Residential Gas-to-Electric Stovetop Conversion NEIs Study (MA22X03-E-GSCNEI) Interim Report

Interim Report

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SUBMITTED TO:
The Massachusetts Program Administrators

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MA Residential Gas-to-Electric Stovetop Conversion NEIs Study

Interim Report

The NMR team used existing Massachusetts studies and other secondary data to assess and adjust the asthma-related NEIs to apply to residential replacements of propane or natural gas stovetops with electric induction stovetops, as well as identify, quantity, and monetize any additional new NEIs, primarily those related to health and safety.

Conclusions & Challenges

- Asthma-related health NEIs are assessed for existing homes and updated with new information
- Non-asthma health-related NEIs will be monetized and presented in the final report
- Insufficient evidence regarding whether induction stovetops pose lower burn and fire risk than traditional stovetops
- The risk posed by induction stoves on individuals with pacemakers is minimal
- Insufficient information on frequency of repairs and maintenance and associated costs for induction stovetops

Recommendations

Non-Energy Impact	Value Suggested (per home per year)
Childhood asthma prevention, occupant lifetime	$4.73
Childhood asthma symptom reduction	$51.45
Adult asthma symptom reduction	$49.77
Total	**$105.95**

The NEI values recommended in the interim report are to be used in 2023, and the values to be presented in the final report can be used in 2024.

Questions

- What updates are needed to the asthma-related algorithms and findings from the RNC NEI Quick Hit Assessment study for existing homes and propane stovetops?
- Are there other health NEIs that can be monetized with available secondary data?
- Are there NEIs associated with fire and burn risk that can be monetized?
- Are there negative health-related NEIs associated with pacemakers and induction cooking?
- What are the incremental costs associated with induction stovetops relating to maintenance and cookware replacements?

Methodology

Review of publicly available literature and secondary data

Assessing and updating existing algorithms for asthma-related NEIs

Leveraging literature reviews recently conducted for related Massachusetts studies

Analysis of data from the National Fire Incident Reporting System (NFIRS) for fire risks

Analysis of data from the National Electronic Injury Surveillance System (NEISS) for burn risks

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Acronyms

Acronym	Definition
BCR	Benefit Cost Ratio
CDR	Clinical Dementia Rating
CI	Confidence Interval
COPD	Chronic Obstructive Pulmonary Disease
CPI	Consumer Price Index
CVD	Cardiovascular Disease
DPU	Department Of Public Utilities
EAS	Electronic Article Surveillance
EMI	Electromagnetic Interference
EPA	Environmental Protection Agency
EUL	Effective Useful Life
FEV1	Forced Expiratory Volume
FPE	Fire Protection Effectiveness
GHG	Greenhouse Gas
GWP	Global Warming Potential
IAP	Indoor Air Pollutants
IAQ	Indoor Air Quality
ICD	Implantable Cardioverter-Defibrillators
IH	Induction Heating
IWG	Interagency Working Group
MEPS	Medical Expenditure Panel Survey
NEI	Non-Energy Impact
NEISS	National Electronic Injury Surveillance System
NFIRS	National Fire Incident Reporting System
NGCB	Natural Gas Cooking Burners
PA	Program Administrators
RNC	Residential New Construction
TRM	Technical Resource Manuals
UFP	Ultra-Fine Particles
VOC	Volatile Organic Compounds

Executive Summary

This report presents the interim results from the *Residential Gas to Electric Stovetop Study* (study number MA22X03-E-GSCNEI). The Cross-Cutting Non-Energy Impacts evaluation team, led by NMR Group, Inc., with the support of Three[3] and DNV, prepared this interim report for the Massachusetts Program Administrators (PAs).[1] The study presents interim adjustments to asthma-related NEI values, which were initially established in the RNC NEI Quick Hit Assessment study (MA20X14-RNCNEI),[2] for replacing a propane or natural gas stovetop with an electric or induction stovetop. The adjustments are interim, meant to be used until the final report is published for the study.

