological innovation, etc.).

The remainder of this chapter is organized as follows. Section 2.1 details the impetus and timeline for regulatory action. Section 2.2 presents EPA's ex ante cost estimates of the Cluster Rule and MACT II, while Section 2.3 discusses the information available to conduct the ex post evaluation of costs. Section 2.4 presents the results of our ex post assessment of compliance costs. Finally, Section 2.5 summarizes our findings and discusses limitations of our analysis.

2.1. Impetus and Timeline for Regulatory Action

A citizen's petition filed in October 1984 by the Environmental Defense Fund (EDF) and the National Wildlife Federation (NWF) represents the origin of the Cluster Rule and MACT II regulations.[25] After EPA denied the petition, the EDF and NWF filed a lawsuit against EPA that ended when EPA signed a consent decree in 1988. The consent decree required EPA to address the issue of discharges of dioxins and furans into surface waters by October 31, 1993, while the Clean Air Act (CAA) amendments of 1990 required EPA to set MACT standards for the industry by 1997. As a result, EPA decided to combine the rulemakings and design the most cost-effective rule *and* reduce cross-media pollution transfers.[26] EPA proposed its regulations on December 17, 1993 and solicited comments and data on the rule.

The 1993 proposed Cluster Rule required complete substitution of elemental chlorine-free bleaching (ECF), which uses chlorine dioxide (ClO_2) as the bleaching agent, for elemental chlorine bleaching as well as the use of oxygen delignification (i.e., O2 delig) and/or extended delignification (i.e., extended delig) for 77 bleached papergrade kraft mills in mid-1995 (see U.S. EPA 1997b, p. 4-5). O2 delig reduces the amount of lignin in the pulp before bleaching process, minimizing the bleaching chemicals required to brighten the pulp. In addition, 10 papergrade sulfite mills were required to use totally chlorine-free bleaching (TCF). EPA anticipated 300 pulp and paper mills would incur costs due to the proposed 1993 Cluster rule, with 11-13 mills confronting the possibility of closure. This led EPA to project that capital expenditures associated with an integrated (i.e., air and water) regulatory strategy would approach $4 billion (in 1992 dollars) with annual operating and maintenance (O&M) costs of $401 million (see U.S. EPA 1993a, pp. 66153- 66154). Non-EPA sources estimated the Cluster Rule would cost $11.5 billion (see Pauksta, 1995, p. 51), while the cost of the combined Cluster Rule and MACT II rule would be $13.2 billion (see Barton, et al., 1995). An important component of the cost of the proposed regulation was the requirement of O2 delig or extended delig. Barton et al. (1995, p. 104) estimated the combined cost of the O2 delig systems and improved brown stock washing would be

[25] The discussion of the origins of the Cluster Rule and MACT II Rule is drawn from Powell (1997, pp. 1-12), and the U.S. EPA (1993c, Chapter 2).

[26] By promulgating the air and water standards simultaneously, EPA was able to develop control options that included process change technology that would control both emissions to air and pollutant discharges to water.

\$2.3 billion, while ClO_2 upgrades and conversions would cost another \$530 million.[27] In the ensuing years, the Cluster Rule underwent substantial modification before the final rule was promulgated in 1998.[28] In addition to fewer mills being affected by the 1998 final rule compared to the 1993 proposal, the final rule dropped the O2 delig / extended delig requirement, which led some companies to petition EPA and request incentives/rewards for mills that installed O2 delig (EPA Asked 1996).

In the final Cluster Rule for air pollutants, EPA set MACT standards (referred to as MACT I & III) that required pulp and paper mills to capture and treat toxic air pollutant emissions produced during the pulping and bleaching stages of the manufacturing process. The MACT I (non-combustion sources) rule covers mills that chemically pulp wood using kraft, semi-chemical, sulfite, or soda processes, while the MACT III rule covers mills that mechanically pulp wood, or pulp secondary fiber or non-wood fibers, or produce paper or paperboard. EPA estimated that HAPs emissions would decline by 139,000 megagrams (one ton equals 0.908 megagrams) per year.[29] These standards could be met in a variety of ways including performance standards (percent reductions in emissions, mass reductions in emissions, and concentration or mass limits), design standards (use of specific technologies operated in a certain way), and routing of emissions to combustion or control devices.

The effluent limitation guidelines (ELGs) established in the Cluster Rule covered two subcategories of mills: bleached papergrade kraft and soda (BPK) and papergrade sulfite (PS). The ELGs and pretreatment standards set technology-based limits on dioxins, furans, chloroform, 12 chlorinated phenolics, and adsorbable organic halides (AOX), requiring a 96 percent reduction in dioxin and furan, and a 99 percent reduction in chloroform. These requirements were based on substituting chlorine dioxide for chlorine in the bleaching process (i.e., using ECF or TCF bleaching). The options for the BPK subcategory (listed in terms of increasing stringency) were 100 percent substitution of chlorine dioxide for elemental chlorine (ECF), 100 percent substitution of chlorine dioxide for elemental chlorine (ECF) plus oxygen delignification and/or extended delig, and total chlorine free (TCF) bleaching. EPA only estimated costs for: TCF bleaching for the calcium- and magnesium-based processes; and 100 percent substitution of chlorine dioxide (ECF) for elemental chlorine ammonium-based processes and specialty grade pulps.

The Cluster Rule encouraged additional pollutant reductions through the Voluntary Advanced Technology Incentives Program (VATIP). Mills who were interested in this program were given extended compliance time in order to explore all technology options or make process changes that would reduce pollution beyond the

[27] The goal of brown stock washing is to remove the maximum amount of spent cooking liquor from the pulp using the minimum amount of wash water. The solids left in the pulp can interfere with the bleaching process and increase the costs of bleaching.

[28] Rule and implementation information for the air portion of the Cluster Rule can be found at: http://www.epa.gov/ttnatw01/pulp/pulppg.html. Information on the Effluent Guidelines for the Cluster Rule can be found at: http://water.epa.gov/scitech/wastetech/guide/pulppaper/index.cfm

[29] The HAPs covered by the Cluster Rule included compounds such as methanol, chlorinated compounds, formaldehyde, benzene, and xylene.

discharge limits required by the rule. The program was voluntary and only available to mills that discharged directly to surface waters. Mills that chose to participate received six years to comply with the air standards (April 15, 2004) and an extension of up to eight years for high volume low concentration (HVLC) system vents at kraft mills (April 17, 2006). This extension was designed to encourage mills to install technology to reduce toxic air pollutant emissions as well as discharges of pollutants to air and water from the bleaching process.[30]

In addition to the MACT I and MACT III standards, on January 12, 2001 EPA published the MACT II rule that regulates chemical recovery combustion sources in the pulp and paper industry. The MACT II rule covers kraft, soda, sulfite, and stand-alone semi-chemical pulp mills. The MACT II standards covered HAP metals and gaseous organic HAPs using particulate matter (PM) as a proxy for HAP metals and methanol, and total hydrocarbons as proxies for gaseous organic HAPs. For existing kraft and soda mills, a PM bubble compliance alternative allowed mills to set PM limits for each emission point, as long as the aggregate of these PM limits was equal to the aggregated promulgated PM limits of the individual emission points.

2.2. Ex Ante Cost Estimates

At the proposal the baseline was 1992; however, EPA later updated the baseline pollutant loadings to mid-1995 (U.S. EPA 1997a, p. 4-1). The updated baseline values are reported in Table 2.1. The updated baseline is also reflected in the EPA ex ante cost estimates of the Cluster Rule and MACT II Rule reported in Table 2.2. With the publication of the final MACT II rule (U.S. EPA 2001a, pp. 3188-3189), EPA revised its estimate of the MACT II capital expenditures to $241 million (in 1997 dollars), and its estimate of the annual cost of MACT II to $32.2 million (in 1997 dollars). According to EPA (1997a, pp. 2-2 and 2-3), "The MACT III rule contains National Emission Standards for Hazardous Air Pollutants (NESHAP) for mechanical pulping, secondary fiber pulping, and non-wood pulping mills. No emission reductions or control costs, however, are associated with the MACT III rule …" Table 2.2 is supplemented by Table 2.3 and Table 2.4, which show estimated ex ante costs from several non-EPA sources.

Table 2.3 is divided into three parts based on which rule(s) is associated with the corresponding cost estimate. First, we list two non-EPA estimates that combine the cost of the Cluster Rule and MACT II rule. Next, we list three non-EPA estimates of the Cluster rule, and finally we list two non-EPA estimates of portions of MACT I. Table 2.4 lists three non-EPA estimates of MACT II. Comparing Tables 2.2, 2.3, and 2.4 reveal: (1) both EPA and the pulp and paper industry believed the Cluster Rule would be more costly than the MACT II rule and (2) industry believed EPA ex ante cost estimates substantially underestimated the cost of the Cluster Rule and MACT II rule.

[30] In exchange for mills reducing discharges beyond BAT levels, the VATIP offered mills "… additional time to comply with the Cluster Rules, … reduced monitoring requirements, and public recognition." (see U.S. EPA 2006, p. 9-5)

Table 2.1. Pre-Regulation and Post-Regulation Releases of Selected Pollutants (mid-1995 baseline)

Air Pollutants	Baseline (Mg/year)	Air Emission Reductions (Mg/year)	
		Final Cluster Rules	Final Cluster Rules and Proposed MACT II
Hazardous Air Pollutants	240,000	139,000	142,000
Volatile Organic Compounds	900,000	409,000	440,000
Total Reduced Sulfur	150,000	79,000	79,000
Particulate	NA	(83)	24,000
Carbon Monoxide	NA	(8,700)	49,000

Water Pollutants	Units	Baseline Discharge (BPK Mills)	Estimated Reductions; Final BAT / PSES (BPK Mills)	Baseline Discharge (PS Mills)	Estimated Reductions; Final BAT / PSES (PS Mills)
2,3,7,8 – TCDD	g/year	15	11	0.78	0.65
2,3,7,8 – TCDF	g/year	115	107	6.7	6.4
Chloroform	kkg/year	48	40	5.4	5.2

g- grams
kkg-metric ton (1,000 kilograms)
Source: U.S. EPA (1998a, p. 18575)

Table 2.2. U.S. EPA Ex Ante Cost Estimates of the Cluster Rule & MACT II Rule
(thousands of 1995 dollars)

	MACT IA	MACT II (alternate A)	BAT/PSES	Cluster Rule (MACT I plus BAT/PSES)	Cluster Rule plus MACT II
Capital	500,758	258,389	1,039,388	1,540,146	1,798,535
O&M	74,718	5,202	158,413	233,131	238,334
Post tax Annualized	81,767	23,139	171,619	253,386	276,525

Source: EPA (1997a, p. 5-27) -

Table 2.3. Non-EPA Ex Ante Cost Estimates of the Cluster Rule

Source	Capital Expenditures	Operating Costs
Cluster Rule plus MACT II		
American Forest & Paper Association (see Miller Freeman Publications, Inc. 1999, p. 77)	$2.6 billion	$273 million
Pulp & Paper Project Report, April 1998 (see Miller Freeman Publications, Inc. 1999, p. 77)	$3.2+ billion	---
Cluster Rule		
Parthasarathy and Dowd (2000, p. 41)	$2.625 billion*	---
National Council for Air and Stream Improvement (2003, p. 5)	$3 billion (1999-2005)	---
Jensen (1999, p. 72)	$2.675-2.916 billion	---
MACT I		
Garner (2001, p. 44)	$2-3 billion **	---
Garner (2001, p. 44)	$0.775 billion***	---

* $1.375 billion for MACT I & III and $1.250 billion for BAT and best management practices (BMP) -
** MACT I (April 2001 compliance) -
*** MACT I (HVLC pollutants, April 2006 compliance) -

Table 2.4. Non-EPA Ex Ante Cost Estimates of MACT II

Source	Capital Expenditures	Operating Costs
Parthasarathy and Dowd (2000, p. 41)	$0.35 billion	---
Garner (2001, p. 45)	$0.90 billion	---
National Council for Air and Stream Improvement (2003, p. 5)	$1 billion or less	---

Treatment of Uncertainty and Baseline

One factor affecting cost estimates of the Cluster and MACT II rules is the number of mills that closed after the introduction of the new regulations. Hence, it is useful to know EPA's ex ante forecast of how many mills would have closed in the absence of the Cluster and MACT II regulations, and its forecast of the number of mill closing as a result of the new rules. According to EPA (1997a, p. 3-23), "A baseline closure is a mill that fails the salvage value test before the addition of incremental pollution control costs."[31] Of the 96 mills expected to bear incremental costs due to ELGs, the available data allowed closure analyses to be performed on 94 mills. EPA determined about 9 of these mills would be baseline closures (see U.S. EPA 1997a, p. 3-24). In addition, EPA projected two mill closures due to the final BAT/PSES and final MACT I. Under all MACT II options, a third mill closure was expected (see U.S. EPA 1997a, pp. 6-16 and 6-18).

2.3. Information Available to Conduct Ex Post Evaluation

Data for our ex post assessment come from several sources. We use data acquired from BECA – a consulting firm – on when O2 delig and extended delig systems were installed and the extent of ClO_2 substitution as a bleach alternative starting in 1997 for mills subject to the BAT provisions of the Cluster Rule. Data on when air pollution control devices (APCD) were installed are acquired from the 2011 survey for the Risk and Technology Review (RTR) of the technology-based standards for hazardous air pollutants (HAPs).

For ex post cost estimates, we rely on publicly available data from the National Council for Air and Stream Improvement, Inc. (NCASI), which produced an annual survey of capital expenditures borne by pulp and paper industry from 1970 through 2002.[32,33] The survey requested information on each firm's capital expenditures, including capital expenditures for pollution abatement. The questionnaire also asked firms to separate their pollution abatement capital expenditures by media (air, water, and solid waste) and by the type of mill (i.e., integrated or non-integrated).[34] Finally, firms divided their pollution abatement capital expenditures into those (1) for "sole-purpose" equipment (e.g., new secondary clarifier) and (2) incremental pollution abatement costs for equipment that would have been purchased in the absence of environmental regulations (e.g., incremental cost of kraft recovery furnace electrostatic precipitator upgrade that increases particulate capture efficiency from 90 to 99.5 percent).

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[31] According to EPA (1997a, p. 3-21), "A facility is projected to close if the salvage value exceeds the present value of future earnings after increased pollution control costs."

[32] We use data from the NCASI survey because only 1 mill reported compliance cost data on EPA's FY2011 survey (see Nicholson et al. 2012, p. 1). This survey included the MACT Subpart S Risk & technology Review (RTR), the MACT Subpart MM RTR, and the Kraft Pulp Mill NSPS (Subpart BB) Review. These reviews are required by the Clean Air Act as part of the process of regulating emissions of HAPs.

[33] Another potential source of data is the annual *Pollution Abatement Costs and Expenditures* (PACE) survey (U.S. Department of Commerce, various years). The PACE survey collects facility-level data on pollution abatement capital expenditures and operating costs associated with compliance to local, state, and federal regulations and voluntary or market-driven pollution abatement activities. Because the PACE Survey was discontinued in 1994 and was only conducted in two subsequent years (1999 and 2005), it cannot be used for the ex post portion of our analysis.

[34] An integrated mill produces at least 20 percent of its total pulp consumption from on-site wood pulping operations (see NCASI 2003, p. 1).

The 1998 to 2002 NCASI surveys collected information from firms that accounted for 84 to 94 percent of wood pulping capacity and 68 to 79 percent of paper and paperboard capacity. From 1973 to 1986, the NCASI survey found pollution abatement capital expenditures values for air, water, and solid waste pollution abatement were approximately 4 percent higher than the PACE values for SIC 26 (Paper and Allied Products). However, its values for 1988 to 1994 were approximately 15 percent higher than PACE. Unlike the PACE survey, which assigned values for missing observations to be able to produce national estimates of pollution abatement costs, NCASI treated missing observations as zero costs. Table 2.5 shows the NCASI pollution abatement capital expenditure data for 1990-2002.[35]

Cost information on MACT II and the implementation of a PM bubble strategy was provided by Abt Associates / RTI International. These sources are supplemented with firm-level data found in the U.S. Securities and Exchange Commission (SEC) 10-K form, which provides some firm-level data for ex ante and ex post costs of Cluster Rule compliance, and data on mill closures during the implementation of the Cluster Rule and MACT II Rule. The SEC 10-K information on mill closures is augmented by the U.S. EPA (2001b, Appendix B and 2006, Appendix), USDA (2005), the *Pulp & Paper North American Fact Book* (Miller Freemen Publications 1998, and Paperloop.com 2000, 2002, and 2003) and internet searches.

2.4. Ex Post Assessment of Compliance Costs

2.4.1. Regulated Universe

According to EPA (1997a, p. 2-1), of the 158 mills that used kraft, soda, sulfite, or semi-chemical processes at the time of the ex post analysis, 155 were expected to incur pollution abatement costs as a result of MACT I and MACT III. In addition, 96 of these mills would incur additional abatement costs as a result of the new

[35] The only other source of data was *Selected Air Pollution Control Equipment* (see U.S. Department of Commerce, 2000). This survey provided data on expenditures for particulate emissions collectors by selected industries including pulp and paper and pulp mill operations. Unfortunately, expenditures on (1) gaseous emissions collectors and (2) other types of industrial air pollution control devices were withheld to avoid disclosing data for individual companies. These data show a 41 percent increase in 1998 expenditures on particulate emissions collectors relative to 1997. Unfortunately, the survey was discontinued after the 1998 survey.

Table 2.5. Pollution Abatement Capital Expenditures (NCASI)
(millions of 1995 dollars)

Year	Water	Air	Solid Waste	Total	Percent of Total Capital Expenditures
1990	669	553	272	1,494	12
1991	765	542	214	1,521	19
1992	533	416	201	1,150	18
1993	354	289	131	774	14
1994	289	252	188	729	14
1995	309	219	97	625	12
1996	343	244	133	720	13
1997	305	142	105	552	12
1998	288	119	172	579	13
1999	340	294	65	699	17
2000	364	633	74	1,071	23
2001	170	287	72	529	12
2002	105	170	29	304	9

Note: current dollar value values are deflated to 1995 dollar values using the *Engineering News -Record* Construction Cost Index (NCASI 2003, pp. A2-A3).

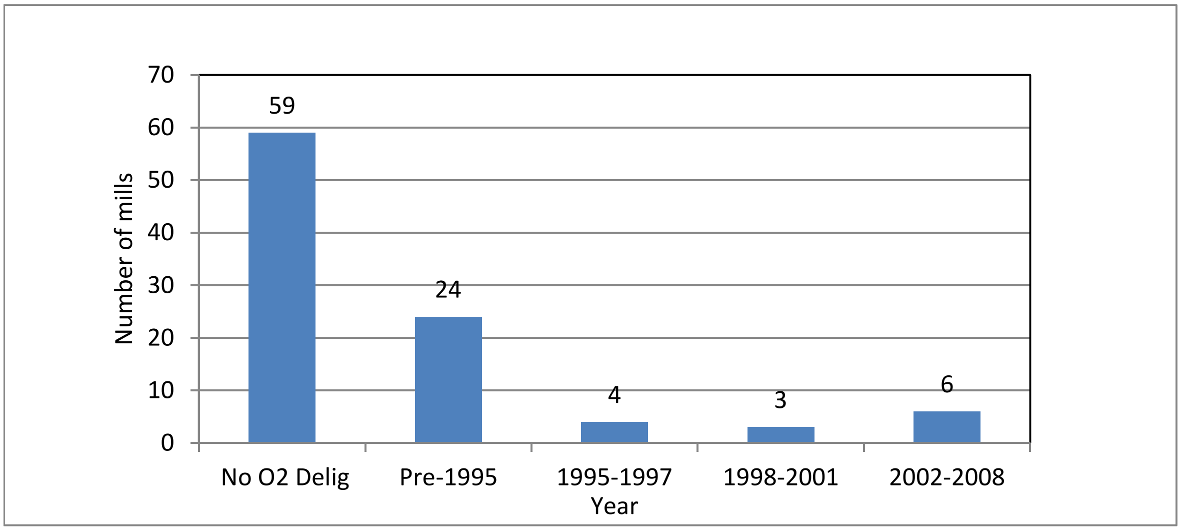
ELGs and pretreatment standards. This constituted the basis of the industry size when ex ante cost estimates of the Cluster Rule and MACT II Rule were generated. By 2001, EPA (2001b, Appendix B) estimated 133 mills would be subject to the MACT II emission standards.[36]

2.4.2. Baseline

It has been argued that some mills undertook pollution abatement actions in anticipation of the Cluster Rule. The 1993 proposal used a 1992 baseline (see U.S. EPA 1997, p. 8-24), which was updated to mid-1995 for the final rule. After the rule was proposed in 1993, "… a number of pulp mill owners and operators announced plans to install new technologies at their facilities …' (see U.S. EPA 1997b, 10-16). Some mills addressed concerns about dioxin releases by installing extended delignification or O2 delig systems (see U.S. EPA 1993b, pp. 4-5 to 4-7 and 4-12). Figure 2.1 shows the number of mills that installed their first O2 delig systems

[36] As of 2004 (see U.S. EPA 2006, Appendix), 77 of the 96 mills subject to the new ELGs and pretreatment standards reported bleached chemical pulp operations.

Figure 2.1. Number of Mills Installing O2 Delig for First Time, by Year



Source: BECA (2013b)

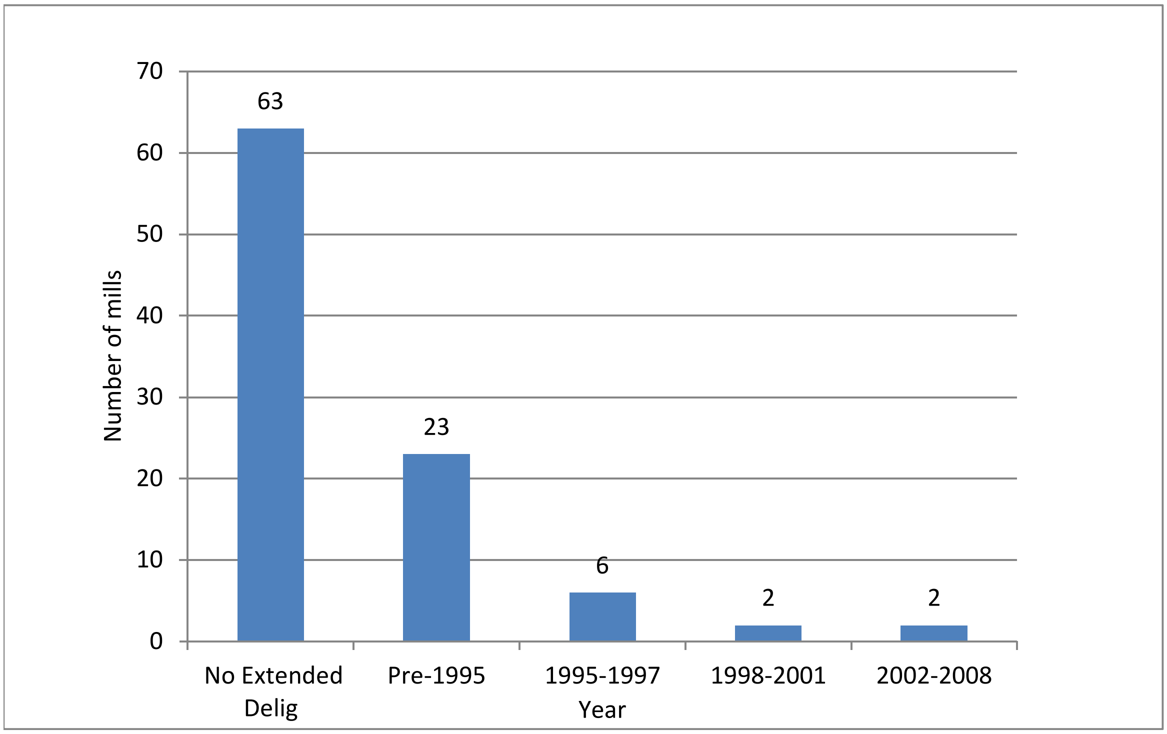
during selected time periods. It can be seen that over half of the mills that installed O2 delig did so by 1993.[37] Only 4 mills installed O2 delig during 1995-1997, the years prior to 1998, the year the rule was promulgated.

This trend was anticipated by Johnson (1995) when he observed the growth of O2 delig installations stagnated in North America during 1993-1994 and few new systems were anticipated prior to 1997. In addition to poor industry profitability, Johnson believed "… a strong industry stand that oxygen delignification is not a required strategy to meet Cluster Rule objectives" was the other reason for the lack of growth in O2 delig installations. Johnson concluded the "… industry position that ECF (full substitution) bleaching alone will accomplish these objectives and the capital expenditures this avoids has dramatically reduced the motivation for employing oxygen delignification."

Unlike O2 delig systems, where we have a complete inventory of installed systems at mills subject to the ELG provisions of the Cluster Rule, lack of data on extended delig systems precludes developing a complete inventory of installed extended delig systems. Nevertheless, EPA (1993b, pp. 4-5 and 4-6) provided a list of installed extended delig systems through 1994. In addition, BECA (2013b) provides a partial list of extended

[37] U.S. EPA (1997b, p. 10-30) provides additional information on changes in mill use of O2 delig and extended cooking between the proposal and final (mid-1995) Cluster Rule.

Figure 2.2. Minimum Number of Mills Installing Extended Delig for First Time, by Year



Source: BECA (2013b)

delig systems installed through 2013.[38] By combining the two sources, we compiled a complete list of mills that were subject to the ELG provisions of the Cluster Rule and installed extended delig systems prior to 1995. In addition, BECA provides the minimum number of mills that installed extended delig systems starting in 1995. It is worth noting that the last installation of an extended delig system on the BECA list occurred in 2003. Remembering the post-1994 information on extended delig systems is incomplete, Figure 2.2 shows a dramatic decline in the installation of extended delig systems after 1997. While not included in Figure 2.2, the Valdosta (GA) mill owned by Packaging Corp, the Jacksonville (FL) mill owned by Jefferson Smurfit, and the Savannah (GA) mill owned by Union Camp were not subject to the ELG provisions of the Cluster Rule, yet choose to install extended delig systems. This coincides with our finding that several mills not subject to the ELG provisions of the Cluster Rule installed O2 delig systems.

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[38] EPA included three mills subject to the Cluster Rule – Alabama Pine Pulp mill in Clairborne (AL), Port Wentworth (GA), and Quinnesec (MI) - that were not on the BECA list, while BECA included the Mobile (AL) mill owned by Kimberly Clark that was not on the EPA list.

The first survey of ClO_2 substitution by U.S. pulp and paper mills was the 104 Mill Study conducted by NCASI and the U.S. EPA (1990, pp. 8-10). Data was collected for 165 lines at 86 kraft mills in 1988. Of the 165 lines, 59 used no ClO_2 substitution. Of the lines employing ClO_2, 99 lines used between 0 and 30 percent, 4 used between 30 and 50 percent, 2 used between 50 and 70 percent, and 1 used more than 70 percent. In addition, of the 18 lines at 16 sulfite mills only one used ClO_2 – at a rate of less than 5 percent. ClO_2 substitution increased rapidly in the following years. According to the U.S. EPA (1997b, p. 10-30), in 1992 (baseline of the Cluster Rule proposal) 6.6 percent of bleached papergrade kraft and soda mill production as total ECF. By 1994, approximately 22 percent of all bleached chemical production was ECF (AET, 2002).[39] This increased to 33.2 percent of bleached papergrade kraft and soda mill production in mid-1995 (see U.S. EPA 1997b, p. 10-30).

While Table 2.5 shows higher pollution abatement expenditures during 1990-1994, we cannot determine whether this reflected pollution abatement undertaken in anticipation of the Cluster Rule and MACT II Rule or was a reaction to local concerns about the undesirable by-products generated by pulp and paper mills. Table 2.1 shows anticipated reductions in releases of key air and water pollutants as a result of the Cluster Rule and MACT II Rule. This is in addition to a substantial decline in releases of dioxins (TCDD) and furans (TCDF) between the proposal (1992 baseline) and the final rule (mid-1995 baseline). The baseline releases of TCDD declined from 70 grams per year in 1992 to 16 grams per year in mid-1995, while TCDF declined from 341 grams per year in 1992 to 122 grams to year in mid-1995 (see U.S. EPA 1997a, p. 8-24 – there are slight discrepancies between these mid-1995 values and those reported in Table 2.1). However, it has been suggested the pulp and paper industry abstained from aggressive abatement efforts until the Cluster rule was finalized (Ferguson, 1995). Ferguson's hypothesis was supported by Maynard and Shortle (2001), who used a double hurdle model and found the uncertainty associated with an irreversible investment (i.e., installing O2 delig, extended delig, or ECF) resulted in a value of waiting that led some bleached kraft mills to delay their investment in cleaner technologies. In addition, Maynard and Shortle found "public pressure" variables were statistically significant in explaining the adoption of cleaner technologies.

2.4.3. Methods of Compliance

Under the Cluster Rule, BAT involves switching to elemental chlorine free (ECF) or total chlorine free (TCF) bleaching. The data in Table 2.6 show that from 1990 to 2001 there was a substantial switch to ECF bleaching. Both Figure 2.3 and Table 2.6 reveal that approximately half the switch to ECF occurred prior to 1998, which is the first year the Cluster Rule was implemented for some mills. Among the mills covered by the water provisions of the Cluster Rule, only the Samoa (CA) mill opted for TCF bleaching.

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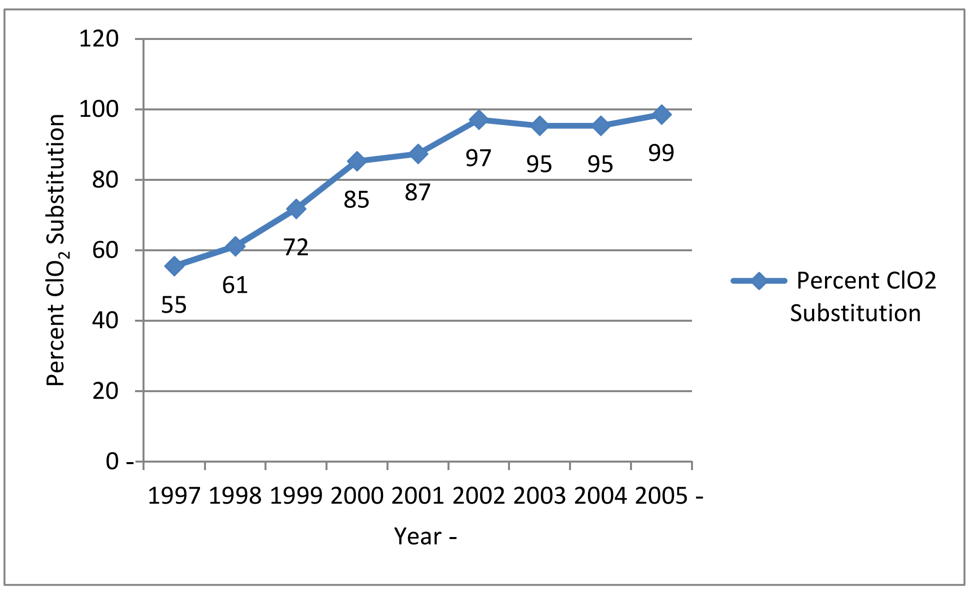
[39] The Paper Task Force (1994, p. 5) found 22 percent of bleached chemical production in 1994 was traditional, enhanced, or ozone ECF. Johnson (1994) reported that in 1994 between 20 and 25 percent of U.S. mills had no ClO_2 substitution, while 10 to 15 percent of U.S. mills had 100 percent ClO_2 substitution.

Table 2.6. United States Bleached Chemical Pulp Production
(millions of tones; 1 tonne = metric ton = 1000 kg = 2204.62 lb)

Year	ECF	TCF	Other
1990	0.5	0.0	26.8
1991	1.6	0.0	25.6
1992	2.8	0.0	24.4
1993	4.0	0.2	23.0
1994	6.0	0.2	21.0
1995	9.1	0.3	17.9
1996	10.4	0.2	16.6
1997	13.3	0.2	13.8
1998	15.5	0.2	11.4
1999	18.1	0.2	8.9
2000	20.7	0.2	6.3
2001	25.9	0.1	0.9

Source: Alliance for Environmental Technology (2002)

Figure 2.3. Percent ClO_2 Substitution (1997-2005)



Source: BECA (2013a)

Starting with 1997, BECA (2013a) provided us with information on the percent of ClO_2 substitution used on lines at mills subject to the ELGs of the Cluster Rule. Weighting the percent of ClO_2 substitution by the production of each line allows us to construct a weighted average of ClO_2 substitution for each year. It should be noted that during 1997 to 2005, the number of active mills subject to the ELGs of the Cluster Rule declined from 95 to 76.[40] Figure 2.2 shows the weighted average of ClO_2 substitution for active mills increased from 55 percent in 1997 to 99 percent in 2005. In order to observe the variation in ClO_2 substitution among mills, Figure 2.4 reports the percentage of active mills that fall in various ranges of ClO_2 substitution. While half of active mills subject to ELGs undertook at least 50 percent ClO_2 substitution in 1997, only 28 percent undertook 100 percent ClO_2 substitution. By 2000, 91 percent of active mills had at least 50 percent ClO_2 substitution, while 67 percent reported 100 percent ClO_2 substitution. In 2002, 90 percent of active mills had 100 percent ClO_2 substitution, and 95 percent of mills had 100 percent ClO_2 substitution in 2005. Although Franklin (VA) reported 100 percent ClO_2 substitution in 2002, it along with two other mills that participated in VATIP - Spring Grove (PA), Catawba (SC), and Franklin (VA) - did not permanently convert to 100 percent ClO_2 substitution until 2005. On the other extreme, 20 percent of the mills undertook no ClO_2 substitution in 1997, which declined to 5 percent in 2005.[41]

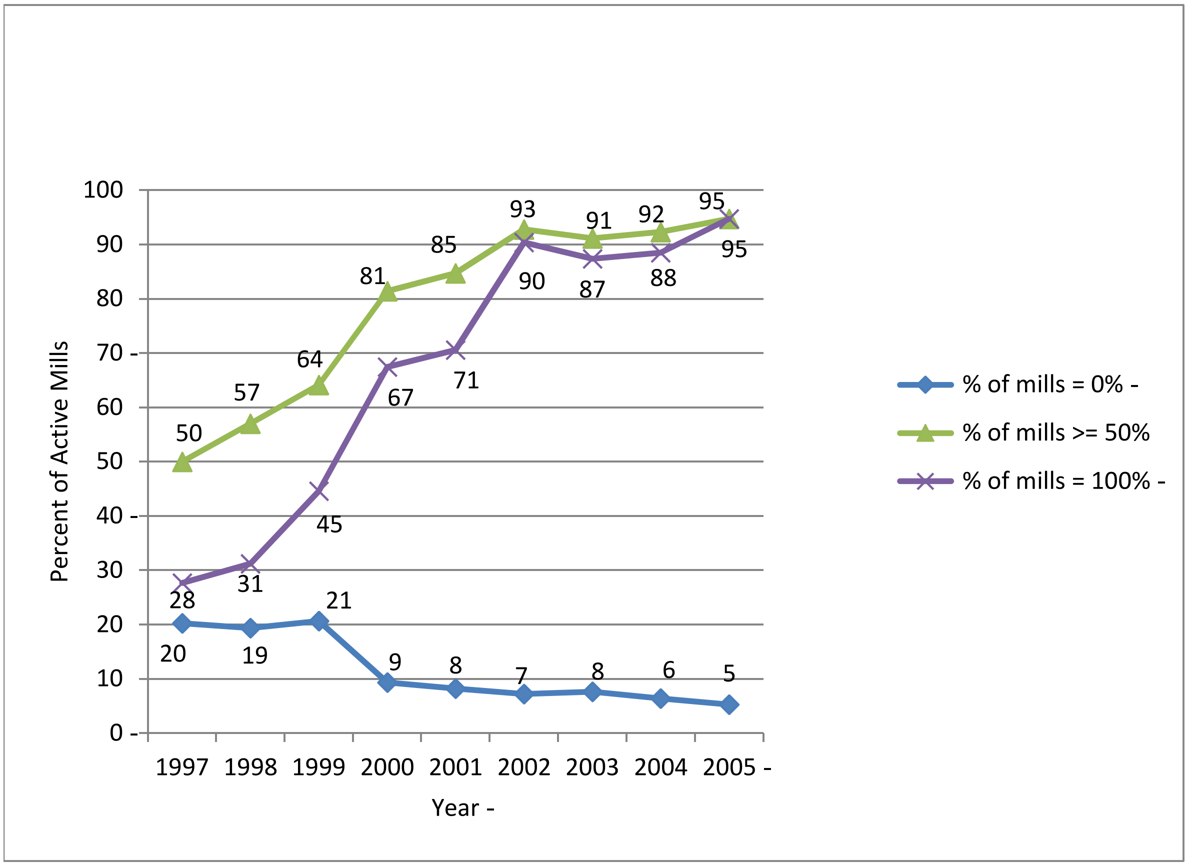
In response to EPA's 2011 technology review survey (Spence and Bradfield 2011, p. 3), which included mills not subject to ELGs, EPA found that in 2009 "…98 facilities reported pulp bleaching with 164 bleaching lines. Elemental chlorine free processing was used in 104 bleaching lines, while TCF was used in 31 lines, and processed chlorine free (PCF) was used in 22 lines. The remaining 7 lines utilized peroxide, sodium sulfate, hypochlorite, chlorine, or a combination of these bleaching chemicals. Oxygen delignification was utilized on 42 of the ECF bleaching lines to reduce emissions and bleaching chemical cost and consumption."

Two previous studies examined the effect of "chlorine" regulations on technological innovation. Snyder, et al. (2003) conducted an econometric analysis of the effects of the Cluster Rule on the diffusion of technological change in the chlorine manufacturing industry. Using plant-level data, their study focused on the diffusion of a new, cleaner production process within the chlorine industry. Snyder, et al.'s results indicate that chlorine facilities affected by the reduction in demand for chlorine resulting from the Cluster Rule (and the Montreal Protocol) were more likely to close than were other facilities. This factor along with the adoption of new technology at existing plants led to an increase in the share of chlorine plants employing a cleaner production technology. Popp and Hafner (2008) used information on regulations affecting dioxins and patents from

[40] For example, in 1997 information on ClO_2 substitution is unavailable for 2 of the original 96 mills – (1) the Longview Fiber (WA) mill, which curtailed chlorine-based bleaching in March 1994 (see U.S. EPA 1997b, p. 4-5), was not included and (2) no production was reported for the Peshitgo (WI) mill. In 1998, the Samoa (CA) mill was added to the list of mills with no reported production.

[41] In 2005, the four mills that did not report 100 percent ClO_2 substitution undertook no ClO_2 substitution. These mills were Somoa (CA), and three mills in Wisconsin: Park Falls, Port Edwards, and Rothschild. Because Somoa (CA) employed TCF bleaching, ClO_2 was not required. Park Falls, Port Edwards, and Rothschild were Segment B papergrade sulfite mills and not required to monitor dioxin under the Cluster Rule (see U.S. EPA 2006, pp. 9-10 to 9-11).

Figure 2.4. Extent of ClO_2 substitution, by percent of mills (1997-2005)

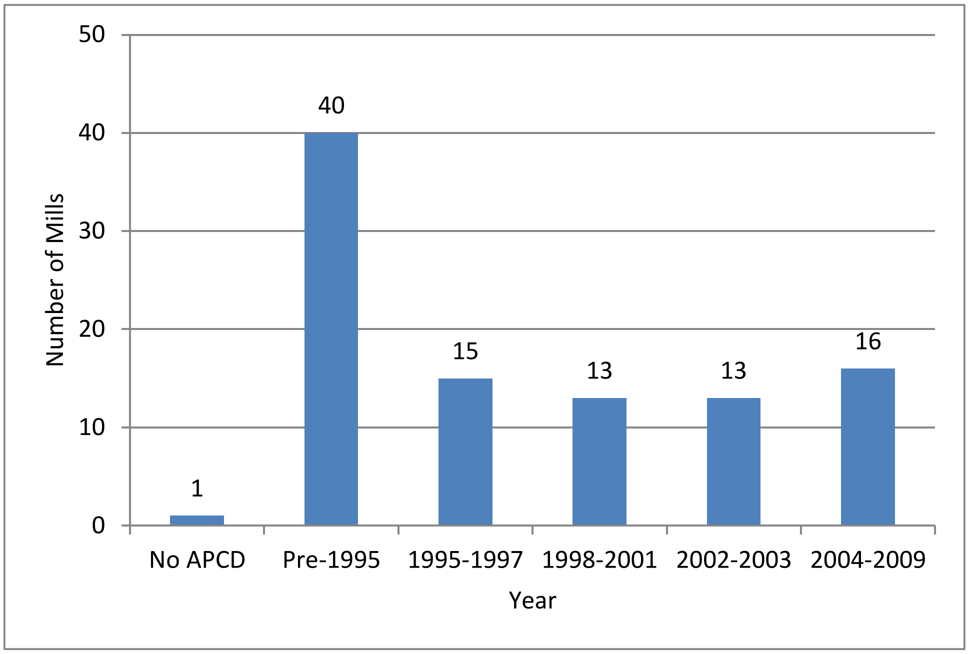


Source: BECA (2013a)

Canada, Finland, Japan, Sweden, and the United States, to investigate the association between regulations and patent activity. They found "substantial innovation" to reduce chlorine use in the bleaching technology occurred as a response to the implementation of environmental regulations.

Summarizing the technology employed to meet the air provisions of the Cluster Rule is more difficult than summarizing the technology used to meet the water provisions. The 2011 technology review survey (Hanks et al. 2013) collected information on air pollution control devices (APCDs) installed at 98 kraft mills in 2009. Of these mills, 67 were subject to both the air and water provisions of the Cluster Rule. Most mills reported multiple emission units (i.e., sources of emissions) and multiple APCDs, sometimes more than one APCD for an emission unit. Hence, summarizing when these devices were installed is challenging. In this paper, we focus on the last year a mill installed or updated an APCD. These results are summarized in Figure 2.5. According to the survey, only one mill reported no installed APCD. For the years prior to the Cluster Rule, 40 mills report their last installation/update prior to 1995, while 14 mills reported their last installation/update during 1995-97. Thirteen mills reported their last installation/update during 1998-2001, which covers the period for implementing the Cluster Rule. Finally, 29 mills reported their last installation/update during 2002-

Figure 2.5. Number of Mills, by Year, of Last Installed or Updated APCD



Source: Hanks et al. (2013)

2011, of which 13 reported their last installation/update in 2002-2003. Of the 29 mills that reported their last APCD installation/update during 2002-2011, 6 mills installed/updated at least one APCD during 1995-2001.

2.4.3.1. Compliance Costs for MACT I and BAT/PSES

Our strategy for determining the ex post cost of the Cluster Rule is to identify the cost of inputs assigned to pollution abatement – see Shadbegian and Gray (2005) and Pasurka (2008). Unfortunately, the NCASI survey focuses on ex post costs of all environmental regulations. Therefore, determining the cost of a specific regulation requires that we obtain data on pollution abatement costs before and after a regulation becomes effective.[42]

While the NCASI survey provides cost estimates for air, water, and solid waste abatement, it does not provide estimates of the costs associated with the Cluster Rule. Hence, we construct a pre-Cluster Rule baseline level of pollution abatement capital expenditures that allows us to identify the incremental capital costs of the

[42] The data on pollution abatement costs prior to the new regulation is required to construct a baseline from which the incremental costs can be calculated.

Cluster Rule. Since the share of the abatement capital expenditures assigned to the Cluster Rule depends upon the baseline, we construct three baseline scenarios.

EPA established a mid-1995 baseline for its economic analysis of the Cluster Rule and MACT II Rule (U.S. EPA 1997a, p. 4-1). Because we want to avoid the possibility of selecting an arbitrary base year in which capital costs may be unusually high (low) which will result in underestimating (overestimating) ex post costs, we use the average capital expenditures for air and water pollution abatement between 1995 and 1997 as our preferred baseline. Since no additional regulations were promulgated on the pulp and paper industry between 1995 and 2001, we assume all increases in air and/or water pollution abatement capital expenditures during 1998 to 2001 relative to the 1995-1997 baseline costs reflect the incremental capital costs of the Cluster Rule.[43]

During 1998 to 2001, the time between the promulgation of the Cluster Rule and its compliance date, capital expenditures for air and water pollution abatement were $2.5 billion (in 1995 dollars). Our preferred baseline yields an estimate of $65 million in Cluster Rule water pollution abatement capital costs and $610 million in Cluster Rule air pollution abatement capital costs during 1998 to 2001 (all values in constant 1995 dollars). This ex post Cluster Rule capital cost estimate of $675 million is 55 percent lower than ex ante capital cost estimate of $1.54 billion. We investigate the sensitivity of our results to the baseline year by repeating the analysis using 1996 and 1997 pollution abatement capital expenditures as alternate baselines.[44,45] Using 1996 and 1997 as the baseline yields ex post Cluster Rule capital expenditure estimates of $503 million and $882 million respectively, which are 67 percent and 43 percent lower than the EPA ex ante capital expenditure estimate.[46]

One important *caveat* is that while most of the compliance dates for the Cluster Rule occurred on or before April 15, 2001, compliance for two MACT provisions: bleaching systems in the voluntary advanced technology incentives program (VATIP) (of which only 4 mills (see U.S. EPA 2006, p. 9-7) participated)[47] and the HVLC system compliance, were not required until April 15, 2004 and April 17, 2006, respectively (see U.S. EPA 1998b, p. 47). While we would prefer to include these MACT provisions in our analysis, the NCASI survey

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[43] For cases when capital expenditures during 1998-2002 were less than the baseline capital expenditures, we assume no capital costs are associated with the Cluster Rule (i.e., ex post costs are nil).

[44] 1996 and 1997 are selected as baseline years because they are both prior to the promulgation of the Cluster Rule. NCASI (see Paperloop.com 2003, p. 85) anticipated the pulp and paper industry would experience its highest levels of capital expenditures associated with the Cluster Rule in 1999 and 2000.

[45] Our results could also be sensitive to which mills are included in the NCASI survey, but since we have no access to the underlying micro-data we cannot test this sensitivity.

[46] NCASI estimates of air and water pollution abatement capital expenditures in 1993 and 1994 (in 1995 dollars) are slightly higher than the 1996 value. Hence, if we include expenditures from 1993 and 1994 in the baseline this will lead to a lower ex post cost estimate of the Cluster Rule.

[47] The four mills participating in VATIP were Eastover (SC), Catawba (SC), Spring Grove (PA), and Franklin (VA). Other over-complying mills were Oglethorpe (GA) which participated in the XL program and Samoa (CA) which employed TCF bleaching.

stopped in 2002. Unfortunately, we do not have any ex post cost estimates of these two MACT provisions to adjust our ex post cost estimates. Therefore, our ex post cost estimate is biased downwards resulting in EPA's ex ante cost estimate appearing to be more of an over-estimate than we found.

2.4.3.2. Compliance Costs for MACT II

In order to meet the HAP metals standards of MACT II, approximately 32 pulp and paper mills employed a "PM bubble compliance alternative" strategy, which uses PM as a proxy for HAP metals (Nicholson et al. 2012, p. 15)[48]. The "PM bubble compliance alternative" gives mills the flexibility to set site-specific PM emissions limits for each existing source in the chemical recovery area (i.e., recovery furnaces, smelt dissolving tanks, and lime kilns), as long as the total emissions from all the existing sources are less than or equal to the total of the promulgated emissions rates for each existing source.[49] This improvement in the efficiency of pollution abatement resulted in lower ex post pollution abatement costs. Although EPA anticipated the PM bubble compliance alternative would improve the efficiency of pollution abatement, it was unable to develop ex ante estimates of cost and emission reductions for this alternative because it could not determine which mills would take advantage of the alternative or what limits the mills would set. The limits mills set determined which, if any, of the emission units in the bubble would require upgrading and which would be unchanged. Table 2.7 provides the EPA ex ante engineering estimates of MACT II, plus BE&K's ex post engineering estimates of the cost of complying with MACT II.

The EPA ex ante cost estimates are based on projected compliance costs presented in the compliance cost memorandum for the MACT II rule (Holloway 2000).[50] The ex ante capital expenditure estimate of $231

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[48] Nicholson et al. 2012 final white paper is available upon request.

[49] The mill-specific bubble limit is calculated based on the promulgated emissions standards (referred to in the rule as reference concentrations or reference emissions rates) for each process unit and mill-specific gas flow rates and process rates.

[50] "The ex-ante costs for the MACT II rulemaking were first developed on a model process unit basis (e.g., model recovery furnaces, model SDTs, model lime kilns), with applicable control option costs developed for each model process unit. … These ex-ante model costs were then assigned to the individual process units at each mill in the NCASI MACT survey database, based on whether the process unit was expected to be impacted under the control option (i.e., whether or not available emissions data showed the mill to be above the emission limit in the control option). … The mill-specific ex-ante costs for each process unit type were then averaged, and those average costs were extrapolated nationwide to determine nationwide ex-ante cost estimates for each process unit type…" (see Nicholson et al. 2012, p. 4)

Table 2.7. Ex Ante and Ex Post Cost Estimates for MACT II (millions of 2001 dollars) -

	Total Capital Investment	Total Annual Costs
Ex Ante (EPA, 1997)	$231	$80.6
Ex Post (BE&K)	$188	$24.2

Source: Research Triangle Institute (2012, pp. 15-16)

million (in 2001 dollars) reported in Table 2.7 is less than the ex ante EPA estimate of $258 million (in 1995 dollars) reported in Table 2.2. Because ex post cost information was not available for individual mills, ex post costs are estimated by combining information on the actual (ex post) compliance methods selected by individual mills with estimated costs of these compliance strategies from the engineering firm BE&K. Thus, the ex post cost estimates are derived from ex ante costs provided by BE&K, applied to actual ex post mill-specific compliance information provided by MACT II mills in their responses to EPA's 2011 RTR survey. These estimates constitute the best ex post compliance cost data for the MACT II rule.

Despite the limitations of this approach, Table 2.7 shows EPA's ex ante total capital investment cost estimate was nearly 25 percent higher than the ex post cost estimate. Furthermore, EPA's ex ante total annual cost estimate was roughly three times higher than the ex post cost estimate. The main reason for the lower ex post cost is the use of the "PM bubble compliance alternative" strategy, which allowed for much more cost-effective strategy for abating PM emissions than command-and-control.[51] In particular, a significant percentage of sources subject to MACT II did not require upgrades or replacements of existing air pollution controls, primarily due to the use of the PM bubble compliance alternative. For example, 19 non-direct contact evaporator (NDCE) recovery furnaces were expected to upgrade or replace their existing electrostatic precipitators (ESP) units, but only 5 were actually upgraded or replaced. In addition, of the 29 direct contact evaporator (DCE) recovery furnaces that expected to upgrade or replace ESP units, only 8 were upgraded or replaced (see Nicholson et al. 2012, p. 15). This is further evidence that more flexible pollution abatement strategies lead to substantially lower abatement costs.

SEC 10-K Cluster Rule Capital Expenditure Data

The U.S. Securities and Exchange Commission (SEC) collects financial information on firms via its Form 10-K (Annual Report Pursuant to Section 13 or 15(d) of the Securities Exchange Act of 1934). Because of the importance of the Cluster Rule, many firms reported anticipated and actual expenditures associated with the Cluster Rule on the Form 10-K. Unfortunately, the Cluster Rule was implemented in several phases (e.g., April 2001 compliance, VATIP, and HVLC system compliance) and some firms were not specific about which

[51] It is possible that regulatory-induced technical change played a role in lowering the cost of the MACT II rule. Mill and equipment shutdowns and consolidations also played a role.

costs were incurred for the different phases of the Cluster Rule and which were incurred for MACT II. As a result, the cost estimates reported by some firms on the Form 10-K cannot be assigned with certainty to either different portions of the Cluster or MACT II rules.

The Cluster Rule cost estimates from the *Pulp & Paper North American Fact Book* (1999 to 2002) provide an overview of the SEC 10-K data. While the *1999 Fact Book* provides estimates of Cluster Rule costs based on another source, the *2000* to *2002 Fact Books* report data collected from the SEC 10-K forms for 30+ pulp and paper companies. These data are reported in Table 2.8. Using the SEC 10-K forms is further complicated when publicly-owned U.S. firms are purchased by foreign firms or by private U.S. companies, neither of which need to submit 10-K forms.

Table 2.9 provides several examples where the SEC data provide a relatively complete picture of the ex ante and ex post costs of the Cluster Rule. While the ex ante cost estimates of Boise Cascade, Pope & Talbot, and Wausau were close to their reported actual ex post costs, the ex ante cost estimates of Gaylord Containers, Potlatch, Smurfit-Stone, and Temple Inland were substantially higher than their ex post costs. Thus, the anecdotal evidence on the accuracy of *ex ante* cost estimates of the Cluster Rule based on the SEC 10-K forms is a bit mixed – some firms accurately predicted the compliance costs, while others substantially overestimated them. However, since no firms clearly underestimated their actual costs, based on the firms that did provide ex ante and ex post costs estimates, the aggregate ex ante cost estimates are higher than the aggregate ex post cost estimates, which is consistent with our findings above.[52]

There are several instances in which firms commented on the costs associated with the Cluster Rule. In its 1999 10-K report, Wausau stated “The Company believes that capital expenditures associated with compliance with the Cluster Rules and other environmental regulations will not have a material adverse effect on its competitive position, consolidated financial condition, liquidity, or results of operation.” In its 1999 10-K report, Potlatch stated “In early 1998 the Environmental Protection Agency published the ’Cluster Rule’ regulations applicable specifically to the pulp and paper industry … the company estimates that compliance will require additional capital expenditures in the range of $20 million to $30 million, the majority of which will be expended over the next 2 to 3 years. The company does not expect that such compliance costs will have a material adverse effect on its competitive position.” Based on these statements and our inability to locate any statements in the SEC 10-K forms indicating pulp and paper firms believed the Cluster Rule had a substantial impact on their profitability or would cause them to close any facilities, it appears paper firms did not believe the costs of Cluster Rule had a substantial impact on their bottom line.

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[52] Because firms were not obligated to disclose specific data regarding their capital expenditures associated with the Cluster Rule, firms such as Rayonier and Kimberley-Clark and Westvaco opted to provide only projected expenditures. As a result it is not possible to draw any conclusions about ex ante and ex post costs for those firms.

