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Technical Memorandum

Estimating Annual Excess PM2.5 Emissions and Associated Health Costs from a 3-year Delay of Step 2 New Source Performance Standards (NSPS) for Residential Wood Burning Devices[1]

October 10, 2018

Background

The federal Clean Air Act requires EPA to review and update New Source Performance Standards (NSPS), if appropriate, at least every eight years. Despite this statutory requirement, EPA did not revise the original Residential Wood Heater NSPS for almost 30 years after its inception in 1988. During that time, the universe of unregulated residential wood heating devices greatly expanded, including outdoor wood boilers, pellet stoves, single-burn-rate stoves, and wood furnaces. In some cases, these units have created significant public health and pollution issues, forcing over 50 state and local regulatory agencies to enact emissions standards for different devices not covered by the federal NSPS.

In 2015, EPA finally revised the 1988 NSPS to address this product diversity, and create a level playing field among the new product categories.[2] Furthermore, the 2015 NSPS program struck a balance between state and industry needs by providing additional time for cleaner technology development through a 2-step process. The more stringent Step 2 NSPS requirements are currently set to take effect in 2020. The 2015 NSPS is already fostering industrial innovation by North American wood burning equipment manufacturers as highlighted by the numerous devices that are now on the market at Step 2 levels. Despite this progress, and the investments made by manufacturers to develop cleaner and more energy efficient devices for consumers, the Step 2 NSPS may be delayed for an additional 3 years beyond 2020, with no assurance that the more advanced Step 2 standards will eventually go into effect.

Estimating Excess Direct PM2.5 Emissions and Health Costs

This document provides estimates of excess direct fine particulate (PM2.5) emissions and health costs if the Step 2 New Source Performance Standards (NSPS) for residential wood burning devices are delayed by 3 years. An accompanying spreadsheet shows the inputs and calculations for the estimates. Also attached are two sources of information used for inputs into the calculations:

[1] This information was developed by the Northeast States for Coordinated Air Use Management (NESCAUM), the regional association of the state air pollution control agencies in Connecticut, Maine, Massachusetts, New Hampshire, New Jersey, New York, Rhode Island, and Vermont. Any opinions expressed in this document reflect the member agencies' majority consensus and are not necessarily the views of an individual member state.
[2] 80 Fed. Reg. 13672-13753 (March 16, 2015).

1. January 30, 2015 memorandum from EC/R to the U.S. Environmental Protection Agency (EPA)[3] that is the source of the assumed emission rates and other data used in the spreadsheet calculations.
2. Tables 7-2 and 7-3 from the February 2015 Regulatory Impact Analysis[4] of the final NSPS rule that provide EPA estimates of health impacts and costs from wood device PM2.5 emissions on a national scale.

The spreadsheet with excess PM2.5 emission estimates is annotated to indicate assumptions taken from the EC/R memo. These include:

1. We use the same Step 1 and Step 2 rates given in the EC/R memo. These rates were used by EPA in the final NSPS RIA (Feb. 2015). Note that the Step 1 rates for residential wood stoves do not differ from the baseline rates, so EPA's estimated benefits do not assume PM2.5 reductions from this source class until the Step 2 rates apply in 2020. EPA indicated in the final NSPS that its approach would automatically certify over 85% of wood heaters/stoves as compliant with Step 1 with no additional effort by the majority of manufacturers. This allows manufacturers instead to focus on R&D to develop Step 2 compliant devices by 2020. The major share of PM2.5 reductions from Step 1 in the RIA occur from regulating previously federally unregulated sources, including single burn rate stoves, indoor cordwood furnaces, and hydronic heating systems. We note that for states with regulations that addressed some or all of these units, Step 1 resulted in little to no emission reductions, with the major share of emission reductions expected under Step 2.
2. We assume that a 3-year delay in the Step 2 limits applies to all device types in EPA's final rule.
3. For annual sales during a 3-year delay, we average the projected calendar year sales across 2020, 2021, and 2022. This technically differs from the current effective NSPS Step 2 date starting on May 15, 2020 but averaging over calendar years should not create a significant difference in estimating 12-month sales during a 3-year period.
4. We assume a 20-year in-use lifespan for all device types, per the EC/R memo. This may be conservative, as the U.S. Energy Information Agency uses a 25-year average lifetime for wood burning devices.[5] To maintain consistency, however, the analysis used the EC/R memo's lifespan assumption.

For estimating annual excess avoidable health incidences and costs, we directly scaled the estimated annual excess PM2.5 emissions from the 3-year NSPS delay (2,536 tons/yr) by the

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[3] Memo to EPA from EC/R Inc., *Estimated Emissions from Residential Wood Heaters*, EPA-HQ-OAR-2009-0734-1760 (Jan. 30, 2015).
[4] U.S. EPA, *Regulatory Impact Analysis (RIA) for Residential Wood Heaters NSPS Revision*, Final Report, EPA-452/R-15-001 (Feb. 2015).
[5] U.S. Energy Information Agency, *Updated Buildings Sector Appliance and Equipment Costs and Efficiencies*, (June 2018). Available at https://www.eia.gov/analysis/studies/buildings/equipcosts/pdf/full.pdf.

PM2.5 emissions and health impacts from EPA's February 2015 RIA for the final NSPS, as shown in the spreadsheet.

Results

Based on this methodology, we estimate that 50,715 tons of excess direct PM2.5 emissions aggregated across an assumed 20-year in-use device lifespan will occur if the Step 2 NSPS is delayed by 3 years. For context, this is comparable to the total 2014 annual residential wood combustion (RWC) emissions occurring collectively in the states of California, Colorado, Idaho, New York, Utah, West Virginia, and Wisconsin.[6] For these states, their summed RWC PM2.5 emissions in 2014 are 50,460 tons. While the timescales differ, the comparison does provide a comparative sense of the magnitude of the excess emissions.

On an annual basis over an assumed 20 year in-use lifetime for the RWC appliances, we estimate 2,536 tons/yr in excess direct PM2.5 emissions from a 3-year delay in the NSPS during the 2020-2022 timeframe. More than half the excess PM2.5 emissions (1,636 tons/yr) are estimated to come from the delay in the wood furnace NSPS due to the high average Step 1 emission rate for this appliance type and the large decrease between its Step 1 and Step 2 emission rates.

Scaling these emissions to the health impacts reported in EPA's February 2015 Regulatory Impact Analysis (EPA-452/R-15-001), we estimate 110 to 360 additional deaths per year from the excess PM2.5 emissions during 2020-2022. Similarly, we estimate the additional health costs from delaying the NSPS by 3 years to be in the range of $1.0 billion to $2.3 billion annually (2013$, 3% discount rate) during the 2020-2022 timeframe.

