Beyond Efficiency: The Multifaceted Impacts of Induction Cooktops, Heat Pumps, and Battery Systems

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ABSTRACT

The Program Administrators (PAs) of Massachusetts implement initiatives aimed at advancing the state's ambitious energy efficiency and strategic electrification goals. Incorporating non-energy impacts (NEIs) from electrification measures into the PAs' benefit-cost analysis is critical to ensuring a comprehensive and accurate assessment of these measures' overall value.

This paper reports on four recent studies completed for the PAs to quantify participant NEIs (i.e., the NEIs that accrue to program participants) for induction stovetops replacing gas stovetops; heat pumps displacing fossil fuel heating systems and/or adding cooling to homes; battery storage measures for low- and moderate-income residential customers; and all-electric residential new construction.

The NEIs explored in these studies centered on participant health, comfort and safety, and resilience (for battery storage). The studies employed a variety of methods, including systematic and extensive evidence assessment of energy efficiency evaluation studies and health sciences research, surveys of program participants, and building energy modeling. The methodologies included both bottom-up approaches that quantified each NEI individually and top-down approaches that quantified all NEIs as a whole.

The studies identified and monetized a wide range of NEIs attributable to the PAs' residential electrification efforts. Total monetized annual NEIs ranged from $162 per participating household for battery storage to up to $392 for a heat pump displacing electric resistance heating. The results of these studies are useful for programs, particularly those in similar climates, that are looking to increase the adoption of electrification measures and improve the benefit-cost assessment of these measures to encompass a wider range of impacts.

Introduction and Background

The Program Administrators (PAs) of Massachusetts's energy-efficiency programs include promoting strategic electrification. This involves the adoption of electric measures that result in reduced emissions and increased energy efficiency by displacing fossil fuels while also minimizing ratepayer costs.[1]

The Green Communities Act (GCA), passed in 2008, is the founding legislation for the modern three-year energy efficiency and electrification plans administered by the Massachusetts PAs and mandates comprehensive plans that capture all-available, cost-effective energy efficiency and demand resources. The GCA was amended in 2018, allowing the PAs to pursue electrification measures that result in cost-effective reductions in greenhouse gas (GHG) emissions.

[1] The Green Communities Act of 2008 mandates the Massachusetts PAs to "pursue all cost-effective energy efficiency that is less expensive than supply" and to construct their Energy Efficiency Plans to meet or exceed the GHG emissions target goals. The PAs plans must be cost-effective, so the PAs plans note that the shift to electrification and away from traditional fossil-fuel based measures will be conducted in a "measured, data-driven manner" (Massachusetts PAs, 2021).

Beginning with their 2019-2021 three year plan, the PAs introduced energy optimization programs which moved customers toward lower total energy usage and increased environmental benefits, including converting homes from delivered heating fuels or electric baseboard heat to either electric air source heat pumps or high efficiency natural gas equipment.

In 2021 Massachusetts enacted the Climate Act, which established new mandates for GHG emissions reductions, and allowed the PAs' three-year energy efficiency plans to further prioritize GHG reductions. As a result, electrification was one of the top priorities of the 2022-2024 three-year plans and the default solution for all residential customers and planned GHG reduction in the 2025 to 2027 three-year plans.

Since 2010, the Massachusetts PAs have sponsored NEI studies and developed a robust set of granular NEIs through rigorous research for use in benefit-cost analysis.[2] This paper synthesizes the findings from four studies recently completed for the PAs to quantify the non-energy impacts (NEIs) that accrue to program participants from the following residential electrification efforts in Massachusetts:

- Heat pumps displacing fossil fuel heating systems and/or adding cooling to homes (NMR and Three[3] 2023b)
- All-electric residential new construction (RNC) (NMR and Three[3] 2021)
- Induction stovetops replacing gas stovetops (NMR and Three[3] 2023a)
- Battery storage measures offered as part of a strategic electrification and energy optimization program for low- and moderate-income residential customers (NMR and Three[3] 2024)

Methodology

This section discusses methodology, organized by study. Each study employed a slightly different approach to identifying and quantifying the relevant NEIs, tailored to the nature of the NEI, available data, and study budget. Table 1 provides a summary of the research approaches for the four residential electrification NEI studies. For a more detailed discussion of the methodologies, the readers can refer to the corresponding study reports, which are listed in the References section.

