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Environmental Emissions Nonenergy Benefits Working Paper: ARRA Period

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Environmental Sciences Division

Environmental Emissions Nonenergy Benefits Working Paper: ARRA Period

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March 2015

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ACRONYMS

APEEP	Air Pollution Emission Experiments and Policy Analysis Model
ARRA	American Recovery and Reinvestment Act
BTU	British Thermal Units
CH4	Methane
CO2	Carbon Dioxide
DOE	U.S. Department of Energy
EPA	Environmental Protection Agency
kWh	Kilowatt hour
LBS	Pounds
MCF	Million Cubic Feet
MMbtu	Million British Thermal Units
NERC	North American Electric Reliability Corporation
NO2	Nitrogen Dioxide
NOx	Nitrogen Oxides
NRC	National Research Council
OMB	U.S. Office of Management and Budget
OWIP	Office of Weatherization and Intergovernmental Programs
PM	Particulate Matter
VOC	Volatile Organic Compound
WAP	Weather Assistance Program

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1. INTRODUCTION

Weatherization reduces energy usage by low-income households, and thereby reduces the environmental impacts of the production and consumption of energy and reduces the social costs associated with those environmental impacts. The nonenergy benefits study conducted as part of the American Recovery and Reinvestment Act of 2009 (ARRA) Weatherization Assistance Program (WAP) evaluation focused on measuring the emissions reductions resulting from WAP program energy usage reductions and estimating the societal value of those emission reductions. While there are other environmental impacts associated with the WAP program, this study focused on emissions impacts because the 2010 National Research Council (NRC) report *Hidden Costs of Energy: The Unpriced Consequences of Energy Production and Use* recommended that Congress focus on emissions costs because they have the highest documented social impact costs.

2. METHODOLOGY

The starting point for estimating emissions nonenergy benefits is to measure the program energy impacts. The American Recovery and Reinvestment Act of 2009 (ARRA) Weatherization Assistance Program (WAP) evaluation measured electric and natural gas energy savings using billing data furnished by energy suppliers for a sample of WAP clients and measured fuel oil savings by directly metering homes heated with fuel oil for a sample of clients that were treated by the program. The evaluation then projected energy savings by fuel and housing unit type for each state (i.e., grantee) using state-specific data on WAP production and installed measures.

The analysis used projected energy savings by building type and state to estimate reductions in state-level emissions. There are two reasons for estimating emissions at the state level. First, emissions associated with electric production are best estimated for North American Reliability Corporation (NERC) regions; each state is assigned to a NERC region and emissions per kWh are estimated for all electric power plants in the region. Second, Air Pollutions Emission Experiments and Policy Analysis Model (APEEP) damage function estimates based on existing emission levels, population, and other local factors; the social cost of a ton of emissions varies substantially from state to state.

The analysis used the APEEP model (recommended by the NRC and updated for purposes of the evaluation) to estimate value of state-level emissions benefits for each of the major criteria air pollutants (SO_2, NO_x, PM 2.5, and VOC). It used OMB guidance on greenhouse gases (CO_2 equivalents) to estimate the value of greenhouse gas emission reductions. National estimates were developed by cumulating state-level values.

This approach to the estimation of emissions benefits is different from what is found in most of the literature on low-income weatherization in two ways. First, most of the literature sources reviewed for this study had lower estimates of the cost per ton for emissions. The estimates in previous studies were generally based on the market price of emissions as established in interstate and/or international emissions trading markets. This study used U.S. Office of Management and Budget (OMB) guidance for valuation of greenhouse gas emissions and the APEEP model for valuation of criteria air pollutant emissions. Second, most of the literature sources reviewed for this study has substantially higher emissions rates per kWh for electricity generation that are reported here. In recent years, there have been substantial reductions in emissions at electric generation plants. By using updated emissions data and by adopting the NRC recommendation of projecting continued reductions in emissions over the analysis time period, the study projected much lower levels of avoided emissions associated with electricity usage reductions. The net effect of these two changes is that this study has higher estimated emissions benefits per weatherized unit than many previously published reports despite showing having lower levels avoided emissions.

3. BENEFITS FROM GREENHOUSE GAS EMISSIONS REDUCTIONS

The estimates of avoided greenhouse gas emissions are made separately for natural gas and propane, fuel oil, and electricity. Each type of fuel has a different amount of avoided greenhouse gases per unit of energy savings. In addition, for electricity, the amount of avoided greenhouse gases varies by geography because of differences in the fuels used to generate electricity in each geographic area.

The unit used for quantification of greenhouse gases is CO_2 equivalents. Greenhouse gases include CO_2, CH_4, and N_2O. Any emissions of CH_4 or N_2O are transformed into their CO_2 equivalent using the global warming potential furnished by EPA.[1]

3.1 NATURAL GAS AND PROPANE

The 2010 NRC report[2] furnished recommendations for computing the greenhouse gases associated with the extraction and combustion of natural gas. The report recommended using a value of 140 lbs per MCF of natural gas used (.062 metric tons per MMBtu). That includes 20 lbs per MCF for extraction and 120 pounds per MCF for combustion. The sources cited by the NRC report include Jaramillo (2007)[3] for upstream (i.e., extraction) and EPA AP-42[4] for downstream (i.e., combustion).

Table 3.1 shows how avoided emissions were computed for one state studied in the WAP evaluation. The calculation for the representative state shows that the average projected savings per unit in the first program year would be 118.56 therms and the avoided emissions per unit would be 0.73 metric tons. The projected lifetime savings per unit would be 2,535.80 therms and the lifetime avoided emissions would be 15.71 metric tons. (Note that installed measures vary in terms of their estimated lifetime. For measures that affect natural gas and propane usage, the lifetime varies between 13 years for a setback thermostat to 25 years for insulation. So, the average savings per unit are lower in some of the later years.)

Table 3.1 Avoided Emissions for CO_2 Equivalents Natural Gas and Propane Usage Reductions – Representative State

Year	Savings per Housing Unit (therms)[5]	Savings per Housing Unit (MMBtu)	Rate (Metric Tons/MMBtu)	Metric Tons per Housing Unit
First Year	118.56	11.86	0.0620	0.73
Lifetime	2,535.80	253.58	0.0620	15.71

For this calculation, it was assumed that the greenhouse gas emission rates for propane were the same as the rates for natural gas. While that is likely to be a reliable assumption for combustion, it is possible that

[1] U.S. Environmental Protection Agency *Overview of Greenhouse Gases Methane Emission*/ Environmental Protection Agency, September 9, 2013, Web. Accessed January 7, 2014. The CO2 equivalents (methane = 21, nitrous oxide = 310) are on the web pages: http://www.epa.gov/climatechange/ghgemissions/gases/ch4.html and http://www.epa.gov/climatechange/ghgemissions/gases/n2o.html.

[2] National Research Council *2010 Hidden Costs of Energy: Unpriced Consequences of Energy Production and Use*. National Academy Press, page 12.

[3] Jaramillo, P., W.M. Griffin, and H.S. Matthews. 2007. *Comparative life cycle air emissions of coal, domestic natural gas, LNG, and SNG for electricity generation*. Environ. Sci. Technol. 41(17):6290-6296.

[4] January 1995 U.S. Environmental Protection Agency *Compilation of Air Pollutant Emission Factors. Vol. 1. Stationary Point and Area Sources, 5th Ed. AP-42*. Environmental Protection Agency. Pp 1.1-5 Web. Accessed April 23, 2009.

[5] The savings per housing unit for any state is the projected aggregate natural gas and propane savings from housing units that use one of those fuels divided by the total number of housing units served by the program in that state.

the process for producing propane has different upstream emissions. However, since propane is a small part of the total energy savings associated with the program (12.4% of savings in the example state), the potential bias is small.

3.2 FUEL OIL

The fuel oil CO_2 equivalent emissions rate was computed using several sources.

1. EIA provides CO_2 emissions factors for a range of fuels in the Technical Guidelines for Voluntary Reporting of Greenhouse Gases.[6] The emission factor for fuel oil used in homes and multifamily buildings was listed as 72.32 kg of CO_2 per MMBtu.

2. EPA furnishes estimates of the CH_4 and N_2O emissions factors in AP-42, Compilation of Air Pollutant Emissions.[7] For residential furnaces, emissions were estimated to be 1.78 lbs of CH_4 and 0.05 lbs of N_2O per 10^3 gallons of fuel oil.

The total CO_2 equivalent for fuel oil is estimated to be 0.0727 metric tons per MMBtu.

Table 3.2 shows how avoided emissions were computed for one state studied in the WAP evaluation. The calculation for the representative state shows that the average projected savings per unit in the first program year would be 6.84 gallons and the avoided emissions per unit would be 0.07 metric tons. The projected lifetime savings per unit would be 149.99 gallons and the lifetime avoided emissions would be 1.51 metric tons. (Note that the installed measures vary in terms of their estimated lifetime. For measures that affect fuel oil, the lifetime varies between 13 years for a setback thermostat to 25 years for insulation. So, the average savings per unit are lower in some of the later years.)

Table 3.2 Avoided Emissions for CO_2 Equivalents Fuel Oil Usage Reductions – Representative State

Year	Savings per Housing Unit (Gallons)[8]	Savings per Housing Unit (MMBtu)	Rate (Metric Tons/MMBtu)	Metric Tons per Housing Unit
First Year	6.84	0.95	0.0727	0.07
Lifetime	149.99	20.80	0.0727	1.51

3.3 ELECTRICITY

The estimate of the emission rates for electricity is based on reported data for the NERC region in which the state is located. EPA's NERC emission summary tables were released in 2012.[9] These tables furnish estimates of baseload and non-baseload emission rates for each NERC region. For this analysis, we used

[6] U.S. Department of Energy, Technical Guidelines Voluntary Reporting of Greenhouse Gases (1605(b)) Program, Chapter 1, Part C, Stationary Source Combustion, January 2007. Page 43.
[7] AP42, Compilation of Air Pollution Emission Factors, Volume 1: Stationary Point and Area Sources, Chapter 1: External Combustion Sources. http://www.epa.gov/ttnchie1/ap42/ch01/ Section 1.3 Fuel Oil Combustion Final Section – Supplement E September 1999, corrected May 2010. CH4 factor is on page 14 and N2O factor is on page 20. http://www.epa.gov/ttn/chief/ap42/ch01/final/c01s03.pdf.
[8] The savings per housing unit for any state is the projected aggregate fuel oil savings from housing units that use fuel oil divided by the total number of housing units served by the program in that state.
[9] EPA *eGRID2012 Version 1.0 Year 2009 Summary Tables.* Environmental Protection Agency. Washington D.C. April, 2012.

the non-baseload emission rates for the NERC region in which the majority of each state's population resides, as recommended by the EPA.[10]

These tables furnish emission rates for CO_2 equivalents per kWh generated at the source. We adjusted the kWh savings from the WAP evaluation to account for transmission losses. These estimates are provided in the EPA NERC summary tables.[11]

Table 3.3 shows how avoided emissions were computed for one state studied in the WAP evaluation. The calculation for the representative state shows that the average projected savings per unit in the first program year would be 678 kWh and the avoided emissions per unit would be 0.68 metric tons. The projected lifetime savings would be 7,874 kWh and the lifetime avoided emissions would be 7.87 metric tons. (Note that the installed measures vary in terms of their estimated lifetime. For measures that affect electricity, the lifetime varies between 7 years for lighting to 25 years for insulation. So, the average savings per unit are lower in some of the later years.)