While we scale mortality impacts to the results in the EPA analysis, recent research indicates that increased mortality risks from short-term and long-term exposure to PM2.5 concentrations below the 24-hour and annual national ambient air quality standards (NAAQS) may be substantially higher than the estimated increased mortality risks used by EPA, which are based on studies at higher PM2.5 concentrations.[7] Therefore, our estimated increases in avoidable deaths from a 3-year delay in the NSPS may be low in light of more recent research.

[6] Based on state-level residential wood combustion emissions reported in the EPA 2014 National Emissions Inventory (NEI).

[7] Di, Q., *et al.* "Air pollution and mortality in the Medicare population." *New England Journal of Medicine* 376.26 (2017): 2513-2522. DOI: 10.1056/NEJMoa1702747; Di, Q., *et al.* "Association of short-term exposure to air pollution with mortality in older adults." *JAMA* 318.24 (2017): 2446-2456. DOI: 10.1001/jama.2017.17923.

MEMORANDUM

DATE: January 30, 2015

SUBJECT: Estimated Emissions from Residential Wood Heaters

FROM: Jill Mozier, EC/R Inc.
Beth Friedman, EC/R Inc.

TO: David Cole, EPA/OAQPS
Gil Wood, EPA/OAQPS
Amanda Aldridge, EPA/OAQPS

The purpose of this memorandum is to present an estimate of the fine particulate matter ($PM_{2.5}$), volatile organic compound (VOC) and carbon monoxide (CO) emissions from wood heater appliances based on projected sales of new units and based on emissions under the final NSPS.

I. PM Methodology

A. Estimating Average Emissions per Appliance

We used the EPA Residential Wood Combustion (RWC) emission estimation tool[1], which is an Access™ database that compiles nationwide RWC emissions using county level, process specific data and calculations. We summed the nationwide number of appliances and total tons of wood burned for each of the relevant emission inventory categories (Table 1) in the inventory.

Table 1. RWC Emission Inventory Categories Used

Woodstove: fireplace inserts; EPA certified; non-catalytic
Woodstove: fireplace inserts; EPA certified; catalytic
Woodstove: freestanding, EPA certified, non-catalytic
Woodstove: freestanding, EPA certified, catalytic
Woodstove: pellet-fired, general
Woodstove: freestanding, non-EPA certified
Hydronic heater: outdoor
Furnaces: indoor, cordwood

[1] Emission factors are based on EPA's Residential Wood Combustion Tool version 4.1 with updates from the 2012 EPA report (Gullett et al. Environmental, Energy Market, and Health Characterization of Wood-Fired Hydronic Heater, Final Report, June 2012).

We then made some adjustments/assumptions to the baseline RWC inventory. First, we deleted data in the RWC database for non-certified stoves and inserts, as these cannot be sold. With the exception of wood stoves, we applied the $PM_{2.5}$ emission factors for each class to the total tons of wood burned and calculated an average emission rate/appliance/category.

In the case of wood stoves, the RWC database uses an average of all PM_{10} AP-42 emission factors.[2] The RWC database assumes that PM_{10} and $PM_{2.5}$ factors are identical. At a minimum, we estimate that all new wood stoves meet the AP-42 PM_{10} emission factors for "Phase II" stoves (the current NSPS promulgated in 1988) and therefore started with the lower AP-42 Phase II emission factors for catalytic and non-catalytic stoves at baseline, rather than the higher average of all AP-42 emission factors used in the RWC database. Furthermore, to avoid any potential for overstating baseline emissions, we went a step further and assumed that all new shipments will meet the current Washington State limits, which are approximately 40 percent less than the 1988 NSPS Phase II limits. We therefore used baseline emission factors which are 60 percent of the AP-42 Phase II emission factors – less than half the value used in the RWC to represent the average of all AP-42 emission factors – in order to ensure a forward-looking and understated baseline.

Second, we estimated that outdoor hydronic heaters and indoor hydronic heaters have the same emission profile.

Single burn rate stoves are not included in the RWC database as separate identifiable units. We estimated that they would have the same baseline emission factor as freestanding non-certified wood stoves, i.e., 30.6 lb/ton of wood burned. We used the average tons burned per appliance factor as representative of these stoves as well.

We used this subset of the RWC database to calculate a baseline average emission rate/appliance (or "emission inventory category"), including an adjustment of the RWC emission factor to the current Washington State limits for currently certified wood stoves, as discussed above. We multiplied the total tons of wood burned for the appliance by the RWC emission factor (adjusted as appropriate) to calculate the total tons of $PM_{2.5}$ emissions. We divided this value by the number of appliances in the category to calculate the baseline average $PM_{2.5}$ emissions per individual appliance (Table 2).

[2] AP-42, Chapter 1.10, Residential Wood Stoves, Table 1.10-1. See: http://www.epa.gov/ttnchie1/ap42/ch01/final/c01s10.pdf.

Table 2. $PM_{2.5}$ Tons per Appliance Estimate (Baseline)

Emission Inventory Category	Pollutant	Baseline Emission factor (lb/ton)	Baseline Emissions (tons)	Baseline Tons/appl
Woodstove: fireplace inserts; EPA certified; non-catalytic	Primary PM2.5	8.76	5,371	0.0041
Woodstove: fireplace inserts; EPA certified; catalytic	Primary PM2.5	9.72	2,023	0.0047
Woodstove: freestanding, EPA certified, non-catalytic	Primary PM2.5	8.76	6,745	0.0077
Woodstove: freestanding, EPA certified, catalytic	Primary PM2.5	9.72	3,769	0.0101
Woodstove: pellet-fired, general	Primary PM2.5	3.06	1,798	0.0021
Single Burn Rate Stoves*	Primary PM2.5	30.6	71,424	0.0324
Hydronic heater: outdoor	Primary PM2.5	64	116,933	0.3208
Furnace: indoor, cordwood	Primary PM2.5	64	83,972	0.2392

*Non-EPA certified wood stove emission factor and tons/appliance were used to represent single burn rate stoves.

The next step was to develop emission factors representing the final NSPS. The NSPS limits used in this analysis are based on phased-in compliance dates, or "steps", for subcategories of appliances. Subpart AAA will regulate "room heaters" and includes adjustable burn rate stoves, single burn rate stoves, and pellet stoves. Subpart QQQQ will regulate "central heaters" and includes outdoor and indoor hydronic heaters and forced-air furnaces. Following is a summary of the current NSPS implementation assumptions for appliances within the regulated subcategories. The final NSPS is a phased standard with compliance dates of 2015 and 2020 for all appliances. In addition, forced-air furnaces will have a Step 1 PM emission limit for small forced-air furnaces in 2016 and for large forced-air furnaces in 2017, as discussed below. The Step 2 PM emission limit compliance date is 2020 for all appliances.