Table 2.8. Projected Capital Expenditures to comply with Cluster Rule -
(millions of dollars) -

	Fact Book 1999		*Fact Book 2000*		*Fact Book 2001*		*Fact Book 2002*	
Company	**Cost**	**Time Frame**	**Cost**	**Time Frame**	**Cost**	**Time Frame**	**Cost**	**Time Frame**
Boise Cascade	100-150	1998-2001	85	2000-2001	32	2001	20.6	2002
Bowater	60-75	1998-2000	150-200	2000-2004	175	2001-2003	30	2002-2003
Alliance Forest Products[1]	-	-	45	2000	8.7	2001-2002		
Buckeye Technologies	40	1998-2000	40	2000-2005	35	2001-2004	40	2002-2005
Chesapeake	5-6	1998-2000						
Consolidated Papers[2]	25	1998-2001	2.6	2000				
Crown Vantage[3]	40	1998-2005	8 22	2000 1999-2003				
Donohue	-	-	52	1999-2001				
Fort James[4]	100	1998-2001	40	2000-2001				
George-Pacific[5]	300	1998-2000 -	160 550	1998-1999 1998-2006	135	2002-2006	118	2002-2006
P.H. Glatfelter	21	1998-1999	30	2000-2004	30	2001-2004	30	2002-2004
International Paper	230 180	1998-2000 2001-2006	229 150-195	2000-2001 2002-2006	116 330-370	2000-2001 2003-2006	82 138 123	2002 2003 2004
Champion Intl.	20-40	1998-2004	25-50	2000-2005				
Union Camp[6]	125-150	1998-2001						
Kimberly-Clark	279	1998-2000	15	2000	0.4	2001	98 99	2002 2003
Longview Fiber	10-20 20-30	1998-2000 2001-2005	10-12 10-20	2000-2001 2002-2006	15-20	2001-2005	3.6	2002
Mead	110	1998-2002	55	2000-2006	54	2001-2003		
Westvaco	257 -	1998-1999 -	100-150	2000-2005	100-150	2001-2004		
MeadWestvaco Corp.[7]							47	2002

	Fact Book 1999		*Fact Book 2000*		*Fact Book 2001*		*Fact Book 2002*	
Company	**Cost**	**Time Frame**	**Cost**	**Time Frame**	**Cost**	**Time Frame**	**Cost**	**Time Frame**
							35	2003
Packaging Corp. of America	-	-	48	2000-2005	2.1	2001	5.8	2002
					25.7	2001-2005	1	2002-2005
Tenneco Packaging [8]	105	1998-2008						
Pope & Talbot	30-35	1998-2000	27	2000-2001	2.8	2001	3	2002-2006
Potlatch	70-95	1998-2006	15	2000	16	2001	5	2002-2006
Rayonier	35	1998-1999	80	2000-2004	70	2001-2005	30	2002-2005
	80	1998-2002						
Riverwood Intl.[9]	55	1998-2005	55	2000-2006	55	2000-2006	55	2000-2006
Schweitzer-Mauduit Intl.	8-16	1998-1999						
Smurfit Stone			200	2000	43	2001		
			290	2001-2004	60	2002-2005	100-125	2002-2007
Stone Container	180	1998-2005	180	1998-2005				
Jefferson Smurfit[10]	175	1998-2002						
Temple Inland	110	1998-2000	20	2000-2001	27	2001-2003	27	2001-2003
Gaylord Container[11]	5-7	1998-2000	10	2000				
			20	2001-2008	26	2001-2007		
S.D. Warren (part of Sappi)	70-112	1998-2000	10-35	2000-2001	10	2001		
Wausau-Mosinee Paper	-	-	20	2000-2001	2.3	2001		
Weyerhaeuser	80	1998-2001	87	2000-2003	50	2001-2003	50	2001-2003
Willamette Industries[12]	120	1998-2002	100	2000-2004	115	2001-2005		
Total			**$1,751-2,600**		**$1,584-1,679**		**$1,156**	
Primary source of data:	*Pulp & Paper*		10-K forms		10-K forms		10-K forms	

Company	*Fact Book 1999*		*Fact Book 2000*		*Fact Book 2001*		*Fact Book 2002*	
	Cost	**Time Frame**	**Cost**	**Time Frame**	**Cost**	**Time Frame**	**Cost**	**Time Frame**
	Project Report (some firms report values for all environmental spending)							

NOTES:

1. Alliance Forest Products was acquired by Bowater in 2001
2. Consolidated Papers was acquired by Stora Enso Oyj of Finland in 2000
3. Crown Vantage declared bankruptcy in 2001
4. Fort James was acquired by Georgia-Pacific in 2000 (see *2001 Fact Book*, p. 40 + p. 41 discusses rules for listing capacity after shutdown)
5. Georgia-Pacific was acquired by Koch Industries in 2005
6. International Paper purchased Union Camp in 1999 and Champion International in 2000
7. Mead merged with Westvaco in 2002
8. Until 1999, the Packaging Corporation of America was known as Tenneco Packaging, a subsidiary of Tenneco
9. Riverwood Holding purchased Graphic Packaging in 2003 and combined Graphic Packaging with Riverwood International
10. Jefferson Smurfit merged with Stone Container to form Smurfit Stone Container in 1998
11. Gaylord Container was acquired by Temple Inland in 2002
12. Willamette Industries was acquired by Weyerhaeuser in 2002

NOTE: Shaded entries indicate a merger occurred during 1999-2002 among firms in contiguous shaded area. -
Sources: Miller Freeman Publications (1998, p. 26), Paperloop.com (*2000,* p. 29), Paperloop.com (*2002,* p. 33), Paperloop.com (2003, p. 33) -

Table 2.9. Cluster Rule Capital Expenditure Estimates (in millions of dollars) from SEC 10-Ks for Firms with Complete Data (millions of dollars)

	1998		1999		2000		2001	
Company	**Cost**	**Time Frame**	**Cost**	**Time Frame**	**Cost**	**Time Frame**	**Cost**	**Time Frame**
Boise Cascade	120	Next 4 years	40 85	Through 1999 (actual) Next 2 years (projected)	96 32	Through 2000 (actual) 2001 (projected)	117	Through 2001 (actual)
Gaylord Containers	22.5	First 3 years – MACT I and III, no BAT costs (projected)	10	For April 2001 standards – MACT I and III, no BAT costs (projected)	10 4.3	For April 2001 standards – MACT I and III (projected), no BAT costs Through fiscal 2000 (actual)	10	Through fiscal 2001 – MACT I and III, no BAT costs (actual)
Pope & Talbot	35	Through first quarter of 2001 (projected)	35 8.2	Through first quarter of 2001 (projected) Through 1999	38.6	Through Nov. 2000 – completed (actual)		
Potlatch	20-30	Next 2-3 years (projected)	15	2000 (projected)	12	Total cost of project (most spent in 2000)		Phase I of Cluster Rule is completed
Smurfit-Stone	310	2-4 years (projected)	310	Next several years (projected)	204 179	through 2000 (actual) 2000 (actual)	232 28	Through 2001 (actual) 2001 (actual)
Temple-Inland	≤110	1999 - 2001 (projected)	1	Through 1999 (actual)	11	Through 2000 (actual)	15	Through December 31, 2001 (actual)
Wausau	16-20	1999-2001 (projected)	20-22	1999-2001 (predicted)	20-22	1999-2001 (projected)	19.1	1999-2001 (actual)

Mill Closures

One factor contributing to ex ante cost estimates exceeding ex post costs are mill closings or a reduction in mill capacity through the shutdown of a machine. Obviously, if a mill shuts down instead of complying with the Cluster Rule this reduces observable ex post costs. We attempt to identify mills affected by the Cluster Rule that permanently closed between 1997 and 2004 and provide documentation on the reason for the mill closing. Complicating this task is the fact that a mill can close, then sold, and reopened under new management. Table 2.10 provides summary statistics on the number of mills that closed between 1971 and 2001.

Table 2.10 shows 26 mills closed in 1998 and 1999, 12 mills closed in 2000, and 23 mills closed in 2001. In contrast, the Paper, Allied-Industrial, Chemical and Energy Workers International Union (see Paperloop.com 2003, p. 69) claimed 36 paper mills permanently closed in 2001. However, these totals do not list the specific mills or the rationale for closing. As a result, we cannot determine how many of these mills were subject to the Cluster Rule nor how many of the closures were permanent.

Jensen (1999, pp. 71-72) discussed claims of mill shutdowns in response to meeting provisions of the Cluster Rule by April 2001. For example, Kimberley-Clark decided against undertaking expenditures to bring its Mobile, AL mill into compliance. In addition, the decision by Sappi to close its Westbrook, ME mill was partially due to pending Cluster Rule expenditures. Finally, Donohue decided against bringing its Champion mill in Sheldon, TX into compliance with the Cluster Rule. Some of this story was confirmed by Miller and Freeman's (1998, p. 26) statement that Proctor & Gamble, Kimberly-Clark, and Donohue, Inc. had closed kraft mills due to the costs of environmental regulations.

We attempted to independently identify the number of closures among the mills that were subject to the Cluster Rule and MACT II rule. Starting with the list of the 155 mills subject to the Cluster Rule (http://www.epa.gov/ttn/atw/pulp/milltab.pdf), we compiled a list of mills that appear to have permanently closed by 2004.[53] This list was compiled from several sources. First, we identified the mills not included in the list of 133 mills subject to MACT II (see EPA 2001b, Appendix B), a 2004 list of the status of the 96 mills subject to the ELG component of the Cluster Rule (see U.S. EPA 2006, Appendix), and annual information on the 96 mills provided by BECA (2013b) . Next, the USDA (2005) provided an inventory of the status of pulp mills in the 2005. This list was supplemented with information from the 1999 to 2002 editions of the *Pulp & Paper North American Fact Book*, and information on mill closures provided on SEC 10-K forms.

[53] Hanks et al. (2013, p. 3) reported trends in the number of chemical pulp mills from 1976 to 2011.

Table 2.10. Pulp and Paper Mill Closures 1971-2001

	1971-1980	1981-1990	1991-1997e	1991-1999e	1991-2000e	1991-2001e
Paper						
Newsprint	1	0	0	0	1	1
Printing / writing	13	10	7	12	16	25
Packaging / industrial converting	15	11	2	7	10	15
Tissue	12	18	9	15	15	15
Total paper	***41***	***39***	***18***	***34***	***42***	***56***
Paperboard						
Unbleached kraft	1	0	0	4	4	4
Solid bleached	1	0	0	0	0	1
Semichemical	2	2	0	1	1	1
Recycled	26	15	5	10	14	22
Total Paperboard	***30***	***17***	***5***	***15***	***19***	***28***
Total Paper / Paperboard	**71**	**56**	**23**	**49**	**61**	**84**

e= estimated

Sources: Miller Freeman Publications (1998, p. 32), Paperloop.com (*2000,* p. 37), Paperloop.com (*2002,* p. 41), Paperloop.com (*2003,* p. 40)

Finally, we sought confirmation of mill closures via searches on the internet. Based on this information, of the 155 mills subject to the Cluster Rule, we identified approximately 18 permanent mill closures through 2004. We were unable to locate any statements in the SEC 10-K forms filed by pulp and paper firms that linked mill closures to environmental regulation, let alone the Cluster Rule. In fact, the most common reasons provided for mill closures were reduced demand for paper products and excess capacity.

The following examples demonstrate some of the additional challenges confronting efforts to identify mill closures. First, there were numerous mill sales and firm mergers during the years the rules were implemented. For example, Scott Paper Co. operated a pulp and mill in Mobile, AL. In December 1994 Scott sold the paper mill to South African Pulp and Paper Inc. (SAPPI), while its pulp mill was sold to Kimberly-Clark in 1995. The Scott Paper Co/SAPPI mill was subject to both the air and water provisions of the Cluster Rule. Kimberly-Clark closed the pulp mill in 1999, and then purchased the paper mill from SAPPI in 2002. Second, the U.S. EPA (2006, p. 7-7 and Appendix) identified the status of the mills subject to the ELG provisions of the Cluster Rule when it was promulgated in 1998. While some mills were either temporarily or permanently idle, 6 were operating but no longer classified as BPK or PS mills. Instead, they were classified as non-bleached chemical mills (e.g., unbleached kraft) and no longer subject to the Cluster Rule.

How did mill closings affect the aggregate ex post costs of complying with the Cluster Rule? Since we do not have mill specific ex post cost data we cannot provide a precise answer to this question. We use the number of mill closures to estimate their effect on ex post costs. The observed number of mill closures (18) represents an upper limit on the number of mill closures associated with the Cluster Rule.[54] Deriving the number of mill closures due to the Cluster Rule requires subtracting the 9 baseline mill closures from the observed number of mill closures after implementing the Cluster Rule. These 15 mills – the 9 permanently closed plus the 6 no longer using bleached chemical processes - represent approximately 10 percent of the mills affected by the Cluster and MACT II Rules. If we assume that they are typical mills and we increase our ex post cost estimate by 10 percent we find that EPA over-estimated the costs of the Cluster and MACT II Rules by 1.5 to 2.5 times depending on the baseline. Based on this, we conclude mill closures did not account for EPA's over-estimating the costs of the Cluster and MACT II Rules.[55]

2.5. Conclusions

Our findings suggest EPA's ex ante cost estimates overstated the costs of both the Cluster Rule and the MACT II rule. Using publicly available data from NCASI, we found that EPA overestimated the capital cost of the Cluster Rule by 30 to 100 percent, depending on the choice of baseline year from which we derived the incremental cost. Among the reasons for EPA's overestimates of these capital costs are the mills' use of the clean condensate alternative (CCA) , flexible compliance options, extended compliance schedules, site-specific rules, use of equivalent-by-permit, and equipment/mill shutdowns and consolidations.[56] However, the lack of detail in the available data means we can only speculate on which reason(s) is primarily responsible for EPA's overestimate.

Furthermore, our findings show that EPA also overstated the compliance costs of the MACT II rule. Specifically, EPA overestimated the capital cost by approximately 25 percent and overestimated the annual cost by 200+ percent. It appears the primary reason for the lower ex post cost is the use of the "PM bubble compliance alternative" strategy, which is a more efficient policy to abate the same level of PM emissions and required fewer mills to upgrade or install new pollution abatement equipment than anticipated by EPA.

Anecdotal evidence of the realized costs of the Cluster Rule provided by the SEC Form 10-K is a bit mixed with some firms accurately predicting their compliance costs, while others substantially overestimating their actual costs. Because no firm dramatically understated its realized costs, the aggregate ex ante costs are likely higher than the aggregate ex post costs. While equipment/mill shutdowns and consolidations also played a role, they are not enough to account for EPA's over-estimate of the actual costs of compliance.

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[54] Appendix 2.1 lists the 18 mill closures, plus 6 mills no longer using bleached chemical processes.

[55] U.S. EPA (http://www.epa.gov/ttn/atw/pulp/milltab.pdf) lists the 155 chemical (kraft, soda, sulfite, standalone semi-chemical) pulp and paper mills in the United States initially subject to the Cluster Rule, while the U.S. EPA (2001b, Appendix B) lists the 133 chemical mills subject to MACT II.

[56] Bradfield and Spence (2011) provide information on the adoption of the clean condensate alternative, which is a pollution prevention option available to kraft HVLC systems that allows the control of HAP emissions without resorting to controlling HVLC system vent streams via combustion devices.

Defining the baseline remains a challenge for assessing not only the ex post costs of the Cluster Rule and MACT II Rule , but the ex post analysis of the costs of any regulation. The baseline determines which pollution abatement expenditures are considered a direct consequence of a regulation and which expenditures would have been incurred in a counter-factual world without the regulation. When determining the cost associated with the final Cluster rule, the U.S. EPA (1997b, p. 10-16):

> "excluded the incurred costs of process changes that were already implemented as of mid-1995 in the cost estimates used to analyze the economic achievability of the rules. However, EPA included the costs of the announced process changes not underway as of July 1, 1995 in the cost estimates used to analyze the economic achievability of the rule. Although EPA included the costs of the process changes announced but not yet underway as of mid-1995 in its final cost estimates, EPA nevertheless evaluated the impact of these costs in an alternative analysis reflecting announced corporate commitments that were not underway as of mid-1995."

The 1995-97 period, which serves as the baseline for our ex post analysis, represents a lull between 1990-94 period when discussions about the Cluster Rule and MACT II Rule were initiated and 1998-2003 period when the rules were implemented. If some (or all) of the increase in pollution abatement expenditures during 1990-1994 can be attributed to actions taken in anticipation of the Cluster Rule, it does not invalidate the findings of this paper. While including expenditures from 1990-1994 would increase the total cost of the Cluster Rule and MACT II Rule, the objective of the paper was to compare our ex post estimate of the Cluster Rule and MACT II rule with the ex ante cost estimates that were derived using a mid-1995 baseline. As a result, because pre-1995 pollution abatement expenditures related to the Cluster Rule and MACT II Rule were excluded from the ex ante cost estimate, consistency requires they be excluded from our *ex post* cost estimates.

While our findings do suggests that EPA overestimated the cost of both the Cluster and MACT II Rules, we encounter several issues that limit the accuracy of our conclusions: 1) for the Cluster Rule, we only have access to industry level data, so our results are somewhat sensitive to how we construct the baseline and the exact mills included in this data; 2) for the Cluster Rule, we have no annual ex post pollution abatement operating cost data, which means conclusions on ex post compliance costs are limited to capital costs[57]; 3) for MACT II, the only industry compliance expert who could provide us with ex post cost information also supported the ex ante cost analysis for the rule and we could not independently verify the accuracy of the data; and 4) for MACT II, the ex post cost data was estimated by RTI, the contractor that supported the ex ante analysis, using a combination of ex ante engineering cost data developed by BE&K based on experience

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[57] Although we did not use the PACE data to determine the capital costs associated with the Cluster and MACT II rules, we can use the PACE data on O&M costs in 1994 and 2005 to provide an estimate of how pollution abatement O&M costs were affected by the Cluster and MACT II rules. Assuming 1994 is representative of the baseline (pre-Cluster and MACT II rules) and 2005 represents the period of compliance (post-Cluster and MACT II rules), we calculate the ratio of 2005 to 1994 pollution abatement O&M costs for both air and water (in constant dollars). The ratio for air is approximately 0.8 and the ratio for water is around 0.7. The decline in O&M costs suggests O&M costs are not a significant component of the Cluster and MACT II rule compliance costs.

of similar projects in the pulp and paper industry and the actual (ex post) compliance methods chosen by the mills.

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U.S. Environmental Protection Agency (1998a), "National Emission Standards for Hazardous Air Pollutants for Source Category: Pulp and Paper Production; Effluent Limitations Guidelines, Pretreatment Standards, and New Source Performance Standards: Pulp, Paper, and Paperboard Category," *Federal Register*, 63, no. 72 (April 15), 18504-18751.

U.S. Environmental Protection Agency (1998b), *Pulp and Paper NESHAP: A Plain English Description*, EPA-456/R-98-008, Office of Air Quality Planning and Standards, Group, Research Triangle Park, NC 27711.

U.S. Environmental Protection Agency (2001a), "National Emission Standards for Hazardous Air Pollutants for Chemical Recovery Combustion Sources at Kraft, Soda, Sulfite, and Stand-Alone Semichemical Pulp Mills," *Federal Register*, 66, no. 9 (January 12), 3180-3203.

U.S. Environmental Protection Agency (2001b), *Pulp and Paper Combustion Sources for National Emission Standards for Hazardous Air Pollutants (NESHAP): A Plain English Description*, EPA-456/R-01-003, Office of Air Quality Planning and Standards, Research Triangle Park, NC 27711.

U.S. Environmental Protection Agency (2006), *Final Report: Pulp, Paper, and Paperboard Detailed Study*, EPA-821-R-06-016, Office of Water, Engineering and Analysis Division, Washington, DC 20460.

U.S. Securities and Exchange Commission (various years and firms), "Form 10-K, Annual Report Pursuant to Section 13 or 15(d) of the Securities Exchange Act of 1934," http://www.sec.gov/answers/form10k.htm

Appendix 2.1: Closed Mills and Mills No Longer Classified as BPK or PS

Company	Mill Location	Listed in EPA (2001)	Status in 2002 EPA (2006)	Status in mill2005p.xls (USDA – Forest Service, 2005)	Shutdown Date	BECA (Status in 2013)	Other Sources
Ketchikan Pulp Co (Louisiana-Pacific)	Ketchikan, AK	No	Not listed	Not listed	1997	Closed	http://en.wikipedia.org/wiki/Ketchikan,_Alaska
International Paper	Mobile, AL	Yes	Idle in 2002	Not listed	2000 The Printing Papers business announced the indefinite closure of the Mobile, Alabama mill and permanent closure of the Lock Haven, Pennsylvania mill. The announcement was in conjunction with the business's plan to realign and rationalize papermaking capacity to benefit future operations.” (2000 K-10)	Demolished	2000 Factbook (p. 416), 2010Closures spreadsheet; 1999 K-10 MACHINE SHUTDOWN http://www.thepineywoods.com/ipcloses.htm http://www.tidewaternews.com/2009/11/21/other-shuttered-ip-mills-repurposed/
International Paper	Camden, AR	Yes	N/A	Not listed	2000 “The Camden mill, which produced unbleached kraft and multi-wall paper, was closed in December 2000 due to the declining kraft paper market, excess internal capacity and shrinking customer demand.”	Not listed (also not listed in 2011 RTR survey)	2001 Factbook (p. 40); 2000 K-10 MILL CLOSURE http://www.arktimes.com/arkansas/camden-comeback-slowed/Content?oid=1217215 http://articles.latimes.com/2001/mar/02/business/fi-32251 http://www.thepineywoods.com/ipcloses.htm

Company	Mill Location	Listed in EPA (2001)	Status in 2002 EPA (2006)	Status in mill2005p.xls (USDA – Forest Service, 2005)	Shutdown Date	BECA (Status in 2013)	Other Sources
Simpson	Anderson, CA	No	Idle in 2002	Closed	2001	Closed	http://www.theshastamill.com/
	Jacksonville, FL	No	N/A	Not listed	1998	Not listed (also not listed in 2011 RTR survey)	Wigmore Street (linerboard) – closed 1998 http://jacksonville.com/tu-online/stories/120298/bus_1f1smurf.html http://www.metrojacksonville.com/article/2012-may-a-historical-stroll-down-talleyrand-avenue/page/4 http://www.nytimes.com/1998/12/02/business/company-news-smurfit-stone-to-close-four-us-containerboard-mills.html http://www.siteselection.com/theEnergyReport/2010/dec/coal.cfm
Florida Coast Paper Co., LLC	Port St. Joe, FL	No	Idle in 2002	Not listed	1998	Demolished	Jensen (1999), Master 2010Closures spreadsheet http://en.wikipedia.org/wiki/St._Joe_Company
	St. Mary's, GA	Yes	Idle after 2002. According to AF&PA, closed October 2002.	Closed	2002	Closed	http://jacksonville.com/tu-online/stories/111502/met_10974474.shtml http://onlineathens.com/stories/091402/bus_20020914026.shtml http://www.georgiaencyclopedia.org/articles/counties-cities-neighborhoods/st-marys

Company	Mill Location	Listed in EPA (2001)	Status in 2002 EPA (2006)	Status in mill2005p.xls (USDA – Forest Service, 2005)	Shutdown Date	BECA (Status in 2013)	Other Sources
							http://www.youtube.com/watch?v=FMzWk0s-d4E
	Millinocker, ME	No	Phase II (no bleached chemical pulp operations)	Idle		Not listed (also not listed in 2011 RTR survey)	
	Westbrook, ME	No	Phase II (no bleached chemical pulp operations)	Not listed		Operating	
International Paper	Moss Point, MS	Yes	Idle in 2002	Closed	2001 "The policy of balancing International Paper production with customer demand resulted in taking approximately 1.7 million tons of market-related downtime across the mill system. Additionally in 2001, the closure of paper mills in Erie, Pennsylvania, and Moss Point, Mississippi, four wood products manufacturing operations and certain consumer packaging facilities, and the down-sizing of the Savannah, Georgia mill and the Hudson River mill located	Closed	Master 2010Closures spreadsheet, 1999 Factbook (p. 534); 2000 K-10 MACHINE SHUTDOWN; http://www.tidewaternews.com/2009/11/21/other-shuttered-ip-mills-repurposed/

Company	Mill Location	Listed in EPA (2001)	Status in 2002 EPA (2006)	Status in mill2005p.xls (USDA – Forest Service, 2005)	Shutdown Date	BECA (Status in 2013)	Other Sources
					in Corinth, New York were announced.” (2001 K-10) “In June 2001, the Consumer Packaging business shut down the Moss Point, Mississippi mill and announced the shutdown of its Clinton, Iowa facility due to excess internal capacity.” (2001 K-10)		
International Paper	Natchez, MS	Yes	N/A	Closed	2003 “In January 2003, International Paper announced that it would close the Natchez, Mississippi dissolving pulp mill by mid-2003 and exit the Chemical Cellulose Pulp business.” “Specialty Businesses recorded a severance charge of $16 million associated with the termination of 447 employees in connection with the July 15th shutdown of the Natchez, Mississippi mill.” (2005 K-10)	Closed	Master 2010Closures spreadsheet, 2000 Factbook (p. 416) and 2000 Factbook (p. 36) and 2002 Factbook (p. 39); 2003 K-10 MILL CLOSURE http://www.clarionledger.com/article/20130812/NEWS01/308120003/ http://www.natchezdemocrat.com/2013/08/04/former-mill-employees-recall-life-without-international-paper/ http://msbusiness.com/blog/2013/08/06/community-learns-hard-lessons-from-ip-mill-closure/
	Missoula, MT	Yes	Phase II (no bleached chemical pulp operations)	Not listed		Closed	

Company	**Mill Location**	**Listed in EPA (2001)**	**Status in 2002 EPA (2006)**	**Status in mill2005p.xls (USDA – Forest Service, 2005)**	**Shutdown Date**	**BECA (Status in 2013)**	**Other Sources**
	Lyons Falls, NY	No	N/A	Open	2000 / 2001	Closed	http://oabonny.com/indexpage69.htm http://www.watertowndailytimes.com/article/20130627/NEWS04/706279878 http://www.lcdevelopment.net/post/_docs/LyonsFallsMillRedevelopment.pdf
Smurfit-Stone Container Corp.	Circleville, OH	No	N/A	Not listed	1998 (containerboard mill)	Not listed (also not listed in 2011 RTR survey)	Jensen (1999), Master 2010Closures spreadsheet http://www.nytimes.com/1998/12/02/business/company-news-smurfit-stone-to-close-four-us-containerboard-mills.html http://www.dispatch.com/content/stories/business/2008/10/13/ZONE1013.ART_ART_10-13-08_C12_7FBIGN9.html
International Paper	Gardiner, OR	No	N/A	Not listed	1998 / 1999 "Management indefinitely closed the Gardiner, Oregon mill because of excess capacity in International Paper's containerboard system." (2000 K-10)	Not listed (also not listed in 2011 RTR survey)	Master 2010Closures spreadsheet http://en.wikipedia.org/wiki/Gardiner,_Oregon http://www.brian894x4.com/LPandNrailroad.html http://www.katu.com/entertainment/3624111.html

Company	Mill Location	Listed in EPA (2001)	Status in 2002 EPA (2006)	Status in mill2005p.xls (USDA – Forest Service, 2005)	Shutdown Date	BECA (Status in 2013)	Other Sources
Weyerhaeuser	North Bend, OR	No	N/A	Not listed	2003	Not listed (also not listed in 2011 RTR survey)	http://www.cpbis.gatech.edu/data/mills-online/changed http://www.paperstudies.org/millsonline/datachange.htm (CLOSED 2003) http://pffc-online.com/news/1921-paper-weyerhaeuser-shutdown-containerboard Pulp mill ceased operation in 1995; operated as recycle paper mill until 2003 http://www.deq.state.or.us/lq/ECSI/ecsidetail.asp?seqnbr=1083
International Paper	Erie, PA	Yes	According to AF&PA mill closed June 2002.	Closed	2002 “The Printing Papers business approved a plan to shut down the Erie, Pennsylvania mill due to excess capacity in pulp and paper and non-competitive cost of operations.” (2001 K-10) CLOSED (2002) “The Printing Papers business approved a plan to shut down	Closed	Master 2010Closures spreadsheet, 2002 Factbook (p. 39), mill2005p.xls, 2002 10-K MILL CLOSURE http://www.goerie.com/apps/pbcs.dll/article?AID=/20020517/FRONTPAGE/105170219 http://connection.ebscohost.com/c/articles/5642488/ip-closes-erie-mill (other IP mills closed – Mobile, Camden, and Moss Point)

Company	Mill Location	Listed in EPA (2001)	Status in 2002 EPA (2006)	Status in mill2005p.xls (USDA – Forest Service, 2005)	Shutdown Date	BECA (Status in 2013)	Other Sources
					the Erie, Pennsylvania mill due to excess capacity in pulp and paper and non-competitive cost of operations." Closed June 2002 (EPA 2006, A-6)		
	Mehoopany, PA	No	Phase II (no bleached chemical pulp operations)	Not listed		Operating	
	Lufkin, TX	Yes	Idle after 2002	Open	2003	Closed	http://www.thepineywoods.com/LufkinPlantJ05.htm
Donohue Industries Inc.	Sheldon, TX	No	Idle after 2002	Open	2004	Closed (listed as Houston mill)	Jensen (1999) http://business.highbeam.com/5874/article-1G1-119881663/abitibiconsolidated-shut-down-sheldon-texas-newsprint Closed in 2004 http://www.recyclingtoday.com/Author.aspx?AuthorID=2825 http://www.cdrecycler.com/Article.aspx?article_id=81528
	Pasadena, TX	No	Phase II (no bleached chemical pulp operations)	Not listed		Closed	

Company	Mill Location	Listed in EPA (2001)	Status in 2002 EPA (2006)	Status in mill2005p.xls (USDA – Forest Service, 2005)	Shutdown Date	BECA (Status in 2013)	Other Sources
Georgia-Pacific	Bellingham, WA	No	Idle after 2002	Closed	2001 "On March 30, 2001, the Corporation announced that it would permanently close its pulp mill and associated chemical plant at Bellingham, Washington. This decision was based on the age of the facility and the extraordinarily high energy costs on the West Coast in late 2000 and because diesel generators and other power alternatives were not cost effective at this facility. These operations had been temporarily closed since December 2000."	Closed	Master 2010Closures spreadsheet; 2001 K-10 MILL CLOSURE Pulp mill closed 2001 http://www.theslowlane.com/bhaminfo/gp.html
Rayonier	Port Angeles, WA	No	N/A	Open	1997 "The Company concluded that the mill was not competitive in world markets because of long-term high wood costs due to federal environmental restrictions on Northwest timber harvests, viscose pulp capacity additions in lower cost regions of the world and anticipated	Closed	Master 2010Closures spreadsheet, 1999 Factbook (p. 547) 1997 K-10 MILL CLOSURE http://wa.sierraclub.org/northolympic/pages/rayonier.html

Company	Mill Location	Listed in EPA (2001)	Status in 2002 EPA (2006)	Status in mill2005p.xls (USDA – Forest Service, 2005)	Shutdown Date	BECA (Status in 2013)	Other Sources
					large expenditures for new environmental regulations.”		
	Peshtigo, WI	No	Phase II (no bleached chemical pulp operations)	Not listed		Operating	

Chapter 3: Retrospective Evaluation of the Costs Associated with Methyl Bromide Critical Use Exemptions for Open Field Strawberries in California

Ann Wolverton

Methyl bromide (MBr) has been widely used as a fumigant to effectively control pests in a variety of agricultural sectors (e.g. tomatoes, walnuts, strawberries, nursery crops, and forest seedlings). It is used to fumigate the soil before planting and in some post-harvest applications as well as to meet export requirements (e.g. quarantine and pre-shipment purposes). However, MBr was identified as a significant ozone-depleting substance in 1992, which brought it under the auspices of the Clean Air Act and the Montreal Protocol, an international treaty to protect the stratospheric ozone layer in the atmosphere. The amount of MBr produced and imported by developed countries was phased out between 1993 and 2005 (Table 3.1).[58] Developing countries agreed to begin phasing out methyl bromide use beginning in 2002 with a complete phase-out by 2015. Carter et al. (2005a) note that a major objective of the long phase-out was to allow time for users to develop competitive substitutes for MBr.

After developed countries reached 100 percent phase-out of methyl bromide in 2005, MBr for controlled (e.g., non-quarantine) uses could only be produced when a critical use exemption (CUE) had been agreed to by the Parties (i.e. signatories) to the Montreal Protocol.[59] This provision was included "in recognition of the uncertainty of the innovation process" to further lengthen the phase-out for critical users such as agriculture when feasible alternatives had not been identified (Carter et al. 2005a). Specifically, under the Protocol, a critical use exemption can be granted to a developed country on behalf of farmers of a particular crop if:

[58] Methyl bromide used for quarantine and pre-shipment purposes is exempt from this phase out schedule.

[59] Title VI of the 1990 Clean Air Act Amendments allows for critical use exemptions for the production, import, or consumption of methyl bromide that are consistent with the Montreal Protocol.

(i) - "The specific use is critical because the lack of availability of methyl bromide for that use would result in a significant market disruption; and

Table 3.1: Methyl Bromide Phase-Out Schedule for Developed Countries

Years	Level of Phase-Out
1993 to 1998	Production frozen at 1991 baseline levels[1]
1999 and 2000	25% reduction from baseline levels
2001 and 2002	50% reduction from baseline levels
2003 and 2004	70% reduction from baseline levels
2005	100% phase out - except for critical use (and a few other) exemptions

Source: EPA website. http://www.epa.gov/ozone/mbr/

(ii) - There are no technically and economically feasible alternatives or substitutes available to the user that are acceptable from the standpoint of environment and public health and are suitable to the crops and circumstances of the nomination" (UNEP 2006).

The threshold for economic infeasibility - or significant market disruption - is not defined by the Montreal Protocol.[60] However, beginning in 2010 the MBTOC indicated that alternatives that "lead to decreases in gross margins of more than around 15 to 20 percent or more are not financially feasible" (MBTOC 2010). The MBTOC (2010) also specifies that economic feasibility should be assessed by comparing the effects of using MBr and its alternatives on "the 'bottom line of individual firms."

This paper examines ex post the per-acre operating cost estimates provided to the nomination process for MBr critical use exemptions by the U.S. Environmental Protection Agency (EPA) to evaluate the economic feasibility of MBr alternatives. In particular, this paper examines how EPA's ex ante cost analyses for open field fresh strawberries grown in California for the 2006-2010 seasons (conducted annually two years prior to the applicable season, 2004 – 2008) compare to an ex post assessment of costs and identifies possible reasons for disparities. It does not attempt to evaluate how much MBr was exempted by the Parties to the Montreal

[60] DeCanio and Norman (2005) calculate a "political willingness-to-pay" to identify possible economic feasibility criteria for CUEs. Since MBr is a global pollutant – a ton of MBr emitted has the same effect on the ozone layer regardless of where it is emitted – the authors argue that continued adherence to the agreement is predicated on the benefits to signatory countries of phasing out MBr being at least as great as the incremental costs of projects financed through a multilateral fund. The projects funded from 1993 to 2001 cost almost $16,000 per ton reduced when weighted by project size (due to economies of scale, larger projects tend to be cheaper per ton than smaller projects) or $32,000 per-ton unweighted. They compare this willingness-to-pay measure with the estimated cost per ton of MBr found in the CUE nominations. The median cost increase is almost $24,000 per ton, indicating that many of the requested CUEs would be economically feasible under the definition offered by the authors.

Protocol for critical use for this time period. It also does not evaluate the extent to which EPA accurately characterized regulatory and technical constraints faced by growers, though it does discuss how they may have affected costs.[61]

While EPA uses the best available science to conduct its ex ante assessments, there are a variety of reasons why ex ante and ex post estimates may differ. For instance, market conditions, energy prices, or the cost and availability of technology may change in unanticipated ways. It is also possible that industry under or overestimated the costs of compliance (EPA often has to rely on industry to supply it with otherwise unavailable information on expected compliance costs). Finally, year-to-year variability of production in the agricultural sector and challenges of estimation in general introduce significant uncertainty into ex ante cost estimates. For this reason, we choose to examine multiple years of EPA analyses conducted in support of the critical use exemption nomination process.

The ex post data also is limited in several key respects. We only have information on operating costs for a typical farmer. We do not have information on the prices of specific fumigant formulations. Data on yield losses associated with methyl bromide alternatives are based on field trials. While we have detailed annual data on what fumigants farmers used, we do not have information on other management practices such as the type of tarp used. It is also analytically challenging to evaluate a counterfactual of what would have farmers done if they had not received the same level of MBr exemptions for the 2006-2010 seasons.[62] Any insights offered herein should be viewed with these limitations in mind.

3.1. Impetus and Timeline for the Regulatory Action

EPA solicits applications for MBr critical use exemptions from agricultural (and a few other) users on an annual basis several years prior to the growing season to which the exemption would apply. As part of the determination of whether and how much methyl bromide is nominated for critical use exemption, EPA conducts a technical assessment, including a cost analysis, to evaluate all applications. Once the evaluation is completed, the U.S. Government submits its critical use exemption nominations by commodity category to the Ozone Secretariat for the Montreal Protocol. This occurs two years in advance of the season to which it will apply. For instance, the 2006 nomination package was submitted in 2004, while a new nomination package for the 2007 season was submitted in 2005. The packages are forwarded to an advisory group set up by the Montreal Protocol, the Methyl Bromide Technical Options Committee (MBTOC), which reviews the packages and makes a recommendation to the Parties for the amount of methyl bromide needed for each critical use.

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[61] While CUE nominations include a cost assessment to help determine economic feasibility, the amount of MBr nominated for exemption is also based on an assessment of technical and regulatory constraints: Is an alternative registered for use? Do state or local governments have buffer zone requirements or caps on use within a given area? Are there terrain and temperature considerations that inhibit use of particular alternatives?

[62] Analyses continue to be conducted annually in support of the critical use exemption nomination process. We stop with the 2010 season due in large part to the availability of ex-post cost information.

The United States has historically been granted about 90 percent of the total amount it has nominated for exemption.[63]

3.1.1. Overall Trends in U.S. Critical Use Exemptions

U.S. critical use exemptions nominations for methyl bromide declined substantially from 2005 to 2010. For instance, the U.S. submitted exemptions for 17 commodity categories for the 2006 growing season, ranging from forest seedling nurseries to strawberries and tomatoes. These submissions represented 35 percent of U.S. baseline use. U.S. nominated critical use exemptions for the 2010 growing season also covered a myriad of categories but constituted 13.4 percent of baseline use (Table 3.2).[64]

Several trends are worth noting (Figure 3.1). First, the aggregate amount of methyl bromide requested by industry for agricultural use was far higher than what the U.S. nominated for exemption for the 2005 – 2010 growing seasons, though it also generally followed a downward trend. Second, the amount approved by the Parties was lower than the U.S. government nominated amount. Third, while the amount of methyl bromide nominated for exemption each year declined, the U.S. sometimes increased nominated amounts for specific crops or regions between years. Finally, the amount of methyl bromide allowed under the critical use exemption was met in part by drawing down the stockpile.[65]

The USDA (2000) notes that prior to phasing out methyl bromide, Florida and California growers accounted for over 75 percent of pre-plant use for fumigation of soils, with California alone accounting for almost 50 percent of the total in the United States. The best disaggregated data on fumigant use and unit costs for fruit and vegetable crops are available for California. No equivalent data are available for Florida. For these reasons, we focus on assessing the ex post costs of critical use exemptions for particular crops in the state of California when the amount granted is less than what was originally requested.

At the national level, five open field crops were granted critical use exemptions at levels substantially below what was originally requested: cucurbits (i.e., squash and melons), eggplant, tomatoes, strawberries, and peppers. In California, cucurbit and eggplant farmers did not request an exemption for MBr use over this time frame. The three remaining crops were responsible for about 62 percent of U.S. methyl bromide use in 1991, just prior to the beginning of the phase-out (Ferguson and Yee 1997; USDA 2000). They constituted 68 percent of the total amount of MBr nominated for critical use exemption in 2009. From these, we choose to

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[63] See "2005-2013 Critical Use Exemption Authorizations" at http://www.epa.gov/ozone/mbr/cueinfo.html.

[64] For the 2014 season, the amounts nominated and authorized for U.S. use decreased to 1.7 and 1.7 percent, respectively, and covered four commodity categories, one of which was California strawberries. Note that EPA anticipates that California strawberry growers will completely transition out of methyl bromide by 2017 through the use of straight choloropicrin at rates up to 350 pounds per acre, steam and anaerobic soil disinfestation. See http://www.epa.gov/ozone/mbr/CUN2016/2016CUNStrawberries.pdf.

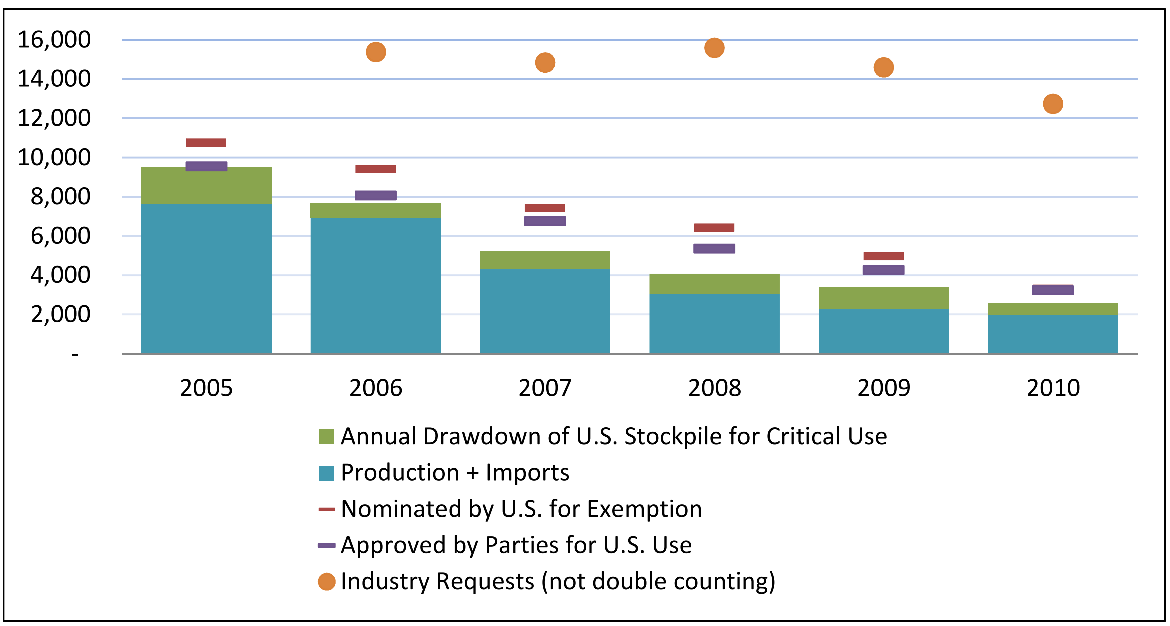
[65] The stockpile consists of MBr produced prior to the 2005 phase-out. Use of stockpiled MBr for the replanting of turf was not allowed after April 2014, though the deadline was extended for golf courses through November 2014. For more information on the potential role of the stockpile, see Appendix 3.2.

Table 3.2: Percent of Baseline MBr Consumption in U.S. Exempted for Critical Use by Year

Calendar Year Growing Season	U.S. Nominated Amount (percent of baseline)	Amount Authorized by Parties for Use in U.S. (percent of baseline)
2005	39	37
2006	35	32
2007	29	26
2008	23	21
2009	19.5	16.7
2010	13.4	12.7

Source: http://www.epa.gov/ozone/mbr/cueinfo.html accessed 03/19/12.

Figure 3.1: U.S. MBr Production, Imports, and Drawdown of Stockpile for Critical Use (2005 – 2010)



Source: US EPA[1] and UNEP (2010).

focus on California open field strawberries for the 2006 to 2010 seasons, though at times we are only be able to evaluate a subset of these years.[66, 67]

Table 3.3 illustrates the amount of MBr the United States nominated for exemption for use on strawberry fields and what this represents in terms of the amount originally requested by growers for the 2006 - 2010 seasons. California made up the vast majority of the requested amount each year (67 percent in 2006 and 80 percent in 2010). This is not surprising as more than 85 percent of all fresh and processed strawberries grown in the United States came from California in 2007. In each state/region that requested a critical use exemption, the amount requested by farmers was almost always higher than what EPA nominated for exemption. However, the rate of decrease in the amount nominated was markedly slower in California than in other parts of the country, mainly due to regulatory constraints discussed later in the paper.[68] Between the 2006 and 2010 growing seasons, the amount of methyl bromide nominated for exemption for strawberry fields in California declined by 12 percent, while it declined by 45 percent and 67 percent in Florida and Eastern states, respectively, over the same period.

3.2. EPA Ex Ante Cost Estimates for Open Field Strawberries in California

In keeping with MBTOC (2010) guidance, three years prior to the year for which the MBr is approved for use EPA evaluates the per acre impacts of using methyl bromide and a set of alternatives on the bottom line finances of a typical farmer on a per-crop basis. As part of this process, EPA assesses the rate at which MBr is applied (e.g., pounds per acre) and the total amount of land where economic, technical, and regulatory constraints inhibit the use of alternatives to determine the aggregate amount of methyl bromide to nominate for critical use exemption in a given year.[69]

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[66] By 2001, MBr use had declined substantially per the Montreal Protocol. Carter et al. (2005b) find that California farmers of non-strawberry crops reduced MBr use by 59 percent between 1996 and 2001, while California strawberry growers only decreased MBr use by 14 percent over the same time period. About 88 percent of California strawberries acreage in 2001 continued to use MBr (Carter et al. 2005a).

[67] Tomatoes grown in open fields also appear to be a good candidate for study. Florida and Eastern U.S. farmers continue to request critical use exemptions for tomatoes. While California tomato growers requested MBr critical use exemptions for hilly terrain for the 2006 and 2007 seasons, they did not apply for CUEs for subsequent seasons. This raises the question of whether California tomato farmers relied on the MBr stockpile, switched to growing other crops, or discovered affordable alternatives to MBr that would work effectively on hilly terrain.

[68] A review of the CUE nomination packages suggests that EPA initially underestimated California regulatory constraints faced by farmers for MBr alternatives and that it modified its requests to account for them in CUEs for subsequent growing seasons (i.e. the amount nominated for exemption jumped by 17 percent from 2006 to 2007).

[69] EPA also tries to eliminate any double counting from the requested amount and subtracts out land that represents growth since 2005 in the industry, since it does not qualify for exemptions.

Table 3.3: Amount of MBr Requested by Industry and Nominated for Critical Use Exemption in California, - Florida and Eastern U.S. for Strawberries[1] -

	Year	2006	2007	2008	2009	2010
California	Amount (kg) Nominated	1,086,777	1,267,880	1,244,656	1,064,556	952,543
	% of Amount Requested by Industry	67%	87%	98%	90%	100%
Florida	Amount (kg) Nominated	295,853	297,909	220,302	176,333	163,440
	% of Amount Requested by Industry	51%	51%	38%	30%	28%
Eastern U.S.	Amount (kg) Nominated	230,332	165,735	137,334	93,488	75,832
	% of Amount Requested by Industry	66%	46%	36%	34%*	28%*

Source: EPA Critical Use Exemption Nominations for open field strawberries for the 2006- 2010 seasons.

Because EPA assesses the burden associated with switching to methyl bromide alternatives, the baseline against which these alternatives are assessed is the continued use of MBr (i.e., continued exemption) instead of zero MBr use (i.e., no exemptions to the phase-out for critical use). Operating costs and gross revenues are calculated for methyl bromide and what were deemed feasible alternatives by EPA at the time of the assessment on a per acre basis.[70] The net revenues from using an alternative are then compared to those for methyl bromide to generate a loss per acre.[71] No aggregate estimates of costs (and revenue loss) are provided by EPA as part of the CUE nomination package, though one could calculate them from the information available assuming that all acreage to which MBr is applied resembles a typical acre.

In the CUE nomination packages for the 2006–2008 seasons, EPA evaluated the operating cost and revenues for methyl bromide combined with chloropicrin (PIC) in a 67:33 formulation and three alternatives that combined fumigants, 1,3-dichloropropene + chloropicrin (1,3-D + PIC), chloropicrin + metam sodium (PIC + MS), and metam sodium alone (MS).[72] For the 2009-2010 seasons, EPA dropped PIC+MS as an evaluated

[70] EPA considers all known chemical and non-chemical alternatives to methyl bromide but focuses the analysis on the subset of the most likely alternatives based on CUE applications, the published literature, and grower input.

[71] For purposes of submitting the package to the MBTOC, all values are converted into kilograms and hectares. The numbers reported here are expressed in pounds and acres.

[72] Methyl bromide is typically combined with other chemicals before being applied to a field. A common formulation in California for use on strawberries in 2000 was 67 parts MBr and 33 parts PIC, though ratios of 57:43 and 75:25 were also regularly used (California Pesticide Information Portal database). How MBr is used to treat strawberry fields varies to some degree by region. In California, the entire surface of the field is typically

alternative from the economic analysis.[73] While EPA recognized several other potential MBr alternatives, it did not analyze them for the 2006 – 2010 seasons (see Table 3.4) because they were not yet registered for use in the United States.

3.2.1. Main Drivers of Ex Ante Cost Estimates

Gross revenues per acre for MBr and its alternatives are calculated by multiplying the market price of the fruit times the yield. They depend on three main components: potential yield loss due to use of an alternative, the expected producer price of strawberries, and the potential loss of revenue due to a planting delay that results in a missed market window. Changes in product quality that could result in lower revenues and additional fixed costs from the use of an alternative (e.g. a drip system for applying it), while discussed, are not quantified. While EPA included an estimate of the effect of missing a market window on revenues in its assessment for the 2006 – 2008 seasons, it dropped it in later year analyses due to lack of evidence of a harvesting delay (i.e. for the 2009 – 2010 seasons, the market price for strawberries was identical whether using MBr or an analyzed alternative).[74]

For the 2006-2010 season CUE nominations, the range of yield losses associated with the three evaluated MBr alternatives were based on a review of the available literature. The estimate of yield loss for a typical California farmer from switching to PIC+MS was drawn from an unpublished report (Locascio et al. 1999). EPA used the mean estimates from Shaw and Larson (1999) to represent yield losses from switching to 1,3-D + PIC or to MS (see Table 3.5). Shaw and Larson used meta-analysis techniques to compare yield estimates for methyl bromide-chloropicrin with four other soil treatments applied to California strawberries in three distinct locations. The test years for the 45 studies underlying the meta-analysis ranged from 1987 to 1997.

EPA retained the same yield loss estimates in the critical use exemption nomination packages for the 2006 – 2010 seasons. The key reason cited by Office of Pesticides Program (OPP) experts for retaining this assumption was a desire to rely on multi-year studies, as many factors can influence realized yield losses

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fumigated, covered by a tarp, and left to sit for a period of time. After the tarp is removed, farmers form planting beds and then again cover them with plastic. Planting begins 2-6 weeks after fumigation. After harvest, new crops are planted that benefit from the initial fumigation. In Florida, MBr is applied when raised beds for strawberries are constructed. The beds are covered with plastic mulch. Two weeks later strawberry plants are transplanted and fed via drip irrigation. After harvest, existing beds are often used to produce a second crop (EPA 2008).

[73] OPP experts indicate that MS+PIC was dropped mainly for technical reasons: It does not distribute evenly or deeply enough in the soil to be effective against nematodes or pathogens and thus is used mostly for weed management after 1,3-D + PIC is applied.

[74] Industry CUE applications stopped mentioning harvesting delays when switching to MBr alternatives.

Table 3.4: Recognized but Non-Registered MBr Alternatives for Growing Strawberries in CA (as reported in the CUEs for the 2006-2010 Growing Seasons) -

Unregistered Alternatives	First Mentioned in CUE	Status as of 2009 Growing Season CUE
Basamid	2006	Registration being considered
Methyl iodide	2006	Registration being considered; trial use only
Propargyl bromide	2006	Under proprietary development for future registration
Sodium azide	2006	Under proprietary development for future registration
Furfural	2007	Registration being considered (used for greenhouse ornamentals)
Muscador ablus strain QST 20799	2008	Registration package received but not yet for sale in US
dimethyl disulfide (DMDS)	2009	Under proprietary development for future registration

Source: CUE nomination packages for the 2006-2010 seasons; OPP provided spreadsheet.

Table 3.5: Estimates of California Strawberry Yield Loss from the Published Literature, as Reported in the CUE Nomination Packages

MBr Alternative	Range of Yield Loss Relative to MBr	"Best" Estimate
PIC+MS	6.6% – 47% loss	27%
1,3-D+PIC	1% gain - 14% loss	14.4%
MS	16% - 29.8% loss	29.8%

Source: EPA CUE Nominations for 2006-2010 seasons.

(e.g., weather, pest pressure) in a given year.[75] The yield per acre for each alternative was derived by multiplying the estimated yield from methyl bromide by the "best" estimate of yield loss for an alternative.[76]

The difference in the price of strawberries per pound between baseline and policy was based on an assessment of the potential for a decrease in price from delaying harvest by several weeks for the 2006 – 2008 seasons. EPA used USDA data to estimate that market prices for strawberries would decline by about 5 percent due to such a harvesting delay ($0.69 per pound x 5% = $0.66). EPA updated the market prices for strawberries to evaluate the CUE for the 2009 and 2010 growing seasons.

[75] Multi-year studies better reflects yield losses from changes in pesticide controls versus seasonal factors.

[76] While not included in the nomination, EPA also evaluated cases where yield loss was at the low end of the range for all three alternatives (7% for PIC+MS; 1% for 1,3-D+PIC; and 16% for MS) and a high case for 1,3-D+PIC.

EPA used a bottom-up approach to estimate operating costs.[77] Based on information provided by industry in their CUE applications, EPA estimated the labor and material costs associated with land preparation (e.g., seed, fertilizer, pesticide, and fumigant), weeding, irrigation, and harvest when using MBr versus its main alternatives.[78] The same basic approach to estimating operating costs was used for each of the 2006-2010 season CUEs, with only slight changes (for instance, updating fumigant prices) for the 2009 and 2010 seasons. To assess the amount of active ingredient applied during fumigation, EPA used the average number of annual applications of methyl bromide or its alternatives (i.e., one application) used to treat the crop.

Overall operating costs were nearly identical for methyl bromide and the analyzed alternatives but differed in three specific areas: the cost of the fumigant, manual labor needed to apply the fumigant, and harvest labor (due to its relationship to yield). According to spreadsheets provided by OPP, the application of MBr alternatives were estimated to require a bit less manual (5 percent less for all alternatives) and harvest labor (between 7 and 15 percent less) than MBr. The analysis assumed that all other aspects of growing strawberries remained unchanged.[79]

Table 3.6 presents a summary of the operating cost and gross revenue information that underlies the critical use exemption analysis for the 2006 planting season. For open field strawberries, the losses per acre from switching to a MBr alternative were driven primarily by the difference in yield, with EPA predicting based on its data and assumptions that 1,3-D+PIC was the next best alternative to methyl bromide.[80] The loss per acre was calculated by examining the change in net revenues relative to using MBr. The alternative that resulted in the lowest loss was determined to be the most likely substitute.

The overall conclusion of the cost analyses for the 2006 – 2010 seasons was that use of the most viable alternative, 1,3-D + PIC, instead of methyl bromide would result in about a 16 percent loss on a per acre basis as a percent of gross revenues.

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[77] EPA did not include fixed costs due to wide variability in factors that influence them (e.g., farm size, technology adoption). Applicants were asked to provide this information on their exemption request forms.

[78] EPA does not quantify the effect of switching to a MBr alternative on the costs of growing a rotation crop. For example, if a lettuce field that has soil pathogens is leased to a strawberry grower who fumigates the soil prior to planting and the field is rotated back to lettuce after three years (the soil pathogen has been controlled), both crops benefit from the strawberry crop soil fumigation. However, only the effects on strawberries are considered.

[79] EPA mentioned but did not include other costs of switching to MBr alternatives. For example, 1,3-D + PIC (the alternative with lowest yield loss) is reportedly less effective with broadcast fumigation than drip fumigation and would therefore requires 40 percent more fumigant (EPA 2005).

[80] On net, the estimated loss from using a MBr alternative was similar across CUEs for the 2006-2010 seasons for 1,3-D + PIC but somewhat higher in 2009 for MS (32 percent instead of 26 percent), according to EPA calculations.

Table 3.6: Yields, Revenues, and Operating Costs for Open Field CA Strawberries (2006 – 2008 Growing Seasons) -

Fumigant	Methyl Bromide	Alternatives		
		PIC+MS	1,3-D+PIC	MS
yield loss	0%	27%	14%	30%
yield (pounds per acre)	43,215	31,547	37,165	30,251
strawberries price per pound	$0.69	$0.66	$0.66	$0.66
gross revenue per acre	$29,818	$20,679	$24,362	$19,829
operating costs per acre	$24,334	$22,395	$23,659	$22,226
net revenue per acre	$5,484	($1,716)	$702	($2,396)
loss per acre	$0	$7,200	$4,782	$7,881
loss as percent of MBr gross revenue	--	24%	16%	26%

Source: EPA CUE Nominations, converted to pounds and acres. Note that the CUEs express application rates and land in kilograms and hectares.

3.2.2. Main Sources of Uncertainty in Ex Ante Cost Estimates

Ex ante analyses are subject to many challenges and uncertainties. Recall that EPA conducts its analyses three years prior to when a CUE is approved, making it difficult to precisely estimate how much methyl bromide will actually be needed in a given growing season, what MBr alternatives will be available for use, and the yield loss and operating costs associated with each option.

