MEMORANDUM

To: Massachusetts Program Administrators

From: Greg Clendenning and Nicole Rosenberg, NMR Group, Inc.; and Beth Hawkins and Michaela Marincic, Three[3]

Cc: Katherine Weber and Christine Smaglia, NMR Group, Inc.; and Jillian Lentz, Three[3]

Date: March 20, 2019

Re: TXC60 Solar and Home Energy Services Safety Remediation Non-Energy Impacts Study – Final Results

---

This memo presents the results of the *Solar and Home Energy Services Safety Remediation Non-Energy Impacts Study* (TXC60) that NMR Group, Inc. and Three[3] (the team) conducted from September 2018 through January 2019. Using a literature review and other secondary research, the team identified non-energy impacts (NEIs) associated with the installation of solar photovoltaic (PV) panels, energy-storage batteries, and the remediation of knob and tube (K&T) wiring and asbestos.

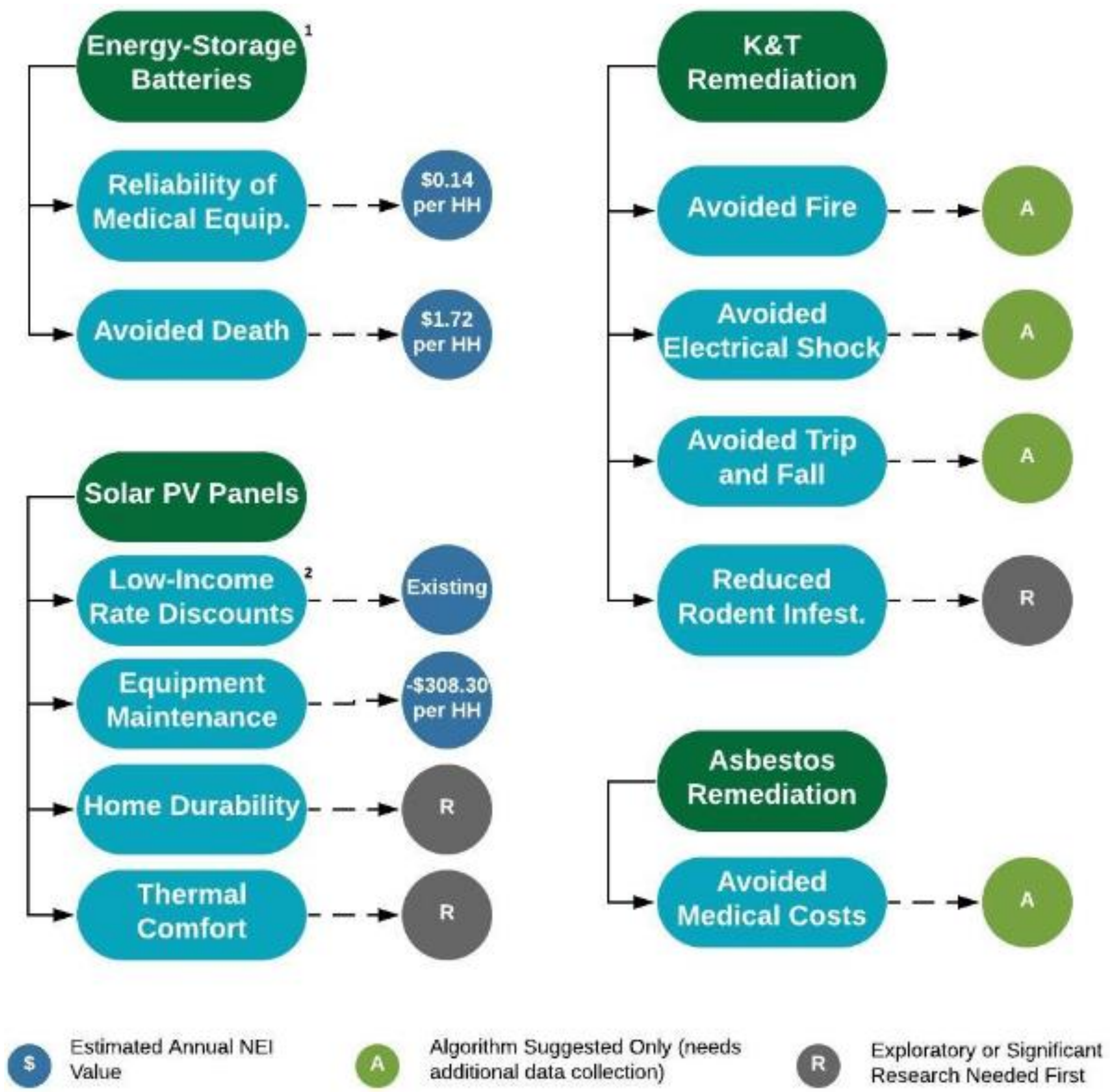
This memo addresses these NEIs together because both are being considered as new offerings in the 2019-2021 program cycle. The Program Administrators (PAs) have proposed or are considering solar PV or energy-storage battery incentives as new components of the energy services offering (see Section 1 for a brief overview of this offering), but solar PV does not yet have quantified NEIs that can be used in regulatory benefit-cost ratio (BCR) models. In addition, the PAs have added program offerings to help customers address K&T wiring and other pre-weatherization barriers as part of the Residential Coordinated Delivery (RCD) Initiative, but the PAs have not yet quantified NEIs that can be used in regulatory BCR models (see Section 2 for more details).

Summary of Findings and Considerations

Figure 1 is a graphical summary of the research findings. It shows the values of monetized NEI we propose for PA consideration based on this research and the next steps for NEIs we identified in each measure category that require additional data collection to be monetized.

The NEIs are organized by four categories of measures: energy storage batteries that are installed with solar PV panels, solar PV panels, knob and tube remediation, and asbestos remediation. **Two of the four monetized NEIs the PAs may wish to consider incorporating into their BCR models are** associated with energy storage batteries (**reliability of medical equipment at $0.14 per household and avoided deaths at $1.72 per household**). The other two are associated with solar PV panels (**low-income rate discounts at the same level the PAs currently claim and cost of equipment maintenance at -$308.30 per household**). As the figure shows, we also prepared **algorithms for the PAs to use should they choose to collect data to quantify** three additional NEIs associated with knob and tube remediation (**avoided fires, electrical shocks, and trips and falls**) and one additional NEI associated with asbestos remediation (**avoided medical costs**). Finally, the figure shows a total of **three NEIs that would require significant research in order to be monetized (home durability and thermal comfort** associated with solar PV panels, **and reduced rodent infestation** associated with knob and tube remediation).

Figure 1: Proposed NEI Values and Next Steps for Each Measure Category



[1] Installed with PV panels.
[2] Applying the same NEIs for the low-income rate discounts for energy savings attributable to low-income energy efficiency programs to the energy generated by the solar PV systems installed at low-income households.

Future Research

Collecting the data or conducting other research to monetize NEIs is costly. Indeed, the cost of monetizing the seven NEIs in Figure 1 that require additional research may outweigh the potential savings the PAs could reap from them. **We conclude that the most worthwhile research to monetize other NEIs would be a study to estimate the avoided medical costs associated with asbestos remediation.** In this summary we estimate the research costs and their value in comparison to the resulting NEIs. The body of this memo describes the research approaches in greater detail.

Considerations for Non-Program Financial Support

Based on findings presented in Section **Error! Reference source not found.**, **the PAs should consider incorporating non-program financial support into their BCR models**, such as federal and state tax credits, **and incentives** such as those offered through the Solar Massachusetts Renewable Target (SMART) Program, **as reductions in participants' out-of-pocket (OOP) costs** (rather than as benefits).

Section 1 Solar-Energy and Energy-Storage

1.1 Background

The PAs have proposed or are considering solar or energy-storage battery incentives but do not currently offer incentives for these measures. We conducted brief interviews with Cape Light Compact (CLC) and National Grid staff to understand the proposed initiatives.[1]

CLC has mapped out a potential program that would offer incentives and/or loans for installing solar PV and energy-storage batteries in conjunction with cold-weather heat pumps. The program would be available to single-family customers, including low-income customers, who do not use natural gas and install all three measures. Levels of support (i.e., incentive amounts and loan offerings) would be based on income. (Note that this study does not attempt to quantify NEIs associated with cold-weather heat pumps.[2])

National Grid staff described a different proposed program model. National Grid would limit their support of solar equipment to an educational platform,[3] funneling customers to an online solar marketplace such as EnergySage.[4] Not currently advertised on the Mass Save website, energy-storage batteries are eligible for HEAT loans[5] (as custom measures) *if* customers participate in a separate demand response program (neither the loan program or the demand response program claim energy savings for the batteries).

1.2 Non-Energy Impacts

Table 1 lists the NEIs associated with solar PV and energy-storage batteries for which we suggest values, algorithms, or primary research. We offer for consideration NEI values for reliability of medical equipment, avoided death, equipment maintenance, and low-income rate discounts. We identified additional potential NEIs of home durability and thermal comfort but do not recommend NEI values. We also do not recommend further research or consideration. The reliability of

[1] Additional details are available in the PA-Specific programming Appendices of the PAs final 2019-21 Three Year Energy Efficiency Plan. http://ma-eeac.org/wordpress/wp-content/uploads/Exh.-1-Final-Plan-10-31-18-With-Appendices-no-bulk.pdf

[2] The PAs currently claim several NEIs for heat pumps. This study did not consider any additional NEIs that may be specific to cold-weather heat pump NEIs.

[3] This memo does not address the question of attribution of participants' adoption of the PV or battery measures. Attribution is a key issue for determining the applicability of any quantified PV NEIs, as PV measures are eligible for sizeable tax credits and other incentives. These are likely more important drivers of measure adoption than providing a link to an educational platform such as EnergySage. We expect the presence of key drivers other than PA program support to be a key topic for future evaluations or regulatory rulings. However, we can still estimate the NEIs associated with these measures.

[4] A private and unrelated enterprise, EnergySage, aggregates offerings from pre-screened installers and gives customers guidance to compare those offerings. For more information see https://www.energysage.com/market-intro/.

[5] A Mass Save-sponsored HEAT loan provides up to $25,000 toward qualified energy efficient home improvements. For more information see: https://www.masssave.com/en/saving/residential-rebates/heat-loan-program/

medical equipment and avoided death values listed in Table 1 require that a battery storage system have been installed with the PV panels. A solar PV system that is connected to the grid will shut off in the event of a power outage and only battery power will be available.[6] Thermal comfort and home durability are only applicable for PV panels as they are associated with the physical structures of the equipment. All other NEIs in Table 1 apply to both solar PV only and solar PV and battery installations.[7]

Table 1: Solar PV and Energy-Storage – Non-Energy Impact Summary

Measure	Non-Energy Impact	Value Suggested	Algorithm Developed Only	Needs Exploratory Research First
Energy-storage battery[1]	Reliability of medical equipment	$0.14 per household per year		
	Avoided death	$1.72 per household per year		
Solar PV panels	Equipment maintenance	-$308 per household per year[3]		
	Home durability			✓
	Thermal comfort			✓
	Rate discounts[2]	PA-specific rate discounts		

[1] Installed with PV panels.
[2] This is for low-income customers only and can be applied to various measures, such as PV.
[3] Because this NEI is based on the cost of the system and the costs of solar PV continue to decline, we suggest updating this value regularly.