Subpart AAA ("room heaters"):

> Adjustable burn rate, single burn rate, and pellet stoves: **Step 1 PM emission limit** of 4.5 g/hr upon promulgation in 2015; and **Step 2 PM emission limit** of 2.0 g/hr five years after promulgation in 2020. **Note**: The Step 1 limit is the 1995 Washington State standard for non-catalytic stoves; and the Step 2 limit is already met by the top performing catalytic, non-catalytic and pellet stove models. Specifically, this industry data from 2010 indicate that approximately 90% (130 out of 145 catalytic, non-catalytic and pellet stoves combined) already meet the Step 1 limit.[3] We expect that manufacturers will focus on existing models that meet the Washington State limits in order to comply with the Step 1 standard. Furthermore, certification data indicate that 26% of non-catalytic and catalytic stoves combined and 70% of pellet stoves already meet the Step 2 standard.[4] Although previously unregulated and a less developed technology than adjustable burn rate stoves, single burn rate

[3] Final HPBA Heater Database version 2/25/10, EC/R received from Bob Ferguson for HPBA on 4/26/10
[4] Memorandum to USEPA from EC/R, Inc. Derivation of wood heater model percentages meeting Step 2 standards. November 2014.

stove designs have been undergoing R&D in anticipation of the proposed NSPS and cleaner designs are nearly market-ready.[5]

Subpart QQQQ ("central heaters"):

- Hydronic heaters (both outdoor and indoor): **Step 1 PM emission limit** of 0.32 lb/mm BTU heat output (weighted average and an 18 g/hr cap for each individual test run) upon promulgation in 2015; and **Step 2 PM emission limit** of 0.10 lb/mm BTU heat output (at each burn rate) five years after promulgation in 2020. **Note**: The Step 1 limit is identical to the EPA "Phase 2" voluntary program limit and is therefore already met by all 50 of the 50 currently Phase 2 qualified hydronic heater models built by U.S. manufacturers participating in the voluntary program. In addition, there are 19 qualification tests that have been recently submitted to EPA and, if valid, are all expected to be added to the Phase 2 qualification list very soon. The Step 2 limit is already met by 9 of the 50 (18%) hydronic heater models built by U.S. manufacturers participating in the voluntary program[6], as well as over 100 European manufacturers per test method EN 303-05.[7] It should be noted that to-date cleaner models continue to become Phase 2 qualified and additional manufacturers not participating in the voluntary program may also have models meeting Step 1 and Step 2. We assume that 18% of existing hydronic heaters can meet the Step 2 limit without intensive R&D efforts.

- Forced-Air Furnaces: Work practice/operational standards will be required of all forced-air furnaces upon the rule's 2015 effective date. A **Step 1 PM emission limit** of 0.93 lb/mm BTU heat output will be required by 2016 (1 year after the 2015 effective date) for small forced-air furnaces (<65,000 BTU/hr models, representing approximately 25% of current sales) and this same limit of 0.93 lb/mm BTU will be required by 2017 (2 years after the 2015 effective date) for large forced-air furnaces (≥65,000 BTU/hr models, representing approximately 75% of current sales). A **Step 2 PM emission limit** of 0.15 lb/mm BTU heat output will be required for all forced-air furnace models five years after promulgation in 2020. **Note**: The phased timelines are based on the technological and economic limitations of testing and certifying approximately 50 previously untested forced–air furnaces in the 60 days between signature and the effective date and also on industry comments on the proposed rule, explaining the design challenges for small and large forced-air furnaces, respectively. The Step 1 PM emission limits and the Step 2 PM emission limits are based on test data from development of the Canadian standard B415.1-10[8], conversations with industry regarding cleaner forced-air furnace models currently being tested in R&D[9] and comments on the proposed rule. Forced-air furnace designs able to meet the Step 2 PM emission limit are expected to be based on technology transferred from hydronic heater designs and/or wood stove designs.

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[5] 2/8/13 telephone discussion between Gil Wood, USEPA, and a manufacturer of single burn rate stoves.
[6] See list of cleaner hydronic heaters participating in EPA's Phase 2 voluntary Hydronic Heater Program at http://www.epa.gov/burnwise/owhhlist.html.
[7] European Wood-Heating Technology Survey: An Overview of Combustion Principles and the Energy and Emissions Performance Characteristics of Commercially Available Systems in Austria, Germany, Denmark, Norway, and Sweden; Final Report; Prepared for the New York State Energy Research and Development Authority; NYSERDA Report 10–01; April 2010.
[8] CSA B415.1-10, Performance Testing of Solid-Fuel-Burning Heating Appliances. Appendix D. March 2010.
[9] 2/8/13 telephone discussion between Gil Wood, USEPA, and a manufacturer of forced-air furnaces.

We developed adjusted emission factors to reflect the limits discussed above, which were then used to calculate new average tons of emissions per appliance for each RWC appliance type in Tables 1 and 2. Adjustments were assumed for NSPS emission factors (as noted below) in order to not over state emission reductions. Actual emission reductions may be greater than reductions resulting from our emission factor adjustments for the purpose of this analysis. Following is a description of how the RWC factors were adjusted for each appliance type.

- Woodstove: all EPA certified. As noted above, we determined the ratio of emissions between the existing 1988 NSPS limits compared to the Washington State standards. For both catalytic and non-catalytic devices, the Washington standard is 60% of the 1988 NSPS. We assumed this same ratio would apply to the emission factors and multiplied the RWC emission factor (for Phase II certified models) by 60%. We used these adjusted RWC emission factors (shown in Table 2) as both baseline and Step 1 PM emission factors for catalytic and non-catalytic stoves. It should be noted that the assumption that at baseline all wood stoves already meet the Washington State standards may slightly underestimate baseline emissions, as not 100% of wood stoves currently sold do meet the Washington State standards. We made this simplifying assumption in order to avoid any potential for overstating baseline emissions.

  Furthermore, we estimated that the Step 1 PM emission factor was the same as the baseline emission factor, because, as noted above, approximately 90% of current wood stove models already meet the Step 1 PM limit according to industry data.[10] For the Step 2 PM emission factor for non-catalytic models, we scaled the Step 1 PM emission factor by the ratio of the Step 2 PM limit to the Step 1 PM limit (or 2.0/4.5 = 0.44). Again, in order to not overstate emission reductions, for catalytic models, we scaled the Step 1 PM emission factor by the ratio of the Step 2 PM limit to the Washington State PM standard for catalytic stoves (or 2.0/2.5 = 0.8). For consistency with our shipment data (described in section B) and because the RWC database provides four separate emission factors for catalytic and non-catalytic, freestanding models and fireplace inserts, we used the weighted average value for all four wood stove types to represent the total population of adjustable burn rate wood stoves. Finally, we multiplied the resulting PM emission factors by the total tons burned for the appliance type (provided by the RWC database) and then divided that by the appliance population (also provided by the RWC database) to derive the tons/appliance of $PM_{2.5}$ emissions. The emission factors and tons/appliance are shown in the green rows in Table 3.