Table 3.3 Avoided Emissions for CO_2 Equivalents Electricity Usage Reductions – Representative State

Year	Savings per Housing Unit (kWh Site)	Savings per Housing Unit (kWh Source	Savings per Housing Unit (MMBtu Source)	Rate (Metric Tons/MMBtu)	Metric Tons per Housing Unit
First Year	678	720	2.46	0.2758	0.68
Lifetime	7,874	8,361	28.53	0.2758	7.87

For some emissions, the NRC observed that emission rates are expected to decline over time. The report recommended explicitly accounting for those expected reductions in emissions. They made no such recommendation for the emissions of greenhouse gases.

3.4 ESTIMATING THE VALUE OF AVOIDED GREENHOUSE GAS EMISSIONS (STATE-LEVEL)

The Office of Management and Budget issued a technical document in May 2013 that furnishes guidance for estimating the social cost of carbon.[12] That document furnishes the current social cost of carbon and annual values for the future cost through 2050. Table 3.4 shows cost statistics for the target analysis period – 2013 through 2037 – in nominal dollars and 2013 dollars (i.e., discounted by the recommended real discount rate furnished by OMB).[13]

[10] Art Diem and Cristina Quiroz, *How to use eGRID for Carbon Footprinting Electricity Purchases in Greenhouse Gas Emission Inventories.* Environmental Protection Agency. Washington D.C. Page 10-11. July 2012.
[11] EPA *eGRID2012 Version 1.0 Year 2009 Summary Tables.* Environmental Protection Agency. Washington D.C. April, 2012. Pages 7 & 9.
[12] OMB *Technical Support Document: Technical Update of the Social Cost of Carbon for Regulatory Impact Analysis Under Executive Order 12866 Interagency Working Group on Social Cost of Carbon,* United States Government. May 2013. Page 18.
[13] Jeffrey D. Zients *M-13-04 Memorandum for the Heads of Departments and Agencies.* Executive Office of Management and Budget. January 24, 2013.

Table 3.4 Social Cost of CO_2 Equivalents ($ per metric ton) By Year (Nominal and 2013 Dollars) – Representative State

Year	$ Per Metric Ton (Nominal Value)	$ Per Metric Ton (2013 Dollars)
2013	$40.32	$40.32
2014	$41.44	$40.23
2015	$42.56	$40.12
2016	$43.68	$39.97
2017	$44.80	$39.80
Average for first five years	$42.56	$40.09
Average for analysis period	$50.48	$38.03

For a representative state, the avoided emissions per housing unit are listed in Tables 3.1-3.3. The total avoided emissions per housing unit for all energy types is multiplied by the dollars per metric ton in 2013 dollars to estimate the avoided emission benefit per unit at the state level. Table 3.5 shows that calculation for a representative state. The aggregate emissions benefit for the state is estimated using the average per unit times the number of units served. Table 3.6 shows the calculation for a representative state.

Table 3.5 Quantity and Value of Avoided Emissions for CO_2 Equivalents Value per Unit by Fuel Type and Year (2013 Dollars) – Representative State

	Natural Gas/Propane		Fuel Oil		Electricity		All Fuels	
Year	Metric Tons per Unit	$ per Unit	Metric Tons per Unit	$ per Unit	Metric Tons per Unit	$ per Unit	Metric Tons per Unit	$ per Unit
2013	0.73	$29.62	0.07	$2.78	0.68	$27.32	1.48	$59.72
2014	0.73	$29.55	0.07	$2.78	0.68	$27.26	1.48	$59.59
2015	0.73	$29.47	0.07	$2.77	0.68	$27.19	1.48	$59.42
2016	0.73	$29.36	0.07	$2.76	0.68	$27.09	1.48	$59.21
2017	0.73	$29.24	0.07	$2.75	0.68	$26.97	1.48	$58.96
First five years	3.67	$147.23	0.34	$13.83	3.39	$135.83	7.41	$296.89
Lifetime	15.71	$591.57	1.51	$56.82	7.87	$308.29	25.09	$956.69

Table 3.6 Quantity and Value of Avoided Emissions for CO_2 Equivalents Aggregate Value – Representative State

Year	Units	Metric Tons Per Unit (All Fuels)	Aggregate Metric Tons	Value per Unit (2013 Dollars – All Fuels)	Aggregate Value (2013 Dollars – All Fuels)
2013	14,417	1.48	21,353	$59.72	$860,971
2014	14,417	1.48	21,353	$59.59	$859,114
2015	14,417	1.48	21,353	$59.42	$856,634
2016	14,417	1.48	21,353	$59.21	$853,570
2017	14,417	1.48	21,353	$58.96	$849,958
First five years	14,417	7.41	106,767	$296.89	$4,280,247
Lifetime	14,417	25.09	361,740	$956.69	$13,792,542

3.5 NATIONAL TOTALS

The state-level analysis furnishes information on the aggregate avoided emissions, the aggregate emissions benefit, and the number of units served for each state. Those are cumulated to develop the aggregate national value of avoided emissions. Table 3.7 shows the aggregate quantity of avoided emissions by fuel type. Table 3.8 shows the aggregate value of avoided emissions by fuel type. In total, the analysis shows that if the 2010 WAP program were implemented in 2013, it would be expected to result in a total reduction of 7,382,524 metric tons of CO_2 emissions (Table 3.7) at a lifetime value of $281,573,912 (Table 3.8). About 46 percent of the avoided emissions are from the reduction in the use of natural gas and propane, 10 percent from reduction in the use of fuel oil, and 44 percent from reduction in the use of electricity.

Table 3.7 Quantity of Avoided Emissions for CO_2 Equivalents National Aggregate Total by Fuel Type and Year

Year	Avoided Emissions (Metric Tons of CO_2)			
	Natural Gas/Propane	Fuel Oil	Electricity	All Fuels
First Year	161,916	36,104	228,784	426,804
Lifetime	3,384,103	753,205	3,245,217	7,382,524

Table 3.8 Value of Avoided Emissions for CO_2 Equivalents National Aggregate Total by Fuel Type and Year

Year	Avoided Emissions (2013 Dollars)			
	Natural Gas/Propane	Fuel Oil	Electricity	All Fuels
2013	$6,528,454	$1,455,708	$9,224,555	$17,208,717
2014	$6,514,368	$1,452,567	$9,204,653	$17,171,589
2015	$6,495,566	$1,448,375	$9,178,085	$17,122,026
2016	$6,472,332	$1,443,194	$9,145,256	$17,060,782
2017	$6,444,940	$1,437,086	$9,106,553	$16,988,580
First five years	$32,455,659	$7,236,931	$45,859,103	$85,551,692
Lifetime	$127,664,103	$28,409,661	$125,500,144	$281,573,912

Table 3.9 shows the calculation for the average amount of avoided emissions and the average value per housing unit served by the WAP program. The estimated avoided emissions per housing unit at the national level are 22.25 metric tons with lifetime value of $848.

Table 3.9 Quantity and Value of Avoided Emissions for CO_2 Equivalents Per Housing Unit – National

Year	Units	Aggregate Metric Tons	Metric Tons Per Unit (All Fuels)	Aggregate Value (2013 Dollars – All Fuels)	Value Per Housing Unit (2013 Dollars – All Fuels)
2013	331,866	426,804	1.29	$17,208,717	$51.85
2014	331,866	426,804	1.29	$17,171,589	$51.74
2015	331,866	426,804	1.29	$17,122,026	$51.59
2016	331,866	426,804	1.29	$17,060,782	$51.41
2017	331,866	426,804	1.29	$16,988,580	$51.19
First five years	331,866	2,134,017	6.43	$85,551,692	$257.79
Lifetime	331,866	7,382,524	22.25	$281,573,912	$848.46

4. BENEFITS FROM SULFUR DIOXIDE EMISSIONS REDUCTIONS

The estimates of avoided SO_2 are made separately for natural gas and propane, fuel oil, and electricity. Each type of fuel has a different amount of avoided SO_2 per unit of energy savings. In addition, for electricity, the amount of avoided SO_2 varies by geographic region because of differences in the SO_2 emissions rates for generation plants.

4.1 NATURAL GAS AND PROPANE

The EPA furnished an estimate of the SO_2 emissions factor from natural gas combustion in boilers and furnaces in AP-42.[14] Emissions are estimated to be 0.6 pounds of SO_2 per 10^6 standard cubic feet of natural gas (2.93×10^{-7} short tons per MMBtu).

Table 4.1 shows how avoided emissions were computed for one state studied in the WAP evaluation. The calculation for the representative state shows that the average projected savings per unit in the first program year would be 118.56 therms and the avoided emissions per unit would be 3.47×10^{-6} short tons. The projected lifetime savings would be 2,535.80 therms and the lifetime avoided emissions would be 7.42×10^{-5} short tons.

Note that the installed measures vary in terms of their estimated lifetime. For measures that affect natural gas and propane usage, the lifetime varies between 13 years for a setback thermostat to 25 years for insulation. So, the average therms of savings per unit are lower in some of the later years.

Table 4.1 Avoided Emissions for SO_2 Natural Gas and Propane Usage Reductions – Representative State

Year	Savings per Housing Unit (therms)[15]	Savings per Housing Unit (MMBtu)	Rate (Short Tons/MMBtu)	Short Tons per Housing Unit
First Year	118.56	11.86	2.93E-07	3.47E-06
Lifetime	2,535.80	253.58	2.93E-07	7.42E-05

For this calculation, it was assumed that the greenhouse gas emission rates for propane were the same as the rates for natural gas. While that is likely to be a reliable assumption for combustion, it is possible that the process for producing propane has different upstream emissions. However, since propane is a small part of the total energy savings associated with the program (12.4% of savings in the example state), the potential bias is small.

4.2 FUEL OIL

The fuel oil SO_2 emissions rate was computed using the EPA estimated SO_2 emissions factor from AP-42[16], Compilation of Air Pollutant Emissions.[17] The EPA factor is 142 pounds per 10^3 gallons multiplied

[14] AP 42, Fifth Edition, Compilation of Air Pollutant Emission Factors, Volume 1: Stationary Point and Area Sources, Chapter 1: External Combustion Sources. http://www.epa.gov/ttnchie1/ap42/ch01/ 1.4 Natural Gas Combustion Final Section - Supplement D, July 1998. http://www.epa.gov/ttn/chief/ap42/ch01/final/c01s04.pdf page 1.4-6.

[15] The savings per housing unit for any state is the projected aggregate natural gas and propane savings from housing units that use one of those fuels divided by the total number of housing units served by the program in that state.

[16] AP42, Compilation of Air Pollution Emission Factors, Volume 1: Stationary Point and Area Sources, Chapter 1: External Combustion Sources. http://www.epa.gov/ttnchie1/ap42/ch01/ Section 1.3 Fuel Oil Combustion Final Section – Supplement E September 1999, corrected May 2010. http://www.epa.gov/ttn/chief/ap42/ch01/final/c01s03.pdf, page 1.3-12.

by the weight percentage of sulfur in the oil. Our model assumes 50% sulfur content for residential fuel oil[18] so the total SO_2 emissions for fuel oil are estimated at 71 pounds per 10^3 gallons (2.56×10^{-4} short tons per MMBtu).