At the time the phase-out began, the USDA (2000) reported that the most promising alternatives to methyl bromide for agricultural use were a combination of the fumigants 1,3-dichloropropene and chloropicrin (1,3-D + PIC), or chloropicrin combined with metam sodium, napropamide (an herbicide registered for use on eggplant), or pebulate (also an herbicide, now de-registered for use on tomatoes). Metam sodium was viewed as a potentially viable alternative in areas where the use of 1,3-D was restricted (see section E.3).[81] As many of the studies up to that time had focused on the performance of MBr alternatives with regard to California strawberries or Florida tomatoes, the USDA document noted even greater uncertainty regarding alternatives for use on other crops.

Other factors that could affect the rate at which MBr alternatives were adopted include use restrictions to protect workers and bystanders from health effects associated with their toxicity, and U.S. EPA and state registration requirements. The USDA (2000) noted that several possible alternatives – for instance,

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[81] Noling et al. (2010) note that a key challenge to transitioning out of MBr has been its effectiveness against nematodes (i.e., roundworms), disease, and weeds. Many of the registered alternatives are only effective against a subset of these problems. For instance, chloropicrin is effective against disease, but far less effective in fighting nematodes or weeds. 1,3-D is effective against nematodes but does less well in fighting disease or weeds. Metam sodium is good for weed control but does little to guard against disease or nematodes. As a result, farmers often use these chemicals in combination.

methyl iodide and propargyl bromide – were not registered under the Federal Insecticide, Fungicide, and Rodenticide Act (FIFRA) at the time that the phase-out began.

In addition, EPA faced the challenge of generating ex ante estimates based on somewhat limited data and poor documentation in source reports on yield loss associated with various MBr alternatives. Without assessing the relative quality of the studies upon which EPA relied, one can observe that the yield loss estimates used to evaluate costs for the 2006 – 2010 seasons were based on fairly old data. The "best" estimates used by EPA in its analysis reflected the high end of the range reported in the CUE nomination packages for yield loss for two of the three alternatives (see Table 3.5). According to OPP experts, EPA used conservative assumptions in the early years of the critical use exemption process because the literature contained a wide range of yield loss estimates for which researchers often did not clearly describe what impacts were included.

Finally, while EPA did not evaluate how lack of a critical use exemption would affect the ability of California farmers to compete in the global marketplace it is a relevant consideration and a source of uncertainty with regard to the ultimate financial welfare of farmers. In particular, it is important to understand how switching to a MBr alternative impacted the ability of conventional production in California to compete with organic production in California and imports from Mexico.

3.2.3. Exogenous Factors that May Affect Estimated Ex Ante Costs

Regulatory and technical constraints or unexpected innovation could result in greater or less use of MBr alternatives by California strawberry farmers. While the focus of the economic analysis is an assessment of per acre costs, EPA also makes a recommendation of the total amount of methyl bromide that should be exempted for use by crop and region based on an assessment of what alternatives are likely to be available and regulatory and technical restrictions. Specifically, the requested amount is based on the rate at which methyl bromide is applied times the total amount of land where technical and regulatory constraints prevent switching to MBr alternatives (and therefore, are eligible for exemption).

Table 3.7 shows that strawberry farmers' initial requests were based on a higher rate and acreage than EPA nomination, but in later years they were similar or identical. Also, note that while the application rate used by EPA initially declined (from 2006 to 2007), it increased for the 2008 -2010 seasons. The amount of land deemed eligible for MBr use followed a similar trend.

EPA noted that the rate of adoption of MBr alternatives was limited by a combination of transitional and regulatory issues. In general, the amount of land assumed to face technical constraints stayed about the same across all five growing seasons – approximately 10-15 percent of land used to grow strawberries in California was assumed to be on hilly terrain that does not support the drip systems required to apply many MBr alternatives. However, EPA accounted for the use of strip fumigation (i.e. about 10 percent of land used this form of fumigation, which has a lower application rate) and the change in the ratio of MBr to PIC from 67:33 to 50:50 in its analysis of the 2009 and 2010 seasons.

Table 3.7: Application Rates and Acreage Underlying Methyl Bromide Exemption Nominations for Open Field CA Strawberries -

Growing Season		2006	2007	2008	2009	2010
Application Rate (lbs/acre)	Requested by farmers	180	160	180	174	175
	Used by EPA in nominations	175	160	180	174	175
Acres	Requested by farmers	20,000	20,000	15,555	14,925	12,000
	Qualified for nomination	13,720	17,470	15,244	13,472	12,000

Source: EPA CUE nominations, converted to pounds and acres. Note that the CUEs express application rates and land in kilograms and hectares.

The impact of regulatory constraints on the use of alternatives is not easy to determine and can be different for every strawberry growing area in California. The main regulatory constraint accounted for by EPA was California's restrictions on the use of 1,3-D. In the CUE nomination package for 2006, EPA assumed these restrictions applied to a smaller subset of the total acreage (47–67 percent, which is identical to the California Strawberry Commission's (CSC) estimate noted in the 2009 CUE) than what it assumed for the subsequent seasons (82–94 percent).[82] This was based on the assumption that some townships would be allowed to exceed the cap by up to 2 times. However, uncertainty regarding how the process would work resulted in EPA interpreting the caps strictly for the 2007 season. EPA noted that fewer townships would find the cap on 1,3-D binding if farmers switched to drip irrigation, as less chemical would be required (also, see Carpenter et al. 2001). However, this could result in a 3-4 week planting delay. According to OPP experts, there were also county-level restrictions on the use of chloropicrin and metam sodium, though the effects of these restrictions were not quantified.

With regard to an ex post assessment, we ask whether the regulatory or technical constraints differ from what was expected and their implications for the cost of alternatives. Ideally, it would be useful to know if any new alternatives had been registered for use; whether state and/or local governments initiated new regulatory requirements; and whether terrain and temperature considerations still inhibited the use of particular alternatives during the 2006 – 2010 seasons.

[82] Information available in the CUE nomination packages indicated that 19,550 to 20,900 acres used MBr pre-phase out between 2000 and 2003. MBr application rates had already begun to decline from 218 pounds per acre in 2000 to 170-179 pounds per acre in 2001-2003. In 2004, the amount of land requiring methyl bromide decreased substantially - to 17,680 acres – and about 10 percent of farmers using MBr switched from flat fumigation to strip fumigation, which had a lower application rate (129 lbs/acre) than flat fumigation (172 lbs/acre).

3.3. Literature and Data Available to Conduct Ex Post Evaluation

There are several key components of costs that can be potentially examined ex post (See the first chapter in this report for a discussion of the conceptual framework for costs): what types and how many entities comply with the regulation; what technologies or strategies are used to comply; the initial costs and the ongoing costs of compliance; any indirect costs such as quality tradeoffs or missed market windows; and other opportunity costs such as costs in related markets. For this case study we largely rely on publically available data and resources. Specifically, we review the existing literature to identify any ex post studies on MBr critical use exemptions as well as available data sources on key inputs to the ex ante cost analysis (e.g., availability of MBr alternatives, fumigant use by type, input and strawberry prices, production, yields, and operating costs).

It is also important to note several data limitations that will affect the extent to which we can opine on some aspects of the ex ante cost analysis. First, ex post evaluations of MBr critical use exemptions are rare in the literature. Second, market data on fruit and vegetable crops are not as widely available as for row crops, particularly at a geographically disaggregated scale. Third, publically available data to evaluate the operating costs associated with switching to a MBr alternative in California are also limited.

3.3.1. Ex Post Literature

A number of papers have evaluated the potential impact of banning MBr use in the United States and, in some cases, have analyzed to what extent critical use exemptions may alleviate this impact. However, a search of the literature and emails to key researchers who have studied the economic impacts of banning methyl bromide uncovered only one published ex post analysis of the impact of critical use exemptions for MBr use by California strawberry farmers (Mayfield and Norman 2012).[83] The authors find little evidence of negative impacts on farmers of the phase out, in part due to exemptions. While no formal counterfactual is evaluated, they point to rising yields, acreage, exports, revenues, and market share as evidence that the industry has not faced substantial negative impacts. A review of the main ex ante studies of a MBr ban or phase-out is available in the appendix.

A number of recent studies also estimate yield effects of various chemical combinations compared to methyl bromide + chloropicrin for strawberries based on field trials. We also identify a meta-analysis covering studies from 1997 – 2006 sponsored and approved by the MBTOC (Porter et al, 2006). The MBTOC also discusses recent evidence in its 2010 assessment report (UNEP 2010). Recent studies by Othman et al. (2009) and

[83] Catherine Norman, Rachel Goodhue, Colin Carter, and Lori Lynch did not know of any other ex-post analyses of the MBr phase out, but they suggested we search for information from the Annual Methyl Bromide Alternatives Conference, the UC-Davis Cost and Impact Estimates Database, and the University of Florida methyl bromide research group. We found no ex-post analysis at any of these forums.

Fennimore and Ajwa (2011) are particularly relevant because of their focus on California. Since yield loss is one of the key uncertainties identified in the ex ante analysis, we discuss these studies in greater detail in section E.4 as part of the ex post evaluation.

3.3.2. Data for Evaluating Costs Ex Post

The EPA critical use exemption nomination packages are a good starting point for information on MBr usage. In particular, EPA included information on the amount of methyl bromide used in prior years as part of each annual nomination package. For instance, information in the nominating package for the 2013 season may reveal actual application rates and overall usage for the 2006 – 2010 seasons.

EPA relied on the 2002 NASS Agricultural Chemical Usage Vegetables Survey for information on the proportion of acreage in California using methyl bromide in the 2006 – 2008 CUE nomination packages. Since that time, 2006 and 2010 data have been published. The survey also reported the average application rate and total pounds applied for several states, including California, which can be used in combination with what was reported in the most recent critical use exemption nominating packages.

To shed light on whether EPA accurately characterized likely MBr alternatives in its ex ante analysis, we rely on two data sources: future year (post 2010) CUE nomination packages indicate if and when new alternatives other than those identified in the original package became available (i.e., were registered for use) and what the experiences of farmers have been with respect to their use. Spatially disaggregated data, available from the state of California by month, year, and crop from 1989 to 2009 through its Pesticide Information Portal (PIP), indicate the amount of a specific chemical used and the acreage treated.[84] Methyl bromide and many of the alternatives in EPA's ex ante cost analyses are in the database. Conversations with experts in EPA's Office of Pesticide Programs as well as discussions in the literature indicate some level of data error in PIP. Carpenter et al. (2001) state that acreage treated with MBr may be overstated for perennial crops due to spot treatments on small areas that are reported as though they are full-acre treatments. On the other hand, a certain amount of MBr use is not reported in the database. Carpenter et al. (2001) note that in 1999 about 2 million pounds used on 8,000 acres (about 13 percent of the total area treated with MBr in California at the time) were not included in the database. Finally, Carpenter et al. (2001) identify a number of duplicate entries for MBr and its alternatives. Possible errors also are flagged in the database based on a statistical analysis of outliers.

Net compliance costs consist, in this case, of gross revenues minus operating costs. As previously stated, gross revenues were estimated using information about the market price of strawberries and yield for MBr and several alternatives. Yield information is mainly drawn from the literature. The market price of strawberries can be evaluated based on national and state-level monthly data on prices received by growers, and retail prices for 1970-2009 from the United States Department of Agriculture (USDA).[85] The USDA's 2009 Fruit and Tree Nut Yearbook also reports the national-level monthly average retail and grower prices by year

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[84] The data can be downloaded from http://calpip.cdpr.ca.gov/main.cfm.

[85] For a list, see http://usda.mannlib.cornell.edu/MannUsda/viewDocumentInfo.do?documentID=1381

back to the mid-1990s. Gross revenues could also be affected by changed in product quality. EPA was not able to assess ex ante the effect of eliminating methyl bromide on the quality of strawberries due to lack of data. For similar reasons, we also are not able to assess any effects on product quality in the ex post analysis.

We explore several sources of information on ex post operating costs. [86] The first source of information is crop budgets for open field strawberries assembled by UC-David researchers for the South Coast region in Santa Barbara and Ventura Counties in 2006 and 2011 and for the Central Coast region in Santa Cruz and Monterrey Counties in 2010, respectively. These studies generated sample operating (and to some extent, fixed) costs and revenues for a representative farm. Operating costs are differentiated by stage of production – land preparation, plant establishment, fertilization, irrigation, pests, harvesting, and end-year clean-up. While the 2011 reports were issued after the last year of ex ante estimates to which we make comparisons, they are useful because they evaluate alternative fumigants to methyl bromide. The 2006 and 2010 studies use MB+PIC as the default fumigant.

We are cognizant of the limitations of using crop budgets for estimating ex post operating costs. They are not necessarily indicative of actual costs for any individual farmer. Instead, they are produced to help farmers assess the profitability of growing particular crops and may include cost categories that do not apply to many growers. That said, the crop budgets are the only ex post information we have on costs, are produced for strawberry-growing regions in California that overlap with areas seeking critical use exemptions, and are described by the authors as representative of costs faced by a typical farmer, which is also the focus of EPA ex ante cost analyses.

The second source of information is the CUE requests for the 2012 growing season. The third source is proprietary data purchased by EPA Office of Pesticides Program from a private pesticide marketing company. It is based on a survey of farmers. This database has information on fumigant and pesticide use, total area treated with methyl bromide or an alternative, total amount of chemical used, average application rates, crop yields, and chemical application expenditures by crop. Sample size is reported but is often small depending on the crop and region of the country, making much of the data not useful for our purposes. In particular, we are only able to rely on fumigant prices for the ex post assessment. Because the database is proprietary, we report data only in highly aggregate form. The final source of information is studies that take a bottom-up approach to estimating costs associated with using methyl bromide or one of its alternatives based on field experiment data.

Information on the role played by California regulatory constraints is limited. We only have information from the literature that pre-dates or coincides with the critical use exemption nomination packages for the 2006 – 2010 seasons. While we discuss these studies as part of our evaluation, it is not possible to come to any definitive conclusions ex post regarding the role of regulatory restrictions on the pace and types of MBr alternatives utilized over this time period.

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[86] A search through the Federal Register for reregistering MBr alternatives did not uncover any additional sources of cost information (i.e., the regulatory notices are largely focused on evaluating exposure risk and health impacts).

Finally, to investigate whether reducing MBr use resulted in unanticipated competitive disadvantages either in the conventional, organic, or international markets for strawberries we examine national level data from USDA on production, utilization, acreage, shipments, and yield per acre for strawberries for 1970-2009. National level monthly data is also reported on imports and exports by country. State-level information is available for a subset of these variables annually: for instance, harvested acreage, yield per acre, and production.[87] The USDA's 2009 Fruit and Tree Nut Yearbook also includes supply, utilization, and trade statistics by year at the national level.[88] [89]

3.4. Assessing Costs of MBr Critical Use Exemptions Retrospectively

Comparing ex ante compliance costs to ex post estimates of actual compliance costs is challenging for all the usual reasons – limited access to cost data in the post-regulatory period, few retrospective analyses, etc. However, a retrospective review of the cost analyses conducted by EPA for MBr critical use exemptions faces additional challenges. Unlike regulations that seek to control a substance, MBr critical use exemptions allow for the use of a substance that is otherwise banned. In a typical ex post evaluation, we compare what analysts estimated ex ante to the cost of actions taken by regulated entities to comply with the rule ex post. In the case of methyl bromide, however, the market does not reveal the cost of actions that would have otherwise been taken in the absence of the exemption – moving to a more expensive or less effective substitute, for example. In other words, we do not have a measurable and quantifiable counterfactual based on real world revealed market behavior. With this limitation in mind, it may still be possible in some cases to learn something useful without having to estimate an approximate counterfactual. In particular, because strawberry farmers request far more than what the U.S. nominates for exemption, we can examine whether growers faced larger than expected costs of switching to non-MBr substitutes by comparing EPA estimates to what we know about costs observed in the marketplace.[90]

While regulations are often revised, the timeframe over which this occurs is typically longer, allowing –in theory – for an ex post analysis to isolate the effect of a regulation on costs from other factors, including previous or subsequent rulemakings that apply to the same industry. In the case of methyl bromide, it is challenging to isolate the cost implications of a CUE in a given year from those of future CUEs. In addition,

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[87] For a list, see http://usda.mannlib.cornell.edu/MannUsda/viewDocumentInfo.do?documentID=1381

[88] The USDA also has a publically available database of own and cross-price demand elasticity estimates from the published literature by commodity. The database was last updated in September 2009 and is available at: http://www.ers.usda.gov/Data/Elasticities/query.aspx. No equivalent database is available for fumigants.

[89] In addition, the USDA publishes typical planting and harvesting dates, the most active growing season by crop and state for strawberries, and the principal producing counties in each state (USDA 2006). However, these data are of limited use since a more recent version of these data are not produced for fruits and vegetables.

[90] Another case where we might potentially be able to estimate the counterfactual is when the amount authorized by the Parties is non-binding for particular agricultural uses; MBr alternatives turned out to be cheaper than anticipated and more growers moved to substitutes than originally anticipated.

some researchers have speculated that there may be a strategic element embedded in the requests made by industry, particularly since it is repeated annually.[91] We choose to examine the cost analyses in the CUE nominations for the 2006 – 2010 growing seasons as a group, given the unique nature of the CUE process. This also makes some sense because EPA did not substantially alter the assumptions or inputs to its cost analyses for California strawberries over this timeframe.

This remainder of this section compares EPA's ex ante cost estimates to available ex post estimates for each cost component, identifying possible reasons for substantial differences. A summary of the main sources of information, study findings for each main cost category and limitations of the study appear in Section X.X.X.

3.4.1. Regulated Universe

EPA ex ante cost analyses conducted for MBr critical use exemption packages only estimated per acre costs for a typical California strawberry farmer, not total costs. For this reason, we have limited information on the potentially regulated universe. For instance, we do not know what types of farms were expected to make use of exempted MBr. However, the ex ante analyses presented some information on overall methyl bromide use, expressed as total strawberry acreage relying on methyl bromide, which sheds some light on the regulated universe affected by critical use exemptions.

It appears that California farmers used slightly less MBr to grow strawberries than requested but that this was approximately in line with EPA expectations. Growers requested MBr for use on 75-85 percent of the California strawberry crop in the 2006-2008 seasons, falling to 50-60 percent in the 2009 and 2010 seasons. Information on how much of this amount was expected to be met from the stockpile in any given year is not available.[92] Actual use in 2006 - 2010 from the USDA and California PIP indicate that farmers used methyl bromide on 67 percent and 40 percent of the acres dedicated to strawberries, respectively, assuming no growth in acreage (EPA assumed strawberry acreage stayed at 2000 levels).

3.4.2. Baseline Information

Typically the baseline for a cost analysis would attempt to identify what emission-reducing technologies or process changes have already been adopted by the regulated universe absent regulation. Voluntary adoption of emission-reducing practices by industry is not typically attributed to the cost of the regulation (US EPA 2010). In the case of CUEs, this would manifest itself as switching to a MBr alternative for economic reasons. In these cases, there would be no reason to request a critical use exemption. That said, proper characterization of baseline conditions is still important for evaluating costs associated with switching away

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[91] Mayfield and Norman (2012) point to the possibility of rent seeking at the Federal and state levels by California strawberry industry groups to avoid the costs of switching to MBr alternatives.

[92] USDA data (from 2002) cited in the CUE for the 2006 season, indicate that approximately 55 percent of California strawberry acreage used methyl bromide at the time. These data inform the assumptions for the 2007 – 2009 season CUEs, as more recent data were unavailable.

from MBr use. In particular, estimates of yield loss associated with alternatives are predicated on assumptions about strawberry yields when using methyl bromide.

EPA's ex ante MBr baseline yield of 43,000 pounds per acre was based on USDA data and was only about 10 percent lower than the national average yield of about 47,000 pounds per acre between 2006 and 2010 (see Figure 3.2). However, USDA data also indicate that California strawberry farmers were generally much more productive than the average: The average yield for a California strawberry farmer between 2006 and 2010 was 62,000 pounds per acre. Compared to the California average, EPA estimate was about 44 percent lower over this time period.

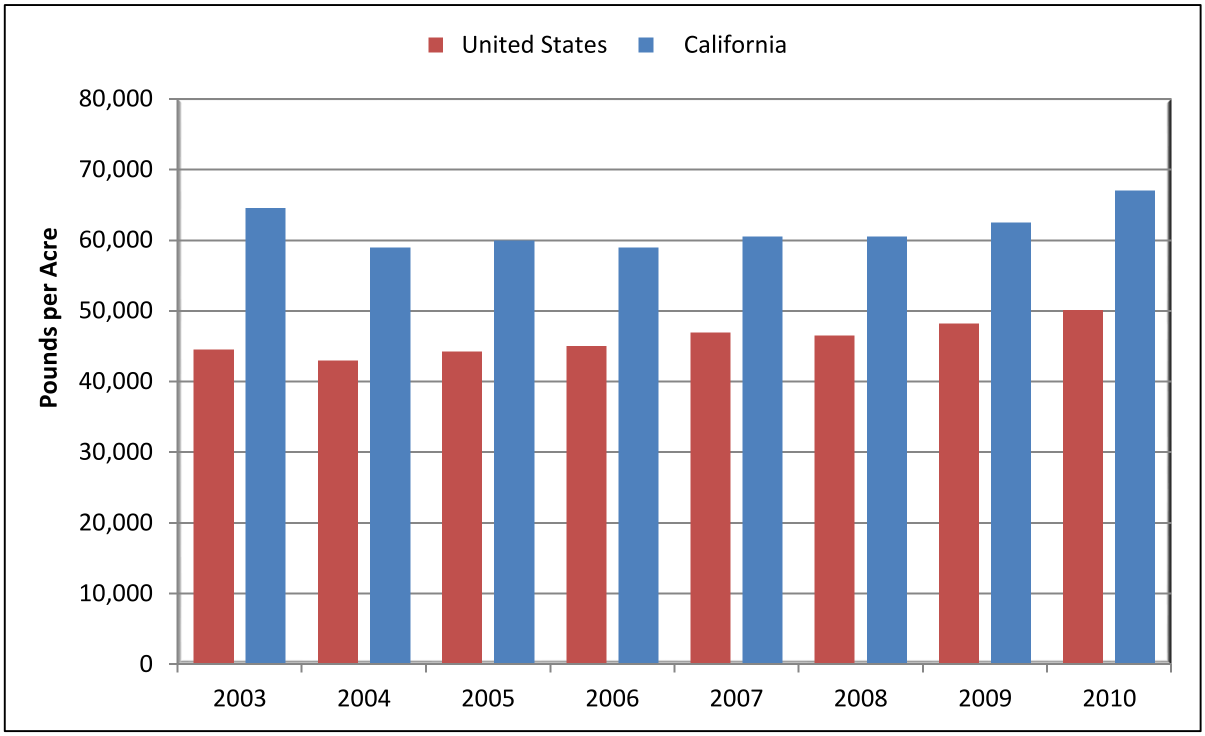
While using the national average underestimates baseline yields for the "typical" California farmer, it does not affect the bottom-line financial assessment since it affects operating costs and gross revenues equally (i.e., thus cancelling out its effect). It is worth noting that our ability to draw conclusions about baseline yields is limited since we only have state and national averages. We have no information on how yields vary by farmer. It is possible that farmers seeking critical use exemptions are less productive on average. For instance, yields may be lower or production costs higher due to hilly terrain, complicating the transition away from methyl bromide.

3.4.3. Methods of Compliance

A key input into estimating the cost of a regulation are the types of technologies or approaches used to comply. In the case of critical use exemptions, we evaluate the available evidence on the use of MBr alternatives in the California strawberry sector for the 2006-2010 growing seasons. Were these alternatives used as frequently as expected? Did any new alternatives become available that were not anticipated by EPA at the time of the ex ante analysis? We also assess the rate of MBr application for those that continue to use it since it is possible that farmers found a way to use less than anticipated. Finally, we examine the role of state regulatory restrictions in slowing the transition to some MBr substitutes, which is also discussed in the CUEs.

Use of Methyl Bromide Alternatives. Recall that EPA analyzed three alternatives to methyl bromide in its 2006 -2010 CUE nomination packages, 1,3-D + PIC, PIC + MS, and MS alone. It identified 1,3-D + PIC as the lowest

Figure 3.2: Fresh Strawberry Yield per Acre in the United States and California, 2003 - 2010



Source: http://usda.mannlib.cornell.edu/MannUsda/viewDocumentInfo.do?documentID=1381; See - table04.xls. -

cost MBr alternative. Ex post data confirm that 1,3-D + PIC was the most commonly used alternative to methyl bromide for strawberry production in California over this time period.

According to the NASS Agricultural Chemical Usage Vegetables Survey, PIC was used on about 17,600 California acres of strawberries in 2000. By 2006, this amount had increased to 18,300 acres. Dichloropropene (1,3-D) was not separately identified in the 2000 USDA survey. In 2006, the USDA reported that it was used on 6,400 acres of strawberries in California. The California PIP tracks the use of specific products, so that it is possible to eliminate double counting (PIC is used alone and in combination with both 1,3-D and MBr). In 2000, 1,3-D + PIC and PIC alone were rarely used by California strawberry farmers. Fewer than 500 acres were treated with one of a variety of possible formulations. By 2006, nearly 10,000 acres were reportedly treated with 1,3-D + PIC, while another 1,700 acres were treated with chloropicrin in 96 and 100 percent formulations. Acreage treated with 1,3-D+ PIC rose to more almost 16,000 acres in 2010, while the amount treated with chloropicrin grew to more than 4,700 acres.

Metam sodium use by California strawberry growers also increased, though it was still not widely used. In 2000, only 313 acres were treated with metam sodium. This increased to 1,500 acres by 2006 (USDA reports a similar estimate of 2,100 acres in 2006) and 2,600 acres by 2010.

It is also possible that other alternatives not analyzed by EPA in the CUEs have since become available. As of March 2011, 10 methyl bromide alternatives were registered at the Federal level for use in the United States (see Table 3.8). The alternatives analyzed in the CUE nomination packages for the 2006 -2010 planting seasons are highlighted in dark grey. Alternatives that were recognized at the time of the CUE request but either not analyzed or not yet registered at the Federal level are highlighted in light grey. Of these, three – dazomet, dimethyl disulfide, and methyl iodide – have been registered since the time that analysis was originally conducted.[93] The UNEP (2010) also notes that several chemicals that showed initial promise were no longer considered viable alternatives to methyl bromide, such as propargyl bromide and sodium azide.[94] However, federal-level registration is not sufficient for use: fumigants must also be approved via a state level registration process. California is particularly strict in this regard. Of the chemicals listed in Table 3.8, 1,3-dichloropropene – with or without chloropicrin-, chloropicrin, metam sodium, and dazomet were registered for use in California as of 2010.[95]

The MBTOC observed in its 2010 assessment report that much progress has been made in replacing methyl bromide in pre-plant uses, "particularly due to improved performance of new formulations of existing chemical fumigants (e.g., 1,3-D + PIC, PIC alone, metam sodium) and new fumigants (e.g., methyl iodide, dimethyl disulfide), but also due to increased uptake of non-chemical alternatives." The California PIP data demonstrate that only three potential chemical alternatives to methyl bromide were used in California between 2006 and 2010, 1,3-D, PIC, and metam sodium, and that strawberry farmers generally did not recombine them in new or novel ways (for instance, they did not utilize the three-way fumigant system of 1,3-D + PIC + MS, increasingly common in Florida).

Methyl iodide (also called iodomethane) has long been recognized as a "near perfect substitute" for methyl bromide, meaning it results in little or no yield loss when compared to methyl bromide (e.g., Hueth et al. 2000; Sances 2000; Goodhue et al. 2004). While it was registered as a fumigant in the United States in 2007, California did not register methyl iodide until December 2010 (and since that time, methyl iodide has been taken off the U.S. market by its producer and therefore is unavailable (Rubin 2012)).[96] Thus, it did not play a role as a MBr substitute in the time frame we analyze.

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[93] At the federal level, methyl iodide was first registered for use as a fumigant in 2007. Dazomet was registered in 2008 for use in California only, while dimethyl disulfide was registered federally in 2010 though it is not yet registered in California. See http://ucanr.edu/sites/PAWMBA/Nursery_Projects/Perennial/Challenges/.

[94] Research into non-chemical alternatives (e.g., solarization, steam treatment, natural herbicides) has increased in recent years (e.g., Samtani et al. 2011). Preliminary data show that some alternatives may hold promise with regard to yield performance and weed control, but it is unclear whether results would continue to hold on a larger scale.

[95] See http://www.cdpr.ca.gov/docs/emon/vocs/vocproj/desc_fieldfum_mthd.htm.

[96] In spite of the more favorable financial implications, recent experience suggests that public concern regarding associated health effects may continue to limit its use, at least in the near term. For instance, see www.panna.org/blog/ca-brings-heat-methyl-iodide and an August 30, and www.grist.org/scary-food/2011-08-29/methyl-iodide-mock-fumigation.

Table 3.8: Federally Registered and Non-Registered Methyl Bromide Alternatives for Strawberries

Federally Registered Alternatives Available	Known Alternatives that Are Not Federally Registered
1,3-Dichloropropene	Furfural
Chloropicrin	Propargyl Bromide
Metam Sodium	
1,3-Dichloropropene + Chloropicrin	
1,3-Dichloropropene + Chloropicrin + Metam Sodium	
Metam Sodium + Chloropicrin	
Terbacil	
Dazomet (Basamid)	
Dimethyl Disulfide	
Methyl iodide (iodomethane)	

Dark grey: alternatives analyzed in the 2006-2010 season CUE nomination packages; Light grey: Alternatives recognized at the time of the CUEs but either not analyzed or not yet registered; White: Currently registered for use but not recognized in the CUEs.

If methyl iodide was once again available on the U.S. market, what role might it play going forward? While the CUE nomination package for the 2012 season continued to assume that 1,3-D + PIC was the most economic MBr alternative for California strawberries, methyl iodide was considered viable in the CUE for the 2013 growing season. EPA estimated that methyl iodide would be financially feasible according to the criteria set out by the MBTOC (the per acre loss was estimated to be 6 percent of the gross revenue per acre compared to MBr, well below the 15-20 percent threshold the MBTOC suggests) and more attractive from a financial perspective than 1,3-D + PIC (which EPA estimated would result in a 15 percent loss in gross revenue per acre for the 2013 growing season). The key reason for a predicted loss in gross revenue from methyl iodide use was higher costs stemming from additional input requirements (i.e. impermeable films are required with methyl iodide applications in California).[97, 98] Fennimore and Ajwa (2011) also point out that

[97] Hueth et al. (2000) point out that it is difficult to predict what will occur to the price of methyl iodide as it is becomes more widely used, as its high price at the time of publication could be due to its relatively specialized use.

[98] While Noling (2005) note that virtually impermeable films were initially very expensive in the United States due in part to high transportation costs and were sometimes subject to long delays because only a few European manufacturers produced them, Noling et al. (2010) report that over a dozen firms manufacturer virtually impermeable films, including several in the U.S. and Canada.

totally impermeable films are approved for use with methyl iodide and that trial results show these films to be effective at retaining the fumigant in the soil.[99]

How Methyl Bromide Is Used. It is possible that farmers that continue to rely on methyl bromide found a way to use less of it than anticipated while maintaining its effectiveness. Ex post evidence indicates that this has not been the case for California strawberry farmers. In its assessment of the 2006-2010 growing seasons, EPA assumed that MBr would be applied at a rate of 175 pounds per acre. USDA chemical usage data demonstrates that it was actually applied to California strawberries at an average rate of about 190 pounds per acre in 2006 (EPA underestimated the application rate by about 8 percent). USDA chemical usage data indicate an average rate of 180 pounds per acre for methyl bromide applied to California strawberries in 2010, while California PIP data show that the average application rate for methyl bromide in 2010 was about 185 pounds per treated acre (an underestimate of 3 - 5 percent).

Regulatory and Other Restrictions. Historically, California farmers tended to use MBr + PIC at a 67:33, 57:43, or 75:25 ratio. The nomination package for the 2012 growing season notes two factors that have complicated California's ability to reduce the proportion of methyl bromide in a given formulation: First, for farmers who continued to use methyl bromide, California restrictions on chloropicrin meant that the lowest formulation likely allowed in California at the time was 57 part methyl bromide to 43 parts chloropicrin. Data from the California PIP confirm that about 94 percent of the methyl bromide used in the 2009 and 2010 growing seasons was formulated at 57:43 or higher. A small amount (about five percent) was available at a 50:50 or 45:55 formulation. Second, two new diseases emerged in fields treated with MBr alternatives, which resulted in some farmers using MBr once every three years to manage these diseases. The reason for these diseases is not known, but it has been posited that it could be the result of switching from broadcast to drip fumigation, the lower rates of fumigant applied via drip, or fundamental differences between methyl bromide and its alternatives.

The most recent technical assessment by the MBTOC points to a third possible reason why California farmers did not reduce methyl bromide use at a faster rate (UNEP 2010). It notes that low permeability barrier films allow for methyl bromide to be applied at significantly lower rates (25–50 percent less than when used with conventional films) without loss of effectiveness or any discernible impact on yields (e.g., Noling 2005, Noling et al. 2010).[100] Planting is typically delayed, however, to allow enough of the chemical to dissipate so that residues in the soil do not injure the plant. While required in the European Union, during our period of study California did not allow virtually impermeable films to be used with methyl bromide due to concerns about worker exposure to the chemical.

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[99] While there is far less data available to evaluate the experience of Florida strawberry farmers, they reportedly were successful at reducing the rate at which MBr was applied by relying on virtually impermeable films (US EPA 2009). Also, methyl iodide was registered for use in Florida shortly after it was federally registered. The CUEs for the 2011-2012 seasons note that the uptake of methyl iodide could be rapid if early adopters met with success.

[100] With more permeable films, 20-90 percent of methyl bromide is allowed to escape into the atmosphere. The wide range is due to the interaction between the chemical, soil and other environmental factors (Noling 2005).

California regulations also limited the use of viable MBr alternatives. For instance, EPA (2006) reported that township caps on the use of 1,3-dichloropropene (1,3-D) were binding for 40-62 percent of California acreage planted in strawberries in 2005 and were one of the main reasons for granting continued critical use exemptions to strawberry farmers.[101] [102] In addition to township caps on 1,3-D use, Nolling and Botts (2010) also credit uncertainty regarding authorization for practices such as virtually impermeable films and bed shank fumigation with slowing the transition away from methyl bromide in California. In addition, the CUE nomination packages for the 2006-2010 and subsequent seasons consistently mention restrictions on application rates for volatile organic compounds (VOCs) such as chloropicrin and metam sodium, and buffer zone requirements for some chemicals (e.g., 1,3-D) in California as complicating factors.[103] [104] Finally, farmers cannot use a chemical until it has also been approved for use in California.[105]

3.4.4. Compliance Costs

In this section, we examine the ex post evidence on compliance costs, which in the case of critical use exemptions is defined by EPA to be the net of changes in gross revenue and operating costs of switching away from MBr to other alternatives. Recall that the EPA ex ante cost analyses focused on net operating

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[101] California began to allow use of 1,3-D on a restricted basis after 1995. Most townships, defined as a 36 square mile area, were allowed to use up to 90,250 pounds annually if applied between February and November at a soil depth of 18 inches or more. Beginning in 2002, California began to allow townships to exceed the cap by up to twice the allowable amount. The degree to which a township is allowed to exceed the cap is proportional to how far below the cap it has been in previous years (i.e., previous over-compliance with the cap is used as a bank), so that on average the original limit is met. If the chemical is applied in December or January or at shallower depths, then the cap is more restrictive. See www.cdpr.ca.gov/docs/ emon/methbrom/telone/mgmtplan.pdf and www.cdpr.ca.gov/docs/emon/pubs/ehapreps/analysis_memos/4327_sanders.pdf.

[102] Carpenter et al. (2001) estimate what demand for 1,3-D would be after the MBr phase-out absent township restrictions. At the time of the study, it was assumed that annual township caps were strictly enforced (i.e. no exceedances are allowed). They estimate that demand for 1,3-D would be 10 million pounds higher absent the limits on its use, affecting 47 townships and almost 27,000 acres (about 32 percent of total acreage likely to demand 1,3-D). The vast majority of this demand is driven by strawberries. If strawberries are not included, then demand is estimated to be 1.5 million pounds over what is allowed, affecting 23 townships and about 6,300 acres.

[103] California requires a buffer zone around an occupied structure and has maximum allowable application rates for 1,3-D and other fumigants, including methyl bromide, to protect workers health (Carter et al. 2004).

[104] Carter et al. (2004) examine the combined effect of 1,3-D township caps and buffer zone requirements. When township caps are binding, increasing buffer zones has little effect on fumigant choice. When there is a close substitute for 1,3-D that can be used in buffer zones (e.g., chloropicrin), growers see little impact on net revenues but when no good alternative is available returns are lower and the growers' choice of fumigant is affected.

[105] This is in contrast to Florida, where there were fewer regulatory constraints on MBr alternatives. The CUE nomination packages for the 2006-2010 seasons mention buffer zone requirements for some chemicals and restrictions on the use of 1,3-D where karst geology is present due to the risk of groundwater contamination. Florida also has a separate process for approving chemicals apart from the Federal registration process but allowed the use of methyl iodide shortly after it was registered at the Federal level.

costs – they do not evaluate one-time or fixed costs of switching away from methyl bromide – but do consider indirect costs such as missing the market window for selling strawberries.

3.4.4.1. Gross Revenues

The accuracy of estimates of gross revenues is driven by the ability to anticipate future strawberry prices and changes in yields. An ex post assessment reveals that EPA's estimates of prices received by California growers for the 2006–2010 harvest are a reasonable approximation of actual prices. However, while EPA relied on the best data available at the time, recent literature indicates that early studies likely overestimated the yield loss associated with switching from methyl bromide to 1,3-D + PIC. EPA also did not update its yield loss estimates over time (e.g., it maintained the same assumption for 1,3-D+PIC throughout the CUEs for the 2006-2010 and subsequent seasons). This would result in an overestimate of the potential loss in gross revenues ex ante, all else equal.

Strawberry Prices. In general, the prices for strawberries used in the CUE nomination packages for the 2006-2010 seasons are consistent with historical (2000-2003) and contemporaneous (2006-2010) prices received by growers in California (see Table 3.9). Using data available at the time, EPA assumed strawberry prices would be $0.69 per pound in the 2006 nomination package (assembled in 2003) and $0.79 per pound in the 2009 nominating package (assembled in 2006).[106] While the prices received by strawberry producers fluctuate from year-to-year - the average annual price was $0.65 per pound in 2006 and $1.01 per pound in 2010 (in 2006 dollars) - the average was $0.65 per pound and $0.86 per pound over the 2003-2006 and 2006–2010 time periods, respectively.

Yield Loss Associated with MBr Alternatives. Recall that the yield losses used by EPA in its ex ante cost analyses for the 2006-2010 seasons were 14 percent and 30 percent for 1,3-D + PIC and metam sodium, respectively. The CUE nomination packages for later growing seasons are one potential source of ex post information. However, the yield loss estimate for 1,3-D + PIC (as well as other aspects of the analysis) were not updated in the CUEs that occur in the time frame most relevant for this analysis. Thus, we must look to other data sources.

A number of recent studies on yield loss of MBr alternatives for growing open field strawberries demonstrate the possible availability of competitive substitutes. The MBTOC discusses some of this recent evidence in its 2010 assessment report, noting that 1,3-D + PIC, methyl iodide + PIC, and DMDS + PIC (as well as other

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[106] From USDA NASS, the national average from 2000-2003 is about $0.69 per pound in 2000 dollars. When adjusted to 2006 dollars, it is about $0.79 per pound.

Table 3.9: Strawberry Prices Received by California Growers (2000-2009)

Year	California Grower's Price (cents per pound)
2000	0.84
2001	0.77
2002	0.59
2003	0.71
2004	0.64
2005	0.60
2006	0.65
2007	0.80
2008	0.91
2009	0.90
2010	1.01
2000-2003 (average)	0.65
2006-2010 (average)	0.86
2000-2010 (average)	0.74

Source: http://usda.mannlib.cornell.edu/MannUsda/viewDocumentInfo.do?documentID=1381 See table06.xls. Prices adjusted to 2006 dollars using BLS Producer Price Index for strawberries.

chemical combinations) performed as well as MBr + PIC in field trials in the United States, Australia, and Spain (UNEP 2010). However, it also notes that California has restricted the maximum rates at which many of these chemicals can be used to a level lower than what was tested in the field trials. (Also, recall that DMDS is not registered for use in California.)

Based on California field trials, Othman et al. (2009) suggest that 1,3-D + PIC (with or without a sequential application of metam potassium), chloropicrin alone, and iodomethane + PIC all perform competitively with 67:33 MBr+PIC (measured as average total yield per acre) when used in conjunction with virtually or totally impermeable films. Fennimore and Ajwa (2011) examine the effectiveness of 1,3-D+PIC under standard and totally impermeable films in California. They find that fumigant retention is substantially higher with totally impermeable films, such that less 1,3-D + PIC (i.e., about 33 percent less than under standard films) is needed to achieve strawberry yields comparable to standard MBr + PIC applications.

The UNEP also sponsored a meta-analysis to summarize what the literature has found with regard to the yield performance of various alternatives relative to methyl bromide for strawberries and tomatoes (Porter et al. 2006).[107] A total of 42 studies published between 1997 and 2006 were identified for strawberries, for

[107] Note that while the underlying studies evaluated in the UNEP-sponsored meta-analysis have been published in peer-reviewed journals, the meta-analysis itself has not - to our knowledge - been externally peer-reviewed.

which there was information on 101 field trials. The majority of the field trials (about 90 percent) took place prior to 2002. Twenty-eight percent of these trials were conducted in California. Because the authors could not express yield loss across the various studies using a common unit of measure, they expressed the results in terms of the within-study yield response of a given treatment (e.g., a given chemical formulation applied at a similar rate using a similar method) relative to methyl bromide. They then examined variation in relative yields of various treatments across studies.

The results show that about one-third of the treatment combinations had average relative yield estimates "either greater or not statistically different from the estimated yield for the standard [MBr-PIC at a 67:33 ratio] by more than 5 percent," including 1,3-D + PIC and methyl iodide + PIC (see Figure 3.3).[108] The estimate for metam sodium, the other main alternative analyzed, was about a 22 percent reduction in relative yield on average, though when combined with other chemicals (e.g. 1,3-D or PIC) it was estimated to be much more effective.

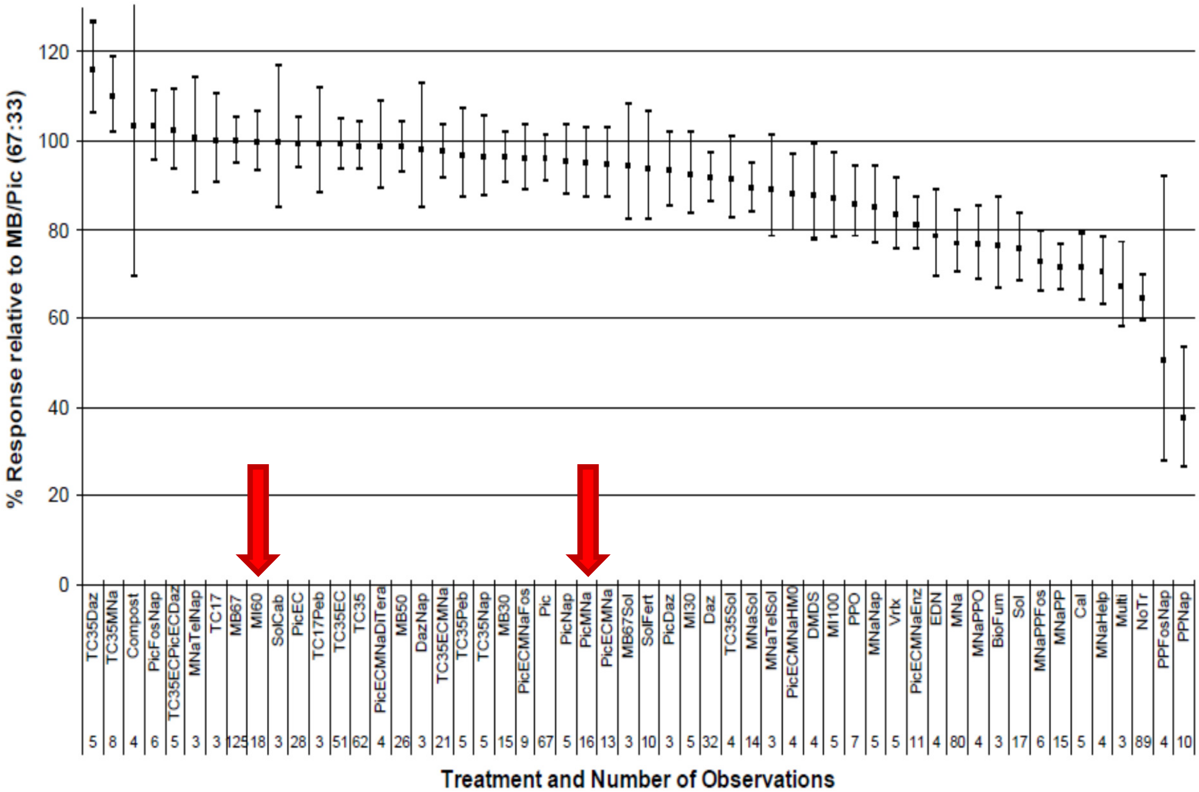
While consistent with the finding of other studies with regard to yield loss, it is difficult to translate the results of this study – expressed in terms of average relative yield - into specific yield loss estimates associated with the methyl bromide alternatives analyzed by EPA in its CUE nominations for the 2006-2010 seasons. The meta-analysis looks at the variability of treatment not at actual harvest weight.[109] It is also not clear the extent to which the meta-analysis results are applicable to California farmers for two reasons. First, more than half of the studies were conducted in Florida, Spain or New Zealand. Second, the results only compare average relative yields derived under specific conditions. It is possible that the field trials conducted in California are still not representative of the soils, terrain, pest profiles, and regulatory constraints of individual farmers requesting critical use exemptions.

What can we learn from the limited ex post evidence available on yield loss with respect to the likely impact of MBr alternatives on farmers for the 2006 – 2010 seasons? If, in fact, switching to 1,3-D + PIC would have resulted in less yield loss than anticipated for this time period, then the ex ante and ex post estimates of the loss in net revenue would differ by 28-87 percent for a yield loss of 10 percent or 0 percent, respectively, for the 2006 – 2010 seasons.

[108] It is worth noting that the average relative yield results for methyl iodide +PIC are much more variable across trials than for many other alternatives. Also, many of the 22 alternatives included perbulate, an herbicide that is no longer registered. Nine of the alternatives that fared well when compared to MBr+PIC did not include perbulate.

[109] In addition, a review of the data by the Office of Pesticides Programs found that some of the individual data points may not to have been correctly inputted into the statistical analysis.

Figure 3.3: Relative Yield for MBr Alternatives for Fresh Strawberries: 1997 to 2005 -



Source: -Figure 6 in the UNEP meta-analysis by Porter et al. (2006). Bars around mean estimates are least significant intervals. The figure only includes treatments with three or more observations. MBr alternatives of interest include 1,3-D+PIC, denoted TC35EC; PIC + MS, denoted PICMNa; and PIC+methyl iodide, denoted MI60. The robustness of the meta-results depend in part on the number of observations available for a given fumigant.

3.4.4.2. Operating Costs

Based on the limited ex post information available, ex ante operating costs for methyl bromide users appear to be fairly accurate for the yield per acre used by EPA in the CUEs (i.e., for a farm that produces strawberries at a yield similar to the national average). Harvesting costs appear to be higher than suggested by the ex ante estimates when the California average is used instead of the national average. However, this is driven by the difference in yield assumption.

Cost Estimates when Using Methyl Bromide. The sample costs from the 2006 and 2010 UC-Davis crop budgets both use methyl bromide + PIC as the default fumigant. Those developed for the South Coast region in 2006 are meant to represent a typical farm of 90 acres, while those developed for the Central Coast region in 2010 define a typical farm as 50 acres. Both of these assumptions are broadly consistent with what was submitted by the California Strawberry Commission for critical use exemption consideration for the 2006–2008 growing seasons in this region. The 2006 and 2010 sample costs apply to different regions in California, while EPA estimates in the CUE nomination packages are averages across regions applying for exemption. We compare these sample costs to the ex ante EPA cost estimates for the 2006-2008 seasons. (Aside from updating fumigant prices, little changed in the underlying assumptions that inform the 2009-2010 CUE cost estimates.)

A difference in average cultivation costs (which do not vary by yield) exists between the UC-Davis sample cost and EPA estimates. UC-Davis cultivation costs were $8,500-$11,000 per acre across the two regions (Table 3.10 presents sample costs for one of the two regions[110]), while EPA estimated them as $16,000 per acre (in 2006 dollars).[111] No one category of costs stands out as the sole reason for this discrepancy. EPA included $6,500 per acre in general material costs, while material costs in the 2006 UC-Davis study totaled to $5,600 per acre. Also, the EPA estimate of MBr fumigation costs per acre was about twice what was assumed in the 2006 UC-Davis study ($1,500 instead of $800 per acre).

When we match the baseline yield used in the CUE nomination packages to that in the sample cost studies we find that per acre harvesting costs are very similar. (UC-Davis estimated harvesting costs as $13,000-$15,000 per acre compared to EPA's ex ante estimate of $13,000.) For a strawberry farm that produces at the California average instead of the national average, the UC-Davis researchers estimated harvesting costs to be about $19,000-23,000 per acre across the two regions (expressed in 2006 dollars). They assumed, however, that harvesting costs increase linearly with yield: the cost per pound of strawberries harvested did not change.

Even with these differences, from the information we have it appears that EPA's ex ante estimates of operating costs – defined as cultivation plus harvesting costs – are relatively close to ex post estimates (i.e., EPA used an estimate of $29,000 while ex post data indicate an estimate of $21,500-$26,000 per acre) for a baseline yield similar to the national average.

MBr Alternative Fumigation Costs. Did EPA do a reasonable job of anticipating the actual fumigant costs of the MBr alternatives analyzed? Information on the cost of using MBr alternatives is scarce. Carter et al. (2005a) note that fumigation of strawberry fields prior to planting accounts for a substantial proportion of total production costs - about 10 percent for bed fumigation and 20 percent for flat fumigation. While the 2010 sample cost study for the Central Coast region suggests that a grower applying 1,3-D + PIC via drip irrigation would incur a cost of $900-$1,600 per acre (in 2006 dollars), it does not evaluate the crop budget

[110] The UC-Davis sample costs include several cost categories that are excluded from the table because they were not considered by EPA in the CUEs - for instance, the cost of cooling picked strawberries and interest on operating capital - that add up to about $2,700-$4,400 per acre for a farm that produces at the national average. EPA considered them to be fixed costs, which would be difficult to adequately capture as they vary widely with acreage and the technologies adopted. As we have no ex-ante estimates to which we can compare the UC-Davis estimates, we also do not include them here.

[111] The EPA cost estimates are adjusted to 2006 dollars, assuming they were reported in nominal terms in 2003. To translate the costs expressed on a tray per acre basis (the 2010 and 2011 sample costs are both reported this way) to pounds per acre, we use the UC-Davis provided average of about 10 pounds per tray.

Table 3.10: Operating Costs per Acre - UC-Davis Sample Cost Study for South Coast Region

	Yield (pounds per acre)						
	44,300	50,600	56,900	63,200	69,500	75,900	82,200
Cultivation	8,446	8,446	8,446	8,446	8,446	8,446	8,446
Harvesting	13,095	14,982	16,869	18,757	20,644	22,531	24,419

Source: Takele et al. (2006). *Sample Costs to Produce Strawberries: South Coast Region – Santa Barbara County*. -

using this alternative. We can gather a bit more information from the 2011 sample cost studies for the South Coast region because they are based on using 1,3-D+PIC as the fumigant. Note that the 2011 sample costs for Santa Barbara and San Luis Obispo Counties continue to use 90 acres as the size of a typical farm in this region. The sample costs for Ventura County use a somewhat smaller size of 70 acres to represent a typical farm (which is the same as the last time this county was analyzed by UC-Davis researchers in 2004).[112]

The direct fumigant cost for 1,3-D+PIC applied through drip irrigation was $1,000-$1,100 (adjusted from 2011 to 2006 dollars) across the two 2011 studies with the slightly higher value used for Ventura County. The 2006-2008 CUE nomination packages used a higher fumigant cost for 1,3-D + PIC - of about $1,700 per acre - but assumed it was applied using a shank (or broadcast) system. Use of 1,3-D+PIC applied by drip irrigation reportedly requires less of the fumigant (overall) because the delivery system is more efficient than broadcast application (CSC 2012b).[113] Unfortunately, however, the difference in the method of application

[112] Ex-ante studies such as Goodhue et al. (2003) also identified 1,3-D applied alone or in combination with metam sodium as having slightly lower costs per acre than methyl bromide based on the cost of fumigant application, weeding, and tarp material. Likewise, Goodhue et al. (2004) find evidence based on field experiments that drip-applied chloropicrin and 1,3-D "may potentially be economically feasible" when compared to MBr+PIC (applied at a 67:33 ratio) for fumigating strawberry fields in California. The range of application rates over which they appear economically feasible increases with a change in the type of tarp used (i.e., virtually impermeable films perform better than high-density polyethelyne films). At the time of the study, it was common to apply fumigants broadly with some of what is applied escaping from permeable tarps into the air as volatile organic compounds. The authors note that, if instead farmers use virtually impermeable film (VIF) and apply fumigants through a drip system, substantially less of the fumigant would escape into the atmosphere allowing them to use less of the chemical and to lower costs. EPA estimated ex-ante that the MBr alternatives analyzed had slightly lower operating costs per acre than MBr, which is consistent with these studies.

[113] Sydorovych et al. (2006) note that applying 1,3-D + PIC by a drip system results in lower labor and machinery costs, but somewhat higher material costs than a shank fumigation system (but this study examines its use in North Carolina, not California).

that underlies the UC-Davis and EPA cost estimates renders a comparison of limited use and makes it difficult to draw solid conclusions.[114]

Data indicate that 1,3-D+PIC was applied via drip irrigation with some regularity in counties where farmers sought critical use exemptions for the 2006-2010 growing seasons. According to the CUE for the 2014 growing season (EPA 2012), 55 percent of strawberry acreage in Ventura and Oxnard counties in 2009 reportedly used a drip system for applying 1,3-D+PIC, decreasing to 30 percent in 2010 (some farmers returned to using methyl bromide every three years to control unanticipated diseases).