1.2.1 Reliability of Medical Equipment

The health of individuals who rely on electricity to operate medical equipment (such as ventilators, at-home dialysis machines, and oxygen) can be severely impacted by an electrical power outage.[8, 9] A power outage can cause some patients to seek emergency department (ED) care and use hospital resources.[10] In some cases, outages can result in death.[11] Energy-storage batteries can help avoid these negative outcomes, as they offer a reliable source of energy separate from the electrical grid.

While energy reliability and the direct material damages related to it are already accounted for in the AESC avoided costs study,[12] the AESC study does not address health impacts. Therefore,

---

[6] Energy Sage, "Solar FAQs 11. Do solar panels work in a blackout?" https://www.energysage.com/solar/solar-faq/
[7] MA Department of Energy and Environmental Affairs, "Historic power outages," (2016).
[8] Peter W. Greenwald, MD et al., "Emergency Department Visits for Home Medical Device Failure during the 2003 North America Blackout," *Academic Emergency Medicine,* 11, (2004): 786-789.
[9] G. Brooke Anderson and Michelle L. Bell, "Lights out: Impact of the August 2003 power outage on mortality in New York, NY," *Epidemiology* 23 (2), (2012): 189-193.
[10] Greenwald et al., *Emergency Department Visits*, 2004.
[11] Anderson and Bell, *Lights Out*, 2012.
[12] Synapse Energy Economics, "Avoided Energy Supply Components in New England: 2018 Report," Submitted to *AESC 2018 Study Group*, March 30, 2018, http://www.synapse-energy.com/sites/default/files/AESC-2018-17-080-June-Release.pdf.

the PAs may wish to consider accounting for the avoided health risks associated with the installation of solar PV and storage batteries. We suggest for consideration an NEI value of **$0.14 per household** for reliability of medical equipment resulting from energy-storage batteries. Table 2 presents the algorithm used to calculate the NEI values. The algorithm assumes that electricity-dependent medical equipment is connected to and will be powered by energy-storage battery measures in the event of an outage.

The U.S. Department of Health and Human Services (HHS) emPOWER Map 3.0 includes a count of Medicare beneficiaries in MA who use electric-dependent medical devices, such as ventilators, dialysis machines, and oxygen concentrators.[13,14] This excludes electricity-dependent patients on Medicaid, private insurance, or those who had not made a claim in the applicable time frames and is therefore a conservative count of the population at risk.

United States Energy Information Administration (EIA) Form 861 collects data on the System Average Interruption Frequency Index (SAIFI) and System Average Interruption Duration Index (SAIDI) for utilities across the U.S. [15] SAIFI is the sum of the total number of customers interrupted over the year divided by the total number of customers served. SAIDI is the sum of customer minutes interrupted over the year divided by the total number of customers served. Major event days (MEDs), or power outages caused by major storms, are included. For this study, we weighted SAIFI and SAIDI for investor-owned MA utilities by the number of customers they serve.

Greenwald et al.'s study of the 2003 power outage that affected New York City for approximately 24 hours compiled data on patients that visited or were admitted to the ED with electricity-dependent medical equipment failure as their main complaint. It found that 23 patients (9% of all presenting patients) were transported to the ED because medical equipment failed during the power outage. The time at which these patients arrived in the ED was also included in the article, which allowed us to compare this outage to an average MA power outage of 4.6 hours.[16] To calculate the rate at which electricity-dependent patients visited the ER and were discharged, we divided those who visited and were discharged by the number of electricity-dependent patients in the Washington Heights neighborhood that the hospital serves. Similarly, we calculated the rate electricity-dependent patients were then admitted to the hospital by dividing the number of inpatients by the number of electricity-dependent patients in the Washington Heights neighborhood that the hospital serves.

---

[13] U.S. Department of Health and Human Services (HHS), "emPOWER Map 3.0," https://empowermap.hhs.gov/ (accessed October 15, 2018).

[14] The count includes those in MA "with claims in Centers for Medicare and Medicaid Services (CMS) databases from the prior month for ventilator, BiPAP, internal feeding, IV infusion pump, suction pump, at-home dialysis, electric wheelchair, and electric bed equipment in the past 13 months; oxygen concentrator equipment in the past 36 months; and an implanted cardiac device (i.e., LVAD, RVAD, BIVAD, TAH) in the past five years."

[15] United States Energy Information Administration (EIA), Form EIA-861, SAIFI with MED for investor operated utilities, weighted by number of customers, last modified 2017, https://www.eia.gov/electricity/data/eia861/.

[16] The length of the average power outage in MA was estimated by dividing SAIDI by SAIFI, weighted by number of customers.

The State Inpatient Databases (SID) and the State Emergency Department Databases (SEDD) of the Healthcare Cost and Utilization Project (HCUP)[17] include data on the treatment charges for inpatients and ED visits, respectively.

We estimated the financial risk to an individual that visits a hospital due to medical equipment failure as a result of a power outage by first estimating the proportion of MA residents who depend on electricity for their medical equipment (0.54%). Then we multiplied this number by the risk that a customer in MA will experience a power outage in a given year (112.8%). Next, we multiplied this value by the chance that someone who is dependent on electrically powered medical equipment would visit the ED (3%) or visit the ED and be admitted to the hospital (2%). Finally, to arrive at the suggested NEI of $0.14, we multiplied this rate by the median charges for an ED visit ($1,300) or hospital admission ($11,000) in MA and by the average percent paid by a patient OOP (8%).

[17] Healthcare Cost and Utilization Project (HCUP) Summary Statistics Report: MA State Emergency Department Databases (SEDD) 2015 Q1-Q3 TOTCHG (Total charges (cleaned)), p. 173, https://www.hcup-us.ahrq.gov/db/state/seddc/tools/cdstats/MA_SEDDC_2015q1q3_SummaryStats_CORE.PDF (accessed October 2018).

Table 2: Energy-Storage – Reliability of Medical Equipment Algorithm

Input		Value	Source
a	Electricity-dependent beneficiaries in MA	37,064	U.S. Department of Health and Human Services[18]
b	MA population (million people)	6.9	2017 U.S. Census Bureau[19]
c	Percent dependent on electricity	0.54%	a / b
d	Average rate of power outages per customer per year	112.8%	Results from 2017 EIA Form 861 (SAIFI)[20]
e	Risk that an electricity-dependent resident will experience a power outage annually	0.61%	c * d
f	Length of an average outage in MA (hours)	4.6	Results from 2017 EIA Form 861 (SAIDI/SAIFI)[21]
g	Electricity-dependent beneficiaries in Washington Heights, NY	168	U.S. Department of Health and Human Services[22]
h	ED visits from electricity-dependent population in first 4.6 hours [f] of power outage (exclusive of admissions)	5	Greenwald et al. [23]
i	ED admissions from electricity-dependent population in first 4.6 hours [f] of power outage	4	Greenwald et al. [24]
j	Rate of ED visits from electricity-dependent population during power outage (exclusive of admissions)	3%	h / g
k	Rate of ED admissions from electricity-dependent population during power outage	2%	i / g
l	Risk that an electricity dependent household will experience a power outage and visit the ED annually	0.018%	e * j
m	Risk that an electricity dependent household will experience a power outage and be admitted to the ED annually	0.015%	e * k
n	Median ED visit charge in MA in 2015	$1,291	HCUP[25]
o	Median charge in MA for "Respiratory failure, insufficiency, arrest (adult)," all discharges, 2018	$10,796	HCUP[26]
p	Average percent of charges paid OOP in MA	8%	Levit et al.[27]
Non-Energy Impact Value			
q	Value of avoided cost of ED visit or admission due to medical equipment failure due to power outage, MA, annual (median)	**$0.14**	((l * n) + (m * o)) * p

[18] HHS, *emPOWER Map 3.0*, October 15, 2018.

1.2.2 Avoided Death

Anderson and Bell found that sustained power outages are linked to increased mortality due to accidents, CO poisoning, hypothermia, and disease-related causes.[28] In their paper covering the 2003 New York City citywide blackout, they estimated the expected daily mortality rate during the blackout, controlling for day-of-week, temperature, dew-point, and long-term and seasonal mortality trends. They then compared the modeled rate to the observed rate and found a 28% increase in mortality, resulting in 90 excess deaths across the city. Excess deaths were primarily from non-accidental causes (i.e., 78 of 90 were disease-related). The air temperature during the outage was hot but average for a New York City day in August and neither day was classified as a heatwave.[29]

As we discuss below, we suggest for consideration an NEI value of **$1.72 per household** for avoided death resulting from energy-storage batteries. The AESC study accounts for energy reliability and the direct material damages related to it but does not address health impacts. Therefore, we suggest accounting for the avoided risk of death resulting from installing storage batteries.

As discussed above, Anderson and Bell found 78 excess deaths due to disease as a result of the 2003 New York City power outage.

We estimated the risk of an individual losing their life in a power outage by dividing the number of non-accidental excess deaths by the number of people living in NYC in 2003. We then multiplied this risk (0.001%) by the EPA's value of a statistical life. Next, we adjusted that value ($89.60) by one-fifth to account for the fact that the average power outage in MA, 4.6 hours, is considerably shorter than the 2003 NYC power outage, to arrive at value of $17.17. Because this mortality rate includes deaths that occur in nursing homes, hospitals, and other non-residential buildings, we suggest counting only a portion of the $17.17 as an NEI for solar PV and energy-storage battery measures. We propose 10%, or $1.72, as a conservative estimate to consider. Table 3 presents the algorithm used to calculate the NEI value.

---

19 U.S. Census Bureau, MA Population Estimates, July 1, 2017.
20 EIA, *Form EIA-861*, 2017.
21 Ibid.
22 HHS, *emPOWER Map 3.0*, October 15, 2018.
23 Greenwald et al., *Emergency Department Visits,* 2004.
24 Ibid.
25 HCUP, *Summary Statistics,* 2018.
26 HCUP, *MA State Inpatient Databases (SID)*, 2015.
27 Levit et al., *Estimating Inpatient Hospital Prices*, 2013.
28 Anderson and Bell, *Lights Out*, 2012.
29 Dominianni et al. compared non-external (i.e., disease-related) mortality following a power outage in the warm (May-September) and cold (October-April) seasons in New York City. Using a lag period of one day, the pooled relative risk of non-external mortality after a power outage was higher in the cold season (1.06) than the warm season (1.00). However, the 95% confidence intervals overlapped considerably (warm season: [0.88, 1.13], cold season: [1.01,1.12]). For this reason, we considered the risk of mortality during a cold weather and warm weather power outage to be equal. Source: Dominianni et al., *Health Impacts of Citywide and Localized Power Outages*, (2012).

