Retrospective Study of the Costs of EPA Regulations:

An Interim Report of Five Case Studies

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Preface

Benefit-cost analyses are often conducted to inform decision-making at the Environmental Protection Agency (EPA) with regard to a particular regulatory approach. However, while the EPA strives to use the best available science and engineering when conducting its economic analyses, they are, by necessity, ex ante. Given that benefits are typically much harder to quantify – for instance, due to the lack of formal economic markets in which prices for environmental goods can be observed – the EPA has invested a lot of effort in improving the methods available for evaluating them.

While new science and the need to quantify more previously unquantified benefits has driven benefits analysis, comparatively less work has been done retroactively 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. 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, they examine key drivers of compliance costs to see if informed *judgments* (weighing the evidence) can be made about whether ex post costs are higher or lower than the estimates of ex ante costs.

As with nearly all case study approaches, there are also lessons learned about how to do better cost analysis. Since these are our initial case studies, we experimented with several different methodologies (i.e., approaches to gathering data on ex post costs) to explore which ones are effective. In doing so, we seek to understand whether methodologies and approaches deployed in these case studies are sufficiently reliable to allow researchers to make informed "weight of evidence" judgments about the relationship between ex ante and ex post costs, and hopefully, provide insights into key drivers of any differences. As with other research efforts, our case studies address some but not all of the key cost drivers that determine ex post costs and are silent or equivocal on others.

If the case study approach is successful, there is much that can be learned from this effort. A careful assessment of ex post costs 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, the EPA can invest in improving methods that better capture these effects on costs ex ante.

This report summarizes the initial findings from a small set of pilot case studies that attempt to evaluate the costs of EPA regulatory and other policy actions ex post. The initial set of case studies rely on a variety of methods for collecting ex post information – some mainly rely on publically available data and literature and are conducted internally, while others rely on industry experts or third-party data collected by a contractor. These case studies were not selected randomly because the primary goal had been to pilot these methods with a variety of media and types of EPA actions. Subsequent case studies have been selected through stratified random sampling techniques.

Interim results are presented in this report for five case studies: the Pulp and Paper "Cluster Rule" (which includes MACT I and III, BAT/PSES as well as the MACT II rules), Methyl Bromide Critical Use Exemptions for the 2006-2010 Growing Seasons for California Strawberries, the National Primary Drinking Water Standard for Arsenic, and the 1998 Emission Standards for Locomotives and Locomotive Engines. While a number 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 the 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 and 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.

Thus, this report should be viewed as interim, demonstrating both the progress made and the challenges encountered, with the goal of soliciting advice from the Science Advisory Board on how to most productively move forward with ex post cost evaluation.

I. Introduction

The Environmental Protection Agency (EPA) conducts benefit-cost analyses (BCA) of many of the new rules it proposes.[1] 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, the 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 *new* EPA analyses, there is significant potential to learn from additional analysis of the benefits and costs of *past* regulations. Researchers have pointed to "quasi-experimental" empirical research and other econometric methods as potential tools to assess ex post benefits (Greenstone and Gayer 2009). These methods may also be useful to evaluate costs.

A careful assessment of ex post cost will allow EPA to learn if systematic differences between ex post and ex ante compliance cost estimation methods exist.[2] Even if systematic differences do not exist, it is still important to understand the uncertainty associated with ex ante cost estimates. This work will address questions such as:

- Are there methodological changes that can be incorporated into new regulatory analyses?
- Do certain costs categories contain more differences or uncertainties than others?
- How can behavioral responses to regulation be better incorporated into ex ante analyses

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[1] Since the Reagan Administration, 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).

[2] A similar exercise could also be conducted for an examination of past benefit analyses; the scope of this project is focused on costs.

The purpose of this Retrospective Cost Study is to examine how the EPA's ex ante cost analyses compare to an ex post assessment of costs using a case study approach. While the 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 from one another. 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 (the 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 (defined as +/- 25 percent). When a substantial difference exists, we seek to identify the particular 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 modeling.

As a first step, NCEE reviewed existing studi*es* that examine the accuracy of ex ante cost estimates. These studies generally compare ex ante total or unit cost estimates with ex post cost estimates developed by other government agencies, academic researchers, or trade organizations. For example, Harrington et al. (2000) compare the ex ante direct costs to ex post assessments for 28 EPA and OSHA regulations in addition to regulations for state entities, Singapore, Norway and Ontario. In general, they find that ex ante total costs are overestimated more often than underestimated: of the 13 EPA regulations they examined, ex ante total cost estimates are higher for seven rules while only two rules had lower ex ante cost estimates. However, their findings are mixed when they examine per unit (or per facility) costs rather than total costs: EPA's ex ante unit cost estimates were accurate in four cases, over-estimated in five cases, and under-estimated in four cases.[3]

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[3] Similarly an Office of Management and Budget (2005) study found that EPA ex ante unit cost estimates were accurate in 6 cases, over-estimated in 6 cases and under-estimated in 6 cases.

The existing literature offers numerous hypotheses for why ex ante and ex post costs may differ, including changing market conditions for inputs; industry incentives to overstate costs; and technological change (both unquantifiable and unanticipated) occurring between the time a rule is developed and promulgated and when a rule is implemented. However, additional case studies may provide important additional evidence and insights regarding the validity and importance of the competing hypotheses

After a review of the literature, NCEE concluded that the data on ex ante/ex post compliance costs comparisons were insufficient to support judgments regarding the relative merits of the competing hypotheses using econometric tools.[4] Hence, NCEE decided to perform a series of case studies to build a database of ex post/ex ante abatement cost comparisons. The purpose of the case studies is not to estimate ex post costs reliably, but rather to see if sufficient information on key drivers of compliance costs 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.

The RCS is being conducted in several phases. In Phase 1 of the project, NCEE selected five regulations targeting different media and using different data collection methodologies to serve as pilot case studies. In Phase 2 of the project, NCEE is completing several tasks held over from Phase 1 in addition to expanding the project to include five new, randomly-selected rules. The Phase 1 rules were selected based on effective implementation date, source category and industries covered, type of regulation (e.g., performance standard versus prescriptive regulations), and analytical approach used to estimate costs. Four methodologies were explored to collect ex post cost information: use of publicly

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[4] One limiting factor has been the lack of ex post cost data. The Pollution Abatement and Cost Expenditures (PACE) survey has been one of the few sources of systematic, plant-level information on the cost to comply with environmental regulations, but has not been conducted since 2005. Furthermore, the PACE survey has not been conducted on an annual basis since 1994 (see section IV below for more information on the PACE survey).

available data sources and literature; consultations with industry compliance experts; facility site visits[5]; and a comprehensive industry survey. For each Phase 1 rule, NCEE assessed whether it would be possible to collect sufficient ex post compliance cost information using only publicly-accessible data sources and explored the applicability and usefulness of the other methodologies to help inform analyses under Phase II of the project, which is still ongoing.

This report presents the results of the RCS to-date, focusing primarily on the Phase 1 rules. The remaining sections are organized as follows. Section II provides an updated literature review on the accuracy of a variety of regulatory ex ante cost estimates. Section III provides a discussion of hypotheses that can cause a divergence between ex ante and ex post compliance costs. Section IV describes our methodology: the selection of rules for Phase 1 and Phase 2 as well as a discussion of the ex post cost estimation strategies. This section also includes a brief discussion of the PACE survey, as it may prove to be a useful source of ex post cost information under some circumstances. Preliminary results from five rules are presented in Sections V through VIII. The five rules are the Pulp and Paper "Cluster Rule" (which includes MACT I and III, BAT/PSES as well as the MACT II rules), Methyl Bromide Critical Use Exemptions, the National Primary Drinking Water Standard for Arsenic, and Locomotive Emission Standards. Table I-1 contains the list of all rules that were considered for inclusion in the RCS and questionnaires developed to engage industry compliance experts as well as other relevant rule specific materials are included as appendices to each individual case study.

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[5] We have opted to reserve the site visits for a Phase 2 rule, due to difficulties in establishing contacts for those selected under Phase 1.

Table I-1. Final EPA Regulations Eligible for Retrospective Study

	Title	Program Office	Year
1	GLI: Water Quality Guidance for Great Lakes System (RIN:2040-AC08SAN:3203; Tier:1)	OW	1995
2	Emission Standards for Marine Tank Vessel Loading Operations (RIN:2060-AD02SAN:3104; Tier:N/A)	OAR	1995
3	NSPS: Municipal Waste Combustion--Phase II and Phase III (Large Units) (RIN:2060-AD00SAN:2916; Tier:1)	OAR	1995
4	NSPS: Municipal Solid Waste Landfills Amendments (RIN:2060-AC42SAN:2535; Tier:3)	OAR	1996
5	Land Disposal Restrictions - Phase III: Decharacterized Wastewaters, Carbamate Wastes, and Spent Aluminum Potliners (RIN:2050-AD38SAN:3365; Tier:1)	OSWER	1996
6	Risk Management Program for Chemical Accidental Release Prevention (RIN:2050-AD26SAN:2979; Tier:N/A)	OSWER	1996
7	Regulation of Fuel and Fuel Additives: Certification Requirements for Deposit Control Additives (RIN:2060-AG06SAN:3597; Tier:2)	OAR	1996
8	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)	OAR	1996
9	Federal Test Procedure for Emissions From Motor Vehicles and Motor Vehicle Engines; Review (RIN:2060-AE27SAN:3323; Tier:N/A)	OAR	1996
10	Final Effluent Limitations Guidelines and Standards for the Coastal Subcategory of the Oil and Gas Extraction Point Source Category (RIN 2040–AB72)	OW	1996
11	Acid Rain Program: Phase II Nitrogen Oxides Reduction Program (RIN:2060-AF48SAN:3575; Tier:3)	OAR	1996
12	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)	OSWER	1998
13	Voluntary Standards for Light-Duty Vehicles (National 49 State Low-Emission Vehicles Program) (RIN:2060-AF75SAN:3646; Tier:1)	OAR	1997
14	Hospital/Medical/Infectious Waste Incinerators (RIN:2060-AC62SAN:2719; Tier:N/A)	OAR	1997
15	Control of Emissions of Air Pollution From Nonroad Diesel Engines (RIN:2060-AF76SAN:3645; Tier:1)	OAR	1997
16	PCBs; Polychlorinated Biphenyls (PCBs) Disposal Amendments (RIN:2070-AD04SAN:2878; Tier:2)	OPPTS	1998

17	Pharmaceutical Manufacturing Category Effluent Limitations Guidelines, Pretreatment Standards, and New Source Performance Standards (RIN 2040-AA13)	OW	1998
18	Control of Emissions of Air Pollution From Nonroad Diesel Engines (RIN:2060-AF76SAN:3645; Tier:1)	OAR	1998
19	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)	OAR	1998
20	National Primary Drinking Water Regulations: Stage I Disinfectant/Disinfection By-Products Rule (RIN:2040-AB82SAN:2772; Tier:1)	OW	1998
21	National Primary Drinking Water Regulations: Interim Enhanced Surface Water Treatment Rule (RIN:2040-AC91SAN:2304; Tier:N/A)	OW	1998
22	Nonroad Spark-Ignition Engines At or Below 19 Kilowatts (25 Horsepower) (Phase 2) (RIN:2060-AE29SAN:3361; Tier:3)	OAR	1999
23	TRI; Reporting Threshold Amendment for Certain Persistent and Bioaccumulative Toxic Chemicals (PBTs) (RIN:2070-AD09SAN:3880; Tier:1)	OEI	1999
24	NPDES Comprehensive Storm Water Phase II Regulations (RIN:2040-AC82SAN:3785; Tier:3)	OW	1999
25	Tier II Light-Duty Vehicle and Light-Duty Truck Emission Standards and Gasoline Sulfur Standards (RIN:2060-AI23SAN:4211; Tier:1)	OAR	2000
26	Nonroad Spark-Ignition Engines At or Below 19 Kilowatts (25 Horsepower) (Phase 2) (RIN:2060-AE29SAN:3361; Tier:3)	OAR	2000
27	Effluent Limitations Guidelines, Pretreatment Standards, and New Source Performance Standards for the Transportation Equipment Cleaning Point Source Category (RIN 2040-AB98)	OW	2000
28	Control of Emissions of Air Pollution From 2004 and Later Model Year Heavy-Duty Highway Engines and Vehicles; Revision of Light-Duty Truck Definition (RIN:2060-AI12SAN:4043; Tier:2)	OAR	2000
29	Protection of Stratospheric Ozone: Incorporation of CAA Amendments for Reduction in Class I, Group VI Controlled Substances (RIN:2060-AI41SAN:4271; Tier:3)	OAR	2000
30	Effluent Limitations Guidelines, Pretreatment Standards, and New Source Performance Standards for the Centralized Waste Treatment Point Source Category (RIN 2040-AB78)	OW	2000
31	Lead; Identification of Dangerous Levels of Lead Pursuant to TSCA Section 403 (RIN:2070-AC63SAN:3243; Tier:1)	OPPTS	2001
32	NESHAP: Chemical Recovery Combustion Sources at Kraft, Soda, Sulfite and Stand-Alone Semichemical Pulp Mills (RIN:2060-AI34SAN:4240; Tier:1)	OAR	2001
33	Heavy-Duty Engine Emission Standards & Diesel Fuel Sulfur Control Requirements (RIN:2060-AI69SAN:4355; Tier:1)	OAR	2001

34	Effluent Limitations Guidelines and New Source Performance Standards for the Oil and Gas Extraction Point Source Category (RIN 2040-AD14)	OW	2001
35	Effluent Limitations Guidelines, Pretreatment Standards, and New Source Performance Standards for the Iron and Steel Manufacturing Point Source Category (RIN 2040–AC90)	OW	2002
36	Emissions from Nonroad Spark-Ignition Engines and Standards for Recreational Spark-Ignition Engines (RIN:2060-AI11SAN:4154; Tier:3)	OAR	2002
37	NESHAP: Surface Coating of Automobiles and Light-Duty Trucks (RIN:2060-AG99SAN:3907; Tier:3)	OAR	2004
38	NESHAP: Reciprocating Internal Combustion Engine (RIN:2060-AG63SAN:3656; Tier:2)	OAR	2004
39	Control of Emissions of Air Pollution from Nonroad Diesel Engines and Fuel (RIN:2060-AK27SAN:4675; Tier:1)	OAR	2004
40	NESHAP: Plywood and Composite Wood Products (RIN:2060-AK27SAN:3820; Tier:3)	OAR	2004
41	Effluent Limitations Guidelines and New Source Performance Standards for the Concentrated Aquatic Animal Production Point Source Category (RIN 2040-AD55)	OW	2004
42	Effluent Limitations Guidelines and New Source Performance Standards for the Meat and Poultry Products Point Source Category (RIN 2040-AD56)	OW	2004

II. Literature Review of Previous Retrospective Cost Studies

In this review of the literature we briefly describe some existing studies and summarize their findings. In addition, we briefly summarize retrospective analyses of Title IV of the 1990 Clean Air Act. Title IV has been examined extensively in the literature and while most of these analyses compare ex post costs against what the costs would have been under a different policy scenario (command and control vs. trading) as opposed to ex ante/ex post cost comparisons, they nevertheless may provide insight for our current undertaking. In the following Section we consider some hypotheses the literature suggests concerning the accuracy of regulatory cost ex ante estimates.

A. Existing Studies of Ex Ante vs. Ex Post Cost Estimates

A number of researchers have studied the accuracy of *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 on studies that survey the existing literature and examine the disparity between *ex ante* and *ex post* cost estimates. Broadly speaking, existing studies find that overestimates are more common than underestimates, with the ratio of *ex ante* to *ex post* estimates greater than one on average.

The first study we are aware of that is devoted specifically to the consideration of the accuracy of *ex ante* projections of the costs of regulation was conducted for EPA by the consulting firm of Putnam, Hayes, and Bartlett and completed in 1980 (hereinafter, "PHB 1980"). The study compared EPA and industry *ex ante* estimates of required capital expenditures with actual capital expenditures for five rules passed in the period from 1974 – 1977. In four of five cases industry overestimated capital costs, while in three of five cases EPA overestimated capital costs. The PHB 1980 results are somewhat more ambiguous for a sixth case study that compared EPA and industry estimates of the effects of environmental regulations on new car prices.

The next major study of the accuracy of cost projections was conducted in 1995 by the Office of Technology Assessment (OTA). The OTA did not consider environmental regulations, but its study of the accuracy of cost projections of Occupational Safety and Health Administration (OSHA) regulations may have implications for the accuracy of regulatory cost estimation more generally. The OTA considered eight regulations in the chemical, manufacturing, and service industries enacted between 1974 and 1989. In all cases in which numerical estimates were reported estimated costs exceeded actual costs. In two industries, the OTA report suggests that costs may actually have been negative -- i.e., in finding ways to reduce risks, producers may actually have identified processes that operate more efficiently.[6]

In 1997, Hodges published a study of twelve environmental and workplace safety regulations initiated between the 1970s and 1990s (Hodges 1997; the results are also summarized in Goodstein and Hodges 1997). In each instance, *ex ante* estimates of costs were greater than *ex post* costs; in eleven of twelve cases, *ex ante* cost estimates were more than double costs realized *ex post*. Hodges focuses on industry's rather than regulators' estimates of costs. To the degree that industry generally has an incentive to overstate costs, the discrepancies Hodges identifies are not surprising.

A very thorough comparison of *ex ante* to *ex post* estimates of costs was conducted by Harrington, Morgenstern, and Nelson (2000). The researchers considered 28 regulations written by EPA, OSHA, and a handful of other regional and international regulators that affected a number of different industries. The authors considered *ex ante* cost estimates to be "accurate" if they were within ± 25% of *ex post* values, and either too high or too low if they fell outside this range. By this standard, total costs of regulation were overestimated in 14 instances, underestimated in only three, and deemed reasonably

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[6] One must be careful in interpreting such findings, 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 their costs. Moreover, there are costs of experimentation, and these are not always reported accurately.

accurate in the remaining 11 (for the 13 EPA regulations considered, the numbers were 7, 2, and 3, respectively). Harrington *et al*. distinguish between *total* and *unit* costs of regulation. Unit costs refer to the costs per unit of output or the cost per plant. Total cost is per unit cost times output or number of plants affected. Harrington, *et al*., find that unit costs tend to be overestimated as often as they are underestimated, in contrast to total cost estimates noted above.

The next major retrospective study of the costs of regulation was completed in 2005 by the Office of Management and Budget (OMB 2005). OMB reviewed 47 regulations initiated between 1976 and 1995. EPA issued 18 of the regulations in the OMB sample, the most of any of the five federal agencies included in the study (the others were the National Occupational Safety and Health Administration [13 regulations included], the National Highway Traffic Safety Administration [8], the Department of Energy [6] and the Nuclear Regulatory Commission [2]). As is generally the case with estimates of regulatory costs, the sample was determined by the availability of data, not by any attempt to generate a random cross-section of regulatory activity. The results of the OMB study are more varied than those of some other researchers. Of 40 regulations for which comparable *ex ante* and *ex post* data are available, 16 *ex ante* projections overestimated cost, 12 underestimated them, and 12 were approximately accurate. The OMB study was not completely independent of earlier work, however. For instance, results for nine of the studies in its sample were taken from Harrington, *et al*. 2000.

At least three studies have been conducted of the accuracy of *ex ante* cost measures in other countries (in addition, Harrington *et al*. 2000 include three examples drawn from Singapore, Norway, and Canada among their 28 case studies). While such inquiries obviously consider costs generated under different legal and regulatory structures than prevail in the U. S., they may still be useful in interpreting general trends in costs of regulation. International standards for the analysis of regulatory impacts have become more similar over time, with the United Kingdom (MacLeod, *et al*., 2006) and the

European Union adopting such requirements.[7] A study conducted by the Stockholm Environmental Institute considered the cost estimates presented by industry in regulatory negotiations, and found them to be consistently higher than *ex post* realizations of actual costs (Bailey, *et al*., 2002).

MacLeod, *et al*. (2006) performed a similar analysis of *ex ante* costs in UK rulemakings. The authors of this study adopted the same ± 25% standard as used in Harrington, *et al*., 2000, and found that by this standard, the costs of five of eight regulations considered were overestimated, those of two regulations were underestimated, and those of one were approximately on target.

In 2006, Oosterhuis, *et al*., published their estimates of *ex ante* and *ex post* costs of regulation with five EU environmental regulations. They report that in four instances, *ex ante* cost estimates exceeded *ex post* costs by a factor of two or more, while the *ex ante* and *ex post* estimates were roughly the same in the fifth case.[8] Oosterhuis, *et al*., also report on an earlier study of costs of compliance with the first Dutch National Environmental Policy Plan of 1988, as predicted *ex ante* by Jantzen (1989) and later estimated *ex post* by RIVM (2001). These Dutch studies were, by the standards of the field, unusually accurate. While the costs of five of the eight regulations considered were overestimated, only one *ex ante* estimate was as much as twice its *ex post* realization, and in aggregate the total *ex ante* estimate was only 13% higher than the *ex post* realization. Oosterhuis *et al*. (2006) credit this unusually accurate performance to the existence of relatively good statistics and studies in the Netherlands.

Finally, two studies that considered the accuracy of *ex ante* cost predictions for specific consumer products are worth noting. Anderson and Sherwood (2002) compare cost estimates for EPA mobile source rules. These include six fuel-quality regulations and eleven vehicle emission standards. In

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[7] See Radaelli 2005, however, who notes that “regulatory impact assessments” may still differ significantly from one jurisdiction to another

[8] Oosterhuis *et al*. 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.

most instances, Anderson and Sherwood found that *ex ante* estimates of price increases induced by regulation were greater than actual price changes observed. They also found, however, that EPA estimates tended to be closer to actual price changes than were industry ex ante estimates.

Dale, *et al*. (2009) considered the costs associated with the Department of Energy's efficiency regulations on consumer appliances such as air conditioners, refrigerators, and washing machines. This study illustrates the challenges inherent in developing estimates for the costs of regulation for consumer goods. Dale, *et al*., derived their *ex post* cost estimates using hedonic regressions to tease out the separate effects of scale, general technological progress, and more competitive behavior from those of the energy efficiency regulations themselves. Having isolated these effects, the authors found that *ex ante* cost estimates generally exceed those developed *ex post*.

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 two. 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.

B. Other Retrospective Cost Analyses – Title IV of the 1990 CAAAs

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. The large SO_2 reductions were to be realized in two phases. The first phase (1995-1999) targeted the dirtiest 110 power plants (with 263 generating units). These "Table A" generating units were responsible for gradually reducing their total emissions to meet targets of 7.2 million tons of SO_2 in 1995, 6.9 million tons in 1996, and then (an average of or stable target of) 5.8 million tons per year from 1997-1999.

To help EGUs make these large SO_2 reductions, Title IV provided EGUs with considerable flexibility on how to comply with the regulations. Before Title IV, EGUs were subject to command-and-control regulations that specified limits on the sulfur content of the coal used at each individual EGU. By comparison, 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. The number of SO_2 allowances each EGU was allocated was based on its average 1985-1987 heat input, multiplied by an average emission rate of 2.5 lbs of SO_2 per million BTUs of heat input. Each allowance gave an EGU the right to emit one ton of SO_2, and EGUs could only emit an amount of SO_2 equal to the number of allowances held. The only requirement an EGU faced under the trading program was that it must have one SO_2 allowance at the end of the year for each ton of SO_2 it emitted that year. An EGU faced a fine of $2,000 for each ton of SO_2 emitted for which it did not hold an allowance. Thus, the SO_2 trading program established by Title IV provided a significant amount flexibility to meet any given emission standard, including allowing for EGUs with high marginal abatement costs to purchase SO_2 permits from EGUs with lower marginal abatement costs rather than installing expensive pollution abatement equipment or switching to low sulfur coal.

This first phase of Title IV has been subject to intensive *ex ante* and *ex post* cost analyses. Researchers studying the compliance costs for this phase of Title IV 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 new regulations. Table I-1 below provides a summary/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.

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 majority of the early estimates of Title IV's compliance costs were based on engineering models, which do not take behavioral changes or technological change into consideration. Furthermore, most of the early studies relied on the data and methodologies previously used to examine traditional command-and-control environmental policies, with simple adjustments to estimate the efficiency gains of an allowance trading program. Later, more sophisticated studies, which included more wide-ranging assessments of both the regulatory impacts as well as outside economic pressures on the industry, produced substantially smaller compliance cost estimates for the Title IV program.

At approximately the time that Title IV became effective, several events occurred that contributed to further lowering the program's *ex post* cost. For example, reductions in the cost of transporting coal due to railroad deregulation helped reduce the price of low-sulfur coal transported from the Powder River Basin in Wyoming. 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)). 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 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., costs savings are a relatively minor source of overall savings of Title IV which ranged from $150 million to $200 million per year, but are important in developing a picture of the program's overall effectiveness. Absent banking as an option, some EGUs would have had to make larger pollution control investments to be certain of meeting their emission targets. Because of the variability in demand for their energy generating services (and consequent emissions), if they could not exercise the option to bank emissions, they would have had to make more expensive investments and/or accelerated their investments in emission controls, both of which would have led to higher actual compliance costs. As such, firms were able to "avoid the much larger losses associated with meeting fixed targets in an uncertain world" (Burtraw and Palmer 2004).

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

Author	*Annual Costs (Billions)*	*Marginal Costs per ton SO_2*	*Average costs per ton of SO_2*
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**

III. Potential Reasons Ex-Ante and Ex-Post Cost Estimates Differ

While the evidence we have reviewed does not definitively establish a relationship between *ex ante* and *ex post* estimates of regulatory costs, there are certainly numerous examples in which *ex ante* estimates have substantially overstated costs. This raises the question as to whether or not there are systematic reasons for this result, or if there any countervailing arguments that would suggest circumstances under which *ex ante* estimates might prove too low?

We will focus first on why costs may be systematically overestimated, noting the incentives that both regulators and regulated entities might have to overstate costs. We then consider the opposite case to try to understand cases where costs are systematically underestimated.

Possible industry incentives to overstate costs. Much of the cost information used in regulatory analysis comes directly from industry. It is entirely plausible that regulated entities may overstate their costs of compliance (Hodges 1997, MacLeod, *et al*. 2006).[9] Industry may be attempting to thwart what it sees as onerous regulations by providing a signal that costs are prohibitive. Or, an alternate explanation may be that industry is providing conservative estimates given the numerous uncertainties associated with regulations. It is therefore problematic, albeit practically unavoidable, that "industry is the source, directly or indirectly, of most of the data used to support cost estimates" by EPA (Harrington *et al*. 2000; p. 20). Regulators must typically elicit outsiders' perceptions of compliance costs, since regulators themselves have limited expertise. It is not uncommon for the EPA to solicit industry

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[9] Oosterhuis, *et al*., offer a somewhat more nuanced view: 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." [2006, p. 9]

compliance cost data through surveys of individual firms or interactions with their trade organizations (Harrington, *et al*., 2000).

Evolution of Technology. 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, particularly, 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).

Ex ante cost estimates typically calculate cost based on the application of existing technologies rather than relatively untested innovative approaches to inputs, abatement, and processes. While it is recognized best practice to at least attempt to factor "learning curve" effects into estimates of the costs of regulation (EPA 2010)[10], analysts may not incorporate potential technological innovation into *ex ante* cost estimates. Reasons for this vary, but generally can be traced back to the regulated industry or the regulators themselves. A few are discussed below.

Many cost estimates essential to EPA analyses come from affected firms that have little incentive to predict the best way to comply or to carefully estimate costs (Harrington et al 2000). When asked for input on costs of compliance, industry is likely to respond by describing a plausible way of complying rather than by evaluating all alternatives before identifying that which will minimize their compliance costs. Harrington, *et al*. suggest that firms are more likely to describe "off-the-shelf"

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[10] Compliance costs tend to decrease over time as regulated entities learn how to more easily comply with the regulation.

technologies in their cost estimates rather than examining opportunities for innovation (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% less than the *ex ante* estimates predicted, 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) that led to lower-than-expected compliance costs. 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, 310).[11]

As another example, cost estimates prior to the implementation 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, 309). The *ex ante* analysis did not account for fuel mixing—the blending of low and high sulfur coal—that lowered sulfur dioxide emissions (Harrington et al 2000, 309). At the time of the estimates, blending fuels seemed impractical (Hodges 1997, 6).

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[11] 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).

While there are other instances in which technological innovation led to much lower costs of complying with regulations than were initially predicted, it is important to note that the collection of rules for which any comparison of *ex ante* to *ex post* cost estimates has been performed remains very small in comparison to the universe of environmental rules that have been promulgated. Over and above the simple admonition not to extrapolate too enthusiastically from small samples, we do not have adequate information to assess whether such analyses represent a random or representative sample. We might hypothesize several reasons for which rules in which unforeseen technological breakthroughs occurred might be overrepresented among rules for which both *ex ante* and *ex post* estimates of costs exist. The first and simplest is just that such cases might be the most celebrated and visible. 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.[12] It was, then, natural to further investigate the divergence between *ex ante* and *ex post* estimates of the cost of regulation. A second reason for suspecting that some selection bias could be at work in identifying *ex ante/ex post* comparisons in which technological innovation proved important is that economists may prefer to study cases where regulated parties were given flexible options for compliance. Harrington, *et al*. (2000) suggest two reasons for which regulations proposing market-based incentives are more common than those specifying a technology among those available for study. The first is that there is more data available; this is particularly true of rules proposing tradable permit markets, as price-of-permit data will be particularly easily observed. The other is, as the authors write, “economists . . . have a proprietary interest in the performance of economic incentives.”

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[12] 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.

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. If we also believe that data are more likely to be available for rules that affect large industries than small ones – regulatory impact analyses are unlikely even to be performed if total economic effect is predicted to be less than $100 million – this could be another source of selection bias.

Varying Input Market Conditions. Factors not directly tied to the regulation, but perhaps indirectly linked to it, could lead to lower costs of compliance. 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 West 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 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.

The Regulatory Process. If a proposed rule appears likely to pass a benefit-cost test even if a conservatively high estimate of costs is reported, 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. 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 other contexts. A 1995 OTA study suggested that OSHA overestimated the costs of their regulations. Similarly, Harrington, et al. (2000) noted that EPA's Office of Water provided upper bound cost estimates in their effluent guidelines program.

Timing, Compliance, and Baseline. Another reason for which regulators' estimates of costs might prove to be too high is that regulatory processes are 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 (PHB 1980, Morgenstern and Landy 1997, Harrington, *et al*., 2000; see also Oosterhuis, *et al*., 2006, who note a similar tendency in European regulation).