Fumigant Prices. We obtain fumigant prices in California from a proprietary pesticide marketing database available through the OPP. Nominal prices are available for methyl bromide and three of its alternatives. We convert these to real prices using the Producer Price Index (PPI) and measure them against methyl bromide in 1999 (which receives a value of 1). Since these chemicals were often combined for use when applied to strawberry fields and the application rates at which they were applied differ, the prices do not indicate the relative difference in cost between the MBr alternatives evaluated by EPA, 1,3-D + PIC, MS alone, and MS + PIC. They are still instructive, however. First, note that methyl bromide has been consistently more expensive per pound than its alternatives (see Figure 3.4). Second, while several authors note that MBr prices will begin to increase relative to other fumigants as exemptions decline and the stockpile is drawn down, it appears that a more than proportional increase in the price for methyl bromide relative to its alternatives has not yet occurred. Prices for 1,3-D and PIC both increased by slightly more than methyl bromide over this time period.[115]

3.4.4.3. Indirect Costs

In the CUE requests for the 2006 – 2008 growing seasons, farmers argued that the use of MBr alternatives would result in a planting delay of several weeks. As a result, the prices they received for the strawberry crop would be lower than otherwise, all else equal. The main explanation offered for the delay was the use of drip irrigation to apply 1,3-D. (According to the California Strawberry Commission, unlike with broadcast fumigation, equipment has to be set up for the entire field before the chemicals can be applied (see EPA

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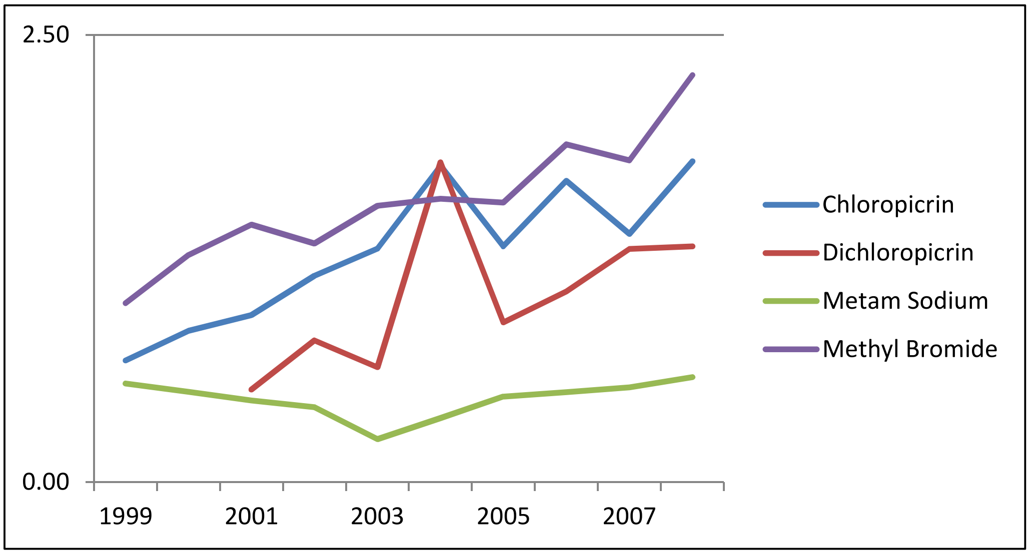
[114] Combined, cultivation and harvesting costs in Santa Barbara and San Luis Obispo counties are similar to UC-Davis estimates for 2006 when using MBr ($22,000 vs. $21,500). The combined cultivation and harvesting costs for Ventura County when 1,3-D+PIC is used are higher, almost $25,000 per acre. A recent ex-post estimate for Ventura County using MBr is not available. The 2006-2008 CUE nomination packages used a slightly lower harvesting cost while cultivation costs remained nearly identical when 1,3-D+PIC was used instead of MBr +PIC. Combined they added about $28,000, $1,000 less than what was estimated when MBr was used. However, it is difficult to draw conclusions given the difference in assumptions about how the chemical is applied (shank vs. drip).

[115] Prices for dichloropicrin only begin in 2001 in the proprietary pesticide marketing data while prices are not reported in 2000, 2004, and 2006 for metam sodium. For purposes of the Figure, metam sodium prices in intervening years are linearly interpolated.

Figure 3.4: Real Prices of Fumigants in California Relative to Methyl Bromide in 1999 -



Source: Proprietary pesticide marketing data, with data masked by index.

2005).)[116] EPA did not analyze the effect of a missed market window on California growers in the CUEs for the 2009-2010 growing seasons since the industry supplied no evidence that it had actually occurred. However, it noted the possibility of a planting delay due to the use of tarps (i.e., it takes longer for the fumigant to dissipate). Carpenter et al. (2000) also indicate that a planting delay of about a week could occur due to phytotoxicity concerns.

In the CUE nomination packages for the 2006-2008 growing seasons, EPA assumed that missing the market window by a few weeks would result in about a 5 percent (or 3 cent per pound) penalty in terms of foregone revenue. This appears to be an accurate characterization of the average monthly differential in national prices received by producers between 2005 and 2010. However, it is worth noting that, because the harvesting season varies markedly by region in California, when a delay occurs could matter greatly from the perspective of the individual farmer.[117] Figure 3.5 illustrates the differences in the prices growers receive by

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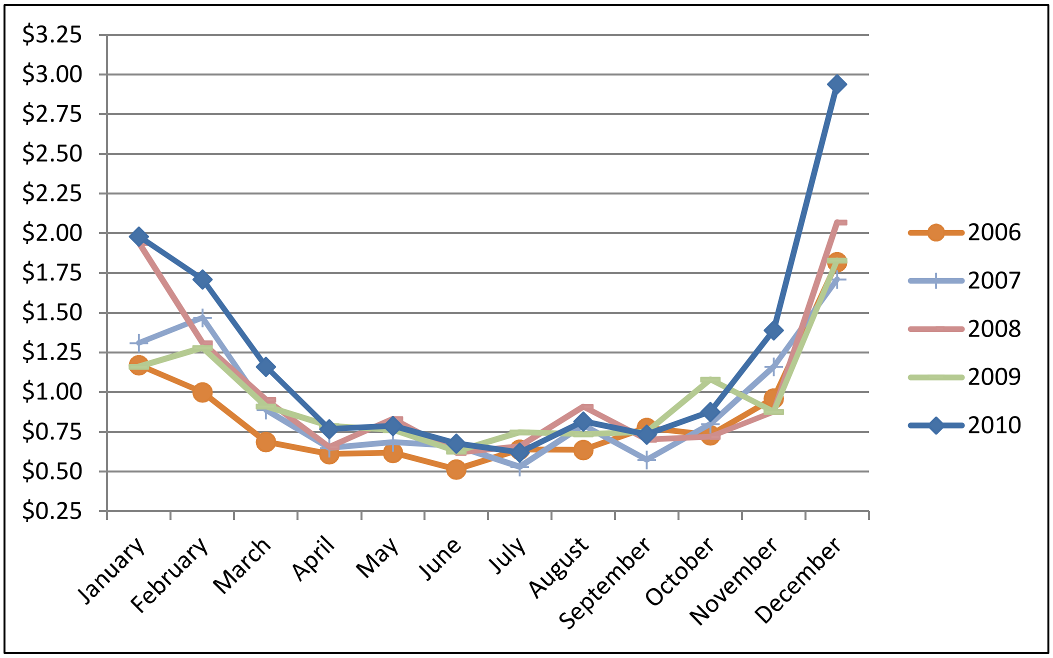
[116] It could also delay planting of rotation vegetable crops planted after strawberries. The California Strawberry Commission contends that this could result in a reduction from two rotation crops to one (US EPA 2005).

[117] For instance, data indicate that the peak harvesting months in California are April–August (CSC 2009; USDA 2006). However, this masks considerable variation by region. Orange and San Diego counties produce fresh strawberries September-early June, but peak harvest is in March-April. Peak harvest in Santa Maria and Salinas-Watsonville is in May-June, and July–August, respectively.

Figure 3.5: National Grower Prices (2006 – 2010) for Strawberries by Month



Source: - http://usda.mannlib.cornell.edu/MannUsda/viewDocumentInfo.do?documentID=1381. See - table08.xls. Reported in nominal prices. -

month for 2006-2010 (the same trend is also evident for earlier years). For instance, a delay from January to February could mean that farmers give up about 16 cents per pound on average (based on the average price differential between the two months from 2006 to 2010). The difference between February and March is even larger: prices are on average about 43 cents per pound lower in March. Delaying harvest from April to May, however, results in prices that are 4 cents higher per pound, on average. An unanswered question is how shifts in production across time affect monthly prices.

3.4.4.4. Opportunity Costs

We next review the ex post evidence on overall strawberry production in California, measured in terms of acreage, compared to organic production and imports from Mexico. While the CUEs for the 2006-2010 seasons did not directly speak to these issues, we examine the trends since much of the ex ante literature makes predictions regarding the ability of farmers growing strawberries conventionally to compete with producers not subject to the MBr phase-out.

Overall Strawberry Production. If methyl bromide and its alternatives proved expensive enough, strawberry acreage could decline as farmers moved out of MBr-intensive crops or let land go fallow. Ex ante studies in the published literature predicted a decrease in strawberry production in California, though they also tended to analyze a complete and immediate MBr ban. For instance, VanSickle et al. (2000) predicted that strawberries would no longer be grown in northern California and that production would experience a decline in southern California. The EPA ex ante analyses assumed that the amount of California land planted in strawberries would remain fixed at 27,600 acres (the 2000 level).

Data indicate that land dedicated to growing strawberries in California continued to increase. Figure 3.6 illustrates the longer-term trends in growth in overall strawberry acreage in California from 1970 – 2010. Recall that the methyl bromide phase-out began in 1993 with a freeze at 1991 levels, reducing MBr until it was no longer in use in 2005 unless an exemption was granted. There are no obvious changes in the overall trend before or after the phase-out began, nor does growth in strawberry acreage seem impacted in the post-2005 period. Likewise, while some strawberry growing areas increased acreage and others decreased in strawberries over time, this trend appears unrelated to the timing of the phase-out. Perez et al. (2011) point to strong U.S. demand for strawberries as the largest driver of growth in production, which could disguise the incremental effect of the MBr phase-out.

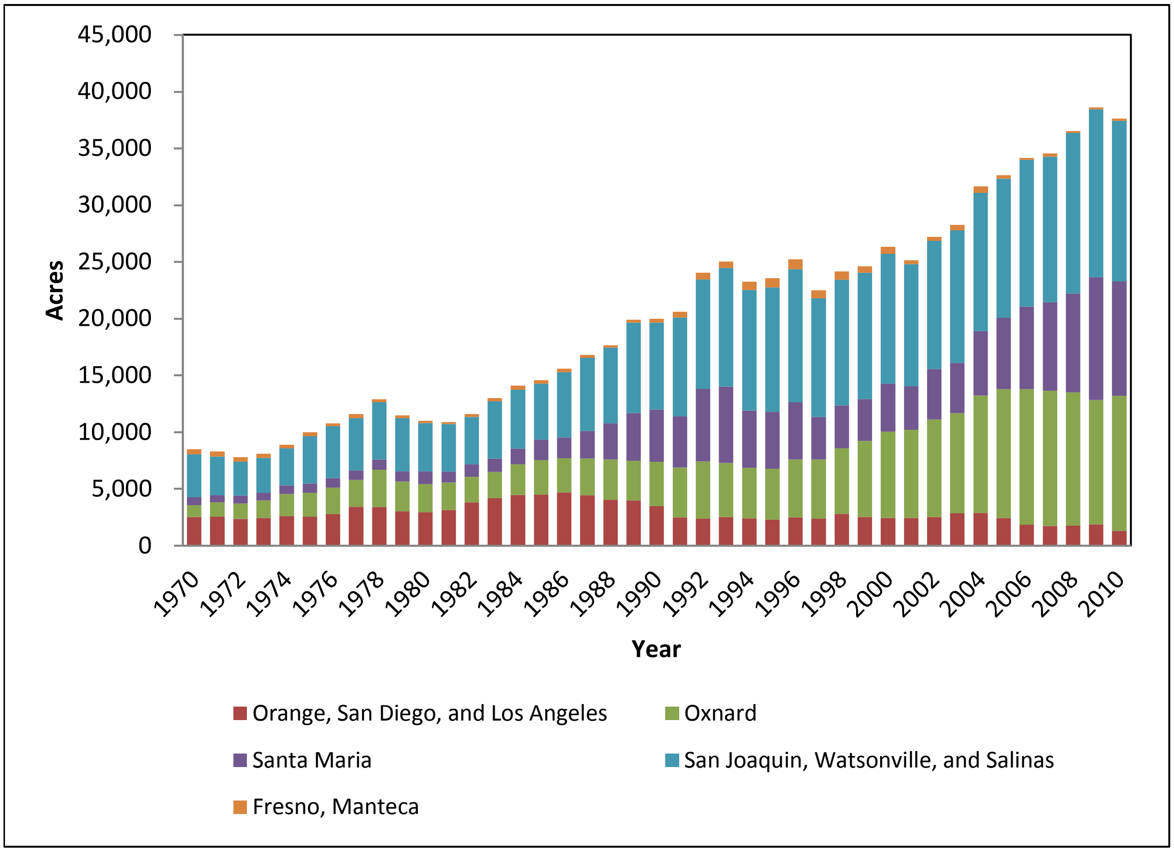
When we examine the data by region, we find that the majority of the growth in strawberry acreage from 2006 – 2010 stemmed from two districts, one in the south - Santa Maria - and the other in the north – San Joaquin-Watsonville-Salinas - both of which historically have grown a substantial portion of strawberries on hillsides where MBr alternatives are reportedly less effective (CSC 2009). These districts were also presumably the main beneficiaries of critical use exemptions given the technical challenges of switching to another fumigant. Acreage dedicated to strawberries in two other southern districts – Orange-San Diego-Los Angeles and Oxnard - remained relatively flat over this time frame.[118]

Organic Strawberry Production. Goodhue et al. (2005) points out that there will likely be very limited opportunities to switch from conventional to organic strawberry production for California farmers. Data confirm that farmers did not engage in large-scale switching to organic strawberry production in response to the phase-out of methyl bromide. According to the California Strawberry Commission (2005), there were about 300 acres planted in organic strawberries in California in 2001. Organic strawberry production had increased to just under 1,000 acres in 2006 and to almost 1,800 acres in 2010. While the rate of increase was high, the total amount of land dedicated to organic production was still relatively small, about 5 percent of total California strawberry acreage in 2010 (California Strawberry Commission 2012a).

Strawberries Imported from Mexico. According to USDA data, imports of fresh strawberries from Mexico almost tripled from 124 million pounds in 2001 to 342 million pounds in 2010. However, domestic consumption of strawberries also increased substantially, from 1.2 billion to 2.2 billion pounds (about an 85 percent increase). Domestic production largely kept pace with demand over the same timeframe, so that

[118] In Orange County, this may have been due to increased competition for land. The CSC (2006) notes that land development and rising property costs in Orange County resulted in lower strawberry acreage in 2006 vs. 2005.

Figure 3.6: California Strawberry Acreage by Major Growing Area: 1970 - 2010



Source: - http://usda.mannlib.cornell.edu/MannUsda/viewDocumentInfo.do?documentID=1381. See - table05.xls. -

Mexico's share of total U.S. demand only increased from 10 to 15 percent.[119] Without controlling for other factors, it is difficult to say what role the phase-out of MBr in the United States has had in encouraging increased imports from Mexico, but it does seem to be far less than what some in the literature had predicted (e.g., VanSickle and NaLampang 2002) and in line with studies that pointed out various factors that would limit growth in Mexican imports (e.g. Norman 2005).

3.5. Overall Implications and Study Limitations

Based on the ex post information available, we find that net operating costs on the typical California strawberry farmer from banning methyl bromide for the 2006-2010 growing seasons was likely less than

[119] Data are compiled by USDA. These statistics are taken from tables 12 and 16 and are available at http://usda.mannlib.cornell.edu/MannUsda/viewDocumentInfo.do?documentID=1381 .

anticipated ex ante (see Table 3.11). It appears that a number of viable MBr alternatives – either new fumigants or new ways of applying existing fumigants – may have become available more quickly and resulted in lower yield loss than initially anticipated. Using what ex post information we have on yield losses associated with 1,3-D +PIC, for example, we find that the ex ante and ex post estimates of the loss in net revenue may differ by 28-87 percent for the 2006 – 2010 growing seasons, all else equal. Likewise, it appears that farmers who substituted away from methyl bromide did so without imposing large negative impacts on production in prime California strawberry growing areas.

We also confirm the effect of California regulatory restrictions in limiting the use of various economically competitive alternatives. For instance, adoption of 1,3-D + PIC has been slowed by township caps on its use. Uncertainty about the effect of regulatory restrictions on the feasibility of some fumigant combinations makes it difficult to precisely identify the extent to which yield losses may have differed from EPA's ex ante estimates. It is also worth noting that unanticipated complications after switching away from MBr, such as new diseases, slowed the transition to alternatives, in particular 1,3-D+PIC applied via drip irrigation.

As previously mentioned, conclusions drawn from the ex post evaluation come with significant caveats. First, we are limited to an evaluation of per acre costs. Second, we only have information on operating costs from crop budgets designed to reflect a typical farmer. Third, yield losses associated with various MBr alternatives are based on field trial research. Fourth, while we have detailed annual data on what fumigants farmers used, we do not have information with regard to other management practices such as the type of tarp used. Fifth, the prices of specific fumigant formulations are not publically available. Finally, it is analytically challenging to evaluate the counterfactual: what would have farmers done if they had not received the same level of MBr exemptions for the 2006-2010 seasons? To draw more robust conclusions, we would need these types of detailed data.

Table 3.11: Summary of Findings -

Components of Cost Estimate			Source of Ex Post Information	Assessment (Compared to Ex Ante)
Regulated Universe	Farm types		--	--
	Strawberry acreage using MBr		USDA and CA PIP data	Reasonable
Baseline Yields using MBr			USDA data	May be underestimate but based on data for typical farmer
Methods of Compliance	MBr alternatives used (Types)		CA PIP data	Reasonable but adopt faster than assumed; no data on some practices
	Rate of application (Usage)		USDA and CA PIP data	MBr application – slight under estimate
Compliance Costs	Direct, One-Time	Fixed Cost	--	--
		Variable Cost		
	Direct, On-Going Net Cost	Gross Revenues	USDA + journal articles + UN meta-analysis	Strawberry prices – reasonable Yield loss for MBr alternatives – likely overestimate
		Operating Costs	Crop budgets + CUE requests + proprietary data	Reasonable
	Indirect – missed market window		USDA data	Inconclusive; also cannot evaluate quality trade-offs
Other Opportunity Costs	Conventional strawberry production loses to imports, organic production		CSC + USDA	Reasonable
PER ACRE NET COSTS	Likely lower than anticipated – driven by yield loss assumptions			
TOTAL COSTS	--			

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Appendix 3.1: Review of the Ex Ante Literature

The ex ante literature disagrees regarding the likely impact of banning methyl bromide on U.S. farmers and the economy more generally. Initial studies tend to predict larger impacts than later studies in part because they often evaluate an immediate and complete ban and assume no technological innovation over time. In contrast, later studies tend to allow for the phase-out of methyl bromide over a longer time period and account for the role of innovation. Another key difference across studies stems from assumptions regarding Mexico's ability to rapidly increase strawberry exports to the U.S. market. [120] (As a developing country, Mexico does not have to fully phase out methyl bromide use until 2015. However, some researchers argue that competition from Mexican imports will likely be limited due to little overlap in growing seasons, the perishable nature of strawberries, and seasonal differences in prices.) We summarize the findings of the main ex ante studies of the methyl bromide phase-out below.

Spreen et al. (1995) produce an extensive report on the impacts of a methyl bromide ban on Florida fruit and vegetable growers. The authors build a partial equilibrium model of the U.S. winter vegetable market, allowing Mexico and Texas to act as alternate suppliers, and extend a Florida grapefruit model to evaluate the effects of a ban. The impacts analyzed are predicated on a complete and immediate national ban of MBr use, the substitution of methyl bromide with the next best technology available as of 1993, and no improvements in technology over time.[121] The report finds that planted acreage would decrease by 43 percent as a result of the ban. Florida strawberry production would decline by almost 70 percent, while tomato production in Florida to supply the winter market would decline by 60 percent. The total economic impact of a ban for the state of Florida alone was estimated to be about $1 billion (including an export multiplier). A previous study by USDA (1993) found that banning methyl bromide would result in an economic loss to all U.S. farmers of $800 million - $1 billion. The lower estimate was predicated on the availability of a substitute (i.e., Vorlex) that was later withdrawn from the EPA registration process. Tomatoes, peppers, and strawberries were expected to face the largest impacts. The report notes that a phase-in of the ban would substantially reduce predicted losses.

[120] Signatories to the Montreal Protocol agreed to a certain level of payment into a multilateral fund when they ratified the agreement. Noting that most countries have complied with promised payments into the fund, Decanio and Norman (2005) find that the cost-per-ton of ozone depleting substances declined by almost $600 per year purely as a function of time (2-4 percent per year) after controlling for factors such as project scale and sector.

[121] Spreen et al. (1995) discuss the known alternatives to MBr, including 1,3-D, metam sodium, and changes in production practices such as changes in the size of the crop bed (which initial studies showed could, alone, reduce MBr use by 33 percent), more frequent crop rotation, and changes in the formulation of MBr and PIC. It is unclear which of these is included as an alternative to MBr and whether the options available vary by crop in the models.

UNEP (1997) updates the Spreen et al. (1995) analysis to consider the role of learning. When relatively small improvements in technologies are incorporated into the model (through smaller impacts on yields), the researchers find that crop production decreases by far less than originally predicted (e.g., a 22 percent decline in U.S. tomato production instead of 60 percent). Cost impacts also are mitigated: Spreen et al (1995) estimated a loss in revenues to farmers of almost $625 million, while the UNEP analysis lowers the loss in revenues to $300 million.

VanSickle et al. (2000) combine a full-year version of the model for winter vegetables used in Spreen et al. (1995) with new information to re-evaluate the impact of a MBr ban on the 1993-1994 season. They note that research has yielded better information on alternatives than was available in the mid-1990s. Their results indicate that impacts would be largest for strawberry farmers with almost $200 million in lost revenues. The authors predict that strawberries will no longer be grown in northern California and that production in southern California will decline slightly, while production in Florida will increase. In aggregate, this results in about a 10 percent decline in California's share in the U.S. strawberry market. The authors do not account for the possibility that Mexico could enter the strawberry market in seasons where it has not previously done so. In total, growers in the United States are expected to see an aggregate loss of revenue of $264 million with some areas of the country – such as South Carolina and Texas - benefiting slightly and California and Florida being most heavily impacted (each experience about a $218 million loss in revenues). Consumer surplus is expected to decline by about $110 million as a result of lower production and higher prices.

VanSickle and NaLampang (2002) use this same model to estimate the impact of phasing out methyl bromide, as opposed to an outright and immediate ban (the focus of Van Sickle et al. 2000). In particular, they evaluate the model's ability to correctly predict the effect of the 50 percent reduction in MBr use between 1991 and 2000 as required by the Montreal Protocol. Once they have confirmed the broad accuracy of the model with regard to production trends, they use it to project the impacts of a further reduction in use between 2000 and 2005 (when complete phase-out is to have occurred). They find that the largest impacts are expected in the strawberry market, where the authors predict that production will decline by about 20 percent and revenues will decrease on net by about $140 million. When comparing these results with the older Van Sickle et al. study, they find that the phase-out delays a substantial portion of the impact associated with an outright ban. They also note the use of new technologies that enable farmers to maintain the effectiveness of MBr while using less of it per acre.

Lynch (1996) also examines the impact of a U.S. ban on methyl bromide for growing strawberries and tomatoes on consumer and producer surplus, based on the assumption that in 2001 methyl bromide production and imports will cease. She builds a regionally disaggregated model with fixed proportions technology[122] that treats prices as endogenous. She finds that a ban on methyl bromide use for growing

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[122] This technology assumption allows the author to assume away any cross-price elasticity between crops so that the price of a commodity is a function only of its own quantity. It is a typical assumption applied by Spreen, VanSickle, and others when they use a fixed proportion or Leontief cost curve.

strawberries would result in a decline in U.S. producer welfare of about $314 million and U.S. consumer welfare of about $70 million. Mexican producers would benefit by about $90 million. Mexican producers are expected to increase methyl bromide use, but by a relatively small amount compared to what was used by U.S. growers. It is also worth noting that the impacts on the strawberry markets depend to some degree on what is assumed about Mexico's ability to respond to U.S. demand. If Mexico cannot adjust quickly enough, then the author expects much higher agricultural prices.

Ferguson and Yee (1997) examine the short-run effect of a ban on methyl bromide use on farmer net revenues and consumer surplus due to changes in production costs and yields. They find that a ban will result in gains to growers that did not rely on methyl bromide prior to the ban, a mix of losses and gains to growers that use methyl bromide that varies by crop based on the price elasticity of demand, and the availability and cost of MBr alternatives. As with previous studies, cross-price elasticities are assumed to be zero. Imports were accounted for in the case of three crops where it was deemed possible that they could increase in the short term: strawberries, tomatoes, and tobacco. Relying on USDA production, price, and acreage data for 21 different crops and demand elasticities from the literature, they estimate an annual increase in production costs of $26 million, almost a third of which is borne by tomato growers.[123] In aggregate, the authors estimate a short-term welfare loss due to banning methyl bromide of $1 billion due to reduced production and changes in prices. The authors point to the wide variation in welfare effects by crop as justification for a gradual phase-out of methyl bromide instead of an outright ban. Peppers, tomatoes, and strawberries all rank in the middle with regard to the estimated economic effect of methyl bromide use on a per pound basis (ranging from about $19 - $30 per pound). [124]

Carpenter et al. (2000) conduct detailed crop-specific analyses for the National Center for Food and Agricultural Policy (NCFAP) to evaluate the economic impacts of banning MBr use in agriculture immediately. They begin by surveying the literature to identify the next best feasible alternative to methyl bromide from a suite of known technologies. Estimated yield and costs effects of switching to this alternative are used as an input into a regionally disaggregated, fixed proportions economic model to estimate changes in producer and consumer surplus. Consumer surplus declines by $160 million due to higher prices and lower availability of particular fruits and vegetables, with 75 percent of the decline stemming from strawberries. The model does

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[123] They also note that yield declines are expected to be particularly large for fresh strawberries and tomatoes due to the limited availability of good substitutes for MBr.

[124] Deepak et al. (1996) evaluate the economic impact of a MBr ban on the winter market in the United States for six major fresh vegetables, including tomatoes and peppers. They focus on the effects of the ban on Florida farm revenues, accounting for competition from Mexico and, to a limited extent, Texas. Using fixed proportions technology on the supply side, they build a spatially explicit mathematical programming model to solve for acreage planted, and market clearing prices and quantities. A MBr ban was simulated through a loss in yield. Results suggest that a ban would eliminate or reduce production of several commodities in Florida with Mexico making up much of the difference in lost supply. For instance, the authors project that tomato acreage in Mexico would double as a result of the ban. The authors estimate that revenues of Florida farmers will decline by 53 percent, while prices will increase by 1 - 11 percent depending on the particular wholesale market.

not predict much of an acreage response for many producers: Higher prices allow many growers to remain profitable in spite of increased costs. On net, producers see a decrease in revenues of about $77 million. The USDA (2000) points out that impacts in the NCFAP study are likely overstated to some degree – particularly as one goes further out in time - because the authors assume that there are no improvements in technology, no new MBr alternatives available than those currently on the market, and no exemptions granted going forward. Even with possible overstatement of impacts, the USDA (2000) notes that the estimates of the impact of a MBr ban by Carpenter et al. (2000) are substantially lower than earlier estimates by the USDA (1993). The USDA (1993) estimated that banning methyl bromide use would result in $1 billion in impacts for pre-plant uses, while Carpenter et al. (2000) estimated impacts for pre-plant uses of $400-$450 million.

Carter et al. (2005a) examined the short-term impact of the MBr ban on California strawberry farmers. Since fresh strawberries are perishable, they assume that supply in a given season is fixed and cannot be easily shifted into the processed strawberry market. Thus, to estimate the impact of the ban the authors only need to know the expected reduction in strawberries harvested due to changes in yield and acreage, and the price elasticity of demand. The authors evaluate a wide range of yield and acreage changes based on interviews with farmers and field trial data, but consider the most likely scenario to be a decline in acreage of about 10 percent (over about a five-year period) and a decline in yields of 10-15 percent. Using a range of price elasticities from the literature that range from -1.2 to -2.8 (with a "best" estimate of -1.9), they estimate that industry revenue would decline by 6 – 17 percent. When the full distribution is taken into account, revenue is estimated to decline by about 12 percent, on average (with a 90 percent probability that the loss is between 4 and 21 percent). These estimates do not account for the possibility that farmers use land previously dedicated to strawberries to grow other crops, which would result in some additional revenue.

Carter et al. (2005a) also note that California competes with Florida and Mexico during the winter months, but that by mid-March only California continues to supply fresh strawberries to the U.S. market due to warmer temperatures that affect fruit quality in these other regions. How these markets interact is an important consideration for estimating the national impact of a ban, particularly since California has its own process for registering MBr alternatives. If Mexico can completely compensate for the decline in domestic production, then strawberry prices would remain unchanged (instead of increasing), which would increase the impact on U.S. strawberry farmers (but impact consumers less). The authors see such a dramatic increase in Mexican exports as unlikely.

Norman (2005) examines the costs to U.S. strawberry growers of switching to MBr alternatives without any exemptions, arguing that farmers will face much smaller net costs as a result of the ban than what growers have suggested in their critical use exemption requests based on production costs alone. For instance, the critical use exemption nomination for California strawberry growers for the 2006 growing season estimated an overall loss of $1,600 to $4,000 per hectare due to lower yields and higher production costs. Norman notes that this translates to 20-57 percent of net returns if market effects are not taken into account. However, she finds that limited price responsiveness by consumers means that much of the cost of the ban will be passed on in the form of higher prices.[125] Using price elasticities from the literature, Norman (2005) finds that producers are expected to pass along about 75 percent of the increase in the cost of fumigation to consumers, reducing farmer losses to $400 - $1,000 per hectare or 5 – 14 percent of net revenues.[126] She also points out that with an increase in the cost of fumigation, growers will seek to substitute toward other inputs to further reduce the cost of the ban (e.g., while many papers start from a fixed proportions supply curve, this may not be a valid assumption). Similar to Carter et al. (2005a), Norman (2005) argues that competition from Mexican imports will likely be limited. She points to several reasons why this is expected to be the case: little overlap between U.S. and Mexico growing seasons, the perishable nature of strawberries, and seasonal differences in prices. Norman finds that seasonal variations in strawberry prices are much larger than the additional costs from phasing out MBr use, making it likely that U.S. farmers will retain a competitive advantage during the peak domestic growing season.[127]

Goodhue et al. (2005) evaluate whether California strawberries qualify for a critical use exemption according to the criteria in the Montreal Protocol (i.e., lack of available alternatives would cause a significant market disruption and/or no technically or economically feasible alternatives that also meet health and safety standards). In evaluating the economic impacts of no longer using methyl bromide, the authors considered three alternatives: 1,3-D, chloropicrin, and metam sodium.[128] They do not evaluate possible changes in crop production practices, such as more integrated pest management techniques or conversion to organic production.[129] Data were taken from field experiments that generated material and weed control costs for methyl bromide and its alternatives. As a result, differences in application costs and effects on yields are not considered. The effect of changes in demand for methyl bromide substitutes on fumigant prices and of costs on total strawberry acreage are also not considered, though the authors acknowledge that these types of effects are likely. Whether an alternative is technically feasible will vary by soil type, climate, and other factors, but for this analysis the authors assume growers have identical production costs to conduct a break-even analysis under different yield loss assumptions. In other words, they evaluate how much price and/or acreage would need to change for farmers to break even using a given methyl bromide alternative. They find

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[125] Decanio and Norman (2005) note that demand is fairly price inelastic for most fruits and vegetables.

[126] Norman (2005) calculates that a cost increase of $2,800 per hectare would translate to a price increase of about $0.50 annually for the average U.S. household. However, price increases are most likely to occur during months when imports from Mexico are less available, which is also when strawberry prices tend to be the lowest.

[127] In addition, Mayfield and Norman (2011) point out that Mexico consumed less MBr than it was allowed under the Montreal Protocol in 2008. Mexico plans to expedite its phase out such that MBr is no longer in use by 2012, three years earlier than required, by switching to methyl iodide.

[128] While not analyzed, they note that methyl iodide and propargyl bromide could be competitive alternatives in the future if they are successfully registered in the United States and California.

[129] The authors view the opportunities for switching to organic production as limited, due to the substantially higher hand weeding costs, lower yields, and land and planting requirements to qualify as organic. In addition, large shifts into organic production would inevitably have price effects.

that for the most likely yield declines (10-15 percent), prices would have to increase by 13 – 23 percent for profits to be unaffected, while acreage would have to decline by 13 – 34 percent.

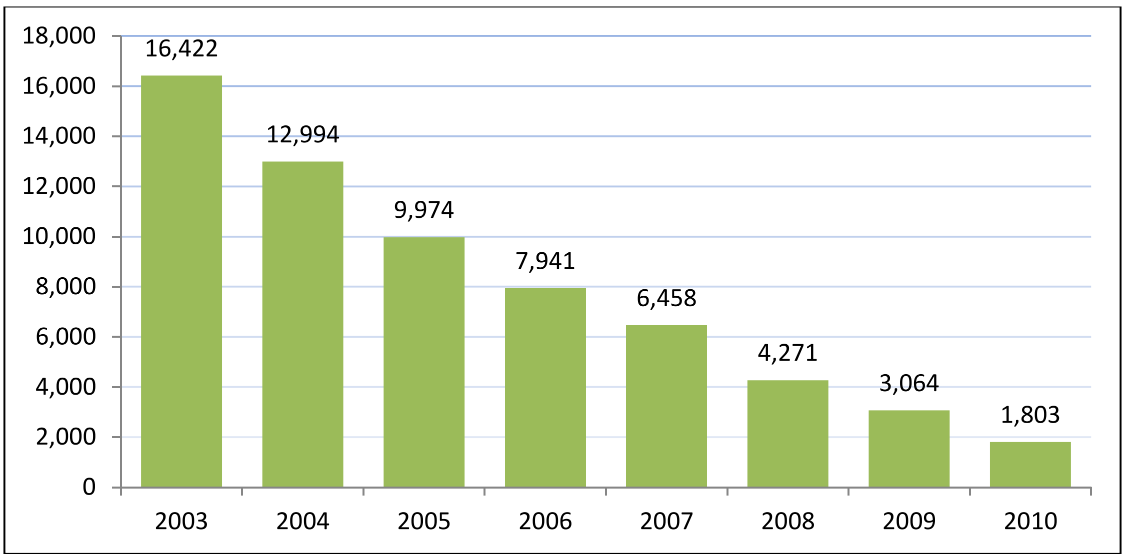
Finally, Carter et al. (2005b) evaluate the impact on strawberry farmers of additional buffer zone restrictions and notification requirements for MBr fumigation put into place in California in 2001.[130] While not a study of the impacts of a national MBr ban, it is indicative of the way farmers may adapt to use restrictions. The authors find that for some acreage farmers no longer grew strawberries and instead switched to less valuable crops. Farms that bordered non-agricultural uses were most affected – they had larger amounts of acreage where strawberries could no longer be grown (assuming application rates and other factors remained unchanged). Smaller fields lost a greater proportion of acreage due to buffer zone restrictions. Using UC-Davis crop budgets combined with expert opinion and surveys of growers, the authors estimated short-run impacts. The buffer zone requirements lengthened the amount of time it took to fumigate a field, delaying harvest and reducing production. Fumigation costs were estimated to increase by about 40 percent due to additional labor and equipment requirements. The authors estimated a loss to the strawberry industry due to inability to fumigate certain pieces of land. Finally, growers that relied on bed fumigation instead of flat fumigation were required to establish larger buffer zones due to higher application rates. This resulted in some switching from bed to flat fumigation by farmers (flat fumigation is about $1,000 per acre more expensive).

[130] EPA finalized new restrictions on the use of many fumigants as part of the re-registration process, including buffer zone requirements and lower maximum allowable application rates to protect air quality and the health of workers and nearby residents. Noling et al. (2010) point out that these new requirements are likely to spur a greater transition into less permeable plastic mulch, which allows for lower application rates without compromising fumigant effectiveness. Most of the new requirements take effect in 2010-2011. See VanSickle et al. (2009) for a discussion of the impacts of these new buffer-zone requirements on Florida strawberry farmers.

Appendix 3.2: The Role of the Stockpile

Agricultural users that receive a critical use exemption can also rely on the MBr stockpile. While EPA tracks the draw-down of the stockpile and the overall amount of methyl bromide used for critical and non-critical uses, it does not know which specific users purchase from it. Figure V-A1 shows declines in the stockpile from 2003 to 2010. Experts note that, as critical use exemptions decline and the stockpile is drawn down, they expect MBr shortages and markedly higher prices in some regions (Noling et al. 2010; Goodhue et al. 2010). Due to a paucity of data, we are not able to say what role the stockpile played in fumigant decisions for California strawberry growers for the 2006 – 2010 seasons.

Figure 3.A1: U.S. Methyl Bromide End-of-Year Stockpile (in metric tons): 2003 - 2010



Source: EPA website. http://www.epa.gov/ozone/mbr/otherreginfo.html

Chapter 4: National Primary Drinking Water Regulation for Arsenic

Cynthia Morgan and Nathalie Simon

On January 22, 2001, EPA published new National Primary Drinking Water Regulations for Arsenic (the "Arsenic Rule"). EPA used sound science and the best available information to estimate the costs associated with the rule in its benefit-cost analysis. The purpose of this paper is to examine how EPA's ex ante cost analysis of the Arsenic Rule compares to an ex post assessment of costs. This is not an evaluation of how well EPA conducted the ex ante analysis at the time of the rulemaking, but rather it is an examination of the key drivers of compliance costs in an effort to make an informed *judgment* as to whether ex post costs are higher or lower than the estimates of ex ante costs for this Rule. We are interested to see if actual costs diverged from ex ante costs and, if so, what factors caused this divergence (e.g., changing market conditions, technological innovation, etc.) as described in Chapter 1 of this report.

This case study is organized as follows. Section 4.1 describes the 2001 Arsenic Rule and the types and size of water systems that were expected to be affected. Section 4.2 summarizes the methods EPA used to produce ex ante compliance costs for the final rule by water system type and size (number of people served). Section 4.3 describes sources of information available to conduct an ex post cost assessment of the Arsenic Rule. Section 4.4 presents a very limited comparison of ex ante and ex post compliance costs using data from a limited set of demonstration projects designed to show the effectiveness of various treatment technologies at reducing arsenic levels. And lastly, Section 5.5 summarizes the analytic challenges we faced in conducting an ex post cost assessment for this Rule.

4.1. Impetus and Timeline for the Regulatory Action

The 2001 National Primary Drinking Water Regulations for Arsenic lowered the Maximum Contaminant Level (MCL) for arsenic in drinking water from 50 micrograms/liter (µg/L) to 10 µg/L. The rule applied to 54,000 Community Water Systems (CWSs) and 20,000 other systems known as Non-Transient Non-Community Water Systems (NTNCWSs) that serve non-residential communities (e.g., schools, churches). Water systems had to comply with this standard by January 23, 2006. EPA estimated that approximately 3,000 CWSs and 1,100 NTNCWSs would initially not meet the 10 µg/L standard and would need to treat their drinking water to reduce the arsenic levels. Of those systems affected, 97 percent were considered "small systems" serving 10,000 people or fewer.

The Arsenic Rule was particularly important in that it was the second drinking water rule in which EPA used the discretionary authority afforded by §1412(b)(6) of the Safe Drinking Water Act to adjust the MCL to a level above that which is technically feasible if the benefits do not justify the costs. While the Agency initially proposed an MCL of 5 µg/L, EPA ultimately set the drinking water standard for arsenic at 10 µg/L, concluding that this level maximized health risk reduction at a cost justified by the benefits (US EPA 2001).[131] The technically feasible level for arsenic removal from water was established at 3 µg/L.

4.2. EPA Ex Ante Cost Estimates

The costs associated with the Arsenic Rule include: 1) the costs to water systems to comply with the standard, including treatment costs, monitoring costs and administrative costs of compliance and 2) costs to States to implement and enforce the rule. The total annual costs of the rule were estimated at approximately $181 million, with treatment costs comprising the bulk at about $177 million. The total costs to CWS were estimated at approximately $172 million, 98 percent of which were expected to accrue to systems serving populations of 1,000,000 people or less. Costs for NTNCWS were estimated to be $8.1 million.[132]

The cost implications for households were dependent on the size of their community water system. For households served by small community water systems (those serving fewer than 10,000 people), the annual increase in cost was expected to range between $38 and $327. For those served by community water systems that serve greater than 10,000 people, the estimated annual household costs for water were expected to increase from $0.86 to $32. The disparity in household costs between systems sizes was due to economies of scale, with larger systems able to spread the costs they would incur over a larger customer base.

4.2.1. Main Components of Ex Ante Compliance Costs

4.2.1.1. Identification of Best Available Treatment Technologies

EPA's ex ante compliance cost estimates for the Arsenic Rule required the identification of the "Best Available Technologies" (BAT) effective at removing arsenic and bringing water systems into compliance with the MCL. In the *Technologies and Costs for Removal of Arsenic from Drinking Water* (EPA, 2000), the various arsenic removal technologies under different conditions are described. These technologies include coagulation/filtration, greensand filtration, activated alumina, ion exchange, and membrane processes such

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[131] Based on the available science at the time, EPA quantified and monetized health benefits associated with the rule included expected reductions in bladder and lung cancers with estimates ranging from $140 to $198 million ($1999). However, a number of health outcomes associated with arsenic exposure remained unquantified, including cancers of the kidney, skin, and prostate, endocrine disorders (e.g., diabetes) and other cardiovascular, pulmonary, and neurological effects.

[132] EPA also estimated total annual treatment costs by system size across CWS and for NTNCWS systems by NTNCWS system service type (see USEPA 2001, Chapter 6).

as reverse osmosis. In addition to the traditional arsenic removal treatment technologies, alternative technologies still in the experimental stages such as sulfur-modified iron, iron filings, iron oxide coated sand, and granular ferric hydroxide are discussed. Included in the discussion of each technology are ways to improve the effectiveness of the technology for the removal of arsenic. The impact on arsenic removal efficiencies from factors such as pH, arsenic oxidation state, and the effect of competing ions are also discussed for each technology. As a result of this assessment, the following technologies were identified by EPA as BAT:

- Modified Lime Softening
- Modified Coagulation/Filtration
- Ion Exchange
- Coagulation Assisted Microfiltration
- Oxidation Filtration (Greensand)
- Activated Alumina

In addition to these centralized treatment technologies, EPA identified point-of-use (POU) devices as appropriate for small systems to achieve compliance with the arsenic MCL. POU involves treatment at the tap such as a water fountain or kitchen sink. However, the Safe Drinking Water Act requires that POU devices be maintained by the public water system which means additional recordkeeping and maintenance costs. The POU treatment options considered were:

- POU Reverse Osmosis
- POU Activated Alumina

Cost equations and the resulting cost curves for both capital and O&M costs for each of these technologies are presented in the *Technologies and Costs for Removal of Arsenic from Drinking Water* (EPA, 2000) and serve as major inputs to EPA's estimation of compliance costs. The capital cost curves are a function of the system design flow (mgd, million gallons per day) while operating and maintenance (O&M) cost curves are a function of the average flow (mgd) of the system. Some of these technologies generate wastes that require disposal or pre-treatment (e.g., pre-oxidation or corrosion control) in order to be effective. The associated costs of waste disposal and pre-oxidation were included in the costs of treatment when relevant (See Appendix 4.2).[133]

With the best available technologies and their unit costs defined, EPA employed different methods to estimate compliance costs for each of three different system categories: NTNCWSs, CWSs serving 1,000,000

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[133] EPA's economic analysis of the arsenic rule captured only the predicted costs of the federal regulation and did not account for disposal costs resulting from state regulations that are more stringent than federal requirements.

people or fewer, and CWSs serving more than 1,000,000 people. In the Economic Analysis (EA), EPA used a Monte Carlo Simulation model (the Safewater XL model) to estimate compliance costs for the CWSs serving 1,000,000 or fewer people and a deterministic spreadsheet analysis to assess compliance costs for the NTNCWSs. EPA estimated compliance costs individually using system specific information for the very large systems (those serving more than 1,000,000 people) with baseline levels of arsenic expected to exceed the 10 µg/L MCL. Total national compliance costs were then calculated by summing the compliance costs for the three system categories. Each methodology is discussed in more detail below.

4.2.1.2. Community Water Systems (systems serving 1,000,000 people or fewer)

To estimate compliance costs for this size category of CWSs, EPA used the Safewater XL model. The model uses a combination of individual system data and distributional data (e.g., arsenic occurrence, number of entry points per system) to estimate costs. The data required for Safewater XL include a list of all water systems, system source type (groundwater or surface water), population served by the system grouped into one of eight size categories (<100; 101-500; 501-1,000; 1,100-3,300; 3,301-10,000; 10,001-50,000; 50,001-100,000; 100,001-1,000,000), and flow rate of the system. These data are available from EPA's Safe Drinking Water Information System (SDWIS) which contains data on all public water systems as reported by States and EPA Regions. Additionally, the model contains probability distributions of the data for the number of entry points per system and the concentration of arsenic in untreated water. [134]

EPA estimated the number of entry points for each water system and its corresponding population size category using data from the 1995 Community Water Supply Survey. Arsenic occurrence data are based on EPA's "Arsenic Occurrence in Public Drinking Water Supplies" report (US EPA 2000b). Mean arsenic distributions for each system were estimated by sampling from observed data for actual systems with the same water source type in eight geographic regions of the country. Each system was assigned a random concentration from the arsenic occurrence distribution. The arsenic concentration for each system was then distributed (preserving the assumed mean) across each of the entry points in the system so that each entry point had its own assumed arsenic concentration.

The Safewater XL model then compared the arsenic concentration at each entry point to the 10 µg/L MCL standard. Entry points with predicted arsenic concentrations above the MCL were assumed to reduce the site concentration to 80 percent of the MCL, while entry points with predicted arsenic concentrations below the MCL were assumed not to employ any treatment. [135] For those entry points that required treatment, the Safewater XL model used a series of decision trees to assign a treatment technology to the entry point appropriate for the size and type of system.[136] Each decision tree assigned a probability to the application of

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[134] Entry points are points at which water enters a water system's distribution network; in general, groundwater systems have more entry points than surface water systems and larger systems have more entry points than smaller systems.

[135] SafewaterXL calculates the percent reduction in arsenic concentration required to reduce the site concentration to 80 percent of the MCL standard (this is a safety factor that includes a 20 percent excess removal to account for system over-design).

[136] OW created sixteen decision trees: two source types for each of the eight group sizes.

a specific treatment technology at a given entry point, with the probability dependent on the source water type, population size, and effectiveness across options based on the amount of arsenic requiring mitigation. Using the design flow and average flow of the system and the cost curves and equations developed in the *Technologies and Costs for Removal of Arsenic from Drinking Water* (EPA, 2000), capital and operating and maintenance (O&M) costs at the site level were calculated for each treatment technology. A system's compliance cost was then determined by summing across the treated entry points in the system. By performing this analysis for each system expected to violate the MCL, EPA calculated a national estimate of compliance costs for CWSs.

4.2.1.3. Non-Transient Non-Community Water Systems

For the NTNCWSs, EPA estimated compliance costs using a deterministic spreadsheet rather than the Safewater XL model. Similar to the methodology employed for the CWSs described above, the spreadsheet relied on the SDWIS data for information on the number of systems affected and the population served and used the same arsenic occurrence distribution developed above. Based on the design flow of the system, one of two treatment technologies was selected: (1) point of entry activated alumina or (2) centralized activated alumina. Point of entry activated alumina was selected for NTNCWSs with design flows less than 2,000 gallons per day and the centralized active alumina was selected for all other systems. Capital and O&M costs were calculated based on the treatment technology selected and the design and average flow of the NTNCWS.

4.2.1.4. Community Water Systems (systems serving populations of more than 1,000,000)

For each of the nation's 25 largest drinking water systems – those serving more than 1,000,000 people, EPA developed individual compliance cost estimates using system specific information including entry point water quality parameters, system layouts, design and average flow, and treatment facility diagrams.[137] The resulting estimates were sent to each of the utilities for review and approximately 30 percent submitted revised cost estimates or additional arsenic occurrence data. EPA revised the cost estimates for those systems using these additional data. Of the 25 drinking water systems, three were expected to exceed the arsenic MCL – those located in Houston, Los Angeles and Phoenix. The cost estimates developed for these three systems accounted for approximately 2 percent of the total compliance costs estimated for the Arsenic Rule.

[137] Some sources of these data included the Information Collection Rule, the Community Water Systems Survey, the Association of Metropolitan Water Agencies Survey, the Safe Drinking Water Information System, the American Water Works Association WATERSTATS Survey as well as discussions with system operators.

4.2.2. Main Sources of Uncertainty in Ex Ante Cost Estimates

Ex ante analyses are subject to many challenges and uncertainties. Selection of the most effective mitigation strategy depends on conditions that are specific to each system. Source of water (e.g., groundwater versus surface water), size of system (population served), and water quality conditions vary across systems. Water quality parameters such as pH, iron, sulfate and even the type of arsenic have implications for the effectiveness of a given treatment technology. However, EPA lacked information on exactly which systems would be out of compliance with the new MCL and relied on modeled outcomes. EPA based its cost estimates for these systems on predicted mitigation strategies. Over 90 percent of compliance costs were derived from, a regulatory cost model, SafeWater XL. Modeled outcomes by design introduce uncertainty.

Location may also affect the choice of mitigation strategy. Proximity to neighboring drinking water systems or other alternative sources of water may favor blending or abandonment of the problem source. Further, waste streams containing arsenic resulting from the use of some technologies may be considered hazardous waste and subject to disposal regulations [138], with some states imposing their own requirements in addition to federal regulations. These waste disposal restrictions may further constrain the choice of technologies and ultimately affect the associated costs. In addition, some states may require pilot testing before the installation of a treatment technology, increasing the costs of compliance with the new MCL (EPA, 2006). Technological innovation or regulatory or technical constraints could result in water systems using different treatment technologies for arsenic removal than the BATs listed by EPA. The SafeWater XL Model is not able to capture these potential exogenous factors that may influence how a water system will reduce their arsenic concentration.

4.3. Information Available to Conduct Ex Post Evaluation

4.3.1. Ex Post Literature

Prior to and after promulgation of the Arsenic rule, a number of studies reviewing EPA's ex ante cost estimates were prepared – some in general support of the Agency's estimates (e.g., Gurian, NDWAC 2001) and others contesting them (e.g., Bitner et al., 2001, Frey et al. 2000). Shortly following the promulgation of the rule, EPA engaged NDWAC in an extensive, independent review of EPA's cost analysis. In spite of the interest the Arsenic Rule generated at the time, our search of the literature identified only two studies that have made comparisons of ex ante and ex post costs of compliance with the arsenic rule: Gurian et al. (2006) and Hilkert Colby et al. (2010).

Gurian et al. (2006) presents some limited comparisons of EPA's ex ante cost estimates and realized ex post cost estimates for the Arsenic rule.   Specifically, using information from the first round of EPA demonstration

[138] See http://www.epa.gov/nrmrl/pubs/600s05006/600s05006.pdf

projects reported in Chen et al. (2004), they make comparisons of ex ante and ex post capital costs for small systems. A number of the demonstration projects utilized iron-based adsorptive media, an emerging technology at the time that was not a BAT in EPA's economic analysis of the rule. Plotting the realized capital costs for the 12 demonstration projects against EPA's cost curves for ion exchange and activated alumina, considered the best options for small systems at the time the rule was promulgated, they find that in 10 out of 12 cases capital costs for the demonstration projects fell below the 1999 estimates. While the demonstration projects do provide seemingly good news related to costs experienced by small systems to mitigate their arsenic levels, Gurian et al. caveat their results by noting potential biases embedded in the demonstration project cost estimates (e.g., biased vendor bids, tendency toward treatment technologies rather than non-treatment solutions, availability of additional expertise in devising a solution, etc.).

Gurian et al. also present the results of a small survey of six large water systems conducted in 2003 in which they ask about the progress each has made in coming into compliance with the new arsenic MCL. Rather than compare these realized costs with EPA ex ante estimates, however, they make comparisons with pre-regulatory estimates derived and presented for these same six systems in Frey et al. 2000.

Hilkert Colby et al. (2010) perform a somewhat more comprehensive comparison of ex ante and ex post costs in their paper looking at costs of arsenic mitigation in the state of California. With help from the California Department of Public Health, they contacted the 43 systems in the state using treatment technologies to mitigate arsenic levels in drinking water. Each system was asked to report on cost and performance metrics for the technologies installed, including capital and O&M costs. They compared these reported costs with those of 13 EPA Demonstration projects from Rounds 1 and 2 that use Adsorptive media (specifically Bayoxide E33). In addition, they compare the realized costs with EPA's affordability threshold (i.e., the total annual household water bill considered affordable) as well as the available expenditure margin for a revised MCL (i.e., the remainder of the threshold amount after subtracting off estimates of annual household water bills) reported in the economic analysis.

Although they find that the median annualized costs for California systems fall within the expected household cost for compliance with the Arsenic Rule of \$0.01-\$5.05/1,000 gallons (2008\$), they report that 22 percent of the systems had annualized costs that exceeded these amounts; 19 percent had costs greater than EPA's expenditure margin; 15 percent had costs greater than EPA's affordability threshold for drinking water. However, in making these comparisons, they admit their assumption that the treatment technology in operation at each location is used to treat all water sources on the property. This assumption could result in an overestimate of costs as "not all the water for the system requires arsenic treatment." They also find that compared to California systems using similar technologies, the selected EPA demonstration sites reported lower median and maximum annualized costs. Specifically, compliance costs among systems in California employing similar technologies were \$0.09/1,000 gallons higher than the 13 selected EPA demonstration projects, with the demonstration projects enjoying somewhat lower labor costs but higher media replacement costs than California systems.

4.3.2. Data for Evaluating Costs Ex Post

We explored several source categories for ex post cost data including publicly available data on water systems and arsenic contaminant levels, EPA's Office of Research and Development (ORD) Demonstration Projects, consultations with industry compliance experts as well as information provided by state authorities and associations in areas known to have levels of arsenic in drinking water exceeding the MCL. Each of these source types and the data uncovered in each category are described below.

4.3.2.1. Publicly Available Data

Working with Abt Associates, we identified ten sources of publicly available data collected on levels of contaminants in U.S. drinking waters and four potential data sources on compliance costs.[139] The potential sources on arsenic contaminant levels in drinking water and ambient levels are as follows:

- Safe Drinking Water Information System (SDWIS)
- Arsenic Occurrence and Exposure Database (AOED)
- Consumer Confidence Reports (CCRs)
- National Tap Drinking Water Database (NTWQD)
- EPA's STORET Data Warehouse – arsenic ambient levels
- National Water Information System (NWIS) – arsenic ambient levels
- National Water-Quality Assessment (NAWQA) Program – arsenic ambient levels
- Community Water System Survey (CWSS)
- National Contaminant Occurrence Database (NCOD)
- National Environmental Public Health Tracking Network

Although not specific to arsenic, potential sources of compliance cost data include:

- Drinking Water Infrastructure Needs Survey and Assessment (DWINSA)
- Community Water System Survey (CWSS)
- Drinking Water Cost Rate Data

A detailed description of each database can be found in Appendix 4.1.

A considerable amount of basic operating information on public water systems appears to be available from SDWIS and CWSS. These data potentially could be combined with arsenic occurrence data from USGS's NWIS and NAWQA, EPA's NCOD and STORET as well as compliance cost estimates from EPA's DWINSA. However, the 2007 DWINSA collections information is on the systems' anticipated capital improvements and associated needs to meet the new arsenic standard, so the focus is on anticipated projects not on actual strategies employed. Still, the data may be useful in identifying small systems that had to address the new arsenic standard, the treatment projects planned by those systems, and the anticipated capital cost of those

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[139] "Background and Data Sources for Five Selected Rules," memo from Abt Associates to Nathalie Simon, August 17, 2010. Note that this list was later augmented with additional information by EPA.

projects. Because the focus of the DWINSA is on capital projects, O&M costs associated with those projects would not be captured, not to mention some non-treatment options.

Even using the data collected in the various arsenic occurrence databases and DWINSA, gaps still remain in the publicly-available data that prevent us from being able to produce a robust estimate of the realized costs of complying with the Arsenic rule. These gaps include mitigation strategies pursued by each system out of compliance with the new arsenic standard and the costs associated with installation and operation of these technologies (O&M costs and capital expenditures).

4.3.2.2. ORD Demonstration Projects

In October 2001, EPA embarked on a project to help small community water systems (<10,000 customers) research and develop cost-effective technologies to meet the new arsenic standard. As part of the Arsenic Rule Implementation Research Program, EPA's ORD conducted three rounds of demonstration projects that applied full-scale, onsite demonstrations of arsenic removal technology, process modifications and engineering approaches for small systems.

EPA funding in combination with additional funding from Congress provided support for the three rounds of demonstration projects from 2005-2007. Treatment technologies were selected from solicited proposals. EPA conducted 50 arsenic removal demonstration projects in 26 states in the US. Treatment systems selected for the projects included 28 adsorptive media (AM) systems, 18 iron removal (IR) systems (including two systems using IR and iron addition (IA)) and coagulation/filtration (CF) systems (including four systems using IR pretreatment followed by AM), two ion exchange (IX) systems, and one of each of the following systems: reverse osmosis (RO), point-of-use (POU) RO, POU AM, and system/process modification. Of the 50 projects, 42 were community water systems (CWS) and eight were non-transient non-community water systems (NTNCWS).