Table 3: Energy-Storage – Avoided Death Algorithm

	Input	Value	Source
a	NYC population (million people)	8.07	2013 U.S. Census Bureau[30]
b	Excess non-accidental deaths from 2003 power outage	78	Anderson and Bell[31]
c	Value of statistical life (million $, 2018)	9.27	EPA[32]
d	Length of 2003 NYC power outage (hours)	24	Greenwald et al.[33]
e	Length of an average outage in MA (hours)	4.6	Results from 2017 EIA Form 861 (SAIDI/SAIFI)[34]
Non-Energy Impact Value			
f	Value of avoided death due to power outage, MA, annual	**$17.17**	(**b** / **a**) * **c** * (**e** / **d**)
g	Value of avoided death due to power outage, MA, annual, conservative adjustment	**$1.72**	**f** * 0.10

1.2.3 Equipment Maintenance and Home Durability

As part of our research into the potential NEIs of equipment maintenance and home durability associated with PV, we reviewed the National Renewable Energy Laboratory (NREL) report *Best Practices in Photovoltaic System Operations and Maintenance*[35] and conducted brief interviews with two solar installation companies to gather anecdotal insights into the NEIs.[36] We asked the solar installers about the installation process, associated risks, recommended maintenance, and region-specific costs and expectations. Both companies indicated that it is best to install PV arrays onto a new roof. If a roof is expected to need repairs in the next five years, they recommend making the repairs before PV installation because removing the panels to re-roof is an expensive project.

---

[30] U.S. Census Bureau, Intercensal Estimates of the Resident Population for Incorporated Places and Minor Civil Divisions: April 1, 2000 to July 1, 2010, https://www.census.gov/data/datasets/time-series/demo/popest/intercensal-2000-2010-cities-and-towns.html (last modified December 2, 2016).
[31] Anderson and Bell, *Lights Out*, 2012.
[32] U.S. EPA, Value of statistical life, 2006, https://www.epa.gov/environmental-economics/mortality-risk-valuation#whatvalue.
[33] Greenwald et al., *Emergency Department Visits,* 2004.
[34] EIA, *Form EIA-861*, 2017.
[35] NREL/Sandia/Sunspec Alliance SuNLaMP PV O&M Working Group, "Best Practices in Photovoltaic System Operations and Maintenance," 2nd edition, (2016), https://www.nrel.gov/docs/fy17osti/67553.pdf.
[36] Though not formally part of the TXC60 Work Plan, we decided to speak with solar installation contractors after finding a lack of existing research and data on home durability and equipment maintenance. We thought that their experiences in the field could direct us to areas of future NEI research.

1.2.3.1 Equipment Maintenance

Based on the Massachusetts Clean Energy Center (MassCEC) database, the average cost paid to install a solar PV system in Massachusetts in 2018 in residential buildings (with three or fewer housing units) was roughly $31,000.[37] The National Renewable Energy Laboratory (NREL) reports in their best practices guide that annual operations and maintenance (O&M) costs for PV panels are 1% of the initial system cost for small systems.[38] The NREL O&M estimate encompasses a wide range of material, equipment and labor costs, including costs for replacement parts over time, preventative maintenance, potential roof repairs from faulty installations, and system cleaning. As shown in Table 4, this equates to a loss of **$308.30** per household per year.

Table 4: Solar PV – Equipment Maintenance Algorithm

Input		Value	Source
a	Average initial PV system cost with design fees in Massachusetts in 2018	$30,830	MassCEC 2019[39]
b	Operations and maintenance cost (percent of initial system cost), annual	1%	NREL 2016[40]
Non-Energy Impact Value			
c	Cost of operations and maintenance per household per year	**-$308.30**	(**a** * **-b**)

1.2.3.2 Home Durability

Exposure to rain, hail, snow, and sunshine can cause roof materials to degrade over time. According to the two PV installers with whom we spoke, rooftop areas covered by a PV array may experience a reduced or delayed need for maintenance and replacement. Our team also speculates that If snow slides off the PV array and bypasses the edge of the roof and gutter, there is a possibility it could avoid melting, refreezing, and hence avoid forming ice dams. However, we did not find any secondary sources confirming any of these notions.

As part of PV installation, contractors often secure PV mounting racks by making holes in the roof. Standard procedure is to cover the holes with flashing and then fill them with a watertight material, like silicone, to guard against leaks. It is possible that mounting panels on a roof could damage roofing materials, present opportunities for physical accidents, and negatively impact the long-term durability of the roof. In addition, installation of a PV system can increase a roof's potential for leaks and damage due to increased rooftop foot traffic during installation and later on during maintenance.[41]

Because we did not find concrete or quantitative evidence supporting the potential NEI associated with improved home durability, the team does not propose a quantified NEI value. Given that roof

---

[37] Massachusetts Clean Energy Center, Production Tracking System (PTS) Solar Photovoltaic Report as of 1-2-19, "PVinPTSwebsite.xls," https://www.masscec.com/pts-reports (accessed January 3, 2019).
[38] NREL/Sandia/Sunspec Alliance SuNLaMP, *Best Practices in Photovoltaic System O&M*, 2016.
[39] MassCEC, *Production Tracking System*, 2019.
[40] NREL/Sandia/Sunspec Alliance SuNLaMP, *Best Practices in Photovoltaic System O&M*, 2016.
[41] Ibid.

maintenance is considered part of the long-term O&M costs by the NREL working group, it seems doubtful that there is a net-positive NEI associated with roof durability.

1.2.4 Thermal Comfort

Evidence supports the hypothesis that PV panels carry insulating properties. A 2011 study published in *Solar Energy* found that a PV system installed on a commercial building in southern California can increase the thermal comfort below the ceilings directly under where the rooftop panels are installed.[42] Modeled results from this study showed that the "daily variability in rooftop surface temperature under the PV array was half that of the exposed roof, indicating a reduction in thermal stresses of the roof structure" and resulted in modeled annual cooling savings of 5.9 kWh per square meter of covered roof. No cooling savings were directly observed because the building did not have an HVAC system. This study also found that ceiling temperatures below panels offset from the roof were cooler than temperatures under a flat array mounted flush with the roof. We found no studies documenting thermal impacts on single-family homes.

Research in this area is limited and not representative of Massachusetts' climate or housing stock. If the PAs wished to consider quantifying this NEI, researchers could potentially implement a questionnaire among top-floor residents of multifamily buildings in MA where some apartments are under the PV array and others are not.[43] Ideally, this study would include buildings with different orientations and extend through the winter and summer seasons. However, such specific sampling and on-site visits can become costly and the likelihood of building a large enough sample would make it a low-feasibility study. Because the NEI would apply to a very small subset of households (just top-floor residents of multifamily buildings), the team found no evidence of a similar benefit for single-family homes, and the magnitude of the benefit is so small, the team considers further research unwarranted.

1.2.5 Low-Income Rate Discounts

The PAs currently claim NEIs for the low-income rate discounts for energy savings attributable to their low-income energy efficiency programs. Because solar PV generation presumably results in the same reduction in energy sold at discounted rates as energy savings, the team suggests the same rate discount NEI is applicable to low-income solar PV programs. For solar PV systems installed at the homes of low-income customers, we suggest that the PAs consider claiming the existing rate discount NEI for each kWh of production from the PV system.[44] The same NEI could be claimed on a per kW basis (of the installed PV systems) by multiplying the per kWh discount by the number of kWh generated per kW of the system.

[42] Anthony Dominquez et al., "Effects of Solar Photovoltaic Panels on Roof Heat Transfer," *Solar Energy* 85 (2011): 2233-2255.

[43] Note that the potential CLC program would not include multifamily buildings.

[44] This is the same rate discount that the PAs claim for low-income energy savings. For more information, see: NMR. 2011. Massachusetts Special and Cross-Sector Studies Area, Residential and Low-Income Non-Energy Impacts (NEI) Evaluation. Prepared for Massachusetts Program Administrators. (http://ma-eeac.org/wordpress/wp-content/uploads/Residential-and-Low-Income-Non-Energy-Impacts-Evaluation-1.pdf)

1.3 Non-Program Financial Support

We considered non-program financial support as potential NEIs. Federal and state tax credits are available for domestic solar installations. The federal tax credit covers 30% of qualified expenses for the cost of installing fuel cells, small wind, and geothermal heat pumps through 2019, after which time the percentage covered will decrease.[45] The MA tax credit covers 15% of net expenditures or $1,000, whichever is less.[46]

Additionally, the Massachusetts Department of Energy Resources (DOER) has created the Solar Massachusetts Renewable Target (SMART) Program, which is set to launch on November 26, 2018.[47] This program will pay a tariff-based incentive to the solar owner through the utility. Note that the SMART program is replacing the existing Solar Renewable Energy Certificates[48] (SRECs) program. SRECs are tradeable certificates that can be sold by owners of solar PV systems to retail electricity suppliers who are required to meet state renewable energy targets.

All three of these incentives will influence customer uptake of solar technologies and should be included as reductions in the cost side of the benefit-cost ratio used in the DPU's Total Resource Cost test.[49] **Therefore, we do not propose including these in any NEI algorithms but instead recommend treating them as reduced costs.**

The team suggests that the PAs collect tax credit and SMART incentives from any participating household to develop cost reduction estimates. Alternatively, the team could conduct a survey of recent PV installations to develop estimates of the tax credits and SMART incentives that the PAs could use in their BCR models.

1.4 Avoided Costs

We considered some NEIs that had the potential to be associated with solar energy and storage efforts but are not appropriate for the BCR models because they are accounted for in the 2018 Avoided Energy Supply Component Study (2018 AESC).[50] The study estimates avoided costs from PA energy-efficiency and demand-side programs. These are accounted for in the PAs' BCR models, so to include them as NEIs would result in double counting. The 2018 AESC avoided

---

[45] https://www.energy.gov/savings/residential-renewable-energy-tax-credit

[46] https://www.mass.gov/regulations/830-CMR-6261-residential-energy-credit

[47] https://www.mass.gov/info-details/solar-massachusetts-renewable-target-smart-program

[48] A renewable energy certificate (REC) represents the property rights to the environmental, social and other non-power attributes of renewable electricity generation. RECs are issued when one megawatt-hour (MWh) of electricity is generated and delivered to the electricity grid from a renewable energy resource. (https://www.epa.gov/greenpower/renewable-energy-certificates-recs)

[49] According to the *California Standard Practice Manual,* any tax credits are considered a reduction in costs for the TRC. See California Public Utilities Commission (CPUC). 2002. *California Standard Practice Manual: Economic Analysis of Demand-Side Programs and Projects.* http://www.calmac.org/events/SPM_9_20_02.pdf

[50] Synapse Energy Economics, *Avoided Energy*, 2018.

costs include the following NEIs, which may otherwise be associated with on-site energy generation and storage:

- Fuel and energy costs
- Capacity costs
- Compliance costs
- Environment[51]
- Demand Reduction Induced Price Effects (DRIPE)
- Transmission and distribution
- Improved reliability[52]

1.5 Further Solar PV and Energy Storage Research

The team has identified several potential areas for future research pertaining to solar PV systems and energy-storage batteries:

- **Program attribution.** On the topic of program attribution, it will be important to separate out the effects of other one-time incentives (tax credits) and ongoing incentives through the SMART program from the effects of any PA-sponsored program, so we suggest that the PAs monitor these incentives and ask about them in any surveys or interviews with trade allies and participants.
- **Thermal comfort.** The team identified thermal comfort as a potential NEI. As noted in Section 1.2.4, a survey of top-floor residents of multifamily buildings in MA where some apartments are under the PV and others are not could determine if there is an effect on cooling needs and comfort and, if so, quantify that impact. However, as we describe in the introduction, this would not be a cost-effective endeavor.
- **Healthcare.** Monetization of several NEIs in this memo requires detailed healthcare data for various conditions, locations of treatment (i.e., urgent care vs. inpatient care), and health insurance statuses. MA compiles this data through the Center for Health Information and Analysis (CHIA) agency. CHIA data is available to non-governmental agencies for health research in the public interest. If desired, the PAs could apply for and purchase CHIA data to refine the values we estimated for reliability of medical equipment and avoided death NEIs, but we do not see an urgent need for it at this time. In addition, the PAs could provide more detailed data on customers on their medical lists and the team could attempt to make further adjustments to the medical equipment NEI.