Table 1. Summary of Research Approaches for Four Residential Electrification NEI Studies

Study	Research Approach	Description of Approach
Residential heat pump NEIs	Bottom-up quantification of individual NEIs	Survey of program participants, literature review, and secondary data
All-electric residential new construction NEIs	Bottom-up quantification of individual NEIs	Literature review and secondary data
Induction stovetop NEIs	Bottom-up quantification of individual NEIs	Literature review and secondary data
Battery storage NEIs	Top-down quantification of all NEIs as a whole	Building modeling, outage data analysis, and literature review

Residential Heat Pump NEI Study Methods

The study team (the Team) conducted a multi-step investigation of the NEIs associated with residential heat pump installations. The Team first explored the applicability of adjusting NEIs that are

[2] As noted in the PAs' 2022-2024 3-Year Plan, the Massachusetts Department of Public Utilities (DPU) has stated that NEIs are "a well established component of the program cost-effectiveness analyses conducted by the PAs" and found that the benefits of the NEIs are quantifiable and flow to Massachusetts ratepayers. The DPU has stated that non-resource benefits, such as NEIs, should be included in cost-effectiveness calculations (Massachusetts PAs, 2021).

currently claimed by the PAs for other heating and cooling systems to heat pumps. The Team then conducted a literature review in the form of a rapid evidence assessment (REA)[3] to identify and monetize additional NEIs or update the values for the NEIs extended from other heating and cooling systems to heat pumps. The review utilized consistent search terms across multiple search engines and research databases, including Google Scholar, JSTOR, PubMed, Science Direct, Web of Science, and the University of Tennessee libraries and databases.

The literature review included studies that did not necessarily identify NEIs as their target or provide NEI factors directly but could be joined with other sources to develop such factors. The Team assigned both a relevancy and robustness quantitative score to each piece of evidence. Relevancy assessed whether the information is sufficiently pertinent to the research objectives. Robustness assessed the rigor of the methods and/or the size of the experimental samples.

The selection criteria used to recommend an NEI for quantification and monetization was the level of evidence for the NEI in the literature; the availability of literature for monetizing the impacts; and the ability to link the impacts to heat pumps and energy optimization programs.

The Team also reviewed a recently completed heat pump NEI study from Connecticut to update NEIs currently claimed by the PAs for thermal comfort, noise, and equipment maintenance (NMR Group, 2023). The Connecticut study included web surveys with program participants to quantify NEIs associated with heat pumps (and heat pump water heaters) in Connecticut. The study used a contingent valuation approach where respondents were asked to place a value on the NEIs they experience using a labeled magnitude scale on non-health related impacts, such as comfort, reduced noise, and equipment maintenance. Respondents were then asked to compare the value of the NEIs to the energy savings associated with their program participation. To avoid double counting of potentially overlapping NEIs, the study asked respondents to identify overlapping NEIs and to estimate overall impacts of the NEIs combined. The study then adjusted the individual NEIs based on the overall NEI value.

The Team assessed and incorporated information from the literature review and other secondary sources into the NEI algorithms to estimate the applicable NEIs.

All Electric Residential New Construction Study Methods

The Team conducted a broad review of available literature, comprising 41 studies, to identify potential secondary data sources with which to update existing NEI values, monetize additional NEIs, and understand potential NEIs related to Residential New Construction (RNC). In addition, the Team conducted a scan of ten jurisdictions outside Massachusetts, reviewing 14 public planning documents, Technical Reference Manuals (TRMs), cost-effectiveness testing documents, and other public documents. The purpose of the scan was to obtain details on how other jurisdictions claim NEIs, specifically those attributed to RNC programs.

The Team relied primarily on academic research to identify new NEIs that the PAs could potentially claim as outcomes from the RNC program. The Team identified two critical pieces of literature for developing monetization algorithms: one meta-analysis on the asthma impacts of exposure to gas stoves in the home, and one randomized controlled trial investigating the impact of heat recovery ventilation (HRV) and energy recovery ventilation (ERV) systems on formaldehyde levels in study homes and the resulting change in asthma-related emergency department visits (see NMR Group and Three3, 2021). In the final step of the evaluation, the Team assessed and incorporated information from the literature review and other secondary sources into the NEI algorithms to estimate the applicable NEIs.

