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Municipal Waste Combustor Rule

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Abstract

This paper compares EPA's ex ante cost analysis of the large municipal waste combustor (MWC) rule to an ex post assessment of its cost. For our analysis of the MWC rule, we use plant-level data from the U.S. Department of Energy annual survey of pollution abatement expenditures by steam-electric power plants and from a survey of municipal waste combustor plants compiled by Government Advisory Associates. We find the ex post capital expenditures for nitrogen oxides control systems are typically lower than the EPA ex ante estimates, while ex post capital expenditures for mercury control systems tend to be higher than the EPA ex ante estimates. Finally, the comparison of ex post capital expenditures for particulate and sulfur dioxide control to ex ante capital costs are mixed. While a few plants are outliers when comparing the ratio of ex post capital costs to ex ante capital, the mean of the comparison across plants is near unity.

JEL Codes: Q52, Q53, Q58

Keywords: retrospective cost analysis, municipal waste combustor, air regulation, compliance costs

I. INTRODUCTION

In 2014, the U.S Environmental Protection Agency (EPA) published the results of an ex post evaluation of the costs of five regulations (Simon and Blomquist, 2014; U.S. EPA, 2014). As had been done in previous evaluations of federal regulations, these assessments used a case study approach that examined the relationship between ex ante and ex post costs. What differentiated EPA's case studies from earlier studies is the EPA developed a conceptual framework for their ex post assessments. This common framework provided a systematic way to evaluate the general accuracy of ex ante estimates and identify factors that led to the differences between ex ante and ex post costs. Reasons ex ante and ex post costs may differ include unanticipated changes in costs of energy, markets, and the rate of technological innovation.

In this paper, we use this conceptual framework to compare ex ante costs to the ex post estimates of costs incurred by large municipal waste combustor plants at the time of December 2000 compliance date of EPA's Municipal Waste Combustor (MWC) rule. This exercise is not an evaluation of the accuracy of the EPA's ex ante analysis at the time of the rulemaking. Instead, we gather 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 estimated ex ante costs. This information allows us to observe whether actual costs diverged from ex ante costs and, if so, what factors caused this divergence.

This case study is unique, because unlike many other case studies that evaluate aggregate ex ante and ex post costs, we compare ex ante and ex post costs of individual MWC plants operating in 2000. Several unanticipated changes occurred between 1995, when the rule was promulgated, and the 2000 compliance date that prevented a comparison of the direct aggregate costs of compliance. First, a 1997 court vacatur of the 1995 MWC rule required the promulgation of separate rules for small and large MWC units. Because the separate rules resulted in some plants being classified as small plants, the number of plants covered by the new large MWC rule was a subset of the plants subject to the original 1995 MWC rule. And then, the number of plants affected by the rule was smaller than predicted due to cancelled construction plans and plant closures. It follows that unless ex post costs per plant were substantially higher than ex ante costs per plant, the decline in the number of MWC plants subject to the rule alone would result in aggregate ex post costs being dramatically lower than the aggregate ex ante cost estimates.

This retrospective analysis of the MWC rule adds to the number of ex post cost evaluations conducted by the EPA (Wolverton et al, 2018; Simon and Blomquist, 2014; U.S. EPA, 2014). The 1995 MWC rule was randomly selected from 42 "economically significant" EPA rules promulgated between 1995 and 2005.[1] Municipal waste combustors (U.S. EPA, 1994b) are waste-to-energy plants that generate energy from combusting municipal solid waste. Combusting MSW generates pollutants such as particulate matter and metals that are released into the air. The EPA is required to regulate non-hazardous emissions from MWCs under Sections 111 and 129 of the Clean Air Act (CAA). As a result, the EPA proposed emission standards and guidelines for the following categories of pollutants generated by new and existing MWC units: (1) organics (including dioxins/furans), (2) metals (cadmium, lead, mercury, particulate matter (PM)), and (3) acid gases (sulfur dioxide (SO_2) and hydrogen chloride (HCl)). The final rule, which plants had to comply with no later than December 2000, sought to reduce emissions of these air pollutants by approximately 145,000 tons per year.

The remainder of this paper is organized in the following manner. Section II outlines the impetus and timeline for regulatory action associated with the rule, and Section III discusses EPA ex ante cost estimates. Section IV outlines information available for the ex post analysis, while Section V compares the ex ante and ex post cost estimates for each MWC plant. Finally, Section VI summarizes the paper.

II. IMPETUS AND TIMELINE FOR REGULATORY ACTION

Using section 111 of the 1977 CAA Amendments, on December 20, 1989 the EPA (1989b, 1989e) proposed new source performance standards (NSPS) – subpart Ea - for new MWC plants and emission guidelines (EG) – subpart Ca - for existing MWC plants. These subparts were promulgated in 1991 and applied to large

[1] A regulation is economically significant if it has costs or benefits of $100 million or more in any single year. The costs and benefits must be assessed for rules that are economically significant as required by Executive Order 12866.

MWCs with capacities above 225 megagrams per day (Mg/day) (approximately 250 tons per day). However, the CAA Amendments were enacted in 1990 and added Section 129. Section 129 required the EPA to develop NSPS and emission guidelines for both large and small MWCs and included a schedule for revising the 1991 standards and guidelines. When the EPA (1995) did not comply with the schedule in section 129, the Sierra Club, National Resources Defense Council, and the Integrated Waste Services Association filed a complaint in the U.S. District Court for the Eastern District of New York.

In December 1995, the EPA promulgated its final MWC rule, which was consistent with sections 111 and 129 of the Clean Air Act and extended the standards and guidelines to all units at plants with aggregate capacities exceeding 35 Mg/day (about 40 tons per day). The emission standards and guidelines applied to the following categories of pollutants generated by new and existing MWC units: (1) organics (including dioxins/furans), (2) metals (cadmium, lead, mercury (Hg), particulate matter (PM)), and (3) acid gases (e.g., sulfur dioxide (SO_2), nitrogen oxide (NO_x)) and hydrogen chloride (HCl)). The standards for new sources under this rule were more stringent than the 1991 final rule. The final standards (subpart Eb) applied to new MWC plants whose construction started after September 20, 1994 or existing plants that initiated modifications or reconstruction after June 19, 1996. The 1991 subpart Ea standards remained in effect for new plants constructed or existing plants modified or reconstructed between December 20, 1989 and September 20, 1994.

While subpart Ea remained in effect in the 1995 final rule, the EPA withdrew subpart Ca guidelines and, in its place, promulgated subpart Cb. The guidelines under subpart Cb were more stringent in some cases than the guidelines under subpart Ea. The control technologies needed to meet subpart Ea NSPS emission limits would also achieve compliance with subpart Cb guidelines (U.S. EPA, 1995). However, subpart Cb now required supplemental technology to reduce Hg and fugitive ash emissions. Subpart Cb guidelines were also more stringent than subpart Ca guidelines (U.S. EPA, 1995) because they required MWC plants to install air pollution control equipment based on Maximum Achievable Control Contrology (MACT) rather the Best Demonstrated Technology (BDT) required by subpart Ca guidelines.

However, in December 1996 the United States Court of Appeals for the District of Columbia in *Davis County Solid Waste Management and Energy Recovery Special Service District v. US EPA* vacated the entire December 1995 rule. The court determined the 1990 CAA Amendments required the EPA to establish separate regulations for large and small MWC units (see Commonwealth of Massachusetts, 1998). As a result, the court decided the EPA incorrectly assigned small MWC units located at plants with aggregate capacities exceeding 225 Mg/day to the large plant category. The EPA appealed the decision and requested the large MWC portion of the rule remain in effect. In March 1997, the U.S. Court of Appeals for the District of Columbia Circuit accommodated EPA's request and revised its vacatur to cover only the NSPS and emission guidelines for small MWC units.

In August 1997, the EPA responded to the court ruling by modifying its 1995 MWC rule so only large MWC units were subject to subparts Cb and Eb.[2] Despite the vacatur, the timeframes established for subparts Cb, Ea, and Eb remained unchanged when the MWC rule was promulgated in December 1995 (US. EPA, 1995). Hence, final compliance with subpart Cb was still mandated by December 19, 2000. Because the revised MACT floors changed the regulated entity from plants to units, those units subject to subpart Cb also needed to achieve compliance with supplemental emission limits for lead, sulfur dioxide, and hydrogen chloride no later than August 26, 2002, or three years after EPA approved the state plan, whichever was first (see U.S. EPA, 1997).

III. EPA EX ANTE COST ESTIMATES

Because the standards and guidelines in the 1995 final rule could be met using the control technologies that were the basis for the standards and guidelines in the proposed rule published in 1994, EPA did not revise the economic analysis (EA) conducted in support of the proposed rule (U.S. EPA, 1994a). In the EA, EPA used two baselines to estimate the air emission and cost impacts of the guidelines and standards: (1) a pre-1989 baseline

[2] In December 2000, the EPA (2000a, 2000b) issued its final rule for NSPS and existing small MWC plants with *units* whose capacities ranged between 35 and 250 tpd.

(control level prior to the 1991 subpart Ea standards) and (2) a 1991 baseline (control level under the 1991 subpart Ea standards).

The EPA estimated 72 MWC plants would be subject to the NSPS provisions of the proposed rule in 2000. Of these plants, 48 would be subject to subpart Ea and 24 would be subject to subpart Eb. The total capital cost of complying with subparts Ea and Eb standards relative to the pre-1989 baseline was estimated to be $769 million (in 1990 dollars). This cost consists of the capital cost of complying with the subpart Ea standards (i.e, the 1991 standards), which was estimated to be $613 million (in 1990 dollars), plus the incremental capital cost of complying with the subpart Eb standards (i.e, incremental to the 1991 standards), which was estimated to be $156 million.

The EPA (1995) also projected a universe of 179 MWC plants would be subject to subpart Cb. The capital cost of complying with subpart Cb relative to the pre-1989 baseline was estimated to be $2,100 million (in 1990 dollars). This total capital cost consists of $888 million in capital costs associated with the subpart Ca guidelines, which would be incurred by 158 plants, plus incremental capital costs of $1,212 million incurred by 21 plants from the impacts of the 1995 subpart Cb guidelines (based on a pre-1989 baseline)

Main Components of the Ex Ante Cost Estimates

Although the MACT was based on per unit capacity, the EPA did not develop cost estimates for actual MWC plants or units. Instead, it developed a set of cost estimates based on model plants that reflected the regulated plants. The EPA (1994a) created 16 model plant categories for existing MWC plants and 11 categories for NSPS MWCs to represent regulated MWC plants. Model plants for existing MWC plants were based on representative characteristics of existing plants, while the model plants for NSPS plants were based on characteristics of recently built plants or plants under construction (UC) at the time the rule was written.

The model plants captured design characteristics such as combustion technologies, air pollution control devices (APCD), and capacity. For existing MWCs, EPA assigned a combustion technology, capacity, and baseline

APCD to each model plant category. New MWCs have no baseline APCDs. The standards and guidelines for new and existing MWCs did not mandate specific technologies. However, the EPA (1994a) assumed various technologies would be installed to meet emission limits. EPA predicted most new MWCs would use a spray dryer (SD) and fabric filter (FF) configuration (i.e., SD/FF), while existing MWCs would retrofit either a SD/FF configuration or a SD and electrostatic precipitator (ESP) configuration (i.e., SD/ESP) to reduce dioxin/furans, acid gas, PM, and metals. EPA expected MWCs would use activated carbon injection (CI) for controlling Hg emissions and selective noncatalytic reduction (SNCR) to control NO_x emissions (U.S. EPA 1995). Contingent on the baseline APCD, the EPA assigned the model plant one or more of these potential control technologies to meet the new standards then estimated incremental capital and annual operating costs of this APCD configuration compared to the baseline APCD.