- Woodstove: pellet fired, general. We used the RWC emission factor shown in Table 2 as both the baseline and Step 1 PM emission factor for pellet stoves because nearly all current pellet stove models already meet the Step 1 PM standard according to industry data.[10] For the Step 2 PM emission factor, we scaled the Step 1 PM emission factor by the ratio of the Step 2 PM limit to the Step 1 PM limit (or 2.0/4.5 = 0.44). We multiplied the resulting emission factors by the total tons burned for pellet stoves and then divided that by the pellet stove appliance population to derive the tons/appliance of $PM_{2.5}$ emissions. The emission factors and tons/appliance are shown in the orange row in Table 3.

[10] Final HPBA Heater Database version 2/25/10, EC/R received from Bob Ferguson for HPBA on 4/26/10

- Woodstove: freestanding, non-EPA certified (single burn rate stoves). As described above, we assumed that the freestanding non-EPA certified wood stove emission inventory category includes the population of single burn rate stoves. We therefore used the RWC emission factor for freestanding non-EPA certified wood stoves (30.6 lb/ton) as the baseline emission factor for single burn rate stoves. For the Step 1 PM emission factor, we used the same emission factor as a certified non-catalytic stove meeting the Washington State PM standards (i.e., 8.76 lb/ton) because the same standard is being proposed for single burn rate stoves as for adjustable burn rate stoves. Likewise, we used the same emission factor used for non-catalytic stoves for the Step 2 PM emission factor. We multiplied the resulting emission factors by the total tons burned for this appliance category and then divided that by the appliance population to derive the tons/appliance of $PM_{2.5}$ emissions. The emission factors and tons/appliance are shown in the grey row in Table 3.

- Hydronic heater: outdoor/indoor. As noted above, we estimated that indoor hydronic heaters (a minority of the hydronic heater population) have the same emission profile as the outdoor hydronic heater appliance category provided in the RWC. According to the EPA voluntary hydronic heater program, the "Phase 2" heaters that are presumed to represent the Step 1 limit are 90% cleaner than older unqualified units, as determined in laboratory tests on crib wood.[11] We estimate that the majority of the existing inventory is represented by these unqualified units, and applied a 90% reduction to the RWC baseline emission factor shown in Table 2 (64 lb/ton) in order to derive the Step 1 PM emission factor (of 6.4 lb/ton). For the Step 2 PM emission factor, we scaled the Step 1 PM emission factor by the ratio of the Step 2 PM limit to the Step 1 PM limit (or 0.10/0.32 = 0.31). We multiplied the resulting emission factors by the total tons burned for the hydronic heater RWC appliance category and then divided that by the hydronic heater appliance population to derive the tons/appliance of $PM_{2.5}$ emissions. The emission factors and tons/appliance are shown in the blue row in Table 3.

- Furnace: indoor, cordwood. At baseline, we estimated that forced-air furnaces have the same updated emission factor as hydronic heaters (64 lb/ton), consistent with the fact that hydronic heaters and forced-air furnaces have the same emission factor in version 4.1 of EPA's RWC tool.[12] For the Step 1 PM emission factor, we scaled the baseline emission factor by 75% (to 16 lb/ton) because background material provided in the Canadian standards review process stated that that the emission limit associated with this method would result in an approximately 75% reduction in emissions compared to a non-qualifying furnace.[13] We estimate that the Step 2 PM emission limit of 0.15 lb/mm BTU (based on cord wood, consistent with the test method) is roughly equivalent to the hydronic heater crib wood-based limit of 0.10 lb/mm BTU. We also estimate that the baseline emission factor for each appliance category is the same; therefore we used the same Step 2 PM emission factor for forced-air furnaces as used for hydronic heaters (2.00 lb/ton). We multiplied the emission factors by the total tons burned for the cordwood furnace RWC appliance category and then

[11] See the EPA Burn Wise Website regarding the Hydronic Heater Voluntary Program: http://www.epa.gov/burnwise/participation.html.
[12] Emission factors are based on EPA's Residential Wood Combustion Tool version 4.1 with updates from the 2012 EPA report (Gullett et al. Environmental, Energy Market, and Health Characterization of Wood-Fired Hydronic Heater, Final Report, June 2012).
[13] CSA B415.1-10, Performance Testing of Solid-Fuel-Burning Heating Appliances. Appendix D. March 2010.

divided that by the furnace appliance population to derive the tons/appliance of $PM_{2.5}$ emissions. The emission factors and tons/appliance are shown in the lavender row in Table 3.

Table 3 shows the baseline, Step 1 PM emission factor and Step 2 PM emission factor for each appliance type resulting from our assumptions and adjustments described above. We used the appropriate tons/appliance with annual shipment data (Section B) to estimate annual $PM_{2.5}$ emissions (Section C), based on the phased emission reduction dates.

Table 3. NSPS Adjusted Emission Factors for $PM_{2.5}$ – Baseline, Step 1 PM Emission Limits and Step 2 PM Emission Limits

Emission Inventory Category	Pollutant	Baseline Emission factor (lb/ton)	Baseline Emissions (tons)	Baseline Tons/appl	2015* Step 1 Emission Factor	2015* Step 1 Emissions (tons)	2015* Step 1 Tons/appl	2020 Step 2 Emission Factor	2020 Step 2 Emissions (tons)	2020 Step 2 Tons/appl
Woodstove: fireplace inserts; EPA certified; non-catalytic	Primary PM2.5	8.76	5,371	0.0041	8.76	5,371	0.0041	3.89	2,387	0.0018
Woodstove: fireplace inserts; EPA certified; catalytic	Primary PM2.5	9.72	2,023	0.0047	9.72	2,023	0.0047	7.78	1,618	0.0038
Woodstove: freestanding, EPA certified, non-catalytic	Primary PM2.5	8.76	6,745	0.0077	8.76	6,745	0.0077	3.89	2,998	0.0034
Woodstove: freestanding, EPA certified, catalytic	Primary PM2.5	9.72	3,769	0.0101	9.72	3,769	0.0101	7.78	3,016	0.0081
Woodstove: pellet-fired, general	Primary PM2.5	3.06	1,798	0.0021	3.06	1,798	0.0021	1.36	799	0.0009
Single Burn Rate Stoves	Primary PM2.5	30.6	71,424	0.0324	8.76	20,447	0.0093	3.89	9,088	0.0041
Hydronic heater: outdoor	Primary PM2.5	64	116,933	0.3208	6.4	11,693	0.0321	2.00	3,654	0.0100
Furnace: indoor, cordwood*	Primary PM2.5	64	83,972	0.2392	16	20,993	0.0598	2.00	2,624	0.0075

0.0060	Baseline woodstove weighted average (Tons/appl)
0.0060	2015 Step 1 woodstove weighted average (Tons/appl)
0.0034	2020 Step 2 woodstove weighted average (Tons/appl)

*For forced-air furnaces, the compliance dates are 2015 for work practice/operational standards, 2016 for the Step 1 PM emission limit for small furnaces and 2017 for the Step 1 PM emission limits for large furnaces.