The report "Costs of Arsenic Removal Technologies for Small Water Systems: U.S. EPA Arsenic Removal Technology Demonstration Program" (Wang and Chen, 2011) summarizes the cost data across all demonstration projects grouped by the type of technology. Total capital costs and operating and maintenance (O&M) costs are presented for each treatment system. Capital costs are broken down by equipment, site engineering, and installation costs. Factors affecting capital costs include system flow rate, construction material, media type and quantity, pre- and/or post-treatment requirements, and level of instruments and controls required. The O&M costs for each treatment system are broken down by media replacement, chemical use, electricity and labor.

Although the number of projects and types of treatment technology represented is limited, the ORD Demonstration projects provide detailed information on the capital and O&M costs associated with select arsenic mitigation technologies. However, due in part to the goals of the program and the use of emerging technologies, a number of biases may be present in the data. Arsenic treatment technologies, especially iron-based adsorptive media were in a developmental stage at the start of the Demonstration program. As such, vendors were still developing an understanding of the effects of various aspects of water quality on their technologies as well as techniques for mitigating these impacts. In addition, the price point for the adsorptive media was not well-established and, because of the speed at which EPA needed to implement the demonstration program, there may not have been sufficient time to negotiate the most competitive media prices. Generally, little to no pilot testing was conducted at Demonstration sites to optimize the design and installation of the technologies at a given facility prior to the selection of a technology and its implementation. On the other hand, vendors wishing to establish their technologies as cost-effective alternatives may have offered EPA more appealing prices. Again, because the goal of the program was to demonstrate the effectiveness of various alternative treatment technologies, non-technological treatment alternatives were not considered and are therefore not represented in the data. However, because of the detailed nature of the data, they nevertheless provide useful information for this exercise.

4.3.2.3. Compliance Assistance Engineering Firms

Water systems needing to respond to new standards often hire engineering firms to aid in designing and installing appropriate water treatment systems. This was the case with some systems needing to comply with the Arsenic Rule. As such, compliance assistance engineering firms have information on the capital cost of projects that they support and may have professional judgment-based estimates of the operating and maintenance costs required for the installed equipment.[140] Depending on the geography covered by a particular engineering firm, it may have access to the cost information for projects in one or more states.

With assistance from Abt, we identified and contacted seven engineering firms as potential industry experts: Malcolm Pirnie, Wright-Pierce, Farr West, Black and Veatch, CH2MHill, Brown and Caldwell, and Brady Associates. To guide the collection effort, we prepared a detailed template that captured inputs to the cost estimate methodology used by the Office of Water as well as a separate document with more general questions on the assumptions and cost estimate framework (See Appendix 4.3). Of the seven, two engineering firms, Malcolm Pirnie and Wright-Pierce, provided information on the technologies used by water systems they assisted and the associated compliance costs as well as providing responses to the general questions.[141, 142]

Specifically, Malcolm Pirnie provided information on the technologies used by water systems and the costs incurred to comply with the Arsenic Rule for projects on which they worked. In addition to answering questions designed to collect feedback on the assumptions and cost estimation equations used by EPA to estimate the costs of treatment technologies, Malcolm Pirnie provided cost information for seventeen water systems located in California and Arizona ranging in size from 0.4 mgd (million gallons per day) to 6 mgd. The

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[140]At the outset of the process for engaging engineering firms in this effort, firms indicated that they may have information and insight on the costs of installing treatment technologies at specific water systems, but would usually not have information on the operation and maintenance costs for those installations.

[141] Malcolm Pirnie provided technical support to EPA during the development of the *Technology and Cost Document* for the Arsenic Rule.

[142] Internal review of this document raised concerns about the potential bias associated with capital cost estimates provided by engineering firms in that they might capture other capital improvements unrelated to arsenic mitigation.

treatment technologies for these systems included three ion exchange (IO), one reverse osmosis (RO) and one point-of-use reverse osmosis (POU-RO), one activated alumina (AA), five granular ferric oxide (GFO), three granular iron media (GIM), one iron-enhanced media and one blending plan

Wright-Pierce provided cost information for two water systems which used greensand filtration as the treatment technology. The two water systems are located in Maine – one in the town of Lisbon and the other in the town of South Berwick. The Willow Drive Pump station in the South Berwick water district serves a population of 3,280 while the Moody River Road Filter plant located in the Lisbon water district serves a population of 6,250.

4.3.2.4. Independent Associations

We considered independent associations of water systems, including national, regional or those covering specific types of water systems, as potential sources of information for this effort. To support their own initiatives, we expected that these associations might sometimes collect information on compliance strategies and costs from their members. Based on this possibility, we asked Abt to investigate whether these associations would be able to share information relevant to our study.

With Abt's assistance, we identified and contacted the following four independent associations: the Association of Metropolitan Water Agencies (AMWA), the American Water Works Association (AWWA), the National Rural Water Association (NRWA), and the Association of State Drinking Water Administrators (ASDWA). For the most part, these associations did not have detailed information readily available on the compliance strategies pursued by their constituents. Nevertheless, discussions with these associations yielded references to other entities that could have the necessary information.

Specifically, AMWA, an organization of large, publicly-owned metropolitan drinking water systems, provided some anecdotal information on the costs of compliance with the arsenic rule for their constituents and, further, suggested we contact the Association of California Water Agencies (ACWA). ACWA is the largest state-wide coalition of public water agencies in the country, with nearly 450 public agency members. Collectively, ACWA's constituents are responsible for 90 percent of the drinking water delivered in California. ACWA had conducted a member survey on compliance with the Arsenic Rule for a different initiative that occurred before our project launched. ACWA was able to share some of the findings of that survey with us and pointed us to peer-reviewed publications they had sponsored using the data collected (Hilkert Colby et al., 2010).

Even though AMWA and ACWA did not provide actual cost data, they both alleged that the costs of complying with the new arsenic MCL were higher than EPA had estimated in its economic analysis, with AMWA reporting that the majority of systems relied on iron-based adsorptive media -- a technology that was not yet demonstrated under field conditions at the time the arsenic rule was promulgated and therefore not considered in the EA (correspondence with Erica Brown, AMWA 2011). AMWA also indicated that a number of the technologies included in the EA -- activated alumina, ion exchange, greensand filtration, and reverse osmosis -- are not widely used by utilities needing to mitigate arsenic levels. Further, they claimed that there have been a number of reports of system failures due to poor design, misrepresentations by vendors regarding the effectiveness of their technologies, the application of technologies inappropriate for specific systems, and the application of systems that are too complex for small systems to maintain.

ACWA, on the other hand, contended that EPA's EA failed to account for additional compliance costs imposed at the state level as a result of California's laws regulating the characterization, generation and disposal of hazardous waste residuals resulting from the arsenic removal process (correspondence with Abby Schneider, ACWA 2011). According to ACWA, more stringent requirements in California related to the management of arsenic residuals were a key driver in the selection of treatment technologies and often resulted in significantly higher compliance costs in California.[143]

In addition, ACWA found fault with EPA's assumption regarding the use of point-of-use (POU) devices by small systems (those serving 500 or less service connections (ACWA 2011)). In California, use of this technology is no longer an option for long-term, permanent treatment of arsenic due to stricter state regulation. Effective December, 2010, POU devices are allowed in CA for a 3-year period in public water systems serving 15-200 service connections. However, these temporary systems need to be replaced with another treatment technology following that period, resulting in higher compliance costs for the small water systems in that category. ACWA did not provide actual cost data to substantiate their claims.

Other independent agencies, specifically NRWA and ASDWA, were helpful in identifying other potential sources of ex post information. Specifically, they suggested that we reach out to individual state agencies with systems known to have exerted a great deal of effort to mitigate arsenic levels in response to the revised MCL. In particular, they suggested we reach out to agencies in Arizona, California, Nevada, New Mexico, and Michigan.

4.3.2.5. State Agencies

Forty nine State agencies and one tribe have primary enforcement responsibility (e.g. primacy) under the Safe Drinking Water Act and, as such, have state-level information on the number of water systems that had to take compliance actions in response to the Arsenic Rule. Specifically, these agencies tend to track the sizes of the systems in question, in addition to general compliance strategy information (i.e., how many systems complied; how many systems installed treatment equipment; and how many opted for non-treatment compliance strategies). Although some state agencies may even have specific information on the arsenic treatment technologies installed, they typically do not have information on their associated costs as tracking costs is outside of their purview.

Through Abt's contact with independent agencies discussed above, we identified five states -- Arizona, California, Michigan, Nevada, and New Mexico – where significant effort was exerted and/or much difficulty

[143] EPA's economic analysis of the arsenic rule captures only the costs of the federal regulation, not the costs of more stringent state regulations.

was experienced in mitigating arsenic levels in response to the new MCL for arsenic. Initial contacts with these states yielded another 4 states with similar experiences, namely Maine, Ohio, Texas and Washington.

Before proceeding with our data gathering efforts, we compared the list of nine states against those identified in two studies on arsenic occurrence – a study by United States Geological Survey (USGS) and a study by Natural Resources Defense Council (NRDC). Each of these studies was carried out prior to the effective date of the Arsenic Rule. The USGS study evaluated arsenic concentration data from ground water sources, a subset of which were located in public water supply sources. The NRDC study examined arsenic compliance monitoring data from ground and surface water community water systems in 25 states that supplied the relevant data. Based on the state-level arsenic occurrence information in the USGS study and the NRDC study, 32 states were identified where the water treatment systems were likely to have had ground water or surface water arsenic levels above the proposed MCL when the Arsenic rule was promulgated ("high arsenic"). We confirmed that all nine states identified through contact with state agencies and independent associations appeared on the "high arsenic" list in at least one of these two studies.

With Abt's assistance we contacted each of the nine states and sent them both a list of general questions related to compliance with the Arsenic MCL as well as a detailed template to give them a sense of the information we were seeking. Abt asked the contacts to provide as much of the information contained therein as they could about their state's experience in complying with the Arsenic MCL. Although none were able to provide cost information, we received responses regarding the types of treatments installed from 4 of the 9 – Maine, Michigan, Nevada and Washington.

Maine. Maine's Drinking Water Program in the Department of Health and Human Services provided some information in response to our inquiries about what transpired in the state in response to the new arsenic MCL but did not otherwise answer the general questions provided. In their response, they indicate that Maine's arsenic compliance issues revolved around public water systems using groundwater and provided some detail on the types of media installed at the various systems needing to mitigate their arsenic levels. These are summarized in Table 4.1 below. Each of the 82 systems listed serve a population of less than 10,000 people, with 78 of the 82 serving populations of less than 1,000. As shown, the majority of systems (67 percent) employed adsorptive media. Anion exchange, installed at 15 percent of systems, was the second most popular compliance technology employed. They also offered, however, that adsorptive media did not last as long as originally estimated by vendors, resulting in more frequent media replacement. Connecting to municipal water systems and installation of new wells accounted for another 6 and 5 percent, respectively.

Table 4.1: Arsenic Mitigation Strategies Employed in Maine

Type of Treatment	Number of Systems Mitigating Arsenic Levels	Percentage of Systems Needing to Mitigate Arsenic Levels
Adsorptive Media	55	67
Anion Exchange	12	15
Combination of Adsorptive Media/Anion Exchange	2	2
Reverse Osmosis	2	2
New Wells	4	5
Connected to Municipal Water System	5	6
Blending Sources	1	1
Unresolved	1	1
TOTAL	82	99*

*Does not sum to 100% due to rounding error

Michigan. According to Michigan's Department of Environmental Quality, 116 systems in Michigan needed to mitigate their arsenic levels. Like Maine, the majority of these systems serve populations of less than 10,000 people, with 96 of the 116 (or roughly 83 percent) serving populations of less than 1,000. Sixty-three of the systems (or 54 percent) opted for the installation of some sort of technology with most utilizing either iron-based adsorptive media, coagulation/filtration or manganese dioxide/greensand process (See Table 2.2).144 An additional 23 systems (20 percent) found new sources of groundwater and 9 (or 8 percent) connected to municipal water systems. Although we do not know the extent of this problem, a major issue in Michigan involved the disposal of arsenic laden backwash water from arsenic removal systems. Because of the high levels of arsenic in the backwash, disposal options were limited, especially for those systems that did not have access to a sanitary sewer. Even so, industrial pretreatment, bio-solids or NPDES concerns of the wastewater treatment facility often precluded systems from utilizing the sanitary sewers for disposal of backwash. Even though Michigan did not provide any cost data to substantiate this statement, they contend that disposal of backwash "in many cases doubled the cost amount of original arsenic removal system."

Nevada. Nevada's Division of Environmental Protection (NDEP) provided responses to the general questions we provided as well as providing some statistics on their Public Water Systems (PWSs). As of December 2010, a total of 326 PWSs were subject to the Arsenic Rule in Nevada with a total of 105 reporting levels greater than 10µg/l. Of these, 75 were community water systems while the remaining 30 were Non-

[144] Michigan did not provide detailed information regarding the frequency with which each specific technology was installed.

Table 2.2: Arsenic Mitigation Strategies Employed in Michigan

Type of Mitigation	Number of Systems Mitigating Arsenic Levels	Percentage of Systems Needing to Mitigate Arsenic Levels
Installation of Treatment Technology	63	54
New Wells	23	20
Connected to Municipal Water System	9	8
Blending Sources	1	1
Unresolved	14	12
Other	6	5
TOTAL	116	100

Transient Non-Community Systems. Although 62 of the 105 (or 59 percent) achieved compliance by December 2010, 64 systems were granted state exemptions along the way allowing them more time to comply, with 34 of the 64 receiving additional state extensions. NDEP reported that, as of December 2010, a total of 43 of the 105 have not yet achieved compliance. As in the other states, adsorptive media figured prominently in the treatment strategies employed especially among systems without access to a sanitary sewer for disposal of backwash. They also offered that Nevada has a pilot testing regulation in place that may serve as something of a deterrent to the application of new innovative technologies. Essentially, it requires that any technology that is not proven successful under similar water quality scenarios must be subject to pilot testing prior to being implemented. As a result proven technologies may get an advantage over alternative technologies since they may be approved without a pilot test.

Washington. In their responses to our general questions, Washington State's Office of Drinking Water (WODW) (within its Department of Health) provided some information on the mitigation strategies utilized in the state as of 2009. Although adsorptive media figured prominently among the strategies employed (25 percent) as in the other states, the most widely used strategy was oxidation/filtration (33 percent). Non-treatment options (including abandoning a contaminated source, drilling new wells, etc.) represented another 17 percent of the mitigation strategies utilized with blending not far behind at 14 percent.

WODW also noted that the volume of water that could be treated by adsorbents was "greatly over predicted." As a result, some water systems using this technology have not had the financial resources to replace the media once exhausted.

In addition, they allege that state rules may have influenced the choice of technologies pursued in that the state requires that treated water samples be collected on a monthly basis to test for the efficacy of treatment. This monitoring requirement and issues regarding access to treatment devices "have been significant barriers to implementation of POU treatment for community water systems" although the issues were not defined in more detail by the state.

4.3.2.6. Summary of Potential Sources of Cost information

Unfortunately, the data available to compare ex post and ex ante costs are very limited. Comprehensive cost information for the treatment technologies installed or other mitigation strategies pursued by water systems affected by the Arsenic Rule is not available. Instead, this case study makes use of ex post cost data from EPA's ORD Demonstration Projects. A total of 50 systems across the U.S. are captured by these data – 8 NTNCWS and 42 CWS. These data represent less than one percent of the NTNCWS and less than 2 percent of the CWSs initially expected to exceed the new standard. These data also reflect costs of treatment technologies and do not capture the frequency of use or the costs associated with non-treatment options such as blending or source switching. While we did obtain cost information for another nineteen water systems from two engineering firms (Malcolm Pirnie and Wright Pierce), we have opted to not compare the reported realized costs with ex ante cost estimates since we cannot verify that the reported costs are specific to arsenic mitigation and do not capture costs associated with other unrelated activities (e.g., control of other contaminants, system improvements, system maintenance, etc.).

Although the states and independent associations provided interesting information on arsenic mitigation strategies employed and related shortfalls, they did not provide the detailed cost information required to make a comparison with ex ante estimates. That said, the information relayed to us through the states and associations reveals an interesting story and suggests some potential reasons why ex ante and ex post costs would diverge. For instance, state regulations governing disposal of backwash contaminated with arsenic had implications on the ex post costs.

4.4. Ex Post Assessment of Compliance Cost

4.4.1. Regulated Universe

All public water systems, which include publicly- and privately-owned CWS and NTNCWS, could potentially be affected by the Arsenic Rule. In addition to being classified by the number of people served by a water system (system size), public water systems are also classified by their water source: surface water vs. ground water. EPA primarily used a December 1998 freeze of SDWIS to characterize the universe of water systems that could potentially be affected by the Arsenic Rule. At the time of the rulemaking, there were a total of 63,984 public/private ground water systems and 11,843 public/private surface water systems that could be potentially affect by the rule. Most of these systems were CWS – 54,352 – while the remaining 20,255 were NTNCWS. The majority (greater than 90 percent) of the CWS serve fewer than 10,000 people.

Recall that the Arsenic Rule was promulgated in 2001 but water systems had until 2006 to meet the new MCL. Looking at the SDWIS summary data for these years, it appears that the size of the regulated universe has decreased from the 1998 baseline. While the differences are not substantial, decreases are apparent for both CWSs and NTNCWSs. In 2001 there were a total of 53,783 CWSs and 20,095 NTNCWSs while in 2006 there were a total of 52,339 CWSs and 19,045 NTNCWSs. Most of the decreases in both years were for systems that serve 500 or fewer people.

4.4.2. Baseline Information

EPA relied on MCL compliance monitoring data from 25 states to develop an estimate of national baseline arsenic occurrence in CWS and NTNCWS (U.S. EPA, 2000b). When EPA was developing the Arsenic Exposure and Occurrence Database (AEOD), they examined other arsenic data sources but each database had limitations. Some of the databases contained old arsenic samples that were considered obsolete while others were used as comparisons for the AEOD. Ultimately, EPA used the state compliance monitoring data voluntarily submitted to EPA from 25 states for several reasons. First, for many of the states, the data collected were representative of almost every ground and surface water CWS in the state in addition to many NTNCWSs. The data sets also contained multiple samples from the individual systems that showed how arsenic levels varied over time or across locations within the system.

EPA then used statistical techniques to estimate the arsenic concentration levels at CWSs and the percentage of those systems that would have one source above the various MCLs. While less than one percent of surface and groundwater systems were predicted to have an arsenic concentration greater than 50 ug/L, 27 percent of groundwater systems and 10 percent of surface water systems were predicted to have an arsenic concentration greater than 2 ug/L. From that, EPA estimated the number of water systems expected to exceed various MCLs.

In their development of the baseline arsenic concentrations, EPA examined other databases such as the National Arsenic Occurrence Survey (NAOS), the United States Geological Society (USGS) ambient ground water arsenic databases, the National Inorganics and Radionuclides Survey (NIRS), and the Metropolitan Water District of Southern California Survey (Metro). However, each database had a drawback. For example, the NAOS and NRIS were not useful because they did not provide arsenic concentrations within the range being considered by EPA for the arsenic MCL. The Metro database only had information for the larger public water systems (those serving greater than 10,000 people). The USGS database was the most comprehensive, collecting samples from 20,000 locations across the U.S. However, some of the samples were taken from wells used for research or used by agriculture and industry. While the USGS database provided significant information, the samples were not collected to inform the development of a national estimate of arsenic concentrations in drinking water supplies. However, EPA used these databases as comparison tools to check the arsenic concentrations predicted by the AEOD (U.S. EPA, 2000b). To the best of our knowledge, EPA has not updated the AEOD.

4.4.3. Methods of Compliance

In the Economic Analysis (EA) for the Arsenic rule, EPA presented estimates of unit costs and national system treatment costs separately for three system categories: small and large CWSs and NTNCWSs.[145] In order to obtain these estimates, EPA made assumptions about the number and types of systems that would need to treat their water; the type of treatment technology they would adopt; and the cost of installing and

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[145] The economic analysis was prepared by Abt Associates, Inc., for the Office of Water and is available here: http://water.epa.gov/lawsregs/rulesregs/sdwa/arsenic/upload/arsenicdwrea.pdf. (US EPA 2000a).

operating that technology. Ultimately, the actual compliance methods chosen by water systems depend not only on their arsenic concentrations and the size of the system but also on location specific characteristics (e.g., iron levels in the water, pH, etc.), treatment methods already in use, and availability of alternative water sources.

At the time of the Arsenic Rule making, iron-based adsorptive media was in the pilot and research phase, so it was not identified as a BAT nor was it included in EPA's compliance forecast for the cost analysis. However, the technology's effectiveness has since been demonstrated by EPA and others, water systems can and have used iron-based adsorptive media for arsenic mitigation. Non-treatment options such as blending, turning off wells with high arsenic levels and drawing water from another area in the aquifer with low arsenic levels were also used and are not considered in the EA.

While we were interested in collecting information on the treatment technologies used by water systems and their costs, we also wanted to know whether new or modified treatment technologies have been used to meet the arsenic standard. In particular, we were interested in determining if treatment technologies have changed since the Arsenic Rule was promulgated. As evidenced by the technologies selected for the ORD Demonstration Projects and responses from the compliance experts, states, and independent associations to our inquiries, iron-based adsorptive media emerged as the preferred treatment technology for mitigating arsenic contamination. In particular, Malcolm Pirnie indicated that adsorption to granular iron media (GIM) has been widely used at wellheads and in POU treatment systems. They also indicated that Granular Ferric Hydroxide or variations of this media have been used frequently.

Even though the four states that provided us information stated that the majority of their systems utilized iron-based adsorptive media, certain BATs were also used. In Washington, oxidation/filtration was the most used technology. This technology was also used by some systems in Michigan. Anion exchange as well as coagulation/filtration were used by systems in Maine and Michigan. As the states indicated, factors affecting use of adsorptive media include how the residuals or backwash water will be disposed and the frequency and cost of media replacement. Systems that did not have access to sanitary sewers to dispose of backwash containing arsenic residuals generated from BATs tended to use adsorptive media.

In addition to treatment technologies, Malcolm Pirnie asserted that non-treatment options such as blending with low or arsenic free water, turning off wells with elevated levels of arsenic, or selective well screening to draw water from regions of the aquifer with low arsenic level were also widely used. Malcolm Pirnie provided data on one utility in Central Arizona that used a blending plan. The total treatment capital cost reported by this utility was $15,000. The states also indicated that systems used non-treatment options that included blending, finding new sources of groundwater and connecting to municipal water sources.

Wright Pierce, on the other hand, indicated that they did not think treatment technologies have changed since the Arsenic Rule was promulgated. However, their responses indicated that they were most familiar with greensand filtration. The pilot testing for their two systems showed greensand filtration to be the best technology for removing arsenic. Wright Pierce did indicate that innovation has occurred within greensand filtration – their two systems used Pureflow high rate media which allowed for a higher filtration rate and fewer filters.

4.4.4. Compliance Costs

The national cost estimates associated with the Arsenic Rule include the costs to the water system to meet the new standard and the costs to the States to implement and enforce the rule. In this section we focus on the method EPA used to estimate compliance methods used by systems and their associated costs. As discussed earlier, EPA considered the following centralized BATs:

- Modified Lime Softening
- Modified Coagulation/Filtration
- Ion Exchange
- Coagulation Assisted Microfiltration
- Oxidation Filtration (Greensand)
- Activated Alumina

as well as the following POU treatments (treatment at the tap) for smaller systems:

- POU Reverse Osmosis
- POU Activated Alumina

Cost equations and the resulting cost curves for both capital and operating and maintenance (O&M) costs for each of the BAT technologies are presented in the *Technologies and Costs for Removal of Arsenic from Drinking Water* (EPA, 2000) and serve as major inputs to EPA's estimation of compliance costs in the EA. The capital cost curves are a function of the system design flow (mgd, million gallons per day) while O&M cost curves are a function of the average flow (mgd) of the system. Some of these technologies require pre-treatment (e.g., pre-oxidation or corrosion control) in order to be effective and/or generate wastes that require disposal. The associated costs of waste disposal and pre-oxidation were included in the costs of treatment when relevant.[146] In the EA a treatment train consisted of the technology along with any pre-treatment and disposal required by that technology. Capital and O&M costs as well as any treatment or waste disposal costs for each treatment train are presented in the EA to show the range of costs across the different treatment trains to achieve the MCL assuming different initial arsenic concentrations.

The Safewater XL model was used by EPA to estimate compliance costs for individual systems. Using statistical methods, sites within a system were assigned an arsenic concentration and for sites where this concentration is higher than the MCL, a treatment train was assigned to the site based on the size and type of system. Capital and O&M costs were calculated for the treatment train selected for this site. By summing across treated sites, a system's compliance cost was estimated.

To the best of our knowledge, the majority of the BAT's listed by EPA were used by systems to comply with the arsenic MCL. However, as evidenced by our discussions with compliance engineering firms and states, there was widespread use by systems of iron-based adsorption media as a treatment technology. It also appears systems were able to use a non-treatment method to comply by blending finished water with a

[146] Appendix A presents the assumptions and cost curves used by EPA in the EA to estimate the costs of these BATs.

source that had low arsenic levels. Unfortunately, we do not have enough data to opine on the cost-effectiveness of adsorptive media compared to the best BAT choice for site remediation.

4.4.4.1. Ex Post Compliance Costs

For the ex post assessment, we focus on the water system information and treatment technology costs reported by the ORD Demonstration Projects. Using these data, we make some general comparisons with the ex ante cost estimates. First, we consider the realized capital costs reported for each of the systems and plot these against the predicted values generated using EPA's cost curves. In so doing, we compare ex post costs for these systems with the predicted values. As we have access to cost information for all of the demonstration projects, this is an extension of the work presented in Gurian et al. (2006).

Second, using information on the design flow rate for each of the systems, we estimate a pseudo ex ante estimate using the cost curves derived by EPA for that given technology. We then compare this estimate with the realized costs reported for each system. In this way, we attempt to determine how well the cost curves performed. Because cost curves were not developed by EPA for all of the technologies represented in the data, we are limited in the comparisons we can make with this methodology.

We also present the water system information and treatment technology costs reported by the two engineering firms: Malcolm Pirnie and Wright Pierce. However, we do not make comparisons with ex ante cost estimates since it is possible that capital and O&M costs for other activities conducted concurrently with the arsenic mitigation are intermingled. For example, construction costs provided by the engineering firms for some systems may include the costs of upgrades to increase the capacity of the system or replacement of existing equipment that are unrelated to the Arsenic Rule but are performed while the system is installing a technology to reduce arsenic. However, even with the addition of the data on these nineteen systems from Malcolm Pirnie and Wright Pierce, our data remain too limited to draw robust conclusions on whether EPA over or under-estimated costs associated with specific technologies.

4.4.4.2. Total Reported Capital and O&M Costs

Adsorptive Media. For the 28 water systems that selected adsorptive media (AM) technology, seven systems were NTNCWS and 21 systems were CWS (there are 28 water systems because Klamath Lake has three POU AM systems). Arsenic concentrations ranged from 12.7 to 67.2 µg/L across the sites. Arsenic removal capacity of AM is highly dependent on pH. Most AM absorb arsenic more effectively at a pH value of 5.5 to 7.5, with adsorptive capacity increasing as pH decreases. Adjusting the pH value of the water can increase the adsorptive capacity and lower the operating costs but the additional pH control equipment increases both the complexity of the system as well the capital cost of the system. Source water pH values ranged from 6.9 to 9.6 across the sites. Source waters at seventeen sites had a pH value greater than 7.5, and seven of these 17 sites adjusted the pH value of the water. Table 4.3 summarizes design flow rate, average flow rate, total capital and O&M costs for the 28 water systems.

Iron Removal or Coagulation/Filtration. Of the 50 demonstration sites, eighteen sites used Iron Removal (IR) or Coagulation/Filtration (CF) as the main treatment technology. Iron removal or oxidation filtration processes involve passing water through a greensand filter to remove iron and arsenic. Four of the eighteen systems that used IR also followed treatment with adsorptive media (AM) to remove iron and arsenic. The four systems primarily used IR as protection against fouling the AM with iron. Table 4.4 summarizes the location, technologies, design and average flow rate, total capital and O&M costs for the IR/CF water systems. Two of the eighteen sites were Non-transient Non-Community Water Systems. Arsenic concentrations in source waters ranged from 11.4 to 84.0 µg/L.

Other Arsenic Treatment Technologies. Table 4.5 summarizes the location, technologies, flow rates, total capital and O&M costs on two systems which use Ion Exchange (IX), one system which used Reverse Osmosis (RO), and two point-of-use (POU) demonstration projects. At the Klamath Falls site, eight POU AM units were installed under a sink or inside a drinking water fountain in eight college buildings. At the Homedale site, POU RO units were installed in nine homes. Arsenic concentrations in source waters ranged from 18.2 to 57.8 µg/L. The presence of co-contaminants in source waters influenced the selection of treatment technology for the different sites.

Industry Compliance Engineering Firms. Table 4.6 summarizes the location, treatment technology, design flow rate and total capital costs provided by Malcolm Pirnie. Six of the facilities used BAT options to reduce arsenic levels – three ion exchange, two reverse osmosis, and one activated alumina. Seven of the utilities used some form of an adsorption technology while one utility choose blending, a non-treatment option. Capital costs are actual costs incurred by the utilities. Although we only report either actual or median total capital costs, when available, Malcolm Pirnie did break down capital costs by treatment equipment and materials, waste disposal equipment and materials, construction, land, engineering, bench and pilot testing, permitting, and other. Malcolm Pirnie provided O&M costs for a few facilities but because it was unavailable for most facilities, we do not report O&M costs here.

Table 4.3. Summary of ORD Adsorptive Media Demonstration Sites -

State	Demonstration Location (Site ID)	Technology	Design Flow Rate (gpm)	Average Flow Rate (gpm)	Total Capital Costs ($)	Total O&M Costs ($/kgal)
ME	Wales (WA)	Iron Modified Media (alumina based)	14	10.4	$16,475	$22.88 $10.44 $5.52[#]
NH	Bow (BW)	Iron Modified Media (silica based)	40	41	$166,050	$5.11
NH	Goffstown (GF)	Granular Ferric Oxide	10	13	$34,201	$2.34
NH	Rollinsford (RF)	Granular Ferric Oxide	120	82	$131,692	$3.59*
VT	Dummerston (DM)	Iron Modified Media (alumina based)	22	6.1	$14,000	$10.86
CT	Woodstock (WS)	Titanium Oxide Media	20	16.4	$51,895	no estimate**
CT	Pomfret (PF)	Iron Modified Media (resin based)	15	9.6	$17,255	$7.67
MD	Stevensville (SV)	Granular Ferric Oxide	300	207	$211,000	$0.61
OH	Buckeye Lake (BL)	Granular Ferric Oxide	10	On demand	$27,255	no estimate**
MI	Brown City (BC)	Granular Ferric Oxide	640	564	$305,000	no estimate**
IL	Geneseo Hills (GE)	Granular Ferric Oxide	200	32	$139,149	no estimate**
SD	Lead (LD)	Iron Modified Media (resin based)	75	71.5	$87,892	$0.98
TX	Alvin (AL)	Granular Ferric Oxide	150	129	$179,750	$0.61
TX	Bruni (BR)	Granular Ferric Oxide	40	40	$138,642	no estimate**
TX	Wellman (WM)	Granular Ferric Oxide	100	91	$149,221	no estimate**
NM	Anthony (AN)	Granular Ferric Oxide	320	260	$153,000	$0.75
NM	Nambe Pueblo (NP)	Granular Ferric Oxide	160	114	$143,113	no estimate**
NM	Taos (TA)	Granular Ferric Oxide	450	503	$296,644	no estimate**
AZ	Rimrock (RR)	Granular Ferric Oxide	45	31	$88,307	$0.86
AZ	Tohono O'odham Nation (TN)	Granular Ferric Oxide	63	60.1	$115,306	no estimate**
AZ	Valley Vista (VV)	Iron Modified Media (alumina based)	37	36	$228,309	$2.47
OR	Klamath Falls (KF)[a]					
	(a)	Iron Modified Media (resin based)	30	On demand	$55,847	no estimate**
	(b)	Granular Ferric Oxide	60	On demand	$59,516	$5.37
	(c)	Titanium Oxide Media	60	On demand	$73,258	no estimate**
NV	Reno (RN)	Granular Ferric Hydroxide	350	275	$232,147	$5.69
CA	Susanville (SU)[a]	Iron Modified Media (alumina based)	12	9.3	$16,930	$12.06

State	Demonstration Location (Site ID)	Technology	Design Flow Rate (gpm)	Average Flow Rate (gpm)	Total Capital Costs ($)	Total O&M Costs ($/kgal)
CA	Lake Isabella (LI)	Iron Modified Media (resin based)	50	23	$114,070	no estimate**
CA	Tehachapi (TE)	Zirconium Oxide Media	150	79.3	$76,840	$1.16

[a] Non-Transient Non-Community Water Systems
associated with three replacement media types: A/I Complex, GFH, and CFH
* Estimated Cost– did not replace media
** No estimate of total O&M but estimates of media replacement costs, electricity, chemicals and labor costs are provided.

Table 4.4. Iron Removal (IR) and Coagulation/Filtration (CF) Systems

State	Demonstration Location (Site ID)	Technology	Design Flow Rate (gpm)	Average Flow Rate (gpm)	Total Capital Costs ($)	Total O&M Costs ($/kgal)
IN	Goshen (GS)[a]	IR + AM	25	15.2	$55,423	$2.90
IN	Fountain City (FC)[a]	IR	60	47	$128,118	$2.26
MN	Sauk Centre (SC)	IR	20	4	$63,547	$0.36
UT	Willard (WL)	IR + AM	30	9.3	$66,362	$1.93
WI	Delavan (DV)	IR	45	20 (max)	$60,500	$0.26
IL	Waynesville (WV)	IR	96	84	$161,560	$0.65
MN	Climax (CM)	IR/IA	140	132	$270,530	$0.29
PA	Conneaut Lake (CL)	CF	250	153	$216,876	$0.46
MT	Three Forks (TF)	CF	250	206	$305,447	$0.18
MN	Sabin (SA)	IR	250	231	$287,159	$0.43
OH	Springfield (SF)	IR + AM	250	89	$292,252	$0.33
MN	Stewart (ST)	IR + AM	250	190	$367,838	$0.16
MI	Sandusky (SD)	IR	340	163	$364,916	$0.27
WI	Greenville (GV)	IR	375	285	$332,584	$0.55
DE	Felton (FE)	CF	375	263	$334,297	$0.31
MI	Pentwater (PW)	IR/IA	400	350	$334,573	$0.17
WA	Okanogan (OK)	CF	550	538	$424,817	$0.18
LA	Arnaudville (AR)	IR	770	335	$427,407	$0.07

[a] Non-transient Non-Community Water Systems
IA = supplemental iron addition; AM = adsorptive media; CF = coagulation/filtration using iron salts and direct pressure filtration, not conventional coagulation-sedimentation-filtration.

Table 4.5. Other Arsenic Treatment Technologies: Ion Exchange (IX), Reverse Osmosis (RO), and Point-of-Use (POU)

State	Demonstration Location (Site ID)	Technology	Design Flow Rate (gpm)	Average Flow Rate (gpm)	Total Capital Costs ($)	Total O&M Costs ($/kgal)
ME	Carmel (CE)[a]	RO	1,200 gpd	0.8 (permeate); 1.2 (reject)	$20,542	$12.89
OR	Klamath Falls (KF-POU)[a]	POU AM	NA	NA	$1,216	
ID	Homedale (HD)	POU RO	NA	NA	$31,877.50	$201.50/yr (total)
ID	Fruitland (FL)	IX	250	157	$286,388	$0.62
OR	Vale (VA)	IX	540	534	$395,434	$0.35

[a] Non-Transient, Non-Community Water System
AM = Adsorptive media; NA = not applicable

Table 4.6. Median and Reported Values of Design Flow Rate and Total Capital Costs to Meet the Arsenic Standard by Treatment Technology for Select Systems in California and Arizona (Malcolm Pirnie)

Type of Value	Treatment Technology	Design Flow Rate (mgd)	Total Capital Costs ($)
Median	Adsorption (10)	3.6	$1,423,440
	Ion Exchange (3)	5.76	ANR
Reported	Reverse Osmosis (1)	1.44	Less than $240,000
	Reverse Osmosis (1)	POU	$400
	Activated Alumina (1)	0.86	Less than $1,575,000
	Blending Plan (1)	4.18	$15,000

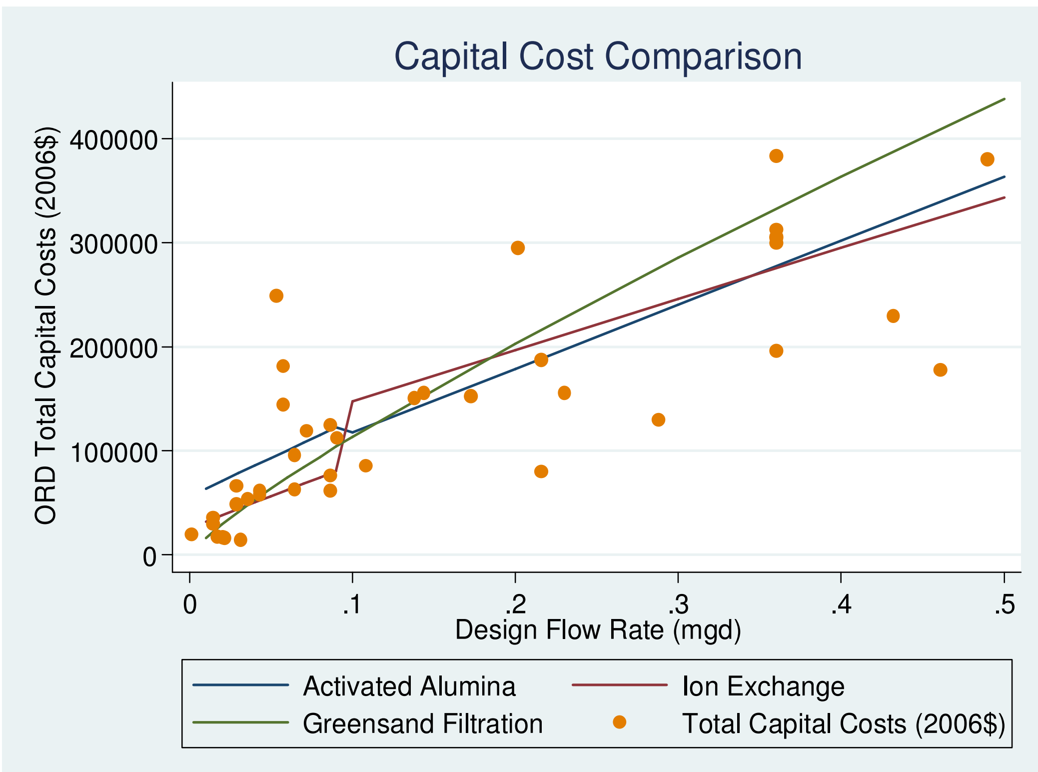
ANR = available but not reported because we cannot verify that the reported costs are specific to arsenic mitigation.
(#) Either number of facilities used in the median calculation or the number using a treatment technology.

In addition, Wright-Pierce provided cost information for two water systems in Maine, both of which used greensand filtration as the treatment technology. The Willow Drive Pump station in the South Berwick water district serves a population of 3,280 and has a design flow rate of 0.792 mgd. Capital costs associated with this project were reported as $1, 329,798 in 2003 and O&M costs of $52,906 per year. The Moody River Road Filter plant serves a population of 6,250 with a design flow rate of 1 mgd. Capital costs associated with this project were reported as $2,582,326 in 2005 and O&M costs of $69,609 per year.

Our only source of pre-regulatory cost information is the cost curves developed in EPA's "Technologies and Costs for Removal of Arsenic from Drinking Water" (US EPA 2000c). At this time we use only one source of post-regulatory costs: ORD Demonstration Projects. A significant share of the post-regulatory cost information from the ORD Demonstration Projects is on iron-based adsorptive media, a technology that was still in the research and pilot stage at the time the Arsenic Rule was promulgated. However, as we have learned iron-based adsorptive media were used by many systems to reduce arsenic levels.

To compare ex ante costs with our limited ex post cost data, we plot our ex post cost data against the capital cost curves used by EPA for treatment technologies recommended for smaller systems – activated alumina, ion exchange and greensand filtration. The capital costs from the ORD Projects are plotted in Figure 4.1 and Figure 4.2.[147] To keep the graphs visually simple, Figure 4.1 plots the capital cost data for the demonstration projects that had a design flow rate between 0.01 mgd and 0.5 mgd while Figure 4.2 plots the data for projects with a design flow rate greater than 0.5 mgd. The results are mixed. In 42 out of 49 demonstration projects, realized capital costs are below the 2006 cost curve estimates for at least one of the three technologies.[148]

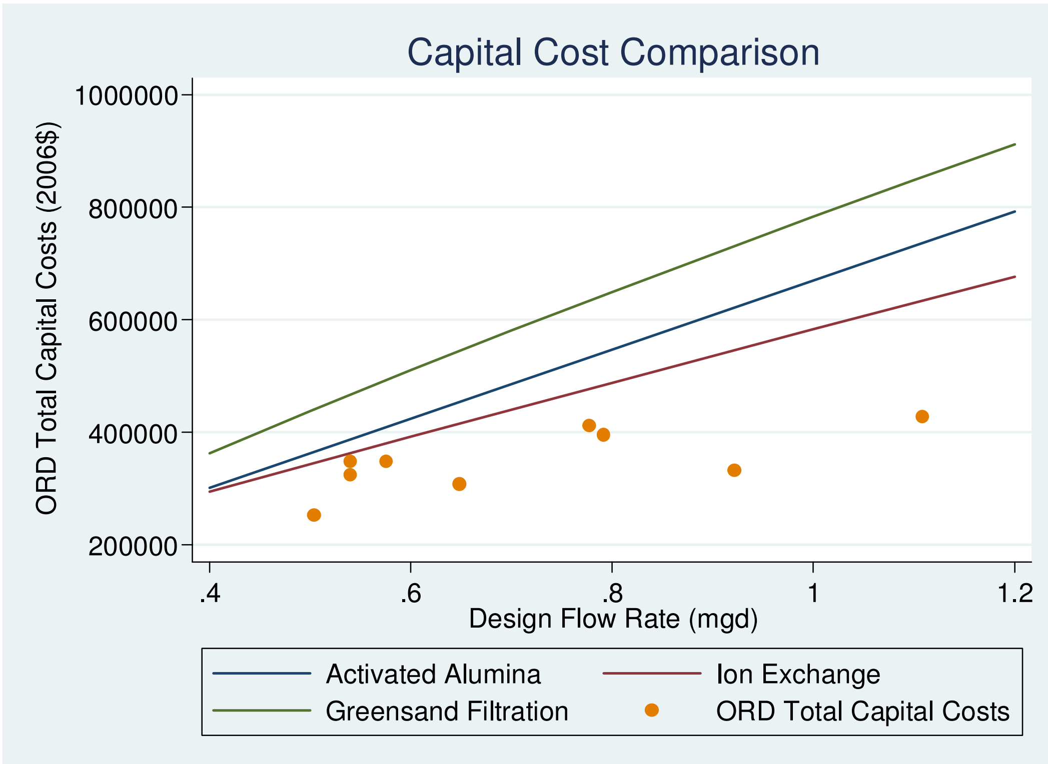
Figure 4.1. Capital Cost Comparison by Design Flow Rate (0.01-0.5mgd) – EPA Cost Curves vs. ORD Demonstration Projects



[147] Total capital costs for the ORD demonstration projects were converted to 2006 dollars from the year of construction using the Engineering News Record Construction Cost Index. See appendix for cost curve equations in $2006.

[148] Two POU ORD projects did not provide design flow rate so they are not included on the graphs.

Figure 4.2. Capital Cost Comparison by Design Flow Rate (0.5-1.2 mgd) – EPA Cost Curves vs. ORD Demonstration Projects



4.4.5. Comparison of Technology Costs

This section presents the actual capital costs and O&M costs compared to predicted costs obtained using the EPA cost curves for two BAT compliance options: Ion Exchange and Greensand Filtration. [149] Before presenting these comparisons, there are a few points to note. First, there is more uncertainty surrounding operating cost estimates than capital cost estimates because of the difficulties in separating incremental activities related to rule compliance from general operating activities. Second, and most importantly, we do not have enough cost data to draw robust conclusions about whether EPA over or under-estimated

[149] We only compare the ORD projects that used a BAT. We do not compare the projects that used a combination BAT and non-BAT (e.g., iron removal (IR) and AM) or a technology that was in the same class but a variation of a BAT. For example, we do not compare ORD projects that used coagulation filtration (CF) to EPA's BAT because EPA assumed modified coagulation/filtration and not new installation of the technology. Also Greensand filtration is the only form of IR or CF that was a BAT. Although similar, other IR technology used by the demonstration projects was not a BAT.

technology costs. We present the cost comparisons for these technologies here to simply illustrate the evaluation we could make if we had more data on ex post technology costs.

Ion Exchange. Table 4.7 presents total capital costs (CapEx) and total O&M costs (OpEx) for the two ORD Demonstration Projects that used Ion Exchange (IX). Using the design flow rate and average flow rate of the systems, we use EPA's cost equations for IX reproduced in Table A5 in the Appendix 4.2 to predict the capital and O&M costs for this technology (EPA Estimate). Column 5 represents the percentage error between these EPA estimates and the realized costs reported by ORD Demonstration Project sites. A positive (negative) percentage error means that the EPA estimate was higher (lower) than actual costs incurred by the individual system.

The EPA estimates of capital costs were mixed. For the smaller system, as measured by design flow, the EPA estimate was lower than the actual cost of the project and higher than the actual cost of the project for the larger system. For both projects, EPA's cost curves predicted lower O&M costs than the actual project costs.

Greensand Filtration. Two community water system ORD Demonstration Projects used Greensand filtration (GF) as a treatment technology. Table 4.8 presents total capital costs (CapEx) and total O&M costs (OpEx) for these two systems. Using the design flow rate and the average flow rate of the systems, we use EPA's cost equations employed in the EA for GF (see Appendix 4.2) to estimate the capital and O&M costs for this technology (EPA Estimate). Column 5 represents the percentage error between the EPA estimate and the costs reported by ORD Demonstration Project sites. A positive (negative) percentage error means that the EPA estimate was higher (lower) than the actual project costs for those systems. In the case of the GF technology, one ORD Demonstration Project had capital costs that were slightly higher than the EPA estimate (-1 percent) while the other had capital costs that were significantly lower than projected (69 percent). For both projects, predicted O&M cost were slightly lower than the realized cost.

4.5. Overall Implications and Study Limitations

As the introduction and the literature survey (Sections I and III) make clear, even the most credible analysis of compliance costs (done before implementation) will vary from actual costs for a large number of reasons. For example, in the case of arsenic, innovation, impossible to forecast, may have reduced the costs. Or, the number of water systems exceeding the standard could be larger or smaller than predicted before the rule.

This case study was particularly challenging in that the systems affected by the new arsenic standard are heterogeneous. In addition to the heterogeneity of sites, it is also challenging to distinguish costs attributable to compliance with the Arsenic Rule from costs incurred by systems as a result of complying with other regulations or to meet other needs of the system. For example, some treatment technologies, such as ion exchange, are capable of removing other contaminants (e.g., uranium) in addition to arsenic. The portion of the treatment cost attributable to arsenic compliance can be difficult to distinguish from the cost of contaminants being removed for other regulations. Additionally capital costs may also include costs associated with other projects unrelated to arsenic treatment, including upgrades that increase the overall

Table 4.7. Cost Comparisons – Ion Exchange (2006$)

	Design Flow/Average Flow (mgd)	ORD Project Costs	EPA Estimate	% Error
CapEx	0.36	$311,988	$275,245	-12%
	0.78	$411,632	$477,021	16%
OpEx	0.23	$55,735	$34,180	-39%
	0.77	$102,258	$43,180	-58%

Table 4.8. Cost Comparisons – Greensand Filtration (2006$) -

	Design Flow/Average Flow (mgd)	ORD Project Costs	EPA Estimate	% Error
CapEx	0.14	$150,692	$149,082	-1%
	0.36	$196,150	$332,473	69%
OpEx	0.12	$26,767	$19,341	-28%
	0.22	$33,457	$27,139	-19%

capacity of the system or replace existing equipment at the treatment plant. Because systems may perform other types of maintenance projects concurrent with their response to the Arsenic Rule, it can be difficult to isolate the costs attributable to the rule. These factors all add to the analytic challenge of how to evaluate the costs faced by systems affected by the Arsenic Rule.

With no comprehensive or even representative data on costs or mitigation strategy selected, our options were limited. Short of conducting a survey of community water systems to gather information on treatment methods used and the costs associated with those methods, we found no other means of collecting the necessary data. Instead, we relied on limited information collected from compliance engineering firms and EPA demonstration projects which have their own potential biases. For example, the ORD projects rely on emerging technologies that were not entirely understood by the vendors. In addition, the price point for the adsorptive media was not well-established and, because of the speed at which EPA needed to implement the demonstration program, there may not have been sufficient time to negotiate the most competitive media prices Generally, little to no pilot testing was conducted at demonstration sites to optimize the design and installation of the technologies at a given facility prior to the selection of a technology and its implementation. On the other hand, vendors wishing to establish their technologies as cost-effective alternatives may have offered EPA more appealing prices. Again, because the goal of the program was to demonstrate the effectiveness of various alternative treatment technologies, non-treatment alternatives were not considered and are therefore not represented in the data. However, because of the detailed nature of the data, they nevertheless provided useful information.

While we do make comparisons of EPA predicted costs and realized costs from the ORD Demonstration Projects, these comparisons are for illustrative purposes only. We plot all of the capital cost data from the ORD Demonstration Projects against the cost curves for the compliance technologies recommended for smaller systems and find that the EPA methodology overestimates capital costs in most cases, especially as the size of the system increases (as measured by the design flow rate). We also compare EPA predicted costs and realized costs from the four ORD Demonstration Projects for two specific BATs (ion exchange and greensand filtration) but make no judgments. Because the number of observations in our data set is very small compared to the number and heterogeneity of the systems affected by the Arsenic Rule, we cannot draw any conclusions regarding EPA's technology cost estimates. Our data capture the costs of treatment technologies for a very small percentage of systems affected by the arsenic standard and as such, our results are not generalizable across affected systems. Instead, our illustrative comparisons offer insights into how we might proceed if better and more comprehensive data were available.

We find that this effort illustrates the characteristics of an environmental control problem that make case study analysis extremely difficult and expensive. Despite our best efforts, our data do not provide enough coverage of CWSs to make any assessment of how ex post costs deviate from EPAs ex ante estimates. As discussed below, the heterogeneity of the affected water systems presents major obstacles to comparing ex post and ex ante costs. These factors and our lessons learned from doing this case study should be considered when designing future case studies assessing ex ante and ex post costs. We do offer limited comparisons of predicted cost estimates obtained using methodologies employed by EPA in the EA with the data we collected on realized compliance costs for the 50 systems.

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Appendix 4.1: Publicly Available Data Related to Arsenic Rule

Working with Abt Associates, we identified ten sources of publicly available data collected on levels of contaminants in U.S. drinking waters and four potential data sources on compliance costs.[150] The potential sources on arsenic contaminant levels in drinking water and ambient levels are as follows:

- Safe Drinking Water Information System (SDWIS)
- Arsenic Occurrence and Exposure Database (AOED)
- Consumer Confidence Reports (CCRs)
- National Tap Drinking Water Database (NTWQD)
- EPA's STORET Data Warehouse – arsenic ambient levels
- National Water Information System (NWIS) – arsenic ambient levels
- National Water-Quality Assessment (NAWQA) Program – arsenic ambient levels
- Community Water System Survey (CWSS)
- National Contaminant Occurrence Database (NCOD)
- National Environmental Public Health Tracking Network

Potential sources of compliance cost data include

- Drinking Water Infrastructure Needs Survey and Assessment (DWINSA)
- Community Water System Survey (CWSS)
- Drinking Water Cost Rate Data

Potential Sources of Arsenic Occurrence Data

Safe Drinking Water Information System (SDWIS): EPA's SDWIS federal (SDWIS/FED) and state (SDWIS/STATE) databases contain basic information submitted by states and EPA regions about public water systems. States supervise their drinking water systems to ensure that each public water system meets state and EPA standards for safe drinking water. SDWIS/STATE contains this information and is designed to help states manage and run their drinking water programs. States are required to report drinking water information periodically to EPA and this information is maintained in the SDWIS/FED database.

SDWIS/FED contains the information EPA uses to monitor approximately 156,000 public water systems, including basic information on each water system (e.g., name, location, source of water as groundwater or surface water, public or private ownership, and population served) as well as information on the reported violation and enforcement actions. However, until 2011 SDWIS/FED did not contain information on the

[150] "Background and Data Sources for Five Selected Rules," memo from Abt Associates to Nathalie Simon, August 17, 2010. Note that this list was later augmented with additional information by EPA.

observed measurement of contaminants that lead to a given violation. Now the violation measure is included for each violation in SDWIS.

EPA routinely evaluates state drinking water programs by conducting data verification audits, which evaluate state compliance decisions and reporting to SDWIS/FED. Every three years, the Agency use to prepare a report that presents the results of a review and evaluation of the data quality in SDWIS/FED every three years but due to budget cuts, EPA is currently not preparing these types of reports.

Arsenic Occurrence and Exposure Database (AOED): [151] The AOED was developed to estimate baseline arsenic occurrence data in the United States. The database is generally based on arsenic data from the following 25 state compliance monitoring dataset and system characteristics from both SDWIS and State compliance monitoring data.[152] The database was published in December 2000 and has not been updated since that time.

Consumer Confidence Reports (CCRs): CWSs with 15 or more service connections (e.g., houses or other buildings where drinking water is consumed) or that regularly serve at least 25 year-round residents must prepare a CCR starting in 1999 (for 1998 calendar year data). CCRs must disclose detected amounts of contaminants even if no violation has occurred, and as of 2001 systems detecting arsenic above the MCL also had to include a statement about the health effects of arsenic (but they did not have to report the measured amount of arsenic). While these reports are to be provided or made available to customers by July 1 of each year, exactly how they are released and distributed varies by system size and other factors. Systems serving 100,000 or more people (approximately 336 systems) are required to post CCRs online as well as mail them to customers. On the other hand, smaller systems (serving fewer than 10,000 people) may be able to provide their customers with this information via other means such as the newspaper (some states have made some exceptions to these requirements).[153]

A number of issues arise when attempting to access CCRs. First, systems are not required to submit CCRs to EPA but only need to submit them to state agencies for compliance monitoring. Second, EPA has a website that is intended to provide links to state CCRs but very few CCRs are linked to this site.[154] CWS that serve

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[151] Described in the report Arsenic Occurrence in Public Drinking Water Supplies http://water.epa.gov/drink/info/arsenic/upload/2005_11_10_arsenic_occurrence.pdf

[152] The states are Alaska, Alabama, Arkansas, Arizona, California, Illinois, Indiana, Kansas, Kentucky, Maine, Michigan, Minnesota, Missouri, Montana, North Carolina, North Dakota, New Hampshire, New Jersey, New Mexico, Nevada, Ohio, Oklahoma, Oregon, Texas, and Utah.

[153] States governors are empowered to give systems serving fewer than 10,000 customers waivers instead of mailing the CCRs to customer. Systems serving fewer than 10,000 customers but more than 500 customers may publish the CCR in the newspaper and notify their customers that the CCR is available. Systems serving fewer than 500 customers may notify their customers that the CCR is available.

[154] http://safewater.tetratech-ffx.com/ccr/index.cfm

greater than 100,000 people must post their CCRs online but are not required to use EPA's website. Most of these systems have their own website.