Main Sources of Uncertainty in Ex Ante Cost Estimates

For the final rule the EPA did not estimate the number of MWC construction plans that might be cancelled or the number of existing plants that might shutdown due to the regulation. At the time the rule was promulgated, EPA (1995) acknowledged new data suggested fewer new MWCs were being constructed, which would reduce the aggregate costs of meeting the standards. EPA also recognized that if the regulation raised tipping fees for MWCs then some MWCs might switch to less costly options for disposing municipal waste. In either case, aggregate costs and emissions would be lower. The EPA recognized its estimates potentially over-estimated the effect of the rule and the impacts of the final rule were characterized as the worst-case scenario from implementation of the new standards.

IV. INFORMATION AVAILABLE TO CONDUCT EX POST EVALUATION

During the implementation of the large MWC rule, the evolution of the MWC industry was well-documented, providing detailed information on plant closures and how the EPA reclassified plants between the large and small size categories. We used a combination of EPA inventories of MWCs and non-EPA sources to identify the names and plant characteristics of the large MWC's subject to the 1995 final rule. These plants make up the database used in our analysis. The various sources and the data collected from these sources are described in this section.

To begin, we used the 1991 EPA inventory of all existing MWC plants that would be subject to the proposed guidelines (see Fenn and Nebel, 1992) to identify the baseline universe of MWCs. Using a combination of EPA inventories and non-EPA sources, we identified plants that were operating and those that shut down during the 1990-1995 period leading up to the promulgation of the 1995 MWC rule. To identify the large MWC plants from that universe we used two EPA inventories: (1) the revised 1995 inventory of large MWC units (see Cone and Kane, 1997), which incorporated changes resulting from the 1997 court vacatur, identified the universe of large MWCs at the time the 1995 rule was promulgated, and (2) the 2000 inventory of large MWC units (see Huckaby, 2002a), which reported the universe of large MWCs when the revised large MWC rule came into effect.[3]

Because some MWC units were reclassified between the large and small categories, inventories of small MWC plants were used to clarify those changes. The inventories of small MWC plants used include: (1) the 1995 inventory (see Tucker, 1999 and 2000), (2) the 1998 inventory (see Tucker, 1998), (3) the 2001 inventory (see Huckaby, 2001), and (4) the 2005 inventory (see Huckaby, 2006). Finally, the 2010 inventory of large and small MWCs (see Rudzinski, 2012) was used to identify plants closures and plant reclassifications from large to small during the decade after the rule came into effect.

We used several non-EPA sources to supplement the EPA inventories to identify plant characteristics such as plant capacity and installed APCDs, but most importantly, these sources were used to obtain information on the start-up year and operating status. The first source is Governmental Advisory Associates, Inc. (GAA), which publishes directories of municipal waste facilities (see Berenyi and Gould 1988, 1991, 1993, and Berenyi

[3] These inventories provide information on unit capacity, unit type, and installed APCDs.

1997, 2006), that provide information on plant shutdowns and APCDs installed at each MWC.[4] GAA also prepared a U.S. DOE (2001) report, which listed 176 large and small MWC plants that operated at least one year between 1980 and 1998. The information in this report included the MWC's name and location (by state), capacity, technology, the year it opened, and the year it closed (if applicable).[5] Another set of directories (Kiser, 1990, 1991, 1992) provided information on the (1) operating status, (2) capacity, and (3) installed APCDs of each plant. We also used an inventory of plants compiled by Denison and Ruston (1990) that classified them based on their status: (1) operating, (2) under construction, (3) planned, (4) blocked/cancelled/delayed, or (5) shut down. Finally, the Energy Recovery Council (ERC), which was formerly known as the Integrated Waste Services Association (IWSA), published directories of waste-to-energy plants which included information on the combustor type, installed APCDs, and the year the plant started (ERC, various years; IWSA, 2007).

Several sources are used to identify MWC plants and units that were subject to subpart Ea or subpart Eb. To identify the number of plants subject to subpart Ea, we use EPA's Office of Compliance and Enforcement (OECA) Supporting Statements for information collection requests (ICRs), which collected data on units/plants subject to the NSPS provisions of the MWC rule. In 1996, the OECA (U.S. EPA, 1996a) estimated 34 plants would respond to its ICR. After discussions with the IWSA, the Supporting Statement for the 2001 ICR estimated seven plants were subject to subpart Ea (U.S. EPA, 2001a, 2001b). Subsequent Supporting Statements for the 2007 and 2011 ICRs also estimated seven respondents were subject to subpart Ea (U.S. EPA, 2007 and 2011). These ICR estimates match the estimate provided in a July 2000 EPA memo to the Commission for Environmental Cooperation (see Department of the Planet Earth et al., 2001) that reported 16 MWC units at 7 plants were subject to subpart Ea. Finally, the Supporting Statement for the 2001 ICR estimated no plants were subject to subpart Eb.

[4] These inventories also provide information on the cancellations of planned MWCs. See Table A.4 in the Appendix for data collected from GAA reports on MWCs. The Appendix is available from the authors upon request.

[5] Prior to its 2001 inventory, in 1988 the U.S. DOE (1988) published an inventory of MWC plants.

An important contribution of this study is identifying two independent surveys – one public and one private – that collected air pollution abatement costs from MWCs. The public source of ex post cost estimates for APCDs is the EIA-767 "Steam-Electric Plant Operation and Design Report" survey (see U.S. Department of Energy, various years), and its successor EIA-860 "Annual Electric Generator Report." These annual surveys request information on (1) the installed costs and operating costs for flue-gas desulfurization (FGD) units which remove SO_2 emissions using spray dry scrubbing coupled with baghouses (fabric filters) and (2) the installed costs of flue-gas particulate (FGP) collectors which remove particulate matter from the flue gas. Each survey also asked respondents to report the year the FGD and FGP systems were installed. While the EIA-767 survey also collected information on whether NO_x or mercury abatement technologies are installed, it did not collect information on their cost. However, the EIA-860 survey includes questions on capital costs of nitrogen oxide and mercury control equipment.

We augment the EIA data with a private source of ex post APCD data. The data from GAA (Berenyi, 2006) includes the type of APCD(s) installed, the year of their installation, and costs of the device. Many MWC plants provided data on the cost of pollution abatement control equipment under the heading of "Additional Capital Cost" in the GAA, including the amount spent, the year the cost was incurred, and an explanation of the purpose of the capital expenditure. Using this information, we can identify capital cost expenditures of FGD and FGP units for some MWCs in addition to the cost of NO_x or Hg control.[6]

V. EX POST ASSESSMENT OF COMPLIANCE COST

Regulated Universe

By mid-1989, there were approximately 161 MWC plants in operation, with construction projected to start on another 120 MWCs prior to 1990. EPA (1989a) estimated all 161 existing MWC plants plus 39 of the projected plants would be subject to its proposed regulations. By the time the 1991 rule was promulgated, the

[6] The authors used their best judgement on whether to include some observations based on the description provided by GAA on the APCD installed and the capital expenditure of those devices.

EPA (1994b) anticipated 158 (large and small) MWC plants would be covered by subpart Ca. Of the 179 plants (372 units) that existed when the rule was proposed in 1994 (U.S. EPA, 1994b),[7] 60 plants (137 units) with aggregate capacities exceeding 35 Mg/day but not greater than 225 Mg/day were classified as small plants, while 119 plants (235 units) with aggregate capacities exceeding 225 Mg per day were classified as large plants. When subpart Cb was promulgated in late 1995, the EPA (1995) anticipated the 179 MWC plants would be subject to the rule.

However, only 128 MWC plants with 307 units were operating when the rule was promulgated in 1995 (Cone and Kane, 1997). Of the 128 plants, 81 plants (209 units) were classified as large while 47 plants (98 units) were classified as small. The 1997 court vacatur resulted in the reclassification of 18 plants (45 units) from the large to small plant category. As a result, the revised 1995 inventory lists 63 large plants (164 units) and 65 small plants (143 units) (see Cone and Kane, 1997). At the time of compliance with the rule, the 2000 inventory of large MWCs (see Huckaby 2002a) lists 66 MWC plants (167 units) subject to subpart Cb. Four factors account for the increase from 63 to 66 large MWC plants between 1995 and 2000: (1) four large MWC plants initiated operations, (2) seven large MWC plants closed, (3) three plants were reclassified from the large MWC category to the small MWC category, and (4) nine plants were reclassified from the small to large MWC category.[8,9] The name and location (by state) of the 66 large MWC plants operating in 2000 are listed in Table 1.

While most of the plants listed in Table 1 are existing MWC plants, some new plants were constructed between 1995 and 2000 and subject to NSPS. When the rule was promulgated in 1995, EPA expected 48 newly constructed plants would be subject to subpart Ea, while 24 plants would be subject to subpart Eb (U.S. EPA, 1995). However, we count only seven plants were subject to subpart Ea and one plant was subject to Eb. These

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[7] We were unable to identify the cause of the discrepancy between the 372 units at 179 plants reported by the U.S. EPA (1994b) and the 436 units reported by the U.S. EPA (1994a).

[8] See Table A.9 in Appendix for a description of plants whose change in status account for the differences between the 1995 (revised) and 2000 EPA inventories of large MWCs.

[9] The nine MWC plants were initially classified as large MWCs, then reclassified as small MWCs in the revised 1995 Inventory (see Cone and Kane, 1997) due to the 1997 court vacatur, and then transferred back to the large MWC category in the 2000 large MWC inventory.

plants are identified by comparing the plants included in the 2000 EPA MWC inventory to the 1991 EPA MWC inventory.

The seven plants subject to subpart Ea are identified in Table 1 by NSPS in parentheses next to the facility name. The decision on whether to classify a plant as subject to subpart Ea or Eb was based on the best available evidence. For example, one of the plants, Union County RRF (NJ), was included – with an SD/FF APCD configuration - in the 1991 EPA inventory of existing MWC plants. However, we include it on our list of plants subject to subpart Ea because both the 1995 and 2000 EPA inventories state that construction on the Union County RRF started in 1992.[10] Another plant, Hudson Falls (NY), is not listed in the 1991 EPA MWC inventory. The 1995 EPA inventory does not provide a date when construction started at Hudson Falls, but lists its startup date as 1992. Other sources (Kiser, 1990; Berenyi and Gould, 1988 and 1991) list its startup date as either 1990 or 1991. Therefore, we decided to classify the Hudson Fall plant as an existing MWC not subject to subpart Ea. Finally, the SEMASS Resource Recovery Facility (MA) added a third boiler in 1993 that is subject to subpart Ea. Using the subpart Eb criteria, only one new unit - unit 3 of the Central Wayne (MI) plant - appears to be subject to subpart Eb in 2000.[11]

Baseline Information

The Economic Analysis conducted in support of the rule developed the model plants using the May 1991 EPA inventory of MWC plants (Fenn and Nebel, 1992). Because we assume APCDs installed on or after December 20, 1989 are undertaken to meet emission limits for the MWC rule, APCDs installed on MWCs operating as of December 20, 1989 constitute baseline APCDs for our analysis. Approximately 30% of existing MWC plants were under construction prior to December 20, 1989 and did not start operating until the early

[10] Additional sources (Berenyi and Gould, 1993; Kiser,1992) corroborated the plant was under construction after 1991. Since construction on Union County RFF appeared to start after 1991, we assume there was an error in the 1991 inventory and include it as a new source and subject to subpart Ea.

[11] In 1996, the U.S. EPA (1996b) determined that if the units of the Central Wayne (MI) plant underwent a waste-to-energy conversion, they would be subject to subpart Eb.

1990's. These plants would have received permits from the state authorizing construction and operation of the municipal waste combustor. The permits specified the pollution control equipment needed to meet emission limits. At the time of construction, these plants would have needed to install ESP and DSI to comply with the existing standards under the Clean Air Act for PM and SO2. For our analysis, these plants are assigned ESP as their baseline APCD configuration.[12]

Unlike the APCDs for new MWCs, which are set by NSPS, baseline APCDs for existing MWCs can vary. For example, the incremental costs of APCDs for existing plants depend on whether they have minimal APCDs (i.e., ESP) in the baseline or more advanced APCDs to reduce gas emissions (i.e., SDs). The baseline APCDs for each plant are reported in Table 1. According to Table 1, 15 plants installed SD/FF as their baseline APCDs to reduce sulfur dioxide and particulate matter emissions.