The EPA Action Development Process is often time-intensive. In 2005, the mean action development time for "significant" rules (those requiring benefit-cost analyses) was 1,261 days, or nearly three and a half years (EPA 2007). 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. During that time, producers may investigate alternative technologies, inputs and processes that would allow them to comply with expected regulations more efficiently. Such possibilities are illustrated by CFC regulation. 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 1997, Harrington et al 2000).

Industry interventions may also interact with process and timing issues to affect the accuracy of initial cost estimates. Industries facing regulation are likely to volunteer cost information through public comments. When industry volunteers such cost estimates without being directly asked to do so by an agency, the Administrative Procedures Act requires agencies to respond through the comment process and explain why cost estimates differ. Morgenstern and Landy (1997) find that industry interventions led to less stringent final standards in all twelve of the rules they considered.

Promulgation of EPA effluent rules in the 1970s demonstrates anecdotally the tendency for industry interventions to lead to less stringent final standards. Proposed rules published in the *Federal Register* received a disproportionate number of comments from the regulated industries highlighting specific issues. Environmental and public interest groups, in contrast, submitted fewer comments, which tended to be less specific—and therefore 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. As a result of this asymmetric distribution of comments final rules often prove less stringent than the versions initially proposed (Magat, Krupnick, and Harrington 1986). 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.

A closely related notion is that cost estimates may assume full compliance with a proposed rule rather than actual compliance, which may be less-than-perfect. Although it is now dated, PHB (1980) found compliance rates of only 54% in the iron and steel industry and 83% in petroleum. MacLeod, *et al*., (2006) cite imperfect compliance as one reason for finding costs overestimated in *ex ante* studies.

A final consideration with regard to regulators' potential cost overstatements concerns the calculation of compliance baselines. When EPA estimated costs under its Enhanced I/M program, 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 less effective at reducing emissions than EPA analysts assumed. Only four states actually implemented the program (Harrington et al 2000).

***Possible private incentives to* under*estimate costs*.** Most analysis presumes that industry would oppose tighter regulation, but this need not always be true of all firms in an industry. Environmental regulation might comprise 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 ostensibly increase their own level of regulation because it would hurt others more. 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 exempt from meeting it. Other examples of purportedly mixed motives for environmental regulation are offered by Adler (1996).

Possible regulators' incentives to understate costs. We have considered the possibility that firms facing regulation might misrepresent their costs in a strategic attempt to influence regulator's actions. 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.

What does the evidence show? Studies in the literature almost always show that regulators overestimate the costs of rules more often than they underestimate them. It is difficult to to compare the accuracy with which the costs of one rule have been estimated relative to the accuracy of cost estimation for another. If one were to hazard a generalization of the accuracy of cost estimation, however, perhaps the most natural summary statistic would be the average of the ratio of ex ante to ex post cost estimates.[13] Again, studies in the literature almost always find that this average ratio is greater than one.

These two empirical regularities – that costs are more often over- than under-estimated, and that the average of the ratio of ex ante to ex post estimates is greater than one – have led a number of commentators to conclude that regulators overestimate costs as a general proposition (see, e. g., Heinzerling 2002). However Simpson (2011) argues that neither fact necessarily establishes that ex ante estimates are biased in the statistical sense. We might expect more over- than under-estimates of costs if the distribution of costs were skewed. Because costs often involve multiplicative relationships, their distribution may be skewed. Even if ex ante estimates were unbiased predictors of ex post estimates, Simpson argues that we would expect the ratio of the former to the latter to be greater than one: a quotient is a convex function of its denominator, and so by Jensen's inequality the quotient of the expectation is less than the expectation of the quotient. Simpson conducts a simple regression test on an admittedly very small and unrepresentative data set and is unable to reject the hypothesis that ex ante cost estimates are unbiased predictors of ex post cost estimates, even if most of the ex ante cost estimates are higher than ex post estimates.

So, we do not consider the current evidence sufficient to provide conclusive evidence concerning the reliability of ex ante cost estimates. Existing studies have been based on samples that cannot be said to have been collected at random. Moreover no clear definition has been adopted

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[13] It may not be clear that the number of overestimates compared to overestimates and the average of the ratio of ex ante to ex post cost estimates are showing different things, so let us give an example. Suppose that a regulator estimates the cost of a rule under uncertainty. She believes there to be a fifty percent chance that costs will be 1.5 and a fifty percent chance that they will be 0.5. Then her estimate of the cost of the rule is ½ x ½ + ½ x 3/2 = 1. Her estimate of the *ratio* of her ex ante estimate to the ex post realization will, however, be ½ x 1/(½) + ½ x 1/(3/2) = 1 1/3.

between, or sometimes even *within*, studies as to what constitutes "costs". Different studies focus on capital, recurring, and other opportunity costs, or some combination of them. Under the circumstances, it is clear that additional case studies would be useful, and the case studies presented herein are intended to make a contribution toward this goal.

IV. Methodology

A. Selection of Rules

To select the rules for inclusion in the RCS, 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. 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 economy of $100 million or more. 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 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).

The resulting eligible inventory (shown in Table I-1) consists of 42 rules promulgated between 1995 and 2005. (Note that this number does not include chemical actions, which are not tracked in the RAPIDS database.) 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.

To date we have selected 10 rules for inclusion in the RCS. The first five, or Phase I rules, (described below) were selected to serve as pilot case studies to help us understand which methodologies are most appropriate to measure ex post compliance costs for a range of rules. Therefore, these five 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 I-1 and the fifth is a critical use exemption nomination of a fumigant identified by the Office of Pesticides Program (OPP) as a good candidate for study. The remaining five, or Phase II rules, were chosen from the master list using stratified random sampling in which three were chosen from regulatory actions developed by the Office of Air and Radiation (OAR), and two were chosen from regulatory actions developed by all the other program offices , Table I-2 lists the 10 selected rules.

Table I-2. EPA Regulations Selected for Retrospective Cost Study

Phase I (Initial Case Studies)		**Program Office**	**Status of Study**
1	National Primary Drinking Water Regulation for Arsenic (2001)	OW	Preliminary results reported in Section VII
2	Integrated NESHAP and Effluent Guidelines for Pulp and Paper (1998)	OAR/OW	Preliminary results reported in Section V
3	NSPS for Nitrogen Oxide Emissions from Fossil-Fuel Fired Steam Generating Units (1998)	OAR	Underway
4	Locomotive Emission Standards (1998)	OAR	Preliminary results reported in Section

			VIII
5	Methyl Bromide Critical Use Nomination for Preplant Soil Use for Strawberries Grown for Fruit in Open Fields on Plastic Tarps	OPP	Preliminary results reported in Section VI
Phase II (Randomly Selected Rules)			
6	Control of Emissions of Air Pollution From Nonroad Diesel Engines (1997)	OAR	Underway
7	NESHAP: Chemical Recovery Combustion Sources at Kraft, Soda, Sulfite and Stand-Alone Semichemical Pulp Mills (2001)	OAR/OW	Preliminary results reported in Section V
8	NESHAP: Surface Coating of Automobiles and Light-Duty Trucks (2004)	OAR	Underway
9	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)	OW/OAR	Underway
10	Effluent Limitations Guidelines, Pretreatment Standards, and New Source Performance Standards for the Transportation Equipment Cleaning Point Source Category (2000)	OW	Underway

B. Ex post Cost Evaluation Strategies

To produce an ex post evaluation of the compliance cost of a regulation, we need information on the key drivers of compliance costs including the number and types of entities that were affected by the rule, the compliance strategies that were adopted, and their associated costs. While the aim here is not to reproduce the ex ante estimates using the same level of rigor employed in the RIAs, we hoped to glean enough information on the drivers of compliance cost to make a weight of evidence determination on the direction of our ex ante estimates – are they generally, too high, too low, or just about right? – using an error bound of +/- 25 percent used by others in the literature (Harrington et al. 2000; OMB 2005). Various methodologies exist for collecting the necessary information, ranging from using publicly available data sources, to reaching out to industry compliance experts, conducting site visits to facilities, and/or administering a comprehensive industry survey.[14]

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[14] In the future it may be possible to collect ex post cost data for particular rules directly from the regulated entities via the Pollution Abatement Costs and Expenditures (PACE) survey (see section C below for more information on 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.

For each Phase 1 rule, NCEE 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, the cost information is generally lacking. A similar assessment was made for the Arsenic, Cluster, and NOx (or "Boiler") Rules. 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.[15] NCEE also explored the applicability and usefulness of the other methodologies for each Phase I rule to help inform analysis under Phase II of the project, which is still ongoing.

Based on the results of this initial exploration, of the first five case studies, our ex post cost estimate for one rule is limited to observations that can be made based on publically available data alone, and four will rely on additional information from industry compliance experts.[16]

For four rules –Cluster, MACTII, Arsenic, and Locomotive rules - 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 information 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, which is our primary source for the

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

[16] Due to difficulties in establishing contacts for the Phase I rules, we have opted to reserve the site visits for a Phase II rule.

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 NCEE staff and the relevant EPA program office 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.[17]

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 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 NCEE staff and relevant program offices 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.

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

Finally, since public data and meetings with experts may not be sufficient for obtaining the necessary ex post cost information for some rules, we explored the viability of other data collection techniques. For example, we explored the viability of conducting an industry-wide survey. Although a comprehensive survey of the affected industry may be a first best strategy in some cases, it is possible that a survey may not be a feasible way to determine the ex post compliance costs due to survey non-response. The PACE survey could provide valuable assistance to this effort, since responses to the PACE survey are mandated by law. For other rules, site visits may be sufficient to collect more complete compliance cost information. Site visits may also be used to confirm the information obtained during interviews with industry compliance experts.

Based on our initial findings and recommendations, we will select one rule from the Phase 2 list for an in-depth analysis through site visits to facilities affected by the regulation. We will identify candidate facilities and include information on plant size, location, pollution sources, and potential pollution controls. We will consult with trade associations to help identify and obtain cooperation from facilities by serving as the initial point of contact with a facility. One environmental economist and one environmental engineer will conduct each on-site interview. Before visiting the facility, we will give the facility official notification of the visit, an explanation of the purpose of the visit, and the names of staff that will participate in the visit. We will send a description of the types of information that will be collected during the visit along with a copy of the pilot questionnaire to the plant personnel identified by the facility contact. We will ask the plant personnel to complete the questionnaire prior to the site visit.

The purpose of the interview during the site visit will be to discuss responses to the pilot questionnaire with a focus on obtaining information on the pollution abatement activities used by the facility to comply with the selected EPA regulation and the costs of those activities. During the site visit, we will review and document the pollution control measures used by the facility. The visit will also include a walk-through of the facility with facility representatives to identify pollution abatement techniques in operation that will later be used to develop independent cost estimates. A similar process was followed during the EPA's redevelopment of the 2005 PACE survey (see Gallaher, Morgan and Shadbegian (2008). We will compare the cost estimates provided by the facility as well as the independent cost estimate to the cost estimates provided by the industry expert. The site visits are expected to be completed by June 2012.

C. Other Potential Sources of Ex post Cost Data - Pollution Abatement Costs and Expenditures (PACE) Survey

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, the 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.[18] Furthermore, the PACE survey intends to capture only *incremental* costs of pollution abatement. EPA uses the PACE data to estimate the aggregate costs of its regulations.[19] Moreover, the PACE data are used by trade associations to track the

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[18] PACE data are collected at the establishment level, therefore abatement costs incurred at the corporate level (such as research and development) are not included in the survey unless they are charged directly to the facility.

[19] EPA has used the PACE data in several reports including the 1990 Cost of Clean Environment, Annual Office of Management and Budget Reports to Congress on Costs and Benefits of Federal Regulation, and Section 812 Clean Air Retrospective Cost Analysis.

costs to its members of complying with environmental regulations, and academic researchers use the data to examine the impact of regulations on important economic variables such as international competitiveness of U.S. manufacturing, job growth, investment demand, opening and closing of manufacturing facilities, and productivity growth.

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.

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.

References

(Sections I through IV)

Ando, A., V. McConnell and W. Harrington. 2000. Costs, Emission Reductions and Vehicle Repair: Evidence from Arizona. *Journal of the Air and Waste Management Association* 50: 174-185.

Burtraw, D., A. Krupnick, E. Mansur, D. Austin and D. Farrell. 1998. Costs and Benefits of Reducing Air Pollutants Related to Acid Rain. *Contemporary Economic Policy* 16(4): 379-400.

Burtraw, D. and K. Palmer. 2004. SO2 Cap-and-Trade Program in the United States: A 'Living Legend' of Market Effectiveness. In *Choosing Environmental Policy: Comparing Instruments and Outcomes in the United States and Europe*, ed. Winston Harrington, Richard D. Morgenstern, and Thomas Sterner. Washington D.C.: Resources for the Future.

Carlson, C., D. Burtraw, M. Cropper, and K. Palmer. 2000. SO2 Control by Electric Utilities: What Are the Gains from Trade? *Journal of Political Economy* 108(6): 1292-326.

Ellerman, A.D., P.L. Joskow, R. Schmalensee, J.P. Montero, and E. Bailey. 2000. *Markets for Clean Air: The U.S. Acid Rain Program*. Cambridge: Cambridge University Press.

Gallaher,M., C. Morgan and R. Shadbegian. 2008. Redesign of the 2005 Pollution Abatement Costs and Expenditure Survey. *Journal of Economic and Social Measurement* 33: 309-360.

Goulder, L., I.W.H. Parry, and D. Burtraw. 1997. Revenue-Raising Versus Other Approaches to Environmental Protection: The Critical Significance of Preexisting Tax Distortions. *RAND Journal of Economics* 28(4): 708-731.

Greenstone, M., and T. Gayer. 2009. Quasi-experimental and experimental approaches to environmental economics**.** *Journal of Environmental Economics and Management* 57: 21-44*.*

Hammitt, J. 2000. Are The Costs of Proposed Environmental Regulations Overestimated? Evidence from the CFC Phaseout. *Environmental and Resource Economics* 16(3): 281-302.

Harrington, W., R. D. Morgenstern, and P. Nelson. 2000. On the Accuracy of Regulatory Cost Estimates. *Journal of Policy Analysis and Management* 19(2): 297-322.

ICF. 1995. Economic Analysis of Title IV Requirements of the 1990 Clean Air Act Amendments. Prepared for U.S. EPA, Washington, DC. September.

James, H. S. jr, 1998. Estimating OSHA Compliance Costs. *Policy Sciences - Special Issue on Regulatory Budgeting* 31: 321-4.

Kerwin, C. M., and S. Furlong. 1992. Time and Rulemaking: An Empirical Test of Theory. *Journal of Public Administration Research and Theory* 2(2): 113–38.

Magat, W. A., A. J. Krupnick, and W. Harrington 1986. *Rules in the Making: A Statistical Analysis of Regulatory Agency Behavior.* Washington, DC: Resources for the Future.

Oosterhuis, F., C. des Abbayes, B. Görlach, D. Huybrechts A. Jarvis, O. Kuik, J. Medhursi, E. Meynaerts, V. Monier, P. Ekins, J. Jantzen, R. Vanner, P. Vercaemst, and H. van der Woerd. 2006. *Ex post estimates of costs to business of EU environmental legislation: Final report*. Amsterdam: Institute for Environmental Studies. Available at: http://ec.europa.eu/environment/enveco/ex_post/pdf/costs.pdf.

Popp, D. 2003. Pollution Control Innovations and the Clean Air Act of 1990. *Journal of Policy Analysis and Management* 22(4): 641-660.

Putnam, Hayes, & Bartlett, Inc. 1980. *Comparisons of estimated and actual pollution capital expenditures for selected industries.* Report Prepared for the Office of Planning and Evaluation, U.S. Environmental Protection Agency, Cambridge, MA. (mimeo).

Simpson, R. D. 2011. Do Regulators Overestimate the Costs of Regulation? U. S. Environmental Protection Agency, National Center for Environmental Economics. Working Paper #11-07.

U.S. Office of Management and Budget, Office of Information and Regulatory Affairs (OMB). 2005. Validating Regulatory Analysis: 2005 Report to Congress on the Costs and Benefits of Federal Regulations and Unfunded Mandates on State, Local, and Tribal Entities.

U.S. Office of Management and Budget (OMB). 1998. *Report to Congress on costs and benefits of federal regulations: Appendix*. Washington, DC: GPO.

White, K. 1997. SO_2 Compliance and Allowance Trading: Developments and Outlook. Prepared for the Electric Power Research Institute (EPRI) EPRI TR-107897 (April).

White, K., Energy Ventures Analysis, Inc., and Van Horn Consulting. 1995. The Emission Allowance Market and Electric Utility SO_2 Compliance in a Competitive and Uncertain Future. Prepared for the Electric Power Research Institute (EPRI), TR-105490, Palo Alto, CA. Final Report: September.

V. Cluster Rule and MACT II Rule

A. Overview

On April 15, 1998, 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. Together, the combined standards and guidelines became known as the "Cluster Rule" because they consisted of integrated air and water rulemakings. For air pollutants, EPA set maximum achievable control technology (MACT) standards (referred to as MACT I & III) for the pulp and paper industry that required mills to capture and treat toxic air pollutant emissions that occurred during the pulping and bleaching stages of the manufacturing process. The MACT I rule covers mills that chemically pulp wood using kraft, semi-chemical, sulfite, or soda processes. The MACT III rule covers mills that mechanically pulp wood, or pulp secondary fiber or non-wood fibers, or produce paper or paperboard. EPA also set effluent limits for toxic pollutants in the wastewater discharged during the bleaching process and in the final discharge from the mills. These requirements, which included best available technology (BAT) effluent limits and pretreatment standards for existing sources (PSES), were based on substituting chlorine dioxide for chlorine in the bleaching process (i.e., using elemental chlorine-free bleaching [ECF]) or using totally chlorine-free (TCF) bleaching. On January 12, 2001, EPA published the MACT II rule, originally included as part of the Cluster Rule, was promulgated in 2001 and 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 promulgation of the Cluster Rule was the result of a lengthy regulatory process. Under the terms of a consent decree with the Environmental Defense Fund (EDF), EPA was required to propose effluent guidelines to control the release of dioxins and furans from pulp and paperboard mills by

October 31, 1993 and to "use its best efforts" to promulgate final regulations. The Clean Air Act (CAA) amendments of 1990 required EPA to set MACT standards for the industry by 1997. EPA therefore decided to combine the rulemakings in order to design the most cost-effective rule, apply pollution prevention techniques, and reduce cross-media pollution transfers.[20] EPA proposed regulations on December 17, 1993 and, in that proposal, solicited comment and data on various aspects of the rulemaking. EPA made that data available in 1995 and 1996 and on July 15, 1996 published a Notice of Data Availability documenting analysis of the submitted data and EPA's "current thinking" regarding the final regulations. After receiving and analyzing comments on this Notice, EPA promulgated the final Cluster Rule and it was published on April 15, 1998.

Under section 112 of the CAA, the EPA is required to set emission standards for toxic air pollutants from stationary sources based on the best performing facilities in an industry with a Maximum Achievable Control Technology (MACT) rule. EPA is required to set MACT standards for sources annually emitting greater than 10 tons of any one HAP or 25 tons of total HAPs. MACT standards are usually written as numerical standards (e.g., concentration limits or percentage reductions) but can be written as performance or technology standards if it is not technically or economically feasible to measure the emission data needed to set a numerical standard. The HAPs covered by the Cluster Rule included compounds such as methanol, chlorinated compounds, formaldehyde, benzene, and xylene. EPA estimated that 155 mills would incur costs because of the new MACT requirements and that mills' emissions of HAPS would be reduced by 139,000 megagrams (one ton=0.908 megagrams) per year. The MACT I and III standards set emission limits for pulping systems at kraft, sulfite, semichemical, and soda mills; bleaching systems at all pulp and paper mills; and pulping

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[20] By promulgating the air and water standards in one simultaneous rulemaking the EPA was able to develop control options that included process change technology that would control both chloroform emissions to air and pollutant discharges to water. If promulgated separately, mill personnel may have been required to install separate control systems for air and water resulting in higher costs.

process condensate streams at kraft mills. These standards could be met in a variety of ways and included 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. For example, mills subject to the kraft pulping vent gas standards could demonstrate compliance by reducing HAP emissions by 98 percent by weight or to 20 parts per million by volume, operating a thermal oxidizer according to specific criteria, or by routing HAP emissions to a boiler, lime kiln, or recovery furnace. 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 was available that 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.

Under the Clean Water Act (CWA), EPA sets effluent limitations guidelines and standards (ELGs) and pretreatment standards for industrial dischargers. ELGs apply to facilities that discharge directly into surface water and pretreatment standards apply to facilities that discharge to publicly-owned treatment works (POTWs). The standards established in this rule covered two subcategories of mills out of twelve originally identified by EPA: the Bleached Paper-grade Kraft and Soda (BPK) and the Paper-grade Sulfite (PS) subcategories. EPA further segmented the PS subcategory, based on variations in manufacturing processes and products, into three segments: calcium- and magnesium-based processes, ammonium-based processes, and specialty grade pulps. The ELGs and pretreatment standards set technology-based limits on levels of pollution in wastewater for these mills. Similar to MACT standards, these standards are concentration- or mass-based limits on the amount of pollutants in wastewater that are determined by the performance of specific technologies (pollution control technologies and/or process changes) but do not require the use of those specific technologies. (Unlike MACT standards, the ELGs do not have design standards as a compliance option.) The Cluster Rule set limits on dioxins, furans, chloroform, 12 chlorinated phenolics, and adsorbable organic halides (AOX). EPA estimated that 96 mills would incur costs because of the new ELGs and pretreatment standards. The options considered for the ELGs were primarily based on technologies for reducing the amount of chlorine used in the bleaching process. The options for the BPK subcategory (listed in terms of increasing stringency) were 100 percent substitution of chlorine dioxide for elemental chlorine (ECF) (Option A), 100 percent substitution of chlorine dioxide for elemental chlorine (ECF) plus oxygen delignification or extended cooking (Option B), and TCF bleaching (Option C).[21] EPA only estimated costs for one option in each of the PS segments: 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. Mills in all affected subcategories were also required to follow best management practices (BMPs) to prevent pollutant spills into wastewater sewers.

Even after the scope of the Cluster Rule was finalized and it was determined that MACT II would be part of a separate rule-making, there remained substantial differences between the ex ante cost estimates of the Cluster Rule submitted by the pulp and paper industry and other groups, and those produced by EPA. Table V-1 below provides estimated costs of the Cluster Rule and MACT II rule from several sources, including EPA. One challenge with comparing the EPA cost estimates provided in Table V-1 with the estimates from other sources is that some sources were not clear regarding whether their cost estimates included costs of MACT II, which some in the pulp and paper industry consider part of the Cluster Rule, or only included the costs of MACT I and MACT III. In any case, two things are clear: (1)

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[21] Option A and B included a number of other technology processes, including chip thickness control, improved brownstock washing, and the elimination of hypochlorite. The EPA used the description of the change in bleaching to stand in as option names because these bleaching changes were the largest component of the compliance costs for the rule.

both EPA and the pulp and paper industry believe that the Cluster Rule is much more costly than the MACT II rule and (2) industry believes that EPA has substantially underestimated the cost of the Cluster Rule.[22]

Table V-1 - Cluster Rule & MACT II Rule Ex-Ante Cost Estimates

Source	**Citation**	**Capital Expenditures**	**Operating Costs**
Economic Analysis for the 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—Phase 1; Prepared for U.S. Environmental Protection Agency	EPA (1997)	$1.8 billion	$277 million
Pulp & Paper (Vol. 73, No. 9, September 1999, pp. 72-73)[23]	Jensen (1999, p. 73)	$2.6 billion	$273 million
National Council for Air and Stream Improvement Special Report No. 02-07 (2001, p.6)	NCASI (2002)	$3 billion (1999-2005)	---
Pulp & Paper North American Fact Book 1999, p. 77 (cites *Pulp & Paper Project Report*, April 1998)	Miller Freeman Publications, Inc. (1998)	$3.2+ billion	---
TAPPI Journal (Vol. 83, No. 9, September 2000, pp. 39-45)	Parthasarathy and Dowd (2000)	$2.625 billion*	---

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[22] Recently, EPA conducted a survey of the pulp and paper industry, to support the risk and technology reviews required under the CAA, which included questions about the methods mills used to comply with the promulgated MACT rules.

[23] AF&PA estimate

MACT II Rule Ex-Ante Cost Estimates

Source	Citation	Capital Expenditures	Operating Costs
"Revised Nationwide Costs, Environmental Impacts, and Cost Effectiveness of Regulatory Alternatives for Kraft, Soda, Sulfite, and Semichemical Combustion Sources"; Memorandum from Midwest Research Institute to project file	MRI (2000)	$0.44 billion	$0.23 billion
TAPPI Journal (Vol. 83, No. 9, September 2000, pp. 39-45)	Parthasarathy and Dowd (2000)	$0.35 billion	---
Pulp & Paper (Vol. 75, No. 10, October 2001, pp. 44-46)	Garner (2001)	$0.775 billion (MACT I)	---
	Garner (2001)	$0.90 billion (MACT II)	---
National Council for Air and Stream Improvement Special Report No. 03-07 (2002, p. 5)	NCASI (2003)	$1 billion or less	---

* $1.375 billion for MACT I & III and $1.250 billion for BAT and BMP

The purpose of this report is to examine how the EPA's ex ante cost analyses the Cluster and MACT II rules compare to an ex post assessment of costs. While the 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 from one another. 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 (the 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 (defined as +/- 25 percent). When a substantial difference exists, we seek to identify the particular reasons for the discrepancy. It is worth noting that information to evaluate costs ex post is also often quite limited. Any insights offered herein should be viewed with this limitation in mind.

In this report, 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 firms until 2002. While there are some differences, the NCASI data appear to approximately cover the same industry as the PACE survey described earlier in this report. We also use data found in the U.S. Securities and Exchange Commission (SEC) 10-K form, which provides some firm-level data for both ex ante and ex post costs of Cluster Rule compliance. Unfortunately, there is no template for submitting the data; therefore, comparisons across firms and over time is challenging. Finally, the cost information on MACT II and the implementation of a PM bubble strategy was provided by Abt Associates / RTI International (see section below).

It is worth noting that during our analysis we encountered several issues which may limit our ability to make firm conclusions: 1) for the Cluster Rule we only have access to industry level data, so our results are at least somewhat sensitive to how we construct the baseline; 2) for MACT II the only industry compliance expert that 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 3) for MACT II the ex post cost data was estimated by the contractor using a combination of ex ante engineering cost data developed by BE&K based on experience of similar projects in the pulp and paper industry and the actual (ex post) compliance methods chosen by the mills. Any insights offered herein should be viewed with these limitations in mind.

The remainder of this chapter is organized as follows. Section A details our efforts to engage with the pulp and paper industry to collect ex post cost data. Section B presents reasons why ex ante cost estimates of the Cluster Rule might differ from the ex post costs. Section C provides information on the implementation of ECF and TCF production by mills. Section D presents survey data for pollution abatement capital expenditures and explains how these data can be used to identify ex post costs associated with the Cluster Rule. Section E outlines evidence on cost savings associated with implementing PM bubble strategies during MACT II. Section F summarizes data on Cluster Rule ex ante costs reported by firms to the SEC. Section G discusses potential effects on the Cluster Rule on mill closings, and finally, Section H summarizes our preliminary findings and issues we encountered with our analysis.

B. Outreach Efforts

Our outreach efforts for the Cluster and MACT II rules focused on (legal) compliance assistance firms, independent associations (pulp and paper industry organizations), engineering compliance assistance firms, and independent information publishers. Although (legal) compliance assistance firms, such as Trinity Consultants, were very helpful in helping to identify the relevant independent associations and engineering compliance assistance firms, they did not have much information pertaining directly to the retrospective cost of compliance with pulp and paper regulations. Likewise, the Technical Association of the Pulp and Paper Industry (TAPPI), which is an independent non-profit professional association for pulp and paper industry,[24] was unable to provide directly relevant information, but referred us to other potential sources of experts. Engineering compliance assistance firms, including URS Corporation, Barr Engineering, Weston Solutions, and others, did not participate.[25]

Two independent associations—the American Forest & Paper Association (AF&PA) and NCASI—also expressed interest in the project. AF&PA is the national trade association of the forest, paper, and wood products industry, which represents its member companies (and related associations) in the

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[24] TAPPI is oriented towards provision of information, education, and knowledge-sharing opportunities for its membership (including engineers, scientists, and companies).

[25] Based on our communications with the engineering compliance firms, we speculate that their unwillingness to engage is due to perceived business concerns. The core clients of these firms are regulated entities, and the engineering firms may have been concerned that supporting EPA in this effort could jeopardize these business relationships.

regulatory arena, with focus on environmental regulations. AF&PA collects environmental health and safety data from its members to support its advocacy activities. NCASI is an independent, non-profit research institute that focuses on environmental topics of interest to the forest products industry, with members including 90 percent of pulp producers in the U.S. AF&PA and NCASI reviewed the Cluster Rule questionnaire and proposed to write a white paper that relies on AF&PA's proprietary compliance cost data (spanning 1970 to 2002) to determine the ex post cost of complying with the Cluster Rule.[26] These data could not be used for estimating the ex post cost of complying with the MACT II rule, because it stops shortly after this rule was promulgated, but can be used to estimate the ex post cost of the Cluster Rule. The independent information publisher, Resource Information Systems Inc. (RISI), provides access to a number of pulp and paper trade journals and maintains Lockwood-Post Directory, which contains details on ownership, location, and technology employed by pulp and paper manufacturing establishments in the U.S. and internationally. Unfortunately, RISI could not identify any internally-collected information that could be relevant to our research.

We then engaged with Abt Associates and RTI International (hereafter referred to as "RTI") to prepare a white paper (RTI [2011]) reviewing the compliance technology choices of pulp and paper mills for the MACT portions of the Cluster Rule and the MACT II rule, as well as the ex ante and ex post costs of the MACT II rule. RTI previously supported EPA in developing the original MACT II rule and is currently supporting EPA in developing amendments to the MACT I and III rule to fulfill the requirements of the residual risk and technology review (RTR) provisions in CAA sections 112(d)(6) and (f)(2). The white paper is based on data from EPA's FY2011 survey supported by RTI, as well as on RTI's data on the 2001 MACT II rule. Appendix V-A includes the Cluster Rule questionnaire to which the white paper is

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[26] As of 3/21/2011 EPA has not received any white paper or other cost materials from AF&PA.

designed to contribute answers.[27] Note that we did not develop a separate MACT II rule questionnaire, because RTI was already very familiar with the cost model assumptions.