[51] We also excluded this NEI because on-site reductions at a single household – who may have displaced fuel oil with solar energy for heating purposes, for example – have minimal impacts on particulate emissions.
[52] This includes direct damages, such as spoiled food, lost wages, theft and damaged equipment.

Assessment of Further Research

Exploring the two solar PV-related NEIs that we determined would require further research – home durability and thermal comfort – does not seem cost-effective or highly feasible.

- Section 1.2.4 describes how we found evidence that PV panels possess insulating properties that could increase thermal comfort. However, we estimate that a study needed to enumerate those effects would require extensive and complex sampling of a very small and specific population, likely with an on-site component that could cost anywhere from **$100,000 to $200,000 and have low feasibility**. To put this into perspective, the thermal comfort NEI values associated with residential insulation (in the TRM and TXC57 reference table) range from $25 to $30 per unit. We would assume that the insulation resulting from PV panels would be even **less than $25** given that PV panels' dedicated purpose is not to provide thermal comfort. Further, the NEI would likely apply to a very small subset of households, top-floor residents of multifamily buildings. Thus, the cost of the research would far exceed the value of the NEIs, so **we do not suggest pursuing research to estimate thermal comfort**.[53]
- We speculated that PV panels might impact the durability of roofs, either positively or negatively (Section 1.2.3), but we found no documented research on this as an NEI. **We do not suggest pursuing research to estimate the value of home durability**.

While we estimated potential NEI values for reliability of medical equipment and avoided death, and describe how the PAs could refine these values either through purchasing healthcare data and/or providing researchers with more detailed data on customers on their medical lists, we do not believe these are high priority efforts.

[53] The team only found limited evidence of a potential thermal comfort benefit for a PV system installed on a commercial building in southern California. See Section 1.2.4 for more details.

Section 2 Knob and Tube Remediation

2.1 Background

For the 2019-2021 program cycle, the PAs have identified K&T wiring as a key impediment to implementing weatherization measures. For those customers who sign a contract committing to install weatherization measures, the PAs will facilitate a visit from an electrician to provide knob and tube evaluation at no charge. In addition, the PAs have added pre-weatherization financing to the HEAT Loan to address pre-weatherization barriers such as K&T wiring and asbestos. [54]

K&T wiring has been considered obsolete since the early 1950s when electricians began to favor newer, safer technologies in its place.[55] Existing K&T wiring is at least 70 years old and can be found hanging unenclosed along the walls, floors, and ceilings of older buildings. When properly maintained, it poses no significant health risks,[56,57] but over time, the wires sag and the equally outdated electrical insulation becomes brittle and chipped and is eaten by rodents.[58,59,60]

Because K&T wiring is easily accessible, it lends itself to unsafe attempts at repair, splicing, or other modification by homeowners and underqualified electricians. For example, electricians report finding exposed wires and bad splices near water, with masking and Scotch tape used instead of electrical tape, at two-pronged (i.e., not grounded) wall outlets renovated by amateurs, and in other situations.[61,62,63] If the stretched wires come in contact with wood or moisture they can potentially cause a fire or electric shock.[64] As the wires age, there is a higher risk of loose

---

[54] Additional details are available in the Residential Coordinated Delivery Initiative section of the PAs final 2019-21 Three Year Energy Efficiency Plan.
http://ma-eeac.org/wordpress/wp-content/uploads/Exh.-1-Final-Plan-10-31-18-With-Appendices-no-bulk.pdf
We note that this memo does not address the question of attribution of participants' remediation of K&T wiring. Attribution is a key issue for determining the applicability of any quantified K&T NEIs as K&T wiring poses serious safety risks, which affect the likelihood a homeowner will remediate the K&T wiring without program support. We expect examination of key drivers other than PA program support to be a key topic for future evaluations as free-ridership and spillover should be accounted for in all calculations and estimates for NEIs that apply to non-low-income participants. However, we can still estimate the NEIs associated with K&T wiring remediation separately from estimating NTG.

[55] Nick Gromicko and Kenton Shepard, "Knob and Tube Wiring," International Association of Certified Home Inspectors, https://www.nachi.org/knob-and-tube.htm (accessed November 1, 2018).

[56] Ibid.

[57] Lutz, B., "Why is Knob and Tube Dangerous?" Generation 3 Electric, (2016), https://www.generation3electric.com/blog/why-is-knob-and-tube-dangerous (accessed October 1, 2018)

[58] Hansen, D., "Knob & Tube Wiring", California Real Estate Inspection Association, (2005), https://www.creia.org/assets/docs/knob_tube_locked.pdf.

[59] Kibbel, W., III., "Knob and Tube Wiring," Old House Web, http://www.oldhouseweb.com/how-to-advice/knob-and-tube-wiring.shtml (accessed October 1, 2018).

[60] https://www.bluecrest.net/electrical-news/knob-tube-wiring/

[61] Gromicko and Shepard, *Knob and Tube Wiring*, 2018.

[62] https://www.bluecrest.net/electrical-news/knob-tube-wiring/

[63] https://mrelectric.com/winnipeg/knob-and-tube-wiring

[64] Lutz, B., *"Why is Knob and Tube Dangerous?"* 2016.

connections, corrosion, and other defects that create electrical resistance and therefore excessive heat that poses a fire risk.[65]

K&T wiring systems allow for fewer outlets and fuses, which often prevents them from accommodating modern electrical loads. When homeowners want to better accommodate the technology they use, including computers, televisions, and sound systems, and avoid blown fuses, they will install new, higher-amperage fuse boxes, causing "over fusing." Because K&T wires are only rated for 15 amperes, the additional current causes excessive heat and fire hazards.[66] Electricians report finding tangles of extension cords and power strips as homeowners try to compensate for the lack of outlets. K&T wiring does not accommodate three-pronged outlets and plugs because it does not have a grounding wire.[67,68,69,70,71] This poses two hazards: unsafe modifications to accommodate three-pronged plugs and a risk of shock from the lack of grounding.

In contrast to modern wiring, K&T does not color-code or pair the hot and neutral wires. As a result, the wires are easily mistaken for one another, potentially causing a reversed polarity that poses a shock hazard.[72] Additionally, the wire insulation used for K&T is not rated for moisture, making it unsafe to use in kitchens, bathrooms, outdoors, or anywhere water is present.[73,74,75] If the cords come in contact with moisture, an electrical shock, short, or fire could result. The National Electric Code forbids placing thermal insulation over K&T wiring because it prevents heat from dissipating and can ignite the insulation.[76,77] A few localities permit thermal insulation in limited situations that require care and consideration.

Mass Save offers Home Energy Services (HES) program participants a free evaluation by a qualified electrician that will address K&T remediation, as well as the opportunity to take advantage of a HEAT Loan of up to $10,000 to remediate K&T wiring if it is observed during the home energy assessment and participants commit to installing the recommended weatherization measures.[78]

---

[65] Armanda, L. D., "Retrofitting Knob and Tube Wiring An Investigation into Codes, Assessment, Wiring Practices and Cost," Pennsylvania College of Technology, (2004), https://www.pct.edu/files/imported/business/nssc/docs/articles/KnobTube_Report_WTC.pdf.

[66] https://mrelectric.com/winnipeg/knob-and-tube-wiring

[67] "Arc-Fault Circuit Interrupters: National Electrical Code Inclusion Was Based on Faulty Reasoning," National Association of Home Builders, (2017), https://www.nahb.org/en/nahb-priorities/construction-codes-and-standards/-/media/74F9BAB115304420AC1E5430DCE82AC0.ashx (accessed October 1, 2018).

[68] Gromicko and Shepard, *Knob and Tube Wiring*, 2018.

[69] https://www.bluecrest.net/electrical-news/knob-tube-wiring/

[70] https://mrelectric.com/winnipeg/knob-and-tube-wiring

[71] Lutz, B., *"Why is Knob and Tube Dangerous?"* 2016.

[72] Ibid.

[73] Hansen, D., *"Knob and Tube Wiring,"* 2005.

[74] https://mrelectric.com/blog/why-is-knob-and-tube-wiring-dangerous

[75] https://mrelectric.com/winnipeg/knob-and-tube-wiring

[76] Lutz, B., *"Why is Knob and Tube Dangerous?"* 2016.

[77] Stratton, J., & Walker, I., *"Health and Safety Guide for Home Performance Contractors,"* (2012), https://www.osti.gov/servlets/purl/1182732 (accessed October, 2018),.

[78] "Knob and tube [wiring] is a form of electrical wiring used in the late 1800s and early 1900s, with a rubber sleeve covering the wires and porcelain knobs to prevent them from touching the wooden components of your home. It is often considered a fire hazard, especially if insulation is blown in around it." *Source*: Mass Save. "Saving Energy Safely: Know what to look out for to keep your home and family safe." https://www.masssave.com/en/learn/residential/saving-energy-safely/ (accessed September 18, 2018).

2.2 NON-ENERGY IMPACTS

Table 5 lists the NEIs associated with K&T remediation for which we present algorithms or suggest primary research. We do not recommend any NEI values for K&T remediation, but we suggest algorithms for avoided fire risk, avoided electrical shock risk, and avoided trip and fall risk.[79] All of the algorithms include inputs that require further research. We offer an algorithm in Appendix C for avoided rodent infestation but suggest the PAs consider exploratory research before accepting that algorithm.

Table 5: Knob and Tube Remediation – Non-Energy Impact Summary

Non-Energy Impact	Value Suggested	Algorithm Developed Only	Needs Exploratory Research First
Avoided fire		□	
Avoided electrical shock		□	
Avoided trip and fall		□	
Reduced rodent infestation			□

2.2.1 Avoided Fire

The proposed monetization in Table 6 suggests comparing the difference between rates of house fires for single-family homes with and without K&T wiring to estimate the risk reduction resulting from remediation. This estimated risk is then multiplied by the Weatherization Assistance Program (WAP) evaluation's estimate of the adjusted cost of a residential fire. Existing data are limited. We suggest the PAs consider conducting further research such as acquiring data from insurance companies or industry implementers (e.g., electricians, fire marshal) and conducting surveys with customers with and without K&T wiring, asking about the history of fires in their homes to establish the rate of fires.