Information on baseline APCDs to control NO_x releases are from Berenyi and Gould (1988), Berenyi (2006), and the U.S. EPA (1989d). Only a few plants had SNCR, the technology used to reduce NOx emissions, installed as a baseline APCD. Commerce (CA), SERRF (CA), and Stanislaus (CA) installed SNCR prior to 1990. In addition, New Hanover (NC) and Huntington (NY) installed SNCRs in 1991 (Berenyi, 2006). Except for New Hanover, these early installations of de-NOx systems are corroborated by the EIA-860, which also reports the early adoption of SNCR and Cl systems by Babylon (NY). Although the 1991 inventory does not list APCD devices to control Hg or NO_x emissions, we view them as being part of the baseline. Therefore, in this paper the costs of these devices are not counted as costs due to the EPA rules.

Methods of Compliance

The standards and guidelines for new and existing MWCs do not mandate specific technologies; however, the EPA (1994a) assumed various technologies would be installed at MWC units to meet emission limits.   EPA expected most new MWCs would use a spray dryer (SD) and fabric filter (FF) configuration (i.e.,

[12] The sources for the baseline APCDs of MWCs that were operating as of December 20, 1989 are discussed in the endnotes of Table 1.

SD/FF) with activated carbon injection, while existing MWC's would retrofit either an SD/FF configuration or a SD and electrostatic precipitator (ESP) configuration (i.e., SD/ESP) with activated carbon injection to reduce dioxin/furans, acid gas, particulate matter, and metals. In addition, EPA assumed carbon injection (CI) would be needed to attain Hg emission limits and selective noncatalytic reduction (SNCR) would be used to control NO_x emissions (U.S. EPA 1995).

Assigning MWCs to model plant categories

For the ex post assessment, we use characteristics of the 66 large MWCs in the 2000 inventory (see Table 1) to assign each large MWC plant to a model plant category based on four factors: (1) existing or NSPS plant, (2) combustion technology, (3) capacity, and (4) baseline APCD. Capital and operating costs vary across the 16 EG model plant categories and 11 NSPS model plants based on design characteristics, baseline control and additional control technology. The characteristics and ex ante costs for each model plant category are summarized in Tables 2 through 7. The combustion capacities for each size category are summarized in Table 2 and Table 3, respectively. Next, the ex ante cost estimates associated with reducing acid gas, particulate matter, and metal emissions by existing MWCs and MWCs subject to NSPS are summarized in Table 4 and Table 5, respectively. Finally, Table 6 provides ex ante cost estimates for Hg control and NO_x control for existing plants, while Table 7 provides ex ante cost estimates for Hg control and NO_x control for new plants.

In the Economic Analysis (1994a), the EPA assigned MWCs to a model plant category using capacity ranges for the combustion technology. For example, an existing MWCs using MB/WW to combust waste with a combustion capacity greater than 1000 Mg/day would have been classified as a large MB/WW and assigned to model plant 4 while a plant with combustion capacity between 225 Mg/day and 1000 Mg/day would have classified as a mid-size MB/WW and assigned to model plant 5. Instead of assigning MWCs to size categories based on the capacity ranges established in the Economic Analysis, we assign them to the model plant category whose model plant capacity point estimate most closely corresponds to their actual combustion capacity (see

Tables 2 and 3).[13, 14] Using capacity point estimates as opposed to ranges to assign MWCs to a capacity size will results in some plants being assigned a different combustion size and respective model plant category, resulting in lower ex ante cost estimates. For example, a MWC plant with a combustion capacity of 1100 Mg/day would have been assigned to model plant 4 assuming a MB/WW (large) combustion technology using EPA's range. However, using actual capacity, we would assume the plant has MB/WW (mid-size) technology and assigned it to model plant 5.[15]

Using the assigned model plant category based on the combustion technology and combustion capacity, and the APCD configuration in 2000, each of the existing MWCs are assigned an ex ante cost. From EIA and GAA, we have information on the type of APCD installed and the year it was installed. Using this information, we assume capital expenditures on APCDs installed between the baseline year and 2000 (note: we include some observations from 2001 and 2002, plus one from 2004) are the ex post costs of complying with the MWC rule. Consequently, for existing MWCs, we compare the ex ante capital costs associated with their assigned model plant category to the ex post capital costs of their APCD configuration in 2000.[16] Because there are no baseline APCDs installed at NSPS MWCs, their ex ante costs are determined by the model plant category to which they are assigned.

While scrubbers, precipitators and fabric filters remove some NOx and Hg, the reductions are insufficient to meet the emission limits set by the rule. The technologies to control Hg and NOx emissions at existing MWC plants are add-on technologies used by MWCs to reduce emissions of those pollutants. Hence,

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[13] For existing plants in Table 2, the MB/WW (large) model plant corresponds to the "very large" model plant size category while the MB/WW (mid-size) model plant corresponds to the "large" model plant size category (U.S. EPA, 1990). In addition, the RDF (large) model plant corresponds to the "very large" model plant size category, while the RDF (small) model plant corresponds to the "large" model plant size category.

[14] For NSPS plants, the MB/WW (large) model plant and the MB/WW (mid-size) model plant (see Table 3) both correspond to the "large" model plant U.S. EPA (1990) size category. However, because Table 5 shows differences in ex ante costs for the two size categories, we separate NSPS MWCs using the same size capacity categories as existing MWCs described in footnote 13.

[15] Table A.7 and Table A.8 in the Appendix summarize the distribution of MWCs across model plant size categories for the capacity ranges and capacity point estimates strategies.

[16] We have limited information on operating costs associated the APCDs. Consequently, we only compare ex ante and ex post capital costs.

the ex ante costs at new and existing MWC plants that install SNCR and CI are based on the model plant category to which the MWC is assigned. The model plant categories for each of the 66 large MWC's are found in Table 8.

Compliance Costs

SO_2 and PM Capital Expenditures (EIA)

For the purposes of this analysis, the costs of implementing good combustion practices (GCP) are assumed to be imbedded in the ex post capital cost data collected by the EIA and GAA. As shown in Table 1, of the 59 existing MWC plants, 15 plants using SD/FF as their baseline APCDs did not change their APCD configuration between 1991 and 2000.[17] While the 1991 inventory lists a SD/FF configuration for Union County (NJ), because Union County is classified as new MWC, it is not included among the 15 plants. Another four plants, which excludes SEMASS (units 1-2) due to its APCD configuration changing from SD/ESP to SD/ESP/FF, installed SD/ESP as their baseline APCDs and maintained that configuration through December 2000. Therefore, these 19 plants incur no incremental costs for reducing SO_2 and particulate emissions due to the large MWC rule.

As shown in Table 8, of the remaining 48 MWC plants, 11 plants failed to submit FGD and/or FGP capital cost data on their EIA survey form, 30 plants submitted both FGD and FGP data, two plants submitted only FGP data, and five plants submitted only FGD data. Because the plants that submitted only FGD or FGP data had already installed the other device, those seven plants are included in our analysis. As a result, we have sufficient data to compare the model plant ex ante capital costs to the capital costs reported on the EIA surveys for the technology used to reduce SO_2 and particulate emissions for 37 existing and NSPS MWC plants.[18]

[17] For the purposes of the ex post analysis, SEMASS (MA) is treated as two MWCs. For SEMASS, units 1-2 are treated as an existing MWC, while unit 3 is treated as an NSPS MWC. Hence, ex ante cost estimates are presented for 59 existing MWCs and 8 NSPS MWCs.

[18] As shown in Table 8, the following plants report identical or almost identical capital expenditures for FGD and FGP on their EIA-860 survey: Hillsborough (FL), Union County (NJ), Wheelabrator Westchester (NY), and Alexandria/Arlington (VA).

The comparisons of ex ante and ex posts capital costs for FGD and FGP systems are summarized in Table 9. Of the 37 MWCs reporting capital expenditures for FGD and/or FGP abatement systems, 17 have ex post to ex ante ratios greater than unity (i.e., the ex post value for MWC exceeds its ex ante cost estimate). The MWCs with the highest ratios of ex post to ex ante costs are Delaware Valley (PA) with a ratio of 3.43 and Lake County (FL) with a ratio of 3.00. For the 20 MWCs that have ex post to ex ante ratios less than one, Greater Detroit (MI) and French Island (WI) have the lowest ratios of 0.01 and 0.08, respectively.

Mercury and NOx Capital Expenditures (GAA and EIA)

The two sources for the year of installation and costs of NO_x or Hg control systems are the EIA and GAA (Berenyi, 2006). For some plants, capital expenditure cost data are reported by both sources. The ex post capital cost for the Hg and NOx control systems and the ex ante predicted costs are presented in Table 10.[19] From GAA (Berenyi, 2006), we have ex post capital costs of SNCR systems for 11 MWC plants and ex post capital costs of CI systems for 19 MWC plants, where six of these plants reported ex post costs for both SNCR and Cl systems.[20] Lastly, eight MWC plants that installed both SNCR and CI systems reported combined ex post capital costs. In addition, EIA reports ex post capital costs of SNCR for 34 plants and CI systems for 33 plants, of which 28 plants reported costs for both SNCR and CI systems.

While the magnitude of the difference between the ex ante and ex post costs reported by GAA and EIA differ, the direction of the difference is usually the same. Of the 9 plants reporting separate cost estimates for SNCR and 16 plants reporting costs for Cl systems on both the GAA and EIA surveys, there are only three MWCs where the direction of the difference between ex post and ex ante costs diverge between the two sources are

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It is possible these expenditures are misreported, and we are unable to validate them. Nevertheless, we accept these values as reported for our analysis.

[19] As shown in Table 10, Haverhill (MA) reports the same capital expenditures for CI and SNCR as reported in Table 8 for FGP. In addition, Onondaga county (NY), Alexandria/Arlington (VA), and I-95 (VA) report identical capital expenditures for Cl and SNCR in Table 10. It is possible these expenditures are misreported, and we are unable to validate them. Nevertheless, we accept these values as reported for our analysis.

[20] SEMASS is excluded because the ex ante cost estimates for model plant number 7 were nil (see Table 4 and Table 10).

Bristol (CT), Lake County (FL), and Essex County (NJ). For Bristol, the ex post cost for NO_x reported by GAA (Berenyi, 2006) is lower than the ex ante cost, whereas the EIA ex post cost is higher than the ex ante costs. On the other hand, Lake County exhibits the opposite relationships for its ex post cost estimate of SNCR. The ex post cost for Hg reported by GAA (Berenyi, 2006) is lower than the ex ante cost, whereas the EIA ex post cost is higher than the ex ante cost for Essex County. Finally, it should be noted that while both the EIA and GAA ex post cost for Hg for the Alexandria/Arlington (VA) plant exceed its ante cost estimate, the EIA value exceeds the GAA value by a factor of ten.

The comparison of ex ante and ex post capital costs for systems installed to reduce Hg and NOx emissions using the data from GAA (Berenyi, 2006) is shown in Table 11. Of the 19 MWCs that report capital expenditures for Hg abatement, 18 have ex post to ex ante ratios greater than unity (i.e., the ex post value exceeds its ex ante cost estimate). The MWCs with the highest ratios of ex post to ex ante costs are Lake County (FL) with a ratio of 19.55 and Gloucester (NJ) with a ratio of 7.81. Only Essex (NJ), with an ex post to ex ante ratio of 0.60, has an ex post value that is less than its ex ante cost estimate, while Bridgeport (CT) has the second lowest ratio of 1.02.

Ten of the 11 MWCs that report capital expenditures for NO_x abatement, have ex post to ex ante ratios less than unity (i.e., the ex post value is less than its ex ante cost estimate). Of these 11 MWCs, Hempstead (NY), with a ratio 0f 0.17, has the lowest ratio of ex post costs to its ex ante cost estimate. The MWCs with the next two lowest ratios are Essex (NJ) with a value of 0.26 and North Broward (FL) and South Broward (FL) with values of 0.34, respectively. Only Lake County (FL), with an ex post to ex ante ratio of 1.34, has an ex post value greater than its ex ante estimate, while the second highest ratio of 0.87 belongs to the Greater Portland (ME) MWC.