C. Reasons Why Ex-Ante Cost Estimates of the Cluster Rule May Differ from Ex-Post Costs

As noted previously, our study found that the ex ante cost estimates of the Cluster Rule and MACT II rule exceed ex post cost estimates. There are a number of potential explanations for this difference:

- Regulatory-induced technological change can result in ex post costs being less than ex ante cost estimates.

- In the absence of exact information regarding what will be done to comply with the Cluster Rule, EPA was conservative in its cost estimates, in order to avoid preparing estimates that were too low and could be challenged.[28]

- MACT II pulp and paper mills were allowed to use a "PM bubble compliance alternative" strategy for reducing PM emissions, and MACT I and III mills were allowed some compliance flexibility (e.g., multiple compliance options, extended compliance times), resulting in more efficient pollution abatement. This improvement in the efficiency of pollution abatement would likely result in lower ex post pollution abatement costs.

- MACT I kraft mills were allowed to use a clean condensate alternative (CCA) to achieve HAP emission reductions that are equivalent to the reductions that would be obtained under the kraft pulping vent gas standards; mills would reduce HAP emissions in the pulping process water used in the pulping, bleaching, causticizing, and papermaking systems in the mill. According to the results of EPA's 2011 survey, 38 mills used the CCA to achieve compliance with MACT I. (Bradfield and Spence 2011)

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[27] RTI's whitepaper (RTI 2011) is available upon request.

[28] For example in the EPA's recently published RTR, the EPA assumed that facilities that would not be in compliance after the proposed tightening of the standard would upgrade their steam strippers and they were assigned a cost for that upgrade. In reality, mills can make process changes (such as increased maintenance) to be in compliance with the new standard without capital costs. The EPA however does not know which facilities will upgrade and which will make process changes so the conservative estimate is to assume that all facilities will spend capital, essentially over estimating the cost.

- Some MACT I and III mills were able to comply under site-specific rules (in §63.459 of the MACT I and III rule) or through equivalency-by-permit provisions (under section 112(l) of the CAA).

- Since the initial (i.e., ex ante) cost estimates of the Cluster Rule and MACT II rule assumed few or no mill closures, any additional mill closures during the implementation of the rules would reduce ex post pollution abatement costs. This would occur because a closed mill reports no pollution abatement costs.

D. Implementation of Elemental Chlorine-Free (ECF) and Totally-Chlorine Free (TCF) Bleaching

Best available technology under the Cluster Rule is to switch to ECF or TCF bleaching. Table V-2, which is taken from an Alliance for Environmental Technology (AET) (2006) report on the world pulp production market, reveals that, from 1990 to 2005, there was a substantial switch in North America to ECF pulp, bleached with chlorine dioxide. Totally chlorine-free production has remained stable and low in North America during the same period. Over half of the switch to ECF occurred prior to 1998, which is the first year the Cluster Rule was implemented for some mills.

Table V-2- North America Bleached Chemical Pulp Production
(millions of tones; 1 tonne = metric ton = 1000 kg = 2204.62 lb)

Year	ECF	TCF	Other
1990	1.2	0.0	37.1
1991	3.0	0.0	35.3
1992	5.4	0.1	32.8
1993	7.9	0.2	30.0
1994	11.5	0.3	26.5
1995	16.4	0.3	22.0
1996	18.5	0.3	20.6
1997	22.0	0.3	17.2
1998	24.6	0.3	14.2
1999	28.6	0.3	10.2
2000	31.4	0.3	7.4
2001	36.3	0.1	1.6
2002	36.4	0.1	1.6
2003	36.6	0.1	0.9
2004	36.2	0.1	0.7
2005	35.9	0.1	0.4

Source: http://www.aet.org/science_of_ecf/eco_risk/2005_pulp.html

In response to EPA's 2011 technology review survey, 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. (Spence and Bradfield 2011)

There have been a few studies, including Snyder, Miller and Stavins (2003) and Popp and Hafner (2008), examining 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 industry. Using plant-level data, their study focused on the diffusion of a new, cleaner production process within the chlorine industry. Diffusion was measured by whether existing plants adopted a cleaner technology, whether new plants installed the most environmentally-friendly technology, or whether existing plants that employed less environmentally-friendly processes closed. Snyder, et al's (2003) results indicate that chlorine facilities indirectly affected by the Cluster Rule (and the Montreal Protocol) were substantially more likely to close than were other facilities. This led to an increase in the share of chlorine plants employing the cleaner production technology. Using information on regulations affecting dioxins and patents from Canada, Finland, Japan, Sweden, and the United States, Popp and Hafner (2008) investigated the association between regulations and patent activity. They concluded that "substantial innovation" to reduce chlorine use in the bleaching technology occurred as a response to the implementation of environmental regulations. Both of these findings would reduce the ex post costs of complying with the Cluster Rule.

E. NCASI Pollution Abatement Cost Data for MACT I & III and BAT/PSES

There are two strategies for identifying the cost of pollution abatement and assessing whether technological improvement reduces the costs of regulations. The first strategy defines the cost of pollution abatement as the opportunity cost of the regulation (i.e., the forgone marketed output of the industry, such as pulp and paper). This is often calculated by modeling the joint production of good and bad outputs (see Färe et al. 1989).[29] Unfortunately, the lack of data on the undesirable by-products (i.e. pollution) generated by pulp and paper mills (i.e., mill-level data) precludes this option.

The second strategy for determining the cost of environmental regulations is to identify the cost of inputs assigned to pollution abatement – see Shadbegian and Gray (2005) and Pasurka (2008). Information like this could be found in the PACE survey. However surveys like the PACE survey focus on ex post engineering costs of all environmental regulations, as opposed to a specific regulation, which requires having pollution abatement data both before and after the regulation becomes effective – the pollution abatement cost data prior to the new regulation is required to construct a baseline from which the incremental costs can be calculated. With this approach, technological improvement in pollution abatement results in a decline over time in the cost of inputs assigned to meet a regulatory standard. This is the strategy we will use in this report to produce ex post cost estimates of the Cluster Rule. By comparing ex ante cost estimates of Cluster Rule compliance costs with ex post estimates of Cluster Rule compliance costs, it will be possible to make some *preliminary* assessments of the role technological change may play in the costs of complying with environmental regulations.

As noted above, the PACE survey was discontinued on an annual basis in 1994 and was only conducted in two years since then (1999 and 2005). Hence, it is necessary to turn to industry surveys of

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[29] Good output is industrial production (e.g. pulp) and bad outputs are pollution emissions or discharges.

pollution abatement costs borne by the pulp and paper industry.[30] For example, NCASI conducted an annual survey of pollution abatement capital expenditures from 1970 through 2002. In March or April of the year following the reference year for which the data will be collected, NCASI distributed its questionnaire to all member firms and selected non-member firms. The questionnaire requested information on all firm capital expenditures for the preceding year, including capital expenditures assigned to pollution abatement. The questionnaire also requested that firms 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).[31] In addition, the questionnaire requested that firms divide 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). Finally, the questionnaire requested that firms provide information on administrative costs and research costs associated with pollution abatement. Unfortunately the NCASI survey does not ask firms to provide estimates of annual pollution abatement operating costs.

The 1998 to 2002 NCASI surveys collected information from companies that accounted for 84 to 94 percent of wood pulping capacity and 68 to 79 percent of paper and paperboard capacity. One difference between the PACE and NCASI surveys is the U.S. Census Bureau that conducts the PACE survey assigned values for missing observations to be able to produce national estimates of pollution abatement costs, while NCASI treated missing observations as cases of zero costs. Another difference is

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[30] We had to rely on survey data because at the time we completed this report only 1 plant reported compliance cost data on EPA's FY2011 survey.

[31] The questionnaire defines an integrated mill as one that produces at least 20 percent of its total pulp consumption from on-site wood pulping operations.

the NCASI survey was an enterprise survey, while the PACE survey was an establishment-level survey. Finally, unlike the NCASI survey the PACE survey did collect information on annual pollution abatement operating costs.

For 1973 to 1986, the average NCASI pollution abatement capital expenditures values for air, water, and solid waste pollution abatement were on average approximately 4 percent higher than the PACE values for SIC 26. For 1988 to 1994, the average NCASI pollution abatement capital expenditures values for air, water, and solid waste pollution abatement were on average approximately 15 percent higher than the PACE values for SIC 26. Therefore, we believe that the NCASI data are a reasonably accurate representation of the actual pollution abatement capital expenditures made by the pulp and paper industry.

Table V-3 below shows the pollution abatement capital expenditures estimates from the NCASI survey.

Table V-3– Pollution Abatement Capital Expenditures

Constant $1995 Dollars (millions)

Year	Water	Air	Solid Waste	Total	Percent of Total Capital Expenditures
1995	309	219	97	625	
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	1071	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).

While the NCASI survey provides cost estimates for air, water, and solid waste abatement, it does not provide specific estimates of the cost associated with the Cluster Rule. Hence, it is necessary to construct a pre-Cluster Rule baseline level of expenditures on pollution abatement capital expenditures from which it will be possible to estimate the incremental capital costs of the Cluster Rule. The share of the abatement capital expenditures assigned to the Cluster Rule will change depending upon the definition of the baseline, thus we will construct several different baselines in addition to our preferred baseline to see how sensitive our results are to the definition of the pre-Cluster Rule baseline.

Our preferred pre-Cluster Rule baseline is the average capital expenditures for air and water pollution abatement between 1995 and 1997. We prefer this average baseline to a baseline that relies on any one particular year since it avoids the chance of having one year in which capital costs are unusually high (low) which would cause our ex post cost estimate to be too low (high) . Since no other new regulations were promulgated on the pulp and paper industry between 1995-2001, we can assume that any increase in air and/or water pollution abatement capital expenditures during 1998 to 2001 relative to the 1995-1997 average reflect the incremental capital costs of the Cluster Rule.[32]

During 1998 to 2001, the time between the promulgation of the Cluster Rule and its compliance date, total capital expenditures for air and water pollution abatement were $2.5 billion (in 1995 dollars). Using 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 results in an ex post Cluster Rule capital cost estimate of $675 million, which is approximately 55 percent lower than the EPA ex ante capital cost estimate of $1.54 billion.[33] To determine the sensitivity of our results to the baseline year, we also repeated the analysis using 1996 and 1997 as alternative baselines. [34,35] Using 1996 and 1997 as the baseline results in an ex

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[32] For cases when the value during 1998-2002 is less than 1997, we assume no capital costs are associated with the Cluster Rule.

[33] Recall AF&PA estimated the capital cost of the Cluster Rule would be $2.6 billion dollars.

[34] 1996 and 1997 both seem like a reasonable years to choose for the baseline as well as they are both prior to the promulgation of the Cluster Rule and NCASI (see 2002 Fact Book, p. 85) anticipated

post Cluster Rule capital cost estimate of approximately $503 million and $882 million respectively, which is roughly 67% and 43% lower than the EPA ex ante capital cost estimate of $1.54 billion.

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, the bleaching systems in the voluntary advanced technology incentives program (which only 3 mills took advantage of) and the HVLC system compliance, were not required until April 15, 2004 and April 17, 2006 respectively. We wanted to extend our analysis to cover these MACT provisions, but the NCASI survey stopped in 2002. Therefore our ex post cost estimate is likely to be somewhat too low making the EPA's ex ante cost estimate appear to be more of an over-estimate than we found. Unfortunately we do not have any ex post cost estimate of the cost of these two MACT provisions to adjust our ex post cost estimates.

F. Pollution Abatement Costs for MACT II

In order to meet the HAP metals standards of MACT II, an estimated 32 pulp and paper mills took advantage of a "PM bubble compliance alternative" strategy, using PM as a proxy for HAP metals. 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.[36] This improvement in the efficiency of pollution abatement resulted in lower ex post pollution abatement costs as described below. Even

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that the pulp and paper industry would experience the highest levels of capital expenditures associated with the Cluster Rule in 1999 and 2000.

[35] 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.

[36] 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.

though EPA staff anticipated that the PM bubble compliance alternative would improve the efficiency of pollution abatement, they were unable to develop ex ante estimates of cost and emission reduction for this alternative because they could not realistically determine how many or which mills would take advantage of the alternative or what limits the mills would set. The limits that mills set would determine which, if any, of the emission units in the bubble would require upgrading and which would be left as is. Table V-4 below provides the EPA ex ante engineering estimates of MACT II, plus ex post engineering estimates of the cost of complying with MACT II:

Table V-4 – Ex-Ante and Ex-Post Cost Estimates for MACT II

	TCI (2001$)	**TAC (2001$)**	**Source**	**Citation**
EPA - Ex-Ante	$231,410,193	$80,592,965	Final White Paper	RTI (2012)
BE&K - Ex-Post	$187,944,842	$24,222,647	Final White Paper	RTI (2012)

Notes: TCI = Total Capital Investment; TAC = Total Annual Costs

The EPA ex ante cost estimates are based on projected compliance costs presented in the compliance cost memorandum for the MACT II rule (MRI [2000]).[37] Because ex post cost information was not available from individual mills impacted by the regulations it was only possible to estimate the ex post costs using information on the actual (ex post) compliance methods selected by individual mills and estimated compliance costs from the engineering firm BE&K that were matched to the selected compliance methods.[38] Thus, the ex post cost estimates are derived mainly from ex ante unit costs

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[37] 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. (EPA 1996) 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.

[38] These ex ante cost estimates were based on BE&K's experience with similar projects in the pulp and paper industry.

provided by BE&K, applied to actual ex post mill-specific compliance change information provided by MACT II mills in their responses to the FY2011 survey; these estimates represent the best ex post compliance cost data for the MACT II rule.[39] Despite the limitations of this approach, it is clear from the above table that EPA overestimated the compliance costs of the MACT II rule. In particular, EPA's ex ante TCI cost estimate was nearly 25 percent higher than the ex post cost estimate.[40] Furthermore, EPA's ex ante TAC cost estimate was roughly three times higher than the ex post cost estimate. At this point, it seems that the main reason for the lower ex post cost is due to the use of the "PM bubble compliance alternative" strategy, which allowed for much more efficient method to abate the same level of PM emissions.[41] In particular, a significant percentage of sources subject to MACT II did not end up requiring any upgrades or replacements of existing air pollution controls, primarily due to the use of a PM bubble compliance alternative. For example, only 19 NDCE recovery furnaces of the expected 119 had to upgrade or replace their existing ESP units and only 29 DCE recovery furnaces of the expected 78 had to do likewise resulting in tremendous cost savings. This is further evidence that more flexible pollution abatement strategies lead to substantially lower abatement costs. However, it should be noted that the only industry compliance expert that 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 – this limitation and other limitations noted above should be kept in mind in drawing any conclusions from this analysis.

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[39] Again we had to rely on unit cost data reported by BE&K because at the time we completed this report only 1 plant reported compliance cost data on EPA's FY2011 survey.

[40] This is on the borderline for being called an accurate/over-estimate based on being within +/- 25% of the realized costs.

[41] It is also possible, as some research has suggested, that regulatory-induced technical change played a role in lowering the actual cost of the MACT II rule. Mill and equipment shutdowns and consolidations also played a role (see section G below).

G. SEC 10-K Pollution Abatement Cost Data

The Securities and Exchange Commission (SEC) collects information on firms via 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. Hence, Form 10-K constitutes another potential useful source of ex ante and ex post cost estimates of the Cluster Rule. Unfortunately, because the Cluster Rule was implemented in several phases and firms were not always specific about which costs were incurred for each phase, the cost estimates reported on the Form 10-K cover different portions of the Cluster and MACT II rules for different firms.

The Cluster Rule cost estimates from *Pulp & Paper North American Fact Book* (1999 to 2002) provide an overview of the challenges of using 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 V-5. As mentioned in the previous paragraph, a shortcoming of the Cluster Rule cost estimates provided by the SEC 10-K forms is their lack of uniformity. 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 foreign firms nor private U.S. firms need to submit 10-K forms.

In spite of these shortcomings, for at least some firms the SEC data provides insights into the accuracy of firm forecasts of the Cluster Rule (sometimes referred to as Phase I of the Cluster Rule by industry). Table V-6 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 remarkably 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 reported actual ex post costs. Thus, the anecdotal evidence of the realized costs 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 over-estimated it. However, since no firms clearly understated the realized costs, based on the firms that did supply 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.[42]

There are instance in which firms commented specifically 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.” It seems clear based on these statements and the fact that we were not able to find any statements in the SEC 10-K forms indicating that pulp and paper firms believed that the Cluster Rule would have a substantial impact on their profitability or would cause them to close any facilities, that paper firms do not believe the costs of Cluster Rule will have any material impact on their bottom line.

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[42] 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 V-5 – Cluster Rule Cost Estimates from SEC 10Ks

	1999		**2000**		**2001**		**2002**	
	1999 Fact Book (p. 26)		***2000 Fact Book (p. 29)***		***2001 Fact Book (p. 33)***		***2002 Fact Book (p. 33)***	
Company	**Cost (million US$)**	**Time Frame**	**Cost (million US$)**	**Time Frame**	**Cost (million US$)**	**Time Frame**	**Cost (million US$)**	**Time Frame**
Boise Cascade[9]	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	2000				
			22	1999-2003				
Donohue	-	-	52	1999-2001				
Fort James[4]	100	1998-2001	40	2000-2001				
George-Pacific[5]	300	1998-2000	160	1998-1999	50	2001	118	2002-2006
	550	1998-2005	190	2000	135	2002-2006		
			550	1998-2006				
P.H. Glatfelter	21	1998-1999	30	2000-2004	30	2001-2002	30	2002-2004

	1999		2000		2001		2002	
	1999 Fact Book (p. 26)		*2000 Fact Book (p. 29)*		*2001 Fact Book (p. 33)*		*2002 Fact Book (p. 33)*	
Company	**Cost (million US$)**	**Time Frame**	**Cost (million US$)**	**Time Frame**	**Cost (million US$)**	**Time Frame**	**Cost (million US$)**	**Time Frame**
International Paper	230	1998-2000	229	2000-2001	116	2000-2001	82	2002
	180	2001-2006	150-195	2002-2006	330-370	2003-2006	138	2003
							123	2004
Champion Intl.	20-40	1998-2004	25-50	2000-2005				
Union Camp	125-150	1998-2001						
Kimberly-Clark	279	1998-2000	15	2000	0.4	2001	98	2002
							99	2003
Longview Fiber	10-20	1998-2000	10-12	2000-2001	15-20	2001-2005	3.6	2002
	20-30	2001-2005	10-20	2002-2006				
Mead	110	1998-2002	55	2000-2006	54	2001-2003		
Westvaco	257	1998-1999	100-150	2000-2005	100-150	2001-2004		
	175-400	1995-2001						
MeadWestvaco Corp.							47	2002
							35	2003
Packaging Corp. of America	-	-	48	2000-2005	2.1	2001	5.8	2002
					25.7	2001-2005	1	2002-2005
Tenneco Packaging	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						

	1999		2000		2001		2002	
	1999 Fact Book (p. 26)		*2000 Fact Book (p. 29)*		*2001 Fact Book (p. 33)*		*2002 Fact Book (p. 33)*	
Company	**Cost (million US$)**	**Time Frame**	**Cost (million US$)**	**Time Frame**	**Cost (million US$)**	**Time Frame**	**Cost (million US$)**	**Time Frame**
Riverwood Intl.[10]	55	1998-2005	55	2000-2006	55	2000-2006	55	2000-2006
Schweitzer-Mauduit Intl.	8-16	1998-1999						
Smurfit Stone Container			200	2000	43	2001	100-125	2002-2007
			290	2001-2004	60	2002-2005		
Stone Container	180	1998-2005	180	1998-2005	27	2001-2003		
Jefferson Smurfit[8]	175	1998-2002						
Temple Inland	110	1998-2000	20	2000-2001			27	2001-2003
Gaylord Container[7]	5-7	1998-2000	10	2000	26	2001-2007		
			20	2001-2008				
S.D. Warren (NOTE: 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[6]	120	1998-2002	100	2000-2004	115	2001-2005		
Total			**$1,751-2,600**		**$1,584-1,679**		**$1,156**	
Source:	Unspecified		10-K forms		10-K forms		10-K forms	

NOTES:

1. Alliance Forest Products was acquired by Bowater
2. Consolidated papers was acquired by Stora Enso Oyj of Finland
3. Crown Vantage declared bankruptcy
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
6. Willamette Industries was acquired by Weyerhaeuser
7. Gaylord Container was acquired by Temple Inland
8. Jefferson Smurfit merged with Stone Container to form Smurfit Stone Container
9. Until October 2004, Boise Cascade was business unit of OfficeMax and not a stand-alone company.
10. 2003 Riverwood Holding purchases Graphic Packaging and combines Graphic Packaging with Riverwood International

NOTE: Shaded entries indicate a merger occurred during 1999-2002 among firms in contiguous shaded area.

Table V-6: Cluster Rule Cost Estimates from SEC 10Ks for Firms with Complete Data

	1998 10-K		1999 10-K		2000 10-K		2001 10-K	
Company	**Cost (Million US$)**	**Time Frame**	**Cost (Million US$)**	**Time Frame**	**Cost (Million US$)**	**Time Frame**	**Cost (Million US$)**	**Time Frame**
Boise Cascade	120	next 4 years (assume it refers to Phase I of Cluster Rule)	40	through 1999 (actual)	96	through 2000 (actual)	117	through 2001 (actual)
Gaylord Containers	22.5	first 3 years (assume it refers to Phase I of Cluster Rule)	10	for April 2001 standards	10	for April 2001 standards	10	through fiscal 2001 (actual)
Pope & Talbot	35	through first quarter of 2001(projected)	35	through first quarter of 2001(projected)	38.6	Through November 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	through 2000 (actual)	232	through 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)

H. Mill Closures

Another factor that will lead to ex ante cost estimates to exceed ex post costs will be either mill closings or a reduction in mill capacity through the shutdown of a machine. Obviously, if a plant shuts down instead of complying with the Cluster Rule that will reduce the observable ex post costs of the Cluster Rule. We attempt to identify mills affected by the Cluster Rule that closed between 1997 and 2009 and provide documentation on the reason for the mill closing. Complicating this task is the fact that mills can close, then be sold and reopened under new management. Table V-7 provides summary statistics on the number of mills that closed between 1971 and 2001.

Table V-7: 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 / Board	71	56	23	49	61	84

e= estimated
Sources: *1999 Fact Book* (p. 32), *2000 Fact Book* (p. 37), *2001 Fact Book* (p. 41), *2002 Fact Book* (p. 40)

The above table estimates a total of 26 mills closed in 1998 and 1999, 12 mills closed in 2000, and 23 mills closed in 2001. The *2002 Fact Book* (p. 69) states that 36 paper mills closed in 2001. Unfortunately, it does not list the specific mills or the rationale for closing. In addition, Jensen (1999, pp. 71-72) discusses some claims of mill shutdowns in response to implementing Phase 1 of the Cluster Rule. For example, Kimberley-Clark decided against undertaking expenditures to bring its Mobile, AL mill into compliance. 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.

In addition, we attempted to identify the number of closures among the mills directly impacted by the Cluster Rule. Starting with the list of mills subject to Cluster Rule (http://www.epa.gov/ttn/atw/pulp/milltab.pdf), we relied on four primary sources to identify mill closings. First, the Center for Paper Business and Industry Studies at Georgia Tech provides a listing of operating, closed, and recently idled mills in the United States (see http://www.cpbis.gatech.edu/data/mills-online/ - September 30, 2011 is the most recent update). Second, we checked the 1999 to 2002 editions of the *Pulp & Paper North American Fact Book*. Third, SEC10-K forms provided information on mill closures. Finally, Pulp and Paperworkers' Resource Council (PPRC) provided a spreadsheet of pulp and paper mill closures and curtailments, machine shutdowns, and idled mills for 1990 to 2010 (http://www.pprc.info/html/millclosures.htm). Based on this information, of the 155 mills subject to the Cluster Rule, a preliminary count of mill closures indicates that approximately 15 mills closed by 2004. As of now, we are unable to locate any claims by the pulp and paper industry in the SEC 10-K forms that mill closures were in anyway linked to environmental regulation, let alone the Cluster Rule. In fact, most of the reasons given were reduced demand for paper products and excess capacity. Furthermore, *Pulp & Paper* (July 1999) reported Proctor and Gamble as stating “Environmental Protection Agency's Cluster Rules had no impact on the decision to close the [Mehoopany, PA] mill.”

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 answer this question with a lot of precision. However, these 15 mills represent roughly 10 percent of the mills affected by the Cluster Rule. If we assume that they are typical mills (and we have no reason to believe otherwise) and we scale up our ex post cost estimate by 10 percent we will still find that the EPA over-estimated the costs of the Cluster Rule by 1.5 to 2.5 times depending on which baseline we use. Based on this we conclude that mill closures alone cannot account for why the EPA over-estimated the costs of the Cluster Rule.

I. Preliminary Conclusions and Future Work

Our *preliminary* findings suggest that EPA overestimated the costs of both the Cluster Rule and the separate MACT II rule. Using publicly available data from NCASI, we found that EPA overestimated the capital cost of the Cluster Rule by roughly 30 to 100 percent, depending on the choice of baseline year from which we derived the incremental cost (as discussed in Section D above). Some of the reasons why EPA overestimated these capital costs include mills’ use of the CCA alternative, flexible compliance options, extended compliance schedules, site-specific rules, use of equivalent-by-permit, and equipment/mill shutdowns and consolidations. However, given the lack of detail in this data we are currently unable to speculate on which reason(s) is mainly responsible for the EPA’s overestimate. Furthermore, our preliminary findings show that EPA overestimated the compliance costs the MACT II rule as well. In particular, EPA overestimated the capital cost by roughly 25 percent and overestimated the annual cost by nearly three times (as discussed in Section E). We found that this is the case even after we take into consideration that less mills were impacted than EPA first thought. At this point, it seems that the main reason for the lower ex post cost is due to the use of the "PM bubble compliance alternative" strategy, which allowed for much more efficient method to abate the same level of PM emissions and required many fewer mills to upgrade or install new pollution abatement equipment than first thought by the EPA. Anecdotal evidence of the realized costs of the Cluster Rule based on the SEC 10-K forms is a bit mixed with some firms accurately predicted the compliance costs, while others substantially over-estimated it. However, since no firms clearly understated the realized costs the aggregate ex ante cost estimates are likely higher than the aggregate ex post cost estimates. Finally, equipment/mill shutdowns and consolidations also played a role, but most likely not enough to account for the EPA's over-estimate.

During our analysis we encountered several issues which may limit our ability to make firm conclusions: 1) For the Cluster Rule we only have access to industry level data, so our results are at least 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; 3) For MACT II the only industry compliance expert that 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 of similar projects in the pulp and paper industry and the actual (ex post) compliance methods chosen by the mills.

References:
(Section V)

Alliance for Environmental Technology (2006), "Trends in World Bleached Pulp Production: 1990 - 2005," http://www.aet.org/science_of_ecf/eco_risk/2005_pulp.html (August).

Bradfield, John and Kelley Spence, U.S. Environmental Protection Agency (2011), "Summary of Clean Condensate Alternative Technology Review," October 20, 2011. Docket EPA-HQ-OAR-2007-0544-0130.

Färe, Rolf, Shawna Grosskopf, C.A. Knox Lovell, and Carl Pasurka (1989), "Multilateral Productivity Comparisons When Some Outputs Are Undesirable: A Nonparametric Approach," *The Review of Economics and Statistics*, 71, No. 1 (February), 90-98.

Garner, Jerry (2001), "Air emission control regulations pose new challenges for mills," *Pulp & Paper*, 75, No. 10 (October), 44-46.

Jensen, Karl P. (1999), "U.S. Bleached Pulp Mills Move towards Compliance of Phase 1 of Cluster Rule," *Pulp & Paper*, 73, No. 9 (September), 71-75.

Midwest Research Institute (2000), "Revised Nationwide Costs, Environmental Impacts, and Cost Effectiveness of Regulatory Alternatives for Kraft, Soda, Sulfite, and Semichemical Combustion Sources," Memorandum from Thomas Holloway, MRI, to project file.

Miller Freeman Publications, Inc. (1998), *Pulp & Paper North American Fact Book 1999*, San Francisco, CA: Miller Freeman Publications, Inc.

National Council for Air and Stream Improvement, Inc. (1999), "A Survey of Pulp and Paper Industry Environmental Protection Expenditures – 1998," Special Report No. 99-05, Research Triangle Park: National Council for Air and Stream Improvement, Inc.

National Council for Air and Stream Improvement, Inc. (2002), "A Survey of Pulp and Paper Industry Environmental Protection Expenditures – 1999," Special Report No. 02-01, Research Triangle Park: National Council for Air and Stream Improvement, Inc.

National Council for Air and Stream Improvement, Inc. (2002), "A Survey of Pulp and Paper Industry Environmental Protection Expenditures – 2000," Special Report No. 02-02, Research Triangle Park: National Council for Air and Stream Improvement, Inc.

National Council for Air and Stream Improvement, Inc. (2002), "A Survey of Pulp and Paper Industry Environmental Protection Expenditures – 2001," Special Report No. 02-07, Research Triangle Park: National Council for Air and Stream Improvement, Inc.

National Council for Air and Stream Improvement, Inc. (2003), "A Survey of Pulp and Paper Industry Environmental Protection Expenditures – 2002, Special Report No. 03-07, Research Triangle Park: National Council for Air and Stream Improvement, Inc.

Paperloop.com, Inc. (2000), *Pulp & Paper North American Fact Book 2000*, San Francisco, CA: Paperloop.com, Inc.

Paperloop.com, Inc. (2002), *Pulp & Paper North American Fact Book 2001*, San Francisco, CA: Paperloop.com, Inc.

Paperloop.com, Inc. (2003), *Pulp & Paper North American Fact Book 2002*, San Francisco, CA: Paperloop.com, Inc.

Parthasarathy, Perry and Steve Dowd (2000), "Impact of the Cluster Rule on the Cost Competitiveness of U.S. Papermaking Industry in the Global Market," *TAPPI Journal*, 83, No. 9 (September), 39-45. http://www.tappi.org/Downloads/unsorted/UNTITLED---00Sep39pdf.aspx

Pasurka, Carl (2008), "Perspectives on Pollution Abatement and Competitiveness: Theory, Data, and Analyses," *Review of Environmental Economics and Policy*, 2, No. 2 (Summer), 194-218.