Table 4.2 shows how avoided emissions were computed for one state studied in the WAP evaluation. The calculation for the representative state shows that the average projected savings per unit in the first program year would be 6.84 gallons and the avoided emissions per unit would be 2.43×10^{-4} short tons. The projected lifetime savings would be 149.99 gallons and the lifetime avoided emissions would be 5.32×10^{-3} short tons.

Note that the installed measures vary in terms of their estimated lifetime. For measures that affect fuel oil, the lifetime varies between 13 years for a setback thermostat to 25 years for insulation. So, the average savings per unit are lower in some of the later years.

Table 4.2 Avoided Emissions for SO_2 Fuel Oil Usage Reductions – Representative State

Year	Savings per Housing Unit (Gallons)[19]	Savings per Housing Unit (MMBtu)	Rate (Short Tons/MMBtu)	Short Tons per Housing Unit
First Year	6.84	0.95	2.56E-04	2.43E-04
Lifetime	149.99	20.80	2.56E-04	5.32E-03

4.3 ELECTRICITY

The estimate of the emissions rates for sulfur dioxide for electricity is based on reported data for the eGRID region in which the state is located. EPA's eGRID emission summary tables were released in 2012.[20] These tables furnish estimates of baseload and non-baseload emission rates for each NERC region. For this analysis, we used the non-baseload emission rates as recommended by EPA.[21]

These tables furnish emission rates for SO_2 per kWh generated at the source. We adjusted the kWh savings from the WAP evaluation to account for transmission losses. These estimates are provided in the EPA eGRID summary tables.[22]

Table 4.3 shows how avoided emissions were computed for one state studied in the WAP evaluation. The calculation for the representative state shows that the average projected savings per unit in the first program year would be 678 kWh and the avoided emissions per unit would be 2.07×10^{-3} short tons. The projected lifetime savings would be 7,874 kWh and the lifetime avoided emissions would be 2.04×10^{-2} short tons.

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[17] 29. N. F. Suprenant, *et al*., *Emissions Assessment Of Conventional Stationary Combustion Systems, Volume I: Gas And Oil Fired Residential Heating Sources*, EPA-600/7-79-029b, U. S. Environmental Protection Agency, Washington, DC, May 1979.
[18] Nishioka et al. "Integrating Risk Assessment and Life Cycle Assessment: A Case Study of Insulation." *Risk Analysis. V*ol. 22, no. 5, 2002, p. 1006.
[19] The savings per housing unit for any state is the projected aggregate fuel oil savings from housing units with fuel oil main heat divided by the total number of housing units served by the program in that state.
[20] EPA *eGRID2012 Version 1.0 Year 2009 Summary Tables.* Environmental Protection Agency. Washington D.C. April, 2012.
[21] Art Diem and Cristina Quiroz, *How to use eGRID for Carbon Footprinting Electricity Purchases in Greenhouse Gas Emission Inventories.* Environmental Protection Agency. Washington D.C. Page 10-11. July 2012.
[22] EPA *eGRID2012 Version 1.0 Year 2009 Summary Tables.* Environmental Protection Agency. Washington D.C. April, 2012. Pages 7 & 9.

Note that the installed measures vary in terms of their estimated lifetime. For measures that affect electricity, the lifetime varies between 7 years for lighting and 25 years for insulation. So, the average savings per unit are lower in some of the later years.

The NRC observed that emission rates of SO_2 from power plants are expected to decline over time due to increased regulation and costs. The report recommended explicitly accounting for those expected reductions in emissions and provided estimates of 2030 emissions reductions varying by pollutant and power plant fuel.[23] We chose to apply a rough estimate of a 50% emissions reduction over the analysis period of 2013 to 2037. This translates to an annual reduction of 2.85% to the rate of SO_2 emissions from electricity generation in our models.

Table 4.3 Avoided Emissions for SO_2 Electricity Usage Reductions – Representative State

Year	Savings per Housing Unit (kWh Site)	Savings per Housing Unit (kWh Source)	Savings per Housing Unit (MMBtu Source)	Rate (Short Tons/MMBtu)	Short Tons per Housing Unit
2013	678	720	2.46	8.42E-04	2.07E-03
2014	678	720	2.46	8.18E-04	2.01E-03
2015	678	720	2.46	7.95E-04	1.95E-03
2016	678	720	2.46	7.72E-04	1.90E-03
2017	678	720	2.46	7.50E-04	1.84E-03
First five years	3,391	3,600	12.28	7.95E-04	9.77E-03
Lifetime	7,874	8,361	28.53	7.15E-04	2.04E-02

4.4 ESTIMATING THE VALUE OF AVOIDED SULFUR DIOXIDE EMISSIONS (STATE-LEVEL)

The NRC report uses the APEEP provided by Muller et al. (2009)[24] to estimate the damages of one additional short ton of criteria air pollutants at the county level. The APEEP model differentiates between damages from ground-level emissions, such as emissions from fuel oil and natural gas heaters, and damages from point-source emissions, such as emissions from electric plants.

APPRISE contracted with the model developer to update the model with 2008 data. The 2008 county-level damage estimates of each additional short ton of ground-level SO_2 were weighted by the county population counts from the 2010 census to estimate the average damage values for each state. The state damage estimates for ground-level emissions were used to calculate the benefit of avoided emissions from natural gas, propane, and fuel oil.

Damage estimates of each additional short ton of point-source SO_2 emissions were calculated for each NERC region. The EPA eGRID data were used to estimate the annual non-baseload electricity generation for each county using procedures described in the eGRID technical support document.[25] The county-

[23] National Research Council *2010 Hidden Costs of Energy: Unpriced Consequences of Energy Production and Use*. National Academy Press, pages 108 and 124.
[24] Muller, N.Z., and R.O. Mendelsohn. 2006. The Air Pollution Emission and Policy Analysis Model (APEEP). Yale University, New Haven, CT. December 2006 [online].
[25] *The Emissions & Generation Resource Integrated Database for 2012 (eGRID2012) Technical Support Document*. Environmental Protection Agency. Washington D.C. April, 2012, page 18.

level damage estimates for point-source emissions were weighted by the county-level quantity of annual non-baseload electricity generation to generate averages for each NERC region. For each state, the benefit of avoided emissions from electricity was calculated using the damage estimate for point-source emissions for the NERC region in which the majority of each state's population resides.

The NRC estimated an increase in damages per ton of pollution of approximately 50% by 2030 due to growth in population combined with increases in the value of a statistical life and other health impact values.[26] We have applied a similar assumption to our models by incorporating an increase of 1.71% per year to damage values for SO_2 emissions.

Table 4.4 shows cost statistics in a representative state for the target analysis period – 2013 through 2037 – in nominal dollars and 2013 dollars (i.e., discounted by the recommended real discount rate furnished by OMB).[27]

Table 4.4 Social Cost of SO_2 ($ per short ton) By Year (Nominal and 2013 Dollars) – Representative State

	Point-Source Emissions		Ground-Level Emissions	
Year	**$ Per Short Ton (Nominal Value)**	**$ Per Short Ton (2013 Dollars)**	**$ Per Short Ton (Nominal Value)**	**$ Per Short Ton (2013 Dollars)**
2013	$27,402	$27,402	$108,363	$108,363
2014	$27,871	$27,059	$110,216	$107,006
2015	$28,347	$26,720	$112,100	$105,665
2016	$28,832	$26,385	$114,017	$104,342
2017	$29,325	$26,055	$115,967	$103,035
Average for first five years	$28,327	$26,744	$112,133	$105,682
Average for analysis period	$30,433	$25,447	$130,469	$95,172

For a representative state, the avoided emissions per housing unit are listed in Tables 4.1-4.3. The total avoided emissions per housing unit for electricity is multiplied by the dollars per short ton in 2013 dollars for point-source emissions. The total avoided emissions per housing unit for natural gas, propane, and fuel oil is multiplied by the dollars per short ton in 2013 dollars for ground-level emissions. The point-source and ground-level emissions benefits are combined to estimate the total avoided emission benefit per unit at the state level. Table 4.5 shows that calculation for a representative state. The aggregate emissions benefit for the state is estimated using the average per unit times the number of units served. Table 4.6 shows the calculation for a representative state.

[26] National Research Council *2010 Hidden Costs of Energy: Unpriced Consequences of Energy Production and Use*. National Academy Press, page 108.
[27] Jeffrey D. Zients *M-13-04 Memorandum for the Heads of Departments and Agencies.* Executive Office of Management and Budget. January 24, 2013.

Table 4.5 Quantity and Value of Avoided Emissions for SO_2 Value per Unit by Fuel Type and Year (2013 Dollars) – Representative State

Year	Natural Gas/Propane		Fuel Oil		Electricity		All Fuels	
	Short Tons per Unit	$ per Unit	Short Tons per Unit	$ per Unit	Short Tons per Unit	$ per Unit	Short Tons per Unit	$ per Unit
2013	3.47E-06	$0.12	2.43E-04	$8.36	2.07E-03	$34.26	2.32E-03	$42.74
2014	3.47E-06	$0.12	2.43E-04	$8.26	2.01E-03	$32.87	2.26E-03	$41.24
2015	3.47E-06	$0.12	2.43E-04	$8.15	1.95E-03	$31.53	2.20E-03	$39.80
2016	3.47E-06	$0.12	2.43E-04	$8.05	1.90E-03	$30.25	2.14E-03	$38.41
2017	3.47E-06	$0.11	2.43E-04	$7.95	1.84E-03	$29.02	2.09E-03	$37.08
First five years	1.73E-05	$0.58	1.21E-03	$40.78	9.77E-03	$157.92	1.10E-02	$199.28
Lifetime	7.42E-05	$2.25	5.32E-03	$160.92	2.04E-02	$316.17	2.58E-02	$479.34

Table 4.6 Quantity and Value of Avoided Emissions for SO_2 Aggregate Value – Representative State

Year	Housing Units	Short Tons Per Unit (All Fuels)	Aggregate Short Tons	Value per Unit (2013 Dollars – All Fuels)	Aggregate Value (2013 Dollars – All Fuels)
2013	14,417	2.32E-03	33.38	$42.74	$616,199
2014	14,417	2.26E-03	32.53	$41.24	$594,582
2015	14,417	2.20E-03	31.70	$39.80	$573,800
2016	14,417	2.14E-03	30.90	$38.41	$553,821
2017	14,417	2.09E-03	30.12	$37.08	$534,612
First five years	14,417	1.10E-02	158.62	$199.28	$2,873,014
Lifetime	14,417	2.58E-02	372.03	$479.34	$6,910,639

4.5 NATIONAL TOTALS

The state-level analysis furnishes information on the aggregate avoided emissions, the aggregate emissions benefit, and the number of units served for each state. Those are cumulated to develop a national aggregate value of avoided emissions. Table 4.7 shows the quantity of avoided emissions by fuel type. Table 4.8 shows the value of avoided emissions by fuel type. The analysis shows that if the 2010 WAP program were implemented in 2013, it would be expected to reduce SO_2 emissions by 10,531 short tons (Table 4.7) at a lifetime value of $286,819,004 (Table 4.8). Most of the avoided emissions accrue from the reductions in the use of fuel oil and electricity.