Of the 8 MWCs that report a combined capital expenditure value for Hg and NOx abatement, Marion County (OR), with a ratio of 1.28, has the highest ex post to ex ante cost ratio. Kent County (MI) reports the second highest ratio of 1.02. I-95 (VA), with a ratio of 0.40, has the lowest ratio of ex post costs to its ex ante cost estimate. The MWCs with the next lowest ratios were Babylon (NY) with a value of 0.51 and Indianapolis (IN) with a value of 0.57, respectively.

Of the 14 MWCs that report either a combined capital expenditure value for Hg and NOx abatement or separate capital expenditure values for both Hg and NOx abatement, four have ratios of ex post costs to ex ante costs greater than unity. Lake County (FL) wand Marion County (OR) have the highest values, with values of 2.26 and 1.28, respectively. Of the 10 MWCs reporting ratios less than unity, Essex County (NJ), with a ratio of 0.28, has the lowest ratio of ex post costs to its ex ante cost estimate. The next lowest ratios are Bridgeport (CT), with a value of 0.39 and I-95 (VA), with a value of 0.40.

The comparison of ex ante and ex posts capital cost for systems to reduce Hg and NOx emissions using data from the EIA are shown in Table 12. Of the 33 MWCs reporting capital expenditures for Hg abatement, all 33 have ex post to ex ante ratios greater than unity. The MWCs with the highest ratios of ex post to ex ante costs are Haverhill (MA) with a ratio of 34.38 and Union County (NJ) with a ratio of 27.97, while Hennepin (MN) has the lowest ratio of 1.57. Of the 34 MWCs reporting capital expenditures for NO_x abatement, 29 have ex post to ex ante ratios less than unity. Of these 29 MWCs, French Island (WI) with a ratio 0f 0.01 has the lowest ratio of ex post costs to its ex ante cost estimate. The MWCs with the next two lowest ratios are Southeastern Connecticut (CT) with a value of 0.10 and Niagara Falls (NY) with a value of 0.25, respectively. Five MWCs have ex post to ex ante ratios greater than unity. The ratio for those five plants ranges from a low of 1.67 for Alexandria/Arlington (VA) to the highest ratio of 2.19 for Pinellas County (FL).

As shown in Tables 11 and 12, the ex post capital costs are almost always greater than the ex ante capital costs for Hg controls, whereas the ex post capital costs are almost always less than the ex ante capital costs for NOx controls. At the time the rule was promulgated, EPA assumed plants would inject activated carbon into the flue gas of their APCD to reduce mercury emissions. The carbon would capture the mercury, which would be collected on a fabric filter and disposed. Because a plant would use existing capital equipment to capture mercury, it was believed the associated capital cost would be low. One plant in British Columbia reported their preliminary capital cost estimates of installing a carbon absorption system was $200,000 (1990 dollars) (Nebel and White, 1991).

However, the use of activated carbon to remove mercury was new to the U.S., and the estimated costs of using carbon absorption varied per ton of municipal waste combusted and the amount of mercury being incinerated in the waste. And at the time, it was unclear if other factors would influence the overall costs. As Shaub (1993) shows, the amounts of mercury in incinerated waste varied according to the consumer products being disposed. Shaub (1993) states the costs of using carbon absorption appear to range from $0.50 - $1.00 per ton of MSW combusted so that if the mercury contamination combusted is in the range of 0.5 – 5.0 g/ton, then the costs to control mercury emissions could range between $100,000 and $2,000,000 per ton of mercury removed. However, Shaub (1993) indicates the cost of removing mercury using carbon injection was still unknown and needed additional investigation. While Shaub provides a range of costs, we are unable to compare our ex post data to his estimates because we do not have plant-level information on the tons of mercury emitted. Furthermore, it is not clear if the estimates include both the operating and capital costs of carbon absorption.

Selective non-catalytic reduction (SNCR) is an add-on post-combustion APCD (fabric filters and spray dryers remove some NOx) that reduces NOx to N_2 without the use of a catalyst. It requires the injection of a reducing agent such as ammonia or urea into the furnace that reacts with the NOx to form N_2. While the capital costs associated with using ammonia tend to be lower, urea has advantages over ammonia. For example, urea is less toxic and less volatile, which means it can be handled and stored more safely. The capital cost to install or retrofit a combustor with the SNCR technology typically increases as the size of the plant increases (as measured by combustion capacity) and varies based on the level of difficulty associated with retrofitting the current APCD system. The cost of this technology is also affected by the cost of the catalyst replacement and disposal. Like mercury control technology, there were still many uncertainties associated with cost of installing a SNCR system at the time of the MWC rule.

In late 1980's, three MM/WW California plants installed SNCR technology using ammonia as the reducing agent (U.S. EPA, 1989d). Information from these California plants were used to develop algorithms to estimate costs of SNCR devices for the model plants used by EPA in its *Economic Analysis*. The costs varied across combustion technology and plant capacity (tpd). By the mid-1990's several additional MWCs installed SNCR and a few used urea as opposed to ammonia as the reagent (White et al., 1994). For those using ammonia, many used aqueous ammonia as opposed to anhydrous ammonia. Aqueous ammonia is less volatile but requires a larger storage tank which leads to slightly higher capital costs. However, we could not find any estimates on the difference in capital costs between the two reagents. Using the information from the MWCs that had installed SNCR systems, White et al. (1994) developed cost estimates for three model combustors (100 tpd, 400 tpd, and 750 tpd) using mass burn/waterwall (MB/WW) combustion and injection as aqueous ammonia. Comparing the capital cost per ton for these three model combustors to the capital costs of the same modeled combustors from the report released in the late 1980's (EPA, 1989d), it appears the model plant costs have decreased. However, it should be noted that at the time of the 1994 study, new technologies, such as furnace temperature monitoring and ammonia monitoring, were being tested as ways to improve the performance of SNCR and lower the costs of the technology.

Given the technologies EPA expected MWCs to use to control NOx and Hg emissions were just beginning to be installed in the U.S., the assumptions used to develop the cost estimates for each model plant may not have reflected actual costs as the technologies were adopted. The ex post cost data from GAA and EIA show the costs associated with SNCR were lower than EPA estimated, while the costs associated with carbon injection were higher than EPA estimated. Unfortunately, the data needed to evaluate the individual components of the model plant cost equations are not available (US EPA, 1989c), therefore, we are unable to quantitatively assess which component or components of capital costs were higher or lower than EPA predicted.

Total Abatement Capital Expenditures (GAA)

Instead of reporting capital expenditures for the individual abatement components, GAA (Berenyi, 2006) reports total capital expenditures for FGD and FGP for 10 MWC plants as well as combined expenditures for FGD, FGP, SNCR and CI systems for another 10 MWCs. The ex post capital cost for the sum of FGD and FGP as well as the ex post capital cost for the sum of FGD, FGP, SNCR and CI control systems, and the ex ante predicted cost for these MWCs are presented in Table 13 with summary statistics reported in Table 14. Of the 10 MWC plants that reported cost estimates for FGD and FGP systems, nine have ex post to ex ante ratios greater than unity. For the 10 MWC plants that reported costs for their FGD, FGP, SNCR and CI systems, five have ex post to ex ante ratios greater than one.

Of the 10 plants that reported capital expenditures for both FGD and FGP systems, seven reported capital cost data on the EIA survey (shown in Table 8) as well. The sum of capital expenditures for FGD and FGP reported by GAA for three plants - Hillsborough County (FL), Saugus (MA), and Wilmarth Plant (MN) – are lower than the sum reported on the EIA survey, while expenditures reported by the other four plants – McKay Bay (FL), Greater Detroit Resource Recovery Facility (MI), Alexandria/Arlington Resource Recovery (VA), and Southeastern Public Service Authority of Virginia (VA) – are higher than the sum reported on the EIA survey. However, for three MWCs - McKay Bay (FL), Great Detroit Resource Recovery Facility (MI), and Southeastern Public Service Authority of Virginia (VA) – the ex post to ex ante ratios are less than one using capital expenditure data reported to EIA, while the ratio is greater than one using data from GAA. While the total capital expenditure data differ across the two sources, the ex post to ex ante ratios are greater than one using data reported by both EIA and GAA for the other four plants. For SEMASS (units 1-2), which only installed a FGP system because it had already had an FGD system, the ex post to ex ante ratio is greater than one using either the EIA or GAA capital expenditure data.

Of the 10 plants in Table 13 that reported costs for their FGD, FGP, SNCR and CI systems, six also reported ex post capital costs for these technologies on the EIA survey. Summing the EIA ex post capital costs in

Tables 8 and 10, the totals reported on the EIA survey are higher than the totals reported by GAA (Berenyi, 2006) in Table 13 for Haverhill (MA), North Andover (MA), Concord (NH), and Westchester Company (NY). The sum reported on the EIA survey for Pinellas County (FL) and Baltimore Refuse (MD) is less than the sum reported by GAA (Berenyi, 2006) in Table 13.

Aggregate Compliance Costs

Publicly traded companies are required to submit reports on their financial status to the Securities and Exchange Commission (SEC). Of the 66 MWC plants (treating SEMASS as a single MWC) with units subject to the large MWC rule, Covanta Energy operated 32 plants and Wheelabrator operated 16 plants. The SEC 10-K form submitted by Wheelabrator (U.S. Securities and Exchange Commission, 1996) commented on the cost of the MWC rule saying that even though expenditures for modifications to comply are estimated to be in the $190-$230 million range, they did not expect these costs to have an adverse effect on the Company's liquidity. In Wheelabrator's 1997 SEC 10-K (U.S. Securities and Exchange Commission, 1997), they changed their estimated cost of the MWC rule to the $180-$200 million range.

Covanta's 1997 SEC 10-K form (U.S. Securities and Exchange Commission, 1997) estimated that the costs to meet the MWC rule would be approximately $40 million between 1998 and 2000, with only moderate additional costs between 2000 and 2002. In subsequent years, Covanta (U.S. Securities and Exchange Commission, 1998) estimated its costs in 1999-2000 would be $54 million, while a year later it (U.S. Securities and Exchange Commission, 1999) estimated its costs in 2000 would be $30 million. The Energy Recovery Council, which is the industry group representing companies and local governments that operate MWC plants, estimated aggregate *ex post* pollution abatement costs borne by existing plants to meet the provisions of the small and large MWC rules.[21] They concluded "America's waste-to-energy facilities spent $1 billion to retrofit pollution control equipment to achieve the strictest federal standards."

[21] http://energyrecoverycouncil.org/industry-faqs/

However, numerous planned MWCs were never constructed and many existing plants shutdown between 1995 and 2000. These plant closings and cancellations of construction resulted in lower aggregate compliance costs. The extent of plant cancellations between 1995 and 2000 is seen in nine MWCs listed as "Inactive" in the revised 1995 MWC inventory (see Cone and Kane, 1997) that closed by 1995 (see Table A.13 in Appendix). Of the 6 MWC plants (comprising 6 large units) classified as "on hold," none attained active status. In addition, of the 20 MWC plants (comprising 24 large units) classified as "planned," only the Robbins (IL) plant (1 unit), which operated from 1997-1998, attained active status. We identified one instance of a statement declaring that the MWC rule played a role in the closure of a MWC plant. According to the Energy Justice Network, the Akron MWC closed in 1995 to avoid the $30 million price tag for installing equipment to meet federal rules.[22]

VI. OVERALL IMPLICATIONS AND STUDY LIMITATIONS

In this paper, we compare the ex ante estimates of the costs to comply with EPA's Municipal Waste Combustor rule to the ex post costs of individual large MWC plants operating in 2000. Three factors hampered comparing aggregate ex ante and ex post costs of the large MWC rule. First, a 1997 court vacatur of the 1995 MWC rule required separate rules for small and large MWC units. As a result, the plants covered by the large MWC rule was a subset of the plants subject to the 1995 MWC rule. Second, numerous facilities existing at the time the rule was developed closed prior to the December 2000 compliance date for the large MWC rule. And finally, in the late 1980s numerous MWC facilities were planned by communities; however, most of those plants were never constructed. Unfortunately, we cannot determine the role the large MWC rule played in either the closure of existing MWCs or the failure to construct new MWC facilities. Because we cannot determine how the cost of APCDs installed at those plants would compare to the costs incurred by plants operating in December

[22] http://www.energyjustice.net/map/displayfacility-68095.htm

2000, we restrict our analysis to individual plants for which we can obtain ex post data on the cost of complying with the MWC rule.