Additional details are available in the Residential Coordinated Delivery Initiative section of the PAs final 2019-21 Three Year Energy Efficiency Plan.
http://ma-eeac.org/wordpress/wp-content/uploads/Exh.-1-Final-Plan-10-31-18-With-Appendices-no-bulk.pdf

[79] With respect to avoided electric shocks and trips and falls only, we have reviewed existing data and are finding the potential NEIS to be minimal. We do not anticipate these safety hazards being incorporated into the K&T remediation NEI (i.e., low priority).

Table 6: Knob and Tube – Avoided Fire Algorithm

Input		Value	Source
a	Rate of fires in homes without knob and tube wiring	--	Further in-field research needed
b	Rate of fires in homes with knob and tube wiring	--	Further in-field research needed
c	Adjusted household cost of residential fire (per fire)	$11,721	WAP Evaluation[80]
Non-Energy Impact Value			
d	Annual Household Benefit (per remediated home)	**--**	(**b** – **a**) * **c**

2.2.2 Avoided Electrical Shock

Table 7 outlines an algorithm to estimate the value of avoided electrical shock. Several of the inputs would require primary research to estimate rates of shock, need for treatment, and OOP costs. This research could include surveys with customers with and without K&T wiring, asking them about any sustained shocks in their homes. The proposed monetization compares rates of seeking medical treatment for shocks for single-family homes with and without K&T wiring and takes the difference as the estimated risk reduction resulting from remediation. Separating out the rate of sustaining an electrical shock and the rate of seeking medical treatment for an electrical shock approximates any change in severity of shock injuries attributable to remediation in addition to reduced shock rates.[81] The algorithm then incorporates the costs of an electrocardiogram (EKG) to assess the impact of the shock for both insured and uninsured populations. The OOP cost for those without insurance was quoted as an average for what an uninsured person would be charged, not a list price. However, we could also apply the 25% discount some hospitals give to uninsured persons (for a figure of $399), or a slightly higher discount to reflect the Health Safety Net and other sources of payment for the uninsured.

[80] Tonn, B. et al., "Health and Household-Related Benefits", 2014. We inflated the cost to meet today's costs instead using those of 2014.
[81] Up to this point, research has indicated a near-zero rate of occupant deaths from in-home electrical shock. Sources indicate that the typical in-home shock patient receives an EKG to ensure the heartbeat is unaffected, and perhaps minor burn treatment if needed. Many residents do not seek medical treatment.

Table 7: Knob and Tube Remediation – Avoided Electrical Shock Algorithm

Input		Value	Source
a	Rate of shocks in homes without knob and tube wiring	--	Further in-field research needed
b	Rate of shocks in homes with knob and tube wiring	--	Further in-field research needed
c	Rate of seeking medical treatment for shocks in homes without knob and tube wiring	--	Further in-field research needed
d	Rate of seeking medical treatment for shocks in homes with knob and tube wiring	--	Further in-field research needed
e	OOP costs of EKG with insurance in MA ($, 2009)	$70	Blue Cross Blue Shield[82]
f	Cost of EKG without insurance in MA ($, 2018)	$532	New Choice Health[83]
g	Percent of MA patients who are uninsured	4.18%	Healthcare Cost and Utilization Project (HCUP)[84]
Non-Energy Impact Value			
h	Annual Household Benefit (per remediated home)	**--**	((**b** * **d**) - (**a** * **c**)) * ((**1** - **g**) * **e**) + (**g** * **f**))

2.2.3 Avoided Trip and Fall

Table 8 suggests an algorithm to estimate the value of avoided trips and falls resulting from K&T remediation, which reduces the need for excessive extension cords and power strips by allowing for more wall outlets and outlets that accommodate three-pronged appliances. The reduction in cords lowers trip hazards. The proposed monetization compares rates of tripping and falling in single-family homes with and without K&T wiring and takes the difference as the estimated risk reduction resulting from remediation. Drawing on previous explorations of trips and falls, the sample should be stratified by age due to differing medical costs for this monetization. Existing data are limited, and further in-field research is needed. This research could include surveys with customers with and without K&T wiring, asking them about any trips and falls sustained in their homes.

[82] Blue Cross Blue Shield of MA, "*Typical Costs,*" 2009.
[83] New Choice Health, "*Boston, MA Electrocardiogram Cost Comparison*," 2018.
[84] HCUP, "*HCUPnet*," 2018.

Table 8: Knob and Tube Remediation – Avoided Trip & Fall Algorithm

Input		Value	Source
a	Average cost of hospitalization for a trip or fall ($, 2018)	$44,385	E.R. Burns et al.[85]
b	Average cost of an ER visit for a trip or fall ($, 2018)	$7,016	E.R. Burns et al.[86]
c	Average cost of doctor's office/urgent care visit for a trip or fall ($, 2018)	$8,446	E.R. Burns et al.[87]
d	Change in number of trips and falls resulting in hospitalization	--	Requires in-field research
e	Change in number of trips and falls resulting in ER visits	--	Requires in-field research
f	Change in number of trips and falls resulting in doctor's office visits	--	Requires in-field research
g	Average percent of charges paid OOP in MA	8%	Levit et al.[88]
Non-Energy Impact Value			
h	Value of avoided patient medical costs for trips and falls	**--**	(**d** * **a**) + (**e** * **b**) + (**f** * **c**)
i	Annual Household Benefit (per remediated home)	**--**	**h** * **g**

2.2.4 Reduced Rodent Infestation

As described above, rodents are known to eat K&T wiring insulation. To estimate the risk reduction from remediation, we would need to compare rates of rodent infestation of single-family homes with and without K&T wiring and take the difference as the estimated risk reduction resulting from remediation. Potential costs include medical bills for rodent-borne illnesses, exterminator bills, and damages to home and property. In-field research would be required to assess change in level and frequency of rodent infestation after remediation. However, given the complexity of this in-field research, we are not suggesting an algorithm at this time. Instead, we present a rough algorithm for future consideration in Appendix B.

2.3 Further Knob & Tube Research

Future research on knob and tube wiring would primarily consist of obtaining rates of fires, electric shocks, and trips and falls in homes with and without knob and tube wiring, most likely through a survey or insurance data. Current talks between Program Administrators and a major homeowners insurance company in MA could provide this data for fires and other common causes of insurance claims.

In addition, it will be important to separate out the effects of other factors, such as homeowner safety concerns or ability to eventually sell a home, from the effects of any PA-sponsored program

---

85 E.R. Burns, et al., "The direct costs of fatal and non-fatal falls among older adults – United States," *Journal of Safety Research*, vol. 58, 2016, p. 99-103, (2016) https://doi.org/10.1016/j.jsr.2016.05.001.
86 Ibid.
87 Ibid.
88 Levit et al., "*Estimating Inpatient Hospital Prices*," 2013.

(i.e., program attribution). Developing an NTG ratio to apply to any quantified NEIs will be an important aspect of future research.

Assessment of Further Research

As Figure 1 shows, we developed algorithms for three of the four NEIs associated with K&T remediation, and suggested exploratory research for the fourth. The algorithms, which are outlined in Section 2.2, would rely on conducting surveys with customers with and without K&T wiring present. We estimate that a short survey specifically asking about occurrences of fires, electrical shocks, trips and falls, and rodent infestations would require large sample sizes given the infrequency of these events. It would likely cost upwards of **$100,000,** depending on the sample's size and derivation (HES participants or a random customer pull) and the survey's length. We conservatively estimate that if these events (e.g., tripping due to electrical wiring) are infrequent, they could sum to benefits of roughly **$9** per year per household, as follows:

- **Avoided Fire.** If we were to assume that rates of fire among K&T homes are five times as likely as among non-K&T homes (0.01% versus 0.05%, for example), the algorithm would result in an NEI value of $4.69 per year per household.
- **Avoided Trips and Falls.** If we were to assume that rates of trips and falls resulting in hospitalizations, ER visits, and doctor's office visits are slightly lower among homes without K&T (a difference of 0.05 percentage points, for example), the algorithm would result in an NEI value of $2.39 per year per household.
- **Avoided Electric shock.** If we were to assume that rates of electric shock among K&T homes are five times as likely as non-K&T homes (0.01% versus 0.05%, for example) and that one-half of people seek treatment following shocks, the algorithm would result in an NEI value of $1.79 per year per household.
- **Reduced Rodent Infestation.** We did not develop an algorithm for rodent infestation, but we could ask exploratory questions during surveys to get a better understanding of the costs and prevalence.

To keep research costs low, surveys could be web-based and samples could be drawn from HES participants, making it easier in the sampling process to identify contacts who do and do not have K&T present and likely resulting in high cooperation rates. However, the infrequency of these events suggests they may be better studied as part of a regional or nationwide effort. Despite the relatively high feasibility and lower costs, NEI values may not be large enough to warrant the cost of this study in the immediate future, but it should not be ruled out entirely.[89] A less costly option that may warrant further consideration would be to pursue data from insurers and industry implementers to attempt to develop incidence rates and costs to yield an NEI for avoided fires. The Program Administrators are in discussions with a major homeowner's insurance company in MA regarding a proposal to offer a discount to policy holders if they have undergone an audit or weatherization. There may be an opportunity to match policyholder data with HES data to examine differences between audited and non-audited households on NEIs of interest, including,

---

[89] For example, a set of NEI questions could be added to a random customer survey or as a follow-up survey with HES respondents.

but not limited to, fires. This could facilitate efforts to quantify the extent to which the HES program has reduced claims.

Section 3 Asbestos Remediation

3.1 Background

Before the US Environmental Protection Agency (EPA) implemented a series of bans in the 1970s and 1980s, residential building materials often contained asbestos because of its heat resistance and low combustibility.[90] Asbestos can originate from industrial processing, urban environments, geologic sites, commercial buildings, and residential buildings. Exposures can be categorized as occupational, environmental, or domestic.[91] According to both the National Institute of Occupational Safety and Health (NIOSH) and the Occupational Safety and Health Administration (OSHA), there are no levels of exposure to asbestos below which clinical effects do not occur. The PAs offer a $250 incentive to evaluate asbestos for remediation if it is observed during a HES program home energy assessment and it prevents customers from implementing weatherization measures. The PAs also offer access to financing for up to $4,000 through the HEAT Loan to remediate asbestos.[92] Appendix B offers extensive background on the health implications of asbestos.

Table 9 lists the NEIs associated with asbestos remediation for which we offer values, algorithms, or primary research for consideration. We do not offer any NEI values for consideration for asbestos remediation, but we suggest an algorithm for avoided medical costs. This algorithm requires additional primary research before we can propose a value.

---

[90] Krakowiak et. al., "Environmental exposure to airborne asbestos fibres in a highly urbanized city," *Annals of Agricultural and Environmental Medicine*,16(1), 121-128, (2009), https://www.ncbi.nlm.nih.gov/pubmed/19572484/. Ibid.

[91] Ibid.