[3] REA is a type of evidence review approach that aims to provide an informed conclusion on the volume and characteristics of an evidence base, a synthesis of what the evidence indicates, and a critical appraisal of the evidence (Collins, Miller and Clark, 2015).

Induction Stovetops Study Methods

The Team gathered evidence on potential outcomes from replacing natural gas or propane stovetops with induction electric stovetops from a literature review and secondary data. In addition to utilizing previously collected literature from various studies, the Team conducted targeted semi-structured searches for each NEI topic outlined in the study plan to identify any relevant new research articles or reports and secondary data sources.

The targeted semi-structured literature and data research utilized consistent search terms, for example applying consistent variations and usage of terms like "gas stove" or "gas cooker" and "premature mortality" were defined prior to reviewing articles. The search terms were then applied across multiple research databases such as Google Scholar, PubMed, University of Tennessee Libraries, and Boston College libraries. Articles were screened based on a review of the abstract and a brief examination of the methods, results, and conclusions to determine their relevance to the research objectives for a given NEI category. The Team also remained vigilant for any additional potential NEIs identified within targeted NEI categories during the literature review. In addition, the Team reviewed additional articles that were referenced in the selected literature.

The Team assessed and incorporated information from the literature review and other secondary sources into the NEI algorithms to estimate the applicable NEIs.

Battery Storage Study Methods

This study aimed to monetize resilience-related NEIs from battery storage measures offered as part of as part the Cape Light Compact's (CLC's) Cape and Vineyard Electrification Offering (CVEO) for low- and moderate-income residential customers in Massachusetts. The study assessed benefits that accrue to program participants from having an uninterrupted electricity supply from the program-supplied battery during a grid power outage.

Rather than assessing each NEI individually, the study employed a top-down approach, which uses the concept of the Value of Lost Load (VoLL) — an estimate of the price that customers are willing to pay for uninterrupted electricity — to monetize all NEIs as a whole.

The study developed two key inputs and used them in an algorithm to monetize resilience NEIs associated with battery storage.

1. A VoLL estimate ($/kWh) appropriate for the CVEO participants
2. Annual estimated lost load (in kWh) battery storage would help avoid

The study first conducted a review of the recent literature on VoLL to assess whether VoLL can be used to value participant resilience NEIs, to evaluate how VoLL differs for low-to-moderate income customers and for customers that live in homes that use electricity for heating, and to identify a VoLL appropriate for the CVEO participants.

Second, the study determined the number, length, and season of outages in the CLC service territory using detailed outage data for 2020, 2021, and 2022. The Team used the Building Energy Optimization (BEopt) software to develop seasonal customer load profiles for modeled CVEO participant homes. By merging outage data with load profiles, the Team estimated the average amount of lost load (in kWh) that battery storage would help avoid based on the capacity of the batteries incentivized through the program.

Next, the Team estimated the NEIs for each individual outage using Equation 1.

NEI per Home per Outage = VoLL_CVEO($/kWh) * Total kWh supplied by the battery system during the outage * The probability of the home being affected by the outage[4]

Equation 1: NEI per Home per Outage

The Team summed all NEIs per home across all outages in 2020, 2021, and 2022 and calculated a single, weighted average for each year and then took a simple average of the total NEIs per home in 2020, 2021, and 2022 to calculate an average annual NEI per home.

Findings

This section presents the key results, organized by study. We have also included one detailed NEI algorithm developed from the literature and secondary data sources to illustrate our use of the literature and secondary data. All dollar figures are reported as they appear in the original source studies and have not been adjusted for inflation.

Residential Heat Pump NEI Study Findings

The Residential Heat Pump NEI study recommended a number of monetized NEIs attributable to installing heat pumps in homes, including NEIs associated with improved indoor air quality (IAQ), reduced thermal stress, reduced fire risk, improved thermal comfort, reduced noise, and reduced equipment maintenance cost. Table 2 provides a summary of the NEIs and their recommended values per home. Some NEIs vary based on the type of heat pump installation and the displaced heating systems. For cooling related NEIs for each heat pump type, the NEI values are based on non-cooling baseline values, i.e., the percentage of participants that would not have installed cooling without the PA-supported heat pump.