These interim results leverage the findings from Task 1 of this study, which provided a review of the literature and secondary data. This interim report provides the PAs with updated asthma-related NEI values to use on an interim basis in their electric benefit cost ratio (BCR) model, until new NEI estimates can be presented in the final report. The values recommended in this interim report are to be used in 2023, and the values to be presented in the final report can be used in 2024. This interim report is a modified version of the Task 1 memo dated September 1, 2022, which presented the asthma-related NEIs that were monetized in the RNC NEI Quick Hit study and findings from the literature and secondary data review that provide evidence of a potential NEI, including a potential pathway to monetization. This report differs from the Task 1 memo only with respect to the asthma-related NEIs. No modifications were made to the other content presented in Task 1 memo.

The NMR team will submit a subsequent, draft report that will provide any new NEI values that were identified as potential monetization pathways in Task 1 (detailed in the main body of this interim report) and that the PAs may consider claiming in addition to the interim NEI values presented in this report. The final report will be completed in time to present NEI values recommended for use beginning in 2024.

Study Overview

Study Objectives

The primary goals of this study were to use existing Massachusetts studies and other secondary data to (1) assess and adjust the asthma-related NEIs to apply to residential replacements of propane or natural gas stovetops (referred to as “gas stovetops”) with electric induction stovetops, (2) identify, quantity, and monetize any additional new NEIs, primarily those related to health and safety, that PAs could claim for their residential induction stovetop measures.

[1] The PAs comprise Berkshire Gas, Cape Light Compact, Eversource, Eversource Gas of Massachusetts, Liberty Utilities, National Grid, and Until.
[2] https://ma-eeac.org/wp-content/uploads/MA20X14_RNC-NEI_Final-Report_-2021.10.06.pdf

Methodology

This study assessed potential outcomes from replacing combustion stovetops with electric induction stovetops based on a review of publicly available literature and secondary data.

The literature review included articles summarizing studies that did not directly monetize NEIs but did provide information that could be used as inputs for monetization. A reference list of articles reviewed for this study is included in Appendix D. The review focused on the following potential NEIs:

- Asthma-related NEIs, comprising a review of asthma-related algorithms and findings from the RNC NEI Quick Hit Assessment study to determine whether any updates are needed to tailor the asthma-related NEIs for 1) existing homes and 2) propane stovetops
- Other non-asthma health-related NEIs
- Avoided fires and burns
- Potential negative health-related NEIs associated with pacemakers and induction cooking
- Potential reduction in greenhouse gas (GHG) emissions from conversion to electric stovetops, and if applicable, treatment of gas stove leaks[3]

The review also included the following items related to incremental costs associated with induction stovetops:

- Comparison of maintenance costs for induction stovetops to those for gas stovetops
- The rate at which existing homes need electric upgrades to enable installing an induction stovetop and the costs associated with these upgrades

KEY FINDINGS

Table 1 provides a summary of the key findings from the literature and secondary data review.

Table 1: Summary of Key Findings

Item	Key findings
Asthma-related NEIs	Asthma-related NEIs estimated in the RNC NEI Quick Hit Assessment for eliminating gas stoves in homes can be applied to households replacing their gas stovetop with an induction stovetop in their existing home after some adjustments to the algorithms and input values. Higher emissions rates of NO_x and SO_2 from combustion of propane

[3] The team notes that recent research has found that existing gas stoves can be a source of methane emissions through leaks. The leaks can be mitigated by tightening couplings, fittings, and connectors to the gas pipes in a home. Addressing gas leaks from gas stoves could be another measure the PAs consider adopting (in addition to gas stove conversion).
https://www.npr.org/2022/01/27/1075874473/gas-stoves-climate-change-leak-methane
https://pubs.acs.org/doi/10.1021/acs.est.1c04707