Table 4.7 Quantity of Avoided Emissions for SO_2 National Aggregate Total by Fuel Type and Year

	Avoided Emissions (Short Tons of SO_2)			
Year	**Natural Gas/Propane**	**Fuel Oil**	**Electricity**	**All Fuels**
2013	0.76	127.11	686.62	814.50
2014	0.76	127.11	667.05	794.93
2015	0.76	127.11	648.04	775.92
2016	0.76	127.11	629.57	757.45
2017	0.76	127.11	611.63	739.51
First five years	3.82	635.57	3,242.91	3,882.31
Lifetime	15.99	2,651.88	7,863.09	10,530.96

Table 4.8 Value of Avoided Emissions for SO_2 National Aggregate Total by Fuel Type and Year

	Avoided Emissions (2013 Dollars)			
Year	**Natural Gas/Propane**	**Fuel Oil**	**Electricity**	**All Fuels**
2013	$38,180	$7,039,926	$15,235,165	$22,313,271
2014	$37,702	$6,951,756	$14,615,591	$21,605,049
2015	$37,230	$6,864,690	$14,021,215	$20,923,135
2016	$36,763	$6,778,715	$13,451,010	$20,266,488
2017	$36,303	$6,693,817	$12,903,992	$19,634,113
First five years	$186,178	$34,328,904	$70,226,975	$104,742,054
Lifetime	$703,590	$126,795,909	$159,319,505	$286,819,004

Table 4.9 shows the calculation for the average amount of avoided emissions and the average value per housing unit served by the WAP program. The estimated avoided emissions per housing unit at the national level is 0.0317 short tons with a lifetime value of $864.

Table 4.9 Quantity and Value of Avoided Emissions for SO_2 Per Housing Unit – National

Year	Units	Aggregate Short Tons	Short Tons Per Unit (All Fuels)	Aggregate Value (2013 Dollars – All Fuels)	Value Per Housing Unit (2013 Dollars – All Fuels)
2013	331,866	814	0.0025	$22,313,271	$67.24
2014	331,866	795	0.0024	$21,605,049	$65.10
2015	331,866	776	0.0023	$20,923,135	$63.05
2016	331,866	757	0.0023	$20,266,488	$61.07
2017	331,866	740	0.0022	$19,634,113	$59.16
First five years	331,866	3,882	0.0117	$104,742,054	$315.62
Lifetime	331,866	10,531	0.0317	$286,819,004	$864.26

5. BENEFITS FROM NITROGEN OXIDE GAS EMISSIONS REDUCTIONS

The estimates of avoided NO_x are made separately for natural gas and propane, fuel oil, and electricity. Each type of fuel has a different amount of avoided NO_x per unit of energy savings. In addition, for electricity, the amount of avoided NO_x varies by geographic region because of differences in the NO_x emissions rates for generation plants.

5.1 NATURAL GAS AND PROPANE

The EPA furnished an estimate of the NO_x emissions factor from natural gas combustion in boilers and furnaces in AP-42.[28] Emissions are estimated to be 94 pounds of NO_x per 10^6 standard cubic feet of natural gas (4.59×10^{-5} short tons per MMBtu).

Table 5.1 shows how avoided emissions were computed for one state studied in the WAP evaluation. The calculation for the representative state shows that the average projected savings per unit in the first program year would be 118.56 therms and the avoided emissions per unit would be 5.44×10^{-4} short tons. The projected lifetime savings would be 2,535.80 therms and the lifetime avoided emissions would be 1.16×10^{-2} short tons.

Note that the installed measures vary in terms of their estimated lifetime. For measures that affect natural gas and propane usage, the lifetime varies between 13 years for a setback thermostat to 25 years for insulation. So, the average therms of savings per unit are lower in some of the later years.

Table 5.1 Avoided Emissions for NO_x Natural Gas and Propane Usage Reductions – Representative State

Year	Savings per Housing Unit (therms)[29]	Savings per Housing Unit (MMBtu)	Rate (Short Tons/MMBtu)	Short Tons per Housing Unit
First Year	118.56	11.86	4.59E-05	5.44E-04
Lifetime	2,535.80	253.58	4.59E-05	1.16E-02

For this calculation, it was assumed that the greenhouse gas emission rates for propane were the same as the rates for natural gas. While that is likely to be a reliable assumption for combustion, it is possible that the process for producing propane has different upstream emissions. However, since propane is a small part of the total energy savings associated with the program (12.4% of savings in the example state), the potential bias is small.

5.2 FUEL OIL

The fuel oil NO_x emissions rate was computed using the EPA estimated NO_x emissions factor from AP-42[30], Compilation of Air Pollutant Emissions.[31] The EPA factor is 18 pounds per 10^3 gallons of residential fuel oil (6.49×10^{-5} short tons per MMBtu).

[28] AP 42, Fifth Edition, Compilation of Air Pollutant Emission Factors, Volume 1: Stationary Point and Area Sources, Chapter 1: External Combustion Sources. http://www.epa.gov/ttnchie1/ap42/ch01/ 1.4 Natural Gas Combustion Final Section - Supplement D, July 1998. http://www.epa.gov/ttn/chief/ap42/ch01/final/c01s04.pdf page 1.4-5.

[29] The savings per housing unit for any state is the projected aggregate natural gas and propane savings from housing units that use one of those fuels divided by the total number of housing units served by the program in that state.

Table 5.2 shows how avoided emissions were computed for one state studied in the WAP evaluation. The calculation for the representative state shows that the average projected savings per unit in the first program year would be 6.84 gallons and the avoided emissions per unit would be 6.16 x 10^{-5} short tons. The projected lifetime savings would be 149.99 gallons and the lifetime avoided emissions would be 1.35 x 10^{-3} short tons.

Note that the installed measures vary in terms of their estimated lifetime. For measures that affect fuel oil, the lifetime varies between 13 years for a setback thermostat to 25 years for insulation. So, the average savings per unit are lower in some of the later years.

Table 5.2 Avoided Emissions for NO_x Fuel Oil Usage Reductions – Representative State

Year	Savings per Housing Unit (Gallons)[32]	Savings per Housing Unit (MMBtu)	Rate (Short Tons/MMBtu)	Short Tons per Housing Unit
First Year	6.84	0.95	6.49E-05	6.16E-05
Lifetime	149.99	20.80	6.49E-05	1.35E-03

5.3 ELECTRICITY

The estimate of the emissions rates for Nitrogen Oxides for electricity is based on reported data for the eGRID region in which the state is located. EPA's eGRID emission summary tables were released in 2012.[33] These tables furnish estimates of baseload and non-baseload emission rates for each NERC region. For this analysis, we used the non-baseload emission rates as recommended by EPA.[34]

These tables furnish emission rates for NO_x per kWh generated at the source. We adjusted the kWh savings from the WAP evaluation to account for transmission losses. These estimates are provided in the EPA eGRID summary tables.[35]

Table 5.3 shows how avoided emissions were computed for one state studied in the WAP evaluation. The calculation for the representative state shows that the average projected savings per unit in the first program year would be 678 kWh and the avoided emissions per unit would be 1.07 x 10^{-3} short tons. The projected lifetime savings would be 7,874 kWh and the lifetime avoided emissions would be 1.06 x 10^{-2} short tons.

Note that the installed measures vary in terms of their estimated lifetime. For measures that affect electricity, the lifetime varies between 7 years for lighting and 25 years for insulation. So, the average savings per unit are lower in some of the later years.

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[30] AP42, Compilation of Air Pollution Emission Factors, Volume 1: Stationary Point and Area Sources, Chapter 1: External Combustion Sources. http://www.epa.gov/ttnchie1/ap42/ch01/ Section 1.3 Fuel Oil Combustion Final Section – Supplement E September 1999, corrected May 2010. http://www.epa.gov/ttn/chief/ap42/ch01/final/c01s03.pdf, page 1.3-12.

[31] 29. N. F. Suprenant, *et al*., *Emissions Assessment Of Conventional Stationary Combustion Systems, Volume I: Gas And Oil Fired Residential Heating Sources*, EPA-600/7-79-029b, U. S. Environmental Protection Agency, Washington, DC, May 1979.

[32] The savings per housing unit for any state is the projected aggregate fuel oil savings from housing units with fuel oil main heat divided by the total number of housing units served by the program in that state.

[33] EPA *eGRID2012 Version 1.0 Year 2009 Summary Tables.* Environmental Protection Agency. Washington D.C. April, 2012.

[34] Art Diem and Cristina Quiroz, *How to use eGRID for Carbon Footprinting Electricity Purchases in Greenhouse Gas Emission Inventories.* Environmental Protection Agency. Washington D.C. Page 10-11. July 2012.

[35] EPA *eGRID2012 Version 1.0 Year 2009 Summary Tables.* Environmental Protection Agency. Washington D.C. April, 2012. Pages 7 & 9.

The NRC observed that emission rates of NO_x from power plants are expected to decline over time due to increased regulation and costs. The report recommended explicitly accounting for those expected reductions in emissions and provided estimates of 2030 emissions reductions varying by pollutant and power plant fuel.[36] We chose to apply a rough estimate of a 50% emissions reduction over the analysis period of 2013 to 2037. This translates to an annual reduction of 2.85% to the rate of NO_x emissions from electricity generation in our models.

Table 5.3 Avoided Emissions for NO_x Electricity Usage Reductions – Representative State

Year	Savings per Housing Unit (kWh Site)	Savings per Housing Unit (kWh Source)	Savings per Housing Unit (MMBtu Source)	Rate (Short Tons/MMBtu)	Short Tons per Housing Unit
2013	678	720	2.46	4.36E-04	1.07E-03
2014	678	720	2.46	4.23E-04	1.04E-03
2015	678	720	2.46	4.11E-04	1.01E-03
2016	678	720	2.46	4.00E-04	9.82E-04
2017	678	720	2.46	3.88E-04	9.54E-04
First five years	3,391	3,600	12.28	4.12E-04	5.06E-03
Lifetime	7,874	8,361	28.53	3.70E-04	1.06E-02

5.4 ESTIMATING THE VALUE OF AVOIDED NITROGEN OXIDE EMISSIONS (STATE-LEVEL)

The NRC report uses the APEEP provided by Muller et al. (2009)[37] to estimate the damages of one additional short ton of criteria air pollutants at the county level. The APEEP model differentiates between damages from ground-level emissions, such as emissions from fuel oil and natural gas heaters, and damages from point-source emissions, such as emissions from electric plants.

APPRISE contracted with the model developer to update the model with 2008 data. The 2008 county-level damage estimates of each additional short ton of ground-level NO_x were weighted by the county population counts from the 2010 census to estimate the average damage values for each state. The state damage estimates for ground-level emissions were used to calculate the benefit of avoided emissions from natural gas, propane, and fuel oil.