National Tap Water Quality Database (NTWQD): [155] The Environmental Working Group (EWG) – an advocacy group – assembled 20 million drinking water quality tests performed by water utilities since 2004 into their National Drinking Water Database to investigate the quality of drinking water across the country. They requested system monitoring data from each state water office. They received water quality tests conducted by 47,667 utilities in 44 states (and the District of Columbia) from 2004 to 2009.[156] The data are presented for all contaminants that are monitored by the system and sent to the state. On the EWG website a drinking water quality report can be obtained for only one drinking water system at a time. The data presented on the report for the system summarizes water quality test results. Detailed data files are not available on their website.

STORET (short for STOrage and RETrieval):[157] EPA maintains all of its ambient water quality data in the STORET database. STORET also includes data collected and submitted by states, tribes, watershed groups, other federal agencies, volunteer groups and universities. STORET contains data on physical, chemical, and biological sampling of waters (including surface water, groundwater, and wetlands) and each observation also contains information about the sampling procedures used, the submitting organization, and the type of sampling project (e.g., a long term monitoring project). Historical water quality data (observations collected before 1999) are contained in the Legacy Data Center. This database contains over 200 million water sample observations from about 700,000 ground and surface water sampling sites.

National Water Information System (NWIS):[158] The U.S. Geologic Survey (USGS) collects water-resources data at approximately 1.5 million sites in the U.S. (including the District of Columbia). Surface-water data are collected from major rivers, lakes and reservoirs, while ground-water data are collected from wells and springs. The types of water-quality data collected include temperature, specific conductance, pH, nutrients, pesticides, volatile organic compounds, and various other contaminants (including arsenic). Both current and historical data on surface water (water flows and levels), groundwater (water levels), and water quality (chemical and physical data) are available by geographic area (i.e., county, hydrologic unit, latitude/longitude).

National Water-Quality Assessment (NAWQA) Program: The USGS NAWQA Program is designed to provide an understanding of water-quality conditions in the U.S. Monitoring data are integrated with geographic information on hydrological characteristics, land use, and other landscape features in order to understand how water-quality conditions are changing over time and how natural features and human activities affect

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[155] http://www.ewg.org/tap-water/methodology

[156] Some states did not respond, some requested large fees for the data, and one only submitted paper records.

[157] http://www.epa.gov/storet/about.html; data collected prior to 1999 is contained in the Legacy STORET database, while more recent data is contained in the main STORET database.

[158] http://waterdata.usgs.gov/nwis/

those conditions. One of the studies includes a National-Synthesis Assessment on trace elements in groundwater and surface waters with a particular focus on arsenic. In the Trace Element National Synthesis Project "Arsenic in Ground Water of the United States," the USGS has developed maps that show the location and extent of arsenic in groundwater across the U.S.[159] The maps are based on arsenic samples taken from 31,350 wells and show widespread high arsenic concentrations across the Midwest, West, and Northeast. The sample database for the 31,350 wells has information on the location of the well, depth of the well, date the sample was taken and the concentration of arsenic in the sample.

Prior to the revision of the Arsenic rule in 2001, USGS conducted a retrospective analysis of arsenic occurrence in groundwater in the U.S.[160] For the retrospective study, USGS selected almost 19,000 groundwater sites from their NWIS database.[161] If five or more observations were available for a given county, all observations within 50 kilometers of the county's centroid were combined to construct a distribution of arsenic concentrations for that county. The arsenic concentrations were associated with data from SDWIS about the size and number of public water supply systems that use groundwater in each county. This information was then used to estimate the number and size of public-water supply systems that exceed different arsenic concentrations in the groundwater source. Targeted arsenic concentrations of 1, 2, 5, 10, 20, and 50 µg/L were exceeded in the ground-water resource associated with 36, 25, 14, 8, 3, and 1 percent of public water supply systems, respectively.

Community Water System Survey (CWSS): EPA conducted the 2000 CWSS to support development and evaluation of all drinking water regulations.[162] The survey collects information on systems including operating information such as ownership, population served, water production, water sources, existing treatment, storage, system distribution as well as contaminant concentrations (including arsenic) from water sampling. The survey also collects information on revenue, operating and capital expenses, rate structure, and number of employees. A sample of approximately 1,800 systems was selected from a list of approximately 53,000 community water systems in SDWIS. Questionnaires were sent to approximately 1,200 medium to large systems, while site visits were conducted on 600 smaller systems. A separate version of the questionnaire was sent to systems serving more than 500,000 people. Additional questions on contaminant concentrations in raw and finished water and well depth were requested from these large systems. In 2006, 1,314 systems responded to the survey and EPA published trends and key findings from the survey.

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[159] http://water.usgs.gov/nawqa/trace/arsenic/

[160] "A Retrospective Analysis on the Occurrence of Arsenic in Ground-Water Resources of the United States and Limitations in Drinking-Water-Supply Characterizations" http://pubs.usgs.gov/wri/wri994279/pdf/wri994279.pdf

[161] Sites that had water samples that were characterized as non-potable (high saline content or high temperature) were not included in the retrospective analysis.

[162] The 1995, 2000 and 2006 surveys are discussed at http://water.epa.gov/infrastructure/drinkingwater/pws/cwssvr.cfm.

National Contaminant Occurrence Database (NCOD): [163] The NCOD was developed by EPA to meet its obligation under the Safe Drinking Water Act (SDWA) to review all MCLs every six years and revise them as necessary. The first six-year review covered 1996-2002 and the second six-year review covered 2003-2009. Compliance monitoring data were voluntarily submitted by 47 state/primacy agencies (45 states plus Region 8 and 9 tribes) to support this process.[164] The NCOD data comprise more than 15 million analytical records from approximately 132,000 public water systems. Approximately 254 million people are served by these systems nationally. The dataset for the second six-year review includes the results of all compliance monitoring data (all sample analytical detections and non-detections) from January 1998 to December 2005 for 69 regulated contaminants, including arsenic.

The NCOD contains approximately 225,000 water samples tested for arsenic between 1998-2005. Each public water system in the database is identified by system type (CWS or NTNCWS), water source (ground or surface water), and by the population it serves. The arsenic contaminant information includes a sampling point identifier established by the state for each sampling location (e.g., source water quality or entry point to the distribution system), the date the sample was taken, whether arsenic levels were detected in the sample, and the actual arsenic level.

National Environmental Public Health Tracking Network (NEPHTN): [165] The NEPHTN was developed by the Centers for Disease Control as a way to integrate health, exposure, and environmental hazard data. Data on the level of arsenic contamination in community water systems are taken from state databases associated with the Safe Drinking Water Act while data on arsenic levels in domestic well water were obtained from the NWAQA program.

Arsenic data are available for sixteen states: California, Connecticut, Florida, Maine, Massachusetts, Minnesota, Missouri, New Hampshire, New Jersey, New York, Oregon, Pennsylvania, South Carolina, Utah, Washington, and Wisconsin. Data for CWS are generally available from 1999-2009 for most of these states while well water data are available for 2000 only. The data for CWSs can be obtained as a quarterly or yearly distribution of the number of CWSs by mean arsenic concentrations or as a quarterly or yearly distribution of number of people served by CWSs by mean arsenic concentrations. The data for domestic wells are self-supplied and are presented as the number of well samples grouped by arsenic concentration levels.

Potential Sources of Compliance Cost Data

Drinking Water Infrastructure Needs Survey and Assessment (DWINSA): [166] Every four years, starting in 1995, EPA surveys local water utilities to obtain information on the anticipated costs of projects to install, upgrade, and replace equipment to deliver safe drinking water. The purpose of the survey is to estimate the 20-year

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[163] http://water.epa.gov/scitech/datait/databases/drink/ncod/databases-index.cfm

[164] The states not included in the NCOD database are Pennsylvania, Mississippi, Louisiana, Kansas, Washington, and the District of Columbia.

[165] http://ephtracking.cdc.gov/showWaterLandingSolution.action

[166] http://water.epa.gov/infrastructure/drinkingwater/dwns/index.cfm

capital investment needs of public water systems to protect public health. The information is used to determine the amount of funding each state receives for its Drinking Water State Revolving Fund. In 2007, EPA mailed questionnaires to each of the 584 largest water systems (serving more than 100,000 people) and 2,266 medium systems (serving between 3,301 and 100,000 people). Approximately 97 percent of the large systems and 92 percent of the medium systems returned completed questionnaires. For small community water systems (serving fewer than 3,300 people), EPA contracted water system professionals to conduct in-person site visits to 600 small systems. Each project listed on the survey had to be accompanied by written documentation on the scope and necessity of the project, as well as the project cost. Acceptable documentation for cost estimates included master and capital improvement plans, preliminary engineering reports, facility plans, bid tabulations and engineering estimates not developed for the assessment. Systems providing cost estimates were encouraged to submit design parameters regarding size or capacity of the infrastructure. If a system could not provide acceptable cost documentation, EPA requested that the system provide the information needed for EPA to model the cost of the project (e.g., design parameters).

Community Water System Survey (CWSS): The CWSS, discussed in greater detail above, collects information on revenue, operating and capital expenses, rate structure, and number of employee for public water systems in 2000.

Cost Rate Data: There are several potential sources of drinking water rates for residential and other customers. Raftelis Financial Consultants have published a survey of drinking water rates biennially since 1986. Since 2004, this survey has been published jointly with the American Water Works Association (AWWA).[167] The most recent survey contains data on over 300 utilities serving 1000 to 9 million customers. Separately, Black and Veatch collect rate data for water and sewer services for residential, industrial and commercial customers. The data are published in their “50 Largest Cities Water/Wastewater Rate Survey” and they find that water and wastewater bills for residential use across the country have increased at a steady rate since 2001.[168]

ORD Demonstration Projects: In October 2001, EPA undertook a project to help small community water systems (<10,000 customers) research and develop cost-effective technologies to meet the new arsenic standard. As part of the Arsenic Rule Implementation Research Program, EPA’s Office of Research and Development (ORD) conducted three rounds of demonstration projects that conducted full-scale, onsite demonstrations of arsenic removal technology, process modifications and engineering approaches for small systems.

EPA program funds in addition to funding from Congress provided support for the three rounds of demonstration projects from 2005-2007. Treatment technologies were selected from solicited proposals. EPA conducted 50 arsenic removal demonstration projects in 26 states in the US. Treatment systems

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[167] In 1996 and 1999, AWWA published the results of their own survey including detailed financial and revenue data as part of their Water:\Stats series, but discontinued this publication after 1999.

[168] http://www.bv.com/Downloads/Resources/Brochures/rsrc_EMS_Top50RateSurvey.pdf

selected for the projects included 28 adsorptive media (AM) systems, 18 iron removal (IR) systems (including two systems using IR and iron addition (IA)) and coagulation/filtration (CF) systems (including four systems using IR pretreatment followed by AM), two ion exchange (IX) systems, and one of each of the following systems: reverse osmosis (RO), point-of-use (POU) RO, POU AM, and system/process modification. Of the 50 projects, 42 were community water systems (CWS) and eight were non-transient non-community water systems (NTNCWS). The report "Costs of Arsenic Removal Technologies for Small Water Systems: U.S. EPA Arsenic Removal Technology Demonstration Program" summarizes the cost data across all demonstration projects grouped by the type of technology. Total capital costs and operating and maintenance (O&M) costs are presented for each treatment system. Capital costs are broken down by equipment, site engineering, and installation costs. Factors affecting capital costs include system flow rate, construction material, media type and quantity, pre- and/or post-treatment requirements, and level of instruments and controls required. The O&M costs for each treatment system are broken down by media replacement, chemical use, electricity and labor.

Appendix 4.2: EPA Cost Curves For Compliance with MCLs for Arsenic in Drinking Water

The following tables present the assumptions and cost curves used by EPA to estimate the costs of treatment technologies. Equations were converted to 2006 dollars from 1998 dollars using the Engineering News Record Construction Cost Index (ENR CCI).

Modified Coagulation/Filtration:

EPA assumed that typical coagulation/filtration treatment plants remove 50 percent of the influent arsenic prior to enhancement, and that O&M (operation and maintenance) costs would only include power and materials and not additional labor. EPA used the following design assumptions to develop cost estimates for small and large drinking water systems:

- Small Systems (< 1 mgd): Additional ferric chloride dose, 10 mg/L; Additional feed system for increased ferric chloride dose; Additional lime dose, 10 mg/L for pH adjustment; and Additional feed system for increased lime dose.
- Large Systems (> 1 mgd): Additional ferric chloride dose, 10 mg/L; Additional feed system for increased ferric chloride dose; Additional lime dose, 10 mg/L for pH adjustment; and Additional feed system for increased lime dose.

Table A1 summarizes the capital and O&M cost equations that EPA used to estimate costs for modified/enhanced coagulation/filtration treatment.

Table A1 - Cost Equations for Modified Coagulation/Filtration (2006 dollars)		
Design Flow (x)	**Capital Cost (y) Equation**	**O&M Cost (z) Equation**
Less than 1 mgd	$y = -5095.4x^2 + 19626x + 9516.5$	$z = -402.68v^2 + 9722v + 294.09$
Between 1 mgd and 10 mgd	$y = 125208x - 101161$	$z = 23282v - 4639.8$
Greater than 10 mgd	$y = -8.9397x^2 + 8634.2x + 1065469$	$z = -0.5291v^2 + 19913v + 10531.3$
Source: U.S. EPA (2000) mgd = million gallons per day; x = design flow; v = average flow; y = capital cost; z = O&M cost		

Coagulation Assisted Microfiltration:

EPA used the following design assumptions to develop cost estimates for small and large drinking water systems:

- Very Small Systems (< 0.10 mgd): Coagulant dosage, ferric chloride, 25 mg/L; No polymer addition; Filtration rate, 2.5 gpm/ft2; and Sodium hydroxide dose, 20 mg/L
- Small Systems (< 1 mgd): Package plant for all small systems; filtration rate 5 gpm/ft2; Ferric chloride dose, 25 mg/L; Sodium hydroxide dose, 20 mg/L; and Standard microfilter specifications, provided by vendors.
- Large Systems (> 1 mgd): Ferric chloride dose, 25 mg/L; Rapid mix, 1 minute; Flocculation, 20 minutes; Sedimentation, 1000 gpd/ft2 in rectangular basins; and Standard microfilter specifications, provided by vendors.

Table A2 summarizes the capital and O&M cost equations EPA used to estimate costs for coagulation assisted microfiltration treatment.

Table A2 - Cost Equations for Coagulation Assisted Microfiltration (2006 dollars)	
Design Flow (x)	**Cost Equation**
Capital Costs (y)	
Less than 0.10 mgd	$y = -15898039x^2 + 6500208x + 125640$
Between 0.10 mgd and 0.25 mgd	$y = 3121141x + 304566$
Between 0.25 mgd and 1 mgd	$y = -644143x^2 + 3075576x + 363826$
Between 1 mgd and 10 mgd	$y = 1373039x + 1422220$
Greater than 10 mgd	$y = 426x^2 + 1227399x + 2835987$
O&M Costs (z)	
Less than 0.03 mgd	$z = 262176v + 26992$
Between 0.03 mgd and 0.09 mgd	$z = 181594v + 29489$
Between 0.09 mgd and 0.35 mgd	$z = 106668v + 35933$
Between 0.35 mgd and 4.25 mgd	$z = 17730v + 67951$
Greater than 4.25 mgd	$z = 20294v + 56410$
Source: U.S. EPA (2000) mgd = million gallons per day; x = design flow; v = average flow; y = capital cost; z = O&M cost	

Modified Lime Softening

EPA assumed that typical lime softening treatment plants remove 50 percent of the influent arsenic prior to enhancement, and that O&M costs would only include power and materials, not additional labor. EPA used the following design assumptions to develop cost estimates for small and large drinking water systems:

- Additional lime dose, 50 mg/L;
- Chemical feed system for increased lime dose;
- Additional carbon dioxide (liquid), 35 mg/L for recarbonation; and
- Chemical feed system for increased carbon dioxide dose.

Table A3 summarizes the capital and O&M cost equations EPA used to estimate costs for modified/enhanced lime softening treatment.

Table A3 - Cost Equations for Modified Lime Softening (2006 dollars)	
Design Flow (x)	**Cost Equation**
Capital Costs (y)	
Less than 1 mgd	$y = -30601x^2 + 64217x + 10519.7$
Between 1 mgd and 10 mgd	$y = 177803x - 133668$
Greater than 10 mgd	$y = -10.042x^2 + 35445x + 1290926$
O&M Costs (z)	
Less than 0.35 mgd	$z = 2986.7v^2 + 40659v + 425.80$
Between 0.35 mgd and 3.5 mgd	$z = 38821v + 1457.6$
Greater than 3.5 mgd	$z = -0.6031v^2 + 34721v + 19921$
Source: U.S. EPA (2000)	
mgd = million gallons per day; x = design flow; v = average flow; y = capital cost; z = O&M cost	

Activated Alumina

EPA's design assumptions for activated alumina vary based on whether pH adjustment is necessary. For natural pH (i.e., no pH adjustment), EPA made the following assumptions:

- pH will not need to be adjusted after the activated alumina process;
- Empty Bed Contact Time (EBCT) is 5 minutes per column;
- The density of the activated alumina media is assumed to be 47 lb/ft3;
- The bed depth ranged from 3 to 6 feet, depending on the design flow;
- The maximum diameter per column is 12 feet;
- 50 percent bed expansion during backwash even though backwashing may not be necessary on a routine basis for smaller systems;
- Redundant column necessary to allow the system to operate while the media is being replaced in the old roughing column.

For systems with pH adjustment, EPA used the same assumptions except included cost to adjust pH to the optimal pH of 6. Table A4 summarizes the capital and O&M cost equations EPA used to estimate costs for activated alumina treatment.

Table A4 - Cost Equations for Activated Alumina (2006 dollars)	
Design Flow (x) and Design Parameters	**Cost Equation**
Capital Costs (y)	
Less than 0.10 mgd; natural pH	y = 686392x + 13605
Greater than 0.10 mgd; natural pH	y = 559821x + 13602
Less than 0.10 mgd; pH adjusted to 6.0	y = 740360x + 56081
Greater than 0.10 mgd; pH adjusted to 6.0	y = 613790x + 56079
O&M Costs (z)	
Less than 0.35 mgd; natural pH 7.0 – 8.0	z = 251601v + 5491.4
Greater than 0.35 mgd; natural pH 7.0 – 8.0	z = 254047v + 13051.2
Less than 0.35 mgd; natural pH 8.0 – 8.3	z = 479114v + 5809.6
Greater than 0.35 mgd; natural pH 8.0 – 8.3	z = 485379v + 20999
Less than 0.35 mgd; pH adjusted to 6.0; 23,100 BVs	z = 220201v + 7718.1
Greater than 0.35 mgd; pH adjusted to 6.0; 23,100 BVs	z = 220298v + 15574
Less than 0.35 mgd; pH adjusted to 6.0; 15,400 BVs	z = 273550v + 8425.8
Greater than 0.35 mgd; pH adjusted to 6.0; 15,400 BVs	z = 274543v + 17439
Source: U.S. EPA (2000) BVs = bed volumes; mgd = million gallons per day; x = design flow; v= average flow; y = capital cost; z = O&M cost	

Ion Exchange

EPA made the following assumptions to estimate costs for ion exchange:

- Empty Bed Contact Time (EBCT) = 2.5 minutes per column
- Bed depth ranged from 3 feet to 6 feet depending on the design flow
- Maximum diameter per column is 12 feet
- Vessel cost has been sized based on 50% bed expansion during backwash
- Capital costs include a redundant column to allow the system to operate while the media is being regenerated in the other column
- The run length when sulfate is at or below 20 mg/L is 1,500 bed volumes (BV); the run length when sulfate is between 20 and 50 mg/L sulfate is 700 BV
- Salt dose for regeneration was 10.2 lb/ft3.
- Incremental labor for the anion exchange is one hour per week plus three hours per regeneration.

Table A5 summarizes the capital and O&M cost equations EPA used to estimate costs for ion exchange treatment.

Table A5: Cost Equations for Ion Exchange (2006 dollars)	
Design Flow (x) and Design Parameters	**Cost Equation**
Capital Costs (y)	
Less than 0.10 mgd; less than 20 mg/L SO_4	y = 458982x + 26035
Greater than 0.10 mgd; less than 20 mg/L SO_4	$y = -8363.2x^2 + 425133x + 48962$
Less than 0.10 mgd; 20 mg/L – 50 mg/L SO_4	y = 605021x + 26035
Greater than 0.10 mgd; 20 mg/L – 50 mg/L SO_4	$y = -12995.1x^2 + 497964x + 97662$
O&M Costs (z)	
Less than 0.35 mgd; less than 20 mg/L SO_4	$z = -90359v^2 + 103289v + 6656.5$
Greater than 0.35 mgd; less than 20 mg/L SO_4	$z = -2258.4v^2 + 49750v + 22021$
Less than 0.35 mgd; 20 mg/L – 50 mg/L SO_4	$z = -110306v^2 + 126338v + 11255.3$
Greater than 0.35 mgd; 20 mg/L – 50 mg/L SO_4	$z = -2455v^2 + 64294v + 32786$
Source: U.S. EPA (2000) mgd = million gallons per day; x = design flow; v = average flow; y = capital cost; z = O&M cost	

Greensand Filtration

EPA used the following design assumptions to develop cost estimates for greensand filtration:

- Potassium permanganate feed, 10 mg/L;
- The filter medium is contained in a ferrosand continuous regeneration filter tank equipped with an underdrain;
- Filtration rate, 4 gpm/ft2;
- Backwash is sufficient for 40 percent bed expansion; and
- Corrosion control measures are not required because pH is not affected by the process.

EPA used the VSS model to estimate capital and O&M costs because greensand filtration costs are not included in either the Water Model or the W/W Model. Thus, while this technology could be effectively operated in larger size systems, the cost equations below may not provide representative costs for large systems.

$$\text{Capital Costs} = 782662x^{0.838}$$

$$\text{O\&M Costs} = 0.0012x^2 + 78483x + 9847.3$$

Point of Use Reverse Osmosis

EPA estimated costs for reverse osmosis (RO) and activated alumina point-of-use (POU) technologies. EPA used "Cost Evaluation of Small System Compliance Options - Point-of Use and Point-of-Entry Treatment Units" (Cadmus Group, 1998) to estimate treatment costs. EPA developed cost curves based on the following assumptions:

- Average household consists of 3 individuals using 1 gallon each per day (1,095 gallons per year)
- Life of unit is 5 years
- Duration of cost study is 10 years (or 2 POU devices per household)
- Cost of water meter and automatic shut-off valve included.

- No shipping and handling costs required.
- Volume discount schedule: retail for single unit, 10 percent discount for 10 or more units, 15 percent discount on more than 100 units.
- Installation time - 1 hour unskilled labor (POU)
- O&M costs include maintenance, replacement of pre-filters and membrane cartridges, laboratory sampling and analysis, and administrative costs.

The capital and O&M cost equations for POU RO are as follows, with x equal to design flow and v equal to average flow.

$$\text{Capital} = 1151.73x^{0.9261}$$

$$\text{O\&M} = 89.14v^{0.9439}$$

The capital and O&M cost equations for POU activated alumina are as follows, with x equal to design flow and v equal to average flow.

$$\text{Capital} = 395.46x^{0.9257}$$

$$\text{O\&M} = 549.6v^{0.9376}$$

Appendix 4.3: Document sent to Compliance Assistance Engineering Firms

EPA's Arsenic Drinking Water Rule

The purpose of this questionnaire is to collect information and feedback from industry experts on the U.S. Environmental Protection Agency's analysis of compliance costs for the arsenic drinking water rule as undertaken for rule development in 2001. The goal of this project is to assess EPA's analysis and estimates of compliance costs at the time of rule promulgation. We also want to determine whether EPA accurately identified all the process technologies that were available to reduce arsenic levels.

This questionnaire summarizes the assumptions and cost estimation frameworks used by EPA to estimate the costs of treatment technologies that the Agency identified as candidates for compliance with the arsenic rule. We want to assess whether the actual costs of arsenic treatment differed substantially from EPA's estimates at the time of rule development. In addition, we hope to understand the reasons for potential differences in these estimates, including insight into whether new or modified treatment technologies may have been implemented to meet the arsenic standard, which EPA did not account for in its cost analysis.

Section 1. Regulatory Background

On January 22, 2001, EPA published a new national primary drinking water regulation for arsenic (Arsenic Rule), which lowered the maximum contaminant level (MCL) 50 µg/L to 10 µg/L. EPA estimated that the rule would apply to 54,000 community water systems (CWSs) and 20,000 non-transient non-community water systems (NTNCWSs) that serve non-residential communities (e.g. schools, churches). The rule gave water systems until January 23, 2006 to comply with the revised arsenic MCL. EPA had estimated that approximately 3,000 CWSs and 1,100 NTNCWSs would need to reduce arsenic levels in their drinking water for compliance with the 10 µg/L standard.

Section 2. Arsenic Treatment Technologies and Costs

EPA identified the following technologies that would effectively remove arsenic and bring a water system into compliance:

- Modified Coagulation/Filtration;
- Coagulation Assisted Microfiltration;
- Modified Lime Softening;
- Activated Alumina (with and without pH adjustment);
- Ion Exchange (groundwater only);
- Greensand Filtration (groundwater only); and
- Point-of-Use Reverse Osmosis (for small groundwater systems only).

EPA used three models to develop costs for these treatment technologies (except activated alumina and ion exchange): Very Small Systems Best Available Technology Cost Document (VSS model; Malcolm

Pirnie, 1993); the Water Model (Culp/Wesner/Culp, 1984); and the W/W Cost Model (Culp/Wesner/Culp, 1994).

All equations for both capital and O&M costs, as well as all monetary figures are presented in 2006 dollars. Equations and monetary figures were converted to 2006 dollars from 1998 dollars using the Engineering News Record Construction Cost Index (ENR CCI).

Q1a: Have treatment technologies changed since the rule was promulgated? For example, have additional or substantially modified treatment technologies or compliance approaches been used to achieve compliance? If so, please explain how.

A1a: >>

Q1b: Based on your professional knowledge and experience, are the treatment technologies that EPA proposed for groundwater and surface water systems for compliance representative of the actual treatment technologies employed for compliance with the Arsenic Rule?

A1b: >>

Q1c: Based on your professional knowledge and experience, please estimate the frequency with which these technology options have been used for compliance? To the extent possible, please identify the principal factors underlying the selection of a particular treatment technology/compliance approach by different categories of drinking water system – e.g., groundwater vs. surface water, small vs. large system.

A1c: >>

2.1 Modified Coagulation/Filtration

EPA assumed that typical coagulation/filtration treatment plants remove 50 percent of the influent arsenic prior to enhancement, and that O&M (operation and maintenance) costs would only include power and materials and not additional labor. EPA used the following design assumptions to develop cost estimates for small and large drinking water systems:

- Small Systems (< 1 mgd): Additional ferric chloride dose, 10 mg/L; Additional feed system for increased ferric chloride dose; Additional lime dose, 10 mg/L for pH adjustment; and Additional feed system for increased lime dose.

- Large Systems (> 1 mgd): Additional ferric chloride dose, 10 mg/L; Additional feed system for increased ferric chloride dose; Additional lime dose, 10 mg/L for pH adjustment; and Additional feed system for increased lime dose.

Table a summarizes the capital and O&M cost equations that EPA used to estimate costs for modified/enhanced coagulation/filtration treatment.

Table 1a - Cost Equations for Modified Coagulation/Filtration (2006 dollars)		
Design Flow (x)	**Capital Cost (y) Equation**	**O&M Cost (z) Equation**
Less than 1 mgd	$y = -5095.4x^2 + 19626x + 9516.5$	$z = -402.68x^2 + 9722x + 294.09$
Between 1 mgd and 10 mgd	$y = 125208x - 101161$	$z = 23282x - 4639.8$
Greater than 10 mgd	$y = -8.9397x^2 + 8634.2x + 1065469$	$z = -0.5291x^2 + 19913x + 10531.3$
Source: U.S. EPA (2000) mgd = million gallons per day; x = design flow; y = capital cost; z = O&M cost		

Table 1b provides capital costs and O&M costs for different design flow thresholds:

Table 1b - Modified Coagulation/Filtration Treatment Costs (2006 dollars)		
Design Flow (mgd)	**Capital Cost ($)**	**O&M Cost ($)**
0.01	$9,700	$400
0.1	$11,400	$1,300
1	$24,000	$18,600
10	$1,150,900	$228,200
50	$1,474,800	$1,004,900
Notes: Costs are derived from equations found in U.S. EPA (2000), mgd = million gallons per day All costs are rounded to the nearest hundred dollars		

Q2.1a: Please comment on the estimated costs and assumptions EPA used to estimate the costs for modified coagulation/filtration.

A2.1a: >>

Q2.1b: Have capital and O&M costs for this technology changed significantly from the time facilities complied with the arsenic rule (i.e., since 2006)? If so, what are the principal reasons for these changes? To the extent possible, please indicate the approximate amount of difference from EPA's estimates.

A2.1b: >>

2.2 Coagulation Assisted Microfiltration

EPA used the following design assumptions to develop cost estimates for small and large drinking water systems:

- Very Small Systems (< 0.10 mgd): Coagulant dosage, ferric chloride, 25 mg/L; No polymer addition; Filtration rate, 2.5 gpm/ft2; and Sodium hydroxide dose, 20 mg/L
- Small Systems (< 1 mgd): Package plant for all small systems; filtration rate 5 gpm/ft2; Ferric chloride dose, 25 mg/L; Sodium hydroxide dose, 20 mg/L; and Standard microfilter specifications, provided by vendors.
- Large Systems (> 1 mgd): Ferric chloride dose, 25 mg/L; Rapid mix, 1 minute; Flocculation, 20 minutes; Sedimentation, 1000 gpd/ft2 in rectangular basins; and Standard microfilter specifications, provided by vendors.

Table a summarizes the capital and O&M cost equations EPA used to estimate costs for coagulation assisted microfiltration treatment.

Table 2a - Cost Equations for Coagulation Assisted Microfiltration (2006 dollars)	
Design Flow (x)	**Cost Equation**
Capital Costs (y)	
Less than 0.10 mgd	$y = -15898039x^2 + 6500208x + 125640$
Between 0.10 mgd and 0.25 mgd	$y = 3121141x + 304566$
Between 0.25 mgd and 1 mgd	$y = -644143x^2 + 3075576x + 363826$
Between 1 mgd and 10 mgd	$y = 1373039x + 1422220$
Greater than 10 mgd	$y = 426x^2 + 1227399x + 2835987$
O&M Costs (z)	
Less than 0.03 mgd	$z = 262176x + 26992$
Between 0.03 mgd and 0.09 mgd	$z = 181594x + 29489$
Between 0.09 mgd and 0.35 mgd	$z = 106668x + 35933$
Between 0.35 mgd and 4.25 mgd	$z = 17730x + 67951$
Greater than 4.25 mgd	$z = 20294x + 56410$
Source: U.S. EPA (2000) mgd = million gallons per day; x = design flow; y = capital cost; z = O&M cost	

Table 2b provides capital costs and O&M costs for different design flow thresholds.

Table 2b - Coagulation Assisted Microfiltration Treatment Costs (2006 dollars)		
Design Flow (mgd)	**Capital Cost ($)**	**O&M Cost ($)**
0.01	$189,100	$29,600
0.1	$616,700	$142,600
1	$2,795,300	$85,700
10	$15,152,600	$259,400
50	$65,271,600	$1,071,100
Notes: Costs are derived from equations found in U.S. EPA (2000), mgd = million gallons per day All costs are rounded to the nearest hundred dollars		

Q2.2a: Please comment on the estimated costs and assumptions EPA used to estimate the costs for coagulation assisted microfiltration.

A2.2a: >>

Q2.2b: Have capital and O&M costs for this technology changed significantly from the time facilities complied with the arsenic rule (i.e., since 2006)? If so, what are the principal reasons for these changes? To the extent possible, please indicate the approximate amount of difference from EPA's estimates

A2.2b: >>

EPA also estimated waste disposal costs, which included mechanical and non-mechanical dewatering with nonhazardous landfill disposal. Table2c summarizes the capital and O&M cost equations that EPA used to estimate costs for coagulation-assisted microfiltration treatment for waste disposal.

Table 3c: Cost Equations for Coagulation Assisted Microfiltration Waste Disposal (2006 dollars)

Design Flow (x)	Cost Equation
Capital Costs (y)	
Less than 0.25 mgd; Mechanical Dewatering	$y = -922800x^2 + 606498x + 35628$
Between 0.25 mgd and 1.75 mgd; Mechanical Dewatering	$y = 281887x + 56001$
Greater than 1.75 mgd; Mechanical Dewatering	$y = -2189.9x^2 + 200335x + 209890$
Less than 0.085 mgd; Non-mechanical Dewatering	$y = 4088388x - 1052$
Between 0.085 mgd and 1.75 mgd; Non-mechanical Dewatering	$y = 2330137x + 143879$
Greater than 1.75 mgd; Non-mechanical Dewatering	$y = 2168456x + 434903$
O&M Costs (z)	
Less than 0.085 mgd; Mechanical Dewatering	$z = -4631178x^2 + 912204x + 7778$
Between 0.085 mgd and 1.75 mgd; Mechanical Dewatering	$z = 33520x + 49094$
Greater than 1.75 mgd; Mechanical Dewatering	$z = 106668x + 35933$
Less than 0.085 mgd; Non-mechanical Dewatering	$z = 25058x^2 + 6242x + 2829$
Between 0.085 mgd and 0.70 mgd; Non-mechanical Dewatering	$z = 148943x - 9257$
Greater than 0.70 mgd; Non-mechanical Dewatering	$z = 22.599x^2 + 80975x + 38308$
Source: U.S. EPA (2000) mgd = million gallons per day, x = design flow, y = capital cost, z = O&M cost	

Table 2d provides capital costs and O&M costs for different design flow thresholds

Table 2d - Coagulation Assisted Microfiltration Waste Disposal Treatment Costs (2006 dollars)		
Design Flow (mgd)	**Capital Cost ($)**	**O&M Cost ($)**
Mechanical Dewatering		
0.01	$41,600	$16,400
0.1	$87,100	$52,400
1	$337,900	$82,600
10	$1,994,300	$1,102,600
50	$4,751,800	$5,369,300
Non-Mechanical Dewatering		
0.01	$39,800	$2,900
0.1	$376,900	$5,600
1	$2,474,000	$119,300
10	$22,119,500	$850,300
50	$108,857,700	$4,143,600
Notes: Costs are derived from equations found in U.S. EPA (2000), mgd = million gallons per day All costs are rounded to the nearest hundred dollars		

Q2.2c: Please comment on the estimated costs and assumptions EPA used to estimate the costs for coagulation assisted microfiltration waste disposal treatments.

A2.2c: >>

Q2.2d: Have capital and O&M costs for this technology changed significantly from the time facilities complied with the arsenic rule (i.e., since 2006)? If so, what are the principal reasons for these changes? To the extent possible, please indicate the approximate amount of difference from EPA's estimates.

A2.2d: >>

2.3. Modified Lime Softening

EPA assumed that typical lime softening treatment plants remove 50 percent of the influent arsenic prior to enhancement, and that O&M costs would only include power and materials, not additional labor. EPA used the following design assumptions to develop cost estimates for small and large drinking water systems:

- Additional lime dose, 50 mg/L;
- Chemical feed system for increased lime dose;
- Additional carbon dioxide (liquid), 35 mg/L for recarbonation; and
- Chemical feed system for increased carbon dioxide dose.

Table a summarizes the capital and O&M cost equations EPA used to estimate costs for modified/enhanced lime softening treatment.

Table 4a - Cost Equations for Modified Lime Softening (2006 dollars)	
Design Flow (x)	**Cost Equation**
Capital Costs (y)	
Less than 1 mgd	$y = -30601x^2 + 64217x + 10519.7$
Between 1 mgd and 10 mgd	$y = 177803x - 133668$
Greater than 10 mgd	$y = -10.042x^2 + 35445x + 1290926$
O&M Costs (z)	
Less than 0.35 mgd	$z = 2986.7x^2 + 40659x + 425.80$
Between 0.35 mgd and 3.5 mgd	$z = 38821x + 1457.6$
Greater than 3.5 mgd	$z = -0.6031x^2 + 34721x + 19921$
Source: U.S. EPA (2000) mgd = million gallons per day; x = design flow; y = capital cost; z = O&M cost	

Table 3b provides capital costs and O&M costs for different design flow thresholds

Table 3b - Modified Lime Softening Treatment Costs (2006 dollars)		
Design Flow (mgd)	**Capital Cost ($)**	**O&M Cost ($)**
0.01	$11,200	$800
0.1	$16,600	$4,500
1	$44,100	$40,300
10	$1,644,400	$367,100
50	$3,038,000	$1,754,500
Notes: Costs are derived from equations found in U.S. EPA (2000); mgd = million gallons per day All costs are rounded to the nearest hundred dollars		

Q2.3a: Please comment on the estimated costs and assumptions EPA used to estimate the costs for modified lime softening.

A2.3a: >>

Q2.3b: Have capital and O&M costs for this technology changed significantly from the time facilities complied with the arsenic rule (i.e., since 2006)? If so, what are the principal reasons for these changes? To the extent possible, please indicate the approximate amount of difference from EPA's estimates.

A2.3b: >>

2.4 Activated Alumina

EPA's design assumptions vary based on whether pH adjustment is necessary. For natural pH (i.e., no pH adjustment), EPA made the following assumptions:

- pH will not need to be adjusted after the activated alumina process;

- Empty Bed Contact Time (EBCT) is 5 minutes per column;
- The density of the activated alumina media is assumed to be 47 lb/ft3;
- The bed depth ranged from 3 to 6 feet, depending on the design flow;
- The maximum diameter per column is 12 feet;
- 50 percent bed expansion during backwash even though backwashing may not be necessary on a routine basis for smaller systems;
- Redundant column necessary to allow the system to operate while the media is being replaced in the old roughing column.

For systems with pH adjustment, EPA used the same assumptions except included cost to adjust pH to the optimal pH of 6. Table a summarizes the capital and O&M cost equations EPA used to estimate costs for activated alumina treatment.

Table 5a - Cost Equations for Activated Alumina (2006 dollars)	
Design Flow (x) and Design Parameters	**Cost Equation**
Capital Costs (y)	
Less than 0.10 mgd; natural pH	y = 686392x + 13605
Greater than 0.10 mgd; natural pH	y = 559821x + 13602
Less than 0.10 mgd; pH adjusted to 6.0	y = 740360x + 56081
Greater than 0.10 mgd; pH adjusted to 6.0	y = 613790x + 56079
O&M Costs (z)	
Less than 0.35 mgd; natural pH 7.0 – 8.0	z = 251601x + 5491.4
Greater than 0.35 mgd; natural pH 7.0 – 8.0	z = 254047x + 13051.2
Less than 0.35 mgd; natural pH 8.0 – 8.3	z = 479114x + 5809.6
Greater than 0.35 mgd; natural pH 8.0 – 8.3	z = 485379x + 20999
Less than 0.35 mgd; pH adjusted to 6.0; 23,100 BVs	z = 220201x + 7718.1
Greater than 0.35 mgd; pH adjusted to 6.0; 23,100 BVs	z = 220298x + 15574
Less than 0.35 mgd; pH adjusted to 6.0; 15,400 BVs	z = 273550x + 8425.8
Greater than 0.35 mgd; pH adjusted to 6.0; 15,400 BVs	z = 274543x + 17439
Source: U.S. EPA (2000) BVs = bed volumes; mgd = million gallons per day; x = design flow; y = capital cost; z = O&M cost	

Table 4b provides capital costs and O&M costs for different design flow thresholds

Table 4b - Activated Alumina Treatment Costs (2006 dollars)	
Design Flow (mgd)	**Capital Cost ($)**
Natural pH	
0.01	$20,500
0.1	$82,200
1	$573,400
10	$5,611,800
50	$28,004,600
pH Adjusted to 6.0	
0.01	$63,500
0.1	$130,100
1	$669,900
10	$6,194,000
50	$30,745,600
Design Flow (mgd)	**O&M Cost ($)**
Natural pH 7.0 – 8.0	
0.01	$8,000
0.1	$30,700
1	$267,100
10	$2,553,500
50	$12,715,400
Natural pH 8.0 – 8.3	
0.01	$13,300
0.1	$56,400
1	$506,400
10	$4,874,800
50	$24,290,000
pH adjusted to 6.0; 23,100 BVs	
0.01	$9,900
0.1	$29,700
1	$235,900
10	$2,218,600
50	$11,030,500
pH adjusted to 6.0; 15; 400 BVs	
0.01	$11,200
0.1	$35,800
1	$292,000
10	$2,762,900
50	$13,744,600
Notes: Costs are derived from equations found in U.S. EPA (2000) All costs are rounded to the nearest hundred dollars mgd = million gallons per day	

Q2.4a: Please comment on the estimated costs and assumptions EPA used to estimate the costs for activated alumina treatment.

A2.4a: >>

Q2.4b: Have capital and O&M costs for this technology changed significantly from the time facilities complied with the arsenic rule (i.e., since 2006)? If so, what are the principal reasons for these changes? To the extent possible, please indicate the approximate amount of difference from EPA's estimates.

A2.4b: >>

EPA also estimated costs for waste disposal which included nonhazardous landfill disposal (for systems operating without regeneration). EPA assumed zero capital cost for nonhazardous landfill disposal. O&M cost vary based on pH and BVs as shown in the following equations.

- Natural pH between 7.0 and 8.0: O&M cost = 10081x
- Natural pH between 8.0 and 8.3: O&M cost = 19387x
- pH adjusted to 6.0; 23,100 BVs: O&M cost = 4364x
- pH adjusted to 6.0; 15,400 BVs: O&M cost = 6547x

Note that the resulting cost estimates from the following equations will be in 2006 U.S. dollars.

Table 4c provides O&M costs for different design flow thresholds for activated alumina waste disposal treatment including nonhazardous landfill.

Table 4c - Activated Alumina Waste Disposal Treatment Costs Including Nonhazardous Landfill (2006 dollars)		
Design Flow (mgd)	**Capital Cost ($)**	**O&M Cost ($)**
	Natural pH between 7.0 and 8.0	
0.01	$0	$100
0.1	$0	$1,000
1	$0	$10,100
10	$0	$100,800
50	$0	$504,000
	Natural pH between 8.0 and 8.3	
0.01	$0	$200
0.1	$0	$1,900
1	$0	$19,400
10	$0	$193,900
50	$0	$969,400
	pH adjusted to 6.0; 23,100 BVs	
0.01	$0	$0
0.1	$0	$400
1	$0	$4,400
10	$0	$43,600
50	$0	$218,200
	pH adjusted to 6.0; 15,400 BVs	

0.01	$0	$100
0.1	$0	$700
1	$0	$6,500
10	$0	$65,500
50	$0	$327,300
Notes: Costs are derived from equations found in U.S. EPA (2000) All costs are rounded to the nearest hundred dollars mgd = million gallons per day		

Q2.4c: Please comment on the estimated costs and assumptions EPA used to estimate the costs for activated alumina waste disposal treatment including nonhazardous landfill.

A2.4c: >>

Q2.4d: Have capital and O&M costs for this technology changed significantly from the time facilities complied with the arsenic rule (i.e., since 2006)? If so, what are the principal reasons for these changes? To the extent possible, please indicate the approximate amount of difference from EPA's estimates.

A2.4d:>>

2.5 Ion Exchange

EPA made the following assumptions to estimate costs for ion exchange:

- Empty Bed Contact Time (EBCT) = 2.5 minutes per column
- Bed depth ranged from 3 feet to 6 feet depending on the design flow
- Maximum diameter per column is 12 feet
- Vessel cost has been sized based on 50% bed expansion during backwash
- Capital costs include a redundant column to allow the system to operate while the media is being regenerated in the other column
- The run length when sulfate is at or below 20 mg/L is 1,500 bed volumes (BV); the run length when sulfate is between 20 and 50 mg/L sulfate is 700 BV
- Salt dose for regeneration was 10.2 lb/ft3.
- Incremental labor for the anion exchange is one hour per week plus three hours per regeneration.

Table a summarizes the capital and O&M cost equations EPA used to estimate costs for ion exchange treatment.

Table 6a: Cost Equations for Ion Exchange (2006 dollars)	
Design Flow (x) and Design Parameters	**Cost Equation**
Capital Costs (y)	
Less than 0.10 mgd; less than 20 mg/L SO_4	y = 458982x + 26035
Greater than 0.10 mgd; less than 20 mg/L SO_4	y = -8363.2x^2 + 425133x + 48962
Less than 0.10 mgd; 20 mg/L – 50 mg/L SO_4	y = 605021x + 26035
Greater than 0.10 mgd; 20 mg/L – 50 mg/L SO_4	y = -12995.1x^2 + 497964x + 97662
O&M Costs (z)	
Less than 0.35 mgd; less than 20 mg/L SO_4	z = -90359x^2 + 103289x + 6656.5
Greater than 0.35 mgd; less than 20 mg/L SO_4	z = -2258.4x^2 + 49750x + 22021
Less than 0.35 mgd; 20 mg/L – 50 mg/L SO_4	z = -110306x^2 + 126338x + 11255.3
Greater than 0.35 mgd; 20 mg/L – 50 mg/L SO_4	z = -2455x^2 + 64294x + 32786
Source: U.S. EPA (2000) mgd = million gallons per day; x = design flow; y = capital cost; z = O&M cost	

Table 5b provides O&M costs for different design flow thresholds

Table 5b - Ion Exchange Treatment Costs (2006 dollars)		
Design Flow (mgd)	**Capital Cost ($)**	**O&M Cost ($)**
Less than 20 mg/L SO_4		
0.01	$30,600	$7,700
0.1	$71,900	$16,100
1	$465,700	$69,500
10	$3,464,000	$293,700
50	$397,500	-$3,136,500
20 mg/L $S0_4$ – 50 mg/L $S0_4$		
0.01	$32,100	$12,500
0.1	$86,500	$22,800
1	$582,600	$94,600
10	$3,777,800	$430,200
50	-$7,491,900	-$2,890,000
Notes: Costs are derived from equations found in U.S. EPA (2000); mgd = million gallons per day All costs are rounded to the nearest hundred dollars		

Q2.5a: Please comment on the estimated costs and assumptions EPA used to estimate the costs for ion exchange treatment.

A2.5a: >>

Q2.5b: Have capital and O&M costs for this technology changed significantly from the time facilities complied with the arsenic rule (i.e., since 2006)? If so, what are the principal reasons for these changes? To the extent possible, please indicate the approximate amount of difference from EPA's estimates.

A2.5b: >>

EPA also estimated waste disposal costs which included discharge to a wastewater treatment plant for treatment. Table 5c summarizes the capital and O&M cost equations EPA used to estimate costs for ion exchange treatment.

Table 5c: Cost Equations for Ion Exchange Waste Disposal (2006 dollars)	
Design Flow (x) and Design Parameters	**Cost Equation**
Capital Costs (y)	
Less than 0.85 mgd; less than 20 mg/L SO_4	y = 5268
Between 0.85 mgd and 25 mgd; less than 20 mg/L SO_4	y = 6773
Greater than 25 mgd; less than 20 mg/L SO_4	y = 28.6x + 6924
Less than 0.85 mgd; 20 mg/L – 50 mg/L SO_4	y = 5268
Between 0.85 mgd and 2.5 mgd; 20 mg/L – 50 mg/L SO_4	y = 6773
Greater than 2.5 mgd; 20 mg/L – 50 mg/L SO_4	y = 28.6x + 6924
O&M Costs (z)	
All flows; less than 20 mg/L SO_4	z = 4567x + 500
All flows; 20 mg/L – 50 mg/L SO_4	z = 9788x
Source: U.S. EPA (2000) mgd = million gallons per day; x = design flow; y = capital cost; z = O&M cost	

Table 5d provides capital and O&M costs for different design flow thresholds

Table 5d - Ion Exchange Waste Disposal Treatment Costs (2006 dollars)		
Design Flow (mgd)	**Capital Cost ($)**	**O&M Cost ($)**
Less than 20 mg/L SO_4		
0.01	$5,300	$500
0.1	$5,300	$1,000
1	$6,800	$5,100
10	$6,800	$46,200
50	$8,400	$228,900
20 mg/L $S0_4$ – 50 mg/L $S0_4$		
0.01	$5,300	$100
0.1	$5,300	$1,000
1	$6,800	$9,800
10	$7,200	$97,900
50	$8,400	$489,400
Notes: Costs are derived from equations found in U.S. EPA (2000) All costs are rounded to the nearest hundred dollars mgd = million gallons per day		

Q2.5c: Please comment on the estimated costs and assumptions EPA used to estimate the costs for ion exchange waste disposal treatment.

A2.5c: >>

Q2.5d: Have capital and O&M costs for this technology changed significantly from the time facilities complied with the arsenic rule (i.e., since 2006)? If so, what are the principal reasons for these changes? To the extent possible, please indicate the approximate amount of difference from EPA's estimates.

A2.5d: >>

2.6 Greensand Filtration

EPA used the following design assumptions to develop cost estimates for greensand filtration:

- Potassium permanganate feed, 10 mg/L;
- The filter medium is contained in a ferrosand continuous regeneration filter tank equipped with an underdrain;
- Filtration rate, 4 gpm/ft2;
- Backwash is sufficient for 40 percent bed expansion; and
- Corrosion control measures are not required because pH is not affected by the process.

EPA used the VSS model to estimate capital and O&M costs because greensand filtration costs are not included in either the Water Model or the W/W Model. Thus, while this technology could be effectively operated in larger size systems, the cost equations below may not provide representative costs for large systems.

$$\text{Capital Costs} = 782662x^{0.838}$$

$$\text{O\&M Costs} = 0.0012x^{2} + 78483x + 9847.3$$

Table 6a shows the capital and O&M costs for greensand filtration treatment.

Table 6a - Greensand Filtration Treatment Costs (2006 dollars)		
Design Flow (mgd)	**Capital Cost ($)**	**O&M Cost ($)**
0.01	$16,500	$10,600
0.1	$113,700	$17,700
1	$782,700	$88,300
10	$5,389,800	$794,700
50	$20,764,000	$3,934,000

Notes:
Costs are derived from equations found in U.S. EPA (2000); mgd = million gallons per day
All costs are rounded to the nearest hundred dollars

Q2.6a: Please comment on the estimated costs and assumptions EPA used to estimate the costs for greens and filtration treatment.

A2.6a: >>

Q2.6b: Have capital and O&M costs for this technology changed significantly from the time facilities complied with the arsenic rule (i.e., since 2006)? If so, what are the principal reasons for these changes? To the extent possible, please indicate the approximate amount of difference from EPA's estimates.

A2.6b: >>

EPA also estimated waste disposal costs which included discharge to a wastewater treatment plant for treatment. EPA assumed capital costs would be $5,300 (in 2006 U.S. dollars), regardless of design flow, and calculated O&M costs based on the following equations:

- Flows less than 0.4 mgd: O&M cost = 10054x + 565
- Flows greater than 0.4 mgd: O&M cost = 10054x + 1505.

Table 6b shows the capital and O&M costs for greensand filtration waste disposal treatment.

Table 6b - Discharge to Wastewater Treatment Plant Treatment Costs (2006 dollars)		
Design Flow (mgd)	**Capital Cost ($)**	**O&M Cost ($)**
0.01	$5,300	$700
0.1	$5,300	$1,600
1	$5,300	$11,600
10	$5,300	$102,000
50	$5,300	$504,200

Notes:
Costs are derived from equations found in U.S. EPA (2000)
All costs are rounded to the nearest hundred dollars
mgd = million gallons per day

Q2.6c: Please comment on the estimated costs and assumptions EPA used to estimate the costs for greens and filtration wastewater treatment.

A2.6c: >>

Q 2.6d: **Have capital and O&M costs for this technology changed significantly from the time facilities complied with the arsenic rule (i.e., since 2006)? If so, what are the principal reasons for these changes? To the extent possible, please indicate the approximate amount of difference from EPA's estimates.**

A 2.6d: >>

2.7 Point-of-Use Reverse Osmosis

EPA estimated costs for reverse osmosis (RO) and activated alumina point-of-use (POU) technologies. EPA used "Cost Evaluation of Small System Compliance Options - Point-of Use and Point-of-Entry Treatment Units" (Cadmus Group, 1998) to estimate treatment costs. EPA developed cost curves based on the following assumptions:

- Average household consists of 3 individuals using 1 gallon each per day (1,095 gallons per year)
- Life of unit is 5 years
- Duration of cost study is 10 years (or 2 POU devices per household)
- Cost of water meter and automatic shut-off valve included.
- No shipping and handling costs required.
- Volume discount schedule: retail for single unit, 10 percent discount for 10 or more units, 15 percent discount on more than 100 units.
- Installation time - 1 hour unskilled labor (POU)
- O&M costs include maintenance, replacement of pre-filters and membrane cartridges, laboratory sampling and analysis, and administrative costs.

The capital and O&M cost equations for POU RO are as follows, with x equal to design flow.

$$\text{Capital} = 1151.73x^{0.9261}$$

$$\text{O\&M} = 89.14x^{0.9439}$$

The capital and O&M cost for POU RO treatment are shown in table 7a:

Table 7a - POU RO Treatment Costs (2006 dollars)		
Design Flow (mgd)	**Capital Cost ($)**	**O&M Cost ($)**
0.01	$0	$0
0.1	$100	$0
1	$1,200	$100
10	$9,700	$800
50	$43,100	$3,600

Notes:
Costs are derived from equations found in U.S. EPA (2000)
All costs are rounded to the nearest hundred dollars
mgd = million gallons per day

Q2.7a: Please comment on the estimated costs and assumptions EPA used to estimate the costs for POU RO treatment.

A2.7a: >>

Q2.7b: Have capital and O&M costs for this technology changed significantly from the time facilities complied with the arsenic rule (i.e., since 2006)? If so, what are the principal reasons for these changes? To the extent possible, please indicate the approximate amount of difference from EPA's estimates.

A2.7b: >>

The capital and O&M cost equations for POU activated alumina are as follows, with x equal to design flow.

$$\text{Capital} = 395.46x^{0.9257}$$

$$\text{O\&M} = 549.6x^{0.9376}$$

The capital and O&M cost POU activated alumina treatment are shown in table 7b.

Table 7b - POU Activated Alumina Treatment Costs (2006 dollars)		
Design Flow (mgd)	**Capital Cost ($)**	**O&M Cost ($)**
0.01	$0	$0
0.1	$0	$100
1	$400	$500
10	$3,300	$4,800
50	$14,800	$21,500
Notes: Costs are derived from equations found in U.S. EPA (2000) All costs are rounded to the nearest hundred dollars mgd = million gallons per day		

Q2.7a: Please comment on the estimated costs and assumptions EPA used to estimate the costs for POU activated alumina treatment.

A2.7a: >>

Q2.7b: Have capital and O&M costs for this technology changed significantly from the time facilities complied with the arsenic rule (i.e., since 2006)? If so, what are the principal reasons for these changes? To the extent possible, please indicate the approximate amount of difference from EPA's estimates.

A2.7b: >>

Section 3 Alternative Technologies

Although EPA identified the following alternative treatment technologies at the time of rule development, it did not consider them in its cost analysis because EPA considered them to be emerging technologies. Following are the alternative treatment technologies:

- Sulfur-Modified Iron
- Granular Ferric Hydroxide
- Iron Filings
- Iron Oxide Coated Sand

Q3a: Do you have any knowledge of water systems using these or any other alternative treatment technologies to comply with EPA's arsenic rule? To the extent possible, please characterize the approximate frequency with which these alternative technologies have been used for rule compliance.

A3a: >>

Q3b: Were any of these alternative treatment technologies less costly to install and operate than the treatment technologies on which EPA based its cost analysis at the time the Arsenic Rule was promulgated? To the extent possible, please describe cost differences or other factors that may have favored these alternative technologies compared to the technologies that EPA considered in the rule analysis.

A3b: >>

Section 4 Additional Questions

Q4a: Did technological innovation occur within the treatment systems for which EPA estimated compliance costs? If so, please indicate which technology or technologies were affected and what was the impact on the respective capital and O&M costs.

A4a: >>

Q4b: Did learning-by-doing play a major role in decreasing O&M compliance costs? If so, please indicate which technology or technologies were affected by it.