However, the EPA did not develop cost estimates for actual MWC plants. Instead, it relied on cost estimates for a set of model plants. Using characteristics of the 66 large MWCs operating in 2000, we assign each plant to a model plant category developed by the EPA to estimate the ex ante costs of complying with the rule. Our ex post cost data come from plant-level data from the U.S. Department of Energy EIA-767 and EIA-860 annual survey of pollution abatement expenditures by steam-electric power plants, and plant-level data on capital expenditures from GAA (Berenyi, 2006). We then compare ex post capital costs from GAA and EIA surveys to the predicted capital costs of the model plant category.

For those MWCs for which we have ex post APCD capital expenditure data, the results are mixed. We found 19 of the 59 existing MWCs operating in 2000 undertook no changes in their FGD/FGP configurations between the baseline and 2000, and thus incurred no costs related to the rule for reducing SO_2 and PM emissions. For the 37 new and existing MWCs for which we have sufficient data from the EIA-860 survey to undertake an ex ante – ex post analysis of the cost of their FGD and FGP systems, the ex posts capital costs are higher than the ex ante costs for 17 plants and lower for 20 plants. While the results are mixed for MWCs that installed FGD and FGP systems, the mean and median of the ratios of ex post to ex ante costs is near unity – 1.18 and 0.90, respectively. For the sample of plants that reported capital costs for FGD and FGP on the GAA survey, nine of the 10 plants reported higher ex post costs.

For the 33 plants that installed systems for Hg abatement and 34 plants that installed NO_x abatement equipment and reported the associated costs on the EIA-860 survey, we find the ex post costs of NO_x control systems are typically lower than the ex ante cost estimates, while the ex post costs of Hg control systems tend to be higher than the ex ante cost estimates. Similar results were reported with GAA. Eighteen out of 19 plants reported higher ex post costs for Hg control on the GAA survey while 10 of the 11 plants reported lower ex post costs for NO_x control. As pointed out in the paper, both SNCR and carbon injection (CI) were new technologies being used in the U.S. Based on the reported data, it appears the costs of SNCR was not as costly to install as EPA predicted while CI was costlier.

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Table 1

APCDs (Baseline and 2000) for 66 Large MWCs operating in 2000

State	Facility Name	Plant ID	Total Plant Capacity (tpd) (in 2000)	Combustion Technology (in 2000)	Baseline APCD	2000 APCD
AL	Huntsville Solid Waste-to-Energy Facility	N/A	690	MB/WW	(ESP)	SD/FF/CI/SNCR
CA	Commerce Refuse-to-Energy Facility	10090	360	MB/WW	SD/FF/SNCR[a,e]	SD/FF/SNCR
CA	Southeast Resource Recovery Facility (SERRF)	50837	1380	MB/WW	SD/FF/SNCR[c,e]	SD/FF/SNCR
CA	Stanislaus County Resource Recovery Facility	50632	800	MB/WW	SD/FF/SNCR[b,e]	SD/FF/CI/SNCR
CT	Bristol Resource Recovery Facility	50648	650	MB/WW	SD/FF[c]	SD/FF/CI/SNCR
CT	Mid-Connecticut Resource Recovery Facility	54945	2025	RDF	SD/FF[a]	SD/FF/SNCR
CT	Riley Energy Systems of Lisbon Connecticut Corp. (NSPS)	54758	500	MB/WW	---*	SD/FF/CI/SNCR
CT	Southeastern Connecticut Resource Recovery Facility	10646	690	MB/WW	(ESP)	SD/FF/CI
CT	Wheelabrator Bridgeport Company, L.P.	50883	2250	MB/WW	SD/FF[a]	SD/FF/CI
FL	Hillsborough County Resource Recovery Facility	50858	1200	MB/WW	ESP[a]	SD/FF/CI/SNCR
FL	Lake County Resource Recovery Facility	50629	528	MB/WW	(ESP)	SD/FF/CI/SNCR
FL	Lee County Resource Recovery Facility (NSPS)	52010	1200	MB/WW	---*	SD/FF/CI/SNCR
FL	McKay Bay Refuse-to-Energy Facility	50875	1000	MB/WW	ESP[a]	SD/FF/CI/SNCR
FL	Miami-Dade County Resource Recovery Facility	10062	2688	RDF	ESP[a]	SD/FF/CI/SNCR
FL	North County Resource Recovery Facility	50071	2000	RDF	SD/ESP[c]	SD/ESP
FL	Pasco County Resource Recovery Facility	50666	1050	MB/WW	(ESP)	SD/FF/CI/SNCR
FL	Pinellas County Resource Recovery Facility	50884	3000	MB/WW	ESP[a]	SD/FF/CI/SNCR
FL	Wheelabrator North Broward, Inc.	54033	2250	MB/WW	(ESP)	SD/FF/SNCR
FL	Wheelabrator South Broward, Inc.	50887	2250	MB/WW	(ESP)	SD/FF/SNCR
GA	Montenay Savannah Operations, Inc.	N/A	500	MB/WW	ESP[a]	SD/FF/CI/SNCR
HI	Honolulu Resource Recovery Venture - HPOWER	49846	2160	RDF	(ESP)	SD/ESP
IN	Indianapolis Resource Recovery Facility	50647	2361	MB/WW	SD/FF[d]	SD/FF/CI/SNCR
MA	Haverhill Resource Recovery Facility	50661	1650	MB/WW	SD/ESP[d]	SD/FF/CI/SNCR
MA	*SEMASS Resource Recovery Facility* (unit 3 NSPS)	*50290*	*2000 (units 1-2)* *1000 (unit 3)*	*RDF*	*SD/ESP (units 1-2)*[d] *--- (unit 3)**	*Units 1-2: SD/ESP/FF/CI (COHPAC)* *Unit 3: SD/FF/SNCR*
MA	Wheelabrator Millbury Inc.	50878	1500	MB/WW	SD/ESP[a]	SD/ESP/CI/SNCR
MA	Wheelabrator North Andover Inc.	50877	1500	MB/WW	ESP[a]	SD/FF/CI/SNCR

MA	Wheelabrator Saugus, J.V.	50880	1500	MB/WW	ESP[a]	SD/FF/CI/SNCR
MD	Baltimore Refuse Energy Systems Company (BRESCO)	10629	2250	MB/WW	ESP[a]	SD/ESP/CI/SNCR
MD	Montgomery County Resource Recovery Facility (NSPS)	50657	1800	MB/WW	---*	SD/FF/CI/SNCR
ME	Greater Portland Resource Recovery Facility	50225	500	MB/WW	SD/ESP[c]	SD/ESP/CI/SNCR
ME	Maine Energy Recovery Company	10338	600	RDF	SD/FF[a]	SD/FF/SNCR
ME	Penobscot Energy Recovery Corp.	50051	720	RDF	SD/FF[a]	SD/FF
MI	Central Wayne Energy (unit 3 is large MWC) (NSPS)	54804	300	MB/WW	---**	SD/FF/CI/SNCR
MI	Greater Detroit Resource Recovery Facility	10033	3300	RDF	ESP	SD/FF
MI	Kent County Waste-to-Energy Facility	50860	625	MB/WW	(ESP)	SD/FF/CI/SNCR
MN	Great River Energy - Elk River Station	2039	750	RDF	SD/FF[c]	SD/FF
MN	Hennepin Energy Resource Co.	10013	1200	MB/WW	SD/FF[b]	SD/FF/CI/SNCR
MN	Xcel Energy - Red Wing Steam Plant	1926	720	RDF	ESP[a]	DSI/FF
MN	Xcel Energy-Wilmarth Plant (Mankato)	1934	720	RDF	ESP[a]	SD/FF/SNCR
NC	New Hanover County-Wastec (unit 3 is large MWC)	50271	301	MB/WW	(ESP)	SD/FF/CI/SNCR
NH	Wheelabrator Concord Company, L.P.	50873	500	MB/WW	DSI/FF	SD/FF/CI/SNCR
NJ	Camden Resource Recovery Facility	10435	1050	MB/WW	(ESP)	SD/ESP/CI/SNCR
NJ	Essex County Resource Recovery Facility	10643	2700	MB/WW	(ESP)	SD/ESP/CI/SNCR
NJ	Union County Resource Recovery Facility (NSPS)	50960	1440	MB/WW	---*	SD/FF/CI/SNCR
NJ	Wheelabrator Gloucester Company, L.P.	50885	576	MB/WW	(ESP)	SD/FF/CI/SNCR
NY	Babylon Resource Recovery Facility	50649	750	MB/WW	SD/FF[c]	SD/FF/CI/SNCR
NY	Hempstead Resource Recovery Facility	10642	2505	MB/WW	SD/FF[b]	SD/FF/SNCR
NY	Huntington Resource Recovery Facility	50656	750	MB/WW	(ESP)	SD/FF/CI/SNCR
NY	Niagara Falls Resource Recovery Facility	50472	2200	MB/WW	ESP[a]	SD/FF/CI/SNCR
NY	Onondaga County Resource Recovery Facility (NSPS)	50662	990	MB/WW	---*	SD/FF/CI/SNCR
NY	Wheelabrator Hudson Falls Inc.	10503	500	MB/WW	(ESP)	SD/ESP/CI
NY	Wheelabrator Westchester Company, L.P.	50882	2250	MB/WW	ESP[a]	SD/FF/CI/SNCR
OK	Walter B. Hall RDD (Tulsa)	50660	1125	MB/WW	ESP[a]	SD/FF/CI/SNCR
OR	Marion County Solid Waste-to-Energy Facility	50630	550	MB/WW	SD/FF[a]	SD/FF/CI/SNCR
PA	Delaware Valley Resource Recovery Facility	10746	2688	MB/RC	(ESP)	SD/FF
PA	Lancaster County Resource Recovery Facility	50859	1200	MB/WW	(ESP)	SD/FF/CI/SNCR
PA	Montenay Energy Resources of Montgomery County, Inc.	54625	1200	MB/WW	(ESP)	SD/FF/CI/SNCR
PA	Wheelabrator Falls Inc. (NSPS)	54746	1500	MB/WW	---*	SD/FF/CI/SNCR
PA	York Resource Recovery Center/Montenay York	50215	1344	MB/RC	SD/FF[b]	SD/FF/CI/SNCR
SC	Montenay Charleston Resource Recovery Inc.	10344	600	MB/WW	SD/ESP[d]	SD/ESP/CI
TN	Nashville Thermal Transfer Corp	50209	990	MB/WW	ESP[a]	SD/FF/CI/SNCR
VA	Alexandria/Arlington Resource Recovery Facility	50663	975	MB/WW	ESP[a]	SD/FF/CI/SNCR
VA	I-95 Energy-Resource Recovery Facility	50658	3000	MB/WW	(ESP)	SD/FF/CI/SNCR

VA	Southeastern Public Service Authority of Virginia	54998	2000	RDF	ESP[a]	SD/FF
WA	Spokane Regional Solid Waste Disposal Facility	50886	800	MB/WW	(ESP)	SD/FF/CI/SNCR
WI	Xcel Energy French Island Generating Plant	4005	576	RDF	EGB[a]	***SD/FF

Note: Plant ID refers to DOE/EIA ORIS Plant Code
Sources: Huckaby (2002a,b) for Total Plant Capacity, Combustion Technology, and 2000 APCDs. McKay Bay and SEMASS 2000 APCDs are from Huckaby (2002b). Cone and Kane (1995) is used to identify the start date for MWCs,
*NSPS (subject to subpart Ea)
**NSPS (subject to subpart Eb)
*** According to the EIA-860, French Island (WI) installed SD/FF APCDs in 2002. When calculating ex ante and ex post costs for French Island (WI), we use the SD/FF configuration reported by GAA and EIA-860 as its 2000 APCD configuration instead of the 2000 APCD configuration of DSI/EGB reported by Huckaby (2002a,b).