Damage estimates of each additional short ton of point-source NO_x emissions were calculated for each NERC region. The EPA eGRID data were used to estimate the annual non-baseload electricity generation for each county using procedures described in the eGRID technical support document.[38] The county-level damage estimates for point-source emissions were weighted by the county-level quantity of annual non-baseload electricity generation to generate averages for each NERC region. For each state, the benefit of avoided emissions from electricity was calculated using the damage estimate for point-source emissions for the NERC region in which the majority of each state's population resides.

[36] National Research Council *2010 Hidden Costs of Energy: Unpriced Consequences of Energy Production and Use*. National Academy Press, pages 108 and 124.
[37] Muller, N.Z., and R.O. Mendelsohn. 2006. The Air Pollution Emission and Policy Analysis Model (APEEP). Yale University, New Haven, CT. December 2006 [online].
[38] *The Emissions & Generation Resource Integrated Database for 2012 (eGrid2012) Technical Support Document*. Environmental Protection Agency. Washington D.C. April, 2012, page 18.

The NRC estimated an increase in damages per ton of pollution of approximately 50% by 2030 due to growth in population combined with increases in the value of a statistical life and other health impact values.[39] We have applied a similar assumption to our models by incorporating an increase of 1.71% per year to damage values for SO_2, NO_X, PM 2.5, and VOC emissions.

Table 5.4 shows cost statistics in a representative state for the target analysis period – 2013 through 2037 – in nominal dollars and 2013 dollars (i.e., discounted by the recommended real discount rate furnished by OMB).[40]

Table 5.4 Social Cost of NO_x ($ per short ton) By Year (Nominal and 2013 Dollars) – Representative State

	Point-Source Emissions		Ground-Level Emissions	
Year	**$ Per Short Ton (Nominal Value)**	**$ Per Short Ton (2013 Dollars)**	**$ Per Short Ton (Nominal Value)**	**$ Per Short Ton (2013 Dollars)**
2013	$5,566	$5,566	$22,361	$22,361
2014	$5,661	$5,496	$22,743	$22,081
2015	$5,758	$5,428	$23,132	$21,804
2016	$5,857	$5,360	$23,527	$21,531
2017	$5,957	$5,292	$23,930	$21,261
Average for first five years	$5,754	$5,432	$23,139	$21,807
Average for analysis period	$6,182	$5,169	$26,862	$19,668

For a representative state, the avoided emissions per housing unit are listed in Tables 5.1-5.3. The total avoided emissions per housing unit for electricity is multiplied by the dollars per short ton in 2013 dollars for point-source emissions. The total avoided emissions per housing unit for natural gas, propane, and fuel oil is multiplied by the dollars per short ton in 2013 dollars for ground-level emissions. The point-source and ground-level emissions benefits are combined to estimate the total avoided emission benefit per unit at the state level. Table 5.5 shows that calculation for a representative state. The aggregate emissions benefit for the state is estimated using the average per unit times the number of units served. Table 5.6 shows the calculation for a representative state.

[39] National Research Council *2010 Hidden Costs of Energy: Unpriced Consequences of Energy Production and Use*. National Academy Press, page 108.
[40] Jeffrey D. Zients *M-13-04 Memorandum for the Heads of Departments and Agencies.* Executive Office of Management and Budget. January 24, 2013.

Table 5.5 Quantity and Value of Avoided Emissions for NO_x Value per Unit by Fuel Type and Year (2013 Dollars) – Representative State

Year	Natural Gas/Propane		Fuel Oil		Electricity		All Fuels	
	Short Tons per Unit	$ per Unit	Short Tons per Unit	$ per Unit	Short Tons per Unit	$ per Unit	Short Tons per Unit	$ per Unit
2013	5.44E-04	$8.26	6.16E-05	$0.94	1.07E-03	$7.05	1.68E-03	$16.24
2014	5.44E-04	$8.15	6.16E-05	$0.92	1.04E-03	$6.76	1.65E-03	$15.84
2015	5.44E-04	$8.05	6.16E-05	$0.91	1.01E-03	$6.48	1.62E-03	$15.45
2016	5.44E-04	$7.95	6.16E-05	$0.90	9.82E-04	$6.22	1.59E-03	$15.07
2017	5.44E-04	$7.85	6.16E-05	$0.89	9.54E-04	$5.97	1.56E-03	$14.71
First five years	2.72E-03	$40.27	3.08E-04	$4.56	5.06E-03	$32.48	8.08E-03	$77.31
Lifetime	1.16E-02	$155.43	1.35E-03	$18.00	1.06E-02	$65.03	2.35E-02	$238.45

Table 5.6 Quantity and Value of Avoided Emissions for NO_x Aggregate Value – Representative State

Year	Housing Units	Short Tons Per Unit (All Fuels)	Aggregate Short Tons	Value per Unit (2013 Dollars – All Fuels)	Aggregate Value (2013 Dollars – All Fuels)
2013	14,417	1.68E-03	24.16	$16.24	$234,122
2014	14,417	1.65E-03	23.72	$15.84	$228,331
2015	14,417	1.62E-03	23.30	$15.45	$222,728
2016	14,417	1.59E-03	22.88	$15.07	$217,308
2017	14,417	1.56E-03	22.48	$14.71	$212,062
First five years	14,417	8.08E-03	116.54	$77.31	$1,114,550
Lifetime	14,417	2.35E-02	339.38	$238.45	$3,437,739

5.5 NATIONAL TOTALS

The state-level analysis furnishes information on the aggregate avoided emissions, the aggregate emissions benefit, and the number of units served for each state. Those are cumulated to develop a national aggregate value of avoided emissions. Table 5.7 shows the quantity of avoided emissions by fuel type. Table 5.8 shows the value of avoided emissions by fuel type. The analysis shows that if the 2010 WAP program were implemented in 2013, it would be expected to reduce NO_x emissions by 5,834 short tons (Table 5.7) at a lifetime value of $52,179,316 (Table 5.8).

Table 5.7 Quantity of Avoided Emissions for NO_x National Aggregate Total by Fuel Type and Year

Year	Avoided Emissions (Short Tons of NO_x)			
	Natural Gas/Propane	Fuel Oil	Electricity	All Fuels
2013	119.84	32.23	230.95	383.02
2014	119.84	32.23	224.37	376.44
2015	119.84	32.23	217.98	370.04
2016	119.84	32.23	211.76	363.83
2017	119.84	32.23	205.73	357.79
First five years	599.19	161.13	1,090.79	1,851.12
Lifetime	2,504.67	672.31	2,657.43	5,834.40

Table 5.8 Value of Avoided Emissions for NO_x National Aggregate Total by Fuel Type and Year

Year	Avoided Emissions (2013 Dollars)			
	Natural Gas/Propane	Fuel Oil	Electricity	All Fuels
2013	$1,868,045	$304,652	$1,166,718	$3,339,415
2014	$1,844,649	$300,837	$1,119,271	$3,264,756
2015	$1,821,546	$297,069	$1,073,753	$3,192,368
2016	$1,798,732	$293,348	$1,030,086	$3,122,167
2017	$1,776,205	$289,675	$988,196	$3,054,075
First five years	$9,109,176	$1,485,581	$5,378,024	$15,972,782
Lifetime	$34,459,893	$5,491,416	$12,228,007	$52,179,316

Table 5.9 shows the calculation for the average amount of avoided emissions and the average value per housing unit served by the WAP program. The estimated avoided emissions per housing unit at the national level is 0.0176 short tons with a lifetime value of $157.

Table 5.9 Quantity and Value of Avoided Emissions for NO_x Per Housing Unit – National

Year	Units	Aggregate Short Tons	Short Tons Per Unit (All Fuels)	Aggregate Value (2013 Dollars – All Fuels)	Value Per Housing Unit (2013 Dollars – All Fuels)
2013	331,866	383.02	0.0012	$3,339,415	$10.06
2014	331,866	376.44	0.0011	$3,264,756	$9.84
2015	331,866	370.04	0.0011	$3,192,368	$9.62
2016	331,866	363.83	0.0011	$3,122,167	$9.41
2017	331,866	357.79	0.0011	$3,054,075	$9.20
First five years	331,866	1,851.12	0.0056	$15,972,782	$48.13
Lifetime	331,866	5,834.40	0.0176	$52,179,316	$157.23

6. BENEFITS FROM PM 2.5 EMISSIONS REDUCTIONS

The estimates of avoided PM 2.5 are made separately for natural gas and propane, fuel oil, and electricity. Each type of fuel has a different amount of avoided PM 2.5 per unit of energy savings. In addition, for electricity, the amount of avoided PM 2.5 varies by geographic region because of differences in the PM 2.5 emissions rates for generation plants.

6.1 NATURAL GAS AND PROPANE

The EPA furnished an estimate of the PM 2.5 emissions factor from natural gas combustion in boilers and furnaces in AP-42.[41] Emissions are estimated to be 1.9 pounds of PM 2.5 per 10^6 standard cubic feet of natural gas (9.27×10^{-7} short tons per MMBtu).

Table 6.1 shows how avoided emissions were computed for one state studied in the WAP evaluation. The calculation for the representative state shows that the average projected savings per unit in the first program year would be 118.56 therms and the avoided emissions per unit would be 1.10×10^{-5} short tons. The projected lifetime savings would be 2,535.80 therms and the lifetime avoided emissions would be 2.34×10^{-4} short tons.

Note that the installed measures vary in terms of their estimated lifetime. For measures that affect natural gas and propane usage, the lifetime varies between 13 years for a setback thermostat to 25 years for insulation. So, the average therms of savings per unit are lower in some of the later years.

Table 6.1 Avoided Emissions for PM 2.5 Natural Gas and Propane Usage Reductions – Representative State

Year	Savings per Housing Unit (therms)[42]	Savings per Housing Unit (MMBtu)	Rate (Short Tons/MMBtu)	Short Tons per Housing Unit
First Year	118.56	11.86	9.27E-07	1.10E-05
Lifetime	2,535.80	253.58	9.27E-07	2.35E-04

For this calculation, it was assumed that the greenhouse gas emission rates for propane were the same as the rates for natural gas. While that is likely to be a reliable assumption for combustion, it is possible that the process for producing propane has different upstream emissions. However, since propane is a small part of the total energy savings associated with the program (12.4% of savings in the example state), the potential bias is small.

6.2 FUEL OIL

The fuel oil PM 2.5 emissions rate was computed using the EPA estimated PM 2.5 emissions factor from AP-42[43], Compilation of Air Pollutant Emissions.[44] The EPA factor is 0.4 pounds of PM 2.5 per 10^3 gallons of residential fuel oil (1.44×10^{-6} short tons per MMBtu).

[41] AP 42, Fifth Edition, Compilation of Air Pollutant Emission Factors, Volume 1: Stationary Point and Area Sources, Chapter 1: External Combustion Sources. http://www.epa.gov/ttnchie1/ap42/ch01/ 1.4 Natural Gas Combustion Final Section - Supplement D, July 1998. http://www.epa.gov/ttn/chief/ap42/ch01/final/c01s04.pdf page 1.4-6.

[42] The savings per housing unit for any state is the projected aggregate natural gas and propane savings from housing units that use one of those fuels divided by the total number of housing units served by the program in that state.