Table 2: Residential Heat Pump (HP) NEIs

NEI Description	Annual per home NEI ($)
Reduction in unintentional, non-fire related CO poisoning deaths resulting from heat pumps full displacing combustion furnaces (IAQ)	$0.34
Reduction in respiratory illness symptoms resulting from heat pumps fully displacing natural gas furnaces with pilot lights (IAQ)	$14.14
Heat-related mortality risk (thermal stress)	$37.82 to $115.06 (varies by HP installation)
Productivity gains due to reduced cognitive impacts from extreme heat (thermal stress)	$6.91 to $21.03 (varies by HP installation)
Avoided home fires (fire risk)	$0.01 to $0.03 (varies by HP installation)
Thermal Comfort, summer (participant survey)	$69.43
Thermal Comfort, winter (participant survey)	$88.05
Noise Reduction (participant survey)	$73.25
Reduced equipment maintenance cost (participant survey)	$26.08

[4] The probability of the home being affected by a given outage was calculated as the number of customers affected by the outage divided by total number of customers.

Indoor Air Quality NEIs

The combustion processes used in fossil fuel furnaces produce multiple byproducts that pose health hazards, such as carbon monoxide (CO) and nitrogen dioxide (NO_2). When not properly vented, these harmful chemicals can infiltrate indoor air and negatively affect occupant health. While rare, operator errors, lack of maintenance, or equipment malfunctions can cause carbon monoxide (CO) from furnaces to build up inside a residence and lead to CO poisoning and, in extreme cases, death. The report estimated an NEI based on the number of unintentional, non-fire-related CO deaths that could be prevented by removing combustion furnaces (i.e., fully displacing them with heat pumps) from homes and the resulting benefit based on the federally established Value of a Statistical Life (VSL).

In addition, older models of natural gas furnaces often have continuously burning pilot lights that emit high levels of combustion byproducts, including nitrogen dioxide (NO_2) (Mullen, N. A. et al, 2015). Displacing natural gas furnaces with pilot lights with heat pumps results in a reduction of respiratory illness symptoms. The impact is limited to homes with non-gas cooktops as homes with natural gas cooktops would continue to have NO_2 levels above the threshold for health impacts even after the furnace pilot light was removed. The prevalence of pilot lights, and therefore the value of this NEI, will decrease over time as more homes buy new furnaces without pilot lights.

Thermal Stress NEIs

The evidence found from the literature review focused primarily on thermal stress impacts related to hot weather, large same-day temperature swings, and heat waves. The evidence highlights the importance of cooling strategies in reducing health risks. Some sources indicate that heat-related morbidity and mortality risks rise on summer days when temperatures increase by 10 degrees Fahrenheit over the mean apparent temperature[5] (Ostro et al., 2010).

Several studies have shown strong evidence of a decrease in heat related mortality risks that are attributable to specific interventions and strategies (Arbuthnott et al. 2016; Kinney 2018). The use of air conditioning is one of the most straightforward strategies to reduce negative health impacts from heat stress. Various studies have evaluated the role of air conditioning in modifying the risks associated with mortality events related to exposure to high temperatures using several individual and aggregated-level study designs (Anderson and Bell 2009; Barreca et al. 2016; Bobb et al. 2014). Heat stress deaths are caused directly by heat illnesses such as heat exhaustion and hyperthermia, and heat-exacerbated deaths happen when heat worsens existing chronic conditions such diabetes or heart disease.

Table 3 presents the algorithm for monetizing avoided heat-related mortality risk associated with the installing heat pumps. The report leveraged data from the state of New York on the annual estimates of heat-related mortality events collected during the months of May through September from 2010 to 2019, then applied the rate of heat-related mortality in the population of New York to the population of Massachusetts to estimate the number of heat-related mortalities that occur annually in Massachusetts. Results from another study show an independent association between increased air conditioning prevalence and reduced heat-related mortality risk (Sera et al. 2020). Excess deaths due to heat decreased during the study periods from 1.70% to 0.53% in the U.S (Sera et al. 2020). Increased air conditioning explained 16.7% of the observed decrease. Accordingly, the algorithm monetizes the benefits of different prevalence rates of adding air conditioning to homes that would not have had cooling if not for installing a PA-supported heat pump (Table 3). The approach estimates the number of heat-related deaths due to lack of air conditioning in homes and the resulting risks and benefits based on the literature review and the federally established VSL (inputs d, g, and h in Table 3).

[5] Apparent temperature, also referred to as the heat index, is what the temperature feels like to the human body when relative humidity is combined with the air temperature (https://www.weather.gov/ama/heatindex).