[92] "Asbestos in homes is usually not a problem unless it is disturbed and releases fibers into the air. If there is evidence of asbestos, your Energy Specialist will take careful precautions not to disturb the material. Asbestos could impact the scope and technical approach to the energy-efficiency installations that Mass Save completes in your home." *Source:* Mass Save. "Saving Energy Safely: Know what to look out for to keep your home and family safe." https://www.masssave.com/en/learn/residential/saving-energy-safely/ (accessed September 18, 2018). Additional details are available in the Residential Coordinated Delivery Initiative section of the PAs final 2019-21 Three Year Energy Efficiency Plan. http://ma-eeac.org/wordpress/wp-content/uploads/Exh.-1-Final-Plan-10-31-18-With-Appendices-no-bulk.pdf

We note that this memo does not address the question of attribution of participants' asbestos remediation. Attribution is a key issue for determining the applicability of any quantified asbestos remediation NEIs as asbestos poses serious safety risks, which affect the likelihood a homeowner will remediate the asbestos without program support. We expect examination of key drivers other than PA program support to be a key topic for future evaluations as free-ridership and spillover should be accounted for in all calculations and estimates for NEIs that apply to non-low-income participants. However, we can still estimate the NEIs associated with asbestos remediation separately from estimating NTG.

Table 9: Asbestos Remediation – Non-Energy Impact Summary

Non-Energy Impact	Value Suggested	Algorithm Developed Only	Needs Exploratory Research First
Avoided medical costs			

3.2 Avoided Medical Costs

We suggest avoided medical costs as the only monetizable NEI associated with asbestos remediation. While the risk of developing medical complications solely from residential exposure is generally low, the mesothelioma, asbestosis, and the lung cancers that can result can be fatal, and thus it is worth considering treatment for homes with high levels of airborne asbestos. The strongest evidence of a causal relationship exists between residential exposure and malignant mesothelioma.[93] Given the lethality of malignant mesothelioma we propose using the cost of physician office, ED visits, and hospitalizations as well as the value of avoided death as inputs into the monetization algorithm.

While we cannot control a resident's level of asbestos exposure before and after they live in the remediated home, abatement will lower their lifetime dose of inhaled asbestos fibers. Using average exposure rates for urban/suburban residents, Figure 2 assists with conceptualizing levels of lifetime exposure for a resident who moves into a contaminated home at age 30 and moves out at age 40.[94]

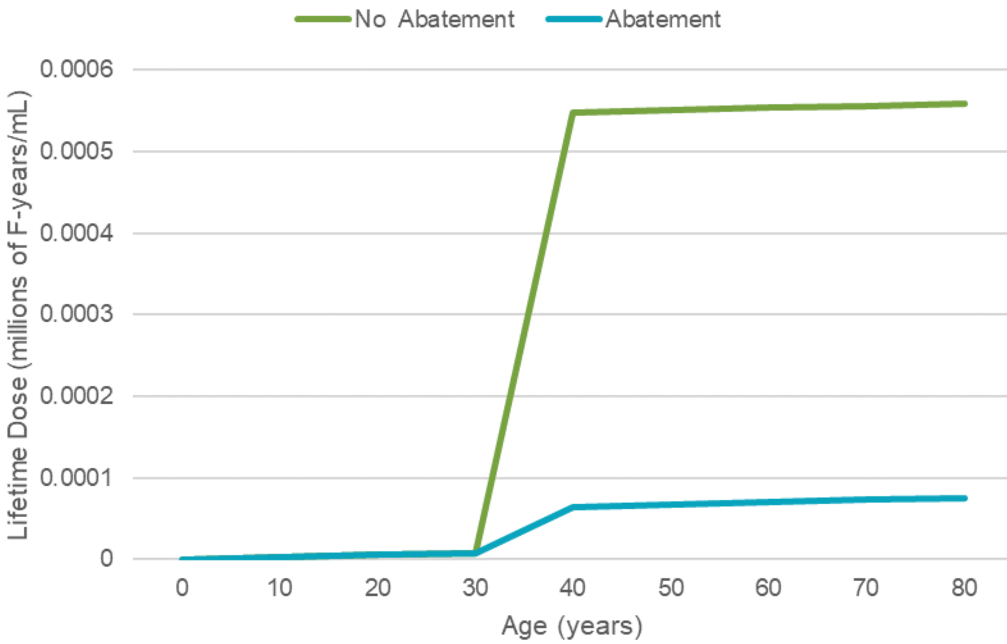
In the example shown in Figure 2, the resident either receives no abatement (green line) or receives abatement after living in the contaminated home for one year (blue line). Even if the resident remains in the contaminated home for a year before receiving abatement, the nine years of lowered asbestos levels equate to a substantial reduction in lifetime exposure and risk.

---

93 Dowell, J., and Patel, S., "Modern management of malignant pleural mesothelioma," *Lung Cancer: Targets and Therapy*, 63, (2016), doi:10.2147/lctt.s83338.

94 "Toxicological Profile for Asbestos," Agency for Toxic Substances and Disease Registry, (2001), https://www.atsdr.cdc.gov/toxprofiles/tp.asp?id=30&tid=4 (accessed October 17, 2018),.

Figure 2: Hypothetical Levels of Lifetime Exposure with and without Abatement



Given the scarcity of data on domestic-only exposure, two models of monetization are proposed. The first, based on actual measurements of airborne concentration, calculates the precise risk to residents both before and after abatement using US EPA's Integrated Risk Management System (IRIS) risk model.[95] Lacking actual measurements of asbestos concentrations in program recipients' homes, one may substitute OSHA's maximum acceptable workplace concentration of airborne asbestos (0.1 fibers (f)/ml) as a pre-abatement concentration and results from a 2008 study by Lee and Orden of asbestos concentrations in buildings across the US as a post-abatement estimate.[96] However, both require significant assumptions.

Alternatively, the relative risk model (Appendix C) calculates the increase in likelihood of developing malignant mesothelioma for those with above-average domestic exposure. Taking the ambient risk cited by Lee and Orden (2008) and multiplying it by the relative risk (RR) of 3.5 reported by Boffetta (2006) for domestic exposure produces the approximate risk of developing malignant mesothelioma for residents with domestic exposure.

While Table 10 estimates an NEI of $19.52 per household per lifetime (assuming a 10-year residence), some inputs should be considered placeholders. The Lee and Orden study only took air samples in buildings in which an occupant was taking legal action against the property owner to recoup medical costs they believed to be the result of asbestos exposure. Only 5 of the 752 buildings were residential.

---

95 https://www.epa.gov/iris

96 Lee, R., & Orden, D.V., "Airborne asbestos in buildings," *Regulatory Toxicology and Pharmacology*, 50(2), 218-225, (2008), doi:10.1016/j.yrtph.2007.10.005.

Additionally, preventative measures meant to seal in asbestos before it can become airborne will have no monetizable outcome unless airborne asbestos is already present in the home. There are several confounding factors involved in predicting how and when asbestos-containing materials (ACMs) will break down and release asbestos, and research in this topic remains scant.

Table 10: Asbestos Remediation – Avoided Medical Costs Algorithm

Input		Value	Source
a	Cost of a hospitalization for MM in MA (per patient, 2015 $)	$64,330	Healthcare Cost and Utilization Project (HCUP)[97]
b	Charges for an ER visit for MM nationally (per patient, 2014 $)	$82,214	Healthcare Cost and Utilization Project (HCUP)[98]
c	Cost of a doctor's office visit for cancer (per patient)	$3,247	Medical Expenditure Panel Survey 2014[99]
d	Average percent of charges paid OOP in MA	8%	Levit et al.[100]
e	Unit Risk Factor (mL/f)	2.3E-1	US EPA Integrated Risk Information System (IRIS)[101]
f	Concentration of airborne asbestos in home without abatement (f/mL)	0.1	Lee and Orden 2008[102]
g	Concentration of airborne asbestos in home with abatement (f/mL)	5E-5	Lee and Orden 2008[103]
h	Exposure duration (approximate length of tenure for a homeowner, years)	10	ValuePenguin[104]
i	Average Lifespan (hours)	700,800	The Health Inequality Project[105]
j	Average time spent at home (hours/year)	4,970	American Time Use Survey[106], assumption of 10 days away from home annually
Non-Energy Impact Value – IRIS model			
k	Risk of developing malignant mesothelioma without abatement	1.63E-3	**e** * **f** * **j** * (**h** / **i**)
l	Risk of developing malignant mesothelioma with abatement	8.16E-7	**e** * **g** * **j** * (**h** / **i**)
m	Value of avoided MM medical costs per home	$244.04	(**k** – **l**) * (**a** + **b** + **c**)

97 Healthcare Cost and Utilization Project (HCUP), *HCUPnet*, 2015.
98 Healthcare Cost and Utilization Project (HCUP), *HCUPnet*, 2014.
99 Medical Expenditure Panel Survey, Table 3a: Mean Expenses per Person with Care for Selected Conditions by Type of Service: United States, (2014).
100 Levit et al., "*Estimating Inpatient Hospital Prices*", 2013.
101 US Environmental Protection Agency Integrated Risk Management System (IRIS), Asbestos; CASRN 1332-21-4, (September 1988), https://cfpub.epa.gov/ncea/iris/iris_documents/documents/subst/0371_summary.pdf (accessed October 12, 2018),.
102 Lee, R., & Orden, D. V., "*Airborne asbestos in buildings*," 2008.
103 Ibid.
104 Moon, C., & Miller, M., "How Long Do Homeowners Stay in Their Homes?" (June 2018), https://www.valuepenguin.com/how-long-homeowners-stay-in-their-homes#nogo.
105 Chetty, R., Stepner, M., & Cutler, D.,The Health Inequality Project, (n.d.), , https://healthinequality.org/ (accessed October 12, 2018).
106 Bureau of Labor Statistics, "American Time Use Survey", (2017), https://www.bls.gov/tus/a1_2017.pdf

	Input	Value	Source
n	Value of avoided OOP MM medical costs per home	$19.52	m * d

Note: MM = malignant mesothelioma

3.3 Further Asbestos Research

Further research is needed to obtain accurate estimates of indoor airborne asbestos concentrations, in Massachusetts homes specifically, both before and after abatement. A thorough review of the literature did not find an applicable value for estimating the concentration of airborne asbestos in a home that would qualify for remediation, and thus we do not have an accurate baseline against which to compare any reduction in risk. Data on residential airborne asbestos produced solely by asbestos-containing materials (ACMs) remains limited. Given the diversity of ACMs as well as housing and environmental conditions, data specific to Massachusetts will provide the most accurate monetization. This could be easily measured by studying the concentrations of airborne asbestos in a sample of participating HES homes before and after remediation.

Without knowing the procedures for asbestos abatement, it is difficult to estimate the decrease in airborne asbestos. As decisions are made regarding operation of the asbestos abatement program, the model can be refined to more accurately reflect how abatement will impact asbestos concentrations in the home.

Further research could also examine the mortality rate for malignant mesothelioma patients and could lead to an estimated NEI value of avoided deaths. This value would be discounted due to the latency period between asbestos exposure and the first signs of cancer.

In addition, it will be important to separate out the effects of other factors, such as homeowner safety concerns or ability to eventually sell a home, from the effects of any PA-sponsored program in the decision to remediate the asbestos (i.e., program attribution). Developing an NTG ratio to apply to any quantified NEIs will be an important aspect of future research.