Table 6.2 shows how avoided emissions were computed for one state studied in the WAP evaluation. The calculation for the representative state shows that the average projected savings per unit in the first program year would be 6.84 gallons and the avoided emissions per unit would be 1.37×10^{-6} short tons. The projected lifetime savings would be 149.99 gallons and the lifetime avoided emissions would be 3.00×10^{-5} short tons.

Note that the installed measures vary in terms of their estimated lifetime. For measures that affect fuel oil, the lifetime varies between 13 years for a setback thermostat to 25 years for insulation. So, the average savings per unit are lower in some of the later years.

Table 6.2 Avoided Emissions for PM 2.5 Fuel Oil Usage Reductions – Representative State

Year	Savings per Housing Unit (Gallons)[45]	Savings per Housing Unit (MMBtu)	Rate (Short Tons/MMBtu)	Short Tons per Housing Unit
First Year	6.84	0.95	1.44E-06	1.37E-06
Lifetime	149.99	20.80	1.44E-06	3.00E-05

6.3 ELECTRICITY

The estimate of the emissions rates for particulate matter for electricity is based on reported data in the 2008 National Emissions Inventory.[46] The inventory furnishes quantities of PM 2.5 emitted by electric generation for each state and fuel sector. We used the EPA eGRID data[47] to calculate plant-level non-baseload generation as described in the eGRID technical support document.[48] These data were combined with the National Emissions Inventory data to calculate average PM 2.5 emission rates from non-baseload generation for each NERC region.

This method yielded emission rates for PM 2.5 per kWh generated at the source. We adjusted the kWh savings from the WAP evaluation to account for transmission losses. These estimates are provided in the EPA eGRID summary tables.[49]

Table 6.3 shows how avoided emissions were computed for one state studied in the WAP evaluation. The calculation for the representative state shows that the average projected savings per unit in the first program year would be 678 kWh and the avoided emissions per unit would be 6.22×10^{-5} short tons. The projected lifetime savings would be 7,874 kWh and the lifetime avoided emissions would be 6.13×10^{-4} short tons.

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[43] AP42, Compilation of Air Pollution Emission Factors, Volume 1: Stationary Point and Area Sources, Chapter 1: External Combustion Sources. http://www.epa.gov/ttnchie1/ap42/ch01/ Section 1.3 Fuel Oil Combustion Final Section – Supplement E September 1999, corrected May 2010. http://www.epa.gov/ttn/chief/ap42/ch01/final/c01s03.pdf, page 1.3-12.

[44] 29. N. F. Suprenant, *et al*., *Emissions Assessment Of Conventional Stationary Combustion Systems, Volume I: Gas And Oil Fired Residential Heating Sources*, EPA-600/7-79-029b, U. S. Environmental Protection Agency, Washington, DC, May 1979.

[45] The savings per housing unit for any state is the projected aggregate fuel oil savings from housing units with fuel oil main heat divided by the total number of housing units served by the program in that state.

[46] 2008 National Emissions Inventory Version 3, updated March 2013. Environmental Protection Agency. http://www.epa.gov/ttnchie1/net/2008inventory.html

[47] EPA *eGRID2012 Version 1.0 Year 2009*, updated May 2012. Environmental Protection Agency. Data files downloaded from http://www.epa.gov/cleanenergy/energy-resources/eGRID/index.html

[48] EPA *eGRID2012 Version 1.0 Year 2009 Technical Support Document*. Environmental Protection Agency. Washington, D.C. Page 18-19. April 2012.

[49] EPA *eGRID2012 Version 1.0 Year 2009 Summary Tables.* Environmental Protection Agency. Washington D.C. April, 2012. Pages 7 & 9.

Note that the installed measures vary in terms of their estimated lifetime. For measures that affect electricity, the lifetime varies between 7 years for lighting and 25 years for insulation. So, the average savings per unit are lower in some of the later years.

The NRC observed that emission rates of PM 2.5 from power plants are expected to decline over time due to increased regulation and costs. The report recommended explicitly accounting for those expected reductions in emissions and provided estimates of 2030 emissions reductions varying by pollutant and power plant fuel.[50] We chose to apply a rough estimate of a 50% emissions reduction over the analysis period of 2013 to 2037. This translates to an annual reduction of 2.85% to the rate of PM 2.5 emissions from electricity generation in our models.

Table 6.3 Avoided Emissions for PM 2.5 Electricity Usage Reductions – Representative State

Year	Savings per Housing Unit (kWh Site)	Savings per Housing Unit (kWh Source)	Savings per Housing Unit (MMBtu Source)	Rate (Short Tons/MMBtu)	Short Tons per Housing Unit
2013	678	720	2.46	2.53E-05	2.53E-05
2014	678	720	2.46	2.46E-05	2.46E-05
2015	678	720	2.46	2.39E-05	2.39E-05
2016	678	720	2.46	2.32E-05	2.32E-05
2017	678	720	2.46	2.26E-05	2.25E-05
First five years	3,391	3,600	12.28	2.39E-05	1.19E-04
Lifetime	7,874	8,361	28.53	2.15E-05	3.44E-04

6.4 ESTIMATING THE VALUE OF AVOIDED PARTICULATE MATTER EMISSIONS (STATE-LEVEL)

The NRC report uses the APEEP provided by Muller et al. (2009)[51] to estimate the damages of one additional short ton of criteria air pollutants at the county level. The APEEP model differentiates between damages from ground-level emissions, such as emissions from fuel oil and natural gas heaters, and damages from point-source emissions, such as emissions from electric plants.

APPRISE contracted with the model developer to update the model with 2008 data. The 2008 county-level damage estimates of each additional short ton of ground-level PM 2.5 were weighted by the county population counts from the 2010 census to estimate the average damage values for each state. The state damage estimates for ground-level emissions were used to calculate the benefit of avoided emissions from natural gas, propane, and fuel oil.

Damage estimates of each additional short ton of point-source PM 2.5 emissions were calculated for each NERC region. The EPA eGRID data were used to estimate the annual non-baseload electricity generation for each county using procedures described in the eGRID technical support document.[52] The county-

[50] National Research Council *2010 Hidden Costs of Energy: Unpriced Consequences of Energy Production and Use*. National Academy Press, pages 108 and 124.
[51] Muller, N.Z., and R.O. Mendelsohn. 2006. The Air Pollution Emission and Policy Analysis Model (APEEP). Yale University, New Haven, CT. December 2006 [online].
[52] *The Emissions & Generation Resource Integrated Database for 2012 (eGRID2012) Technical Support Document*. Environmental Protection Agency. Washington D.C. April, 2012, page 18.

level damage estimates for point-source emissions were weighted by the county-level quantity of annual non-baseload electricity generation to generate averages for each NERC region. For each state, the benefit of avoided emissions from electricity was calculated using the damage estimate for point-source emissions for the NERC region in which the majority of each state's population resides.

The NRC estimated an increase in damages per ton of pollution of approximately 50% by 2030 due to growth in population combined with increases in the value of a statistical life and other health impact values.[53] We have applied a similar assumption to our models by incorporating an increase of 1.71% per year to damage values for SO_2, NO_X, PM 2.5, and VOC emissions.

Table 6.4 shows cost statistics in a representative state for the target analysis period – 2013 through 2037 – in nominal dollars and 2013 dollars (i.e., discounted by the recommended real discount rate furnished by OMB).[54]

Table 6.4 Social Cost of PM 2.5 ($ per short ton) By Year (Nominal and 2013 Dollars) – Representative State

	Point-Source Emissions		Ground-Level Emissions	
Year	**$ Per Short Ton (Nominal Value)**	**$ Per Short Ton (2013 Dollars)**	**$ Per Short Ton (Nominal Value)**	**$ Per Short Ton (2013 Dollars)**
2013	$51,270	$51,270	$455,079	$455,079
2014	$52,147	$50,628	$462,861	$449,380
2015	$53,038	$49,994	$470,776	$443,751
2016	$53,945	$49,368	$478,826	$438,194
2017	$54,868	$48,749	$487,014	$432,706
Average for first five years	$53,002	$50,038	$470,911	$443,822
Average for analysis period	$56,941	$47,612	$546,718	$400,270

For a representative state, the avoided emissions per housing unit are listed in Tables 6.1-6.3. The total avoided emissions per housing unit for electricity is multiplied by the dollars per short ton in 2013 dollars for point-source emissions. The total avoided emissions per housing unit for natural gas, propane, and fuel oil is multiplied by the dollars per short ton in 2013 dollars for ground-level emissions. The point-source and ground-level emissions benefits are combined to estimate the total avoided emission benefit per unit at the state level. Table 6.5 shows that calculation for a representative state. The aggregate emissions benefit for the state is estimated using the average per unit times the number of units served. Table 6.6 shows the calculation for a representative state.

[53] National Research Council *2010 Hidden Costs of Energy: Unpriced Consequences of Energy Production and Use*. National Academy Press, page 108.
[54] Jeffrey D. Zients *M-13-04 Memorandum for the Heads of Departments and Agencies.* Executive Office of Management and Budget. January 24, 2013.

Table 6.5 Quantity and Value of Avoided Emissions for PM 2.5 Value per Unit by Fuel Type and Year (2013 Dollars) – Representative State

Year	Natural Gas/Propane		Fuel Oil		Electricity		All Fuels	
	Short Tons per Unit	$ per Unit	Short Tons per Unit	$ per Unit	Short Tons per Unit	$ per Unit	Short Tons per Unit	$ per Unit
2013	1.10E-05	$0.87	1.37E-06	$0.11	6.22E-05	$1.21	7.45E-05	$2.19
2014	1.10E-05	$0.86	1.37E-06	$0.11	6.04E-05	$1.16	7.28E-05	$2.13
2015	1.10E-05	$0.85	1.37E-06	$0.11	5.87E-05	$1.11	7.11E-05	$2.07
2016	1.10E-05	$0.84	1.37E-06	$0.10	5.70E-05	$1.07	6.94E-05	$2.01
2017	1.10E-05	$0.83	1.37E-06	$0.10	5.54E-05	$1.02	6.78E-05	$1.96
First five years	5.49E-05	$4.26	6.84E-06	$0.53	2.94E-04	$5.57	3.56E-04	$10.36
Lifetime	2.35E-04	$16.42	3.00E-05	$2.09	6.13E-04	$11.15	8.78E-04	$29.67

Table 6.6 Quantity and Value of Avoided Emissions for PM 2.5 Aggregate Value – Representative State

Year	Housing Units	Short Tons Per Unit (All Fuels)	Aggregate Short Tons	Value per Unit (2013 Dollars – All Fuels)	Aggregate Value (2013 Dollars – All Fuels)
2013	14,417	7.45E-05	1.0747	$2.19	$31,568
2014	14,417	7.28E-05	1.0492	$2.13	$30,682
2015	14,417	7.11E-05	1.0244	$2.07	$29,828
2016	14,417	6.94E-05	1.0002	$2.01	$29,003
2017	14,417	6.78E-05	0.9768	$1.96	$28,207
First five years	14,417	3.56E-04	5.1253	$10.36	$149,288
Lifetime	14,417	8.78E-04	12.6649	$29.67	$427,706

6.5 NATIONAL TOTALS

The state-level analysis furnishes information on the aggregate avoided emissions, the aggregate emissions benefit, and the number of units served for each state. Those are cumulated to develop a national aggregate value of avoided emissions. Table 6.7 shows the quantity of avoided emissions by fuel type. Table 6.8 shows the value of avoided emissions by fuel type. The analysis shows that if the 2010 WAP program were implemented in 2013, it would be expected to reduce PM 2.5 emissions by 403.64 short tons (Table 6.7) at a lifetime value of $22,401,066 (Table 6.8). Most of the avoided emissions accrue from the reductions in the use of electricity.