B. Shipment Data, Model Design Lifespan and Emitting Lifespan

We used data in the Frost & Sullivan Market (F&S) report[14] on 2008 shipments by product category, and F&S revenue forecasts which incorporated the weak economy in years 2009 and 2010, to calculate the reduced number of shipments in years 2009 and 2010. Forced air furnaces were outside the scope of the F&S report. Instead, we used manufacturer estimates of total industry sales in 2008[15] and applied the F&S market factors to estimate shipments through 2010. The F&S wood stove numbers included both certified and non-certified stoves, so we estimated numbers of non-certified stove shipments out of the total reported wood stove category (i.e., 40,000 single burn rate stoves shipped in 2008).[15] These shipments were deleted from the total wood stove category shipments. We expanded the 2008 single burn rate estimate using the F&S factors.

For years 2011 through 2029 estimated shipments are generally based on a forecasted revenue growth rate of 2.0%, in keeping with the average annual growth in real GDP predicted by the US Bureau of Economic Analysis.[16] There is not a perfect correlation between shipments and revenue (for example, because of their higher unit cost, pellet stoves generate more absolute revenue than wood stoves), but we think the overall trend in the projection is reasonable in the absence of specific shipment projections. The only exceptions to the use of a 2.0% GDP-based growth rate are for years 2012 and 2018, in which we used industry estimates for hydronic heater and wood stove shipments, respectively. For year 2012, an HPBA consultant estimated there were 13,100 baseline hydronic heater sales.[17] For year 2018, the same HPBA consultant projected there to be 100,000 wood stove sales.[18] We adjusted our estimated shipment data accordingly. (It should be noted that these two industry estimates are slightly higher than the estimates for those years would be based on the 2.0% GDP-based growth rate; but over the entire analysis period, using the predicted GDP growth rate as a basis is appropriate.) Table 4 on the next page shows a truncated summary of the shipment data through year 2023.

Our cost effectiveness analysis (CE)[19] assumes a 10-year model design lifespan as well as a 20-year use/emitting appliance lifespan. These assumptions were made to best characterize the actual model design and use lifespans. For proposal, we used a 20-year model design lifespan, reasoning that many models developed for the 1988 NSPS are still being sold (after 25 years), with many "new" models retaining the same internal working parts with merely exterior cosmetic changes. Respectful of comments on the proposed rule[20], however, in which some

[14] Market Research and Report on North American Residential Wood Heaters, Fireplaces, and Hearth Heating Products Market. Prepared by Frost & Sullivan. April 26, 2010. P. 31 -32.
[15] NSPS Review and Comments. Confidential Business Information submitted by manufacturer. September 2010.
[16] Global Economic Outlook 2014, projections prepared by the Conference Board, May 2014 update; http://www.conference-board.org/data/globaloutlook.cfm
[17] Cost-Effectiveness Analysis of Alternative Hydronic Heater New Source Performance Standards, prepared for the Hearth, Patio, and Barbecue Association by NERA Economic Consulting, May 2014. (Attachment 3 of HPBA's comment to the Docket EPA-HQ-OAR-2009-0734)
[18] Cost-Effectiveness Analysis of Alternative Woodstove New Source Performance Standards, prepared for the Hearth, Patio, and Barbecue Association by NERA Economic Consulting, May 2014. (Attachment 2 of HPBA's comment to Docket EPA-HQ-OAR-2009-0734)
[19] Memorandum to USEPA from EC/R, Inc. Residential Wood Heater Cost Effectiveness Analysis. January, 2015.
[20] Comments on the proposed NSPS are available electronically through http://www.regulations.gov by searching Docket IDs EPA-HQ-OAR-2009-0734.

industry representatives commented that a shorter model lifespan is more accurate, we reduced our assumed model design lifespan to 10 years for this analysis. Regarding the emitting lifespan of the appliance, most wood heaters in consumer homes emit for at least 20 years and often much longer. Therefore our CE analysis tracks shipments through year 2029 (assuming a 10-year design life for a model meeting the Step 2 limit in year 2020) and emissions through year 2048 (assuming a 20-year emitting life for an appliance shipped in year 2029). Table 4 is a truncated summary of our actual shipment data which extended through years 2029. See the CE analysis spreadsheets[21] for the complete shipment data.

C. Estimated $PM_{2.5}$ Emissions from Shipments of New Appliances

As described above, we calculated the average emissions per appliance type using the emission factor for each category multiplied by the inventory value of total tons of wood burned divided by the number of appliances in the inventory population. This tons/appliance value was then multiplied by the number of shipments to calculate total emissions from each appliance category per year under baseline conditions, i.e., in the absence of an NSPS. In order to not overstate potential emission reductions, baseline emissions were discounted by the percentage of appliances already meeting the Step 2 PM emission limits (i.e., the 26% of wood stoves, 70% of pellet stoves, and 18% of hydronic heaters estimated to already meet Step 2 PM emission limits, as noted in subsection A).

Table 5 on the next page shows a truncated summary of the estimated $PM_{2.5}$ emissions (in tons) under baseline conditions through year 2023. We then estimated emissions under the NSPS (Table 6) based on the phased-in timeline for each appliance. The emission estimates assume that the total number of shipped units meet the PM emission limit in the year the PM emission limit is required. As noted above, we discounted NSPS emissions by the percentage of appliances already meeting the Step 2 PM emission limit. Tables 5 and 6 show emission estimates out to year 2023 under baseline and NSPS scenarios. Like Table 4, these are truncated summaries.

Our CE analysis tracks emission reductions out through 2048, assuming a 10-year design life for a model meeting each phased-in (stepped) limit, and assuming that stoves shipped in the 10^{th} year of design life will be emitting in homes for another 20 years. The CE analysis[22] incorporates "trailing emissions" as part of our 20-year emitting lifespan assumption. For example, our analysis estimates that a stove shipped in 2015 will emit in homes for 20 years – or until 2034 (inclusive of both 2015 and 2034). We therefore drop emissions from this stove in our analysis in year 2035. Likewise, we drop emissions for a stove shipped in 2016 in year 2036, and so on. The CE analysis spreadsheets show all years of emission data, under both baseline and NSPS scenarios, as well as cumulative $PM_{2.5}$ emission reductions through year 2048. Spreadsheets are provided for appliances regulated under Subpart AAA "Room Heaters" (i.e., wood stoves, pellet stoves, and single burn rate stoves), as well as for appliances under Subpart QQQQ "Central Heaters" (i.e., forced air furnaces and hydronic heaters). The CE analysis[22] also includes a spreadsheet showing cumulative emissions and emission reductions for Subparts AAA and QQQQ combined.

[21] *See* January 2015 cost effectiveness (CE) spreadsheets including for $PM_{2.5}$ the *Revised Final Wood Heater NSPS PM CE 7%* for the CE analysis supporting the NSPS. All of these spreadsheets are found in the public docket for this rulemaking.