Popp, David and Tamara Hafner (2008), "Policy versus Consumer Pressure: Innovation and Diffusion of Alternative Bleaching Technologies in the Pulp Industry," (Chapter 3), in *Environmental Policy, Technological Innovation and Patents*, OECD Studies on Environmental Innovation, pp. 107-138, OECD Publications: Paris, France.

Pulp and Paperworkers' Resource Council (PPRC) provides a spreadsheet of pulp and paper plant closures and curtailments for 1990 to 2010, mill2005p.xls: http://www.pprc.info/html/millclosures.htm

RTI International (2011), "DRAFT White Paper," Memorandum from Rebecca Nicholson, Tom Holloway, and Corey Gooden , RTI, to Anna Belova, Abt Associates, October 17, 2011**.**

Shadbegian, Ronald and Wayne Gray (2005), "Pollution Abatement Expenditures and Plant-Level Productivity: A Production Function Approach," *Ecological Economics*, 54, 196-208.

Snyder, Lori D., Nolan H. Miller, and Robert N. Stavins (2003), "The Effects of Environmental Regulation on Technology Diffusion: The Case of Chlorine Manufacturing," *American Economic Review*, 93, No. 2 (May) *Papers and Proceedings*, 431-435.

Spence, Kelley and John Bradfield, U.S. Environmental Protection Agency (2011), "Summary of Pulp Bleaching Technology Review," November 22, 2011. Docket EPA-HQ-OAR-2007-0544-129.

Urmanbetova, Aselia (2004), "U,S. Pulp and Paper Industry, Report on Data and Preliminary Research Issues," The Center for Paper Business and Industry Studies, Working Paper No. CPBIS-WP-04-

11.http://www.cpbis.gatech.edu/files/papers/CPBIS-WP-04-11%20Urmanbetova_US%20Pulp%20and%20Paper%20Industry%20Review.pdf

U.S. Environmental Protection Agency (1997), *Economic Analysis for the 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—Phase 1;* Prepared for U.S. Environmental Protection Agency, Office of Air and Radiation, Office of Air Quality Planning and Standards, Innovative Strategies and Economics Group, Research Triangle Park, NC 27711; and Office of Water, Office of Science and Technology, 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; http://en.wikipedia.org/wiki/Form_10-K

Appendix V-A: Document Shared with Consultants

EPA's Pulp and Paper Cluster Rule

The purpose of this questionnaire is to collect information and feedback from experts in the pulp and paper industry on the U.S. Environmental Protection Agency's analysis of compliance costs for the Pulp and Paper Cluster Rule as undertaken for rule development in 1998. 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 mills to reduce emissions.

The Cluster Rule for the pulp, paper, and paperboard industry was an integrated effort to set limits for releases of toxic and nonconventional pollutants to both air and water. EPA promulgated the Cluster Rule on April 15, 1998. For air pollutants, EPA set MACT standards that required mills to capture and treat toxic air pollutant emissions that occur during the cooking, washing, and bleaching stages of the pulp manufacturing process. For water pollutants, EPA set effluent limits (BAT/PSES requirements) for toxic pollutants in the wastewater discharged during the bleaching process, and in the final discharge from the mills, based on substituting chlorine dioxide for chlorine in the bleaching process. The rule also required mills to implement BMPs to prevent spills of black liquor into sewers. The rule affected three pulp and paper mill categories: (1) Bleached Papergrade Kraft and Soda (BPK) mills; (2) Papergrade Sulfite (PS) mills, and (3) Semi-Chemical mills.

Section 1: EPA's Rationale for the Combined Rule

The rulemaking for the pulp, paper, and paperboard industry was an integrated effort coordinated by the Office of Air and Radiation and the Office of Water. EPA developed the air and water regulations jointly because of the multimedia nature of pollution control in the pulp and paper industry. The comprehensive perspective afforded by considering both CAA and CWA requirements allowed EPA to (U.S. EPA, 1997a):

- **Encourage pollution prevention approaches that reduce the formation of pollutants, consistent with the Pollution Prevention Act of 1990**;
  Control technologies considered by EPA include process changes that avoid or minimize the formation of pollutants along with end-of-pipe control technologies, which remove pollutants before their release to air or water.

- **Reduce the possibility of cross-media pollutant transfers**:
  EPA's engineering analysis of the Cluster Rule used a systems-analysis approach to evaluate the interactions among pulp and paper production process changes, the amount and type of contaminants sent to water and air pollution control treatment, and the final releases (U.S. EPA, 1997a). For example:
  - A process change that prevents chloroform formation (e.g., elemental chlorine-free bleaching instead of chlorine bleaching) might also prevent or minimize the formation of dioxin and chlorinated organics. The same process change, however, could affect the amount and type of volatile contaminants sent to the air pollution control equipment.
  - The effluent limitation guidelines and standards, established by EPA's Office of Water, have the potential to increase the solids loading sent to the recovery process (U.S. EPA, 1997b). EPA considered this scenario in developing their cost and benefit analysis for the effluent guidelines;

- **Select controls that optimize pollutant reduction**:
  - The MACT standards and the effluent limitation guidelines required 100 percent ClO_2

substitution, which reduced the chlorine and chlorinated HAPs being sent to the bleach plant scrubber. EPA recognized that ClO_2 substitution would decrease the amount of chlorine in bleach plant scrubber inlets, which would have made the required 99 percent reduction of chlorinated HAPs from a ClO_2 application stage infeasible (U.S. EPA, 1997b). Thus, EPA incorporated a scrubber outlet chlorine concentration and a mass emission limit as options for the bleaching system requirement (U.S. EPA, 1997b).

- **Fully assess the combined economic impact of separate EPA regulations on an industry, more clearly representing real-world conditions**.
  Industry benefits from the integrated rulemaking through compliance savings by knowing the requirements for all rules in advance of investment. Industry can select the best combination of controls to meet all rules, thus potentially reducing capital equipment costs (U.S. EPA, 1997a).

Q1: Please comment on whether the combined rule approach reduced uncertainty associated with compliance and led to lower compliance costs compared to separate promulgation of these rules.
A1:>>>

Section 2: MACT I Cost Model Overview and Questions

For control of hazardous air pollutants, EPA promulgated MACT I standards, which would regulate hazardous air pollutants from the 155 pulp and paper mills that chemically pulp wood using the kraft, sulfite, soda, and semi-chemical methods. EPA subcategorized the pulp and paper industry by four chemical pulping processes for the purpose of selecting MACT technologies. Table 1 describes the mill types and number of such mills that would be affected by the promulgated MACT I standards.

Table 1: Summary of Mills Affected by MACT I Standards

Mill Type	Number of Mills
Kraft Mill	112
Semi-chemical Mill	16
Soda Mill	2
Sulfite Mill	14
Collocated Kraft and Semi-chemical Mill	10
Collocated Kraft and Sulfite Mill	1

Source: U.S. EPA (1997b).

EPA estimated national costs by calculating the cost of each control option applicable to each mill (i.e., the specific option each mill would need to comply with the rule) and summing the mill-specific results to obtain a national total (U.S. EPA, 1997b). Mill-by-mill variations in costs and impacts were a function of mill design, equipment, and operating parameters, which were derived from the site specific mill data that EPA obtained from the 1992 voluntary MACT survey and the Office of Water survey. (These data were updated from comments and information provided in response to the proposed rule (U.S. EPA, 1997b).) EPA calculated control costs by mill area (pulping vents, pulping wastewater, bleaching vents) and summed the area costs for the total mill, instead of calculating costs for each equipment system since add-on controls may be applied to multiple systems (i.e., EPA assumed multiple vents are routed to control devices through a common header).

2.1 BPK Mills

EPA evaluated potential costs based on converting to Low Volume High Concentration (LVHC) systems with the following (U.S. EPA, 1997b):

- Option 1: Washing System, Oxygen Delignification, high-emitting deckers, high-emitting; knotters and screens, steam stripping combined with hard piping;
- Option 2: Option (1) equipment plus weak black liquor storage tanks;
- Option 3: Option (2) equipment plus low emitting deckers;
- Option 4: Option (3) plus low-emitting knotters and screens.

MACT I costs differed depending on the BAT/PSES option selected for the 86 mills in the bleached papergrade kraft and soda subcategory, because of the increased boiler capacity and emissions for oxygen delignification (OD) found in BAT/PSES Option B.

Q2.1a: Are these options representative of the controls that facilities have employed for compliance with CAA permits since EPA adopted the Cluster Rule? If not, then please describe what other technologies have been employed by mills?

A2.1a:>>>

Q2.1b: Have any mills have retained HVLC systems?

A2.1b:>>>

Q2.1c: Please estimate the frequency with which these options have been used for compliance?

A2.1c:>>>

2.2 Soda and Semi-chemical Mills

EPA evaluated potential costs based on converting to LVHC systems with the following (U.S. EPA, 1997b):

- Option 1: Digesters and evaporators;
- Option 2: Option (1) equipment plus washing system.

Q2.2a: Are these options representative of the controls that facilities have employed for compliance with CAA permits since EPA adopted the Cluster Rule? If not, then please describe what other technologies have been employed by mills?

A2.2a:>>>

Q2.2b: Have any mills have retained HVLC systems?

A2.2b:>>>

Q2.2c: Please estimate frequency with which these options have been used for compliance?

A2.2c:>>>

2.3 Sulfite Mills

EPA evaluated potential costs based on converting to LVHC systems with the following (U.S. EPA, 1997b):

- Option 1: Digesters, evaporators, and red stock washer;
- Option 2: Option (1) equipment plus weak liquor, and strong liquor.

Q2.3a: Are these options representative of the controls that facilities have employed for compliance with CAA permits since EPA adopted the Cluster Rule? If not, then please mention what other technologies have been employed by mills?

A2.3a:>>>

Q2.3b: Have any mills have retained HVLC systems?
A2.3b:>>>

Q2.3c: Please estimate the frequency with which these options have been used for compliance?
A2.3c:>>>

2.4 Assumptions Underlying Estimated Costs

EPA estimated costs for various components needed for each control option, such as enclosures, ductwork/ conveyance, combustion devices, scrubbers, and steam strippers. Following is a summary of the EPA assumptions about control options. (Source: U.S. EPA (1993a)). All cost figures in this section are in 2002 U.S. dollars, which is approximately the time at which facilities would have been incurring costs for rule compliance. The costs were converted from the original year of the estimates to 2002 using the Engineering News Record Construction Cost Index (ENR CCI).

2.4a Enclosures

The emission points that require enclosures before an end-of-pipe control device can be used are the pulp washers, knotters, and screens/deckers. The resulting total capital investment for enclosures is approximately $84,800 for each screen, knotter and decker, and $310,500 for washers (2002 dollars). For the rule analysis, EPA annualized costs assuming a 10 year equipment life at a 10 percent interest rate. The resulting total annualized costs were $13,780 for each screen, decker, and knotter and $50,700 for washers (2002 dolllars).

Q2.4a: Please comment on these estimates, including both the costs of the control equipment and the assumptions for annualization. Were the actual capital investments for enclosures higher or lower than those mentioned above? If so, please indicate the approximate difference and the basis of the differences?
A2.4a:>>>

2.4b Ductwork

Ductwork is used for the conveyance of vent streams from discrete points or from enclosures to the control devices. EPA assumed that the mill would combine vent streams and send them through a single duct to the control device; therefore, EPA sized the ductwork system to allow multiple emission points from a process area (i.e., knotter and pulp washers) to be routed together to be conveyed through a common ductwork system. For 19-inch ducts, 1,000 feet in length with 20 elbows, EPA estimated capital costs of approximately $67,600 (2002 dollars).

Q2.4b: Please comment on these estimates. Were the actual unit costs of ductwork higher or lower than those mentioned above? If so, please indicate the approximate difference and the basis of the differences?
A2.4b:>>>

2.4c Combustion Devices

The thermal incinerator system for halogenated streams consists of the following equipment: combustion chamber, instrumentation, blower, collection fan, ductwork, and stack. EPA estimated the equipment cost as a function of total volumetric flow through the incinerator and is accurate to within 30 percent. For halogenated streams, EPA used the following equation in the cost analysis:

$$EC = 14{,}482 * Q_{Tot}^{0.2355}$$

where:
EC = Equipment costs (2002 dollars);
Q_{Tot} = Total volumetric flow rate through the incinerator including any additional air and fuel.

EPA estimated the total capital investment at 1.61 times the purchased equipment cost to account for installation costs (e.g., auxiliary equipment, instrumentation, sales tax, and freight). EPA assumed fuel and electricity costs equal to $4.71 per 1,000 cubic feet of natural gas and $0.05/kW-hr, respectively. The incinerator requires 0.5 hour of operating labor per 8-hour shift. EPA assumed maintenance labor requirements are identical to operating labor requirements, and supervisory cost is 15 percent of the operating labor cost. EPA assumed maintenance material costs are equal to maintenance labor costs, and taxes, insurance, and administrative costs are 4 percent of the total capital investment. EPA estimated overhead to be 60 percent of the total labor and maintenance costs.

Q2.4c: Please comment on these estimates and cost analysis assumptions. Were the actual cost elements associated with combustion devices higher or lower than those mentioned above? If so, please indicate the approximate difference and the basis of the differences?
A2.4c:>>>

2.4d Scrubbers

EPA applied scrubber systems as secondary control to remove acid gases from the incinerator exhaust after combustion of halogenated bleach plant streams (i.e., post-incineration scrubbers), and as a primary control for bleach plant vent streams, without incineration (i.e., standalone scrubbers). The main components in scrubber cost are: tower, packing, and ductwork to the scrubber. EPA estimated tower costs based on the following equation:

EC = (156,\$/ft^2) * (S,ft^2)
where:
EC = Equipment cost (2002 U.S. dollars);
S = Column surface area (ft^2), approximated by n * D (HT + D/2);
D = Diameter of the tower (ft); and
HT = Height of the tower (ft).

EPA estimated the total capital investment to be 2.20 times purchased equipment costs and include auxiliary equipment, instrumentation, sales taxes, and freight. EPA assumed water and caustic costs to be negligible because EPA assumed the scrubbing medium was on-site. For this analysis, EPA used an electricity cost of $0.05/kW-hr. The assumptions for operating labor, maintenance labor, supervisory labor, maintenance material costs, taxes, insurance, administrative costs, and overhead are the same as for combustion devices.

Q2.4d: Please comment on these assumptions. Were the actual cost elements associated with scrubbers higher or lower than those mentioned above? If so, please indicate the approximate difference and the basis of the differences?
A2.4d:>>>

2.4e Stream Stripper

The capital costs for the steam stripper system are based on the following equipment components: reflux tank (for integrated system); steam stripper column (including column shell, skirts, nozzles, manholes, platforms and ladders, and stainless steel sieve trays); flame arrestor; pumps; and feed preheater. EPA assumed that these components would be constructed of stainless steel because they are subject to the greatest wear and are exposed to the harshest condition. EPA did not include capital costs for additional boilers or cooling towers. EPA estimated the total capital investment for a steam stripper system to be 2.20 times the purchased equipment costs. Purchased equipment includes equipment components, auxiliary piping, instrumentation, sales tax, and freight. For example, total capital costs for a model mill (11 feet diameter and 29 feet height stripper tray) are approximately $4.7 million.

EPA used electricity cost of $0.05/kW-hr, and estimated steam costs using the design steam loading of 0.180 kg of steam per liter (1.50 lb/gal) of wastewater feed. For integrated systems, make-up steam use is approximately 12 percent of the steam use for the stand-alone system. EPA used a steam cost of $5.44/Mg. The assumptions for operating labor, maintenance labor, supervisory labor, maintenance material costs, taxes, insurance, administrative costs, and overhead are the same as for combustion devices.

Q2.4e: Please comment on these assumptions. Were the actual cost elements associated with stream strippers higher or lower than those mentioned above? If so, please indicate the approximate difference and the basis of the differences?

A2.4e:>>>

2.5 Example of Estimated Costs

Table 2 provides capital and annual costs for example mills with varying capacities, based on EPA analysis at the time of rule development. All cost figures in this section are in 2002 U.S. dollars. Costs were brought forward to 2002 using the Engineering News Record Construction Cost Index (ENR CCI).

Table 2: Comparison of Capital and Annual Costs for Example Mills with Varying Capacities[1]

Option	Emission Point	Mill Capacity					
		500 tons per day		1,000 tons per day		1,500 tons per day	
		Capital	Annual ($/yr)	Capital	Annual ($/yr)	Capital	Annual ($/yr)
Combustion of pulping vents not requiring enclosures	Brownstock foam tank Weak black liquor storage tank	$78,416	$229,840	$112,216	$378,560	$148,720	$554,320
Combustion of pulping vent requiring enclosures	Brownstock washer Knotter Deckers/screens	$283,920	$1,352,000	$473,200	$2,163,200	$608,400	$2,839,200
Scrubbing of bleaching vents	Bleach plant washers Bleach plant towers Bleach plant seal tanks	$216,320	$540,800	$392,080	$1,162,720	$446,160	$1,487,200
Combustion of bleaching vents followed by scrubbing	Bleach plant washers Bleach plant towers Bleach plant seal tanks	$3,555,760	$3,609,840	$5,137,600	$5,813,600	$10,140,000	$9,464,000
Steam stripping of pulping wastewater followed by conveyance of vent stream to an existing combustion device	Digester blow tank condensates Evaporator foul condensates	$1,135,680	$2,190,240	$2,568,800	$4,732,000	$3,109,600	$6,219,200

Source: U.S. EPA (1993a), Table 5-13 page 5-33. Costs in 2002 U.S. dollars.

Q2.5a: Based on the table above, please comment on the reasonableness of EPA's assessment of capital and annual costs for the varying mill sizes. To the extent possible, please describe the approximate amount by which your estimates of these costs would differ from those estimated by EPA.
A2.5a:>>>

Q2.5b: Have costs for the various components (both capital and O&M) changed significantly since the time that facilities began complying with the Cluster Rule (that is, within the last 10 years)?
A2.5b:>>>

Q2.5c: If so, please list some of the important reasons for these changes and, to the extent possible, the approximate amount of change from EPA's estimates.
A2.5c:>>>

Section 3: BAT / PSES Cost Model Overview and Questions

EPA identified 86 BPK mills and 11 PS mills (with one mill producing in both subcategories) that would potentially be affected by the Cluster Rule (U.S. EPA, 1997c). EPA determined the existing technology in place at each mill as of January 1, 1993 to estimate the incremental control necessary for meeting BAT/PSES requirements. Where effluent data were not available for specific pollutants at the necessary monitoring points, EPA assumed that the facility was not in compliance with BAT/PSES limits and would need incremental controls (U.S. EPA 1993b). In its analysis, EPA acknowledged this assumption as a likely source of overestimation of potential costs (U.S., EPA 1993b).

After proposal of BAT and PSES in 1993, six corporations announced plans to install new technologies that would achieve BAT and PSES at their facilities. The announced plans involved a total of 24 mills. The process changes were implemented at 12 of these mills by mid-1995; for these mills, EPA excluded the costs of these technology improvements from its analysis of the economic achievability of this rule (U.S. EPA, 1997c). Process changes at the other 12 mills were not underway as of July 1, 1995. The costs anticipated for these 12 mills were included in EPA's economic achievability analysis (U.S. EPA, 1997c). EPA also noted, however, that including these announced corporate plans did not change the results of its analysis.

Section 3.1 BPK Mills

For BPK mills, EPA classified each mill into a cost group. First, EPA classified each pulping and bleaching line at every mill as Group A through Group K (representing 10 groups; EPA did not include a Group F in its analysis) based on the technologies already in place (U.S. EPA, 1997c). For mills with only a single bleach line, the group classification applied to the mill as well as the bleach line. For mills with more than one type of bleach line, EPA used engineering judgment to assign the mill to a cost group for estimating the cost of implementing each option. EPA developed costs based on 10 model mills (i.e., hypothetical mills represent general characteristics of all mills in the universe), one from each group classification (Groups A – K), to estimate the average cost of compliance for all the mills in a group (U.S. EPA, 1997c). EPA extrapolated the estimated capital and annual (variable) compliance costs for each model mill for the entire technology group by multiplying the model mill's costs by the total annual brown stock production for all mills in that group. After summing the results for all 10 groups, EPA obtained total estimated compliance costs.

EPA made the following additional assumptions in estimating potential costs (U.S. EPA, 1997c):

- After compliance with the rule, mills would continue to produce the same quality and quantity of product as prior to rule implementation;

    - Please replace the summary bullets below with those noted in the STDD at Section 8.2.1.1, which presents nine elements common to EPA's analysis of both Options A and B
- Use of precursor-free defoamers is part of industry's process baseline, and any mill not currently using such defoamers can use them without incurring significant cost;
- It is possible for mills to achieve adequate chip size control through low or negligible cost beyond current practices. That is, improvement in quality and uniformity chip size can be achieved without the need to purchase chip thickness screens. The mills with poor chip thickness control may choose to install thickness screens. However, this enhancement will pay for itself by improving yield and reducing bleaching chemical requirements;
- The use of efficient biological wastewater treatment is part of baseline technology at BPK mills.

Q3.1a: Please comment on the reasonableness of EPA's cost analysis assumptions. Do any of these assumptions lead to significant over-estimation or under-estimation of compliance costs? If so, please describe how the assumptions diverge from your assessment, including, to the extent possible, the approximate degree of difference.
A3.1a:>>>

EPA estimated that mills could implement one of four options (two potential ECF options or two TCF options) to comply with BAT/PSES requirements. However, the final compliance cost estimates for the rule are based on mills implementing Option A (U.S. EPA, 1997c).

Option A (ECF) includes:

- Improved brown stock washing;
- Closed brown stock screening;
- Hypochlorite elimination;
- Oxygen and peroxide enhanced caustic extraction (Eop);
- 100% chlorine dioxide substitution (ECF bleaching);
- Implementing strategies to minimize kappa factor and brown stock precursors.
- Approx. bleach sequence: DEopD

Option B (ECF) includes:

- Improved brown stock washing;
- Closed brown stock screening;
- Hypochlorite elimination;
- Oxygen and peroxide enhanced caustic extraction (Eop);
- 100% Chlorine Dioxide Substitution (ECF bleaching);
- Implementing strategies to minimize kappa factor and brown stock precursors;
- Kappa number of 15 for softwood and 10 for hardwood entering the first bleaching stage through addition of oxygen delignification and/or extended cooking.
- Approx. bleach sequence: ODEopD

Option C (TCF; ozone-based) includes:

- Improved brown stock washing;
- Closed brown stock screening;
- Kappa number of 10 for softwood and 6 for hardwood entering the first bleaching stage though oxygen delignification and anthraquinone addition to the digester;
- Ozone bleaching (delignification);
- Oxygen and peroxide enhanced caustic extraction;
- Substitution of peroxide bleaching for all chlorinated bleaching compounds (TCF bleaching);
- Chelant addition;
- Approx. Bleach Sequence: OZEopQPZP.

Option D (TCF; peroxide-based) includes:

- Improved brown stock washing;
- Closed brown stock screening;
- Kappa number of 10 for softwood and 6 for hardwood entering the first bleaching stage though addition of oxygen delignification and anthraquinone addition to the digester;
- Substitution of peroxide bleaching for all chlorinated bleaching compounds (TCF bleaching);
- Chelant addition;
- Approx. Bleach sequence: OQPP.

Q3.1b: Are these control options representative of the controls facilities have employed for meeting NPDES permit requirements since the time EPA adopted the Cluster Rule?
A3.1b:>>

Q3.1c: If not, what other technologies are currently employed by mills?
A3.1c:>>

Q3.1d: Please estimate the frequency with which these options have been used for compliance?
A3.1d:>>

Section 3.2 PS Mills

Since this subcategory consists of only 11 mills, EPA estimated mill-specific compliance costs and did not use model mills. (Source: U.S. EPA, 1997c).

3.2.1 Calcium- and magnesium-based pulping

EPA selected totally chlorine free (TCF) as the compliance option for BAT/PSES for these segments. EPA evaluated the following process technologies to achieve TCF:

- Totally chlorine free bleaching (bleaching with peroxide);
- Elimination of hypochlorite;
- Oxygen and peroxide enhanced extraction;
- Improved pulp cleaning.

Q3.2.1a: Are these control options representative of the controls facilities have employed with NPDES permit since the time EPA adopted the Cluster Rule?
A3.2.1a:>>

Q3.2.1b: If not, what other technologies are currently employed by mills?
A3.2.1b:>>

Q3.2.1c: Please estimate the frequency with which these options have been used for compliance?
A3.2.1c:>>

3.2.2 Ammonia-based and specialty grade pulping

EPA selected elemental chlorine free (ECF) as the compliance option for BAT/PSES for these segments. EPA evaluated the following process technologies to achieve ECF:

- 100% chlorine dioxide substitution (ECF bleaching);
- Elimination of hypochlorite;
- Oxygen and peroxide enhanced extraction.

Q3.2.2a: Are these control options representative of the controls facilities have employed with NPDES permit since the time EPA adopted the Cluster Rule?
A3.2.2a:>>

Q3.2.2b: If not, what other technologies are currently employed by mills?
A3.2.2a:>>

Q3.2.2c: Please estimate the frequency with which these options have been used for compliance?
A3.2.2c:>>

3.2.3 Technology upgrades to BAT technologies

In order for each PS mill to comply with BAT, PSES and BMPs, EPA evaluated the following technology upgrades to BAT technologies or affected process units (U.S. EPA, 1997c):

- Installation of Final P-Stage;
- ClO_2 Generator Upgrades;
- Eliminate Hypochlorite (adding new D-tower);
- Add Eop;
- Evaporator Upgrades.

Q3.2.3a: Are these upgrades representative of the upgrades that facilities have employed for compliance with NPDES permits since EPA adopted the Cluster Rule?
A3.2.3a:>>

Q3.2.3b: If not, what upgrades are mills currently implementing?
A3.2.3b:>>

Q3.2.3c: Please estimate the frequency with which these options have been used for compliance?
A3.2.3c:>>

Section 3.3 Estimated Unit Costs

EPA estimated capital and operating costs for BAT control options and BMP costs using a unit cost framework. All cost figures in this section are in 2002 U.S. dollars. Conversion was made using Engineering New Record Construction Cost Index (ENR CCI).

Capital Costs

EPA (1996) developed capital costs for the unit operations representing the various compliance options; many of the unit operations are the same across control options (e.g., brown stock washing and chlorine dioxide generators). EPA scaled the capital costs by capacity using the following equation (U.S. EPA, 1996):

$$C = \text{BaseDoll} \, (\text{Cap}/\text{BaseCap})^n$$

where,
C = Calculated capital cost of system in dollars
BaseDoll = Base cost for a similar system of capacity BaseCap
BaseCap = Capacity corresponding to the base cost BaseDoll
Cap = Capacity of system for which capital costs is being calculated
n = Index which reflects economy of scale for adjusting equipment costs for various capacities

Table 3 shows the base cost, base capacity, and index values for each unit process for BAT unit operations.

Table 3: Capital Costs for BAT Unit Operations (2002 U.S. dollars)

Unit Operation	Base Cost	Base Capacity	Index	Units for Base Capacity and Assumptions
Retrofit extended cooking to continuous digester	$3,740,350	1,000	0.40	ADt unbleached pulp/day
New continuous digester	$63,335,000	1,000	0.50	ADt unbleached pulp/day
Anthraquinone handling and dosage	$89,625	-	-	ADt unbleached pulp/day
New brown stock washing line	$18,283,500	550	0.40	ADt unbleached pulp/day
Additional brown stock washer	$5,377,500	850	0.65	ADt unbleached pulp/day
Close brown stock screens	$1,673,000	750	0.40	ADt unbleached pulp/day
Oxygen delignification stage	$20,912,500	720	0.35	ADt unbleached pulp/day
Convert ClO_2 generator	$2,390,000	10	0.20	Tons/day ClO_2; Convert R3 or SVP to R8 or SVP Lite process; ClO_2 storage
New chlorine dioxide generator	$18,881,000	30	0.80	Tons/day ClO_2; extra ClO_2 storage; use existing chemical handling
Greenfield ClO_2 plant	$23,900,000	30	0.80	Tons/day ClO_2; chemical unloading and storage
Additional ClO_2 storage	$1,314,500	24	0.90	Tons/day ClO_2; 12-hr capacity
Improve ClO_2 mixing and control	$1,254,750	550	0.60	ADt unbleached pulp/day; high substitution conversion

New D-stage tower and washer	$16,371,500	815	0.60	ADt unbleached pulp/day; If required to allow replacement of hypo with ClO_2
Install oxidative extraction	$1,314,500	825	0.30	ADt unbleached pulp/day
Peroxide unloading and storage	$149,375	1,100	0.00	Constant cost per mill
Install P of an Eop stage	$35,850	1,100	0.00	Fixed cost (peroxide unloading and storage separate)
Monitor bleach filtrates	$145,790	700	0.05	ADt unbleached pulp/day; 2 stations per bleach line
Upgrade evaporators	$7,170,000	1,700	0.70	Tons/day water evaporated
Pulp cleaning for sulfite	$478,000	200	0.60	ADt unbleached pulp/day
Recovery boiler upgrade	$7,170,000	2,900	0.65	GJ/day heat input to boiler
Upgrade recausticizing	$3,704,500	1,000	0.80	ADt unbleached pulp/day
Black liquor oxidation	$597,500	1,500	0.80	Mt/day black liquor solids
Source: U.S. EPA (1996), Table 6-3 page 6-11. ADt = air dry ton, ClO_2 = chlorine dioxide, GJ = gigajoules, Mt = metric ton				
EPA based its estimates of necessary unit processes on the presence of existing treatment processes and operations.				

Q3.3a: Please comment on whether EPA's capital costs, as shown in Table 3, for each unit process are representative of the costs facilities may have incurred for complying with BAT requirements. Also, please comment on the reasonableness of the unit cost concepts that EPA used in its analysis (i.e., do the unit cost concepts provide an appropriate basis for understanding how capital costs would vary for mills of varying processing capacity?).
A3.3a:>>>

Operating Costs

Operating costs are based on survey results from actual mills. EPA calculated the costs for electricity, steam, labor, raw materials, and operation and maintenance as increments from baseline conditions (U.S. EPA, 1996). Table 4 shows the unit costs for those operating components that apply generically to most of the unit operations. Quantities for operating costs were calculated as increments over base/existing conditions so they vary for each mill.