A4b: >>

Q4c: Were there any factors that may have caused greater implementation difficulty and higher costs with the Arsenic Rule? For example, were there:

- **Any technical challenges to meet compliance requirements?**
- **Issues with financing support for technology installation?**
- **Limitations on compliance in terms of compliance assistance or compliance schedule?**
- **Terms of regulatory requirements, and specific aspects of the rule requirements?**

A4c: >>

Q4d: Did treatment technology used by systems you assisted vary based on existing (pre-rule) arsenic levels (e.g., did systems needing smaller reductions in arsenic concentrations employ different technologies than systems needing greater reductions)? Explain

A4d: >>

Q4e: Did state-level regulations influence the choices treatment technologies that you helped to install? Explain

A4e: >>

Q4e: Do you have any broader knowledge about treatment technologies and their costs installed by facilities in the region where your projects were located? What treatment technologies did the systems typically use? Were there differences: by state, system size, source of water (ground/ surface)?

A4c: >>

Q4f: Please provide any other comments / suggestions that you feel are not covered in this questionnaire, but would be helpful in reaching the goals of this project.

A4f: >>

References

United States Environmental Protection Agency (U.S. EPA). 2000. Technologies and Costs for Removal of Arsenic from Drinking Water. EPA 815-R-00-028. December.

General Questions on Arsenic Rule:

EPA identified the following technologies that would effectively remove arsenic and bring a water system into compliance and developed costs for these treatment technologies:

- Modified Coagulation/Filtration;
- Coagulation Assisted Microfiltration;
- Modified Lime Softening;
- Activated Alumina (with and without pH adjustment);
- Ion Exchange (groundwater only);
- Greensand Filtration (groundwater only); and
- Point-of-Use Reverse Osmosis (for small groundwater systems only).

1. - Have treatment technologies changed since the rule was promulgated? For example, have additional or substantially modified treatment technologies or compliance approaches been used to achieve compliance? If so, please explain how.

2. - Based on your professional knowledge and experience, are the treatment technologies that EPA proposed for groundwater and surface water systems for compliance representative of the actual treatment technologies employed for compliance with the Arsenic Rule?

3. - Based on your professional knowledge and experience, please estimate the frequency with which these technology options have been used for compliance? To the extent possible, please identify the principal factors underlying the selection of a particular treatment technology/compliance approach by different categories of drinking water system – e.g., groundwater vs. surface water, small vs. large system.

4. - Did technological innovation occur within the treatment systems for which EPA estimated compliance costs? If so, please indicate which technology or technologies were affected and what was the impact on the respective capital and O&M costs.

5. - Did learning-by-doing play a major role in decreasing O&M compliance costs? If so, please indicate which technology or technologies were affected by it.

EPA identified the following alternative treatment technologies that EPA knew existed but did not consider since these were emerging technologies:

- Sulfur-Modified Iron
- Granular Ferric Hydroxide
- Iron Filings
- Iron Oxide Coated Sand
- Others, please describe

6. - Do you have any knowledge of water systems using these or any other alternative treatment technologies to comply with EPA's arsenic rule? To the extent possible, please characterize the approximate frequency with which these alternative technologies have been used for rule compliance.

7. - Were any of these alternative treatment technologies cheaper to install and operate than treatment technologies that existed at the time the Arsenic Rule was promulgated? To the extent possible, please describe cost differences or other factors that may have favored these alternative technologies compared to the technologies that EPA considered in the rule analysis.

Additional Questions:

8. - Were there any factors that may have caused greater implementation difficulty and higher costs with the Arsenic Rule? For example, were there:

   - Any technical challenges to meet compliance requirements?
   - Issues with financing support for technology installation?
   - Limitations on compliance in terms of compliance assistance or compliance schedule?
   - Terms of regulatory requirements, and specific aspects of the rule requirements?

9. - Did treatment technology used by systems you assisted vary based on existing (pre-rule) arsenic levels (e.g., did systems needing smaller reductions in arsenic concentrations employ different technologies than systems needing greater reductions)? Explain

10. - Did state-level regulations influence the choices treatment technologies that you helped to install? Explain

11. - Do you have any broader knowledge about treatment technologies and their costs installed by facilities in the region where your projects were located? What treatment technologies did the systems typically use? Were there differences: by state, system size, source of water (ground/ surface)?

Please provide any other comments / suggestions that you feel are not covered in this questionnaire, but would be helpful in reaching the goals of this project

Chapter 5: EPA's 1998 Locomotive Emission Standards

Elizabeth Kopits

This paper examines how EPA's ex ante cost analysis of the 1998 Locomotive Emission Standard Final Rule compares to an ex post assessment of costs. This is not an evaluation of how well EPA conducted the ex ante analysis at the time of the rulemaking. As Chapter 1 makes clear, even the most credible analysis of compliance costs (done before implementation) will vary from actual costs for a large number of reasons. For instance, it is possible that market conditions, energy prices, or available technology change in unanticipated ways. It is also possible that industry overstated the expected costs of compliance. (EPA often has to rely on industry to supply it with otherwise unavailable information on expected compliance costs.) A key analytic question we attempt to address is whether ex ante and ex post cost estimates vary by a substantial degree and why. We organize the discussion according to the conceptual framework outlined in Section III. An important challenge we face in conducting this assessment is that information to evaluate costs ex post is quite limited. Any insights offered herein should be viewed with this limitation in mind.

This chapter is organized as follows. Section 5.1 describes the 1998 locomotive rulemaking and the timing of the engine emission standards. Section 5.2 summarizes the methods EPA used to produce ex ante estimates of the compliance costs for the final rule. Section 5.3 describes the information sources available to conduct an ex post cost assessment. Section 5.4 provides our assessment of how the assumptions and estimates used for each part of EPA's ex ante analysis compare to what occurred in the locomotive industry in the first decade of the program. Section F offers some preliminary conclusions and summarizes the data limitations and remaining methodological challenges we face on the parts of the cost analysis where our ex post assessment is still inconclusive at this time.

5.1. Impetus and Timeline for Regulatory Action

The focus of EPA's 1998 rulemaking was on reducing oxides of nitrogen (NOx) emissions. Since most locomotives in the U.S. are powered by diesel engines, they have significant NOx emissions, as well as hydrocarbon (HC) and particulate matter (PM) emissions, all of which have significant health and environmental effects. At the time of the rulemaking, locomotive NOx emissions were estimated to represent about 5.5 percent of NOx emissions from all mobile and stationary sources in the U.S. On April 16, 1998, EPA published a rule for a comprehensive emission control program that subjected locomotive manufacturers and railroads to emission standards, test procedures, and a full compliance program. The rule was applicable to all locomotives manufactured in 2000 and later, and any remanufactured locomotive originally built after 1973. The rule exempted locomotives powered by an external source of electricity, steam-powered locomotives, and locomotives newly manufactured prior to 1973.

The rule established three separate sets of emission standards (Tiers), with applicability of the standards dependent on the locomotive's date of manufacture:

- Tier 0 applied to locomotives originally manufactured from 1973 through 2001
- Tier 1 applied to locomotives and locomotive engines originally manufactured from 2002 to 2004; and
- Tier 2 applied to locomotives and locomotive engines originally manufactured in 2005 or later.

Table 5.1 lists the HC, CO, NOx, and PM emission standards and smoke standards for each locomotive tier. Companies were allowed to meet these performance standards using any technology available to them. The rule also included average, banking and trading provisions to allow manufacturers and remanufacturers the flexibility to meet overall emissions goals at lower cost.

In 2008, EPA adopted a new set of emission standards, Tier 3 and Tier 4, for locomotives newly manufactured or remanufactured after 2008. The revised standards for remanufacturing existing locomotives took effect by January 1, 2010 for some models, or as soon as certified remanufacture systems were available, and the requirements for newly-built locomotives were phased-in starting in 2011. Therefore, ***the universe of locomotives that were subject to the 1998 rule is limited to locomotives originally built or remanufactured between 2000 and 2009, after which the 2008 revisions began taking effect.***

5.2. EPA Ex Ante Cost Estimates

Table 5.2 summarizes EPA's ex ante estimate of the total costs and emission reductions of the 1998 rule. EPA estimated these impacts over a forty-one year program run to ensure complete fleet turnover, due to the extremely long service life of the typical locomotive. Over 2000-2040, the new standards were estimated to cost $1.33 billion (NPV, 7 percent discounting, 1997$), and reduce NOx emissions from locomotives by nearly two-thirds, and HC and PM emissions by half. EPA did not monetize the health and environmental benefits from these emission reductions. The lifetime cost per locomotive was estimated to be approximately $70,000 for the Tier 0 standards, $186,000 for the Tier 1 standards and $252,000 for the Tier 2 standards. The average annual cost of this program was estimated to be $80 million per year, or about 0.2 percent of the total freight revenue for railroads in 1995. The average cost-effectiveness of the standards was expected to be about $163 per ton of NOx, PM and HC (EPA 1997).

Because the 1998 rule no longer applies to all the locomotives for which EPA estimated costs due to the promulgation of the 2008 rule, we limit our assessment in this paper to the compliance costs incurred over roughly the first decade of the program (2000-2009). EPA's ex ante analysis projected that approximately

Table 5.1. Summary of Emission and Smoke Standards for the 1998 Locomotive Rule

Locomotive Type	Gaseous and Particulate Emissions (g/bhp-hr)				Smoke Standards (% Opacity-Normalized)		
	HC2	CO	NOX	PM	Steady State	30-sec Peak	3-sec Peak
Tier 0 Line-haul Duty-cycle	1.00	5.0	9.5	0.60	30	40	50
Tier 0 Switch Duty-cycle	2.10	8.0	14.0	0.72	30	40	50
Tier 1 Line-haul Duty-cycle	0.55	2.2	7.4	0.45	25	40	50
Tier 1 Switch Duty-cycle	1.20	2.5	11.0	0.54	25	40	50
Tier 2 Line-haul Duty-cycle	0.30	1.5	5.5	0.20	20	40	50
Tier 2 Switch Duty-cycle	0.60	2.4	8.1	0.24	20	40	50

Source: EPA (1998).

Notes: EPA set standards for emissions weighted by typical in-use duty cycle. Duty-cycle is a usage pattern expressed as the percentage of time in use in each of the predetermined throttle notches of a locomotive. The two distinct types of duty-cycles for freight locomotives are line-haul and switching. Line-haul locomotives, which perform the line-haul operations, generally travel between distant locations, such as from one city to another. Yard locomotives, which perform yard operations, are primarily responsible for moving railcars within a particular railway yard.

$600 million (NPV, 7 percent), or 45 percent of the total program costs, would occur over this period, achieving 12 percent of the expected NOx reductions. To calculate what EPA estimated the cost per locomotive to be over 2000-2009, we limit operating costs (fuel and remanufacturing costs) to 10 years, as a way to approximate the operating costs incurred until each locomotive is remanufactured to the revised (Tier 3 and 4) standards. Using this approach, EPA's ex ante analysis implies the cost per locomotive over 2000-2009 was approximately $50,000 for the Tier 0 standards, $100,000 for the Tier 1 standards and $98,000 for the Tier 2 standards.

5.2.1. Main Components of the Ex Ante Cost Analysis

To estimate costs of the Locomotive rule, EPA developed model locomotive categories for each tier to represent different locomotive model types.[169] For each model locomotive, EPA estimated the incremental per locomotive compliance costs including:

- Initial compliance costs - initial equipment costs (i.e., hardware needed to comply with the standards initially, but which are not typically replaced at remanufacture), and other costs such as research and development, engineering, certification, and testing costs.

[169] All descriptions of EPA's ex-ante estimates come from the regulatory support document for the rulemaking (US EPA 1998).

- Remanufacture costs – maintenance and other costs associated with keeping locomotives in compliance with the standards through subsequent remanufactures.

Table 5.2. Total Costs and Emission Reductions of the 1998 Locomotive Rule (EPA Ex-Ante Analysis)
(1997$)

Category	Total Program Costs (2000-2040)
TIER 0	
INCREMENTAL COSTS:	
Initial Manufacture	$470,446,480
Fuel consumption	$435,742,226
Maintenance	$217,159,792
TOTAL (undiscounted)	$1,123,348,498
NPV (7%)	$584,926,672
TIER 1	
INCREMENTAL COSTS:	
Initial Manufacture	$102,890,062
Fuel consumption	$79,754,324
Maintenance	$32,013,080
TOTAL (undiscounted)	$214,657,446
NPV (7%)	$132,572,277
TIER 2	
INCREMENTAL COSTS:	
Initial Manufacture	$669,994,839
Fuel consumption	$1,186,615,407
Maintenance	$78,433,920
TOTAL (undiscounted)	$1,935,044,166
NPV (7%)	$613,541,238
TOTAL COSTS (undiscounted)	$3,273,050,130
NPV (7%)	$1,331,040,187
TOTAL NOx REDUCTIONS (metric tons)	20,052,552
TOTAL PM REDUCTIONS (metric tons)	275,000
TOTAL HC REDUCTIONS (metric tons)	400,000

Source: Locomotive Rule Regulatory Support Document, Table 7-4 (EPA 1998).

- Fuel cost - the cost of any fuel economy penalties associated with compliance.

EPA assumed the initial compliance cost (i.e., fixed and variable costs), together with a manufacturer markup for overhead and profit, comprise the total manufacturing costs and thus represent the initial cost increase to the operator. The annual remanufacture and fuel costs calculated over the service life of the locomotive comprised the additional operating costs incurred by the operator due to the rule. The per locomotive initial cost plus the per locomotive operating costs equaled the total per locomotive compliance cost estimate. The total per locomotive compliance cost, together with the estimated number of locomotives subject to the rule, was used to calculate the total costs of the program.

5.2.2. Treatment of Uncertainty and Baseline

The ex ante compliance costs were based in part on materials supplied by locomotive manufacturers and the railroad industry, contractor studies of the most likely compliance technologies, and public comments on the proposed rule or other information available to EPA. The EPA contractors and subcontractors included ICF, Incorporated, Acurex Environmental Corporation, and Engine, Fuel, and Emissions Engineering, Incorporated (EF&EE). The regulatory support document does not include a separate formal uncertainty analysis of these various inputs to the cost estimates, but it does state that the final cost estimates "tend to be somewhat conservative; that is, for those costs with significant uncertainty, EPA used the higher end of the estimated range" (US EPA 1998). In some areas, EPA presented a range of costs, especially when contractor estimates or public comments differed from EPA's initial estimates. A high cost case is included as a sensitivity analysis to show the effects of modifying base case assumptions regarding some components of the fixed costs (engineering costs, testing costs, number of suppliers) and the fuel economy penalty (which determines the additional fuel cost incurred from the added control equipment). These are discussed in greater detail in Section E below.

It should also be noted that for the most part, the regulatory support document did not include a detailed discussion of the counterfactual for each component of the cost analysis – e.g., to what extent that more efficient line-haul locomotives would have been developed and adopted over time in the absence of the rule. Baseline assumptions about technology (availability, cost, fuel economy), fuel costs, and other inputs (e.g., annual fuel consumption) used in EPA's ex ante analysis reflected current conditions rather than a forecast of future conditions in absence of the regulation. EPA estimated the number of newly manufactured and remanufactured locomotives of each model type based on information on the number of locomotives currently in service and existing production, remanufacture, and retirement rates for Class I, II, and III and passenger rail locomotives.[170] For projections of newly manufactured locomotives, the ex ante estimates do reflect an expectation that the two largest western railroads will purchase large numbers of Tier 2 locomotives during 2005-2010 in order to accelerate their introduction into Southern California. The EPA ex ante analysis did not discuss other potential exogenous factors that could influence the size of the regulated universe – e.g., demand side factors that could shift railroad market share relative to trucking and hence the number of new locomotives purchased.

[170] In 1994, Surface Transportation Board (STB) classified a railroad as Class I if its revenue was higher than $255.9 million. Railroads with revenue between $20.5 and $255.8 million were considered Class II, while railroads with annual revenue less than $20.5 million were Class III.

5.3. Information Available to Conduct Ex Post Evaluation

To conduct the ex post assessment, we explored the following avenues for collecting ex post compliance information. We first assessed whether it would be possible to collect compliance cost information using only publicly-accessible data sources, such as the Census of Manufactures (CMF), Annual Survey of Manufactures (ASM), American Association of Railroad (AAR) publications, EPA's AirControlNet database, and Railinc Equipment Registration and Information System (Umler). Overall, we found that while some data is readily available to help us determine the number of locomotives affected by the regulation, information on the realized cost of particular control mechanisms is generally lacking.

Next we sought to identify appropriate industry experts with sufficient information about the ex post regulatory compliance costs. We approached numerous independent associations, including the Manufacturers of Emission Controls Association, the Association of American Railroads (AAR), the American Shortline and Regional Railroad Association (ASLRRA), and the Engine Manufacturers Association, but they were unresponsive to our information requests. We then contacted two engineering consulting firms: Power Systems Research and Engine, Fuel, and Emissions Engineering, Incorporated (EF&EE). Power Systems Research is the leading global supplier of business information to the engine, power products and components industries. We identified its PartsLink database as a potentially useful source for obtaining information on the historical locomotive fleet but in the end we did not pursue a subscription to this database due to funding constraints. EF&EE is a research, development, and consulting firm specializing in motor vehicle emissions and emissions control. The president and founder of EF&EE, Mr. Chris Weaver, was responsive to our requests and willing to respond to all parts of a questionnaire we prepared based on our review of EPA's ex ante cost estimation methodology. A copy of the questionnaire is provided in Appendix 5.1.

Ultimately, our analysis below is based on information provided by EF&EE, the sole respondent to the questionnaire (under a contract with Abt Associates), augmented by publicly available data where possible. Since Mr. Weaver's firm helped develop EPA's 1997 ex ante cost estimates for this regulation, efforts were made to provide as much documentation and supporting evidence for his input as possible. Any assessment and statements based on his professional experience and expert opinion are referenced as such throughout the paper. A summary of the information sources we relied on for assessing each main component of the cost estimate is provided in Section 5.5 below.

5.4. Ex post Assessment of Compliance Cost

5.4.1. Regulated Universe

5.4.1.1. Locomotive Model Types

Railroads can be separated into three classes based on size: Class I, Class II, and Class III. Class I railroads represent the largest railroad systems in the country, carry most of the interstate freight and passenger service, and buy almost all of the new locomotives. Class II and III railroads represent the remainder of the rail transportation system and generally operate within smaller, localized areas, and their fleet of locomotives tends to be older. Locomotives in each class can perform two different types of operations: line-haul and yard (or switch). Line-haul locomotives, which perform the line-haul operations, generally travel between distant locations, such as from one city to another. Switch locomotives, which perform yard operations, are primarily responsible for moving railcars within a particular railway yard. Switchers make up a relatively small share of the locomotive market, accounting for approximately 7-8 percent of total Class I fuel consumption in recent years.[171]

For the 1998 rulemaking, EPA assumed that the Tier 0 locomotives could be grouped into 5 model categories (or engine families): switch locomotives from Electro-Motive Diesel (Model A), older and newer line-haul locomotives from the Electro-Motive Diesel (Model B and C), and older and newer line-haul locomotives from General Electric Transportation Systems (Model D and E).[172] For Tier 1 locomotives, EPA believed that early versions of the new engine designs used to meet the Tier 2 standards made their appearance during the Tier 1 period. Thus, EPA assumed there would be two Tier 1 models for each of the two manufacturers. Models A and B are Tier 1 line-hauls from EMD and GE respectively, and Models C and D are early version Tier 2 design line-hauls from EMD and GE, respectively. EPA assumed that for Tier 2, each manufacturer would have a single model (Model A – EMD, Model B – GE).

Each manufacturer deployed more versions or types of their locomotive models than estimated by EPA.[173] However, for the most part the model categories used by EPA were sufficient for purposes of estimating compliance costs (EF&EE expert opinion). EMD and GE both deployed direct current (DC) and alternating current (AC) versions of their basic line-haul locomotives at each Tier level, but the engines and emission control systems in the DC and AC engines were essentially the same, so it is not clear that these should count as separate models. EMD also deployed passenger locomotive models for each Tier, generally with twelve-

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[171] In 2008, 7.7% of Class I fuel consumption was for switchers; 7.4% in 2009-2010 (STB Schedule 750 of Annual Report Form R-1). Switchers mad up about 7.3% of Class I locomotive fuel consumption in 2007 (ERTAC 2012).

[172] GE did not make switch locomotives at that time, or since.

[173] Rather than the number of locomotive models offered, another measure would be the number of locomotive engine families certified. In 2005 and 2008, EMD certified two new locomotive engine families, and GE certified only one (twelve and 16-cylinder versions of each engine were presumably included in the same family). In 2006 and 2007, they certified one each. Smaller manufacturers such as National Railway Equipment Co. also certified a number of new as well as remanufactured models. These were probably all genset switchers.

cylinder engines rather than 16 cylinders. GE also deployed a 6000 hp, 16-cylinder version of its GEVO engine.

5.4.1.2. Number of Locomotives Affected by the Regulation

EPA estimated the number of newly manufactured and remanufactured locomotives affected by the regulation based on information on the number of locomotives currently in service and existing production, remanufacture, and retirement rates for Class I, II, and III and passenger rail locomotives.

EPA obtained information on Class I locomotives from the Association of American Railroads Annual Railroad Facts publication. About 17,500 of Class I locomotives were manufactured post 1972, most of which were used in line-haul service (Tier 0, Models B through E). The 3,500 older locomotives that were manufactured prior to 1972 are used as switchers (Tier 0, Model A). EPA assumed that by 2008, almost all 1973 through 1999 line-haul locomotives (13,200) would be remanufactured to meet EPA's standards. EPA also assumed there would be 400 newly manufactured line-haul locomotives for years 2000-2004, 600 for years 2005-2010, and 300 new units for all subsequent years.

For Class II and III locomotives, EPA obtained information from American Short Line Railroad Association, which represents most Class II and Class III railroads. EPA projected that there would be about 600 post-1972 locomotives and 3600 older locomotives in the 1999 Class II and III fleet (Tier 0, Models A through C). EPA assumed that during the first 10 years of the program, Class II and III railroads would bring about 50 locomotives into compliance with Tier 0 standards each year. EPA further assumed that in 2012, these railroads would purchase about 150 complying Tier 0 locomotives each year from Class I railroads. For passenger locomotives, EPA primarily relied on information from Amtrak and the American Public Transportation Association. There were roughly 463 diesel locomotives in commuter rail service in 1995, with 397 of these manufactured after 1972. EPA projected that about 100 locomotives would be brought into compliance during each of the first five years of the program, and that all uncontrolled locomotives would be removed from passenger service by 2011.

Table 5.3 includes EPA's ex ante estimate of the total number of locomotives in each Tier for each model type.

New Locomotives. Class I railroads buy almost all of the new locomotives in the U.S., and in the timeframe addressed in the 1998 rule, the bulk of the non-Class I railroad locomotives were not covered by the rule. So we focus here on Class I.

As shown in Table 5.4, actual sales were higher than EPA's estimate. Over 3,800 newly manufactured locomotives were in the fleet from 2000 through 2004, or an average of 760 per year. Nearly 4000 were added from 2005 through 2009, or about 790 per year. This increase was likely driven at least in part by demand side factors. As fuel prices increased, railroads gained a lot of market share compared to trucks, so

Table 5.3: Calculation of Per Locomotive Compliance Costs (1997 US Dollars) (EPA Ex Ante Analysis) -

	Tier 0					Tier 1				Tier 2 (2005-2010)		Tier 2 (After 2010)	
Cost Component	Model A	Model B	Model C	Model D	Model E	Model A	Model B	Model C	Model D	Model A	Model B	Model A	Model B
Number of Locomotives	3000	4900	2930	2035	2965	360	360	360	360	1700	1700	300	300
Initial Costs													
Variable Costs													
Hardware Costs													
2 deg timing retard	$0	$0	$0	$0	$0	$0	$0	$0	$0	--	--	--	--
4 deg timing retard	$0	$0	--	--	--	--	--	--	--	$0	$0	$0	$0
4 pass aftercooler	--	$5,000	$5,000	$5,000	--	--	--	--	--	--	--	--	--
Improved mechanical injectors	--	$800	--	--	--	--	--	--	--	--	--	--	--
Add electronic fuel injection	--	--	--	$35,000	--	--	--	--	--	--	--	--	--
Improved electronic injectors	--	--	$2,000	--	$2,000	$2,000	$2,000	$2,000	$2,000	$2,000	$2,000	$2,000	$2,000
Increased compression ratio	--	--	--	--	$800	$800	$800	--	--	--	--	--	--
Improved turbocharger	--	--	--	$25,000	$25,000	--	$25,000	--	--	--	--	--	--
Split cooling	--	--	--	--	--	$25,000		$25,000	$25,000	$25,000	$25,000	$25,000	$25,000
High pressure injection	--	--	--	--	--	$2,000	$2,000	$2,000	$2,000	$2,000	$2,000	$2,000	$2,000
Combustion chamber design	--	--	--	--	--	$800	$800	$800	$800	$800	$800	$800	$800
Assembly costs	$0	$4,480	$6,720	$4,480	$6,720	$6,720	$6,720	$560	$560	$560	$560	$560	$560
Subtotal Variable cost per locomotive	$0	$10,280	$13,720	$69,480	$34,520	$37,320	$37,320	$30,360	$30,360	$30,360	$30,360	$30,360	$30,360
Fixed Costs													
Engineering costs	$800,000	$1,700,000	$2,800,000	$1,700,000	$2,800,000	$3,600,000	$3,600,000	$3,600,000	$3,600,000	$4,000,000	$4,000,000	--	--
Testing costs	$422,783	$422,783	$845,566	$422,783	$845,566	$4,227,829	$4,227,829	$4,227,829	$4,227,829	$8,455,659	$8,455,659	$582,900	$582,900
Tooling	--	--	--	--	--	$1,000,000	$1,000,000	$1,000,000	$1,000,000	$1,000,000	$1,000,000	--	--
Technical support	$200,000	$350,000	$500,000	$350,000	$500,000	$500,000	$500,000	$350,000	$350,000	$350,000	$350,000	--	--
Total fixed costs per supplier	$1,422,783	$2,472,783	$4,145,566	$2,472,783	$4,145,566	$9,327,829	$9,327,829	$9,177,829	$9,177,829	$13,805,659	$13,805,659	$582,900	$582,900
Total Fixed Costs1	$4,268,409	$7,418,409	$12,436,818	$2,472,803	$4,145,606	$9,328,029	$9,328,029	$9,178,029	$9,178,029	$13,806,059	$13,806,059	$582,915	$582,915
Subtotal Fixed cost per locomotive2	$1,423	$1,514	$4,245	$1,215	$1,398	$25,911	$25,911	$25,495	$25,495	$8,121	$8,121	$1,943	$1,943
Initial Cost Per Locomotive3	$1,707	$14,153	$21,558	$84,834	$43,102	$75,877	$75,877	$67,025	$67,025	$46,177	$46,177	$38,764	$38,764
Fuel Costs													
Average Fuel Consumption	104000	104000	297000	104000	297000	297000	297000	350000	350000	350000	350000	350000	350000
FE Penalty	2%	1%	1%	1%	2%	1%	1%	1%	1%	2%	2%	2%	2%
Gallons of fuel/year4	2,080	1,040	2,970	1,040	5,940	2,970	2,970	3,500	3,500	7,000	7,000	7,000	7,000
Cost per year (@ $0.70/Gal.)	$1,456	$728	$2,079	$728	$4,158	$2,079	$2,079	$2,450	$2,450	$4,900	$4,900	$4,900	$4,900
Fuel Costs Per Locomotive	$21,840	$10,920	$43,659	$10,920	$87,318	$83,160	$83,160	$98,000	$98,000	$196,000	$196,000	$196,000	$196,000
Remanufacture Costs													
Cost per year	$0	$400	$846	$400	$846	$1,000	$1,000	$240	$240	$240	$240	$240	$240
Service life	15	15	21	15	21	40	40	40	40	40	40	40	40
Remanufacture Cost Per Locomotive	$0	$6,000	$17,766	$6,000	$17,766	$40,000	$40,000	$9,600	$9,600	$9,600	$9,600	$9,600	$9,600
TOTAL COST PER LOCOMOTIVE	$23,547	$31,073	$82,983	$101,754	$148,186	$199,037	$199,037	$174,625	$174,625	$251,777	$251,777	$244,364	$244,364

1. Represents the fixed cost per supplier multiplied by the number of suppliers for each model type (e.g., 3 suppliers for Tier 0 Models A, B and C, and 1 supplier for the remaining model types).
2. Total fixed costs for all suppliers divided by the number of locomotives in each model category.
3. Sum of total hardware (variable) cost per locomotive and total fixed cost per locomotive plus 20% manufacturer markup.
4. Represents average fuel consumption multiplied by the fuel economy penalty.

Source: US EPA (1998)

Table 5.4. Class I Rail Statistics, 1990-2010 -

Year	Gallons fuel consumed (millions)	Average fuel cost (1997$) ($/gal)	Number of locomotives in service	Number of locomotives new	Number of locomotives rebuilt	Revenue ton-miles (billions)	Revenue ton-miles per gallon fuel consumed (millions)	Average fuel consumed per locomotive (thousand gallons)
1990	3134	69.22	18835	530	176	1034	330	166
1991	2926	67.24	18344	472	112	1039	355	160
1992	3022	63.29	18004	321	139	1067	353	168
1993	3112	63.05	18161	504	203	1109	356	171
1994	3356	59.87	18496	821	393	1201	358	181
1995	3503	60.01	18810	928	201	1306	373	186
1996	3601	67.66	19267	761	60	1356	377	187
1997	3603	67.82	19682	743	68	1349	374	183
1998	3619	57.00	20259	889	172	1377	380	179
1999	3749	55.45	20254	709	156	1433	382	185
2000	3720	87.46	20026	640	81	1466	394	186
2001	3730	85.54	19743	710	45	1495	401	189
2002	3751	73.33	20503	745	33	1507	402	183
2003	3849	89.25	20772	587	34	1551	403	185
2004	4082	106.98	22015	1121	5	1663	407	185
2005	4120	151.42	22779	827	84	1696	412	181
2006	4214	192.11	23732	922	158	1772	421	178
2007	4087	218.24	24143	902	167	1771	433	169
2008	3911	312.05	24003	819	129	1777	454	163
2009	3220	177.12	24045	460	103	1532	476	134
2010	3519	224.29	23893	259	181	1691	481	147
2000-01 Average	3725	87	19885	675	63	1481	397	187
2002-04 Average	3894	90	21097	818	24	1574	404	185
2005-09 Average	3910	210	23740	786	128	1710	439	165

Data is for Class I railroads. Class I railroads represent 70 percent of the U.S. rail mileage.

Source: AAR Railroad Facts 2002 and 2011 editions railroads purchased more new locomotives as a result. In addition, improvements in fuel efficiency and/or a slowdown in the number of rebuilds may have played a role. If companies opted to retire old locomotives earlier instead of remanufacturing them to comply with Tier 0 requirements during a rebuild, this could have contributed to an increase in new locomotives in compliance with Tier 1 standards. Similarly, improvements in fuel efficiency and lower maintenance costs could have led to a rebound effect for locomotive travel, thus contributing to the robust sales of Tier 2 locomotives.

Remanufactured Locomotives. As shown in Table 5.4, a total of 839 Class I locomotives were rebuilt during the first decade of the program (2000-2009), and far fewer rebuilds occurred over 2000-2004 than during the previous or following five year periods. There were only 40 rebuilds per year on average over 2000-2004, but about 130 per year on average over 1995-1999 and 2005-2009. The slowdown in rebuilds may reflect a strategic decision on the part of the railroads in response to the 1998 standards. Typically, line-haul locomotives are overhauled about every eight years and repowered at least once[174], but because the emission limits were mandated at the time of remanufacture, rather than on a fixed schedule, railroads may have found it cheaper to deal with the inefficiencies/costs associated with delaying rebuilds or retiring locomotives earlier and buying more new ones than rebuilding older models to comply with Tier 0 requirements. Continuous improvements in engine durability, improved maintenance practices, and other factors may have also played a role in increasing the remanufacturing interval over time even absent emission standards. The increase in rebuilds in the second half of the decade could reflect strategic behavior in anticipation of the revised locomotive standards. (The advanced notice of proposed rulemaking for the Tier 3/4 standards was published in mid-2004.) Operators may have opted to rebuild older locomotives ahead of schedule to Tier 0 standards before the more stringent emission standards took effect.

The number of switch locomotives that were affected by the 1998 rule is likely much less than the number EPA assumed. Any new switch locomotives sold will be of the genset type, but the large supply of old locomotives that can be kept running at low cost limits the potential sales of new switchers and old switchers can be run for a long time without remanufacturing.

In sum, the number of remanufactured locomotives complying with Tier 0 over the first decade of the program is likely lower than EPA anticipated, and the number of new locomotives complying with Tier 0, 1 and 2 standards is higher than EPA anticipated, by about 140 percent, 70 percent, and 16-23 percent, respectively.

5.4.2. Methods of Compliance

This section discusses the emission control technologies that EPA expected would already be available at the time the locomotive emissions standards would take effect. Among those, EPA considered use of the following technologies:

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[174] http://www.fhwa.dot.gov/environment/air_quality/conformity/research/mpe_benefits/mpe06.cfm

Table 5.4. Class I Rail Statistics, 1990-2010 -

Year	Gallons fuel consumed (millions)	Average fuel cost (1997$) ($/gal)	Number of locomotives in service	Number of locomotives new	Number of locomotives rebuilt	Revenue ton-miles (billions)	Revenue ton-miles per gallon fuel consumed (millions)	Average fuel consumed per locomotive (thousand gallons)
1990	3134	69.22	18835	530	176	1034	330	166
1991	2926	67.24	18344	472	112	1039	355	160
1992	3022	63.29	18004	321	139	1067	353	168
1993	3112	63.05	18161	504	203	1109	356	171
1994	3356	59.87	18496	821	393	1201	358	181
1995	3503	60.01	18810	928	201	1306	373	186
1996	3601	67.66	19267	761	60	1356	377	187
1997	3603	67.82	19682	743	68	1349	374	183
1998	3619	57.00	20259	889	172	1377	380	179
1999	3749	55.45	20254	709	156	1433	382	185
2000	3720	87.46	20026	640	81	1466	394	186
2001	3730	85.54	19743	710	45	1495	401	189
2002	3751	73.33	20503	745	33	1507	402	183
2003	3849	89.25	20772	587	34	1551	403	185
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2006	4214	192.11	23732	922	158	1772	421	178
2007	4087	218.24	24143	902	167	1771	433	169
2008	3911	312.05	24003	819	129	1777	454	163
2009	3220	177.12	24045	460	103	1532	476	134
2010	3519	224.29	23893	259	181	1691	481	147
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2005-09 Average	3910	210	23740	786	128	1710	439	165

Data is for Class I railroads. Class I railroads represent 70 percent of the U.S. rail mileage.

Source: AAR Railroad Facts 2002 and 2011 editions

- Retarding fuel injection - optimizing injection timing and duration to achieve significant NOx emissions reductions at minimal cost (2 degree or 4 degree timing retard depending on potential fuel economy impacts);
- 4 pass after cooler – changing from two-pass to a four-pass aftercooler to lessen the degree of timing retard needed through enhanced charge air cooling;
- Improved mechanical and electrical injectors - optimizing spray pattern from the nozzle in conjunction with the configuration of the combustion chamber and induction swirl to achieve emission reductions;
- Add electronic fuel injection – to improve control of injection rate and timing;
- Engine Modifications - reduction in engine size to achieve the desired lower power rating;
- Improved turbocharger –ensuring that fuel consumption and emissions formation are minimized, including preventing smoke generation due to turbo lag; changing the geometry of the gas flow passages in the turbine to improve the response time of the turbocharger;
- Split cooling - an aftercooler that uses a coolant system separate from the engine coolant system;
- High pressure injection – to shorten the duration of the fuel injection event, which allows a delay in the initiation of fuel injection causing lower peak combustion temperatures and reduced NOx formation, and also reduces fuel economy penalties associated with retarded injection timing; and
- Combustion chamber design - redesign of the shape of the combustion chamber and the location of the fuel injector to optimize the motion of the air and the injected fuel with respect to emission control.

The effective use of some of these technologies can be optimized through the use of other technologies, and adverse effects of some technologies can be limited or eliminated through the application of other technologies. For this reason, in estimating compliance costs EPA considered use of multiple technologies together to form a larger emission reduction system.

Table 5.5 presents EPA’s ex ante crosswalk between the expected compliance technologies, their usage, and the locomotive model types by tier. We discuss the emission control technologies used for each of the Tiers in turn.

5.4.2.1. Emission Control Technologies for Tier 0 Locomotives.

The main emission control technologies that EPA expected to be used to comply with Tier 0 were:

- Locomotives equipped with turbocharged engines would be able to employ: modified/improved fuel injectors, enhanced charge air cooling, injection timing retard, and in some cases, improved turbochargers, to reduce NOx emissions.
- EPA expected that engine coolant would continue to be the cooling medium in most cases, rather than a separate cooling system, and that it would be cost-effective to replace two-pass aftercoolers with four-pass aftercoolers during the remanufacturing process.

Table 5.5: Control Options, Expected Usage and Locomotive Models (EPA Ex Ante Analysis) -

	Expected Technology Usage and Models Developed for Cost Analysis	**2 deg timing retard**	**4 deg timing retard**	**4 pass aftercooler**	**Improved mechanical injectors**	**Add electronic fuel injection**	**Improved electronic injectors**	**Increased compression ratio**	**Improved turbocharger**	**Split cooling**	**High pressure injection**	**Combustion chamber design**
Tier 0 (1973–2001)	Percent locomotives using technology	50	50	60	30	13	27	20	30	-	-	-
	Models using technology											
	A	X	X									
	B	X	X	X	X							
	C	X		X			X					
	D	X		X		X			X			
	E	X					X	X	X			
Tier 1 (2002–2004)	Percent locomotives using technology	100	-	-	-	-	100	50	25	75	100	100
	Models using technology											
	A	X					X	X		X	X	X
	B	X					X	X	X		X	X
	C	X					X			X	X	X
	D	X					X			X	X	X
Tier 2 (2005–2010)	Percent locomotives using technology	-	100	-	-	-	100	-	-	100	100	100
	Models using technology											
	A		X				X			X	X	X
	B		X				X			X	X	X
Tier 2 (after 2010)	Percent locomotives using technology	-	100	-	-	-	100	-	-	100	100	100
	Models using technology											
	A		X				X			X	X	X
	B		X				X			X	X	X
Source: U.S. EPA (1998).												

- The tools available to manufacturers to reduce emissions for naturally-aspirated and Roots-blown engines would be modifications to the fuel system, modifications to the combustion chamber and injection timing.

All of the technologies listed by EPA were actually used to comply with Tier 0, except for engine modifications to reduce power output, where the approach was instead to substitute smaller non-road engines (EF&EE expert opinion). For low-power switch locomotives, the EPA regulatory support document discussed two approaches that appeared to be available to manufacturers: “One approach would be the continued use of large displacement naturally aspirated engines employing electronic control of the fuel system, improved fuel injection and improved combustion chambers. Another approach wouldbe to use turbocharging and other technologies used on line-haul locomotives, but with a reduction in engine size to achieve the desired lower power rating. A reduction in engine size could be achieved either through the use of fewer power assemblies of the same configuration as those used on line-haul locomotives or by the use of a different engine design than that used in line-haul applications. Locomotive manufacturers could also use large non-road engines (1000-2000 hp) that were originally designed for use in non-locomotive applications” (US EPA 1998).

After the rule was enacted, the two major locomotive manufactures abandoned the switch locomotive market, and with it, the market for naturally aspirated and Roots-blown engines, leaving it to smaller companies. The preferred approaches of those smaller companies were the “Hybrid” and “Genset Switcher”. The hybrid substitutes one smaller non-road engine plus a large battery back for the large locomotive engine, while the genset switcher substitutes (typically) two or more small non-road engines. EPA correctly predicted the potential to substitute non-road engines for locomotive engines in switchers, but did not foresee the use of batteries or two or three smaller non-road engines in place of a single larger one.

Two other technologies that were used to meet Tier 0 requirements were increasing the compression ratio and modifying the cylinder liner and piston rings to reduce lubricating oil consumption. EPA had expected compression ratio changes to be introduced for compliance with Tier 1, but GE did so for Tier 0 as well (Chen et al. 2003).

Finally, the usage frequencies assumed by EPA for several technologies for Tier 0 were too low because they were used by more models than anticipated. For example, EF&EE reports that Model B used electronic fuel injectors (EFI) (Fritz et al. 2005). Note these EFI systems may not have been absolutely necessary to meet the emission standards themselves. Rather, they were likely used to minimize the loss in fuel economy from retarding injection timing to meet the NOx standards. In addition, EF&EE reports that new Tier 0 locomotives (Models C and E) used split cooling (Uzkan and Lenz, 1999), increased compression ratios, and combustion chamber design, and Chen et al. (2003) comment in their conclusions that the same technology package can also be used to upgrade baseline engines to the same standards. As with EFI, EF&EE expects that it was not strictly necessary to add split cooling in order to meet the standards. Rather, it was used to minimize the need to retard injection timing, with the resulting adverse impact on fuel economy and mechanical reliability.

5.4.2.2. Emission Control Technologies for Tier 1 Locomotives.

The main emission control technologies that EPA expected to be used for to comply with Tier 1 were:

- Tier 1 locomotives would be able to incorporate all the technologies available for Tier 0 locomotives.
- Additionally, electronic controls and enhanced aftercooling could be used for Tier 1 compliance. Further, timing retard could be used to reduce NOx emissions without a negative impact on PM.
- In addition, some models could use in-cylinder and turbocharger modifications.
- Increased compression ratios could be used to reduce PM emissions and ignition delay. Upgraded turbocharger designs would reduce smoke emissions.

All of the technologies listed were, in fact, used on line-haul locomotives in order to comply with Tier 1 standards (Dillen and Gallagher 2002). In addition, changes were made to the cylinder liner and piston rings to reduce lubricating oil consumption and all Tier 1 units used 4-pass aftercooling (EF&EE expert opinion). As for switch locomotives, the principal compliance mechanism was to employ non-road engines certified to Tier 1 or Tier 2 standards in genset switchers.

5.4.2.3. Emission Control Technologies for Tier 2 Locomotives.

The main emission control technologies that EPA expected to be used for compliance with Tier 2 were:

- With the change from DC to AC traction motors, manufacturers would be using new four-stroke engines, which would have lower PM emissions as they achieve better oil control.
- EPA expected additional NOx and PM emission reductions to be possible through continued refinements in charge air cooling, fuel management, and combustion chamber configuration.
- Improved fuel management would include increased injection pressure, optimized nozzle hole configuration, and rate-shaping.
- Potential combustion chamber redesigns would include the use of reentrant piston bowls and increased compression ratio.

All of the technologies considered by EPA for Tier 2 compliance were, in fact, used, in both two-stroke and four-stroke engines (Flynn et al. 2003). Combustion chamber designs were extensively optimized, but this optimization did not include the use of re-entrant combustion chambers. For engines in the size and speed range, the optimal combustion chamber has been found to be wide and flat (the so-called Mexican hat shape) rather than re-entrant. The usage frequencies noted in Table 5.5 for each technology were reasonable, the one exception being that all Tier 2 units ended up using 4-pass aftercooling (EF&EE expert opinion).

There were some other changes in the locomotive market in the years following the rulemaking that were unanticipated by EPA, but for the most part these did not impact the cost of meeting Tier 2. For example, the anticipated migration from 2-stroke to 4-stroke engine designs for EMD did not occur, but this did not create a cost divergence because the rulemaking did not ascribe the switch to 4-strokes as being due to EPA's program in the first place. EMD wound up using the same technologies on its two-stroke engine, and they were equally effective. Similarly, the widespread change from 4400 HP DC locomotives to 6000 HP AC locomotives that was anticipated in 1998 has largely failed to occur. Although a substantial number of AC locomotives are in service, line-haul locomotives with DC propulsion continue to make up a substantial fraction of new locomotive sales. Those AC locomotives that are sold are primarily in the 4300 to 4400 horsepower range. EMD locomotives in this power range have 16-cylinder two-stroke engines, while GE units have 12-cylinder four-stroke GEVO engines. Although DC and AC locomotives differed in their electrical systems, there was little or no difference in the engine and emission control systems. The same engine families were used in DC and AC locomotives, so this also should not have altered the compliance cost of meeting the Tier 2 standards (EF&EE expert opinion).

In sum, except for the use of Tier 2 and Tier 3 non-road engines in genset switchers, we are not aware of any major emission control technologies not considered by EPA that were actually employed in a significant number of locomotives (EF&EE expert opinion).[175]

5.4.3. Per Locomotive Compliance Cost

5.4.3.1. Initial Compliance Cost

EPA estimated the initial cost increase to the operator as the sum of the fixed costs and variable costs of hardware needed for compliance, adjusted by a 20 percent manufacturer's markup for overhead and profit.

Fixed Costs. EPA's fixed costs of manufacturing locomotive models compliant with the emissions standards included costs of testing, engineering, tooling, and technical support.

- The *testing costs* included developmental testing, as well as certification testing, production line testing and in-use testing. Testing costs also included the costs of any necessary additional facilities and equipment for emissions testing, plus engineering, operating and maintenance costs for the testing facility. These costs, when allocated over the estimated testing requirement, were estimated to amount to about $21,000 per test prior to 2010 and about $39,000 per test after 2010 when the developmental testing would be completed (U.S. EPA 1998).
- The *engineering costs* category represented the estimated average cost for the number of engineering work years EPA projected to be required to develop the calibrations and hardware necessary for meeting the emission standards. This also included the effort for any ancillary changes made to the locomotives to accommodate the required new hardware.
- The *tooling costs* included costs for any additional or modified tooling necessary to produce the emission control hardware, as well as for any required setup changes. Because EPA estimated that

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[175] In the public comments on the proposed rule, EMD stated that exhaust gas recirculation (EGR) would be the likely technology of choice for meeting Tier 2 standards. EMD also projected a 5-10 percent fuel economy penalty, rather than the 1 percent estimated by EPA, based on the experience of others in the use of EGR. EGR was not used to meet Tier 2 (EF&EE expert opinion).

A very small number of switch locomotives were built using alternative fuels such as LNG for demonstration purposes, but they were not offered as commercial products.

Tier 0 compliance would be achieved through calibration changes or hardware obtained from suppliers (particularly in the case of aftermarket remanufacturers), EPA did not estimate specific tooling costs for Tier 0.

- The *technical support* costs included the costs of any changes that would be required in the technical support that manufacturers provide to users, including any necessary operator or maintenance training and changes to technical publications that provide operating and maintenance guidance.

EPA estimated these fixed costs for each locomotive supplier, multiplied by the number of suppliers for each model type, and divided by the total number of locomotives (assuming suppliers would recover costs from the locomotives) to derive the total per locomotive fixed cost by model type. EPA assumed that there were three suppliers each for Tier 0 Model A, B, and C locomotives, and one supplier each for Tier 0 Model D and E, Tier 1 Model A, B, C, and D, and Tier 2 Model A and B locomotives. EPA based this assumption on the numbers of independent part suppliers and remanufacturers for the various locomotive models at the time of the analysis. The number of suppliers EPA estimated for each model category was less than the total number of suppliers in existence at the time because EPA assumed that the manufacturers for which initial costs were cost prohibitive would pay other manufacturers with the ability to incur initial costs to perform the necessary services.

Because the fixed costs were for goods and services that are useful for more than one year of production, EPA amortized initial costs over 5 years (i.e., manufacturers would recover costs within the first five years of production). For Tier 2, because the standards were to be in effect for longer than 5 years, EPA developed two sets of unit costs (because initial fixed costs would be recovered by 2010). EPA did not calculate separate compliance costs reflecting fully-recovered fixed costs for Tier 0 and Tier 1 as it did for Tier 2, because the initial hardware costs occur only at original manufacture (for Tier 1) or the first remanufacture (for Tier 0), and thus are applicable only during the first few years of the program.

Table 5.3 above summarizes the fixed costs of manufacturing for each Tier and model type that were estimated by EPA.

Certification data published in 2005 shows that the number of suppliers, and especially the number of different Tier 0 remanufacturing systems developed, were higher than EPA estimated. EPA estimated that a total of 11 remanufacturing systems would be developed and certified for Tier 0 locomotive models, from a total of three suppliers. In 2005, there were 37 remanufacturing systems certified, from four suppliers (US EPA 2005). EPA's estimates of the *cost per remanufacturing system certified* are probably too high, as they assume that the same level of effort went into certifying remanufacture systems as new engines which is probably not the case (EF&EE expert opinion). Even taking this into account, however, the large number of systems certified means that the total costs of certification of Tier 0 remanufacturing systems were probably about double EPA's estimate (EF&EE expert opinion). This suggests that the total realized fixed costs for the Tier 0 line-haul locomotives (Models B-E) were closer to $53 million (1997$) than EPA's original estimate of $26.5 million. What this implies about the realized per locomotive fixed cost depends on how EPA's estimate of the number of remanufactured locomotives compares to the number of locomotives actually affected by the rule in each model category. Since the total number of locomotives to be remanufactured was overestimated (see more on this below), the fixed cost per locomotive for remanufactured locomotives were likely higher than EPA's estimate.

EF&EE's expert opinion indicates that EPA's assumptions regarding the total fixed costs of certification for newly built locomotives were fairly accurate. Since the total number of newly built locomotives over 2000-2009 was underestimated (see more on this below), the realized fixed cost per locomotive for new locomotives were likely lower than EPA's estimate.

Variable Costs. EPA's estimate of the initial incremental variable compliance costs included costs of hardware and assembly.

The *hardware costs* represented the emission reduction technologies EPA projected that manufacturers would employ for compliance with the standards. EPA developed hardware cost estimates for the following technologies:

- Retarding fuel injection (2 degree or 4 degree timing retard)
- 4 pass after cooler
- Improved mechanical and electrical injectors
- Electronic fuel injection
- Engine Modification
- Improved turbocharger
- Split cooling
- High pressure injection
- Combustion chamber design

Table 5.3 shows the costs assumed for each of these technologies and specifies the combinations of these technologies that were expected to be used for each locomotive model type and Tier.

Assembly costs included the labor and overhead costs for retrofitting (in the case of Tier 0) or for initial installation of the new or improved hardware. These also varied with the characteristics of individual locomotives and the type of hardware necessary for compliance with the applicable emission standards.

EF&EE's expert opinion indicates that EPA's estimate of the hardware cost of each emission control technology was reasonable. However, since the usage frequency of several technologies was higher than EPA anticipated (as discussed in Section C.2), per locomotive total hardware costs for line-haul locomotives were likely higher than EPA's ex ante estimate. For Tier 0, the use of electronic fuel injectors would have added $35,000 in hardware costs for an older line-haul EMD locomotive (Model B), and the use of split cooling, increased compression ratios, and combustion chamber design would have added about $26,000 in hardware costs for newer line-hauls (Model C and E locomotives).[176] For Tier 1 and 2, the use of 4-pass

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[176] These price increases are based on EPA assumed costs of these emission control technologies for other Model types, as shown in Table 5.4.

aftercooling may not have added to the hardware costs per locomotive since the aftercooling costs may have already been included in the assumption of split cooling being used in these locomotives (EF&EE expert opinion).

The industry move to genset switchers instead of remanufacturing old ones to comply with the new standards means the realized Tier 0 per locomotive compliance cost was likely different that what EPA estimated for the switch locomotives (Model A). Presumably companies found gensets to be more cost-effective than remanufacturing to Tier 0 standards. However, it is unclear to what extent genset switchers were developed in reaction to the rule or other factors. The genset has major benefits in terms of availability/reliability and fuel consumption, so EF&EE's expert opinion indicates that this technological change would likely have been undertaken even in the absence of the emission standards. Better reliability means one unit can often replace two old conventional units, and fuel consumption is at least 50 percent less.[177] The genset switcher is significantly more expensive but costs have come down in recent years. EF&EE reported that the current price of a new genset switcher is around $700,000 whereas a standard switcher such as an SW1200 could be sold for about $236,000 (although that does not include the cost of remanufacturing the engine to Tier 0).

EF&EE's expert opinion indicates that the assembly costs were reasonable for new locomotive but were likely underestimated by a factor of two or three for remanufactured locomotives. EPA's assembly cost estimates for remanufactured locomotives in Tier 0 were similar to those for new ones in Tier 1. However, remanufacturing takes place in locomotive repair shops that perform a variety of activities, rather than in assembly areas that specialize in only one locomotive model. EF&EE observed that these operations are much less efficient. If assembly costs were double or triple what EPA estimated, this would add about $4500-9000 per locomotive for older line-hauls meeting Tier 0 (models B and D) and close to $7000-13000 per locomotive for newer line-hauls subject to Tier 0 (models C and E) (since remanufactured locomotives make up most of the ones subject to Tier 0).

5.4.4.2. Remanufacture Costs

EPA's estimate of the costs associated with keeping locomotives in compliance with the standards through subsequent remanufactures included:

- Costs of replacing electronic fuel injectors every two years;
- Costs of electronic injection wiring harnesses, which need to be replaced in Tier 0 and Tier 1 locomotives every seven years due to embrittlement of the insulation from the heat generated by the engine;
- Cost of improved injector replacement for Tier 2 locomotives every two to three years.

[177] Estimates based on EF&EE discussion with a genset switcher company.

Table 5.3 summarizes the remanufacture cost per locomotive for each Tier and model type that was estimated by EPA.

For line-haul locomotives, expert opinion indicates that EPA's estimate of the annual remanufacture cost per locomotive and assumptions about remanufacture frequency were reasonable (EF&EE expert opinion). On the other hand, most switchers would not be remanufactured at all over the first decade of the program.

5.4.4.3. Fuel Costs

EPA estimated increases in fuel consumption due to various emission control technologies and the corresponding incremental fuel costs. Based on past developments in the industry, EPA believed that manufacturers would make every effort to eliminate any initial fuel consumption penalties, and would have largely succeeded by 2010. However, EPA included fuel economy penalties for the full 41 years covered by the analysis.

As shown in Table 5.3, fuel costs made up a large share of EPA's total per locomotive cost estimates for all model types except older line-haul models (Models B and D, Tier 0). For Tier 0, for switchers (Model A), fuel cost makes up over 90 percent of cost of compliance. For older line-haul models (B, D), fuel cost make up smaller share of the per locomotive compliance cost (11-35 percent). For newer line-haul models (C, E), fuel cost make up about half (42-56 percent) of per locomotive cost. For Tier 1 and Tier 2, fuel costs account for 53-59 percent and 70-80 percent of EPA's total cost per locomotive, respectively.

EPA's estimates of per locomotive fuel costs were calculated as: average annual fuel consumption (gal/yr) * FE penalty (%) * price ($/gal) *service life (15-21 yrs for Tier0, 40 yrs for Tier 1&2). We assess each component of the annual fuel cost calculation in turn.

Fuel price. EPA assumed a constant fuel price of $0.70 per gallon of diesel consumed (1997$). Actual prices over the first decade of compliance were substantially higher. See Table 5.4. Locomotive fuel averaged $1.20/gal (1997$) over 2000-2009[178], or over 70 percent more than EPA's estimate (AAR 2002, 2011).[179] Most of the increase in diesel price over this period was likely unanticipated. Around the time of the rulemaking, the Energy Information Administration (EIA) was forecasting a modest increase in fuel prices –

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[178] This estimate includes the impact of hedging. The railroads use hedging to stabilize the impact of fuel price volatility. In some cases, hedging saves the railroad money. In other cases, the railroad may have to spend more for fuel then it would have without hedging. The source for the data is Annual Report Form R-1, Schedule 750.

[179] The other potential source of fuel price data is the AAR Monthly Railroad Fuel Price Indexes report. The source for this report is AAR survey of the largest Class I railroads, using a methodology decided by the Interstate Commerce Commission. Data from this survey are used for the Rail Cost Adjustment Factor, which is required by law to be published by the Surface Transportation Board (and earlier, the Interstate Commerce Commission).