Assessment of Further Research

The algorithm for avoided medical costs associated with asbestos remediation yielded a "placeholder" NEI value of **$19.52** per household per lifetime (assuming a 10-year residence time). However, we do not suggest using this value given that some inputs are not precisely applicable to Massachusetts homes. Section 3.2 explains how this value could be more accurately quantified by measuring the indoor airborne asbestos concentrations in a sample of treated homes before and after remediation.[107] If the PAs were to agree on a small sample size for this testing effort, it would likely cost **less than $30,000**. Given that sample homes will be easily obtainable and testing services already exist, we conclude that **feasibility is high enough and the study costs could be low enough that it would be worthwhile to study avoided medical costs.** The PAs may also be able to capture NEI savings from avoided deaths due to asbestos

[107] As decisions are made regarding operation of the asbestos abatement program, the model can be refined even more greatly to more accurately reflect how abatement will impact asbestos concentrations in the home.

remediation, but the mortality rate for malignant mesothelioma patients would need to be determined.

Appendix A References

In the expanded references from tables below, the indented letters correspond to the lettered rows of the table.

A.1 Solar-Energy and Energy Storage References

A.1.1 Reliability of Medical Equipment

G. Brooke Anderson and Michelle L. Bell, "Lights out: Impact of the August 2003 power outage on mortality in New York, NY," *Epidemiology* 23 (2), (2012): 189-193.

Peter W. Greenwald, MD et al., "Emergency Department Visits for Home Medical Device Failure during the 2003 North America Blackout," *Academic Emergency Medicine* 11, (2004): 786-789.

Synapse Energy Economics, "Avoided Energy Supply Components in New England: 2018 Report," Submitted to *AESC 2018 Study Group*, March 30, 2018, http://www.synapse-energy.com/sites/default/files/AESC-2018-17-080-June-Release.pdf.

A.1.1.1 Table 2: Energy-Storage – Reliability of Medical Equipment Algorithm:

a) U.S. Department of Health and Human Services (HHS), "emPOWER Map 3.0," https://empowermap.hhs.gov/ (accessed October 15, 2018).

b) U.S. Census Bureau, MA Population Estimates, last modified July 1, 2017, https://www.census.gov/quickfacts/fact/table/ma/AGE775217#viewtop.

d) U.S. Energy Information Administration (EIA), Form EIA-861, SAIFI with MED for investor operated utilities, weighted by number of customers, release date October 12, 2018, https://www.eia.gov/electricity/data/eia861/.

f) U.S. Energy Information Administration (EIA), Form EIA-861, SAIDI with MED divided by SAIFI with MED for investor operated utilities, weighted by number of customers, release data October 12, 2018, https://www.eia.gov/electricity/data/eia861/.

g) U.S. Department of Health and Human Services (HHS), "emPOWER Map 3.0," https://empowermap.hhs.gov/ (accessed October 15, 2018).

h) Peter W. Greenwald, MD et al., "Emergency Department Visits for Home Medical Device Failure during the 2003 North America Blackout," *Academic Emergency Medicine* 11, (2004): 786-789.

i) Ibid.

n) Healthcare Cost and Utilization Project (HCUP), Summary Statistics Report: MA State Emergency Department Databases (SEDD) 2015 Q1-Q3 TOTCHG (Total charges (cleaned)), p. 173, https://www.hcup-us.ahrq.gov/db/state/seddc/tools/cdstats/MA_SEDDC_2015q1q3_SummaryStats_CORE.PDF (accessed October 2018).

o) Healthcare Cost and Utilization Project (HCUP), MA State Inpatient Databases (SID), 2015, Respiratory failure, insufficiency, arrest (adult), p. 115, https://www.hcup-us.ahrq.gov/db/state/siddbdocumentation.jsp (accessed October 2018).

p) Katharine R Levit et al., "Estimating Inpatient Hospital Prices from State Administrative Data and Hospital Financial Reports", *Health Services Research* 48(5), (2013):1779-1797.

A.1.2 Avoided Death

G. Brooke Anderson and Michelle L. Bell, "Lights out: Impact of the August 2003 power outage on mortality in New York, NY", *Epidemiology* 23(2), (2012): 189-193.

Christine Dominianni et al., "Health Impacts of Citywide and Localized Power Outages in New York City", *Environmental Health Perspectives* 126(6), (2012): 067003.

Synapse Energy Economics, "Avoided Energy Supply Components in New England: 2018 Report," Submitted to *AESC 2018 Study Group*, March 30, 2018, http://www.synapse-energy.com/sites/default/files/AESC-2018-17-080-June-Release.pdf.

A.1.2.1 Table 3: Energy-Storage Avoided Death Algorithm

a) U.S. Census Bureau, Intercensal Estimates of the Resident Population for Incorporated Places and Minor Civil Divisions: April 1, 2000 to July 1, 2010, last modified December 2, 2016, https://www.census.gov/data/datasets/time-series/demo/popest/intercensal-2000-2010-cities-and-towns.html.

b) G. Brooke Anderson and Michelle L. Bell, "Lights out: Impact of the August 2003 power outage on mortality in New York, NY", *Epidemiology* 23(2), (2012): 189-193.

c) U.S. EPA, Value of statistical life, 2006, https://www.epa.gov/environmental-economics/mortality-risk-valuation#whatvalue.

d) Peter W. Greenwald, MD et al., "Emergency Department Visits for Home Medical Device Failure during the 2003 North America Blackout," *Academic Emergency Medicine* 11, (2004): 786-789.

e) U.S. Energy Information Administration (EIA), Form EIA-861, SAIDI with MED divided by SAIFI with MED for investor operated utilities, weighted by number of customers, release date October 12, 2018, https://www.eia.gov/electricity/data/eia861/.

A.1.3 Equipment Maintenance and Home Durability

A.1.3.1 Table 4: Solar PV – Equipment Maintenance Algorithm

a) Massachusetts Clean Energy Center. Production Tracking System (PTS) Solar Photovoltaic Report as of 1-2-19. https://www.masscec.com/pts-reports. "PVinPTSwebsite.xls." (accessed Jan 3, 2019).

b) NREL/Sandia/Sunspec Alliance SuNLaMP PV O&M Working Group. "Best Practices in Photovoltaic System Operations and Maintenance." 2nd edition, 2016. https://www.nrel.gov/docs/fy17osti/67553.pdf.

A.1.4 Thermal Comfort

Anthony Dominquez et al., "Effects of Solar Photovoltaic Panels on Roof Heat Transfer," *Solar Energy* 85 (2011): 2233-2255.

A.1.5 Rate Discounts

NMR Group, Inc., "Massachusetts Special and Cross-Sector Studies Area, Residential and Low-Income Non-Energy Impacts (NEI) Evaluation". Prepared for Massachusetts Program Administrators. (2011) http://ma-eeac.org/wordpress/wp-content/uploads/Residential-and-Low-Income-Non-Energy-Impacts-Evaluation-1.pdf.

A.1.6 Non-Program Financial Support

U.S. Department of Energy. "Residential Renewable Energy Tax Credit" https://www.energy.gov/savings/residential-renewable-energy-tax-credit (accessed November 8, 2018).

Massachusetts Department of Revenue. "830 CMR 62.6.1: Residential Energy Credit," https://www.mass.gov/regulations/830-CMR-6261-residential-energy-credit (accessed November 8, 2018).

Massachusetts Department of Energy Resources. "Solar Massachusetts Renewable Target (SMART) Program, https://www.mass.gov/info-details/solar-massachusetts-renewable-target-smart-program (accessed November 8, 2018).

A.2 Knob and Tube Remediation References

A.2.1 Table 6: Knob and Tube – Avoided Fire Algorithm

c) Tonn, B., Rose, E., Hawkins, B. (2014). Health and Household-Related Benefits Attributable to the Weatherization Assistance Program (Rep.). Oak Ridge, TN: Oak Ridge National Laboratory. doi: ORNL/TM-2014/345.

A.2.2 Table 7: Knob and Tube – Avoided Electrical Shock Algorithm

e) Typical Costs for Common Medical Services. (2009). Retrieved November 4, 2018, from Blue Cross Blue Shield of Massachusetts: https://www.bluecrossma.com/blue-iq/pdfs/TypicalCosts_89717_042709.pdf

f) Boston, MA Electrocardiogram Cost Comparison. (n.d.) https://www.newchoicehealth.com/places/massachusetts/boston/ekg/electrocardiogram (accessed November 4, 2018).

g) Healthcare Cost and Utilization Project (HCUP) *HCUPnet.* 2015. Agency for Healthcare Research and Quality, Rockville, MD., http://hcupnet.ahrq.gov/ (accessed November 6, 2018).

A.2.3 Table 8: Knob and Tube Remediation – Avoided Trip and Fall Algorithm

a) Elizabeth R. Burns, Judy A. Stevens, Robin Lee. The direct costs of fatal and non-fatal falls among older adults – United States, J of Safety Res, Vol. 58, 2016, pgs 99-103. https://doi.org/10.1016/j.jsr.2016.05.001.

b) Ibid.

c) Ibid.

g) Katharine R Levit et al., "Estimating Inpatient Hospital Prices from State Administrative Data and Hospital Financial Reports", *Health Services Research* 48(5), (2013):1779-1797.

A.3 Asbestos Remediation References

A.3.1 Table 10: Asbestos Remediation – Avoided Medical Costs Algorithm

a) Healthcare Cost and Utilization Project (HCUP) *HCUPnet.*. 2015. Agency for Healthcare Research and Quality, Rockville, MD. http://hcupnet.ahrq.gov/ (accessed Nov 6, 2018).

b) Healthcare Cost and Utilization Project (HCUP) *HCUPnet.*. 2014. Agency for Healthcare Research and Quality, Rockville, MD. http://hcupnet.ahrq.gov/ (accessed Nov 6, 2018).

c) Agency for Healthcare Research and Quality. Medical Expenditure Panel Survey. 2014. Table 3a: Mean Expenses per Person with Care for Selected Conditions by Type of Service: United States, 2014. https://meps.ahrq.gov/mepsweb/index.jsp (accessed Jan 10, 2018).

d) Katharine R Levit et al., "Estimating Inpatient Hospital Prices from State Administrative Data and Hospital Financial Reports", *Health Services Research* 48(5), (2013):1779-1797.

e) US Environmental Protection Agency Integrated Risk Management System (IRIS). Asbestos; CASRN 1332-21-4(Tech.). (1988, September 26), https://cfpub.epa.gov/ncea/iris/iris_documents/documents/subst/0371_summary.pdf (accessed October 12, 2018).

f) Lee, R., & Orden, D. V.,Airborne asbestos in buildings. Regulatory Toxicology and Pharmacology,50(2), 218-225, 2008, doi:10.1016/j.yrtph.2007.10.005.

g) Ibid.

h) Moon, C., & Miller, M.,*"How Long Do Homeowners Stay in Their Homes?"* June 2018, https://www.valuepenguin.com/how-long-homeowners-stay-in-their-homes#nogo.

i) Chetty, R., Stepner, M., & Cutler, D.,The Health Inequality Project, (n.d.) https://healthinequality.org/ (accessed October 12, 2018),

j) Bureau of Labor Statistics, "American Time Use Survey", (2017) https://www.bls.gov/tus/a1_2017.pdf.