Table 4: Summary of Operating Costs (2002 U.S. dollars)	
Component	**Unit Cost**
Chemicals	
Molecular Chlorine	$0.26/kg
Chlorine Dioxide	$1.21/kg
NaOH (ECU)	$0.67/kg
NaOH (non-ECU)	$1.84/kg
Oxygen, by truck	$0.10/kg
Oxygen, onsite	$0.04/kg
Hydrogen Peroxide	$1.37/kg
Hypochlorite	calculated individually for each mill
Sulfuric Acid	$0.08/kg
Anthraquinone	$7.19/kg
Energy	
Electricity	$0.05/kWh
Steam	$4.80/ton steam
Raw Materials	
Softwood Logs	$100.62/ODt wood
Hardwood Logs	$59.01/ODt wood
Labor	
Technician	$30.46/hour
Process Engineer	$101,983.69/year
Additional Supervision and Technical Support	0.5% of capital cost
Source: U.S. EPA (1996), Table 4-1 page 4-5. ECU = electrochemical unit, kg = kilogram, ODt = oven dry ton	

Q3.3b: Please comment on whether EPA's operating unit costs, as shown in Table 4, are representative of the costs facilities incurred for compliance with BAT requirements.
A3.3b:>>>

BMP Costs

To develop BMP estimates for BPK and PS mills, EPA first classified each mill by the level of complexity of its pulping and chemical recovery systems. For each mill complexity category, EPA determined the types of equipment necessary to implement spent pulping liquor spill prevention, and control and containment measures for soap and turpentine (U.S. EPA, 1997d). Table 5 shows the total BMP costs EPA estimated for each type of mill (represents average per mill BMP costs).

Table 5: Estimated BMP Costs Associated with BAT/PSES (in U.S. 2002 dollars)		
Type of Mill	**BPK Mill BMP Costs**	**PS Mill Costs**
Single Line Mills	$2,906,800	$1,757,600
Moderately Complex Mills	$4,394,000	None
Complex Mills	$5,475,600	None
Source: U.S. EPA (1997d), pg 9-3.		

Q3.3c: Please comment on whether EPA's BMP costs, as shown in Table 5, are representative of the costs facilities would incur to implement various spent pulping liquor spill prevention, and control and containment measures for soap and turpentine.
A3.3c:>>>

Section 4 Additional Questions

Q4.1: 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?
A4.1:>>

Q4.2: What are the factors that may have caused greater implementation difficulty and higher costs with the Cluster 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 pollution prevention equipment?**
- **Limitations on compliance in terms of compliance assistance or compliance schedule?**
- **Terms of regulatory requirements, and specific aspects of the rule requirements?**

A4.2:>>

References

United States Environmental Protection Agency (U.S. EPA). 1997a. Economic Analysis for the 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—Phase 1. October.

United States Environmental Protection Agency (U.S. EPA). 1997b. Pulp, Paper and Paperboard Industry – Background Information for Promulgated Air Emission Standards: Manufacturing Processes at Kraft, Sulfite, Soda, Semi-chemical, Mechanical, Secondary and Non-wood Fiber Mills. October. EPA 453/R-93-050b.

United States Environmental Protection Agency (U.S. EPA). 1997c. Supplemental Technical Development Document for Effluent Limitations Guidelines and Standards for the Pulp, Paper, and Paperboard Category, Subpart B (Bleached Papergrade Kraft and Soda) and Subpart E (Papergrade Sulfite). October. EPA-821-R-97-011.

United States Environmental Protection Agency (U.S. EPA). 1997d. Technical Support Document for Best Management Practices for Spent Pulping Liquor Management, Spill Prevention, and Control. October. EPA 821-R-97-015.

United States Environmental Protection Agency (U.S. EPA). 1996. BAT Cost Model Support Document. Prepared by Eastern Research Group Inc. June.

United States Environmental Protection Agency (U.S. EPA). 1993a. Pulp, Paper and Paperboard Industry – Background Information for Proposed Air Emission Standards: Manufacturing Processes at Kraft, Sulfite, Soda, Semi-chemical, Mechanical, Secondary and Non-wood Fiber Mills. October. EPA 453/R-93-050a.

United States Environmental Protection Agency (U.S. EPA). 1993b. Development Document for Proposed Effluent Limitations Guidelines and Standards for the Pulp, Paper, and Paperboard Point Source Category.

Federal Register, April 15, 1998, page 18399 - 18751

VI. Retrospective Evaluation of the Costs Associated with Methyl Bromide Critical Use Exemptions for Open Field Strawberries in California

A. Introduction

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, methyl bromide 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 methyl bromide produced and imported by developed countries was phased out between 1993 and 2005 (see Table V-1).[43] 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.

Table V-1: Methyl Bromide Phase-Out Schedule for Developed Countries

Years	Level of Phase-Out
1993 to 1998	Production frozen at 1991 baseline levels[44]
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/

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

[44] U.S. consumption in 1991 was about 25,500 metric tons (MT) where consumption is defined as production plus imports minus exports.

After developed countries reached 100 percent phase-out of methyl bromide in 2005, methyl bromide 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.[45] 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:

(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

(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.”

This paper reports the initial results of an ongoing ex-post examination of the unit (per acre) operating cost estimates provided by the EPA as an input into the critical use nomination process for methyl bromide critical use exemptions in a given year. In particular, the purpose of this paper is to examine how the EPA’s ex-ante cost analyses for open field fresh strawberries grown in California for the 2006-2010 seasons compare to an ex-post assessment of costs. It does not attempt to evaluate the decisions regarding the amounts of methyl bromide ultimately exempted by the Parties to the Montreal Protocol for critical use for this time period. It also does not evaluate the extent to which the EPA

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

accurately characterized regulatory and technical constraints faced by growers in the CUE nomination packages, though it does discuss how they may have affected the costs.

While the 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 from one another. For instance, the literature points to the possibility that market conditions, energy prices, or the cost and availability of technology change in unanticipated ways. It is also possible that industry overestimated the costs of compliance (the 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. A key analytic question we attempt to address is whether ex-ante and ex-post cost estimates vary by a substantial degree (defined here as +/- 25 percent based on Harrington et al. 2000). When a substantial difference exists, we seek to identify the particular reasons for the discrepancy.

The ex-post data we have is limited in several key respects. We only have information on operating costs from crop budgets designed to reflect a typical farmer. We do not have information on the prices of specific fumigant formulations. Data on yield losses associated with various methyl bromide alternatives are based on field trials. 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. 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. Any insights offered herein should be viewed with these limitations in mind.

B. Background

The U.S. Environmental Protection Agency (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, the EPA conducts a technical assessment to evaluate all applications according to the above criteria. Once the evaluation is completed, the U.S. Government submits critical use exemption nomination packages by commodity category to the Ozone Secretariat for the Montreal Protocol for consideration. This occurs two years in advance of the season to which it will apply. 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. The United States has historically been granted about 90 percent of the total amount it has nominated for exemption.[46]

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 (referred to as 1,3-D + PIC), or chloropicrin combined with metam sodium (a fumigant), 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 the section H.4). As many of the studies up to that time had focused on the performance of MBr alternatives with regard to California

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

strawberries or Florida tomatoes, the USDA document noted that there was greater uncertainty regarding alternatives for use on other crops.

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

Other challenges that could have an effect on the rate at which methyl bromide alternatives are adopted include: MBr alternatives are often subject to use restrictions to protect workers and bystanders from health effects associated with their toxicity, and they cannot be adopted unless they have been registered by the U.S. EPA and the state where they will be used. The USDA (2000) notes that several possible alternatives – for instance, 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 spite of these challenges, the critical use exemptions nominated by the U.S. government have declined substantially over time during the period of study, 2006 - 2010. For instance, the U.S. submitted exemptions for 17 different commodity categories for the 2006 growing season ranging from forest seedling nurseries and food facilities to strawberry and tomato growers. These submissions represented 35 percent of U.S. baseline use. U.S.-nominated critical use exemptions for the 2010 growing season continued to cover a myriad of categories– but constituted 13.4 percent of baseline use (see Table V-2).

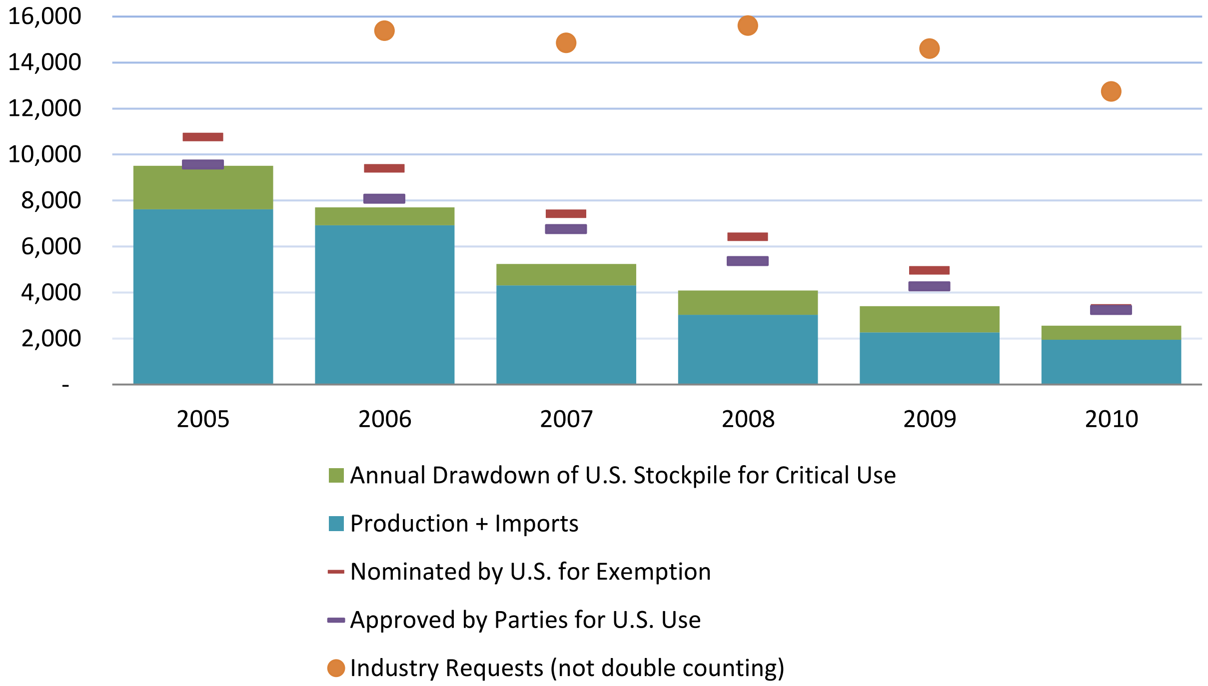
Table V-2: Percent of Baseline MBr Consumption in U.S. Exempted for Critical Use by Year

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 V-1 shows how U.S. consumption of methyl bromide has changed between 2005 and 2010. First, in aggregate the amount of methyl bromide requested for agricultural use by applicants is far higher than what the U.S. has nominated for exemption, though it has generally followed a downward trend. Second, what is ultimately approved by the Parties for use in the United States has always been lower than the amount the U.S. government nominates for consideration. Third, on an aggregate basis, the U.S. has nominated less methyl bromide for exemption each year. However, it has retained some flexibility on a crop and region-specific basis, sometimes increasing the nominated amounts for specific crops between years. Finally, the amount of methyl bromide allowed under the critical use exemption is met in part by drawing down the stockpile.

Figure V-1: U.S. MBr Production and Imports, and Drawdown of the Stockpile for Critical Use (2005 – 2010)



Source: US EPA[47] and UNEP (2010).

The stockpile consists of methyl bromide that was produced prior to the 2005 phase-out. Users of methyl bromide that do not receive a critical use exemption – for instance, golf courses – reportedly rely on this source of methyl bromide.[48] However, agricultural users that receive a critical use exemption can also rely on this source of methyl bromide. While the 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-2 shows how the stockpile has declined from 2003 to 2010.

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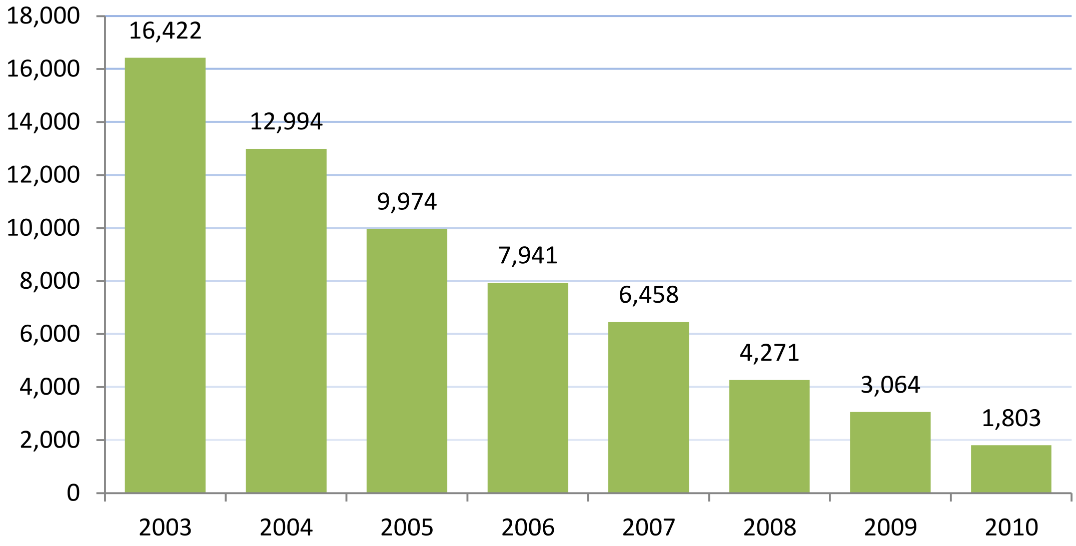
[47] EPA data for this figure come from http://www.epa.gov/ozone/mbr/otherreginfo.html, and http://www.regulations.gov/#!documentDetail;D=EPA-HQ-OAR-2009-0277-0044. Also, note that in lieu of information on the actual stockpile drawdown for 2005, we used the authorized amount. If other years are any indication, the actual drawdown was likely less than the authorized amount for this year.

[48] In May 2011, EPA issued a Federal Register notice cancelling the use of methyl bromide for particular registered uses under FIFRA. Use of stockpiled methyl bromide on golf courses or athletic fields for the replanting of turf will no longer be allowed after December 31, 2013.See http://www.gpo.gov/fdsys/pkg/FR-2011-05-20/html/2011-12478.htm

Experts have noted that, as critical use exemptions decline and the stockpile is drawn down, they expect MBr shortages and markedly higher prices in some regions (e.g., Noling et al. 2010; Goodhue et al. 2010). Due to a paucity of data, we are not able to say what role the stockpile has played in fumigant decisions for California strawberry growers for the 2006 – 2010 seasons.

Figure V-2: U.S. Methyl Bromide End-of-Year Stockpile (in metric tons): 2003 - 2010



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

C. Assessing Costs of Methyl Bromide 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 the EPA for MBr critical use exemptions faces an additional challenge. 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 mid, there are two cases where we still may be able to learn something useful from comparing ex-ante and ex-post cost information used to evaluate critical use exemptions without having to estimate an approximate counterfactual. They are:

(1) Farmers request far more than what EPA nominates for exemption. In this case, we can examine whether growers faced larger than expected costs of switching to non-MBr substitutes by comparing EPA estimates to costs observed in the marketplace.

(2) The amount authorized by the Parties is non-binding for particular agricultural uses. In this case, MBr alternatives turned out to be cheaper than anticipated and more growers moved to substitutes than had been originally anticipated.

We will focus on the first of these, recognizing that some researchers have speculated that there may be a strategic element embedded in the requests made by industry.[49] In selecting fruits or vegetables on which to focus, cases where there are documented alternatives to methyl bromide use, even if they are expected to be more expensive, are more likely to result in a nominated amount that is less than the requested amount. A market where a fruit or vegetable can be grown organically as well as

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[49] Mayfield and Norman (forthcoming) 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.

conventionally may offer an interesting case to examine since the farmer would have the additional option to change his or her production practices to avoid methyl bromide use (in addition to switching to a MBr alternative to continue conventional production). Data constraints are also a consideration as information at a disaggregated geographic scale for non-row crops is not widely available.

Critical use exemption nominations are also different from a regulatory decision in that they are reviewed annually. Two years in advance of the season to which the exemption will apply, the EPA produces a cost analysis that is submitted to an international body for consideration and potential approval in whole or in part as an element of the U.S. nomination. For instance, the 2006 nomination package was prepared and submitted in 2004, while a new nomination package for the 2007 season was prepared and submitted in 2005. While regulations are often revised, the timeframe over which this occurs is typically longer, allowing – at least in theory – for an ex-post analysis to isolate the effect of a single 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. 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 the EPA did not substantially alter the assumptions or inputs to its cost analyses for California strawberries over this timeframe.

Scope of an Ex-Post Cost Analysis

The USDA (2000) notes that prior to phasing out methyl bromide, growers in Florida and California accounted for over 75 percent of its use in pre-plant fumigation of soils, with California alone accounting for almost 50 percent of total pre-plant methyl bromide use in the United States. In addition, 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. In particular, we focus on the unit compliance costs associated with critical use exemptions for California open field strawberries for the 2006 to 2010 seasons, but will at times only be able to evaluate a subset of these years.

At a 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 methyl bromide use over this time frame. The three remaining crops - strawberries, tomatoes, and peppers - were responsible for about 62 percent of methyl bromide used in the United States in 1991, just prior to the beginning of the phase-out (Ferguson and Yee 1997; USDA 2000). They constitute 68 percent of the total amount of methyl bromide nominated for critical use exemption in 2009. From these, we choose to initially focus on strawberries.[50]

Table V-3 illustrates the amount of MBr nominated for exemption by the United States for use on strawberry fields and what this represents in terms of the amount originally requested by growers for the 2006 through 2010 seasons. California makes 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 is almost always higher than what EPA nominated for exemption. However, the rate of decrease in the amount

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[50] Tomatoes grown in open fields also appear to be a good candidate for study but will not be included in this report, though we may expand later analysis to consider them. Florida and Eastern U.S. farmers continue to request critical use exemptions for tomatoes. While California tomato growers requested a MBr critical use exemption for use on hilly terrain in their critical exemption requests for the 2006 and 2007 seasons, they no longer applied for a CUE beginning in the 2008 season. This raises the question of whether California tomato farmers relied on the MBr stockpile, switched to growing crops other than tomatoes, or discovered affordable alternatives to MBr that would work effectively on hilly terrain in 2008 and subsequent years.

nominated has been markedly slower in California than it has been in other parts of the country, mainly due to regulatory constraints that are discussed later in the paper. Between the 2006 and 2010 growing seasons, the amount of methyl bromide nominated for exemption for use on strawberry fields in California has declined by 12 percent, while it declined by 45 percent and 67 percent in Florida and the Eastern states, respectively, over the same time period.

Table V-3: Amount of MBr Requested by Industry and Nominated for Critical Use Exemption in California, Florida and Eastern U.S. for Strawberries

	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.
*Note that the amount of methyl bromide requested by Eastern states was adjusted by the EPA to eliminate double counting and growth acreage, which does not qualify for a CUE.

A review of the critical use exemption nomination packages also suggests that EPA initially underestimated the regulatory constraints faced by farmers on the use of MBr alternatives in California and that it modified its requests to account for them in CUEs for subsequent growing seasons (i.e. the amount nominated for exemption by the EPA jumped by about 17 percent between 2006 and 2007). Carter et al. (2005a) note that about 23 percent of methyl bromide used in the United States was applied to strawberries in 1996. By 2001, methyl bromide use had declined substantially in keeping with the phase out schedule established by the Montreal Protocol. However, strawberries still continued to rely on it heavily: Carter et al (2005a) note that about 88 percent of California acres planted in strawberries in 2001 continued to use MBr. They also 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.[51]

D. Overview of Ex-Ante Methyl Bromide Cost Estimates

While the critical use exemption nomination packages for the 2006 – 2010 seasons include an assessment of costs on a per hectare basis to help determine economic feasibility, the aggregate amount of methyl bromide nominated by the United States for exemption is also based on an assessment of technical and regulatory constraints. For instance, is an alternative registered for use? Do state and/or local governments have buffer zone requirements or caps on how much can be used within a given area? Are there terrain and temperature considerations that inhibit the use of particular alternatives? In this report, we do not evaluate the extent to which EPA accurately characterized regulatory and technical constraints faced by growers in its CUE nominations.

The threshold for economic infeasibility - or significant market disruption - is not defined by the Montreal Protocol.[52] However, beginning in 2010 the MBTOC indicated that alternatives that "lead to

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[51] Methyl bromide is typically combined with other chemicals before being applied to a field. For instance, a common formulation in California for use on strawberries in 2000 was 67 parts methyl bromide and 33 parts chloropicrin, though ratios of 57:43 and 75:25 were also regularly used (according to the California Pesticide Information Portal database). How methyl bromide is used to treat strawberry fields varies to some degree by region. In California, the entire surface of the field is typically 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, methyl bromide is applied when raised beds for growing strawberries are constructed. The beds are then 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).

[52] DeCanio and Norman (2005) calculate a "political willingness-to-pay" to identify possible criteria for determining economic feasibility for critical use exemptions. They examine contributions governments have made

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 via a financial analysis comparing the effects of using methyl bromide and its alternatives on "the 'bottom line' of individual firms."

Three years prior to the year for which the MBr is approved for use, the EPA assesses on a per-crop basis the rate at which MBr is currently applied (e.g., in 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. The 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.

Because the EPA is assessing 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 a small subset of feasible alternatives on a per hectare basis.[53] [54] The net revenues from using an alternative are then compared to those for methyl bromide to generate a loss per hectare. The EPA also presents this information in a

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to a multilateral fund set up to help meet the goals of the Montreal Protocol. Since methyl bromide 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 they fund to meet this goal. 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 political 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 critical use exemptions would be economically feasible under the definition offered by the authors.

[53] The EPA considers all known feasible alternatives but focuses the analysis on the subset of feasible alternatives it considers the most likely based on internal discussion as well as grower input.

[54] The EPA does all of its calculations in pounds and acres and then converts estimates to kilograms and hectares.

variety of other forms: loss per kilogram of methyl bromide, loss as a percent of gross revenue (i.e., net revenues minus operating costs), and loss as a percent of net revenue. No aggregate estimates of costs (and revenue loss) are provided by the EPA as part of the CUE nomination package, though one could calculate them from the information available assuming that all acreage to which MBr would be applied resembles a typical acre.

Gross revenues per acre for methyl bromide 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 the alternative), while discussed, are not quantified. While the 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 associated with the use of MBr alternatives.

The EPA also provides an estimate of operating costs. It does not include fixed costs in the assessment due to wide variability in factors that influence them (e.g., size, technology adoption, etc.). Applicants are asked to provide this information on their exemption request forms. To assess the amount of active ingredient applied, the EPA used the average number of annual applications of methyl bromide or its alternatives (i.e., one application) used to treat the crop. The loss per acre is calculated by examining the change in net revenues relative to using MBr. The alternative that results in the lowest loss is determined to be the most likely substitute. We discuss the costs estimates in greater detail for strawberries in Section F.

E. Ex-Post Literature and Data

Before embarking on our own comparison of ex ante and ex post cost estimates, we review the existing literature to identify any ex post studies on which we could build and identified what data sources are available on fumigant use, input and strawberry prices, production, yields, and operating costs.

1. Ex-Post Literature

A number of papers have evaluated the potential impact of banning the use of methyl bromide in the United States under the Montreal Protocol 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 found only one published ex-post analyses of the impact of critical use exemptions for methyl bromide use in agriculture. It examines whether California strawberry farmers have been negatively impacted by the MBr phase-out (Mayfield and Norman, forthcoming). The authors find little support for this hypothesis, 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.

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.

(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.) A review of the main ex-ante studies of the methyl bromide phase-out is available in the appendix.

2. Data for Evaluating Costs Ex-Post

The critical use exemption nomination packages are a good starting point for identifying data sets and other sources of information that may prove useful for evaluating costs. Market data on fruit and vegetable crops are not as widely available as for row crops (many USDA surveys do not include non-row crops). Publically available ex-post data to evaluate the costs of eliminating the use of methyl bromide for the typical California farmer are also limited. What publically available data are collected by the Federal government and by the state of California are described below. In addition, the University of California - Davis occasionally assembles cost estimates for specific crops in California that may prove useful in a retrospective analysis. A number of recent publications summarize the results of field trials for various MBr alternatives. Finally, the EPA Office of Pesticides Program has purchased access to proprietary marketing data that may provide some limited information on fumigant prices.

EPA Critical Use Exemption (CUE) Nomination Packages. EPA includes information on the amount of methyl bromide used in prior years as part of each nomination package that can be used to compare actual use rates and overall usage to what was estimated at the time that the exemption decision was evaluated (two years prior to actual use). It also includes data on methyl bromide use prior to 2005 when the phase-out took effect. These packages also report which MBr alternatives were registered for use at the time that an evaluation took place. Reviewing future year packages will indicate if and when new alternatives other than those identified in the original package became available and what the experiences of farmers have been with respect to their use.

***USDA - National Agricultural Statistics Service (NASS) and Economic Research Service (ERS)*.** The 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 data have been published (USDA 2007). The survey also reports the average usage rate and total pounds applied for several states, including California.

A variety of general market information is available through NASS and ERS at the national level for strawberries: production, utilization, prices, and values, acreage, and yield per acre for 1970-2009. National level monthly data are available on shipments, prices received by growers, and retail prices. Finally, national level monthly data is reported on imports and exports by country. State-level information is available for a subset of these variables annually: harvested acreage, yield per acre, production, and prices received by growers from 1970-2009.[55]

In addition, USDA publishes typical planting and harvesting dates as well as the most active growing season are available by crop and state for fruits and tree nuts, which includes strawberries (USDA 2006). The survey also lists the principal producing counties in each state. However, these data are of limited use since a more recent version of these data have not been produced for fruits and vegetables. Finally, the 2009 Fruit and Tree Nut Yearbook reports the national-level monthly average

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

retail and grower prices by year back to the mid-1990s. Though of less immediate interest, the Yearbook also includes supply, utilization, and trade statistics by year at the national level.[56]

***California Pesticide Information Portal*.** The state of California collects data on the amount of a specific chemical used and the acreage treated by month, year, and crop at a spatially disaggregated level from 1989 to 2009.[57] Methyl bromide and many of the alternatives mentioned in the EPA's evaluation of critical use exemption requests 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. For instance, Carpenter et al. (2001) indicate 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 methyl bromide 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) identified a number of duplicate entries for MBr and its alternatives. In addition, possible errors are flagged in the database based on a statistical analysis of outliers.

University of California - Davis Crop Budget Database. University of California - Davis researchers have conducted cost studies for conventional strawberries produced in California in 2006, 2010, and 2011. There are two 2011 studies: one focuses on Ventura County (by Daugovish et al.) and the other focuses on Santa Barbara and San Luis Obispo counties (by Dara et al.). While these reports were issued after

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[56] 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.

[57] The data can be downloaded from http://calpip.cdpr.ca.gov/main.cfm. While 2010 data were recently released, acreage information does not yet appear available.

the last year of ex-ante estimates to which we make comparisons, they are useful to include because they evaluate alternative fumigants to methyl bromide. The earlier studies use MB+PIC as the default fumigant. The 2010 study (by Bolda, et. al) focuses on Santa Cruz and Monterrey counties, while the 2006 study (by Takele et al.) focuses on Santa Barbara County. These studies generate 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 there is some discussion of alternatives to methyl bromide, the main cost estimates assume the use of MBr and do not evaluate the cost implications of an alternative fumigant. While this is our primary source of information on ex-post operating costs, we are cognizant of the limitations of using crop budgets for this purpose. They are typically produced to help farmers assess the profitability of growing particular crops but may include cost categories that do not apply to many growers. That said, the crop budgets are the only ex-post data we have on costs, are produced for strawberry-growing regions that overlap with areas seeking critical use exemptions, and are described by the authors as representative of costs faced by a typical farmer. As the EPA did not include fixed costs in its assessment, we also exclude them from the crop budget to ensure we approximate an apples-to-apples comparison.

***Other Data Sources*.** The EPA Office of Pesticides Program has purchased access to a proprietary marketing database that 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. Because it is proprietary, when using information from this database we report data in aggregate form.

Finally, for information on the estimated yield effects of various chemical combinations compared to methyl bromide + chloropicrin for strawberries we rely on recent publications reporting the results of field trials as well as a meta-analysis sponsored and approved by the MBTOC (Porter et al, 2006). The meta-analysis may have limited applicability in an ex-post assessment of EPA costs because it looks at the variability of the treatment not at the actual harvest weight. That is, the study tells you if the variabilities are similar or not, rather than if the harvests weights are similar or not. In addition, a review of the data by the Office of Pesticides Programs found that some of the individual data points were not correctly inputted into the statistical analysis.

A search through Federal Register documents associated with reregistering methyl bromide 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).

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

In keeping with MBTOC (2010) guidance, the EPA evaluates the per acre impacts of using methyl bromide and a set of alternatives on the bottom line finances of a typical farmer. In the CUE nomination packages for the 2006–2008 seasons, the EPA evaluated the operating cost and revenues for methyl bromide + PIC (in a 67:33 formulation) and three alternatives, chloropicrin + metam sodium (PIC + MS), 1,3-dichloropropene + chloropicrin (1,3-D + PIC), and metam sodium (MS). For the 2009-2010 seasons, the EPA dropped PIC+MS as an evaluated alternative from the economic analysis.[58] While the EPA recognized several other potential alternatives to MBr, it did not analyze them in the CUEs for the 2006 – 2010 seasons (see Table V-4) because they were not yet registered for use in the United States.

Table V-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.

Ex-ante analyses are subject to many challenges. Recall that the 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. In addition to these uncertainties, ex-ante estimates are often faced with the challenge of generating estimates based on limited data and poor documentation in source reports on how yield (defined in the EPA critical use exemption nominations as pounds of strawberries produced per acre) and economic impacts are derived by the authors.

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

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[58] 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.

for a typical California farmer from switching to PIC+MS is drawn from an unpublished report (Locascio et al. 1999). The 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 V-6). Shaw and Larson use 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 range from 1987 to 1997.

The EPA retained the same yield loss estimates in the critical use exemption nomination packages for the 2006 – 2010 seasons. The key reason cited by OPP experts for retaining this assumption was a desire to rely on multi-year studies, as many factors can influence realized yield losses (e.g., weather, pest pressure) in a given year. Using studies that cover more than one year helps to better reflect yield losses that are attributed to changes in pesticide controls instead of seasonal factors.