Determining baseline APCDs for the 59 existing MWCs requires identifying APCDs for MWCs that initiated operations prior to 1990. For 19 of the 59 existing MWCs whose construction started prior to December 20, 1989, but did not start operating until 1990 or later, we assume their baseline APCD FGD/FGP configuration is ESP (denoted in parentheses).

For the remaining 40 existing MWCs, the preferred sources for baseline FGD/FGP APCD configurations are Radian Corporation (1988) – 24 MWCs noted by superscript a, or U.S. EPA (1989c) – 4 MWCs noted by superscript b. Radian Corporation (1988) does includes not information about APCD configuration for the other 12 MWCs - except for Lake County (FL) and New Hanover County (NC) unit 3, which were not included as planned MWCs.

For six of the 12 MWCs, the EIA-860 is the source of baseline FGP/FGD configurations. The six plants, noted by superscript c, are SERRF (CA), Bristol (CT), North County (FL), Greater Portland (ME), Elk River (MN), and Babylon (NY). Except for Elk River, the baseline APCD configurations obtained from the EIA-860 for these MWCs match their December 1991 APCD configurations reported by Fenn and Nebel (1992). While EIA-860 reports a SD/FF configuration for Elk River by 1990, Fenn and Nebel (1992) report the APCD configuration of Elk River as DSI/FF. Confirmation of the Elk River (MN) baseline as SD/FF was obtained by checking additional sources from Minnesota (see https://www.pca.state.mn.us/sites/default/files/14100003-001-aqpermit.pdf).

For the remaining 6 MWCs, the APCD configurations reported by Berenyi and Gould (1988) and Kiser (1990) are compared. If the APCD configurations match, we assume these APCD configurations are the December 1989 baseline APCD configurations for those MWCs – noted by superscript d. This strategy was used for the following 4 MWCs: Indianapolis (IN), Haverhill (MA), SEMASS (MA), and Charleston (SC) plants. The baseline APCD configurations for these 4 MWCs also match their December 1991 APCD configurations reported by Fenn and Nebel (1992).

For the final two MWCs - Concord (MA), Greater Detroit (MI) - Berenyi and Gould (1988) and Kiser (1990) report Concord (MA) installed a dry scrubber system (DSI) – most likely prior to 1990. Fenn and Nebel (1992) report Concord installed DSI systems by the early 1990s, The EIA-860 survey reports Concord incurred expenditures for a SD system in 2000. Hence, we assign DSI/FF as the baseline APCD configuration for Concord.

Berenyi and Gould (1988) and Kiser (1990) report that Greater Detroit installed a dry scrubber system – most likely prior to 1990. Fenn and Nebel (1992) report Greater Detroit installed a SD system by the early 1990s, while the EIA-860 survey reports Greater Detroit incurred expenditures for SD systems in 1993-1995. However, in their technical descriptions of the planning and construction of Greater Detroit, Yaffe and Brinker (1988) and Davis (1992) have ESP listed as the baseline APCD configuration. We opted to use the ESP configuration.

The source of baseline SNCR/Cl configurations is U.A. DOE, EIA Form 860 (2013) – noted by superscript e.

Table 2

Model plants - Existing MWCs

Model Plant	Abbreviation	Description of Combustion Technology	Combustion Capacity (Mg MSW/day)
1	MB/REF/TG	Mass burn refractory wall traveling gate	680
2	MB/REF/RG	Mass burn refractory wall rocking gate	218
3	MB/REF/RK	Mass burn refractory wall rotary kiln	816
4	MB/WW (large)	Mass burn waterwall, large	2,041
5	MB/WW (mid-size)	Mass burn waterwall, mid-size	980
6	MB/WW (small)	Mass burn waterwall, small	181
7	RDF (large)	Refuse-derived fuel, large	1,814
8	RDF (small)	Refuse-derived fuel, small	544
9	MOD/SA/TR	Modular starved air, transfer rams	136
10	MOD/SA/G	Modular starved air, grates	45
11	MOD/EA	Modular excess air	181
12	MB/RWW	Mass burn rotary waterwall	454
14	MB/WW (UC)	Transitional mass burn waterwall	181
15	RDF (large) (UC)	Transitional refuse-derived fuel, large	1,814
16	RDF (small) (UC)	Transitional refuse-derived fuel, small	544
17	MB/RWW (UC)	Transitional mass burn rotary waterwall	454

Source: U.S. EPA (1994a)

Note: EPA dropped model plant #13 from its 1994 *Economic Analysis* (U.S. EPA, 1994a).

Table 3

Model plants - NSPS MWCs

Model Plant	Abbreviation	Description of Combustion Technology	Combustion Capacity (Mg MSW/day)
1	MB/WW (small)	Mass burn waterwall, small	181
2	MB/WW (mid-size)	Mass burn waterwall, mid-size	726
3	MB/WW (large)	Mass burn waterwall, large	2,041
4	MB/REF	Mass burn refractory wall	454
5	MB/REF	Mass burn refractory wall	952
6	RDF	Refuse-derived fuel	1,814
8	MOD/EA	Modular excess air	218
9	MOD/SA (small)	Modular starved air, small	45
10	MOD/SA (mid-size)	Modular starved air, mid-size	91
11	FBC/BB	Fluidized bed combustion, bubbling bed	816
12	FBC/CB	Fluidized bed combustion, circulating bed	816

Source: U.S. EPA (1994a)

Note: EPA dropped model plant #7 from its 1994 *Economic Analysis* (U.S. EPA, 1994a).

Table 4
Ex Ante Costs for Model Existing MWCs: Acid Gas, Particulate Matter, and Metals Control
(thousands of 1990 dollars)

		GCP+ESP		GCP+DSI/ESP or FF		GCP+SD/ESP		GCP+SD/ESP (m)		GCP+SD/FF	
Model Plant Number	Baseline APCD	Installed Capital Costs	Annual Operating Costs	Installed Capital Costs	Annual Operating Costs	Installed Capital Costs	Annual Operating Costs	Installed Capital Costs	Annual Operating Costs	Installed Capital Costs	Annual Operating Costs
1	ESP	18,968	-211	21,754	644	36,075	1,712	36,075	1,997	39,077	2,300
2	ESP	6,783	490	8,041	857	12,217	1,094	12,217	1,277	13,602	1,367
3	ESP	1,480	283	10,208	1,810	30,939	3,315	30,939	3,867	34,784	4,130
3	SD/FF	0	0	0	0	0	0	0	0	0	0
4	ESP	96	146	19,172	2,725	33,671	3,597	33,671	4,088	45,625	5,035
4	SD/ESP	0	0	0	0	0	0	0	491	21,987	2,618
4	SD/FF	0	0	0	0	0	0	0	0	0	0
5	ESP	96	146	10,085	1,767	20,433	2,314	20,433	2,528	25,873	3,193
5	SD/ESP	0	0	0	0	0	0	0	214	11,259	1,265
5	SD/FF	0	0	0	0	0	0	0	0	0	0
6	ESP	3,600	341	5,188	894	8,648	1,037	8,648	1,210	9,992	1,292
6	SD/FF	0	0	0	0	0	0	0	0	0	0
7	ESP	13,577	263	20,449	2,129	53,245	3,345	53,245	3,902	64,115	4,814
8	ESP	5,267	187	12,862	1,348	23,720	1,686	23,720	1,879	28,223	2,310
9	none	2,154	234	3,232	536	5,072	517	5,072	604	5,176	708
10	none	1,284	217	1,762	502	4,125	532	4,125	621	3,862	607
11	ESP	1,523	66	2,612	416	4,897	527	4,897	614	5,556	688
12	ESP	3,403	138	5,792	946	11,101	1,176	11,101	1,372	12,969	1,597
14	ESP	2,621	195	4,576	765	8,102	904	8,102	1,054	9,443	1,150
14	SD/FF	0	0	0	0	0	0	0	0	0	0
15	ESP	0	0	6,872	1,942	26,477	3,079	26,477	3,431	33,491	4,357
15	SD/ESP	0	0	0	0	0	0	0	352	23,016	2,568
15	SD/FF	0	0	0	0	0	0	0	0	0	0
16	ESP	0	0	6,992	1,144	14,510	1,499	14,510	1,670	16,980	1,986
16	SD/FF	0	0	0	0	0	0	0	0	0	0
17	ESP	2,824	126	5,213	988	10,774	1,163	10,774	1,357	12,636	1,586
17	SD/FF	0	0	0	0	0	0	0	0	0	0

Source: U.S. EPA (1994a)
Note: EPA dropped model plant #13 from its 1994 *Economic Analysis* (U.S. EPA, 1994a).

Table 5

Ex Ante Costs for Model NSPS MWCs: Acid Gas, Particulate Matter, and Metals Control
(thousands of 1990 dollars)

	GCP+ESP		GCP+DSI/FF		GCP+SD/FF	
Model Plant Number	Installed Capital Costs	Annual Operating Costs	Installed Capital Costs	Annual Operating Costs	Installed Capital Costs	Annual Operating Costs
1	178	12	1,222	600	4,533	732
2	533	45	3,744	1,446	9,855	1,666
3	1,500	131	8,699	3,314	20,365	3,740
4	689	57	3,089	1,223	9,799	1,504
5	600	40	4,244	1,887	12,743	2,185
6	1,378	122	8,510	3,638	21,842	4,064
8	233	18	1,400	526	3,955	625
9	591	80	1,555	358	3,100	436
10	625	36	1,398	397	3,064	454
11	0	0	500	1,057	9,510	1,542
12	0	0	500	1,746	9,510	1,542

Source: U.S. EPA (1994a)
Note: EPA dropped model plant #7 from its 1994 *Economic Analysis* (U.S. EPA, 1994a).

Table 6

Ex Ante Capital and Annual Operating Costs for Existing MWCs:
Hg and NOx Control
(thousands of 1990 dollars)

	Mercury				NO_x	
		Annual Operating Costs (by type of APCD)				
Model Plant Number	Installed Capital Costs	DSI/ESP or DSI/FF	SD/ESP	SD/FF	Installed Capital Costs	Annual Operating Costs
1	160	245	156	63	0	0
2	81	75	48	19	0	0
3	179	346	221	89	0	0
4	310	865	553	222	5,322	781
5	310	865	553	222	3,271	486
6	72	77	49	20	1,364	201
7	0	0	0	0	5,196	711
8	0	0	0	0	2,599	336
9	61	37	24	9	1,063	162
10	32	16	10	4	832	142
11	72	74	47	19	53	39
12	126	192	123	49	53	40
14	72	77	49	20	1,364	201
15	0	0	0	0	5,196	711
16	0	0	0	0	2,599	336
17	126	192	123	49	53	40

Source: U.S. EPA (1994a)
Note: EPA dropped model plant #13 from its 1994 *Economic Analysis* (U.S. EPA, 1994a).

Table 7

Ex Ante Capital and Annual Operating Costs for Model NSPS MWCs:
Hg and NOx Control
(thousands of 1990 dollars)

	Mercury			NO_x	
Model Plant Number	Installed Capital Costs	Annual Operating Costs (by type of APCD)		Installed Capital Costs	Annual Operating Costs
		DSI/FF	SD/FF		
1	72	50	13	1,122	163
2	167	308	79	2,244	337
3	310	865	222	4,155	691
4	126	192	49	0	0
5	196	404	104	80	61
6	0	0	0	3,966	699
8	81	89	23	53	39
9	32	13	3	684	121
10	48	37	9	870	148
11	179	340	87	53	40
12	179	340	87	53	40

Source: U.S. EPA (1994a)
Note: EPA dropped model plant #7 from its 1994 *Economic Analysis* (U.S. EPA, 1994a).