Table 6.7 Quantity of Avoided Emissions for PM 2.5 National Aggregate Total by Fuel Type and Year

	Avoided Emissions (Short Tons of PM 2.5)			
Year	**Natural Gas/Propane**	**Fuel Oil**	**Electricity**	**All Fuels**
2013	2.42	0.72	29.85	32.99
2014	2.42	0.72	29.00	32.14
2015	2.42	0.72	28.17	31.31
2016	2.42	0.72	27.37	30.51
2017	2.42	0.72	26.59	29.73
First five years	12.11	3.58	140.99	156.68
Lifetime	50.63	14.94	338.07	403.64

Table 6.8 Value of Avoided Emissions for PM 2.5 National Aggregate Total by Fuel Type and Year

	Avoided Emissions (2013 Dollars)			
Year	**Natural Gas/Propane**	**Fuel Oil**	**Electricity**	**All Fuels**
2013	$385,219	$156,441	$1,221,662	$1,763,322
2014	$380,395	$154,481	$1,171,980	$1,706,856
2015	$375,630	$152,547	$1,124,319	$1,652,496
2016	$370,926	$150,636	$1,078,596	$1,600,158
2017	$366,280	$148,749	$1,034,732	$1,549,762
First five years	$1,878,451	$762,854	$5,631,288	$8,272,593
Lifetime	$7,045,088	$2,793,680	$12,562,298	$22,401,066

Table 6.9 shows the calculation for the average amount of avoided emissions and the average value per housing unit served by the WAP program. The estimated avoided emissions per housing unit at the national level is 0.001216 short tons with a lifetime value of $67.50.

Table 6.9 Quantity and Value of Avoided Emissions for PM 2.5 Per Housing Unit – National

Year	Units	Aggregate Short Tons	Short Tons Per Unit (All Fuels)	Aggregate Value (2013 Dollars – All Fuels)	Value Per Housing Unit (2013 Dollars – All Fuels)
2013	331,866	32.99	0.000099	$1,763,322	$5.31
2014	331,866	32.14	0.000097	$1,706,856	$5.14
2015	331,866	31.31	0.000094	$1,652,496	$4.98
2016	331,866	30.51	0.000092	$1,600,158	$4.82
2017	331,866	29.73	0.000090	$1,549,762	$4.67
First five years	331,866	156.68	0.000472	$8,272,593	$24.93
Lifetime	331,866	403.64	0.001216	$22,401,066	$67.50

7. BENEFITS FROM VOC EMISSIONS REDUCTIONS

The estimates of avoided VOC are made separately for natural gas and propane, fuel oil, and electricity. Each type of fuel has a different amount of avoided VOC per unit of energy savings. In addition, for electricity, the amount of avoided VOC varies by geographic region because of differences in the VOC emissions rates for generation plants.

7.1 NATURAL GAS AND PROPANE

The EPA furnished an estimate of the VOC emissions factor from natural gas combustion in boilers and furnaces in AP-42.[55] Emissions are estimated to be 5.5 pounds of VOC per 10^6 standard cubic feet of natural gas (2.68×10^{-6} short tons per MMBtu).

Table 7.1 shows how avoided emissions were computed for one state studied in the WAP evaluation. The calculation for the representative state shows that the average projected savings per unit in the first program year would be 54.82 therms and the avoided emissions per unit would be 1.47×10^{-5} short tons. The projected lifetime savings would be 1,152.74 therms and the lifetime avoided emissions would be 3.09×10^{-4} short tons.

Note that the installed measures vary in terms of their estimated lifetime. For measures that affect natural gas and propane usage, the lifetime varies between 13 years for a setback thermostat to 25 years for insulation. So, the average therms of savings per unit are lower in some of the later years.

Table 7.1 Avoided Emissions for VOC Natural Gas and Propane Usage Reductions – Representative State

Year	Savings per Housing Unit (therms)[56]	Savings per Housing Unit (MMBtu)	Rate (Short Tons/MMBtu)	Short Tons per Housing Unit
First Year	118.56	11.86	2.68E-06	3.18E-05
Lifetime	2,535.80	253.58	2.68E-06	6.80E-04

For this calculation, it was assumed that the greenhouse gas emission rates for propane were the same as the rates for natural gas. While that is likely to be a reliable assumption for combustion, it is possible that the process for producing propane has different upstream emissions. However, since propane is a small part of the total energy savings associated with the program (12.4% of savings in the example state), the potential bias is small.

7.2 FUEL OIL

The fuel oil VOC emissions rate was computed using the EPA estimated VOC emissions factors from AP-42[57], Compilation of Air Pollutant Emissions.[58] The EPA provided individual emissions factors from

[55] AP 42, Fifth Edition, Compilation of Air Pollutant Emission Factors, Volume 1: Stationary Point and Area Sources, Chapter 1: External Combustion Sources. http://www.epa.gov/ttnchie1/ap42/ch01/ 1.4 Natural Gas Combustion Final Section - Supplement D, July 1998. http://www.epa.gov/ttn/chief/ap42/ch01/final/c01s04.pdf page 1.4-6.

[56] The savings per housing unit for any state is the projected aggregate natural gas and propane savings from housing units that use one of those fuels divided by the total number of housing units served by the program in that state.

[57] AP42, Compilation of Air Pollution Emission Factors, Volume 1: Stationary Point and Area Sources, Chapter 1: External Combustion Sources. http://www.epa.gov/ttnchie1/ap42/ch01/ Section 1.3 Fuel Oil Combustion Final Section – Supplement E September 1999, corrected May 2010. http://www.epa.gov/ttn/chief/ap42/ch01/final/c01s03.pdf, page 1.3-21.

fuel oil combustion for 21 speciated organic compounds. These were aggregated to get total VOC emissions for fuel oil estimated at 1.48 x 10^{-7} short tons per MMBtu.

Table 7.2 shows how avoided emissions were computed for one state studied in the WAP evaluation. The calculation for the representative state shows that the average projected savings per unit in the first program year would be 6.04 gallons and the avoided emissions per unit would be 1.24 x 10^{-7} short tons. The projected lifetime savings would be 127.46 gallons and the lifetime avoided emissions would be 2.61 x 10^{-6} short tons.

Note that the installed measures vary in terms of their estimated lifetime. For measures that affect fuel oil, the lifetime varies between 13 years for a setback thermostat to 25 years for insulation. So, the average savings per unit are lower in some of the later years.

Table 7.2 Avoided Emissions for VOC Fuel Oil Usage Reductions – Representative State

Year	Savings per Housing Unit (Gallons)[59]	Savings per Housing Unit (MMBtu)	Rate (Short Tons/MMBtu)	Short Tons per Housing Unit
First Year	6.84	0.95	1.48E-07	1.40E-07
Lifetime	149.99	20.80	1.48E-07	3.08E-06

7.3 ELECTRICITY

The estimate of the emissions rates for volatile organic compounds for electricity is based on reported data in the 2008 National Emissions Inventory.[60] The inventory furnishes quantities of VOC emitted by electric generation for each state and fuel sector. We used the EPA eGRID data[61] to calculate plant-level non-baseload generation as described in the eGRID technical support document.[62] These data were combined with the National Emissions Inventory data to calculate average PM 2.5 emission rates from non-baseload generation for each NERC region.

This method yielded emission rates for VOC per kWh generated at the source. We adjusted the kWh savings from the WAP evaluation to account for transmission losses. These estimates are provided in the EPA eGRID summary tables.[63]

Table 7.3 shows how avoided emissions were computed for one state studied in the WAP evaluation. The calculation for the representative state shows that the average projected savings per unit in the first program year would be 1,346 kWh and the avoided emissions per unit would be 1.53 x 10^{-5} short tons. The projected lifetime savings would be 23,281 kWh and the lifetime avoided emissions would be 2.65 x 10^{-4} short tons.

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[58] 29. N. F. Suprenant, *et al*., *Emissions Assessment Of Conventional Stationary Combustion Systems, Volume I: Gas And Oil Fired Residential Heating Sources*, EPA-600/7-79-029b, U. S. Environmental Protection Agency, Washington, DC, May 1979.
[59] The savings per housing unit for any state is the projected aggregate fuel oil savings from housing units with fuel oil main heat divided by the total number of housing units served by the program in that state.
[60] 2008 National Emissions Inventory Version 3, updated March 2013. Environmental Protection Agency. http://www.epa.gov/ttnchie1/net/2008inventory.html
[61] EPA *eGRID2012 Version 1.0 Year 2009*, updated May 2012. Environmental Protection Agency. Data files downloaded from http://www.epa.gov/cleanenergy/energy-resources/eGRID/index.html
[62] EPA *eGRID2012 Version 1.0 Year 2009 Technical Support Document*. Environmental Protection Agency. Washington, D.C. Page 18-19. April 2012.
[63] EPA *eGRID2012 Version 1.0 Year 2009 Summary Tables.* Environmental Protection Agency. Washington D.C. April, 2012. Pages 7 & 9.

Note that the installed measures vary in terms of their estimated lifetime. For measures that affect electricity, the lifetime varies between 7 years for lighting and 25 years for insulation. So, the average savings per unit are lower in some of the later years.

Table 7.3 Avoided Emissions for VOC Electricity Usage Reductions – Representative State

Year	Savings per Housing Unit (kWh Site)	Savings per Housing Unit (kWh Source)	Savings per Housing Unit (MMBtu Source)	Rate (Short Tons/MMBtu)	Short Tons per Housing Unit
2013	678	720	2.46	6.43E-06	1.58E-05
2014	678	720	2.46	6.43E-06	1.58E-05
2015	678	720	2.46	6.43E-06	1.58E-05
2016	678	720	2.46	6.43E-06	1.58E-05
2017	678	720	2.46	6.43E-06	1.58E-05
First five years	3,391	3,600	12.28	6.43E-06	7.89E-05
Lifetime	7,874	8,361	28.53	6.43E-06	1.83E-04

7.4 ESTIMATING THE VALUE OF AVOIDED VOLATILE ORGANIC COMPOUNDS EMISSIONS (STATE-LEVEL)

The NRC report uses the APEEP provided by Muller et al. (2009)[64] to estimate the damages of one additional short ton of criteria air pollutants at the county level. The APEEP model differentiates between damages from ground-level emissions, such as emissions from fuel oil and natural gas heaters, and damages from point-source emissions, such as emissions from electric plants.

APPRISE contracted with the model developer to update the model with 2008 data. The 2008 county-level damage estimates of each additional short ton of ground-level VOC were weighted by the county population counts from the 2010 census to estimate the average damage values for each state. The state damage estimates for ground-level emissions were used to calculate the benefit of avoided emissions from natural gas, propane, and fuel oil.