Without assessing the relative quality of the underlying studies, one can still observe that the yield loss estimates are based on fairly old data. The “best” estimates used by the EPA in its analysis reflect the high end of the range reported in the CUE nomination packages for yield loss for two of the three alternatives (see Table V-5). According to OPP experts, the 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.

Table V-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.

Table V-6 presents a summary of the operating cost and revenue information that underlies the critical use exemption analysis for the 2006 planting season. The EPA uses the same data and assumptions to evaluate the 2007 and 2008 growing seasons as used to evaluate the 2006 season, resulting in identical estimates of net revenue loss.   For open field strawberries, the losses per acre from switching to a MBr alternative are driven primarily by the difference in yield, with the EPA predicting based on its data and assumptions that 1,3-D+PIC is the next best alternative to methyl bromide.

The yield per acre for each alternative is derived by multiplying the estimated yield from methyl bromide by the "best" estimate of yield loss for an alternative.[59] The difference in the price of strawberries per pound is based on an assessment of the potential for a decrease in price from delaying harvest by several weeks. The 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). Gross revenue per acre for methyl bromide and the alternatives is calculated by multiplying the market price times the yield.[60]

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[59] While not included in the nomination, EPA also evaluated cases where the 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.

[60] For purposes of submitting the package to the MBTOC, all values are converted into kilograms and hectares. While the conversion was done incorrectly in the nomination package, the underlying numbers that are reported here are based on the underlying data to inform that process and therefore are correct.

Table V-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.

Overall operating costs are nearly identical for methyl bromide and the analyzed alternatives but differ 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). The analysis assumes that all other aspects of growing strawberries remain unchanged (e.g., irrigation, amount of insecticide and herbicide applied) when farmers switch to using a MBr alternative.[61] According to spreadsheets provided by the Office of Pesticides Program, the application of alternatives are estimated to require a bit less manual (5 percent less for all alternatives) and harvest labor (between 7 and 15 percent less) than MBr.

To evaluate the CUE for the 2009 and 2010 growing seasons, the EPA relied on much of the same data used in the previous CUE nomination packages, including operating cost and yield loss estimates for MBr alternatives. The EPA updated the market prices for strawberries, which affects the estimate of gross revenues, and made some slight changes to operating costs (for instance, updating

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[61] The EPA mentions but does 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 require that 40 percent more fumigant be used (EPA 2005).

fumigant prices). Unlike for the analysis of the 2006 – 2008 seasons, the EPA did not include an estimate of potential revenue loss due to delayed harvest (i.e. the market price for strawberries is identical whether using MBr or an analyzed alternative). As previously mentioned, industry stopped mentioning in its applications that it faced harvesting delays when switching to MBr alternatives. On net, the estimated loss from using a MBr alternative are similar across the CUEs for the 2006-2010 seasons for the preferred alternative, 1,3-D + PIC, but somewhat higher in 2009 for MS (32 percent instead of 26 percent), according to EPA calculations.

The overall conclusion of the cost analyses for the 2006 – 2010 seasons is 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. While not in place at the time of these analyses, recall that recent MBTOC guidance suggests that alternatives which “lead to decreases in gross margins of more than around 15 to 20 percent or more are not financially feasible” (MBTOC 2010).

While the focus of the economic analysis is an assessment of net cost per acre, the EPA also makes a recommendation of the total amount of methyl bromide that should be exempted for use by crop and region. 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). Both have changed over time. Table V-7 shows that farmers initial request were based on a higher rate and acreage than the EPA nomination. However in later years they were similar or identical. Also, note that while the application rate used by the 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.

California growers requested enough MBr for the 2006 planting season for use on 75 – 85 percent of the total state strawberry crop. The EPA continued to assume that MBr would be used on this percent of land for the 2007–2008 seasons. However, the California Strawberry Commission estimated that MBr was only required on 50-60 percent of land used to grow strawberries in 2009. The EPA reflected this lower estimate in its analysis for the 2009 and 2010 growing seasons and noted that the rate of adoption of MBr alternatives was limited primarily by a combination of transitional and regulatory issues.

Table V-7: Application Rates and Acreage Underlying Methyl Bromide Exemption Nomination

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.

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, the 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.

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 the EPA is California's restrictions on the use of 1,3-D. In the CUE nomination package for 2006, the 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 estimate noted in the 2009 CUE) than what it assumed for the subsequent seasons (82–94 percent).[62] 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 the EPA interpreting the caps strictly for the 2007 season. The EPA notes that fewer townships would find the cap on 1,3-D use binding if farmers switch to drip irrigation, as less chemical is required (also, see Carpenter et al. 2001). However, this could result in a 3-4 week planting delay. According to OPP experts, there are also county-level restrictions on the use of chloropicrin and metam sodium, though the effects of these restrictions are not quantified.

The effects of fumigation on rotation crops also are not easy to quantify. For example, a lettuce field that has soil pathogens is leased to a strawberry grower who then fumigates the soil prior to planting. After three years the field is rotated back to lettuce and the soil pathogen has been controlled. The lettuce crop cannot generate enough profit on its own to pay for soil fumigation but both crops benefit from the strawberry crop soil fumigation. The EPA does not attempt to quantify the effect of switching to a MBr alternative on the costs of growing the rotation crop.

G. How Do We Assess Costs Ex-Post?

To begin a comparison of the ex-ante and ex-post costs of methyl bromide critical use exemptions for the 2006-2010 growing seasons, we rely on available data and literature. (See section E for a review of these data sources.) As previously mentioned, a key analytic question we attempt to address is whether ex-ante and ex-post cost estimates vary by a substantial degree (defined as +/- 25

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[62] Information available in the CUE nomination packages indicates 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).

percent). When a substantial difference exists, we seek to identify the particular reasons for the discrepancy.

Table V-8 identifies some of the main inputs into the EPA's analyses for which we seek ex-post information. In some cases, no or very limited data are available. Any insights offered herein should be viewed with this limitation in mind. For this exercise, we do not interview industry experts, which could potentially broaden our understanding of any unanticipated changes in input or product markets, energy prices, or technology, though it would not be precluded from ongoing work in the future.

Table V-8: Inputs of EPA's Cost Analyses - Main Candidates for Ex-Post Evaluation

Operating costs	Foregone revenues	Other
Latest production cost estimates	Product prices	Regulatory and technical constraints
Rate at which each chemical is applied per acre	Yield loss for any evaluated alternatives	Total amount of methyl bromide used
Any other additional input requirements	Extent of harvesting delay	Amount of crop grown that used methyl bromide

While there are very few ex-post analyses available, the EPA analysis and some of the literature speak to the costs of widely available, known MBr alternatives as well as the likelihood that particular options for reducing costs will play a role in the future (e.g. methyl iodide). We review the data available for evidence on:

- Did MBr alternatives not originally anticipated by the EPA and other industry experts become available over this time frame?
- Were there unanticipated economic, technical, or regulatory constraints that prevented using MBr at lower rates or switching to the MBr alternatives suggested by the EPA?
- Did switching to MBr alternatives result in unanticipated costs?

- Were costs of adoption lower than anticipated?[63]

When possible, we also investigate the following larger-scale questions posited in the literature but outside the scope of a financial analysis that estimates the effects of eliminating methyl bromide on a typical farmer:

- Did switching to a MBr alternative impact conventional production in California?
- Did switching to a MBr alternative impact organic production in California?
- Did switching to a MBr alternative impact imports from Mexico?

H. Ex-Post Assessment of Strawberry Production and MBr Use for California Open Field Strawberries

This section begins with a review of the ex-post evidence on MBr use, acreage, organic production, and imports. While the CUEs do not directly speak to these issues, we examine the overall trends since much of the ex-ante literature makes predictions on how the phase-out of methyl bromide will affect them. We also examine the role of state regulatory restrictions in slowing the transition to some MBr substitutes as well as which chemical alternatives farmers used, both of which are discussed in the CUEs.

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[63] The EPA was not able to assess 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.

1. Methyl Bromide Use and Strawberry Acreage in California

Based on initial evidence, it appears that California farmers used about as much methyl bromide to grow strawberries as expected. However, contrary to what some in the literature predicted, California farmers increased total acreage dedicated to strawberry production over this time period. This may be due in part to the critical use exemptions granted, which were typically not considered by the ex-ante literature. That said, methyl bromide use for growing strawberries in California has declined over time. Growers have demonstrated a continued ability to compete in the global marketplace, though it is still possible that production increased by less than it would have absent the phase-out of methyl bromide.

Recall that growers requested through the CUEs methyl bromide 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.

NASS data (from 2002) cited in the CUE for the 2006 season, indicate that approximately 55 percent of California strawberry acreage used methyl bromide. These data also inform the 2007 – 2009 season CUEs, as more recent data were unavailable. Actual use in 2006 - 2009 from the USDA and California Pesticide Information Portal indicate that farmers used methyl bromide on 40-65 percent of the acres dedicated to strawberries, respectively, assuming no growth in acreage. By 2009, the California data indicate that strawberry acreage using methyl bromide fell to about 50 percent.

Many ex-ante studies in the published literature predicted a decrease in strawberry production in California, though they also tended to analyze the effects of a complete and immediate MBr ban. 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. USDA data indicate that land dedicated to growing strawberries in California continued to grow. Figure V-3 illustrates the longer-term trends in growth in overall strawberry acreage in California from 1970 – 2009. 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 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 – 2009 stems from two districts, one in the south - Santa Maria - and the other in the north - Watsonville-Salinas - both of which historically have grown a substantial portion of their strawberries on hillsides, where MBr alternatives are reportedly less effective (California Strawberry Commission 2009). These districts are 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 – San Diego-Orange and Oxnard - remained relatively flat over this time frame.[64]

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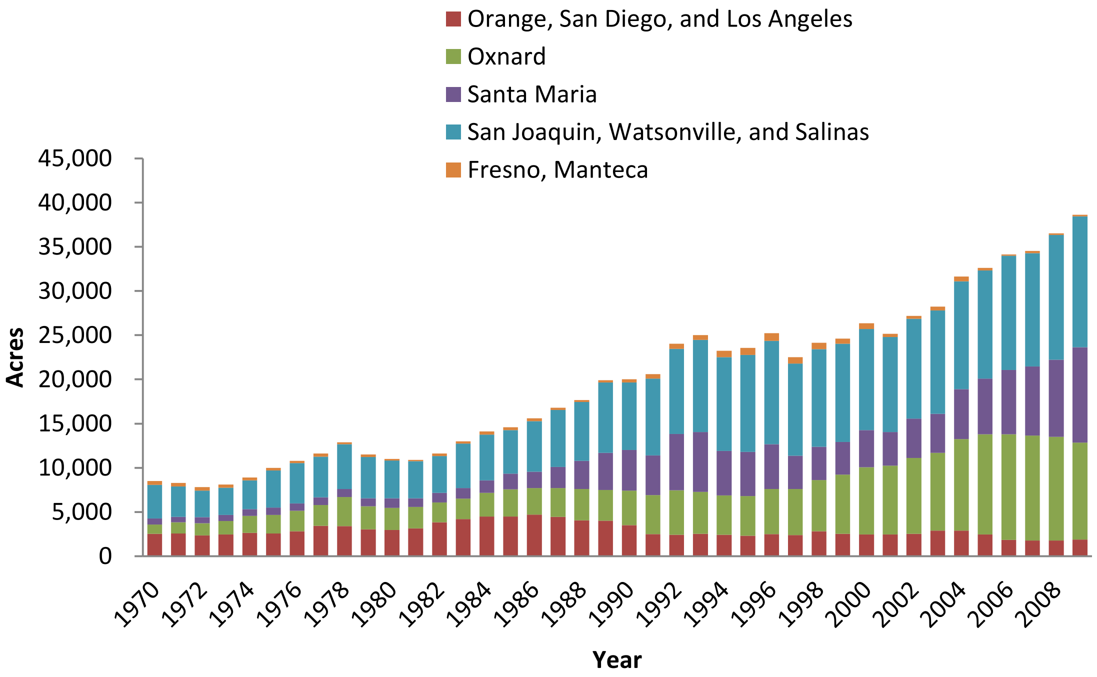
[64] In Orange County, this may be due to increased competition for land. The California Strawberry Commission (2006) notes that land development and rising property costs in Orange County resulted in lower acreage in strawberries in 2006 relative to 2005.

Figure V-3: California Strawberry Acreage by Major Growing Area: 1970 - 2009



Source: California Strawberry Commission, as reported in USDA spreadsheets.

2. The Role of Organic Production and Imports from Mexico

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 2009. While the rate of increase is high, the total amount of land dedicated to organic production is still relatively small, about 4.6 percent of total California strawberry acreage in 2009 (California Strawberry Commission 2009).

According to USDA data, imports of fresh strawberries from Mexico increased 1.5 fold over this time period, from 124 million pounds in 2001 to 307 million pounds in 2009. However, domestic consumption of strawberries also increased substantially, from 1.2 billion to 2.2 billion pounds (an 83 percent increase). Domestic production has largely kept pace with demand, increasing by about 80 percent over the same timeframe, so that Mexico's share of total demand has only increased from 10 to 13 percent.[65] 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. How Methyl Bromide Is Used

It is possible that farmers that continued to rely on methyl bromide found a way to use less of it than anticipated while maintaining its effectiveness. The evidence indicates that this has not been the case for California strawberry farmers. For the initial set of years, it appears that the EPA was relatively accurate in its assessment of the rate at which methyl bromide would be applied in fields where it would continue to be used. For instance, in its assessment of the 2006 growing season, the EPA assumed that MBr would be applied at a rate of 175 pounds per acre. USDA chemical usage data demonstrates that methyl bromide was actually applied to California strawberries at a higher average rate of about 190

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[65] Data are taken 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 .

pounds per acre in 2006 (in other words, the EPA underestimated the application rate by about 8 percent).

In its assessment of the 2009-2010 growing seasons, the EPA estimated MBr would be applied at a rate of about 175 pounds per acre. The nomination package for the 2012 growing season – analyzed in 2010 – used a rate of 152 pounds per acre, which is 13 percent lower than what EPA assumed ex-ante. It is not clear what this assumption is based upon as California strawberry farmers have only slightly modified the application rate used in their CUE requests over time (perhaps for strategic reasons) and California data show that the average application rate for methyl bromide was about 185 pounds per treated acre in 2009.

Historically, California farmers have typically used methyl bromide combined with chloropicrin 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 continue to use methyl bromide, California restrictions on chloropicrin mean that the lowest formulation likely allowed in California is 57 part methyl bromide to 43 parts chloropicrin. Data from the California Pesticide Information Portal confirm that 94 percent of the methyl bromide used in the 2009 growing season was formulated at 57:43 or higher. A small amount (about 5 percent) was available at a 50:50 or 45:55 formulation. Second, two new diseases have emerged in fields treated with MBr alternatives, which has 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 have not reduced 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).[66] 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, California does not allow virtually impermeable films (one type of low permeability film) to be used with methyl bromide due to concerns about worker exposure to the chemical.

4. Regulatory Restrictions

California implemented its own phase out of methyl bromide consistent with the schedule established by the Montreal Protocol: it required a 50 percent reduction in MBr use by 2001 from 1991 levels. Carter et al. (2005b) note that MBr use by California strawberry growers experienced only a modest decline as a result of the ban. Acreage using MBr changed little between 1996 and 2001, but the rate at which it was applied declined by 17 percent. In aggregate, MBr use by strawberry farmers only declined by 14 percent. As a result, according to Carter et al. (2005b), the largest impact on these farmers took the form of higher prices paid for methyl bromide. Farmers of other crops were much more successful at reducing their use of MBr use. Overall, its use declined by 59 percent in California between 1996 and 2001.

Researchers point to California regulations that restrict the use of viable MBr alternatives as one reason why strawberry farmers may have made fewer strides in moving away from methyl bromide. These regulations are still in place and, in some cases, have become more restrictive over time. For

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[66] 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).

instance, the EPA (2006) reports 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.[67]

Carpenter et al. (2001) estimated what demand for 1,3-D would be after the phase-out of methyl bromide absent township restrictions. It was assumed that 1,3-D would be the most likely alternative for about 90 percent of the crops using MBr (i.e. strawberries, perennials, sweet potatoes, watermelons, peppers, tomatoes, carrots, lettuce, and nursery crops). At the time of the study, it was assumed that annual township caps were strictly enforced (i.e. no exceedances are allowed). They estimated 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.

Carter et al. (2004) examine the combined effect of 1,3-D township caps and buffer zone requirements. When township caps on 1,3-D are binding, increasing buffer zone requirements has little effect on the choice of pesticide. The authors also find that when there is a close substitute for 1,3-D such as chloropicrin that can be used in buffer zones, growers see little impact on net revenues since yield is relatively unaffected. However, when no good alternative is available, returns are lower and the growers' choice of pesticide is affected.

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[67] 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 (i.e., 180,500 pounds per year). Townships were only allowed to avail themselves of this option if they had been under the original cap since 1995. 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 (e.g., 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. For more information, see www.cdpr.ca.gov/docs/emon/pubs/ehapreps/analysis_memos/4327_sanders.pdf, and www.cdpr.ca.gov/docs/emon/methbrom/telone/mgmtplan.pdf.

Township caps on 1,3-D use and uncertainty regarding authorization for practices such as virtually impermeable films and bed shank fumigation are credited with slowing the transition away from methyl bromide in California (Noling and Botts 2010). Regulatory restrictions on 1,3-D in California are also listed as one of the main reasons for granting continued critical use exemptions to strawberry farmers. 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.[68] Finally, farmers cannot use a chemical until it has also been approved for use in California. For instance, while methyl iodide has been registered for use as a fumigant in the United States since 2007, it was only registered in California at the end of 2010.[69][70]

5. Use of Methyl Bromide Alternatives

In this section, we evaluate the available evidence on the use of MBr alternatives in the California strawberry sector for the 2006-2010 growing seasons. Recall that EPA analyzed three main alternatives to methyl bromide in its 2006 -2010 CUE nomination packages, 1,3-D + PIC, PIC + MS, and MS alone. According to the USDA chemical usage survey for vegetables, chloropicrin (PIC) was used on

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[68] California requires that 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).

[69] This is in contrast to Florida, where there appear to be 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.

[70] This is in contrast to Florida, where there appear to be 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.

about 17,600 California acres planted in strawberries in 2000. By 2006, this amount had increased slightly to 18,300 acres. Dichloropropene (1,3-D) was not tracked in the 2000 USDA survey. In 2006, the USDA reports that it was used on 6,400 acres of strawberries in California.

The California Pesticide Information Portal 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 methyl bromide). In 2000, 1,3-D + PIC and PIC alone were hardly 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 remained almost unchanged in 2009, while the amount treated with chloropicrin grew to almost 4,000 acres.

Metam sodium use by California strawberry growers has also increased, though it is 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) but decreased slightly to 1,350 acres by 2009.

It is possible that other alternatives not analyzed by the 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 V-9). 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.[71] The UNEP (2010) also notes that several chemicals

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[71] 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 in 2010.

that showed initial promise are no longer considered viable alternatives to methyl bromide, such as propargyl bromide and sodium azide.[72] 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 V-11, 1,3-dichloropropene – with or without chloropicrin-, chloropicrin, metam sodium, dazomet, and methyl iodide are registered for use in California.[73]

Table V-9: 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	
Iodomethane (methyl iodide)	

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.

The MBTOC made the general observation 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

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[72] Research into non-chemical alternatives such as solarization, steam treatment, and natural herbicides has increased in recent years (for instance, see Samtani et al. 2011). Preliminary data show that some of these 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.

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

fumigants (e.g., methyl iodide, dimethyl disulfide), but also due to increased uptake of non chemical alternatives." The California Pesticide Information Portal data demonstrate that only three potential chemical alternatives to methyl bromide were used in California between 2006 and 2009, 1,3-D, PIC, and metam sodium, and that strawberry farmers have generally not recombined them in new or novel ways (for instance, they have not utilized the three-way fumigant system of 1,3-D + PIC + MS that has become increasingly common in Florida).

Iodomethane (also called methyl iodide) 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. Thus, it did not play a role as a MBr substitute in the time frame we analyze.

What role may iodomethane play going forward? While the CUE nomination package for the 2012 season finds 1,3-D + PIC is the most economic alternative to methyl bromide for California strawberries, iodomethane is considered a viable MBr alternative in the CUE for the 2013 growing season. The EPA estimates that iodomethane is estimated to be financially feasible according to the criteria set out by the MBTOC (the per acre loss is 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 the 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 iodomethane use is higher costs stemming from additional input requirements (i.e. impermeable films are required with iodomethane applications in California).[74] [75]

In spite of the more favorable financial implications, however, recent experience suggests that public concern regarding associated health effects may limit its use, at least in the near term.[76] [77] While Fennimore and Ajwa (2011) point out that totally impermeable films are approved for use with iodomethane and that trial results show these films to be effective at retaining the fumigant in the soil, the company that produces iodomethane for fumigant use recently announced its intention to stop selling it in the United States (Rubin 2012).

I. Ex-Post Assessment of the Costs of Switching to MBr Alternatives for California Open Field Strawberries

This section compares the ex-ante EPA estimates of the unit (per acre) costs to a typical California strawberry farmer of switching to a methyl bromide alternative to available ex-post unit cost

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[74] Hueth et al. (2000) also 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.

[75] 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 there are now over a dozen manufacturers of virtually impermeable films, including several in the U.S. and Canada.

[76] For instance, see a July 20, 2011 story at www.panna.org/blog/ca-brings-heat-methyl-iodide and an August 30, 2011 story at www.grist.org/scary-food/2011-08-29/methyl-iodide-mock-fumigation .

[77] 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 methyl bromide 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. They also noted that protocols for the product – including use rate, formulations, and application techniques - needed to be developed. The EPA anticipated a transition period to allow for these protocols to be put in place.

estimates. In particular, we discuss evidence on the actual gross revenues and operating costs of switching away from methyl bromide to other alternatives.

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 the EPA's estimates of prices received by California growers for the 2006–2010 harvest are a reasonable approximation of actual prices. However, while the 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. The 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 2006-2013 seasons). This would result in an overestimate of the potential loss in gross revenues ex-ante, all else equal. Finally, the EPA assumed that the typical California farmer using methyl bromide had yields akin to the national average. However, California farmers tend to be much more productive than the national average.

*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 (2006-2009) prices received by growers in California (see Table V-10). Using data available at the time, the EPA assumed strawberry prices would be $0.69 in the 2006 nomination package (assembled in 2003) and $0.79 per pound in the 2009 nominating package (assembled in 2006).[78] While the prices received by strawberry producers fluctuate from year-to-year - the average annual price was $0.65 per pound in

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[78] 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.

2006 and $0.90 per pound in 2009 (in 2006 dollars) - the average was $0.65 per pound and $0.82 per pound over the 2003-2006 and 2006–2009 time periods, respectively.

Table V-10: 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
2000-2003 (average)	0.65
2006-2009 (average)	0.82
2000-2009 (average)	0.71

Source: USDA, National Agricultural Statistics Service, *Non-Citrus Fruits and Nuts Summary*. Prices are adjusted to 2006 dollars using the Bureau of Labor Statistics Commodity Price Index for strawberries.

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 2005).)[79] The 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 notes the possibility of a planting delay due to the

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[79] 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).

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, the 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 2009. 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.[80] Figure V-4 illustrates the differences in the prices growers receive by month for 2006-2009 (the same trend is also evident for earlier years). For instance, a delay from January to February could mean that farmers give up about 15 cents per pound on average (based on the average price differential between the two months from 2006 to 2009). The difference between February and March is even larger: prices are on average about 40 cents per pound lower in March. Delaying harvest from April to May, however, results in prices that are 5 cents higher per pound, on average. An unanswered question is how shifts in production across time affect monthly prices.

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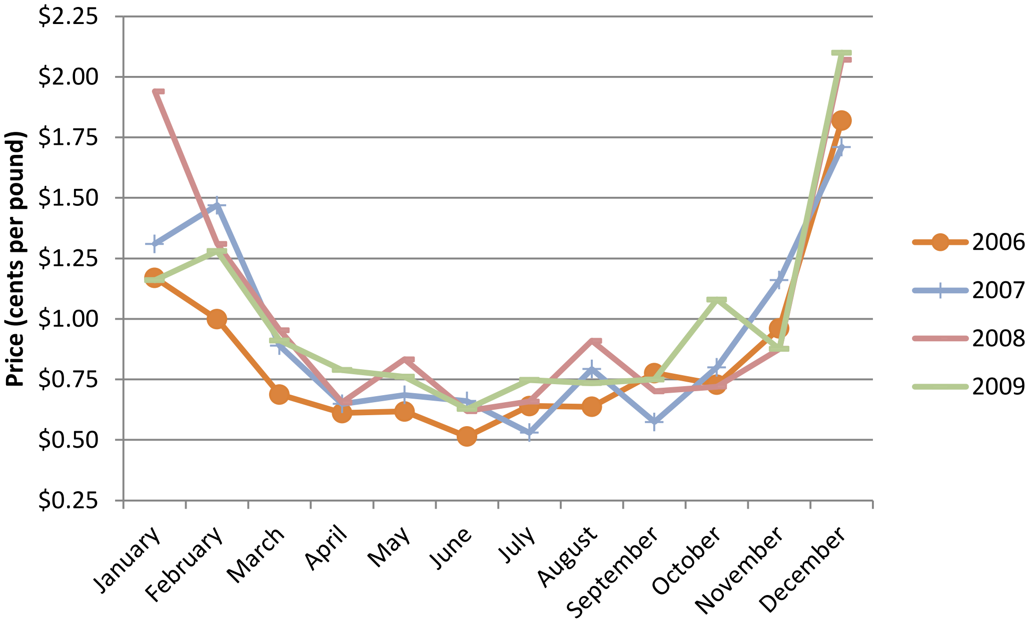
[80] For instance, data indicate that the peak harvesting months in California are April–August (CSC 2009; USDA 2006). However, this masks considerable variation by region. Orange and San Diego counties produce fresh strawberries from September through early June, but have their peak harvest in March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

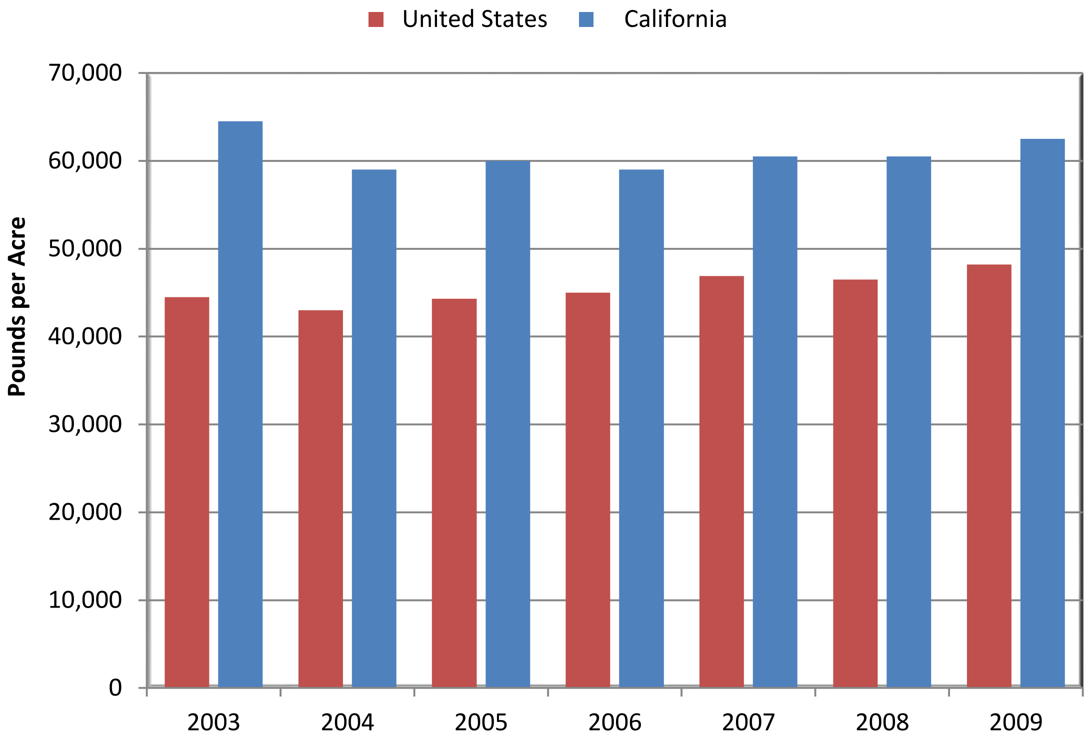
Figure V-4: National Grower Prices (2006 – 2009) for Strawberries by Month



Source: USDA, National Agricultural Statistics Service, *Agricultural Prices*. Various issues. (Prices are nominal.)

Baseline Yield Estimates. The EPA's MBr baseline yield of 43,000 pounds is based on USDA data and is fairly comparable to the national average yield (see Figure V-5). However, USDA data also indicate that California strawberry farmers are generally much more productive than the average. For instance, the average yield for a California strawberry farmer in 2004 – the year for which the EPA baseline assumption matches the national average - was 59,000 pounds per acre. 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).

Figure V-5: Fresh Strawberry Yield per Acre in the United States and California, 2003 - 2009



Source: USDA, National Agricultural Statistics Service, *Non-Citrus Fruits and Nuts Summary*. Various issues.

Yield Loss Associated with MBr Alternatives. Recall that the yield losses used by the 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 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.)

Trial results in California reported by Otham 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).[81] A total of 42 studies published between 1997 and 2006 were identified for strawberries, for which there was information on 101 field trials. The majority of the field trials

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[81] 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.

(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 V-6).[82] 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.