Appendix B Asbestos Background

EPA (2018) lists some of the most common places to find asbestos in homes built before 1990:

- Attic and wall insulation containing vermiculite
- Vinyl floor tiling and adhesives
- Roofing and siding shingles
- Textured paint and patching compounds
- Walls and floors around wood-burning stoves
- Hot water and steam pipes
- Oil and coal furnaces and door gaskets

B.1 Health Risks

The effects of asbestos do not fade over time because asbestos fibers are retained in airways and lung tissue.[108] The Mayo Clinic states that prolonged exposure to these fibers can cause lung tissue scarring and shortness of breath.[109] Depending on the level and duration of exposure, there are several asbestos-related medical complications that can occur, including mesothelioma and asbestosis.[110] According to the National Cancer Institute, malignant mesothelioma is an aggressive and deadly form of cancer that occurs in the thin layer of tissue that covers the majority of the inner organs (mesothelium). The risk of developing mesothelioma "is proportional to the cumulative dose of exposure."[111] Additional associations with asbestos include pleural abnormalities, lung cancer, and other cancers though these are mostly casual correlations.[112]

Conditions in the home can increase the risks for certain residents. Older homes pre-date asbestos bans and are more likely to have wear and tear that exposes asbestos fibers embedded in construction materials.

B.2 Latency

Though the development of mesothelioma can be directly attributed to asbestos exposure, the disease has a latency period of a decade or more. A minimum of ten years must pass from the time of exposure in order to attribute the mesothelioma to asbestos exposure, but most commonly

---

108 Ibid.
109 https://www.mayoclinic.org/diseases-conditions/asbestosis/symptoms-causes/syc-20354637
110 https://www.cancer.gov/types/mesothelioma
111 Marsili, D., et. al., "Prevention of Asbestos-Related Disease in Countries Currently Using Asbestos," *International Journal of Environmental Research and Public Health,13*(5), 494, (2016), doi:10.3390/ijerph13050494.
112 Kava, R., "Asbestos exposure: how risky is it?" American Council on Science and Health, (2007), https://www.acsh.org/wp-content/uploads/2007/10/20071015_Asbestos.pdf (accessed October 12, 2018).

a latency period lasts between 30 and 40 years.[113] This complicates the monetization of the health impacts of asbestos abatement. While the physical benefits of asbestos abatement may not be visible in the short-term, domestic (i.e., residential) asbestos remediation can create an immediate reduction in the amount, or dose, of asbestos inhaled, reducing residents' risk of developing mesothelioma for the remainder of their lives.

B.3 Residential Exposure

According to a review published in Mutation Research (2006), household exposures can increase a resident's relative risk (RR) of mesothelioma (RR 3.5, 95% CI 1.8-7.0); the increased risk of lung cancer was slight and not statistically significant (RR 1.1, 95% CI 0.9-1.5).[114] Such activities as renovation and demolition, along with the installation, degradation, removal and repair of asbestos-containing products, contribute to the risk. However, the article also asserts that the majority of residential exposure "results from outdoor pollution related to asbestos mining or manufacturing, in addition to natural exposure from the erosion of asbestos or asbestiform rocks."[115]

Measurements of airborne asbestos resulting solely from residential building materials are difficult to obtain given the amount of possible environmental sources. Further data are needed to identify actionable indoor asbestos concentration levels. This threshold would assist with identifying homes that are eligible for the abatement program.

Though there are several sources of asbestos in the home, the most common problematic material is asbestos-containing insulation. Once this material has started to decay, the fibers can more easily become airborne and can spread to other parts of the home.[116] This type of insulation can be found in attics, walls, and surrounding piping and water heaters.

Asbestos-contaminated materials may be "treated" by being sealed (i.e., enclosed), encapsulated, or removed (i.e., abated). If done incorrectly, the abatement process can disturb otherwise embedded asbestos and cause it to become airborne.

Households with high levels of airborne asbestos that have young occupants, especially infants, may be considered high priority candidates for treatment. According to a study by Kang et al. (2013), the risk of developing medical complications from exposure in youths is higher than exposed adults at the same dose level.[117] Though the effects are not well studied, according to Haque et al. (1996), it has been proved that asbestos can have detrimental in utero impacts.[118]

---

[113] Wolff et. al., "Asbestos, asbestosis, and cancer, the Helsinki criteria for diagnosis and attribution," *Scandinavian Journal of Work, Environment & Health, 41 (1*), 5-15, (2015). doi:10.5271/sjweh.3462.
[114] P. Boffetta, Human cancer from environmental pollutants: The epidemiological evidence. Mutation Research/Genetic Toxicology and Environmental Mutagenesis, 608(2), 157-162 (2006). Doi:10.1016/j.mrgentox.2006.02.015.
[115] Ibid.
[116] Krakowiak et al. 2009.
[117] Kang, D., Myung, M., Kim, Y., Kim, J. (2013). Systematic Review of the Effects of Asbestos Exposure on the Risk of Cancer between Children and Adults. Annals of occupational and environmental medicine, 25(1), 10-16. doi:10.1186/2052-4374-25-10.
[118] Haque, A.K., et. al., "Is there transplacental transfer of asbestos?" *Fetal and Pediatric Pathology*,16(6), 877-892 (1996) doi:10.3109/15513819609168711.

In the Kang study, rates of stillborn infants whose mothers reside in a city with high levels of airborne asbestos were explored and found to be correlated. These high levels may not be common, but with this potential risk of asbestos affecting fetal development and survivorship, considering treatment is all the more important.[119]

[119] Haque, A. K., et. al., “Assessment of asbestos burden in the placenta and tissue digests of stillborn infants in south Texas,” *Archives of Environmental Contamination and Toxicology,*35(3), 532-538 (1998) doi:10.1007/s002449900413.

Appendix C Supplemental Algorithms

This appendix contains algorithms that we have included to add context to the study, but do not offer for consideration by the PAs at this time.

Table 11: Knob and Tube Fire NEI – Societal Impact

Input		Value	Source
a	Rate of fires in homes without knob and tube wiring	--	Further in-field research needed
b	Rate of fires in homes with knob and tube wiring	--	Further in-field research needed
c	Adjusted societal cost of residential fire (per fire)	$11,961	WAP Evaluation[120]
Non-Energy Impact Value			
d	Annual Societal Benefit (per remediated home)	**--**	**(b – a) * c**

Table 12: Avoided Electric Shock NEI – Societal Benefit

Input		Value	Source
a	Rate of shocks in homes without knob and tube wiring	--	Further in-field research needed
b	Rate of shocks in homes with knob and tube wiring	--	Further in-field research needed
c	Rate of seeking medical treatment for shocks in homes without knob and tube wiring	--	Further in-field research needed
d	Rate of seeking medical treatment for shocks in homes with knob and tube wiring	--	Further in-field research needed
e	OOPS cost of EKG with insurance in MA ($, 2009)	$70	Blue Cross Blue Shield[121]
f	Cost of EKG without insurance in MA ($, 2018)	$532	New Choice Health[122]
g	Percent of MA patients who are uninsured	4.18%	Healthcare Cost and Utilization Project (HCUP)[123]
Non-Energy Impact Value			
h	Annual Societal Benefit (per remediated home)	**--**	**((b * d) - (a * c)) * (1 - g) * (f - e)**

[120] Tonn, B. et al., *Health and Household-Related Benefits*, 2014.
[121] Blue Cross Blue Shield of MA, *Typical Costs,* 2009.
[122] New Choice Health, *Boston, MA Electrocardiogram Cost Comparison*, 2018.
[123] HCUP, *HCUPnet*, 2018.

Table 13: Avoided Trip and Fall NEI – Societal Benefit

Input		Value	Source
a	Average cost of hospitalization for a trip or fall ($, 2018)	$44,385	E.R. Burns et al.[124]
b	Average cost of an ER visit for a trip or fall ($, 2018)	$7,016	E.R. Burns et al.[125]
c	Average cost of doctor's office/urgent care visit for a trip or fall ($, 2018)	$8,446	E.R. Burns et al.[126]
d	Change in number of trips and falls resulting in hospitalization	--	Requires in-field research
e	Change in number of trips and falls resulting in ER visits	--	Requires in-field research
f	Change in number of trips and falls resulting in doctor's office visits	--	Requires in-field research
g	Percent of MA patients who are uninsured	4.18%	Healthcare Cost and Utilization Project (HCUP)
h	Percent of bill paid OOP by MM patients with insurance	--	Further research required
Non-Energy Impact Value			
i	Value of avoided medical costs for trips and falls	**--**	**d * a + e * b + f * c**
j	Annual Societal Benefit (per remediated home)	**--**	**i *(1 - g) * (1 - h)**

Table 14: Knob and Tube – Reduced Rodent Infestation

Input		Value	Source
a	Rate of infestation in homes with knob and tube wiring	--	Requires in-field research
b	Rate of infestation in homes without knob and tube wiring	--	Requires in-field research
c	Societal cost of rodent-borne illness (per home)	--	Further research required
d	Household cost of rodent-borne illness (per home)	--	Further research required
e	Cost of an exterminator and structural repair (per home)	$309	HomeAdvisor[127]
f	Cost of damage to goods in home (per home)	--	Requires in-field research
Non-Energy Impact Value			
g	Annual Societal Benefit (per remediated home)	**--**	**(a - b) * c**
h	Annual Household Benefit (per remediated home)	**--**	**(a - b) * (d + e + f)**

[124] E.R. Burns, *Direct Costs of Fatal and Non-Fatal Falls*, 2016.
[125] Ibid.
[126] Ibid.
[127] Learn how much it costs to Remove or Exterminate a Rodent. (n.d.). Retrieved from https://www.homeadvisor.com/cost/environmental-safety/rodent-removal/

Table 15:Asbestos Avoided Medical Costs – Relative Risk Model

	Input	Value	Source
a	Cost of a hospitalization for MM in MA (per patient, 2015 $)	$64,330	Healthcare Cost and Utilization Project (HCUP)[128]
b	Charges for an ER visit for MM nationally (per patient, 2014 $)	$82,214	Healthcare Cost and Utilization Project (HCUP)
c	Cost of a doctor's office visit for MM (per patient)	--	Further research required
d	Average percent of charges paid OOP in MA	8%	Levit et al.[129]
e	Risk of developing MM from ambient exposure	0.4 per million	Lee and Orden 2008
f	Relative Risk of developing MM from domestic exposure	3.5	Boffetta 2006[130]
Non-Energy Impact Value – IRIS model			
g	Value of avoided MM medical costs per home	--	**((e * f) - e) * (a + b + c)**
h	Value of avoided MM medical costs (household)	--	**g * d**

[128] Healthcare Cost and Utilization Project (HCUP), *HCUPnet,* 2015.
[129] Levit et al., *Estimating Inpatient Hospital Prices*, 2013.
[130] P. Boffetta, *Human cancer from environmental pollutants*, 2006.