Damage estimates of each additional short ton of point-source VOC emissions were calculated for each NERC region. The EPA eGRID data were used to estimate the annual non-baseload electricity generation for each county using procedures described in the eGRID technical support document.[65] The county-level damage estimates for point-source emissions were weighted by the county-level quantity of annual non-baseload electricity generation to generate averages for each NERC region. For each state, the benefit of avoided emissions from electricity was calculated using the damage estimate for point-source emissions for the NERC region in which the majority of each state's population resides.

The NRC estimated an increase in damages per ton of pollution of approximately 50% by 2030 due to growth in population combined with increases in the value of a statistical life and other health impact values.[66] We have applied a similar assumption to our models by incorporating an increase of 1.71% per year to damage values for SO_2, NO_X, PM 2.5, and VOC emissions.

[64] Muller, N.Z., and R.O. Mendelsohn. 2006. The Air Pollution Emission and Policy Analysis Model (APEEP). Yale University, New Haven, CT. December 2006 [online].
[65] *The Emissions & Generation Resource Integrated Database for 2012 (eGRID2012) Technical Support Document*. Environmental Protection Agency. Washington D.C. April, 2012, page 18.
[66] National Research Council *2010 Hidden Costs of Energy: Unpriced Consequences of Energy Production and Use*. National Academy Press, page 108.

Table 7.4 shows cost statistics in a representative state for the target analysis period – 2013 through 2037 – in nominal dollars and 2013 dollars (i.e., discounted by the recommended real discount rate furnished by OMB).[67]

Table 7.4 Social Cost of VOC ($ per short ton) By Year (Nominal and 2013 Dollars) – Representative State

	Point-Source Emissions		Ground-Level Emissions	
Year	**$ Per Short Ton (Nominal Value)**	**$ Per Short Ton (2013 Dollars)**	**$ Per Short Ton (Nominal Value)**	**$ Per Short Ton (2013 Dollars)**
2013	$4,901	$4,901	$42,908	$42,908
2014	$4,985	$4,840	$43,642	$42,371
2015	$5,071	$4,779	$44,388	$41,840
2016	$5,157	$4,720	$45,147	$41,316
2017	$5,245	$4,660	$45,919	$40,799
Average for first five years	$5,072	$4,780	$44,401	$41,847
Average for analysis period	$5,505	$4,516	$51,508	$37,760

For a representative state, the avoided emissions per housing unit are listed in Tables 7.1-7.3. The total avoided emissions per housing unit for electricity is multiplied by the dollars per short ton in 2013 dollars for point-source emissions. The total avoided emissions per housing unit for natural gas, propane, and fuel oil is multiplied by the dollars per short ton in 2013 dollars for ground-level emissions. The point-source and ground-level emissions benefits are combined to estimate the total avoided emission benefit per unit at the state level. Table 7.5 shows that calculation for a representative state. The aggregate emissions benefit for the state is estimated using the average per unit times the number of units served. Table 7.6 shows the calculation for a representative state.

[67] Jeffrey D. Zients *M-13-04 Memorandum for the Heads of Departments and Agencies.* Executive Office of Management and Budget. January 24, 2013.

Table 7.5 Quantity and Value of Avoided Emissions for VOC Value per Unit by Fuel Type and Year (2013 Dollars) – Representative State

Year	Natural Gas/Propane		Fuel Oil		Electricity		All Fuels	
	Short Tons per Unit	$ per Unit	Short Tons per Unit	$ per Unit	Short Tons per Unit	$ per Unit	Short Tons per Unit	$ per Unit
2013	3.18E-05	$0.241	1.40E-07	$0.001	1.58E-05	$0.029	4.77E-05	$0.27
2014	3.18E-05	$0.238	1.40E-07	$0.001	1.58E-05	$0.029	4.77E-05	$0.27
2015	3.18E-05	$0.235	1.40E-07	$0.001	1.58E-05	$0.029	4.77E-05	$0.26
2016	3.18E-05	$0.232	1.40E-07	$0.001	1.58E-05	$0.028	4.77E-05	$0.26
2017	3.18E-05	$0.229	1.40E-07	$0.001	1.58E-05	$0.028	4.77E-05	$0.26
First five years	1.59E-04	$1.176	7.01E-07	$0.005	7.89E-05	$0.144	2.39E-04	$1.32
Lifetime	6.80E-04	$4.539	3.08E-06	$0.020	1.83E-04	$0.318	8.67E-04	$4.88

Table 7.6 Quantity and Value of Avoided Emissions for VOC Aggregate Value – Representative State

Year	Housing Units	Short Tons Per Unit (All Fuels)	Aggregate Short Tons	Value per Unit (2013 Dollars – All Fuels)	Aggregate Value (2013 Dollars – All Fuels)
2013	14,417	4.77E-05	0.69	$0.27	$3,916
2014	14,417	4.77E-05	0.69	$0.27	$3,867
2015	14,417	4.77E-05	0.69	$0.26	$3,819
2016	14,417	4.77E-05	0.69	$0.26	$3,771
2017	14,417	4.77E-05	0.69	$0.26	$3,724
First five years	14,417	2.39E-04	3.44	$1.32	$19,097
Lifetime	14,417	8.67E-04	12.50	$4.88	$70,312

7.5 NATIONAL TOTALS

The state-level analysis furnishes information on the aggregate avoided emissions, the aggregate emissions benefit, and the number of units served for each state. Those are cumulated to develop a national aggregate value of avoided emissions. Table 7.7 shows the quantity of avoided emissions by fuel type. Table 7.8 shows the value of avoided emissions by fuel type. The analysis shows that if the 2010 WAP program were implemented in 2013, it would be expected to reduce VOC emissions by 65.34 short tons (Table 7.7) at a lifetime value of $647,474 (Table 7.8). Most of the avoided emissions accrue from the reductions in the use of fuel oil and electricity.

Table 7.7 Quantity of Avoided Emissions for VOC National Aggregate Total by Fuel Type and Year

Year	Avoided Emissions (Short Tons of VOC)			
	Natural Gas/Propane	Fuel Oil	Electricity	All Fuels
2013	7.01	0.07	4.77	11.85
2014	7.01	0.07	4.77	11.85
2015	7.01	0.07	4.77	11.85
2016	7.01	0.07	4.77	11.85
2017	7.01	0.07	4.77	11.85
First five years	35.06	0.37	23.83	59.25
Lifetime	146.55	1.53	67.59	215.67

Table 7.8 Value of Avoided Emissions for VOC National Aggregate Total by Fuel Type and Year

Year	Avoided Emissions (2013 Dollars)			
	Natural Gas/Propane	Fuel Oil	Electricity	All Fuels
2013	$105,698	$1,512	$15,363	$122,573
2014	$104,374	$1,493	$15,171	$121,038
2015	$103,067	$1,475	$14,981	$119,522
2016	$101,776	$1,456	$14,793	$118,025
2017	$100,501	$1,438	$14,608	$116,547
First five years	$515,416	$7,375	$74,916	$597,707
Lifetime	$1,933,351	$27,017	$196,431	$2,156,799

Table 7.9 shows the calculation for the average amount of avoided emissions and the average value per housing unit served by the WAP program. The estimated avoided emissions per housing unit at the national level is 0.000760 short tons with a lifetime value of $7.53.

Table 7.9 Quantity and Value of Avoided Emissions for VOC Per Housing Unit – National

Year	Units	Aggregate Short Tons	Short Tons Per Unit (All Fuels)	Aggregate Value (2013 Dollars – All Fuels)	Value Per Housing Unit (2013 Dollars – All Fuels)
2013	331,866	11.85	0.000036	$122,573	$0.37
2014	331,866	11.85	0.000036	$121,038	$0.36
2015	331,866	11.85	0.000036	$119,522	$0.36
2016	331,866	11.85	0.000036	$118,025	$0.36
2017	331,866	11.85	0.000036	$116,547	$0.35
First five years	331,866	59.25	0.000179	$597,707	$1.80
Lifetime	331,866	215.67	0.000650	$2,156,799	$6.50

8. SUMMARY OF ENVIRONMENTAL BENEFITS

Table 8.1 furnishes information on the 2010 WAP program emissions impacts, both in tons of avoided emissions and in the estimated social value of emissions. The table shows that the aggregate value of avoided emissions is over $645 million and that the average value per housing unit is $1,944. SO2 emissions and CO2 equivalents account for almost 90 percent of the benefits. The other emissions represent a little over 10 percent of the aggregate value.

Table 8.1 Quantity and Value of Avoided Emissions by Type of Emissions Aggregate and Per Housing Unit - National

Type of Emissions	Housing Units	Aggregate Tons	Tons Per Unit (All Fuels)	Aggregate Value (2013 Dollars – All Fuels)	Value Per Housing Unit (2013 Dollars – All Fuels)
CO_2 Equivalents	331,866	7,382,524*	22.25	$281,573,912	$848
SO_2		10,531**	0.0317	$286,819,004	$864
NOx		5,834**	0.0176	$52,179,316	$157
PM 2.5		404**	0.001216	$22,401,066	$68
VOCs		216**	0.000650	$2,156,799	$7
TOTAL		N/A	N/A	$645,130,097	$1,944

*Metric Tons
**Short Tons

Table 8.2 shows how each fuel contributes to the aggregate value of savings for each type of emissions. Natural gas and propane account for about 27 percent of the value of avoided emissions, fuel oil accounts for about 25 percent, and electricity accounts for about 48 percent.

Housing units with fuel oil main heat account for about 10 percent of WAP housing units. However, they represent about one-fourth of the benefits of avoided emissions for a number of reasons. Fuel oil has higher SO_2 emissions per MMBtu than other fuels, is a ground source pollutant (i.e., is emitted at the level where it has the greatest health impact), and is emitted in areas where the social cost is highest.

Natural gas and propane account for the social cost of about 45 percent of greenhouse gas emissions (i.e., CO_2 equivalents), two-thirds of NO_x emissions, and almost 90 percent of the VOC emissions. About 60 percent of housing units treated by the WAP program are heated by natural gas or propane.

Electricity generation accounts for a significant share of all of the listed emissions, except for VOCs. Electricity accounts for over 50 percent of the value of avoided PM 2.5 emissions, 45 percent of the value of avoided emissions of CO_2 equivalents, and 55 percent of value of avoided emissions of SO_2. About 30 percent of homes treated by the WAP program use electricity as their main heating fuel.

Table 8.2 Value of Avoided Emissions by Type of Emissions and Fuel Type Aggregate Value – National

Type of Emissions	Natural Gas and Propane	Fuel Oil	Electricity	Aggregate Value - All Fuels
CO_2 Equivalents	$127,664,107	$28,409,661	$125,500,144	$281,573,912
SO_2	$703,590	$126,795,909	$159,319,505	$286,819,004
NOx	$34,459,893	$5,491,416	$12,228,007	$52,179,316
PM 2.5	$7,045,088	$2,793,680	$12,562,298	$22,401,066
VOCs	$1,933,351	$27,017	$196,431	$2,156,799
TOTAL	$171,806,029	$163,517,683	$309,806,385	$645,130,097