[22] Memorandum to USEPA from EC/R, Inc. Residential Wood Heater Cost Effectiveness Analysis. January, 2015.

Table 4. Estimated Annual Shipped Units

	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022	2023
Wood Stoves	126,527	80,851	77,617	79,169	80,752	82,367	84,015	85,695	87,409	89,157	100,000	102,000	104,040	106,121	108,243	110,408
Single Burn Rate Stoves	40,000	25,560	24,538	25,028	25,529	26,039	26,560	27,091	27,633	28,186	28,750	29,325	29,911	30,509	31,120	31,742
Pellet Stoves	130,381	83,313	79,981	81,581	83,212	84,876	86,574	88,305	90,072	91,873	93,710	95,585	97,496	99,446	101,435	103,464
Furnace: indoor, cordwood	41,000	26,199	25,151	25,654	26,167	26,690	27,224	27,769	28,324	28,891	29,468	30,058	30,659	31,272	31,898	32,536
Hydronic Heating Systems	13,385	8,553	8,211	8,375	13,100	13,362	13,629	13,902	14,180	14,463	14,753	15,048	15,349	15,656	15,969	16,288

Table 5. Estimated $PM_{2.5}$ Emissions (Tons) – Baseline Scenario*

	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022	2023
Wood Stoves	563	360	345	352	359	367	374	381	389	397	445	454	463	472	482	491
Single Burn Rate Stoves	1,295	827	794	810	826	843	860	877	895	912	931	949	968	988	1,007	1,027
Pellet Stoves	83	53	51	52	53	54	55	56	57	59	60	61	62	63	65	66
Furnace: indoor, cordwood	9,808	6,267	6,017	6,137	6,260	6,385	6,513	6,643	6,776	6,911	7,049	7,190	7,334	7,481	7,631	7,783
Hydronic Heating Systems	3,520	2,250	2,160	2,203	3,446	3,514	3,585	3,656	3,730	3,804	3,880	3,958	4,037	4,118	4,200	4,284
Total	**15,269**	**9,757**	**9,367**	**9,554**	**10,944**	**11,163**	**11,386**	**11,614**	**11,846**	**12,083**	**12,365**	**12,612**	**12,865**	**13,122**	**13,384**	**13,652**

*Estimates are reduced for the percentage of appliances assumed to already meet the Step 2 PM emission limit (26% of wood stoves, 70% of pellet stoves and 18% of hydronic heaters), in order to not overstate emission reductions attributable to this NSPS.

Table 6. Estimated $PM_{2.5}$ Emissions (Tons) – NSPS Scenario*

	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022	2023
Wood Stoves	563	360	345	352	359	367	374	381	389	397	445	454	259	264	269	275
Single Burn Rate Stoves	1,295	827	794	810	826	843	860	251	256	261	266	272	123	126	128	131
Pellet Stoves	83	53	51	52	53	54	55	56	57	59	60	61	28	28	29	29
Furnace: indoor, cordwood	9,808	6,267	6,017	6,137	6,260	6,385	6,513	6,643	5,505	1,728	1,762	1,798	229	234	238	243
Hydronic Heating Systems	3,520	2,250	2,160	2,203	3,446	3,514	3,585	366	373	380	388	396	126	129	131	134
Total	**15,269**	**9,757**	**9,367**	**9,554**	**10,944**	**11,163**	**11,386**	**7,697**	**6,581**	**2,825**	**2,922**	**2,980**	**765**	**780**	**796**	**812**

*Step 1 PM emission limit in 2015 and Step 2 PM emission limit in 2020 for all appliances, except forced-air furnaces have work practice/operational standards in 2015, Step 1 PM emission limits for small furnaces in 2016, Step 1 PM emission limits for large furnaces in 2017 and Step 2 PM emission limits for all furnaces in 2020. In order to not overstate emission reductions attributable to this NSPS, estimates are reduced for the percentage of appliances estimated to already meet the Step 2 PM emission limits (26% of wood stoves, 70% of pellet stoves and 18% of hydronic heaters). In this analysis, emission reductions for forced-air furnaces are not quantified for the work practice/operational standard required in 2015, although stakeholders agree that work practice/operational standards will reduce emissions.

II. Volatile Organic Compound Methodology

We used the same methodology described in Section I to develop emission estimates for VOC emissions. Using the RWC database, we developed an estimate of VOC emissions per appliance using baseline emission factors. Then, using the same NSPS phase-in assumptions and anticipated emission reductions (i.e., that VOC reductions are comparable to $PM_{2.5}$ reductions), we developed emission factors, as shown in Table 7.

Next, using the same assumptions as we used for $PM_{2.5}$, we calculated VOC emissions at baseline and under the NSPS scenario for each stepped limit, as shown in Tables 8 and 9.

Finally, cumulative VOC emissions and emission reductions under the NSPS were calculated based on a 10-year model design lifespan for shipments and a 20-year appliance use lifespan for emissions, as explained in Sections I-B and I-C. Although VOC emissions are not being regulated under this NSPS, estimated VOC emissions and emission reductions are provided separately in our CE analysis spreadsheets.[23]

III. Carbon Monoxide Methodology

We used the same methodology described in Section I to develop emission estimates for CO emissions. Using the RWC database, we developed an estimate of CO emissions per appliance using baseline emission factors. Then, using the same NSPS phase-in assumptions and anticipated emission reductions (i.e., that CO reductions are comparable to $PM_{2.5}$ reductions), we developed emission factors, as shown in Table 10.

Next, using the same assumptions as we used for $PM_{2.5}$, we calculated CO emissions at baseline and under the NSPS scenario for each stepped limit, as shown in Tables 11 and 12.

Finally, cumulative CO emissions and emission reductions under the NSPS were calculated based on a 10-year model design lifespan for shipments and a 20-year appliance use lifespan for emissions, as explained in Sections I-B and I-C. Although CO emissions are not being regulated under this NSPS, estimated CO emissions and emission reductions are provided separately in our CE analysis spreadsheets.[24]

[23] *See* January 2015 cost effectiveness (CE) spreadsheets for VOC entitled *Revised Final Wood Heater NSPS VOC CE 7%,* available in the public docket for this rulemaking.
[24] *See* January 2015 cost effectiveness (CE) spreadsheets for CO entitled *Revised Final Wood Heater NSPS CO CE 7%*, available in the public docket for this rulemaking.