Item	Key findings
	compared to natural gas suggest that asthma-related NEIs from eliminating propane stoves could be greater.
Non-asthma health-related NEIs	The research evidence suggests strong links from gas stoves to respiratory infections, chronic obstructive pulmonary disease (COPD) exacerbations, and cardiovascular diseases, and that the health impacts can be greater on children than adults. There are potential pathways to monetize these health-related NEIs.
Avoided fires	Overall, there are more fires caused by electric (resistance) stoves than gas stoves in Massachusetts. There is insufficient evidence in the literature regarding whether induction stoves reduce (or increase) fire risk relative to electric resistance and gas stoves. The team does not recommend monetizing an avoided fires NEI.
Avoided burns	Overall, electric resistance stoves cause a substantially higher number of burn injuries than gas stoves, but the severity of burns caused by gas stoves appears to be higher. There is insufficient evidence in the literature regarding whether induction stoves reduce (or increase) burn risk relative to electric resistance and gas stoves. The team does not recommend monetizing an NEI for avoided burns.
Pacemakers	Overall, the evidence suggests that the risk posed by induction stoves on individuals with pacemakers is minimal. The team does not recommend monetizing the risk of induction stoves on individuals with pacemakers.
Methane leaks	Natural gas stovetops emit 0.7−1.2% of the gas they use as unburned methane, and more than three-quarters of methane emissions occur while the stovetop is shut off. Indoor natural gas leakage is a source of not only methane emissions but also associated air pollutants, including benzene, with potential health impacts for occupants. The team's understanding is that the societal impacts from GHG emissions are out of scope for the NEI studies as they are being handled as part of the AESC 2021 Study.[4] Therefore, the team does not recommend monetizing this as an NEI. But the teams recommends that the impacts associated with uncombusted methane emissions from gas stovetops be accounted for as part of the broader GHG impacts study.
Maintenance costs	The team did not uncover evidence that provided information on the frequency of repairs and maintenance and on associated costs for induction stoves. Therefore, the team does not recommend monetizing a maintenance cost NEI.
Electric upgrade costs	The team did not find any academic research, evaluations, or TRMs that systematically detailed either costs or frequencies of electric upgrades needed to enable installing an induction stove. The team recommends that the cost associated with upgrading electrical capacity in homes that install induction stoves should be treated as an incremental cost rather than an NEI.

[4] https://www.synapse-energy.com/project/aesc-2021-materials

RECOMMENDATIONS

Recommendation. The team recommends applying on an interim basis the NEI values detailed in Table 2 to induction stovetops that replace propane or natural gas stovetops. The values we recommend are based on adjustments to NEI values that were originally developed in the RNC NEI Quick Hit Assessment study for electric stoves (both stovetop and ovens). The team adjusted them to reflect the values for stovetops only and made several other adjustments to incorporate the new data sources identified, as discussed in Section 2.1.

Table 2: Asthma-Related NEIs from Replacing Propane or Natural Gas Stovetops with Induction Stovetops in Existing Homes (2020 $)

Non-Energy Impact	Value Suggested
Childhood asthma prevention, occupant lifetime	$4.73 per home per year
Childhood asthma symptom reduction	$51.45 per home per year
Adult asthma symptom reduction	$49.77 per home per year
Total	**$105.95 per home per year**

Section 1 Introduction

This report presents the interim results from the *Residential Gas-to-Electric Stove Study* (study number MA22X03-E-GSCNEI). The Cross-Cutting Non-Energy Impacts evaluation team, led by NMR Group, Inc., with the support of Three[3] and DNV, prepared this interim report for the Massachusetts Program Administrators (PAs).[5] The study interim adjustments to NEI values that were established in the Residential New Construction (RNC) NEI Quick Hit Assessment study (MA20X14-RNCNEI)[6] for replacing a propane or natural gas stovetop with an electric or induction stovetop. The adjustments are interim in that they are meant to be used until the final report is published for the study.

These interim results leverage the findings from Task 1 of this study, which provided a review of the literature and secondary data. This interim report provides the PAs with updated asthma-related NEI values to claim on an interim basis in their electric benefit cost ratio (BCR) model, until new NEI measurements can be presented in the final report. The values recommended in this interim report are to be used in 2023, and the values presented in the final report can be used beginning in 2024. This interim report is a modified version of the Task 1 memo dated September 1, 2022, which presented the asthma-related NEIs that were monetized in the RNC NEI Quick Hit study and findings from the literature and secondary data review that provide evidence of a potential NEI, including a potential pathway to monetization. This report differs from the Task 1 memo only with respect to the asthma-related NEIs. No modifications were made to the other content presented in Task 1 memo.