Table 8

Ex Ante and Ex Post Capital Expenditures for Acid Gas, Particulate Matter, and Metals Control APCDs
(thousands of 1990 dollars)
(Source: EIA-860, 2013)

State	Facility Name	Plant ID	Model Plant	Baseline APCD	Ex Ante	Ex Post FGD	Ex Post FGP
AL	Huntsville Solid Waste-to-Energy Facility	N/A	5	(ESP)	25,873	na	na
CA	Commerce Refuse-to-Energy Facility	10090	6	SD/FF	0		
CA	Southeast Resource Recovery Facility (SERRF)	50837	5	SD/FF	0		
CA	Stanislaus County Resource Recovery Facility	50632	5	SD/FF	0		
CT	Bristol Resource Recovery Facility	50648	5	SD/FF	0		
CT	Mid-Connecticut Resource Recovery Facility	54945	7	SD/FF	0		
CT	Riley Energy Systems of Lisbon Connecticut Corp	54758	(NSPS) 2	---	9,855	5,630	8,445
CT	Southeastern Connecticut Resource Recovery Facility	10646	5	(ESP)	25,873	9,983	2,937
CT	Wheelabrator Bridgeport Company, L.P.	50883	4	SD/FF	0		
FL	Hillsborough County Resource Recovery Facility	50858	5	ESP	25,873	36,421	36,421
FL	Lake County Resource Recovery Facility	50629	6	(ESP)	9,992	18,000	12,000
FL	Lee County Resource Recovery Facility	52010	(NSPS) 2	---	9,855	7,480	7,772
FL	McKay Bay Refuse-to-Energy Facility	50875	5	ESP	25,873	7,983	9,434
FL	Miami-Dade County Resource Recovery Facility	10062	7	ESP	64,115	6,352	89,577
FL	North County Resource Recovery Facility	50071	7	SD/ESP	0		
FL	Pasco County Resource Recovery Facility	50666	5	(ESP)	25,873	2,375	3,563
FL	Pinellas County Resource Recovery Facility	50884	4	ESP	45,625	34,948	27,191
FL	Wheelabrator North Broward, Inc.	54033	4	(ESP)	45,625	13,551	8,985
FL	Wheelabrator South Broward, Inc.	50887	4	(ESP)	45,625	13,858	8,908
GA	Montenay Savannah Operations, Inc.	N/A	6	ESP	9,992	na	na
HI	Honolulu Resource Recovery Venture - HPOWER	49846	7	(ESP)	53,245	**na	**
IN	Indianapolis Resource Recovery Facility	50647	4	SD/FF	0		
MA	Haverhill Resource Recovery Facility	50661	4	SD/ESP	21,987	*	*10,656
MA	*SEMASS Resource Recovery Facility (units 1-2)*	*50290*	*7*	*SD/ESP*	[a]*10,870*	*	**12,159*
MA	*SEMASS Resource Recovery Facility (unit 3)*	*50290*	*(NSPS) 6*	---	*21,842*	*4,878*	*3,484*
MA	Wheelabrator Millbury Inc.	50878	5	SD/ESP	0		

MA	Wheelabrator North Andover Inc.	50877	5	ESP	25,873	32,666	10,889
MA	Wheelabrator Saugus, J.V.	50880	5	ESP	25,873	49,419	24,710
MD	Baltimore Refuse Energy Systems Company (BRESCO)	10629	4	ESP	33,671	**25,017	**
MD	Montgomery County Resource Recovery Facility	50657	(NSPS) 3	---	20,365	na	na
ME	Greater Portland Resource Recovery Facility	50225	6	SD/ESP	0		
ME	Maine Energy Recovery Company	10338	8	SD/FF	0		
ME	Penobscot Energy Recovery Corp.	50051	8	SD/FF	0		
MI	Central Wayne Energy (unit 3 is large MWC)	54804	(NSPS) 1	---	4,533	8,563	3,154
MI	Greater Detroit Resource Recovery Facility	10033	7	ESP	64,115	552	261
MI	Kent County Waste-to-Energy Facility	50860	5	(ESP)	25,873	2,956	3,448
MN	Great River Energy - Elk River Station	2039	8	SD/FF	0		
MN	Hennepin Energy Resource Co.	10013	5	SD/FF	0		
MN	Xcel Energy - Red Wing Steam Plant	1926	8	ESP	12,862	na	***1,996
MN	Xcel Energy-Wilmarth Plant	1934	8	ESP	28,223	5,275	2,247
NC	New Hanover County-Wastec (unit 3 is large MWC)	50271	6	(ESP)	9,992	na	na
NH	Wheelabrator Concord Company, L.P.	50873	6	DSI/FF	[a]4,804	**7,735	**
NJ	Camden Resource Recovery Facility	10435	5	(ESP)	20,433	**23,457	**
NJ	Essex County Resource Recovery Facility	10643	4	(ESP)	33,671	**6,000	**
NJ	Union County Resource Recovery Facility	50960	(NSPS) 3	---	20,365	8,670	8,670
NJ	Wheelabrator Gloucester Company, L.P.	50885	6	(ESP)	9,992	3,000	6,000
NY	Babylon Resource Recovery Facility	50649	5	SD/FF	0		
NY	Hempstead Resource Recovery Facility	10642	4	SD/FF	0		
NY	Huntington Resource Recovery Facility	50656	5	(ESP)	25,873	***14,846	na
NY	Niagara Falls Resource Recovery Facility	50472	4	ESP	45,625	7,984	7,169
NY	Onondaga County Resource Recovery Facility	50662	(NSPS) 2	---	9,855	4,653	3,643
NY	Wheelabrator Hudson Falls Inc.	10503	6	(ESP)	8,648	**900	**
NY	Wheelabrator Westchester Company, L.P.	50882	4	ESP	45,625	53,195	53,195
OK	Walter B. Hall RDD (Tulsa)	50660	5	ESP	25,873	5,851	59,857
OR	Marion County Solid Waste-to-Energy Facility	50630	6	SD/FF	0		
PA	Delaware Valley Resource Recovery Facility	10746	12	(ESP)	12,969	14,846	29,693
PA	Lancaster County Resource Recovery Facility	50859	5	(ESP)	25,873	na	na
PA	Montenay Energy Resources of Montgomery County, Inc.	54625	5	(ESP)	25,873	na	na
PA	Wheelabrator Falls Inc.	54746	(NSPS) 3	---	20,365	9,831	6,995
PA	York Resource Recovery Center/Montenay York	50215	12	SD/FF	0		

SC	Montenay Charleston Resource Recovery Inc.	10344	5	SD/ESP	0		
TN	Nashville Thermal Transfer Corp	50209	5	ESP	25,873	na	na
VA	Alexandria/Arlington Resource Recovery Facility	50663	5	ESP	25,873	15,071	16,382
VA	I-95 Energy-Resource Recovery Facility (Fairfax)	50658	4	(ESP)	45,625	22,000	30,000
VA	Southeastern Public Service Authority of Virginia	54998	7	ESP	64,115	31,268	28,702
WA	Spokane Regional Solid Waste Disposal Facility	50886	5	(ESP)	25,873	na	na
WI	Xcel Energy French Island Generating Plant	4005	8	EGB	28,223	542	1,627

Note: Plant ID refers to DOE/EIA ORIS Plant Code

Note: Sources of baseline APCDs are listed in endnotes for Table 1.

Note: GAA and EIA capital expenditure data are converted to 1990 dollars using the Chemical Engineering Plant Cost Index (see Vatavuk, 2002, and Economic Indicators, 2007).

Note: Because Central Wayne closed in 2003, the 2001 EIA-767 survey is the source of its cost data.

Note: New Hanover (NC) is assigned to a model plant category based solely on its unit 3 characteristics (its only unit subject to the large MWC rule)

Note: Because SEMASS NSPS unit has SD/FF configuration, ESP costs listed in EIA-860 are excluded from FGP ex post costs. Expenditures for ESP/FF by SEMASS existing units in 2000 are assumed to be related to COHPAC installation and are included in FGP ex post costs.

na = data not available (EIA, Form 860, 2013)

* FGP changed between baseline and 2000 with no change in FGD

** FGD added between baseline and 2000 with no change in FGP

*** Because Red Wing (MN) only reports FGP costs and Huntington (NY) only reports FGD costs, their costs are excluded from the summary results presented in Table 9.

[a] = ex ante cost estimate derived by authors because Table 4 does not include the change in APCD configuration between baseline and 2000 exhibited by MWC (see Table A.14 in the Appendix for a more detailed explanation of derivation of ex ante values)

Table 9
Comparison of Ex Ante and Ex Post Capital Costs FGD and FGP (PM and SO_2) for Existing and NSPS MWCs
(Source: EIA-860, 2013 and EIA-767, 2006)

# of MWCs	
Ex post > Ex ante	17
Ex post < Ex ante	20
Ex post / Ex ante	
Mean	1.16
Median	0.90
Minimum	0.01
Maximum	3.43

Table 10

Ex Ante and Ex Post Capital Expenditures for Hg and NO_x APCDs (1,000s of 1990 dollars)

State	Facility Name	Plant ID	Model Plant	Ex Ante		Ex Post (GAA, 2006)		Ex Post (EIA, 2013)	
				CI(Hg)	SNCR (NO_x)	CI(Hg)	SNCR (NO_x)	CI(Hg)	SNCR (NO_x)
AL	Huntsville Solid Waste-to-Energy Facility	N/A	5	310	3,271	*2,722	*		
CA	Commerce Refuse-to-Energy Facility	10090	6						
CA	Southeast Resource Recovery Facility (SERRF)	50837	5						
CA	Stanislaus County Resource Recovery Facility	50632	5	310				1,814	
CT	Bristol Resource Recovery Facility	50648	5	310	3,271		1,220	1,299	5,900
CT	Mid-Connecticut Resource Recovery Facility	54945	7		5,196		1,906		
CT	Riley Energy Systems of Lisbon Connecticut Corp.	54758	(NSPS) 2	167	2,244	318		726	1,360
CT	Southeastern Connecticut Resource Recovery Facility	10646	5	310	3,271	[a]904		627	335
CT	Wheelabrator Bridgeport Company, L.P.	50883	4	310	5,322	317	1,898	1,360	2,041
FL	Hillsborough County Resource Recovery Facility	50858	5						
FL	Lake County Resource Recovery Facility	50629	6	72	1,364	1,408	1,831	938	916
FL	Lee County Resource Recovery Facility	52010	(NSPS) 2		2,244				2,040
FL	McKay Bay Refuse-to-Energy Facility	*50875*	*5*	310	3,271			1,452	2,722
FL	Miami-Dade County Resource Recovery Facility	10062	7		5,196				1,996
FL	North County Resource Recovery Facility	50071	7						
FL	Pasco County Resource Recovery Facility	50666	5	310	3,271	938		915	953
FL	Pinellas County Resource Recovery Facility	50884	4	310	5,322			4,084	11,649
FL	Wheelabrator North Broward, Inc.	54033	4		5,322		1,814		2,041
*FL	Wheelabrator South Broward, Inc.	50887	4		5,322		1,815		2,041
GA	Montenay Savannah Operations, Inc.	N/A	6						
HI	Honolulu Resource Recovery Venture—HPOWER	49846	7						
IN	Indianapolis Resource Recovery Facility	50647	4	310	5,322	*3,204	*		
MA	Haverhill Resource Recovery Facility	50661	4	310	5,322			10,656	10,656
MA	*SEMASS Resource Recovery Facility (units 1-2)*	*50290*	*7*	*0*		***1,361*		***216*	
MA	*SEMASS Resource Recovery Facility (unit 3)*	*50290*	*(NSPS) 6*						
MA	Wheelabrator Millbury Inc.	50878	5	310	3,271	*2,541	*	907	1,360
MA	Wheelabrator North Andover Inc.	50877	5	310	3,271			907	1,360