Table 3. Heat-Related Mortality Risk NEI (Mini-split HP with Fossil Fuel-Fired Pre-Retrofit Heating System & No Cooling Baseline)

Input		Value	Source
a	Total MA population (2020)	6,984,723	U.S. Census Bureau
b	Number of homes in MA (Occupied, 2020)	2,749,225	U.S. Census Bureau
c	Annual heat related death rate in NY (2010-2019)	0.00228%	NYC Environmental Health 2021
d	Estimated annual heat related deaths in MA state	159	**a** * **c**
e	Percentage of households with AC in Massachusetts	87%	U.S. EIA 2023
f	Percentage of households without AC in MA	13%	U.S. EIA 2023
g	Excess risk reduction in heat related mortality due to AC	0.09	Sera, F. et al. 2020
h	($) VSL (avoided death), adjusted for 2022	$10,491,655	Adjusted for inflation using Consumer Price Index (https://www.bls.gov/data/inflation_calculator.htm)
i	Number of heat related deaths in MA due to not using AC	14.31	**d** * **g**
j	Value of heat-related deaths avoided due to AC (MA)	$150,135,583	**h** * **i**
k	Annual Heat related mortality impact per home without AC	$420.21	**j** / (**b** * **f**)
l	Mini-split HP with a fossil fuel-fired pre-retrofit heating system (no cooling baseline)	30%	Distribution of Counterfactual Baseline Cooling Types from Guidehouse 2021.
m	% of Mini-split HP installations with added cooling that meet 50% of the home's overall cooling load	74%	Guidehouse and Ridgeline 2024.
NEI Value			
o	Annual NEI estimate per home due to MSHP (Delivered Fuel Baseline)	$93.28	**k** * **l** * **m**

High indoor temperatures during hot weather can impact cognitive functioning, even in younger, healthy populations. The evidence suggests that when indoor temperatures are below 27 degrees Celsius (80.6 degrees Fahrenheit) improvements in general health and wellbeing are observed (Cedeño et al. 2016). The presence of air conditioning can reduce negative impacts on cognitive function, such as concentration and productivity, that occur from high indoor temperatures during heat waves (Cedeño et al. 2016). Cognitive performance decreased linearly with an increase in indoor temperature exposure, indicating impacts on educational attainment, economic productivity, and workplace safety (Cedeño et al. 2016). The report estimated the impacts of reducing negative impacts on cognitive function due to the presence of air conditioning for individuals that work from home. The estimate only considers homes that have added cooling due to the heat pump installation but would not have otherwise.

Avoided Fire NEI

Based on analysis of data from the National Fire Incident Reporting System (NFIRS), replacing furnaces and boilers with heat pumps will yield a small NEI for avoided home fires, with the NEI based on the value of avoided building losses and avoided medical costs from fire-related injuries.

Thermal Comfort, Noise and Equipment Maintenance NEIs

As noted in the Methodology section, the recommended NEIs of thermal comfort, noise, and equipment maintenance were adapted from a Connecticut study that used a contingent valuation approach to monetize heat pump NEIs.

All-Electric RNC NEIs Study Findings

The RNC NEIs study quantified three-health related NEIs associated with improved IAQ attributed to use of electric stoves (rather than gas stoves) and installation of an ERV / HRV (Table 4). Note that the baseline for the RNC NEIs is a non-program new construction home. Because only a portion of these homes have gas stoves, the NEIs associated with electric stoves are smaller than those estimated for induction stovetops.[6] Due to limitations of the secondary data, these monetized NEI values are based only on the removal of combustion stoves. They do not consider the additional impact on health outcomes that may result from reductions in concentrations of NO_2 and other byproducts, such as levels of PM2.5 from also removing combustion heating and water heating equipment.

Table 4: All-Electric RNC NEIs

NEI Description	Link to Program	Annual per home NEI ($)
Childhood asthma prevention, occupant lifetime	Electric Stoves (elimination of exposure to gas stove combustion byproducts)	$8.00
Adult asthma symptom reduction		$27.36
Childhood asthma symptom reduction		$5.13
Reduced asthma ED visits	ERV/HRV (reduction in formaldehyde)	$0.02

The health NEIs are associated with reducing the risks to asthma patients posed by gas combustion stoves and formaldehyde from poor ventilation. The NEIs are attributable to improving IAQ by eliminating byproducts of combustion from stoves. These byproducts include NO_2, $PM_{2.5}$, CO, and others. The NEIs are also due to reducing formaldehyde concentrations that build up in the home due to limited or poor ventilation.[7] Increased levels of $PM_{2.5}$ and CO from combustion stoves are associated with negative health outcomes, such as damage to respiratory systems (Seals and Krasner 2020; Hu, Singer and Logue 2012). IAQ can also be improved by removing similar emissions by eliminating other gas combustion appliances, such as heating and water heating, but the literature did not specify the asthma impact from these additional end-uses. Formaldehyde can be reduced in the home through high-efficiency ventilation, such as HRV or ERV (Lajoie et al. 2015).