The NMR team will produce a subsequent, final report that will present any new NEI values that were identified in subsequent research tasks and that the PAs may consider claiming in addition to the interim NEI values presented in this report. The final report will be completed in time to present NEI values recommended for use beginning in 2024.

1.1 Study Objectives, Background, and Methods

The primary goals of this study were to use secondary data to (1) assess and adjust the asthma-related NEIs associated with replacing propane or natural gas stovetops (referred to as "gas stovetops") with electric stoves; (2) identify new participant NEIs, primarily those related to health and safety, that are associated with replacing gas stovetops with induction stovetops; and (3) quantify and monetize these new, currently unclaimed NEIs associated with the PAs' residential induction stovetop initiatives.

[5] The PAs comprise Berkshire Gas, Cape Light Compact, Eversource, Eversource Gas of Massachusetts, Liberty Utilities, National Grid, and Until.

[6] https://ma-eeac.org/wp-content/uploads/MA20X14_RNC-NEI_Final-Report_-2021.10.06.pdf

1.1.1 Background

Medical research increasingly indicates that the elevated levels of NO_2 resulting from cooking with a gas stove can increase the risk of developing asthma and exacerbate asthma symptoms.[7,8,9,10] The Massachusetts Medical Society issued an official resolution in December 2019 stating that it "recognizes the association between the use of gas stoves, indoor NO_2 levels, and asthma."[11] Proper ventilation appears to mitigate, but not eliminate, the risks of cooking on gas stoves.[12, 13]

The RNC NEI Quick Hit Assessment study[14] identified and monetized new NEIs associated with reducing the risks to asthma patients posed by gas combustion stoves. These NEIs are due to improving indoor air quality (IAQ) by eliminating byproducts of combustion from stoves, including NO_2, $PM_{2.5}$, CO, and others. Increased levels of $PM_{2.5}$ and CO from combustion stoves are associated with negative health outcomes, such as damage to respiratory systems.[15,16]

In this study, we leveraged the asthma-related algorithms and findings from the RNC NEI study and adjusted them based on new available literature and on considerations for replacing just the stovetop compared to the entire range.

1.1.2 Methodology

This study assessed potential outcomes from replacing combustion stovetops with induction electric stovetops based on a review of publicly available literature and secondary data.

The evaluation team built on the literature review from the RNC NEI Quick Hit Assessment study and the Residential Heat Pump NEIs study (MA21X21-E-RHPNEI) to identify and monetize NEIs – primarily those related to health and safety – that the PAs could potentially claim as outcomes from replacing combustion stovetops with induction electric stovetops. The team also leveraged the literature review conducted for the RNC Electrification Barriers study (MA21R44) regarding

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[7] Belanger, K., Holford, T. R., Gent, J. F., Hill, M. E., Kezik, J. M., & Leaderer, B. P. (2013). Household levels of nitrogen dioxide and pediatric asthma severity. *Epidemiology (Cambridge, Mass.)*, *24*(2), 320–330. https://doi.org/10.1097/EDE.0b013e318280e2ac

[8] U.S. EPA. Integrated Science Assessment (ISA) for Oxides of Nitrogen – Health Criteria (Final Report, Jan 2016). U.S. Environmental Protection Agency, Washington, DC, EPA/600/R-15/068, 2016.

[9] Lin, W., Brunekreef, B., Gehring, U. Meta-analysis of the effects of indoor nitrogen dioxide and gas cooking on asthma and wheeze in children, *International Journal of Epidemiology*, Volume 42, Issue 6, December 2013, Pages 1724–1737, https://doi.org/10.1093/ije/dyt150

[10] Luke D Knibbs, Solomon Woldeyohannes, Guy B Marks and Christine T Cowie
Med J Aust 2018; 208 (7): 299-302. || doi: 10.5694/mja17.00469
Published online: 16 April 2018

[11] Informing Physicians, Health Care Providers, and the Public That Cooking with a Gas Stove Increases Household Air Pollution and the Risk of Childhood Asthma, Massachusetts Medical Society, December 2019. https://gbpsr.org/wp-content/uploads/sites/11/2020/01/gas-cooking-and-asthma-2019-mms.pdf

[12] Ibid.