The individual railroad pricing information is confidential. A weighted average of the fuel price (total dollars divided by total gallons) is used to construct our index. Note that estimates based on this index indicate fuel prices were even higher than the Railroad Facts data suggests - i.e., averaging more than $2/gal (1997$) over 2000-2009 (AAR 2001, 2003, 2006, 2009).

e.g., about 0.4 percent annual growth in the end user price of distillate fuel between 1995 and 2015 (EIA 1997) – but world oil prices, the main determining factor in the price of diesel, increased substantially more than EIA was projecting at the time. Over 2000-2009, oil prices were on average 76 percent higher than what EIA had projected in the 1997 Annual Energy Outlook (AEO) (EIA 2011).

Average annual fuel consumption per locomotive. Table 5.3 includes the fuel consumption assumptions used for calculating fuel costs. For Tier 0, EPA assumed average annual fuel consumption per locomotive of 104,000 gallons for switchers and remanufactured older line-hauls (Models A, B, and D), 297,000 for newer (mostly remanufactured) line-hauls (Models C and E). Average annual fuel consumption per locomotive was assumed to be 297,000 gallons for the Tier 1 line-hauls (Models A and B), and 350,000 gallons for the remaining Tier 1 line hauls (early versions of Tier 2 design) and all Tier 2 locomotives.

EPA assumed that fuel consumption remained constant. EPA recognized that there was a short-term trend of increasing fuel consumption, but was not confident that the trend would continue. The long-term trend up to that time was for fuel consumption to remain fairly constant as a result of continual improvements in locomotive fuel economy, which offset the significant increase in ton-miles of freight hauled.

EF&EE's expert opinion is that EPA's estimates of average annual per locomotive fuel consumption were reasonable, but there is little data available against which to check this claim. The data in Table 5.4 shows that on a fleetwide basis per locomotive fuel consumption fluctuated in the early years of the program and declined more significantly after 2004. Annual per locomotive fuel consumption for all Class I locomotives in use averaged about 187,000 gallons over 2000-2001, 185,000 gallons over 2002-2004, and 165,000 gallons over 2005-2009. These fleetwide averages are lower (at least for 2002-09) than the annual fuel consumed per locomotive assumed in EPA's analysis, but without more information on the share of fuel consumption coming from new locomotives, it is difficult to draw ex post conclusions about this element of EPA's analysis. The fleetwide averages could be consistent with the EPA assumptions if operators run the newest line-haul engines more per year than the older ones in their fleet (outweighing any fuel efficiency gains from newer models). It is also possible that annual per locomotive fuel consumption was lower than EPA estimated due to fuel efficiency improvements in the new engines. (Since fuel efficiency of newer models is likely better than that of older models, and since the newest engines are likely to handle more ton-miles per year than the fleetwide average[180], all we can reasonably conclude based on existing data is that annual fuel consumption of a new locomotive was more than 186,000 gallons over 2000-2004 and more than 165,000 gallons over 2005-2009).

For switch locomotives, there is little data available with which to estimate annual fuel consumed by a new or remanufactured switcher over 2000-2009. However, it is likely that average annual fuel consumption of genset switchers was lower than EPA's assumed 104,000 gallons per year for a switch locomotive (Tier 0,

[180] Over 2000-2006, new locomotives comprised approximately 25% of the fleet, but given the higher power and more intensive use of newer locomotives, they probably handled 35-40% of total gross ton-miles (FRA 2009).

Model A). Gensets were introduced around 2005 (EF&EE expert opinion), and currently, switcher fuel consumption is about 40,000 to 70,000 gallons a year, or 30-60 percent lower than EPA's estimate.[181]

Fuel Economy Penalty. EPA used the existing engines as the fuel-economy baseline and then estimated increases in fuel consumption due to various emission control technologies and the corresponding incremental fuel costs. EPA assumed fuel penalties of:

- 2 percent for Tier 2 locomotives,
- 1 percent for Tier 1 locomotives, and
- 1-2 percent for Tier 0 locomotives.

Based on past developments in the industry, EPA believed that manufacturers would make every effort to eliminate any initial fuel consumption penalties, and would have largely succeeded by 2010. However, EPA included fuel economy penalties for the full 41 years covered by the analysis. EPA also conducted a high case sensitivity analysis with 2-4 percent fuel economy penalties (but did not adjust assumptions about fuel price or fuel consumption in the sensitivity analysis).

To determine the realized fuel economy penalty from compliance with the rule, one needs to compare the actual fuel economy of new and remanufactured locomotives over 2000-2009 with the fuel economy of new and remanufactured locomotives that would have been achieved in absence of the rule. Both of these are extremely difficult to estimate – the former because in use, model specific fuel economy information is not readily available from manufacturers, and the latter because locomotive manufacturers are constantly striving to reduce fuel consumption, as this is one of the principal decision for Class I railroads in selecting a locomotive.

For competitive reasons, locomotive manufacturers generally do not release fuel consumption data,[182] and our ability to glean anything about the realized fuel economy using existing aggregate data is extremely limited. For example, one common measure of the fuel efficiency of freight rail is revenue ton-miles per gallon of fuel consumed. By this measure, as shown in Table 5.4, the overall fuel efficiency of Class I rail has consistently improved over time, especially after 2005. As with the fuel consumption estimates discussed above, however, these measures provide an underestimate of the fuel economy of locomotives subject to the rule, since newer (and rebuilt) engines will have higher fuel efficiency than the fleetwide average. A slowdown in rebuild frequency would also be reflected in the observed fleetwide change in fuel efficiency. If we could make reasonable assumptions about the percentage of total fuel consumed and travel done by new line-haul locomotives, then we could apply these shares along with data on the number of new locomotives to get rough estimates of how much fuel economy of new line-haul locomotives improved over 2000-2009.

[181] Estimate based on EF&EE discussion with a genset switcher company.

[182] See, for instance, Figure 2 of Flynn et al. (2003), which shows the general relation between NOx and fuel economy, but omits the units from the fuel-economy axis.

Even so, the challenge of constructing the counterfactual would remain. Given the long term trend of improved fleetwide rail efficiency observed before the rule,[183] and projections made in the year before the rule was promulgated,[184] the fuel economy of new locomotives may have increased even more than observed over 2000-2009 in absence of the emission standards. However, with other changes going on in the industry over this period (e.g., increasing share of unit train service, increasing congestion),[185] we are skeptical that it will be possible to identify a fuel economy change attributable to the rule based on aggregate data.

Model specific information from the trade press indicates that manufacturers were able to develop new locomotives and remanufacture kits to meet emission standards without sacrificing fuel economy. For example, in 2009 EMD Tier 0+ kits offered up to 2 percent fuel savings versus previous engine configurations.[186] It is unclear, however, to what extent fuel economy improvements would have been implemented in the absence of the rule. It is therefore also unclear to what extent fuel economy improvements actually achieved were motivated by the rule and associated actions to comply. Locomotive suppliers would have had incentive to continue to look for ways to offer improvements in fuel efficiency, especially in the face of rising fuel prices, so it is possible that they would have been able to tweak existing models or introduce even more fuel-efficient ones in the absence of pollution controls.

Compared to a counterfactual case in which the locomotive manufacturers were able to use the latest technical advances to optimize fuel consumption without regard to NOx or PM emissions, EF&EE expert opinion is that the fuel consumption penalty was higher than anticipated, probably about 2 to 4 percent. This is based on experience and professional judgment, and interpretation of optimization studies undertaken on an EMD 710-series locomotive engine (Dolak and Bandyopadhyay 2011), however, and not on public-domain data. Dolak and Bandyopadhyay (2011) show that even for engines developed to meet Tier 2 standards, there remains a tradeoff between NOx and fuel-efficiency. The results shown in the paper suggest that, for

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[183] Based on data in Table 5.4, revenue ton-miles per gallon fuel consumed increased on average nearly 2% annually between 1990 and 2000 (AAR 2002).

[184] EIA forecast in the year before the rule was promulgated projected a continued increase in efficiency. Overall rail efficiency (ton miles per BTU) was forecast to achieve on average a 1% improvement annually between 1995 and 2015 (EIA 1997).

[185] Unit train service, typically 100 cars or more, is loaded at the origin point with one commodity follows a direct route to the destination point without passing through yards or terminals on the way and remains intact. Most unit trains are either intermodal or coal trains, It is more fuel efficient than carload service which is a fuel-intensive operation because of the need for switch engines in breaking up trains and making new ones in every terminal through which the shipment passes. In recent years, there has been a strong trend towards unit trains—partly due to the growth of intermodal traffic from West-coast ports and coal traffic from the Powder River Basin (FRA 2009).

[186] See, for example, article in Progressive Railroading, August 2009, "Locomotive Manufacturers Offer Information on their Fuel-Saving Models", http://www.progressiverailroading.com/mechanical/article/Locomotive-Manufacturers-Offer-Information-on-their-FuelSaving-Models--21139#.

the range of plausible injection timing settings, the difference between lowest NOx (subject to PM limitations) and lowest fuel consumption fuel efficiency is roughly 2 to 4 percent in fuel efficiency.

In addition, it is important to keep in mind that efforts to control emissions may lead to other improvements in production processes and/or equipment which would not have occurred in the absence of the regulation. Manufacturers could have added technologies to new locomotives and remanufacture kits that were not strictly needed to comply with the emission standards but helped to offset any fuel economy loss from the pollution controls. The Tier 0 discussion in Section C.2 above and the locomotive manufacturer's own assessment[187] suggest that this occurred. In this case, the fuel penalty associated with operating costs would be offset to some unknown extent, though an additional hardware cost would be attributable to the regulation.

As for switch locomotives, EPA assumed this group could be brought into compliance with Tier 0 by retarding injection timing alone, with a fuel economy penalty of only 2 percent. EF&EE's expert opinion is that additional changes were also needed – i.e., improvements in fuel injectors at a minimum. In practice, however, very few if any, of these units were remanufactured. Some operators instead moved to genset switchers which, as already mentioned, had significant fuel savings compared to conventional older switchers. One industry source reports fuel cost savings with a genset are at least 50 percent (EF&EE); another reports "fuel savings of more than 20 percent, compared to existing diesel locomotive technology in side-by-side use, have been demonstrated."[188] However, most purchases of gensets or hybrids to date have been financed in part with air quality improvement grants, and it may be hard to compete with existing four-axle locomotives on the second-hand market (FRA 2009).

5.5. Overall Implications and Study Limitations

As stated at the outset, the purpose of this paper is not to review the ex ante cost analysis of the 1998 Locomotive rule. Rather, the goal is to explore available data to gauge whether actual compliance costs may have diverged from ex ante cost estimates and, if so, what factors might have contributed to any divergence (e.g., changing market conditions, technological innovation, etc.) as described in Chapter 1 of this report. Our findings are summarized in Table 5.6 and discussed briefly below.

We encountered significant methodological challenges in conducting an ex post assessment of the 1998 Locomotive rule. There is a paucity of data needed to calculate various components of the realized costs, especially information on the actual costs of individual control technologies, and data on fuel consumption and fuel economy of new and remanufactured locomotives. We are also extremely limited in our ability to

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[187] Lawson, Pete, General Electric Transportation Systems, Faster Freight Cleaner Air Conference, Long Beach, CA, February 27, 2007, www.fasterfreightcleanerair.com/presentations.html#California2007. Also see GE's promotional materials for the Evolution Series locomotive: http://www.getransportation.com/resources/doc_download/275-evoloution-series-engine.html

[188] http://www.gwrr.com/about_us/community_and_environment/gwi_green/genset_locomotives.be

Table 5.6: Summary of Findings -

Components of Cost Estimate			Source of Ex Post Information	Assessment (Compared to Ex Ante)
Regulated Universe	Types of Entities		EF&EE	Reasonable
	Number of Entities		AAR for all Class I EF&EE for switch	New – Higher Remanufactured - Lower Switch – Lower
Methods of Compliance	Types		EF&EE + journal articles	Reasonable
	Usage		EF&EE + journal articles	Higher than anticipated for some technologies on some model types
Per Locomotive Compliance Costs	Direct, One-Time	Per Locomotive Fixed Cost	EF&EE + EPA certification data	New- Reasonable Remanufactured – Higher than projected
		Per Locomotive Variable Cost	Hardware Costs: EF&EE + journal articles	Hardware Costs: Line Haul – Higher than projected Switch – Inconclusive
			Assembly Costs: EF&EE	Assembly Costs: New- Reasonable Remanufactured - Higher than projected
	Direct, On-Going	Operating (Additional Fuel Costs)	Fuel price: AAR	Fuel price: Higher than projected
			Annual Fuel Consumption: EF&EE for line haul, genset websites for switch	Annual Fuel Consumption: Line Haul – Reasonable Switch – Lower
			Fuel economy penalty: EF&EE+ journal articles, AAR, FRA , manufacturer promotional materials	Fuel economy penalty: Line Haul – Likely higher Remanufactured Switch –Likely higher
		Maintenance	EF&EE	Reasonable
	Indirect			
Opportunity Costs				
Total Per Locomotive Cost				Line Haul – Likely higher Switch – Inconclusive (difficult to assess whether alternative technology would have been developed in absence of the rule)
TOTAL COSTS				Line Haul – INCONCLUSIVE Switch – LIKELY LOWER (very few remanufactured and new units adopted alternate technology, but with some support from air quality grants)

construct a reasonable counterfactual for each component of the cost analysis. For example, to the extent that more efficient line-haul locomotives (through advancements in engine design, cooling systems, etc.) would have been developed and adopted over time in the absence of the rule, the costs of these technologies should not be attributed to the 1998 rule, and the costs of the Tier 1 and Tier 2 standards were less than EPA's ex ante estimate. Due to data limitations and our minimal ability to speculate about what would have occurred in the absence of the rule, most of our assessment is limited to comparing the opinion of one industry expert about how industry complied with the emission standards and some ex post information to what EPA assumed. Finally, examining whether EPA's method for building up the fixed costs of compliance provides an accurate reflection of the true initial cost is outside the scope of our preliminary analysis. We have not investigated the extent to which the 20 percent manufacturer markup on per locomotive initial compliance cost was appropriate. We are also not able to determine to what extent manufacturers and remanufacturers used average, banking and trading provisions of the rule to meet overall emissions goals at lower cost.

Keeping the above caveats in mind, a number of EPA's ex ante estimated or assumed cost factors were fairly similar to the limited ex post empirical data and EF&EE opinion. These assumptions include: locomotive model types, the types of compliance technologies, fixed costs and assembly costs for newly manufactured locomotives, hardware costs of each emission control technology, and annual remanufacture costs per locomotive. However, our assessment identified other areas in which the ex ante estimates differed from the realized per-unit compliance costs over the first decade of the program (2000-2009). First, the initial per-unit costs for remanufactured line-haul locomotives (Tier 0) were likely higher than EPA estimated because the large number of remanufactured engine families certified and the smaller number of units remanufactured increased the fixed cost per locomotive. Second, increased usage rates for some technologies caused variable costs for remanufactured locomotives to be higher than the EPA estimates for most model types. Third, operating costs per locomotive (new or remanufactured) imposed by the rule may have been higher than anticipated because actual fuel prices were much higher than EPA assumed. This implies, the same percentage fuel consumption penalty could have contributed to higher dollar cost due to higher fuel prices; over the first decade of the program, total per locomotive costs could have been 5-32 percent higher for Tier 0 (line-hauls built 2000-2001 or remanufactured), 14-19 percent higher for newly built line-haul locomotives over 2002-2004 (Tier 1), and 36 percent higher for newly built line-haul locomotives over 2005-2009 (first five years of Tier 2).[189]

The impact of the higher fuel price may have been offset to some extent by lower fuel consumption and/or lower fuel penalties than anticipated by EPA. The information available to us suggests that manufacturers were able to reduce fuel penalties from the pollution controls by designing more fuel efficient locomotives, but we are unable to quantitatively assess how the additional costs incurred to bring about these fuel efficiency improvements compare to the ex ante fuel economy penalty costs of the rule. In addition, the

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[189] These percentages are calculated with only 10 years of the fuel and remanufacture costs as a way to approximate the operating costs incurred until each locomotive is remanufactured to the revised standards. Attributing all operating costs over the remaining life of the locomotive to the 1998 rule would be inappropriate given the 2008 revisions to the standards.

difficulty in constructing the counterfactual remains. Given the strong incentive for manufacturers to improve fuel efficiency, especially in the face of rising fuel prices as occurred in the 2000s, it is likely that fuel efficiency improvements would have occurred over time in the absence of the regulation. In fact, compared to the counterfactual case in which the locomotive manufacturers would have used the latest technical advances to optimize fuel consumption without regard to NOx and/or PM emissions, it is possible that the fuel economy penalties were higher than EPA's assumptions, which would further increase the fuel costs of compliance. Taken together, these issues suggest that, given the information currently available to us, it is extremely difficult to estimate the extent to which the impact of higher fuel price may have been offset by changes in other components of the fuel cost of the rule. However, even setting aside the operating cost impact of the rule, EF&EE expert opinion and accompanying information about the variable and fixed costs of compliance suggest that the total per locomotive cost was likely higher than EPA's ex ante analysis projected for most new line-haul and especially most remanufactured line-haul locomotives subject to the rule over 2000-2009.

Our ex post assessment of the total cost of bringing line-haul locomotives into compliance with the 1998 rule is inconclusive. This is because total compliance cost depends not only on the per locomotive compliance cost but also on the number of locomotives affected by the regulation. Over 2000-2009, the number of newly built line-haul locomotives was higher but the number of remanufactured line-haul locomotives was lower than EPA's estimate. It is difficult to tease out the extent to which this was driven by an industry reaction to the 1998 rule (or the 2008 rule) or by external factors. If operators found it to be more cost-effective to buy new rather than remanufacture the old units to Tier 0 standards, then it would be inappropriate to conclude that the higher-than-expected sales of new Tier 2 locomotives added to the cost of complying with the standards without accounting for the offsetting savings from lower maintenance and fewer remanufactures over this time period. It is possible that the lower costs due to far fewer remanufactures taking place than anticipated may have outweighed the higher compliance costs from new line-hauls.

The total costs of bringing switch locomotives into compliance with the 1998 rule was likely lower than anticipated by EPA, but this has not had a major impact on overall costs of the 1998 locomotive rule because switchers comprise a relatively minor part of the overall locomotive market. Any new switch locomotives sold would be of the genset type, which have higher initial costs but lower fuel and maintenance costs than the conventional switchers EPA anticipated would be remanufactured to meet emission standards, but without knowing to what extent the development of gensets would have occurred in absence of the rule, it is difficult to draw conclusions about the total per locomotive cost of compliance for this segment of the market. Regardless, the large supply of old locomotives that can be kept running at low cost limits the potential sales of new switchers and old ones can be run for a long time without remanufacturing so very few switch locomotives were likely remanufactured over 2000-2009.

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Appendix 5.1: EPA's Emission Standards for Locomotives and Locomotive Engines

The purpose of this questionnaire is to collect information and feedback from industry experts on the U.S. Environmental Protection Agency's analysis of compliance costs for the emission standards rule for locomotives as undertaken for rule development in 1998. The goal of this project is to assess whether EPA's estimates of compliance costs at the time of rule promulgation were accurate. We also want to determine whether EPA correctly identified all the process technologies that were available to reduce emissions from locomotives.

This questionnaire summarizes the assumptions and cost estimation framework used by EPA to determine the costs of treatment technologies that were identified as candidates for compliance with the locomotives emissions standards rule. We want to assess whether the actual costs of emission reduction treatments differed substantially from EPA's estimates at the time of rule development. In addition, we hope to understand the reasons for potential differences in these estimates, including insight into whether new or modified treatment technologies may have been implemented to meet the emission standards, which EPA did not account for in its cost analysis.

According to the Paperwork Reduction Act of 1995, an agency may not conduct or sponsor, and a person is not required to respond to, a collection of information unless it displays a valid OMB control number. The valid OMB control number for this information collection is 2090-0028.

Section 1 Regulatory Background

On April 16, 1998, EPA published a rule for a comprehensive emission control program that subjected locomotive manufacturers and railroads to emission standards, test procedures, and a full compliance program. The rule was applicable to all locomotives manufactured in 2000 and later, and any remanufactured locomotive originally built after 1973. The rule exempted locomotives powered by an external source of electricity, steam-powered locomotives, and locomotives newly manufactured prior to 1973.

The rule established three separate sets of emission standards (Tiers), with applicability of the standards dependent on the locomotive's date of manufacture:

- Tier 0 applied to locomotives and locomotive engines originally manufactured from 1973 through 2001;
- Tier 1 applied to locomotives and locomotive engines originally manufactured from 2002 to 2004; and
- Tier 2 applied to locomotives and locomotive engines originally manufactured in 2005 or later.

Table 1 presents the emission and smoke standards for each locomotive tier.

Table 1. Summary of Emission and Smoke Standards for Locomotive Rule							
Locomotive Type	**Gaseous and Particulate Emissions (g/bhp-hr)**				**Smoke Standards (% Opacity-Normalized)**		
	HC2	**CO**	**NOX**	**PM**	**Steady State**	**30-sec Peak**	**3-sec Peak**
Tier 0 Line-haul Duty-cycle	1.00	5.0	9.5	0.60	30	40	50
Tier 0 Switch Duty-cycle	2.10	8.0	14.0	0.72	30	40	50
Tier 1 Line-haul Duty-cycle	0.55	2.2	7.4	0.45	25	40	50
Tier 1 Switch Duty-cycle	1.20	2.5	11.0	0.54	25	40	50
Tier 2 Line-haul Duty-cycle	0.30	1.5	5.5	0.20	20	40	50
Tier 2 Switch Duty-cycle	0.60	2.4	8.1	0.24	20	40	50

In 2008, EPA adopted a new set of emission standards, Tier 3 and Tier 4, for locomotives newly manufactured or remanufactured after 2008. Therefore, ***the universe of locomotives that were subject to the 1998 rule would be limited to locomotives originally built or remanufactured between 2001 and 2008, after which the 2008 revision took effect for newly manufactured or remanufactured locomotives.*** The 1998 rule's emission standards continue to apply to locomotives built or remanufactured between 2001 and 2008 after 2008 until they are remanufactured or taken out of service. EPA estimated the costs for the 1998 rule through 2040 to ensure complete fleet turnover due to the long service life of the typical locomotive. However, because the 1998 rule no longer applies to all the locomotives for which EPA estimated costs due to the promulgation of the 2008 rule, the most relevant costs for this analysis are likely the annual per locomotive costs (and not the total 40-year or net present value costs).

Section 2 Compliance Technologies

To estimate costs of the proposed rule, EPA projected the number of new and remanufactured locomotives for several categories defined by emission standard and locomotive model type. This section discusses the emission control technologies that EPA expected would already be available at the time the locomotive emissions standards would take effect. Among those, EPA considered use of the following technologies:

- Retarding fuel injection - optimizing injection timing and duration to achieve significant NOx emissions reductions at minimal cost (2 degree or 4 degree timing retard depending on potential fuel economy impacts);
- 4 pass after cooler – changing from two-pass to a four-pass aftercooler to lessen the degree of timing retard needed through enhanced charge air cooling;
- Improved mechanical and electrical injectors - optimizing spray pattern from the nozzle in conjunction with the configuration of the combustion chamber and induction swirl to achieve emission reductions;
- Add electronic fuel injection – to improve control of injection rate and timing;
- Engine Modifications - reduction in engine size to achieve the desired lower power rating;
- Improved turbocharger –ensuring that fuel consumption and emissions formation are minimized, including preventing smoke generation due to turbo lag; changing the geometry of the gas flow passages in the turbine to improve the response time of the turbocharger;

- Split cooling - an aftercooler that uses a coolant system separate from the engine coolant system;
- High pressure injection – to shorten the duration of the fuel injection event, which allows a delay in the initiation of fuel injection causing lower peak combustion temperatures and reduced NOx formation, and also reduces fuel economy penalties associated with retarded injection timing; and
- Combustion chamber design - redesign of the shape of the combustion chamber and the location of the fuel injector to optimize the motion of the air and the injected fuel with respect to emission control.

The effective use of some of these technologies can be optimized through the use of other technologies, and adverse effects of some technologies can be limited or eliminated through the application of other technologies. For this reason, in estimating compliance costs EPA considered use of multiple technologies together to form a larger emission reduction system.

The emission control technologies that EPA expected to be used for each of the Tiers are discussed below.

Emission Control Technologies for Tier 0 Locomotives

- Locomotives equipped with turbocharged engines would be able to employ: modified/improved fuel injectors, enhanced charge air cooling, injection timing retard, and in some cases, improved turbochargers, to reduce NOx emissions.
- EPA expected that engine coolant would continue to be the cooling medium in most cases, rather than a separate cooling system, and that it would be cost-effective to replace two-pass aftercoolers with four-pass aftercoolers during the remanufacturing process.
- The tools available to manufacturers to reduce emissions for naturally-aspirated and Roots-blown engines would be modifications to the fuel system, modifications to the combustion chamber and injection timing.

Q1a: Were all Tier 0 emission control technologies captured by EPA? Were there any emission control technologies that were never used to achieve compliance? Were there any additional emission control technologies or substantially modified emission control technologies used to achieve compliance? If so, please explain.

A1a: >>

Emission Control Technologies for Tier 1 Locomotives

- Tier 1 locomotives would be able to incorporate all the technologies available for Tier 0 locomotives.
- Additionally, electronic controls and enhanced aftercooling could be used for Tier 1 compliance. Further, timing retard could be used to reduce NOx emissions without a negative impact on PM.

- In addition, some models could use in-cylinder and turbocharger modifications.
- Increased compression ratios could be used to reduce PM emissions and ignition delay. Upgraded turbocharger designs would reduce smoke emissions.

Q2a: Were all Tier 1 emission control technologies captured by EPA? Were there any emission control technologies that were never used to achieve compliance? Were there any additional emission control technologies or substantially modified emission control technologies used to achieve compliance? If so, please explain.

A2a: >>

Emission Control Technologies for Tier 2 Locomotives

- With the change from DC to AC traction motors, manufacturers would be using new four-stroke engines, which would have lower PM emissions as they achieve better oil control.
- EPA expected additional NOx and PM emission reductions to be possible through continued refinements in charge air cooling, fuel management, and combustion chamber configuration.
- Improved fuel management would include increased injection pressure, optimized nozzle hole configuration, and rate-shaping.
- Potential combustion chamber redesigns would include the use of reentrant piston bowls and increased compression ratio.

Q3a: Were all Tier 2 emission control technologies captured by EPA? Were there any emission control technologies that were never used to achieve compliance? Were there any additional emission control technologies or substantially modified emission control technologies used to achieve compliance? If so, please explain.

A3a: >>

Q3b: Were selective catalytic reduction and/or alternative-fueled engines used as emission control strategies? How often were they used?

A3b: >>

EPA assumed that the Tier 0 locomotives could be grouped into 5 model categories (or engine families): switch locomotives from Electro-Motive Diesel (Model A), older and newer line-haul locomotives from the Electro-Motive Diesel (Model B and C), and older and newer line-haul locomotives from General Electric Transportation Systems (Model D and E). For Tier 1 locomotives, EPA believed that early versions of the new engine designs used to meet the Tier 2 standards made their appearance during the Tier 1 period. Thus, EPA assumed there would be two Tier 1 models for each of the two manufacturers. EPA assumed that for Tier 2 locomotive each manufacturer would have a single model.

Table 2 presents a crosswalk between the expected compliance technologies, their usage, and the locomotive model types by tier.

TABLE 2: CONTROL OPTIONS, EXPECTED USAGE AND LOCOMOTIVE MODELS

Tier	Expected Technology Usage and Models Developed for Cost Analysis	2 deg timing retard	4 deg timing retard	4 pass aftercooler	Improved mechanical injectors	Add electronic fuel injection	Improved electronic injectors	Increased compression ratio	Improved turbocharger	Split cooling	High pressure injection	Combustion chamber design
Tier 0 (1973–2001)	Percent locomotives using technology	50	50	60	30	13	27	20	30	-	-	-
	Models using technology											
	A	X	X									
	B	X	X	X	X							
	C	X		X			X					
	D	X		X		X			X			
	E	X					X	X	X			
Tier 1 (2002–2004)	Percent locomotives using technology	100	-	-	-	-	100	50	25	75	100	100
	Models using technology											
	A	X					X	X		X	X	X
	B	X					X	X	X		X	X
	C	X					X			X	X	X
	D	X					X			X	X	X
Tier 2 (2005–2010)	Percent locomotives using technology	-	100	-	-	-	100	-	-	100	100	100
	Models using technology											
	A		X				X			X	X	X
	B		X				X			X	X	X
Tier 2 (after 2010)	Percent locomotives using technology	-	100	-	-	-	100	-	-	100	100	100
	Models using technology											
	A		X				X			X	X	X
	B		X				X			X	X	X

Source: U.S. EPA (1998).

Q4a: Based on your professional knowledge and experience, were the expected usage frequencies for each technology considered by EPA for each Tier representative of actual technology usage frequencies over the time period 1998 to 2008? If not, please explain.

A4a: >>

Q4b: Based on your professional knowledge and experience, were models used by EPA to estimate costs for each Tier representative of the actual locomotive models employed for compliance with the Locomotive rule over the time period 1998 to 2008?

A4b: >>

Q4c: If not, were there any other locomotive models (aside from the ones used by EPA) that were compliant with the rule? If so, please describe.

A4c: >>

Section 3 Estimated Number of Locomotives

EPA estimated the number of newly manufactured and remanufactured locomotives based on information on the number of locomotives currently in service and existing production, remanufacture, and retirement rates for Class I, II, and III and passenger rail locomotives[190].

EPA obtained information on Class I locomotives from the Association of American Railroads Annual Railroad Facts publication. About 17,500 of Class I locomotives were manufactured post 1972, most of which were used in line-haul service (Tier 0, Models B through E). The 3,500 older locomotives that were manufactured prior to 1972 are used as switchers (Tier 0, Model A). EPA assumed that by 2008, almost all 1973 through 1999 line-haul locomotives (13,200) would be remanufactured to meet EPA's standards. EPA also assumed there would be 400 newly manufactured line-haul locomotives for years 2000-2004, 600 for years 2005-2010, and 300 new units for all subsequent years.

For Class II and III locomotives, EPA obtained information from American Short Line Railroad Association, which represents most Class II and Class III railroads. EPA projected that there would be about 600 post-1972 locomotives and 3600 older locomotives in the 1999 Class II and III fleet (Tier 0, Models A through C). EPA assumed that during the first 10 years of the program, Class II and III railroads would bring about 50 locomotives into compliance with Tier 0 standards each year. EPA further assumed that in 2012, these railroads would purchase about 150 complying Tier 0 locomotives each year from Class I railroads.

For passenger locomotives, EPA primarily relied on information from Amtrak and the American Public Transportation Association. There were roughly 463 diesel locomotives in commuter rail service in 1995, with 397 of these manufactured after 1972. EPA projected that about 100 locomotives would be brought into compliance during each of the first five years of the program, and that all uncontrolled locomotives would be removed from passenger service by 2011.

[190] In 1994, Surface Transportation Board (STB) classified a railroad as Class I if its revenue was higher than $255.9 million. Railroads with revenue between $20.5 and $255.8 millions were considered Class II, while railroads with annual revenue less than $20.5 million were Class III.

Table 2 shows the estimated total number of locomotives in each Tier for each model type.

TABLE 2: ESTIMATED NUMBER OF NEW AND REMANUFACTURED LOCOMOTIVES AFFECTED BY THE RULE		
Tier	**Model**	**Number of Locomotives**
Tier 0 (1973 – 2001)	A	3,000
	B	4,900
	C	2,930
	D	2,035
	E	2,965
	Total	***15,830***
Tier 1 (2002 – 2004)	A	360
	B	360
	C	360
	D	360
	Total	***1,440***
Tier 2 (2005 – 2010)	A	1,700
	B	1,700
	Total	***3,400***
Tier 2 (after 2010)	A	300
	B	300
	Total	***600***
Source: U.S. EPA (1998).		

Note that because EPA adopted new standards applicable to any locomotives manufactured after 2008, EPA's estimate of Tier 2 locomotives after 2010 is not relevant.

Q5a: Was EPA's estimate of the number of locomotives affected by each Tier of standards accurate? If not, please explain why or how the estimate is inaccurate.

A5a: >>

Q5b: If possible, please provide an estimate of the number of locomotives affected by each Tier of standards for each model type in the table below

A5b: >>

Tier	Model	Number of Class I Locomotives	Number of Class II Locomotives	Number of Class III Locomotives	Number of Passenger Locomotives
Tier 0 (1973 – 2001)	A				
	B				
	C				
	D				
	E				
	Total				
Tier 1 (2002 – 2004)	A				
	B				
	C				
	D				
	Total				
Tier 2 (2005 – 2010)	A				
	B				
	Total				

Section 4 Costs

Manufacturers who produce new locomotives incurred **fixed costs** (initial investments made before the beginning of production) and **variable costs** (production costs proportional to the number of locomotives manufactured) that were dependent on the technology and emission standard.

The incremental costs incurred by the manufacturers (along with the assumed 20% manufacturer markup)

-increased the prices of the new locomotives that were purchased by the operators. This increase in price was the **initial cost** of compliance experienced by the operators. In addition to the initial costs, the operators were expected to incur the following operation and maintenance costs: **remanufacture costs** (i.e., costs associated with keeping the locomotive in compliance with the standards through subsequent remanufactures) and **fuel costs** (i.e., cost of fuel economy penalties associated with compliance).

Detailed descriptions of each type of cost and EPA's assumptions are provided in the sub-sections below. Table 3 summarizes the cost per locomotive estimated by EPA for each Tier and model type.

Table 3: Calculation of Per Locomotive Compliance Costs (1997 US Dollars)													
	Tier 0					Tier 1				Tier 2 (2005-2010)		Tier 2 (After 2010)	
Cost Component	**Model A**	**Model B**	**Model C**	**Model D**	**Model E**	**Model A**	**Model B**	**Model C**	**Model D**	**Model A**	**Model B**	**Model A**	**Model B**
Number of Locomotives	3000	4900	2930	2035	2965	360	360	360	360	1700	1700	300	300
Initial Costs													
Variable Costs													
Hardware Costs													
2 deg timing retard	$0	$0	$0	$0	$0	$0	$0	$0	$0	--	--	--	--
4 deg timing retard	$0	$0	--	--	--	--	--	--	--	$0	$0	$0	$0
4 pass aftercooler	--	$5,000	$5,000	$5,000	--	--	--	--	--	--	--	--	--
Improved mechanical injectors	--	$800	--	--	--	--	--	--	--	--	--	--	--
Add electronic fuel injection	--	--	--	$35,000	--	--	--	--	--	--	--	--	--
Improved electronic injectors	--	--	$2,000	--	$2,000	$2,000	$2,000	$2,000	$2,000	$2,000	$2,000	$2,000	$2,000
Increased compression ratio	--	--	--	--	$800	$800	$800	--	--	--	--	--	--
Improved turbocharger	--	--	--	$25,000	$25,000	--	$25,000	--	--	--	--	--	--
Split cooling	--	--	--	--	--	$25,000		$25,000	$25,000	$25,000	$25,000	$25,000	$25,000
High pressure injection	--	--	--	--	--	$2,000	$2,000	$2,000	$2,000	$2,000	$2,000	$2,000	$2,000
Combustion chamber design	--	--	--	--	--	$800	$800	$800	$800	$800	$800	$800	$800
Assembly costs	$0	$4,480	$6,720	$4,480	$6,720	$6,720	$6,720	$560	$560	$560	$560	$560	$560
Subtotal Variable cost per locomotive	*$0*	*$10,280*	*$13,720*	*$69,480*	*$34,520*	*$37,320*	*$37,320*	*$30,360*	*$30,360*	*$30,360*	*$30,360*	*$30,360*	*$30,360*
Fixed Costs													
Engineering costs	$800,000	$1,700,000	$2,800,000	$1,700,000	$2,800,000	$3,600,000	$3,600,000	$3,600,000	$3,600,000	$4,000,000	$4,000,000	--	--
Testing costs	$422,783	$422,783	$845,566	$422,783	$845,566	$4,227,829	$4,227,829	$4,227,829	$4,227,829	$8,455,659	$8,455,659	$582,900	$582,900
Tooling	--	--	--	--	--	$1,000,000	$1,000,000	$1,000,000	$1,000,000	$1,000,000	$1,000,000	--	--
Technical support	$200,000	$350,000	$500,000	$350,000	$500,000	$500,000	$500,000	$350,000	$350,000	$350,000	$350,000	--	--
Total fixed costs per supplier	$1,422,783	$2,472,783	$4,145,566	$2,472,783	$4,145,566	$9,327,829	$9,327,829	$9,177,829	$9,177,829	$13,805,659	$13,805,659	$582,900	$582,900
Total Fixed Costs[1]	$4,268,409	$7,418,409	$12,436,818	$2,472,803	$4,145,606	$9,328,029	$9,328,029	$9,178,029	$9,178,029	$13,806,059	$13,806,059	$582,915	$582,915
Subtotal Fixed cost per locomotive[2]	*$1,423*	*$1,514*	*$4,245*	*$1,215*	*$1,398*	*$25,911*	*$25,911*	*$25,495*	*$25,495*	*$8,121*	*$8,121*	*$1,943*	*$1,943*
Initial Cost Per Locomotive[3]	**$1,707**	**$14,153**	**$21,558**	**$84,834**	**$43,102**	**$75,877**	**$75,877**	**$67,025**	**$67,025**	**$46,177**	**$46,177**	**$38,764**	**$38,764**
Fuel Costs													
Average Fuel Consumption	104000	104000	297000	104000	297000	297000	297000	350000	350000	350000	350000	350000	350000
FE Penalty	2%	1%	1%	1%	2%	1%	1%	1%	1%	2%	2%	2%	2%
Gallons of fuel/year[4]	2,080	1,040	2,970	1,040	5,940	2,970	2,970	3,500	3,500	7,000	7,000	7,000	7,000
Cost per year (@ $0.70/Gal.)	$1,456	$728	$2,079	$728	$4,158	$2,079	$2,079	$2,450	$2,450	$4,900	$4,900	$4,900	$4,900
Fuel Costs Per Locomotive	**$21,840**	**$10,920**	**$43,659**	**$10,920**	**$87,318**	**$83,160**	**$83,160**	**$98,000**	**$98,000**	**$196,000**	**$196,000**	**$196,000**	**$196,000**
Remanufacture Costs													
Cost per year	$0	$400	$846	$400	$846	$1,000	$1,000	$240	$240	$240	$240	$240	$240
Service life	15	15	21	15	21	40	40	40	40	40	40	40	40
Remanufacture Cost Per Locomotive	**$0**	**$6,000**	**$17,766**	**$6,000**	**$17,766**	**$40,000**	**$40,000**	**$9,600**	**$9,600**	**$9,600**	**$9,600**	**$9,600**	**$9,600**
TOTAL COST PER LOCOMOTIVE	**$23,547**	**$31,073**	**$82,983**	**$101,754**	**$148,186**	**$199,037**	**$199,037**	**$174,625**	**$174,625**	**$251,777**	**$251,777**	**$244,364**	**$244,364**

1. Represents the fixed cost per supplier multiplied by the number of suppliers for each model type (e.g., 3 suppliers for Tier 0 Models A, B and C, and 1 supplier for the remaining model types).
2. Total fixed costs for all suppliers divided by the number of locomotives in each model category.
3. Sum of total hardware (variable) cost per locomotive and total fixed cost per locomotive plus 20% manufacturer markup.
4. Represents average fuel consumption multiplied by the fuel economy penalty.

4.1 Initial Costs

4.1a Fixed Costs

Fixed costs of manufacturing locomotive models compliant with the emissions standards included costs of testing, engineering, tooling, and technical support.

- The *testing costs* included developmental testing, as well as certification testing, production line testing and in-use testing. Testing costs also included the costs of any necessary additional facilities and equipment for emissions testing, plus engineering, operating and maintenance costs for the testing facility. These costs, when allocated over the estimated testing requirement, were estimated to amount to about $21,000 per test prior to 2010 and about $39,000 per test after 2010 when the developmental testing would be completed (U.S. EPA, 1998).
- The *engineering costs* category represented the estimated average cost for the number of engineering work years EPA projected to be required to develop the calibrations and hardware necessary for meeting the emission standards. This also included the effort for any ancillary changes made to the locomotives to accommodate the required new hardware.
- The *tooling costs* included costs for any additional or modified tooling necessary to produce the emission control hardware, as well as for any required setup changes. Because EPA estimated that Tier 0 compliance would be achieved through calibration changes or hardware obtained from suppliers (particularly in the case of aftermarket remanufacturers), EPA did not estimate specific tooling costs for Tier 0.
- The *technical support* costs included the costs of any changes that would be required in the technical support that manufacturers provide to users, including any necessary operator or maintenance training and changes to technical publications that provide operating and maintenance guidance.

EPA estimated these fixed costs for each locomotive supplier and divided by the total number of locomotives (assuming suppliers would recover costs from the locomotives) to derive per locomotive costs. EPA assumed that there were three suppliers each for Tier 0 Model A, B, and C locomotives, and one supplier each for Tier 0 Model D and E, Tier 1 Model A, B, C, and D, and Tier 2 Model A and B locomotives. EPA based this assumption on the numbers of independent part suppliers and remanufacturers for the various locomotive models at the time of the analysis (U.S. EPA, 1998). The number of suppliers EPA estimated for each model category was less than the total number of suppliers because EPA assumed that the manufacturers for which initial costs were cost prohibitive would pay other manufacturers with the ability to incur initial costs to perform the necessary services.

Because the fixed costs were for goods and services that are useful for more than one year of production, EPA amortized initial costs over 5 years (i.e., manufacturers would recover costs within the first five years of production). For Tier 2, because the standards were to be in effect for longer than 5 years, EPA developed two sets of unit costs (because initial fixed costs would be recovered by 2010). EPA did not calculate separate compliance costs reflecting fully-recovered fixed costs for Tier 0 and Tier 1 as it did for Tier 2, because the initial hardware costs occur only at original manufacture (for Tier 1) or the first remanufacture (for Tier 0), and thus are applicable only during the first few years of the program.

Table 3 summarizes the fixed costs of manufacturing for each Tier and model type that were estimated by EPA.

Q6a: Were EPA's assumptions regarding number of suppliers and distribution of fixed costs reasonable?

A6a: >>

Q6b: Based on your professional knowledge and experience, were the fixed costs per locomotive for the various control options and Tiers in Table 3 over- or under-estimated? If so, please explain why.

A6b: >>

4.1b Variable Costs

Initial incremental variable compliance costs included costs of hardware and assembly.

- The *hardware costs* represented the emission reduction technologies EPA projected that manufacturers would employ for compliance with the standards. EPA developed hardware cost estimates for the following technologies:
    - Retarding fuel injection (2 degree or 4 degree timing retard)
    - 4 pass after cooler
    - Improved mechanical and electrical injectors
    - Electronic fuel injection
    - Engine Modification
    - Improved turbocharger
    - Split cooling
    - High pressure injection
    - Combustion chamber design

Table 3 specifies combinations of these technologies that were expected to be used for each locomotive model type and Tier.

- *Assembly costs* included the labor and overhead costs for retrofitting (in the case of Tier 0) or for initial installation of the new or improved hardware. These also varied with the characteristics of individual locomotives and the type of hardware necessary for compliance with the applicable emission standards.

Q7a: Based on your professional knowledge and experience, were the per locomotive hardware costs for each technology in Table 3 over- or under-estimated? If so, please explain why.

A7a: >>

Q7b: Based on your professional knowledge and experience, were the per locomotive assembly costs for each model and Tier in Table 3 over- or under-estimated? If so, please explain why.

A7b: >>

4.2 Remanufacture Costs Incurred by the Train Operators

The costs associated with keeping locomotives in compliance with the standards through subsequent remanufactures included:

- Costs of replacing electronic fuel injectors every two years;
- Costs of electronic injection wiring harnesses, which need to be replaced in Tier 0 and Tier 1 locomotives every seven years due to embrittlement of the insulation from the heat generated by the engine;
- Cost of improved injector replacement for Tier 2 locomotives every two to three years.

Q8a: Based on your professional knowledge and experience, were the annual per locomotive remanufacture costs for each model type and Tier in Table 3 over- or under-estimated? If so, please explain why.

A8a: >>

Q8b: Were EPA's assumptions about replacement frequencies reasonable? If not, please explain why.

A8b: >>

4.3 Fuel Costs Incurred by the Train Operators

EPA estimated increases in fuel consumption due various emission control technologies and the corresponding incremental fuel costs. EPA assumed fuel penalties of:

- 2% for Tier 2 locomotives,
- 1% for Tier 1 locomotives, and
- 1%-2% for Tier 0 locomotives.

Based on past developments in the industry, EPA believed that manufacturers would make every effort to eliminate any initial fuel consumption penalties, and would have largely succeeded by 2010. However, EPA included fuel economy penalties for the full 41 years covered by the analysis.

Q9a: Were EPA's assumptions regarding fuel penalties reasonable, including the average fuel consumption rate and fuel costs (in $ per gallon)?

A9a: >>

Q9b: Based on your professional knowledge and experience, what can you say about elimination of initial fuel consumption penalties by 2010? If this occurred, did learning by doing play a role?

A9b: >>

The last line of Table 3 presents the total per locomotive cost estimated by EPA for each model type and Tier.

Q10a: Did actual total per locomotive compliance costs differ significantly from EPA's estimates over the time period in which this rule was applicable (1998 to 2008)? If so, what are the principal reasons for these changes? To the extent possible, please indicate the approximate amount of difference from EPA's estimates.

A10a: >>

Q10b: Did technological innovation occur within the emission control technologies? If so, please indicate which technology or technologies were affected and what the compliance cost implications were.

A10b: >>

Section 5 Emission Reductions

EPA first calculated baseline national emissions for each type of locomotive service (line-haul and switch) by multiplying fuel consumption rates (gal/yr) by a conversion factor of 20.8 bhp-hr/gal to obtain total fleet bhp-hr/yr values. EPA then multiplied these fleet bhp-hr/yr numbers by the applicable fleet average emission rates to calculate emissions inventories (tons/yr). EPA estimated the fleet average emission rates for each year based on the number of each type of locomotive it projected to be in the fleet at the end of the respective year. EPA estimated the total reductions expected for each future year by subtracting the expected controlled inventory from the estimated 1999 baseline inventory.

EPA calculated fleet average emission rates as weighted averages of uncontrolled, Tier 0, Tier 1, and Tier 2 emission rates based on estimated relative class- and service type-specific fuel consumption rates (e.g., the percent of total fuel consumed by Tier 1 line-haul locomotives in Class I for a given year).

Assumptions Used for Class I Analysis:

- The relative fuel consumption rates used to create average emission rates for Class I line-haul locomotives were proportional to the product of the number of locomotives (N_{loc}), average horsepower (HP_{avg}), and a relative use rate factor (F_{RU}) based on average locomotive age, as shown below:

$$\text{Relative Fuel Consumption} = \frac{N_{loc} HP_{avg} F_{RU}}{\sum N_{loc} HP_{avg} F_{RU}};$$

- EPA assumed 7.5% of fuel consumption by Class I railroads is for switching.
- Calculations of the relative fuel consumption rates used to create average emission rates for Class I switch locomotives did not account for differences in average horsepower and relative use rates due to a lack of specific information. (Emission rates were weighted by numbers of locomotives only.) EPA believed that this simplification did not significantly affect the overall analysis because the differences in locomotive horsepower and usage rates for this class, as a function of the tier of applicable standards, were less significant than for Class I freight locomotives.
- EPA assumed that fuel consumption remained constant at the 1996 level of 3.601 billion gallons per year. EPA recognized that there was a short-term trend of increasing fuel consumption, but was not confident that the trend would continue. The long-term trend was for fuel consumption to remain fairly constant as a result of continual improvements in locomotive fuel economy, which offset the significant increase in ton-miles of freight hauled.

Table 4 shows the estimated emission rates of various pollutants for Class I locomotives.

TABLE 4: ESTIMATED EMISSION RATES (G/BHP-HR) FOR CLASS I LOCOMOTIVES

Pollutant	Tier	Line-Haul Locomotive	Switch Locomotive
Hydrocarbons	Uncontrolled	0.48	1.01
	Tier 0	0.48	1.01
	Tier 1	0.47	1.01
	Tier 2	0.26	0.51
Carbon Monoxide	Uncontrolled	1.28	1.83
	Tier 0	1.28	1.83
	Tier 1	1.28	1.83
	Tier 2	1.28	1.83
Nitrous Oxides	Uncontrolled	13.0	17.4
	Tier 0	8.6	12.6
	Tier 1	6.7	9.9
	Tier 2	5.0	7.3
Particulate Matter	Uncontrolled	0.32	0.44
	Tier 0	0.32	0.44
	Tier 1	0.32	0.43
	Tier 2	0.16	0.19

Source: U.S. EPA (1998)

Q11a: Was EPA's method of determining relative fuel consumption for Class I locomotives by service type (line-haul and switch) for each Tier reasonable? If not, please explain why.

A11a: >>

Q11b: Was EPA's assumption about constant fuel consumption reasonable? Was the amount of fuel consumed by Class I locomotives per year over- or under-estimated on average for the time period 1998-2008? If so, please explain why.

A11b: >>

Q11c: Was EPA's assumption about the share of fuel consumed by Class I switch locomotives reasonable? If not, please explain why.

A11c: >>

Q11d: Were the estimates of emission rates for each pollutant and locomotive type and Tier reasonable given your knowledge and professional experience?

A11d: >>

Assumptions used for Class II/III Analysis

- For Class II/III locomotives, EPA did not account for differences in average horsepower and relative use rates in calculating relative fuel consumption rates due to lack of specific information for these classes (emission rates were weighted by numbers of locomotives only).
- EPA used information from the American Short Line Railroad Association (which represents most of the Class II and Class III railroads) to estimate that the 4,200 locomotives in service with the Class II and III railroads in service in 1994 consumed about 215 million gallons of diesel.
- Due to a lack of specific information, EPA assumed that average Class II and III emission rates were the same as the average emission rates for Class I line-haul locomotives. EPA acknowledged that actual emission rates could be somewhat higher since smaller railroads typically have lower power duty-cycles (i.e., more time at idle and low power notches, and less at notch 8), especially those railroads performing primarily switch and terminal services.

Q12a: Was EPA's method of determining relative fuel consumption for Class II/III locomotives for each Tier reasonable? If not, please explain why.

A12a: >>

Q12b: Was the amount of fuel consumed by Class II/III locomotives per year over- or under-estimated on average for the time period 1998-2008? If so, please explain why.

A12b: >>

Q12c: Was EPA's assumption that the emission rates of each pollutant (by Tier) for Class II/III locomotives was same as emission rates for Class I line-haul locomotives reasonable given your knowledge and professional experience? If not, please explain why.

A12c: >>

Assumptions used for Passenger Locomotives Analysis

- For passenger locomotives, EPA did not account for differences in average horsepower and relative use rates in calculating relative fuel consumption rates due to lack of specific information for these classes. (Emission rates were weighted by numbers of locomotives only.)
- EPA estimated that 463 passenger locomotives consumed about 61 million gallons of diesel fuel per year.
- EPA estimated that the 315 diesel Amtrak locomotives in service consumed about 72 million gallons of diesel fuel per year.
- EPA assumed that average passenger locomotive emission rates were the same as the average emission rates for Class I line-haul locomotives.

Q13a: Was EPA's method of determining relative fuel consumption for passenger locomotives for each Tier reasonable? If not, please explain why.

A13a: >>

Q13b: Was the amount of fuel consumed by passenger locomotives per year over- or under-estimated on average for the time period 1998-2008? If so, please explain why.

A13b: >>

Q13c: Was EPA's assumption that the emission rates of each pollutant (by Tier) for passenger locomotives was same as emission rates for Class I line-haul locomotives reasonable given your knowledge and professional experience? If not, please explain why.

A13c: >>

Section 6 Additional Questions

Q14a: Since the time of rule development and promulgation, have technological innovations occurred within the compliance technology options considered by EPA? If so, what innovations occurred and approximately what impact did these innovations have on the cost of complying with the rule?

A14a: >>

Q14b: Did any learning by doing in development and use of the new technologies occur since the time of rule development and promulgation? If so, what impact did these innovations have on the cost of complying with the rule?

A14b: >>

Q14c: Were there factors that may have caused greater implementation difficulty and higher costs with the Rule? For example, were there:

- **Any technical challenges in designing process changes to meet compliance requirements?**
- **Issues with financing support for technology installation?**
- **Technical performance issues in operating and maintaining the equipment?**
- **Limitations on compliance in terms of compliance assistance or compliance schedule?**
- **Terms of regulatory requirements, and specific aspects of the rule requirements?**

A14c: >>

References

United States Environmental Protection Agency (U.S. EPA). 1998. Locomotive Emission Standards: Regulatory Support Document. April.

Chapter 6: Lessons Learned and Next Steps

The four case studies presented in this report represent a first step in generating a larger body of evidence on key drivers of compliance costs. While individual case studies of particular regulations are informative, perhaps the more significant contribution of this effort is the application of a common conceptual framework to the ex post assessments. Applying this framework to our case studies underscores the difficulties and impediments to conducting consistent, comprehensive retrospective analyses of regulatory costs.

6.1. Lessons Learned

Our retrospective analyses proved more challenging than originally anticipated and were often limited by the paucity of evidence on how facilities chose to comply with the selected regulations and their associated costs. In short, each of the case studies suffer from a lack of comprehensive cost information on treatment technologies and mitigation strategies at the facility level, limiting our ability to make definitive statements on the reasons for differences between ex ante and ex post cost estimates. Instead, the case studies either rely on accessible industry level data (as opposed to facility level data), bottom-up cost estimates for a typical "model" facility, or information from a limited number of industry experts. Each of these approaches, while useful, also met with its own problems. For some case studies, the arsenic rule in particular, the regulated sources were quite heterogeneous, varying by size, attributes, compliance technology, and vintage, giving rise to complicated decision strategies for identifying appropriate technologies.

Disentangling the expenditures made expressly for pollution control was a challenge for several of the case studies. Compliance expenditure data sometimes include expenditures - referred to as "might as well do this" costs – those that occur at the same time as the compliance costs but that are, in truth, unrelated to the regulation (i.e., upgrades, maintenance, etc.). For others, namely the pulp and paper rules, the methyl bromide critical use exemption analyses, and the locomotive rule, defining the counterfactual was difficult (i.e., what would have occurred had the rule not been promulgated).

In cases where EPA relied on outside experts, it also sometimes proved challenging to find qualified industry experts. They were sometimes few in number to begin with, making it particularly difficult to identify individuals who had not offered expertise during the development of the rule. In reaching out to trade associations for assistance, we found that some were helpful but others were reluctant to become involved.

6.2. Next Steps

While informative, the added evidence provided by the four case studies in this report is insufficient to draw - broad conclusions about EPA cost estimation practices. As already noted, the rules were not selected to be -

representative but rather to shed light on the process of conducting ex post analyses and the challenges analysts engaged in these activities may face.

As a next step in this process, EPA has selected additional rules for retrospective analysis from the list of eligible rules described in Chapter 1. Unlike the rules discussed in the case studies presented here, these rules were selected using a stratified random selection process and include:

- Control of Emissions of Air Pollution From Nonroad Diesel Engines (1997);
- NSPS for Nitrogen Oxide Emissions
- NESHAP: Surface Coating of Automobiles and Light-Duty Trucks (2004);
- Effluent Limitations Guidelines, Pretreatment Standards, and New Source Performance Standards for the Commercial Hazardous Waste Combustor Subcategory of the Waste Combustors Point Source Category (2000);
- Effluent Limitations Guidelines, Pretreatment Standards, and New Source Performance Standards for the Transportation Equipment Cleaning Point Source Category (2000).
- NSPS: Municipal Waste Combustion--Phase II and Phase III (Large Units) (1995)

As we pursue additional case studies, we will continue to explore the feasibility of other data collection strategies including site visits, focus groups, and industry surveys to augment the publically available information we are able to identify. Eventually, we hope to amass enough information to draw generalizable conclusions about factors that cause ex ante and ex post cost estimates to differ, as discussed in Chapter 1, with the ultimate goal of informing improvements to our cost estimation methodologies.