Induction Stovetop NEIs Study Findings

The Induction Stovetop NEI study recommended a number of monetized NEIs attributable to installing induction stovetops that replace propane or natural gas stovetops, including health-related NEIs associated with improved indoor air quality, such as asthma-related impacts, respiratory infections and COPD exacerbations, as well as a negative NEI for the cost of replacing older cookware with induction-compatible cookware (Table 5). The study also examined potential NEIs associated with fire risks, burns, and risks to individuals with pacemakers but did not find sufficient evidence of an impact.

[6] We should note that the induction stovetop algorithms included estimates of annual productivity losses due to in-home exposure to gas stoves—impacts that were not quantified in the RNC NEIs study.

[7] Formaldehyde is a VOC with negative health effects and is a known carcinogen. It can be released by many products and materials used in energy-efficiency measures and other applications. The NEI focuses on outcomes associated with removing formaldehyde concentrations through ventilation strategies. It does not address outcomes from using materials that may emit lower levels of formaldehyde or other VOCs.

Table 5: Induction Stovetop NEIs

NEI Description	Annual per home NEI ($)
Childhood asthma prevention, occupant lifetime (annual)	$4.73
Childhood asthma symptom reduction (annual)	$51.45
Adult asthma symptom reduction (annual)	$49.77
Lower respiratory tract symptom reduction (annual)	$88.26
COPD-related hospitalization reduction (annual)	$0.28
NEI for partial cookware replacements (one-time)	-$19.37
NEI for full cookware replacements (one-time)	-$38.41

Asthma-Related NEIs

The Team reexamined the asthma-related algorithms and input values used in the RNC NEI Quick Hit Assessment study, then applied several adjustments to estimate the NEI values for households that replace their gas stovetop with an electric induction stovetop in their existing home. For example, the RNC study looked at asthma-related NEIs from eliminating gas stoves, including both ovens and stovetops. The Team applied a 40% adjustment factor to estimate the NEI values for stovetops only.[8] For child asthma prevention, the Team used the new federal guidance, which includes lifetime medical and productivity losses (while the RNC study was limited to medical losses). Additionally, the Team removed the discount factor, which was applied as an adjustment for the ratio of medical costs to symptoms in the RNC study for the adult and childhood symptom reduction NEIs.[9] The Team also adjusted all monetary figures for inflation and Massachusetts cost of living. Finally, the Team updated the effective useful life (EUL) assumption from 25 years to 16 years, to reflect the EUL for induction stovetops.

A meta-analysis on the association between exposure to gas cooking and asthma estimated that the risk of having asthma symptoms increases by 42% (due to combustion byproducts such as NO_2) for children living in a home with gas cooking over those without gas cooking (Lim et al. 2022).

Other Health-Related NEIs

The Induction Stovetop study found evidence for the impacts of gas stovetops on respiratory infections and COPD exacerbations. The study monetized the impact of gas stovetops on lower respiratory tract (LRT) infections and symptoms and associated medical costs in the form of a doctor's office visit (Chauhan and Johnston 2003). Because the article studied total emissions from gas stoves, which include both stovetops and ovens, the Team adjusted the NEI to account only for stovetops. The study also found evidence that COPD hospitalizations rise in association with increases in peak one-hour average concentrations of ambient NO_2 at levels that residents in homes with gas stovetops are exposed to and quantified the impact of gas stovetops on COPD hospitalizations and associated medical costs.