[13] Luke D Knibbs, Solomon Woldeyohannes, Guy B Marks and Christine T Cowie
Med J Aust 2018; 208 (7): 299-302. || doi: 10.5694/mja17.00469
Published online: 16 April 2018

[14] Note that the NEI Quick Hit Assessment looked at the impacts from the elimination of combustion stoves in all types of homes, not just new construction.
https://ma-eeac.org/wp-content/uploads/MA20X14_RNC-NEI_Final-Report_-2021.10.06.pdf

[15] https://rmi.org/insight/gas-stoves-pollution-health

[16] https://www.osti.gov/servlets/purl/1172959

the risks to people with pacemakers in homes with induction stovetops. In addition to leveraging previously reviewed literature, the team conducted targeted semi-structured searches for each NEI topic detailed here to identify any articles or secondary data sources that were not included in previous evaluations.[17] Appendix D presents a reference list of articles reviewed for this study

- The literature review included articles summarizing studies that did not directly monetize NEIs but did provide information that could be used as inputs for monetization. The review focused on the following potential NEIs:
    - Asthma-related NEIs, comprising a review of asthma-related algorithms and findings from the RNC NEI Quick Hit Assessment study to determine whether any updates were warranted
    - Other non-asthma health-related NEIs
    - Avoided fires and burns
    - Potential negative health-related NEIs associated with pacemakers and induction cooking
    - Potential reduction in greenhouse gas (GHG) emissions from conversion to electric stovetops, and if applicable, treatment of gas stove leaks[18]

  The review also included the following items related to incremental costs associated with induction stovetops:

    - Comparison of maintenance costs for induction stovetops to those for gas stovetops
    - The rate at which existing homes need electric upgrades to enable installing an induction stovetop and the costs associated with these upgrades

[17] The team conducted searches using the same search terms in multiple research databases. The team pulled articles based on relevant titles and descriptions, followed by a review of the abstract and brief scan of the methods, results, and conclusions of each to determine whether the article was relevant to the research objectives for a given research task (e.g., NEI category). The team did not conduct robustness or relevancy scoring as a part of this review.

[18] The team notes that recent research has found that existing gas stoves can be a source of methane emissions through leaks. The leaks can be mitigated by tightening couplings, fittings, and connectors to the gas pipes in a home. Addressing gas leaks from gas stoves could be another measure the PAs consider adopting in addition to gas stove conversion.
https://www.npr.org/2022/01/27/1075874473/gas-stoves-climate-change-leak-methane
https://pubs.acs.org/doi/10.1021/acs.est.1c04707

Section 2 Indoor Air Quality

2.1 Asthma-Related NEIs

For asthma-related NEIs, the team reviewed the asthma-related algorithms and findings from the RNC NEI Quick Hit Assessment study to determine whether any updates were needed to tailor the NEIs for 1) existing homes and 2) propane stovetops.

The RNC NEI Quick Hit Assessment study identified and monetized new NEIs associated with reducing the risks to asthma patients posed by gas combustion stoves. These NEIs were due to improving IAQ by eliminating byproducts of combustion from stoves, including NO_x, $PM_{2.5}$, and other pollutants. Increased levels of $PM_{2.5}$ and NO_x from combustion stoves are associated with negative health outcomes, such as damage to respiratory systems.[19,20] The RNC NEI Quick Hit Assessment study developed two sets of asthma-related NEIs; one for an average RNC program home and one for an all-electric RNC program home. The first set was based on observed differences between saturation of gas stoves in RNC program homes and non-program homes, which was only 8%; the second reflects the impact from complete removal of gas stoves from homes – a 100% reduction in exposure to gas stove combustion byproducts (see Table 4 for a comparison on NEI values).