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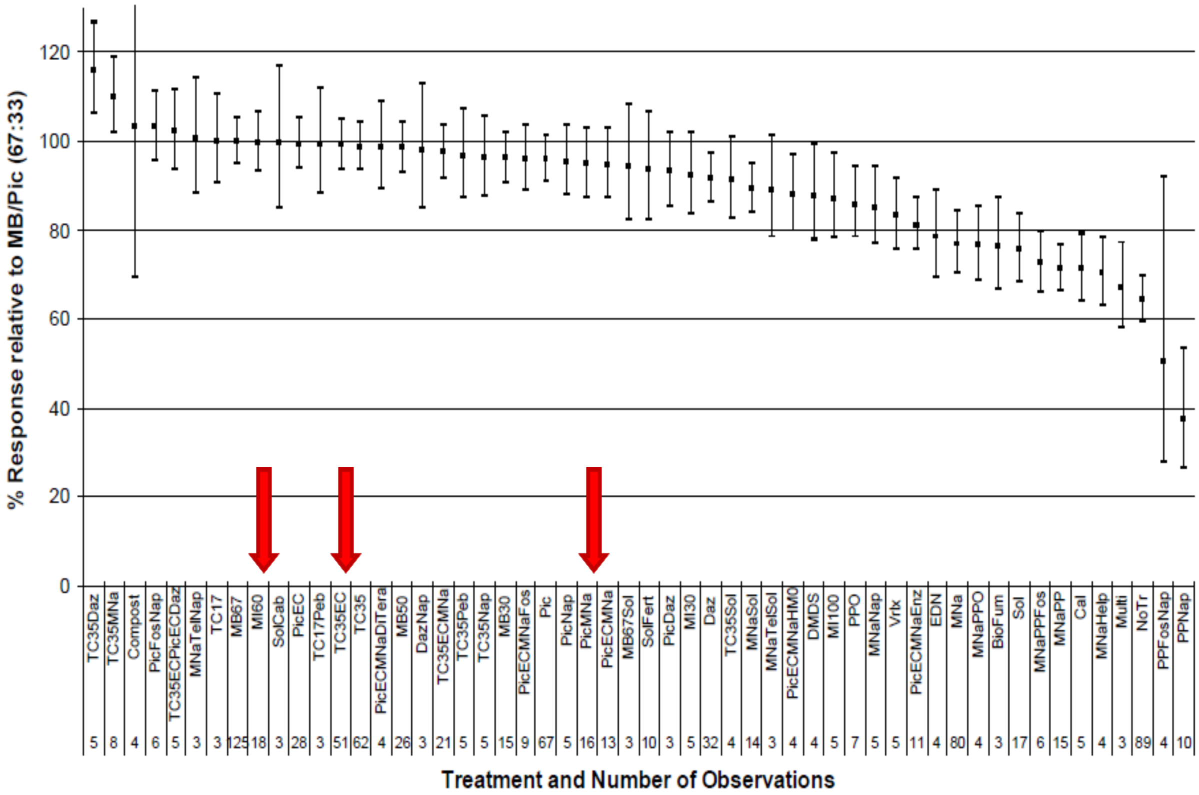
[82] It is worth noting that the average relative yield results for methyl iodide +PIC are much more variable across trials than were the results for many other fumigant alternatives. The authors also note that many of the 22 alternatives included perbulate, an herbicide that is no longer registered.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

Figure V-6: 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.

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 the EPA in its CUE nominations for the 2006-2010 seasons. 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 even for the field trials conducted in California this is 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 more than 25 percent for the 2006 – 2010 growing seasons, all else equal (for instance, they would differ by 28-87 percent for a yield loss of 10 percent or 0 percent, respectively).

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.

We explore several possible sources of information for comparing the ex-ante EPA estimates to actual operating costs. The first source of information is sample costs (also known as 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. The second source of information is the CUE requests for the 2012 growing season. The third source is proprietary data from a private pesticide marketing company. 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. Recall that crop budgets are bottom-up estimates used for planning purposes and attempt to characterize costs for a representative farmer in the region at different yields. They are not indicative of actual costs for any individual farmer.

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 exemption consideration for the 2006–2008 growing seasons in this region. Given that the 2006 and 2010 sample costs apply to different regions in California, while the EPA estimates in the CUE nomination packages are averages across regions applying for exemption, we compare them both 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 are $8,500-$11,000 per acre across the two regions (Table V-11 presents sample costs for one of the two regions), while the EPA estimates them as $16,000 per acre (in 2006 dollars).[83] No one category of costs stands out as the sole reason for this discrepancy. The EPA includes $6,500 per acre in general material costs, while material costs in the 2006 UC-Davis study total to $5,600 per acre. Also, the EPA estimate of MBr fumigation costs per acre is about twice what is assumed in the 2006 UC-Davis study ($1,500 instead of $800 per acre).

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[83] 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 V-11: Operating Costs per Acre - UC-Davis Sample Cost Study for South Coast Region[84]

	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*.

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 estimates 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 estimate harvesting costs to be about $19,000-23,000 per acre across the two regions (expressed in 2006 dollars). They assume, however, that harvesting costs increase linearly with yield: the cost per pound of strawberries harvested does 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 within 25 percent of 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. One can ask a slightly different question with regard to the cost estimates: Does the EPA do a reasonable job of anticipating the actual fumigant costs of the MBr

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[84] The UC-Davis sample costs include several cost categories that are excluded from this table because they not considered by the 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. The 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.

alternatives analyzed? Information on the cost of using MBr alternatives is scarce. While the 2010 sample cost study for the Central Coast region suggests that a grower applying 1,3-D + PIC via drip irrigation will incur a cost of $900-$1,600 per acre (in 2006 dollars), it does not evaluate the crop budget using this alternative. We can gather a bit more information from the 2011 sample cost studies for the South Coast region because they are built up using 1,3-D+PIC as the default 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-David researchers in 2004).

The direct fumigant cost for 1,3-D+PIC applied through drip irrigation is $1,000-$1,100 (adjusted from 2011 to 2006 dollars) across the two 2011 studies with the slightly higher value used for Venture County. The 2006-2008 CUE nomination packages use a higher fumigant cost for 1,3-D + PIC - of about $1,700 per acre - but assume it is 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 2012).[85] [86] Unfortunately, however, the difference in the method of application that underlies the UC-Davis and EPA cost estimates renders a comparison of limited use and makes it difficult to draw solid conclusions.[87]

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[85] See the California Strawberry Commission website: http://www.calstrawberry.com/research/mbromide.asp .

[86] 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).

[87] Combined, cultivation and harvesting costs in Santa Barbara and San Luis Obispo counties are very similar to those estimated by UC-Davis for 2006 when using methyl bromide (about $22,000 versus $21,500). The combined cultivation and harvesting costs for Ventura County when 1,3-D+PIC is used are higher than for the other counties, almost $25,000 per acre. A recent ex-post estimate for Ventura County using methyl bromide is not available. The 2006-2008 CUE nomination packages use a slightly lower harvesting cost while cultivation costs

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).

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.[88] 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. The EPA estimated ex-ante that the MBr alternatives analyzed had slightly lower operating costs per acre than MBr, which is consistent with these studies.

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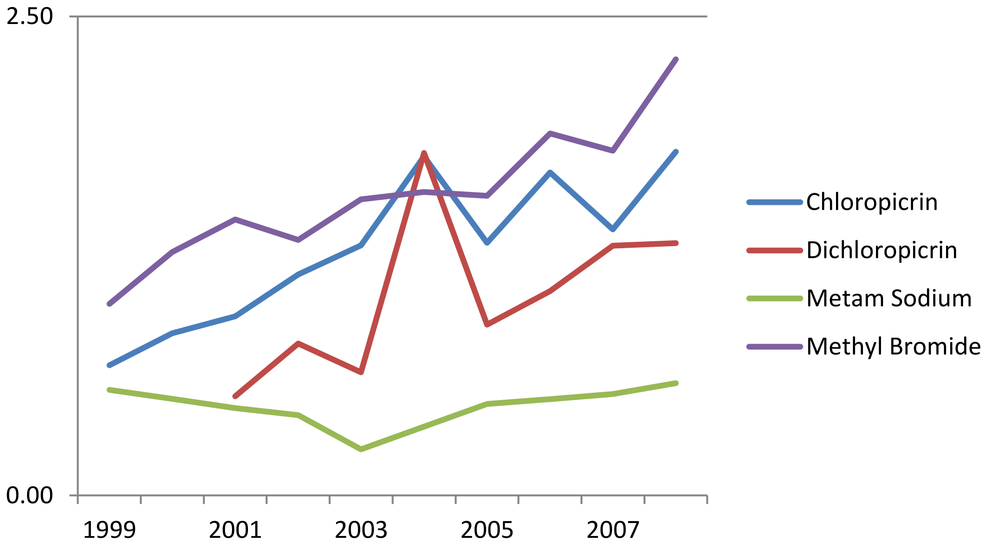
remain nearly identical when 1,3-D+PIC is used instead of methyl bromide +PIC. Combined they add to about $28,000, about $1,000 less than what is estimated when methyl bromide is used. However, again, it is difficult to draw conclusions given the difference in the assumption about how the chemical is applied (shank vs. drip).

[88] Other studies of this type that precede our study period or focus on fruits or vegetables other than strawberries and tomatoes include Aegerter and Folwell (2000), Byrd et al. (2006), Fonsah et al. (2006), and Ferrer et al. (2010).

Figure V-7: Real Prices of Fumigants in California Relative to Methyl Bromide in 1999



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

Fumigant Prices. The one piece of information from a proprietary pesticide marketing database available through the Office of Pesticides Program that we are able to use for comparison purposes is the fumigant prices in California from 1999 to 2008. Nominal prices are available for methyl bromide and three of its alternatives. We have converted these to real prices using the Producer Price Index (PPI) and measured them against methyl bromide in 1999 (which receives a value of 1). Since these chemicals are often combined for use when applied to strawberry fields and the application rates at which they are 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 is consistently more expensive per pound than its alternatives (see Figure V-7). Second, while several authors noted 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 have both increased by slightly more than methyl bromide over this time period.[89]

J. Overall Implications and Study Limitations

Based on the ex-post information available, we find that the net operating costs imposed on the typical California strawberry farmer from banning methyl bromide for the 2006-2010 growing seasons was likely less than anticipated at the time the CUEs were completed. 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 more than 25 percent for the 2006 – 2010 growing seasons, all else equal. Likewise, it appears that farmers who have substituted away from methyl bromide have done so without imposing large negative impacts on production in prime California strawberry growing areas.

Ex-post evaluation also confirms 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. It is also worth noting that unanticipated complications after switching away from methyl bromide, such as new diseases, has slowed the transition to MBr alternatives, in particular 1,3-D+PIC applied via drip irrigation.

As previously mentioned, we encountered a number of challenges in acquiring ex-post cost data. For instance, we only have information on operating costs from crop budgets designed to reflect a

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[89] 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 were linearly interpolated.

typical farmer. Any conclusions with regard to yield losses associated with various methyl bromide alternatives are based on research that uses field trials. 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. The prices of specific fumigant formulations also are not publically available. It is also 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 or the benefit of expert opinion.

References:
Section VI

Aegerter, A. and R. Folwell. 2000. Economic Aspects of Alternatives to Methyl Bromide in the Postharvest and Quarantine Treatment of Selected Fresh Fruits. *Crop Protection:* 161-168.

Bolda, M., L. Tourte, K. Klonsky, and R. De Moura. 2010. Sample Costs to Produce Strawberries. Central Coast Region: Santa Cruz and Monterey Counties. University of California Cooperative Extension.

Byrd, M., G. Fonsah, C. Escalante, and M. Wetzstein. 2006. The Impact of Farm Profitability and Yield Efficiency of Bell Pepper Production of the Methyl Bromide Phase-Out Program in Georgia. *Journal of Food Distribution Research* 37(1): 48-50.

California Strawberry Commission. 2005. Strawberry Review: 2005 Acreage Survey Results.

California Strawberry Commission. 2006. Strawberry Review: 2006 Acreage Survey.

California Strawberry Commission. 2009. California Strawberry Revised 2009 Acreage Survey.

California Strawberry Commission. 2012. The Facts about Methyl Bromide. Available at: http://www.calstrawberry.com/research/mbromide.asp (accessed March 5, 2012).

Carpenter, J., L. Gianessi, and L. Lynch. 2000. The Economic Impact of the Scheduled U.S. Phaseout of Methyl Bromide. National Center for Food and Agricultural Policy.

Carpenter, J., L. Lynch, and T. Trout. 2001. Township Limits on 1,3-D Will Impact Adjustment to Methyl Bromide Phase-Out. *California Agriculture* 55(3): 12-18.

Carter, C., J. Chalfant, R. Goodhue, K. Groves, and L. Simon. 2004. Impacts of Pesticide Regulation on the California Strawberry Industry. Working Paper.

Carter, C., J. Chalfant, R. Goodhue, F. Han, and M. DeSantis. 2005a. The Methyl Bromide Ban: Economic Impacts on the California Strawberry Industry. *Review of Agricultural Economics* 27(2): 181-197.

Carter, C., J. Chalfant, R. Goodhue, G. McKee. 2005b. Costs of 2001 Methyl Bromide Rules Estimated for California Strawberry Industry. *California Agriculture* 59(1): 41-46.

Dara, S., K. Klonsky, and R. De Moura. 2011. Sample Costs to Produce Strawberries. South Coast Region: Santa Barbara and San Luis Obispo Counties. University of California Cooperative Extension.

Daugovish, O., K. Klonsky, and R. De Moura. 2011. Sample Costs to Produce Strawberries. South Coast Region: Ventura County. University of California Cooperative Extension.

DeCanio, S., and C. Norman. 2005. Economics of the ‘Critical Use’ of Methyl Bromide under the Montreal Protocol. *Contemporary Economic Policy* 23(3): 376-393.

Deepak, M., T. Spreen, and J. VanSickle. 1996. An Analysis of the Impact of a Ban of Methyl Bromide on the U.S. Winter Fresh Vegetable Market. *Journal of Agricultural and Applied Economics* 28(2): 433-443.

Fennimore, S., and H. Ajwa. 2011. Totally Impermeable Film Retains Fumigants, Allowing Lower Application Rates in Strawberry. *California Agriculture* 65(4): 211-215.

Ferguson, W., and J. Yee. 1997. Phasing out Registered Pesticide Uses as an Alternative to Total Bans: A Case Study of Methyl Bromide. *Journal of Agribusiness* 15(1): 69-84.

Ferrer, M., G. Fonsah, C. Escalante, and S. Culpepper. 2010. Profitability Efficiency Analysis of Methyl Bromide Fumigants and Mulch Systems: Alternatives for Pepper Production in Georgia. Working Paper.

Fonsah, G., C. Escalante, S. Culpepper, D. Langston, and M. Byrd. 2006. Economics of Methyl Bromide Alternatives in Pepper. White Paper.

Goodhue, R., S. Fennimore, and H. Ajwa. 2003. Economic Feasibility of Methyl Bromide Alternatives: Field-Level Cost Analysis. White Paper.

Goodhue, R., S. Fennimore, and H. Ajwa. 2005. The Economic Importance of Methyl Bromide: Does the California Strawberry Industry Qualify for a Critical Use Exemption from the Methyl Bromide Ban? *Review of Agricultural Economics* 27(2): 198-211.

Goodhue, R., S. Fennimore, K. Klonsky, and H. Ajwa. 2004. After Methyl Bromide: The Economics of Strawberry Production with Alternative Fumigants. Working Paper. Giannini Foundation of Agricultural Economics.

Goodhue, R., P. Howard, and R. Howitt. 2010. Costs of Methyl Iodide Non-Registration: Economic Analysis. *Agricultural and Resource Economics Update* 13(5): 5-8.

Harrington, W., R. Morgenstern, and P. Nelson. 2000. On the accuracy of regulatory cost estimates. *Journal of Policy Analysis and Management* 19 (2): 297–322.

Hueth, B., B. McWilliams, D. Sunding, and D. Zilberman. 2000. Analysis of an Emerging Market: Can Methyl Iodide Substitute for Methyl Bromide? *Review of Agricultural Economics* 22(1): 43-54.

Locascio S., S. Olson, C. Chase, T. Sinclair, D. Dickson, D. Mitchell, and D. Chellemi. 1999. Strawberry production with alternatives to methyl bromide fumigation. Annual International Research Conference on Methyl Bromide Alternatives and Emissions Reductions.

Lynch, L. 1996. Agricultural Trade and Environmental Concerns: Three Essays Exploring Pest Control, Regulations, and Environmental Issues. Dissertation.

Mayfield, E., and C. Norman. Forthcoming. Moving Away from Methyl Bromide: Political Economy of Pesticide Transition for California Strawberries since 2004. *Journal of Environmental Management*.

Noling, J. 2005. Reducing Methyl Bromide Field Application Rates with Plastic Mulch Technology. Paper ENY046. Institute of Food and Agricultural Science, University of Florida.

Noling, J., and D. Botts. 2010. Transitioning to Methyl Bromide Alternatives: A Current U.S. Assessment. White Paper. Unpublished.

Noling, J., D. Botts, and A. MacRae. 2010. Alternatives to Methyl Bromide Soil Fumigation for Florida Vegetable Production. Vegetable Production Handbook. University of Florida, IFAS Extension.

Norman, C. 2005. Potential Impacts of Imposing Methyl Bromide Phaseout on U.S. Strawberry Growers: A Case Study of a Nomination for a Critical Use Exemption under the Montreal Protocol. *Journal of Environmental Management* 75: 167-176.

Othman, M., H. Ajwa, S. Fennimore, F. Martin, K. Subbarao, G. Browne, and J. Hunzie. 2009. Strawberry Production with Reduced Rates of Methyl Bromide Alternatives Applied under Retentive Film. Proceedings for 2009 Annual International Research Conference on Methyl Bromide Alternatives and Emission Reductions.

Perez, A., K. Plattner, and K. Baldwin. 2011. Fruit and Tree Nuts Outlook. FTS-347. National Agricultural Statistical Service, U.S. Department of Agriculture.

Porter, I., L. Trinder, and D. Partington. 2006. Validating the Yield Performance of Alternatives to Methyl Bromide for Pre-Plant Fumigation. Special report commissioned by the Methyl Bromide Technology Options Committee, Technology and Economic Assessment Panel, UNEP.

Rubin, S. 2012. Arysta to pull methyl iodide from U.S. *Monterey County Weekly*. March 22.

Samtani, J., H. Ajwa, J. Weber, G. Browne, S. Klose, J. Hunzie, and S. Fennimore. 2011. Evaluation of non-fumigant alternatives to methyl bromide for weed control and crop yield in California strawberries. *Crop Protection* 30(1): 45-51.

Sances, F. 2000. Conventional and organic alternatives to methyl bromide on California strawberries. Working paper. Presented at Methyl Bromides Alternatives Conference.

Shaw, V., and K. Larson. 1999. A Meta-Analysis of Strawberry Yield Response to Pre-plant Soil Fumigation with Combinations of Methyl Bromide-chloropicrin and Four Alternative Systems. *HortScience* 34: 839-845.

Spreen, T., J. VanSickle, A. Moseley, M. Deepak, and L. Mathers. 1995. Use of Methyl Bromide and the Economic Impact of Its Proposed Ban on the Florida Fresh Fruit and Vegetable Industry. University of Florida. Institute of Food and Agricultural Science. *Bulletin 898.*

Sydorovych, O., C. Safley, L. Ferguson, E. Poling, G. Fernandez, P. Brannen, D. Monks, and F. Louws. 2006. Economic Evaluation of Methyl Bromide Alternatives for the Production of Strawberries in the Southeastern United States. *HortTechnology* 16(1): 1 – 11.

Takele, E., K. Klonsky, and R. De Moura. 2006. Sample Costs to Produce Strawberries. South Coast Region: Santa Barbara County, Santa Maria Valley. University of California Cooperative Extension.

UNEP. 1997. Montreal Protocol on Substances that Deplete the Ozone Layer: Technology and Economic Assessment Panel. Volume II, Annex I.

UNEP. 2010. 2010 Report of the Methyl Bromide Technical Options Committee.

U.S. Department of Agriculture. 1993. The Biologic and Economic Assessment of Methyl Bromide. National Agricultural Pesticide Impact Assessment Program.

U.S. Department of Agriculture. 2000. Economic Implications of the Methyl Bromide Phaseout. Economic Research Service. *Agriculture Information Bulletin 756.*

U.S. Department of Agriculture. 2002. Agricultural Chemical Usage Vegetable Survey. National Agricultural Statistical Service.

U.S. Department of Agriculture. 2006. Fruits and Tree Nuts: Blooming, Harvesting, and Marketing Dates. National Agricultural Statistical Service.

U.S. Department of Agriculture .2007. Agricultural Chemical Usage 2006 Vegetables Survey. National Agricultural Statistical Service.

U.S. EPA. 2004. Methyl Bromide Critical Use Nomination for Preplant Soil Use for Strawberries Grown for Fruit in Open Fields on Plastic Tarps. Submitted for 2006 season.

U.S. EPA. 2005. Methyl Bromide Critical Use Nomination for Preplant Soil Use for Strawberries Grown for Fruit in Open Fields. Submitted for 2007 season.

U.S. EPA. 2006. Methyl Bromide Critical Use Nomination for Preplant Soil Use for Strawberries Grown for Fruit in Open Fields. Submitted for 2008 season.

U.S. EPA. 2007. Methyl Bromide Critical Use Renomination for Preplant Soil Use (Open Field or Protected Environment). Submitted for 2009 season.

U.S. EPA. 2008. Methyl Bromide Critical Use Renomination for Preplant Soil Use (Open Field or Protected Environment). Submitted for the 2010 season.

U.S. EPA. 2009. Methyl Bromide Critical Use Nomination for Preplant Soil Use for Strawberry Fruit Grown in Open Fields. Submitted for 2011 season.

U.S. EPA. 2010. Methyl Bromide Critical Use Nomination for Preplant Soil Use for Strawberry Fruit Grown in Open Fields. Submitted for 2012 season.

U.S. EPA. 2011. Methyl Bromide Critical Use Nomination for Preplant Soil Use for Strawberry Fruit Grown in Open Fields. Submitted for 2013 season.

U.S. EPA. 2012. Methyl Bromide Critical Use Nomination for Preplant Soil Use for Strawberry Fruit Grown in Open Fields. Submitted for 2014 season.

VanSickle, J., C. Brewster, and T. Spreen. 2000. Impact of a Methyl Bromide Ban on the U.S. Vegetable Industry. University of Florida, Institute of Food and Agricultural Science. *Bulletin 333.*

VanSickle, J., and S. NaLampang. 2002. The Impact of the Phase Out of Methyl Bromide on the U.S. Vegetable Industry. Policy Brief 02-1. University of Florida. International Agricultural Trade and Policy Center.

VanSickle, J., S. Smith, and R. Weldon. 2009. Impacts of EPA Proposed Buffer-Zone Restrictions on Profitability of Florida Strawberry Growers. Paper FE795. University of Florida. Institute of Food and Agricultural Science.

Appendix VI-A: Review of the Ex-Ante Literature on the Impact of a Ban on Methyl Bromide

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.[90] 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.[91] The report finds that planted acreage would decrease by 43 percent as a result of the ban. Florida strawberry production

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[90] Decanio and Norman (2005) examine contributions governments have made to a multilateral fund set up to help meet the goals established by the Montreal Protocol. Signatories to the Montreal Protocol agreed to a certain level of payment into the multilateral fund when they ratified the agreement, and most countries have complied with promised payments. The authors find that, after controlling for factors such as project scale and sector, the cost-per-ton of ozone depleting substances has declined by almost $600 per year purely as a function of time (about 2-4 percent per year).

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

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 (which includes 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 between $800 million and $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 are expected to face the largest impacts. The report notes that a phase-in of the ban under the Clean Air Act would substantially reduce predicted losses.

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[92] that treats prices as endogenous. She finds that a ban on methyl bromide use for growing 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

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[92] 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.

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.[93] 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).[94]

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[93] 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.

[94] 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

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 methyl bromide 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 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.

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.

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.[95] 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.[96] 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.[97]

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

[96] 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.

[97] In addition, Mayfield and Norman (2011) point out that Mexico consumed less methyl bromide 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 using iodomethane.

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.[98] They do not evaluate possible changes in crop production practices, such as more integrated pest management techniques or conversion to organic production.[99] 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 that for the most likely yield declines (10-15%), prices would have to increase by 13 – 23 percent for profits to be unaffected, while acreage would have to decline by 13 – 34 percent.

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

[99] 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.

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.[100] While not a study of the impacts of a national MBr ban, it is indicative of the way farmers 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 also lost a greater proportion of acreage due to buffer zone restrictions. Using cost and return study information from UC-Davis combined with expert opinion and surveys of growers, the authors estimated the short term impacts on strawberry growers. 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 the 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).

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[100] 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.

VII. National Primary Drinking Water Regulation for Arsenic

A. Overview

On January 22, 2001, EPA published new National Primary Drinking Water Regulations for Arsenic (the “Arsenic Rule”). This rule 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 the water to reduce the arsenic levels in their drinking water. Of those systems affected, 97 percent serve 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, the EPA ultimately set the drinking water standard for arsenic at 10 μg/L, concluding that this final MCL of 10 μg/L maximized health risk reduction at a cost justified by the benefits (US EPA 2001). The technically feasible level for arsenic removal from water was established at 3 μg/L.

Based on the available science at the time, EPA quantified and monetized 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. The total annual costs of the rule were estimated to be approximately $181 million, with treatment costs comprising the bulk at about $171 million. 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.

Because of the importance of the Arsenic Rule and the national debate surrounding it related to science and costs, EPA's Administrator publicly announced on March 20, 2001, that the Agency would take additional steps to reassess the scientific and cost issues associated with the Arsenic Rule. As part of that review, the Agency worked with its National Drinking Water Advisory Council (NDWAC) to review the assumptions and methodologies underlying the Agency's estimated costs for arsenic compliance. Upon finishing their review, NDWAC concluded that EPA "produced a credible estimate of the cost of arsenic compliance given the constraints of present rulemaking, data gathering, and cost models" (NDWAC 2001).

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 extent of arsenic concentrations exceeding the standard could be larger or smaller than predicted before the rule. The purpose of this report is not to review the ex ante cost analysis nor the outcome of the NDWAC review. Rather, the goal is to examine how the ex post costs differ from the ex ante cost estimates and, if possible, to identify the drivers of any deviation between ex ante and ex post costs. EPA used sound science and the best available information to estimate the costs associated with the Rule in its benefit cost analysis. Our goal here is not to re-estimate the costs of the Rule but rather to see if we can 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 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 Section III of this report.

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

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[101] 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).

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% 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 present the data here until we can 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.). These data will be incorporated into the retrospective analysis once we have determined they are of specific to arsenic mitigation.

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 the EPA in the EA with the data we collected on realized compliance costs for the 50 systems.

We evaluate the ORD Demonstration Project data in two ways. First, we compare realized compliance costs for all 50 systems regardless of technology implemented against the predicted ex ante costs for selected BATs to discern by how much costs diverge. Second, we compare ex ante and ex post unit cost estimates for the two BAT technologies captured by the Demonstration Projects. In addition, we summarize information shared by several states and independent associations on the types (but not costs) of treatment technologies used by systems as well anecdotal information on aspects of arsenic mitigation that they indicated were not adequately captured by EPA in its ex ante cost estimates. These comparisons offer insights into how we might proceed if better and more comprehensive data were available. Because our data are very limited, however, we are not able to draw any conclusions as to how well the methodology used by EPA to estimate ex ante costs predicted costs for systems that had to comply with the Arsenic Rule.

We begin by describing the analytic challenges we faced in conducting an ex post cost assessment for this rule. We then describe how the cost estimates were produced by the EPA for the EA, discussing first the best available technologies identified by the EPA, then the cost estimation methodologies employed in the EA for the different size and type of systems. Following a brief review of two existing retrospective cost studies of the Arsenic Rule, we describe the data employed for this retrospective cost effort more fully and explain how they were obtained. We then describe the methodology applied in this report prior to reporting the results of our comparisons.

B. Analytic Challenges

This case study was particularly challenging in that the systems affected by the new arsenic standard are heterogeneous. 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.

Location may also affect the choice of mitigation strategy. Proximity to other municipal 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[102], 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).

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 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.

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

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. 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.

C. Estimating Unit Costs for the Best Available Treatment Technologies

EPA's ex ante compliance cost estimates for the Arsenic Rule begin with the identification of the Best Available Technologies (BAT) effective at removing arsenic and bringing water systems into compliance with the MCL.[103] *Technologies and Costs for Removal of Arsenic from Drinking Water* (EPA, 2000) describes the various arsenic removal technologies under different conditions. These technologies include coagulation/filtration, greensand filtration, activated alumina, ion exchange, and membrane processes such as reverse osmosis. In addition to the traditional arsenic removal treatment technologies, this document also discusses alternative technologies such as sulfur-modified iron, iron

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[103] Identification of BATs is required under the Safe Drinking Water Act and forms the basis of establishing any new MCL.

filings, iron oxide coated sand, and granular ferric hydroxide, which were still in the experimental stages at the time the rule was being promulgated. The discussion of each technology also covers ways to improve the effectiveness of the technology for the removal of arsenic and discusses the impact on arsenic removal efficiencies of factors such as pH, arsenic oxidation state, and the effect of competing ions. As a result of this assessment, the following technologies were identified by the 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 operating and maintenance (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 the 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.

The technologies and costs document used three models to develop cost curves for most of the different treatment technologies. Each model uses a different flow range to estimate capital and O&M costs for that range. Linear trends were used to estimate costs in the transition between the models to develop capital and O&M cost curves for systems with design flows ranging from 0.01 to 430 million gallons per day (mgd).

In the technologies and costs document, a different methodology was used to estimate cost curves for activated alumina and ion exchange because the existing models could not be modified for estimating costs of arsenic treatment. Specifically, for activated alumina, the models assume media regeneration and parallel operation of columns. Instead, EPA assumed that the alumina columns would be operated in a series of small columns to provide better utilization of the media. Similarly, the three models are not used to estimate costs for ion exchange because they assume higher sulfate ranges than those under consideration at the time. Instead cost curves were developed based on different design assumptions. Appendix A presents the assumptions and cost curves used by EPA in the EA to estimate the costs of these BATs.

D. Methodology EPA Used in the EA to Estimate Compliance Costs

With the best available technologies and their unit costs defined, the EPA employed different methods to estimate compliance costs for each of three different system categories: NTNCWSs, CWSs serving fewer than 1,000,000 people and CWSs serving 1,000,000 people or more. In the EA, EPA used a Monte Carlo Simulation model (the Safewater XL model) to estimate compliance costs for the smaller CWSs and a deterministic spreadsheet analysis to determine compliance costs for the NTNCWSs. The EPA estimated compliance costs individually for the large systems (those serving 1,000,000 people or more) 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 by system category.

1. Community Water Systems (systems serving less than 1,000,000 people)

To estimate compliance costs for smaller CWSs, EPA used the Safewater XL model. The model uses a combination of individual system data and distributional data (e.g., arsenic occurrence, system intake sites) 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.[104]

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.