Table 7. NSPS Adjusted Emission Factors for Volatile Organic Compounds – Baseline, Step 1 and Step 2

Emission Inventory Category	Pollutant	Baseline Emission factor (lb/ton)	Baseline Emissions (tons)	Baseline Tons/appl	2015 Step 1 Emission Factor	2015 Step 1 Emissions (tons)	2015 Step 1 Tons/appl	2020 Step 2 Emission Factor	2020 Step 2 Emissions (tons)	2020 Step 2 Tons/appl
Woodstove: fireplace inserts; EPA certified; non-cataly	Volatile Organic Compounds	12	7,357	0.0056	12	7,357	0.0056	5.33	3,270	0.0025
Woodstove: fireplace inserts; EPA certified; catalytic	Volatile Organic Compounds	15	3,121	0.0073	15	3,121	0.0073	12.00	2,497	0.0058
Woodstove: freestanding, EPA certified, non-catalytic	Volatile Organic Compounds	12	9,240	0.0106	12	9,240	0.0106	5.33	4,107	0.0047
Woodstove: freestanding, EPA certified, catalytic	Volatile Organic Compounds	15	5,817	0.0155	15	5,817	0.0155	12.00	4,654	0.0124
Woodstove: pellet-fired, general	Volatile Organic Compounds	0.041	24	0.0000	0.041	24	0.0000	0.02	11	0.0000
Single Burn Rate Stoves	Volatile Organic Compounds	53	123,709	0.0561	12	28,010	0.0127	5.33	12,449	0.0056
Hydronic heater: outdoor	Volatile Organic Compounds	67.4	123,145	0.3378	6.74	12,314	0.0338	2.11	3,848	0.0106
Furnace: indoor, cordwood	Volatile Organic Compounds	67.4	88,433	0.2519	16.85	22,108	0.0630	2.11	2,764	0.0079

0.0086	Baseline woodstove weighted average (Tons/appl)
0.0086	2015 Step 1 woodstove weighted average (Tons/appl)
0.0049	2020 Step 2 woodstove weighted average (Tons/appl)

* For forced-air furnaces, the compliance dates are 2015 for work practice/operational standards, 2016 for the Step 1 PM emission limit for small furnaces and 2017 for the Step 1 PM emission limits for large furnaces.

Table 8. Estimated Volatile Organic Compound Emissions (Tons) – Baseline Scenario*

	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022	2023
Wood Stoves	803	513	493	502	512	523	533	544	555	566	635	647	660	673	687	701
Single Burn Rate Stoves	2,243	1,433	1,376	1,403	1,431	1,460	1,489	1,519	1,549	1,580	1,612	1,644	1,677	1,711	1,745	1,780
Pellet Stoves	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
Furnace: indoor, cordwood	10,329	6,600	6,336	6,463	6,592	6,724	6,859	6,996	7,136	7,278	7,424	7,572	7,724	7,878	8,036	8,197
Hydronic Heating Systems	3,707	2,369	2,274	2,320	3,629	3,701	3,775	3,851	3,928	4,006	4,086	4,168	4,251	4,336	4,423	4,512
Total	**17,083**	**10,916**	**10,480**	**10,689**	**12,165**	**12,409**	**12,657**	**12,910**	**13,168**	**13,431**	**13,758**	**14,033**	**14,313**	**14,600**	**14,892**	**15,189**

Table 9. Estimated Volatile Organic Compound Emissions (Tons) – NSPS Scenario*

	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022	2023
Wood Stoves	803	513	493	502	512	523	533	544	555	566	635	647	376	383	391	399
Single Burn Rate Stoves	2,243	1,433	1,376	1,403	1,431	1,460	1,489	344	351	358	365	372	169	172	176	179
Pellet Stoves	1	1	1	1	1	1	1	1	1	1	1	1	0	0	0	0
Furnace: indoor, cordwood	10,329	6,600	6,336	6,463	6,592	6,724	6,859	6,996	5,798	1,820	1,856	1,893	241	246	251	256
Hydronic Heating Systems	3,707	2,369	2,274	2,320	3,629	3,701	3,775	385	393	401	409	417	133	136	138	141
Total	**17,083**	**10,916**	**10,480**	**10,689**	**12,165**	**12,409**	**12,657**	**8,269**	**7,097**	**3,145**	**3,265**	**3,330**	**919**	**937**	**956**	**975**

*Step 1 PM emission limit in 2015 and Step 2 PM emission limit in 2020 for all appliances, except forced-air furnaces have work practice/operational standards in 2015, Step 1 PM emission limits for small furnaces in 2016, Step 1 PM emission limits for large furnaces in 2017 and Step 2 PM emission limits for all furnaces in 2020. In order to not overstate emission reductions attributable to this NSPS, estimates are reduced for the percentage of appliances estimated to already meet the Step 2 PM emission limits (26% of wood stoves, 70% of pellet stoves and 18% of hydronic heaters). In this analysis, emission reductions for forced-air furnaces are not quantified for the work practice/operational standard required in 2015, although stakeholders agree that work practice/operational standards will reduce emissions.

Table 10. NSPS Adjusted Emission Factors for Carbon Monoxide – Baseline, Step 1 and Step 2

Emission Inventory Category	Pollutant	Baseline Emission factor (lb/ton)	Baseline Emissions (tons)	Baseline Tons/appl	2015 Step 1 Emission Factor	2015 Step 1 Emissions (tons)	2015 Step 1 Tons/appl	2020 Step 2 Emission Factor	2020 Step 2 Emissions (tons)	2020 Step 2 Tons/appl
Woodstove: fireplace inserts; EPA certified; non-cataly	Carbon Monoxide	140.8	86,323	0.0662	140.8	86,323	0.0662	62.6	38,366	0.0294
Woodstove: fireplace inserts; EPA certified; catalytic	Carbon Monoxide	104.4	21,725	0.0509	104.4	21,725	0.0509	83.5	17,380	0.0407
Woodstove: freestanding, EPA certified, non-catalytic	Carbon Monoxide	140.8	108,418	0.1241	140.8	108,418	0.1241	62.6	48,186	0.0552
Woodstove: freestanding, EPA certified, catalytic	Carbon Monoxide	104.4	40,486	0.1082	104.4	40,486	0.1082	83.5	32,389	0.0866
Woodstove: pellet-fired, general	Carbon Monoxide	15.9	9,344	0.0110	15.9	9,344	0.0110	7.1	4,153	0.0049
Single Burn Rate Stoves	Carbon Monoxide	230.8	538,716	0.2442	140.8	328,645	0.1489	62.6	146,064	0.0662
Hydronic heater: outdoor	Carbon Monoxide	360	657,748	1.8042	36	65,775	0.1804	11.3	20,555	0.0564
Furnace: indoor, cordwood	Carbon Monoxide	360	472,341	1.3456	90	118,085	0.3364	11.3	14,761	0.0421

0.0863	Baseline woodstove weighted average (Tons/appl)
0.0863	2015 Step 1 woodstove weighted average (Tons/appl)
0.0458	2020 Step 2 woodstove weighted average (Tons/appl)

* For forced-air furnaces, the compliance dates are 2015 for work practice/operational standards, 2016 for the Step 1 PM emission limit for small furnaces and 2017 for the Step 1 PM emission limits for large furnaces.