MA	Wheelabrator Saugus, J.V.	50880	5	310	3,271	1,724		907	1,360
MD	Baltimore Refuse Energy Systems Company (BRESCO)	10629	4	310	5,322			1,361	2,082
MD	Montgomery County Resource Recovery Facility	50657	(NSPS) 3						
ME	Greater Portland Resource Recovery Facility	50225	6	72	1,364	454	1,190	408	907
ME	Maine Energy Recovery Company	10338	8						
ME	Penobscot Energy Recovery Corp.	50051	8						
MI	Central Wayne Energy	54804	(NSPS) 1						
MI	Greater Detroit Resource Recovery Facility	10033	7						
MI	Kent County Waste-to-Energy Facility	50860	5	310	3,271	*3,662	*	1,282	1,373
MN	Great River Energy - Elk River Station	2039	8						
MN	Hennepin Energy Resource Co.	10013	5	310		729		486	
MN	Xcel Energy - Red Wing Steam Plant	1926	8						
MN	Xcel Energy-Wilmarth Plant	1934	8						
NC	New Hanover County-Wastec (unit 3 is large MWC)	50271	6						
NH	Wheelabrator Concord Company, L.P.	50873	6	72	1,364			726	1,360
NJ	Camden Resource Recovery Facility	10435	5	310		1,166		563	
NJ	Essex County Resource Recovery Facility	10643	4	310	5,322	187	1,408	901	3,302
NJ	Union County Resource Recovery Facility	50960	(NSPS) 3	310	4,155			8,670	8,670
NJ	Wheelabrator Gloucester Company, L.P.	50885	6	72	1,364	562	681	751	1,361
NY	Babylon Resource Recovery Facility	50649	5	310	3,271	*1,831	*	[c]916	[c]2,014
NY	Hempstead Resource Recovery Facility	10642	4		5,322		907		1,361
NY	Huntington Resource Recovery Facility	50656	5	310	3,271	1,190		2,042	1,485
NY	Niagara Falls Resource Recovery Facility	50472	4	310	5,322	[b]1,779		1,808	1,312
NY	Onondaga County Resource Recovery Facility	50662	(NSPS) 2	167	2,244			845	845
NY	Wheelabrator Hudson Falls Inc.	10503	6	72		454		726	
NY	Wheelabrator Westchester Company, L.P.	50882	4	310	5,322			1,373	2,060
OK	Walter B. Hall RDD (Tulsa)	50660	5						
OR	Marion County Solid Waste-to-Energy Facility	50630	6	72	1,364	*1,836	*	459	505
PA	Delaware Valley Resource Recovery Facility	10746	12						
PA	Lancaster County Resource Recovery Facility	50859	5	310	3,271	*2,479	*		
PA	Montenay Energy Resources of Montgomery County, Inc.	54625	5	310	3,271	1,373	1,874		
PA	Wheelabrator Falls Inc.	54746	(NSPS) 3	310	4,155			751	1,457
PA	York Resource Recovery Center/Montenay York	50215	12	126		937		2,286	
SC	Montenay Charleston Resource Recovery Inc.	10344	5	310		1,373			

TN	Nashville Thermal Transfer Corp	50209	5						
VA	Alexandria/Arlington Resource Recovery Facility	50663	5	310	3,271	498		5,461	5,461
VA	I-95 Energy-Resource Recovery Facility (Fairfax)	50658	4	310	5,322	*2,268	*	1,451	1,451
VA	Southeastern Public Service Authority of Virginia	54998	7						
WA	Spokane Regional Solid Waste Disposal Facility	50886	5	310		455			
WI	Xcel Energy French Island Generating Plant	4005	8		2,599				36

Note: Plant ID refers to DOE/EIA ORIS Plant Code

* cost value in ex post Hg column represents combined cost of Hg and NO_x APCDs.

** Because SEMASS (MA) existing units have nil ex ante costs for Cl (Hg), costs listed in EIA-860 survey are excluded from the summary results presented in Table 11 and Table 12.

[a] Expenditure undertaken in 2002 (Berenyi, 2006)

[b] Expenditure undertaken in 2003 (Berenyi, 2006)

[c] EIA-860 lists year of Cl and SNCR expenditures for Babylon (NY) as 1989. Due to lack of evidence that those APCDs were installed pre-1990, we changed the date from 1989 to 1999 to be consistent with the GAA date of expenditures.

Table 11
Comparison of Ex Ante and Ex Post Capital Costs (Hg and NOx)
(Source: GAA, 2006)

# of MWCs	CI(Hg)	SNCR(NOx)	CI + SNCR (combined)	CI + SNCR (8 MWCs combined & 6 MWCs – report separate CI & SNCR)
Ex post > Ex ante	18	1	2	4
Ex post < Ex ante	1	10	6	10
Ex post / Ex ante				
Mean	4.74	0.50	0.74	0.85
Median	3.84	0.37	0.70	0.73
Minimum	0.60	0.17	0.40	0.28
Maximum	19.55	1.34	1.28	2.26

Table 12
Comparison of Ex Ante and Ex Post Capital Costs (Hg and NOx)
(Source: EIA-860, 2013)

# of MWCs	CI(Hg)	SNCR(NOx)
Ex post > Ex ante	33	5
Ex post < Ex ante	0	29
Ex post / Ex ante		
Mean	7.60	0.69
Median	4.68	0.42
Minimum	1.57	0.01
Maximum	34.38	2.19

Table 13

Ex Ante and Ex Post Capital Expenditures for Acid Gas, Particulate Matter, and Metals Control plus Hg and NO_x APCDs
(thousands of 1990 dollars)
(Source: GAA, 2006)

State	Facility Name	Plant ID	Model Plant	Ex Ante (FGD + FGP)	Ex Post (FGD + FGP)	Ex Ante Total (FGD+FGP SNCR+CI)	Ex Post Total (FGD+FGP +SNCR+CI)
AL	Huntsville Solid Waste-to-Energy Facility	N/A	5	25,873	na		
CA	Commerce Refuse-to-Energy Facility	10090	6	0			
CA	Southeast Resource Recovery Facility (SERRF)	50837	5	0			
CA	Stanislaus County Resource Recovery Facility	50632	5	0			
CT	Bristol Resource Recovery Facility	50648	5	0			
CT	Mid-Connecticut Resource Recovery Facility	54945	7	0			
CT	Riley Energy Systems of Lisbon Connecticut Corp	54758	(NSPS) 2	9.855	na		
CT	Southeastern Connecticut Resource Recovery Facility	10646	5	25,873	na		
CT	Wheelabrator Bridgeport Company, L.P.	50883	4	0			
FL	Hillsborough County Resource Recovery Facility	50858	5	25,873	33,052		
FL	Lake County Resource Recovery Facility	50629	6	9,992	na		
FL	Lee County Resource Recovery Facility	52010	(NSPS) 2	9,855	na		
FL	McKay Bay Refuse-to-Energy Facility	50875	5	25,873	64,086		
FL	Miami-Dade County Resource Recovery Facility	10062	7	64,115	na	69,311	57,165
FL	North County Resource Recovery Facility	50071	7	0			
FL	Pasco County Resource Recovery Facility	50666	5	25,873	na		
FL	Pinellas County Resource Recovery Facility	50884	4	45,625	na	51,257	83,547
FL	Wheelabrator North Broward, Inc.	54033	4	45,625	na		
FL	Wheelabrator South Broward, Inc.	50887	4	45,625	na		
GA	Montenay Savannah Operations, Inc.	N/A	6	9,992	12,853		
HI	Honolulu Resource Recovery Venture—HPOWER	49846	7	53,245	na		
IN	Indianapolis Resource Recovery Facility	50647	4	0			
MA	Haverhill Resource Recovery Facility	50661	4	21,987	na	27,619	*25,634
MA	*SEMASS Resource Recovery Facility (units 1-2)*	*50290*	*7*	[a]*10,870*	**27,222*		

MA	*SEMASS Resource Recovery Facility (unit 3)*	*50290*	*(NSPS) 6*	*21,842*	*na*		
MA	Wheelabrator Millbury Inc.	50878	5	0			
MA	Wheelabrator North Andover Inc.	50877	5	25,873	na	29,454	35,842
MA	Wheelabrator Saugus, J.V.	50880	5	25,873	69,283		
MD	Baltimore Refuse Energy Systems Company (BRESCO)	10629	4	33,671	na	39,303	**37,591
MD	Montgomery County Resource Recovery Facility	50657	(NSPS) 3	20,365	na		
ME	Greater Portland Resource Recovery Facility	50225	6	0			
ME	Maine Energy Recovery Company	10338	8	0			
ME	Penobscot Energy Recovery Corp.	50051	8	0			
MI	Central Wayne Energy (unit 3 is large MWC)	54804	(NSPS) 1	4,533	na		
MI	Greater Detroit Resource Recovery Facility	10033	7	64,115	118,771		
MI	Kent County Waste-to-Energy Facility	50860	5	25,873	na		
MN	Great River Energy - Elk River Station	2039	8	0			
MN	Hennepin Energy Resource Co.	10013	5	0			
MN	Xcel Energy - Red Wing Steam Plant	1926	8	12,862	13,611		
MN	Xcel Energy-Wilmarth Plant	1934	8	28,223	6,250		
NC	New Hanover County-Wastec (unit 3 is large MWC)	50271	6	9,992	na		
NH	Wheelabrator Concord Company, L.P.	50873	6	[a]4,804	na	6,240	**7,268
NJ	Camden Resource Recovery Facility	10435	5	20,433	na		
NJ	Essex County Resource Recovery Facility	10643	4	33,671	na		
NJ	Union County Resource Recovery Facility	50960	(NSPS) 3	20,365	na		
NJ	Wheelabrator Gloucester Company, L.P.	50885	6	9,992	na		
NY	Babylon Resource Recovery Facility	50649	5	0			
NY	Hempstead Resource Recovery Facility	10642	4	0			
NY	Huntington Resource Recovery Facility	50656	5	25,873	na		
NY	Niagara Falls Resource Recovery Facility	50472	4	45,625	na		
NY	Onondaga County Resource Recovery Facility	50662	(NSPS) 2	9,855	na		
NY	Wheelabrator Hudson Falls Inc.	10503	6	8,648	na		
NY	Wheelabrator Westchester Company, L.P.	50882	4	45,625	na	51,257	69,328
OK	Walter B. Hall RDD (Tulsa)	50660	5	25,873	na	29,454	22,402
OR	Marion County Solid Waste-to-Energy Facility	50630	6	0			
PA	Delaware Valley Resource Recovery Facility	10746	12	12,969	na		
PA	Lancaster County Resource Recovery Facility	50859	5	25,873	na		
PA	Montenay Energy Resources of Montgomery County, Inc.	54625	5	25,873	na		

PA	Wheelabrator Falls Inc.	54746	(NSPS) 3	20,365	na		
PA	York Resource Recovery Center/Montenay York	50215	12	0			
SC	Montenay Charleston Resource Recovery Inc.	10344	5	0			
TN	Nashville Thermal Transfer Corp	50209	5	25,873	na	29,454	36,084
VA	Alexandria/Arlington Resource Recovery Facility	50663	5	25,873	39,367		
VA	I-95 Energy-Resource Recovery Facility (Fairfax)	50658	4	45,625	na		
VA	Southeastern Public Service Authority of Virginia	54998	7	64,115	116,354		
WA	Spokane Regional Solid Waste Disposal Facility	50886	5	25,873	na		
WI	Xcel Energy French Island Generating Plant	4005	8	28,223	na	***30,782	***9,121

Note: Plant ID refers to DOE/EIA ORIS Plant Code

Note: Discussion of baseline APCDs is found in Table 1.

na = data not available

* FGP changed between baseline and 2000 with no change in FGD

** FGD added between baseline and 2000 with no change in FGP

*** Although French Island (WI) has nil ex ante and ex post Cl (Hg) costs, it is included in the summary results in Table 14.

[a] = ex ante cost estimate derived by authors because Table 4 does not include the change in APCD configuration between baseline and 2000 exhibited by MWC (see Table A.14 in the Appendix for a more detailed explanation of derivation of ex ante values)

Table 14
Comparison of Ex Ante and Ex Post Aggregate Capital Costs for Existing MWCs
(Source: GAA, 2006)

# of MWCs	FGD+FGP	FGD+FGP+SNCR+CI
Ex post > Ex ante	9	5
Ex post < Ex ante	1	5
Ex post / Ex ante		
Mean	1.69	1.04
Median	1.67	1.06
Minimum	0.22	0.30
Maximum	2.68	1.63