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[104] 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.

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.[105] For those entry points that required treatment, the Safewater XL model used a decision tree to assign a treatment technology to the entry point appropriate for the size and type of system.[106] Each decision tree assigned a probability to the application of 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.

2. 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

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[105] 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).

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

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.

3. Community Water Systems (systems serving populations of 1,000,000 or more)

For each of the nation's 25 largest drinking water systems – those serving 1,000,000 people or more, EPA developed individual compliance cost estimates using system specific information including water quality parameters, system layouts, design and average flow, intake and aquifer location, and treatment facility diagrams.[107] 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 20-25% of the total compliance costs estimated for the Arsenic Rule.

4. Summary

Based on this quick review, we identified the following variables as key drivers of national costs of this rule: the extent of arsenic in current drinking water supplies, the ability of systems to blend water to reduce arsenic levels, the ability of systems to find new source water supplies with lower arsenic levels, the size of each system that must adopt controls, other water quality parameters as well as other

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[107] 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.

engineering design parameters. It is worth noting that relatively complete ex post data on these variables is not available, making it impossible to assess total ex post costs.

E. Existing Comparisons of Ex Ante and Ex Post Costs

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). As noted earlier, shortly following the promulgation of the rule, EPA engaged NDWAC in an extensive, independent review of EPAs 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 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 substracting 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% of the systems had annualized costs that exceeded these amounts; 19% had costs greater than EPA's expenditure margin ; 15% 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.

F. Potential Sources of Ex Post Cost Data

To produce an ex-post cost estimate for complying with the Arsenic rule that could be compared to the unit costs and national costs in the EA, we would need information on the population served, source water, and treatment technology used by each water system along with the O&M costs and capital expenditures associated with the technology required to remove arsenic. If we were able to obtain all of this information for a representative sample of systems, then we could calculate the total compliance costs by multiplying the number of water systems requiring arsenic removal in each category (system size and type, design flow, source water, and treatment technology) by the realized unit costs and sum them up. 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.

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.[108] 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 VII-A.

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

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[108] "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.

systems, and the anticipated capital cost of those 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).

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 conducted full-scale, onsite demonstrations of arsenic removal technology, process modifications and engineering approaches for small systems.

EPA program funds 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.

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.[109] 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 and 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 VII-C). Of the seven, two engineering firms, Malcolm Pirnie and Wright-Pierce, provided information on

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[109] 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.

the technologies used by water systems they assisted and the associated compliance costs as well as providing responses to the general questions.[110, 111]

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 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. Malcolm Pirnie attempted to apportion the total capital costs and O&M costs attributable to arsenic mitigation versus the control of other co-contaminants or other system improvements.

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 and has a design flow rate of 0.792 mgd. The Moody River Road Filter plant located in the Lisbon water district serves a population of 6,250 with a design flow rate of 1 mgd.

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

[111] 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.

Before these data can be incorporated into our retrospective analysis, we need to verify that they represent realized costs associated with arsenic mitigation. At this time, we have not included the water system cost data provided by the engineering firms in our analysis. It may be 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. Additional information will be sought from the engineering firms to verify the portion of the costs attributable to arsenic mitigation before including them in our ex post cost assessment. However, even with the addition of the data on these nineteen systems from Malcolm Pirnie and Wright Pierce, our data will remain too limited to draw robust conclusions on whether EPA over or under-estimated technology costs.

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% 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.

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 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.

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 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 VII-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 %) employed adsorptive media. Anion exchange, installed at 15% 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%, respectively.

Table VII-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

Michigan's Department of Environmental Quality provided responses to our general questions as well as additional information on the compliance strategies employed by systems in the state. In Michigan, 116 systems 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 %) serving populations of less than 1,000. Sixty-three of the systems (or 54%) 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 VII-2).[112] An additional 23 systems (20%) found new sources of groundwater and 9 (or 8%) 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

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

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, they contend that disposal of backwash “in many cases doubled the cost amount of original arsenic removal system.”

Table VII-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

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-Transient Non-Community Systems. Although 62 of the 105 (or 59%) 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%) as in the other states, the most widely used strategy was oxidation/filtration (33%). Non-treatment options (including abandoning a contaminated source, drilling new wells, etc.) represented another 17% of the mitigation strategies utilized with blending not far behind at 14%. 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.

6. Summary of Potential Sources of Cost information

Two sources identified above provide both capital costs and (partial information) on O&M costs, albeit limited: ORD Demonstration Projects and Industry Compliance Engineering Firms. Although the states and independent associations provided interesting information on arsenic mitigation strategies employed and related shortfalls, the information lacked 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 reveal an interesting story and suggest 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.

G. Retrospective Cost Methodology

For the remainder of this exercise, 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.

1. 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 VII-3 summarizes design flow rate, average flow rate, total capital and O&M costs for the 28 water systems.

Table VII-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
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.

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 VII-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.

Table VII-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

Other Arsenic Treatment Technologies. Table VII-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.

Table VII-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

2. Ex Ante and Ex Post Cost Comparisons

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 has been 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 Graphs 1 and 2.[113] To keep the graphs visually simple, Graph VII-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 Graph VII-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.[114]

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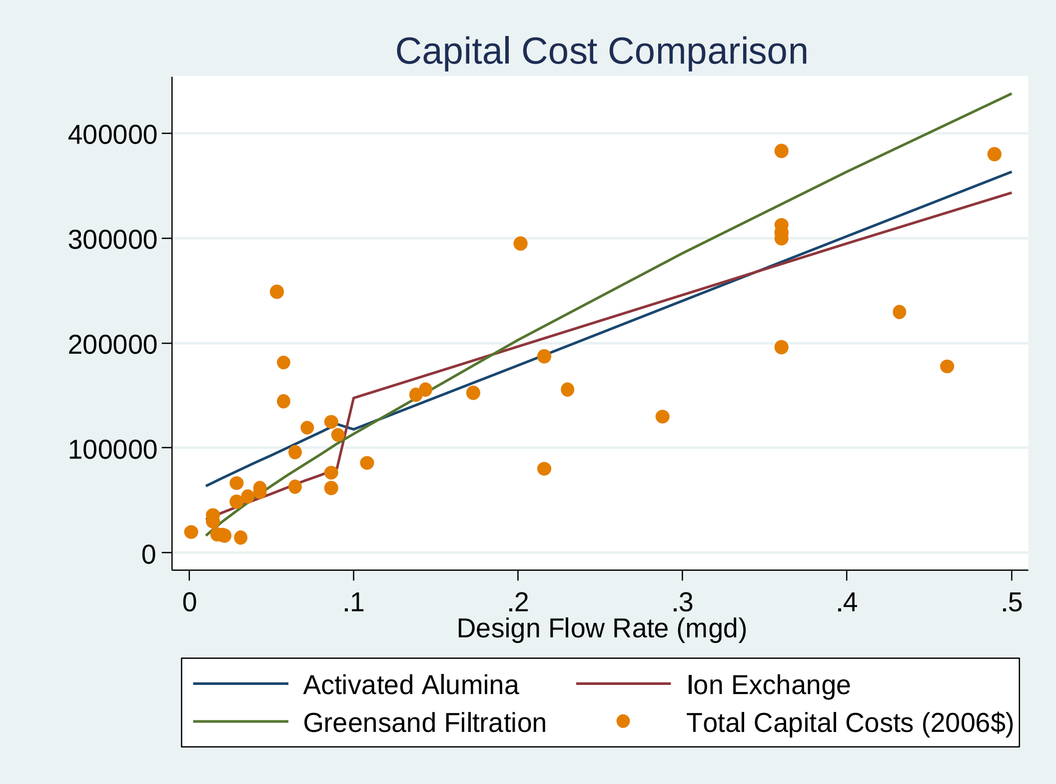
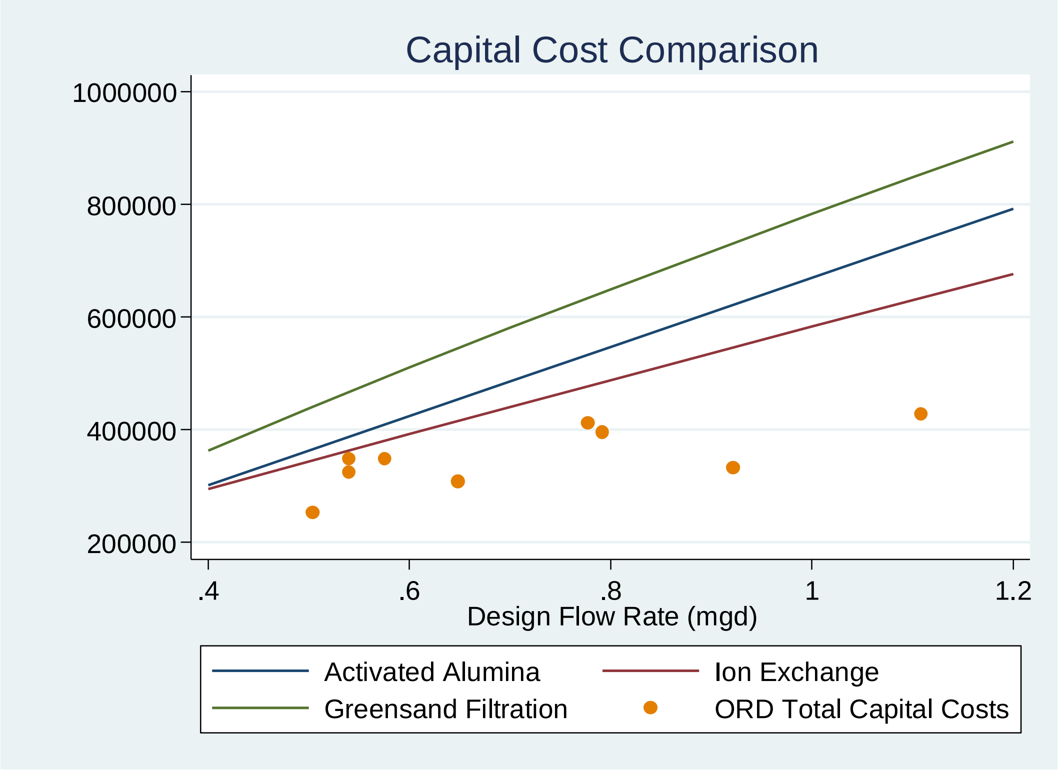
[113] Total capital costs for the ORD demonstration projects were converted to 2006 dollars from the year of construction using the Engineering News Record Construction Cost Index. See appendix for cost curve equations in $2006.

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

Graph VII-1. Capital Cost Comparison by Design Flow Rate (0.01-0.5mgd) – EPA Cost Curves vs. ORD Demonstration Projects



Graph VII-2. Capital Cost Comparison by Design Flow Rate (0.5-1.2 mgd) – EPA Cost Curves vs. ORD Demonstration Projects



3. Comparison of Technology Costs

Although the data are limited, some of the demonstration projects used BAT to reduce arsenic levels. 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.[115] For purposes of assessing the "accuracy" of estimated ex ante costs we use an error bound of +/- 25% as applied by others in the literature (OMB 2005; Harrington et al., 2000). Before presenting

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[115] 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.

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 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 VII-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 VII-B to predict the capital and O&M costs for this technology (EPA Estimate). Column 5 represents the percentage difference between these EPA estimates and the realized costs reported by ORD Demonstration Project sites. A negative (positive) percentage difference means that the EPA estimate was higher (lower) than actual costs incurred by the individual system.

Table VII-7. Cost Comparisons – Ion Exchange (2006$)

	Design Flow/Average Flow (mgd)	**ORD Project Costs**	**EPA Estimate**	**% Difference**
CapEx	0.36	$311,988	$275,245	13%
	0.78	$411,632	$477,021	-15%
OpEx	0.23	$55,735	$34,180	48%
	0.77	$102,258	$43,180	81%

The EPA estimates of capital costs were mixed but the percentage differences were within the +/-25% threshold. 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. The percentage differences in total operating costs reported by the ORD Demonstration Projects and the EPA estimates are outside the range of the +/-25% threshold.

Greensand Filtration. Two community water system ORD Demonstration Projects used Greensand filtration (GF) as a treatment technology. Table VII-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 VII-B) to estimate the capital and O&M costs for this technology (EPA Estimate). Column 5 represents the percentage difference between the EPA estimate and the costs reported by ORD Demonstration Project sites. A negative (positive) percentage difference 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%) while the other had capital costs that were significantly lower than projected (-38%). For both projects, predicted O&M cost were slightly lower than the realized cost but well within the +/-25% threshold.

Table VII-8. Cost Comparisons – Greensand Filtration (2006$)

	Design Flow/Average Flow (mgd)	**ORD Project Costs**	**EPA Estimate**	**% Difference**
CapEx	0.14	$150,692	$149,082	1%
	0.36	$196,150	$332,473	-38%
OpEx	0.12	$26,767	$19,341	8%
	0.22	$33,457	$27,139	5%

H. Responses to the Questionnaire

In addition to collecting information on the treatment technologies used by water systems and their costs, we also provided the engineering firms a questionnaire asking about the assumptions and cost estimation framework used by the EPA. The questionnaire also included general questions about whether new or modified treatment technologies may 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. Malcolm Pirnie agreed that treatment technologies have changed. Iron-based adsorption media has emerged as the treatment technology preferred by water systems. 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. Factors affecting use of adsorptive media include how the residuals or backwash water will be disposed and the frequency and cost of media replacement. 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.

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.

I. Conclusion

In the EA for the Arsenic Rule, EPA estimated average unit costs of the best available treatment technologies identified for CWSs. These compliance technologies included centralized treatment technologies such as ion exchange and activated alumina as well POU treatment technologies. Using data from the CWSS, EPA estimated the number of entry points for each affected water system. For that water system, and based on the size of the system and the amount of arsenic needing to be reduced, a treatment technology was assigned to reduce arsenic level below the MCL. Design and average flow rate were then estimated and, using the cost curves for that technology found in the *Costs and Technology Document for the Arsenic Rule* (EPA, 2000), capital costs and O&M costs were estimated for that treatment technology.

Our sources of realized cost data are the ORD Demonstration Projects and compliance assistance engineering firms, Malcolm Pirnie and Wright Pierce. These ex post data are limited in several key respects. Most importantly, our data capture the costs of treatment technologies for a very small percentage of systems affected by the arsenic standard. As such, these results are not generalizable across affected systems. Due to site-specific characteristics, treatment methods and actual compliance costs will vary by water system.

While the capital and O&M costs provided by the engineering firms are compliance costs for specific systems located in California, Arizona and Maine, these nineteen systems represent only a small fraction of those required to mitigate arsenic levels to comply with the Arsenic Rule. As mentioned earlier, because these cost data may include costs associated with the control of contaminants in response to other regulations or may include other water system upgrades or modifications, we refrain from using them in our analysis until they can be further validated.

The ORD Demonstration Project data are similarly limited in that they represent only a small number of systems and the cost data from these projects may contain their own biases due to the reliance on emerging technologies that were not entirely understood by the vendors, the lack of established price points for these emerging technologies at the onset of the project, the goals of the Demonstration project (demonstrating the effectiveness of treatment technologies as opposed to non-treatment alternative), lack of pilot testing, etc. Further, our data focus on treatment technologies and do not capture other approaches, including non-treatment approaches such as blending, used by some systems.

Looking only at the ex post cost data from the ORD Demonstration Projects, we present these data in two ways: 1) we compare all the ex post cost data against the cost curves for three treatment technologies, activated alumina, greensand filtration, and ion exchange and 2) for the subset of BATs represented in our data, we compare actual compliance costs to pseudo ex ante compliance costs. Plotting all of the capital cost data from the ORD Demonstration Projects against the cost curves for the compliance technologies recommended for smaller systems, we 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).[116] Focusing next on BATs, our comparisons of EPA predicted costs and realized costs from the four ORD Demonstration Projects for two specific BATs (ion exchange and greensand filtration) are provided for illustrative purposes only. The goal of both types of comparisons was to see if we could make informed judgments about whether ex post costs are higher or lower than the estimates of ex ante costs. However, because we only have data for a very small number of water

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[116] Note that we do not employ the threshold of +/- 25% when comparing all of the realized costs regardless of technology employed against the EPA cost curves. Because most of the Demonstration projects employed an emerging technology that was not BAT, a corresponding cost curve for this technology is not available to make this determination.

systems affected by the Arsenic Rule, we cannot draw any conclusions regarding EPA's technology cost estimates.

While our correspondences with states and associations did not lead to additional cost information, they did share with us information on the types of treatment technologies used by systems in their state and problems encountered. In particular, disposing of arsenic treatment residuals in some states was allegedly more costly than EPA initially estimated.

As evidenced by the technologies selected for the ORD Demonstration Projects and responses from the compliance experts and states to our questionnaire, iron-based adsorptive media emerged as the preferred treatment technology for mitigating arsenic contamination. 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, because EPA has demonstrated that this is an effective technology since promulgation of the arsenic standard, water systems can and have used this technology. 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 were also widely used and are not captured in our data.

References:

Bitner, K., B. Thomson, and J. Chwirka. 2001. The cost of compliance with a new drinking water standard for arsenic in New Mexico. *New Mexico Geology* 23:10–12.

Chen, A. S. C., L. Wang, J. L. Oxenham, W. E. Condit. 2004. Capital Costs of Arsenic Removal Technologies, U.S. EPA Arsenic Removal Technology Demonstration Program Round 1. EPA/600/R-04/201.

Fisher, D. C., C. D. Whitehead and M. Melody. 2006. National and Regional Water and Wastewater Rates For Use in Cost-Benefit Models and Evaluations of Water Efficiency Programs. Lawrence Berkeley National Laboratory.

Frey, M. M., J. Chwirka, R. Narasimhan, S. Kommineni, and Z. Chowdhury. 2000. Cost Implications of a Lower Arsenic MCL. AWWA Research Foundation and American Water Works Association, Denver, CO.

Gurian, P.L., R. Bucciarelli-Tieger, M. Chew, A. Martinez, and A. Woocay. 2006. Validating Pre-regulatory Cost Estimates for the Revised Arsenic MCL. Proceedings of the AWWA Annual Conference and Exposition in San Antonio, TX.

Harrington, W., R. D. Morgenstern, and P. Nelson. 2000. On the Accuracy of Regulatory Cost Estimates. *Journal of Policy Analysis and Management* 19(2): 297-322.

Hilkert Colby, E. J., T. M. Young, P. G. Green, and J. L. Darby. 2010. Costs of Arsenic Treatment for Potable Water in California and Comparison to U.S. Environmental Protection Agency Affordability Metrics. *Journal of the American Water Resources Association* 46(6): 1238-1254.

National Drinking Water Advisory Council (NDWAC). 2001. Report of the Arsenic Cost Working Group to the National Drinking Water Advisory Council. Available at: http://water.epa.gov/drink/info/arsenic/upload/2005_11_10_arsenic_ndwac-arsenic-report.pdf.

US EPA. 2000a. Arsenic in Drinking Water Rule Economic Analysis. EPA 815-R-00-026. Prepared by Abt Associates, Inc. for EPA OGWDW, December

US EPA. 2000b. Arsenic Occurrence in Public Drinking Water Supplies. EPA 815R00023. Prepared by ISSI Consulting Group under contract 68C70005, The Cadmus Group under contract 68C99206 and ICF Consulting for EPA OGWDW.

US EPA. 2000c. Technologies and Costs for Removal of Arsenic from Drinking Water. EPA 815R00028. Prepared by Malcolm Pirnie, Inc. under contract 68C60039 for EPA ORD.

US EPA. 2005. Treatment Technologies for Arsenic Removal. EPA 600/S-05/006. EPA's National Risk Management Research Laboratory, November.

US EPA. 2007. Environmental Technology Verification (ETV) Program Case Studies: Demonstrating Program Outcomes. EPA 68-C-02-067. Prepared by Science Applications International Corporation for EPA ORD, January.

US EPA. 2011. Costs of Arsenic Removal Technologies for Small Water Systems: US EPA Arsenic Removal Technology Demonstration Program. EPA 600R11090. Prepared by Lili Wang and A.S.C. Chen, under contract EPC05057 for EPA ORD.

Appendix VII-A: 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.[117] 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

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[117] "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.

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 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): [118] 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.[119] The database was published in December 2000 and has not been updated since that time.

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[118] 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

[119] 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.

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).[120]

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.[121] CWS that serve 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):[122] The Environmental Working Group (EWG) – an advocacy group – assembled 20 million drinking water quality tests performed by water utilities

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[120] 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.

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

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

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.[123] 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):[124] 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):[125] 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

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

[124] 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.

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

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 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.[126] 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.[127] For the retrospective study, USGS selected almost

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

[127] "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

19,000 groundwater sites from their NWIS database.[128] 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.[129] 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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[128] Sites that had water samples that were characterized as non-potable (high saline content or high temperature) were not included in the retrospective analysis.

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

National Contaminant Occurrence Database (NCOD):[130] 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.[131] 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):[132] 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.

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

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

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

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):[133] 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 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

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

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).[134] 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. [135]

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

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[134] 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.

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

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 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 VII-B: EPA Cost Curves

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.

Capital Costs = $782662x^{0.838}$

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.

Capital = $1151.73x^{0.9261}$

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.

Capital = $395.46x^{0.9257}$

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

Appendix VII-C: 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 6a - 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 7a - 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 8c: 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 9a - 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 10a - 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 11a: 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.

Capital = $1151.73x^{0.9261}$
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.

Capital = $395.46x^{0.9257}$
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

VIII. EPA's 1998 Locomotive Emission Standards

A. Introduction

The purpose of this paper is to examine how the 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 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 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. (The 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 (defined as +/- 25 percent by Harrington et al. (2000)). When a substantial difference exists, we seek to identify the particular reasons for the discrepancy. 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.

To conduct this 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 VIII-A.

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. All descriptions of EPA's ex-ante estimates come from the regulatory support document for the rulemaking (US EPA 1998).

The remainder of the paper is organized as follows. Section B describes the 1998 locomotive standards and summarizes the methods EPA used to produce ex-ante estimates of the compliance costs for the final rule. Section C 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 D 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.

B. Background

1. Description of Rule

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 VIII-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.***

Table VIII-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 $1.33 billion (NPV, 7% discounting, 1997$), 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 $600 million (NPV, 7%), or 45% of the total program costs, would occur over this period, achieving 12% 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

2. EPA's approach for 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. 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.

- Remanufacture costs – maintenance and other costs associated with keeping locomotives in compliance with the standards through subsequent remanufactures.
- 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 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). In some areas, the EPA presented a range of costs, especially when contractor estimates or public comments differed from EPA's initial estimates. The regulatory support document states 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. It should also be noted that for the most part, the baseline assumptions about technology (availability, cost, fuel economy) and other inputs 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.[136]

The incremental per locomotive compliance costs together with the estimated number of locomotives subject to the rule were used to calculate the total costs of the program.

C. Ex post Assessment of Compliance Cost

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% of total Class I fuel consumption in recent years.[137]

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[136] 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.

[137] 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).

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).[138] 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.[139] 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-cylinder engines rather than 16 cylinders. GE also deployed a 6000 hp, 16-cylinder version of its GEVO engine.

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[138] GE did not make switch locomotives at that time, or since.

[139] 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.

2. Compliance Technologies

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.

Table VIII-3 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.

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.
- 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 would be 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.

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.

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 VIII-3 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).[140]

3. Per Locomotive Cost

a) 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% manufacturer's markup for overhead and profit.

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[140] 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.

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 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 VIII-4 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 over-estimated (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 VIII-4 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).[141] For Tier 1 and 2, the use of 4-pass 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.

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[141] These price increases are based on EPA assumed costs of these emission control technologies for other Model types, as shown in Table VIII-4.

Better reliability means one unit can often replace two old conventional units, and fuel consumption is at least 50% less.[142] 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).

b) 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.

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[142] Estimates based on EF&EE discussion with a genset switcher company.

Table VIII-4 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.

c) 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 VIII-4, 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% 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%). For newer line-haul models (C, E), fuel cost make up about half (42-56%) of per locomotive cost. For Tier 1 and Tier 2, fuel costs account for 53-59% and 70-80% 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 VIII-5. Locomotive fuel averaged $1.20/gal (1997$) over 2000-2009[143], or over 70% more than EPA's estimate (AAR 2002, 2011).[144] 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 – e.g., about 0.4% 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% higher than what EIA had projected in the 1997 Annual Energy Outlook (AEO) (EIA 2011).

Average annual fuel consumption per locomotive. Table VIII-4 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.

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[143] 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.

[144] 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).

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 VIII-5 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[145], all we can reasonably conclude based on existing data is that annual fuel

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[145] 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).

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, 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% lower than EPA's estimate.[146]

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% 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. EPA also conducted a high case sensitivity analysis with 2-4% 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

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[146] Estimate based on EF&EE discussion with a genset switcher company.

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,[147] 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 VIII-5, 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.

Even so, the challenge of constructing the counterfactual would remain. Given the long term trend of improved fleetwide rail efficiency observed before the rule,[148] and projections made in the year

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[147] 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.

[148] Based on data in Table 5, revenue ton-miles per gallon fuel consumed increased on average nearly 2% annually between 1990 and 2000 (AAR 2002).

before the rule was promulgated,[149] 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),[150] 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.[151] 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.

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[149] 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).

[150] 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).

[151] 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#.

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%. 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 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% 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[152] 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%. EF&EE's expert opinion is

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[152] 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

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% (EF&EE); another reports "fuel savings of more than 20%, compared to existing diesel locomotive technology in side-by-side use, have been demonstrated."[153] 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).

4. Number of locomotives affected by the rule

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.

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.

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[153] http://www.gwrr.com/about_us/community_and_environment/gwi_green/genset_locomotives.be

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 VIII-4 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 VIII-5, 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 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 VIII-5, 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[154], 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.)

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[154] http://www.fhwa.dot.gov/environment/air_quality/conformity/research/mpe_benefits/mpe06.cfm

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%, 70%, and 16-23%, respectively.

D. Summary and Methodological Challenges

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 was 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 Section III of this report.

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 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% higher for Tier 0 (line-hauls built 2000-2001 or remanufactured), 14-19% higher for newly built line-haul locomotives over 2002-2004 (Tier 1), and 36% higher for newly built line-haul locomotives over 2005-2009 (first five years of Tier 2).[155]

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 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

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[155] 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.

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.

References
(Section VIII)

American Association of Railroads (AAR). 2009. Monthly Railroad Fuel Price Indexes.

American Association of Railroads (AAR). 2006. Monthly Railroad Fuel Price Indexes.

American Association of Railroads (AAR). 2003. Monthly Railroad Fuel Price Indexes.

American Association of Railroads (AAR). 2001. Monthly Railroad Fuel Price Indexes.

American Association of Railroads (AAR). 2011. Railroad Facts, 2011 Ed.

American Association of Railroads (AAR). 2002. Railroad Facts, 2002 Ed.

Chen, G., P.L. Flynn, S.M. Gallagher, and E.R. Dillen. 2003. Development of the Low-Emission GE 7-FDL High-Power Medium-Speed Locomotive Diesel Engine. *J. Engineering for Gas Turbines and Power* 125: 505-512.

Dillen, E.R., and S.M. Gallagher. 2002. Development of the Tier 1 Emission Reduction Control Strategy for GE-7FDL High-Power Medium-Speed Locomotive Diesel Engine. Proceedings of the 2002 Fall Technical Conference of the ASME Internal Combustion Engine Division, ICEF2002-504.

Dolak, J., and D. Bandyopadhyay. 2011. A Computational Investigation of Piston Bowl Geometry for a Large Bore Two-cycle Diesel Engine. Proceedings of the ASME Internal Combustion Engine Division's 2011 Fall Technical Conference, ICEF2011-60155.

Eastern Regional Technical Advisory Committee (ERTAC). 2012. Rail Emissions Inventory. Available at: http://www.gaepd.org/air/airpermit/downloads/planningsupport/regdev/locomotives/class2_3_doc2012.pdf.

Energy Information Administration (EIA). 2011. AEO2010 Retrospective Review. Available at: http://205.254.135.7/forecasts/aeo/retrospective/.

Energy Information Administration (EIA). 1997. Annual Energy Outlook. Available at: ftp://ftp.eia.doe.gov/forecasting/038397.pdf.

Federal Railroad Administration (FRA). 2009. Comparative Evaluation of Rail and Truck Fuel Efficiency on Competitive Corridors. Available at: http://www.fra.dot.gov/Downloads/Comparative_Evaluation_Rail_Truck_Fuel_Efficiency.pdf.

Flynn, P., P. Hupperich, S. Napierkowski, and E. Reichert. 2003. General Electric GEVO Engine For Tier 2 Locomotive Application. Proceedings of the 2003 Fall Technical Conference of the ASME Internal Combustion Engine Division, ICEF2003-708.

Fritz, S., J. Hedrick, and B. Smith. 2005. Exhaust Emissions from a 1,500 kW EMD 16-645-E Locomotive Diesel Engine Using Several Ultra-Low Sulfur Diesel Fuels. ASME Paper No. ICEF2005-1228.

Harrington, W., R.D. Morgenstern, and P. Nelson. 2000. On the accuracy of regulatory cost estimates. *Journal of Policy Analysis and Management* 19(2): 297 – 322.

US EPA. 2005. Locomotive Compression-Ignition Engines Certification Data. Available at: http://www.epa.gov/otaq/certdata.htm#locomotive.

US EPA. 1998. Locomotive Emission Standards Regulatory Support Document. Available at: http://www.epa.gov/oms/regs/nonroad/locomotv/frm/locorsd.pdf.

US EPA. 1997. Regulatory Announcement: Final Emissions Standards for Locomotives. Available at: http://www.epa.gov/otaq/regs/nonroad/locomotv/frm/42097048.pdf.

Uzkan and Lenz 1999. On the Concept of Separate Aftercooling for Locomotive Diesel Engines. *Journal of Engineering for Gas Turbines and Power* 121:205-210.

Table VIII-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: The 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.

Table VIII- 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).

Table VIII- 3: 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).

Table VIII-4: 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 VIII- 5. 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

Appendix VIII-A: 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[156].

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 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

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[156] 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: Estimated Number of New and Remanufactured Locomotives Affected by the Rule		
Tier	**Model**	**Number of Locomotives**
	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).

<u>Assumptions Used for Class I Analysis:</u>

- 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

Table 4: Estimated Emission Rates (g/bhp-hr) for Class I Locomotives			
Pollutant	**Tier**	**Line-Haul Locomotive**	**Switch Locomotive**
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.