Table 11. Estimated Carbon Monoxide Emissions (Tons) – Baseline Scenario*

	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022	2023
Wood Stoves	8,079	5,163	4,956	5,055	5,156	5,259	5,365	5,472	5,581	5,693	6,385	6,513	6,643	6,776	6,912	7,050
Single Burn Rate Stoves	9,766	6,241	5,991	6,111	6,233	6,358	6,485	6,614	6,747	6,882	7,019	7,160	7,303	7,449	7,598	7,750
Pellet Stoves	432	276	265	270	275	281	287	292	298	304	310	316	323	329	336	342
Furnace: indoor, cordwood	55,170	35,254	33,844	34,520	35,211	35,915	36,633	37,366	38,113	38,876	39,653	40,446	41,255	42,080	42,922	43,780
Hydronic Heating Systems	19,803	12,654	12,148	12,391	19,381	19,769	20,164	20,567	20,979	21,398	21,826	22,263	22,708	23,162	23,625	24,098
Total	**93,249**	**59,586**	**57,203**	**58,347**	**66,256**	**67,582**	**68,933**	**70,312**	**71,718**	**73,152**	**75,194**	**76,698**	**78,232**	**79,796**	**81,392**	**83,020**

Table 12. Estimated Carbon Monoxide Emissions (Tons) – NSPS Scenario*

	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022	2023
Wood Stoves	8,079	5,163	4,956	5,055	5,156	5,259	5,365	5,472	5,581	5,693	6,385	6,513	3,524	3,595	3,667	3,740
Single Burn Rate Stoves	9,766	6,241	5,991	6,111	6,233	6,358	6,485	4,035	4,116	4,198	4,282	4,368	1,980	2,020	2,060	2,101
Pellet Stoves	432	276	265	270	275	281	287	292	298	304	310	316	143	146	149	152
Furnace: indoor, cordwood	55,170	35,254	33,844	34,520	35,211	35,915	36,633	37,366	30,967	9,719	9,913	10,112	1,289	1,315	1,341	1,368
Hydronic Heating Systems	19,803	12,654	12,148	12,391	19,381	19,769	20,164	2,057	2,098	2,140	2,183	2,226	710	724	738	753
Total	**93,249**	**59,586**	**57,203**	**58,347**	**66,256**	**67,582**	**68,933**	**49,222**	**43,060**	**22,054**	**23,073**	**23,535**	**7,647**	**7,800**	**7,956**	**8,115**

*Step 1 PM emission limit in 2015 and Step 2 PM emission limit in 2020 for all appliances, except forced-air furnaces have work practice/operational standards in 2015, Step 1 PM emission limits for small furnaces in 2016, Step 1 PM emission limits for large furnaces in 2017 and Step 2 PM emission limits for all furnaces in 2020. In order to not overstate emission reductions attributable to this NSPS, estimates are reduced for the percentage of appliances estimated to already meet the Step 2 PM emission limits (26% of wood stoves, 70% of pellet stoves and 18% of hydronic heaters). In this analysis, emission reductions for forced-air furnaces are not quantified for the work practice/operational standard required in 2015, although stakeholders agree that work practice/operational standards will reduce emissions.

Table 7-2. Summary of Annual Monetized $PM_{2.5}$-Related Health Benefits Estimates for the Residential Wood Heaters NSPS in the 2015–2020 Time Frame (2013$)[a]

Pollutant	Average Annual Emissions Reductions (tons)	Benefit per ton (Krewski, 3%)	Benefit per ton (Lepeule, 3%)	Benefit per ton (Krewski, 7%)	Benefit per ton (Lepeule, 7%)	Total Monetized Annual Benefits (millions 2013$ at 3%)			Total Monetized Annual Benefits (millions 2013$ at 7%)		
Proposed											
Direct $PM_{2.5}$	8,269	$410,000	$920,000	$370,000	$830,000	$3,400	to	$7,600	$3,100	to	$6,900
$PM_{2.5}$ Precursors											
VOC[b]	9,265	NA	NA	NA	NA	NA	to	NA	NA	to	NA
					Total	**$3,400**	**to**	**$7,600**	**$3,100**	**to**	**$6,900**

[a] All monetized benefits are annual estimates that reflect the average of annual emission reductions expected to occur between 2015 and 2020 (inclusive) resulting from rule implementation. All estimates are rounded to two significant figures so numbers may not sum across columns. It is important to note that the monetized benefits do not include reduced health effects from direct exposure to NO_2, ozone exposure, ecosystem effects, or visibility impairment. All fine particles are assumed to have equivalent health effects, but the benefit per ton estimates vary depending on the location and magnitude of their impact on $PM_{2.5}$ levels, which drive population exposure. The monetized benefits incorporate the conversion from precursor emissions to ambient fine particles. Confidence intervals are unavailable for this analysis because of the benefit-per-ton methodology.

[b] Estimates of VOCs health benefits are currently not monetized and will be addressed only qualitatively.

7-10

Table 7-3. Summary of Reductions in Health Incidences from $PM_{2.5}$-Related Benefits for the Residential Wood Heaters NSPS in the 2015-2020 Time Frame[a]

Health Incidences	RWH NSPS
Avoided Premature Mortality	
Krewski et al. (2009) (adult)	360
Lepeule et al. (2012) (adult)	810
Avoided Morbidity	
Emergency department visits for asthma (all ages)	180
Acute bronchitis (age 8–12)	550
Lower respiratory symptoms (age 7–14)	7,000
Upper respiratory symptoms (asthmatics age 9–11)	10,000
Minor restricted-activity days (age 18–65)	280,000
Lost work days (age 18–65)	48,000
Asthma exacerbation (age 6–18)	25,000
Hospital admissions—respiratory (all ages)	92
Hospital admissions—cardiovascular (age > 18)	110
Non-Fatal Heart Attacks (age >18)	
Peters et al. (2001)	390
Pooled estimate of 4 studies	42

[a] All estimates are rounded to whole numbers with two significant figures. Confidence intervals are unavailable for this analysis because of the benefit-per-ton methodology.

the 12 functions supplied by experts. Figure 7-2 provides a breakdown of monetized benefits by pollutant. In Table 7-4, we provide the benefits using our anchor points of Krewski et al., and Lepeule et al., as well as the results from the 12 experts' elicitation on PM mortality.

7.2.5 Characterization of Uncertainty in the Monetized $PM_{2.5}$ Benefits

In any complex analysis using estimated parameters and inputs from numerous models, there are likely to be many sources of uncertainty. This analysis is no exception. This analysis includes many data sources as inputs, including emission inventories, air quality data from models (with their associated parameters and inputs), population data, population estimates, health effect estimates from epidemiology studies, economic data for monetizing benefits, and assumptions regarding the future state of the world (i.e., regulations, technology, and human behavior). Each of these inputs may be uncertain and would affect the benefits estimate. When