[8] According to a proposed rule by DOE on 12/14/2020 re: Energy Conservation Standards for Consumer Conventional Cooking Products, a standard gas cooktop uses about 1,443 kBtu/year whereas a standard conventional gas oven uses between 1,960 and 2,093 kBtu/year. So, of the combined cooktop/oven energy consumption for a home, about 40% is for the cooktop and 60% is for the oven. https://www.federalregister.gov/documents/2020/12/14/2020-26874/energy-conservation-program-energy-conservation-standards-for-consumer-conventional-cooking-products. It is common practice to assume a linear relationship between NO_2 exposure and respiratory impacts (Huangfu and Atkinson 2020).

[9] While the studies reviewed indicated that costs of asthma increase with asthma severity (Godard et al. 2002) and lower asthma control (See Lai et al. 2006), they did not include data on the relationship between changes in symptoms and changes in medical costs or productivity losses. The Team assumed that reductions in symptoms have a one-to-one relationship with reductions in medical costs or in productivity losses. The Team suggests updating this ratio assumption if future literature reviews find studies documenting the relationship between changes in symptoms and changes in medical costs or productivity losses.

Cookware Replacement NEIs

Induction stovetops require cookware made from magnetic material, such as cast iron, stainless steel, and carbon steel, so that the stovetop can induce a magnetic field to generate heat. The Team researched the costs of five separate induction cookware sets each from seven online retailers to estimate the average cost of full sets of cookware and of individual cookware that is compatible with induction stovetops. These costs represent the potential replacement cost of cookware that is incompatible with induction stoves tops.

There is no clear estimate of the percentage of the average home's cookware that will need to be replaced, nor is there an estimate of what proportion of households will need to purchase new cookware. The Team applied a placeholder assumption that 30% of households would need to replace their existing cookware with induction-compatible cookware.[10] In developing the NEI estimates, the Team used the average price of the four lowest-cost retailers.

Battery Storage NEIs Study Findings

The resilience NEI values (uninterrupted electricity supply during an outage from the program-supplied battery) were estimated using standard BEopt battery management strategy, which assumed that the battery storage system is charged by the PV system and discharges throughout the day to offset kWh drawn from the grid. The report includes NEI estimates for a second battery management strategy scenario that assumed that the battery system is configured to always have a full charge at the beginning of an outage. In other words, the battery system would be used for resilience purposes only and would discharge only during outages. Table 7 presents the annual NEI value for homes using a standard battery management strategy.

Table 7: Battery Storage NEIs, Standard Battery Management

NEI Description	Annual per home NEI ($)
Resilience NEIs: having an uninterrupted electricity supply from the program-supplied battery during a grid power outage.	$162.08 (home with one battery) or $181.00 (home with two batteries), standard battery management strategy

Conclusions and Recommendations

Residential electrification measures, including heat pumps, induction stovetops, and battery storage, offer a wide array of important co-benefits beyond energy efficiency and greenhouse gas emissions reductions. By reducing or eliminating the combustion of fossil fuels within homes, introducing cooling to previously unconditioned spaces, or providing uninterrupted power during grid outages, these measures can lead to significant improvements in health, comfort, and safety for the occupants of homes implementing them.

These NEI studies illustrate the value of leveraging existing research and secondary data to estimate individual health and safety impacts. For electrification NEIs, this involves chaining algorithmic inputs from prior studies; for battery resilience NEIs, it entails using building energy modeling and outage data to produce a top-down estimate. Relying on existing data and studies, rather than conducting new primary research, allows for the monetization of non-energy impacts within relatively modest study budgets. However, a key limitation is that these approaches do not directly measure NEIs resulting from the PAs' programs. Instead, they apply findings from other contexts to estimate those impacts. If more direct evidence is needed, PAs across multiple states could consider pooling resources to fund what would

[10] The Team assumed 15% of households would require a full set of new induction-compatible pans, and the other 15% of households only need to replace a subset of cookware.

likely be a costly but more rigorous research effort. Given ongoing research on the impacts of global climate change and the health effects of fossil fuel combustion in homes, the evidence base for potential health, safety, and other NEIs from residential electrification should be periodically reassessed. This would help ensure that NEI estimates used in monetization algorithms remain current. Reassessments could also evaluate whether sufficient evidence has emerged to monetize new NEIs or previously identified NEIs that lacked adequate support for monetization.

This paper presents detailed NEI values associated with residential electrification measures. These findings are particularly valuable for program administrators and policymakers aiming to incentivize the adoption of electrification strategies. By incorporating a broader range of impacts into benefit-cost assessments, the results support more comprehensive and accurate evaluations of these measures' overall value relative to their cost.

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