The team reexamined the asthma-related algorithms and input values used in the RNC NEI Quick Hit Assessment study and applied several adjustments to estimate the NEI values for households that replace their gas stovetop with an electric induction stovetop in their existing home. The RNC study looked at asthma-related NEIs from eliminating gas stoves, which include both ovens and cooktops. The team applied a 40% adjustment factor to estimate the NEI values for stovetops only.[21] For child asthma prevention, the team substituted the values used in the RNC study with the values in the new federal guidance published in 2022, which included a comprehensive cost of illness valuation for new onset asthma that includes lifetime medical and productivity losses. The team used the values from a study that was the basis for the cost of illness valuation for new onset asthma in the 2022 federal guidance.[22] The team included avoided productivity losses in addition to the avoided medical costs in the algorithms. 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. The team also adjusted all monetary figures for inflation and Massachusetts cost of living. Finally, the team updated the

[19] https://rmi.org/insight/gas-stoves-pollution-health
[20] https://www.osti.gov/servlets/purl/1172959
[21] 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 1443 kBtu/year whereas a standard conventional gas oven uses between 1960 and 2093 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
[22] Belova, A., Fann, N., Haskell, J., Hubbell, B., & Narayan, T. (2020). Estimating Lifetime Cost of Illness. An Application to Asthma, 2020. Annals of the American Thoracic Society.

effective useful life (EUL) assumption from 25 years to 16 years, to reflect the EUL for induction stovetops.

Table 3 provides the asthma-related NEI values after these adjustments while Table 4 compares the asthma-related NEIs developed in this study to those originally developed in the RNC NEI Quick Hit Assessment study. The underlying monetization algorithms are presented in Appendix C for reference. The NMR team notes that the updated total asthma-related NEIs in this study ($105.95) are nearly three times as large those estimated in the RNC NEI Quick Hit Assessment study ($40.49) for eliminating gas stoves.[23] The inclusion of the cost of productivity losses and the removal of the discount factor for the ratio of costs to symptoms in the algorithm explains most of the increase in the NEI estimates.[24] Unlike medical care costs, which are adjusted to reflect only the participant out-of-pocket portion of the costs, the cost of productivity losses is assumed to be fully borne by the participants.

[23] The total asthma-related NEIs for an average RNC program home was estimated to be only $3.28 in the RNC NEI Quick Hit Assessment study due to the fact that the observed difference between saturation of gas stoves in RNC program homes and non-program homes was only 8%.

[24] While the reviewed studies indicated that costs of asthma increase with asthma severity (See P. Godard, P. Chanez, L. Siraudin, N. Nicoloyannis, G. Duru (2002)) and lower asthma control (See Lai, C. K. W., Kuo, S.-H., de Guia, T., Lloyd, A., Williams, A. E., & Spencer, M. D. (2006)), they did not include data on the relationship between changes in symptoms and changes in medical costs or productivity losses. The evaluation 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.

Table 3: Asthma-Related NEIs from Replacing Propane or Natural Gas Stovetops with Induction Stovetops in Existing Homes (2020 $)

Non-Energy Impact	Value Suggested
Childhood asthma prevention, occupant lifetime[1]	$4.73 per home per year
Adult asthma symptom reduction	$51.45 per home per year
Childhood asthma symptom reduction	$49.77 per home per year
Total	**$105.95 per home per year**

[1] Removing gas stovetops is associated with lower rates of children developing asthma

Table 4: Comparison of Asthma-Related NEIs from Replacing Propane or Natural Gas Stovetops with Electric Stovetops, RNC vs. Existing Homes (2020 $)

Non-Energy Impact	Average RNC Home	All Electric RNC Home	Gas to Electric Stovetop Conversion Existing Home
Childhood asthma prevention, occupant lifetime	$0.65	$8.00	$4.73
Adult asthma symptom reduction	$0.42	$5.13	$51.45
Childhood asthma symptom reduction	$2.21	$27.36	$49.77
Total	$3.28	$40.49	**$105.95**

The literature on the health effects from propone stovetops is not as extensive as that from natural gas stovetops. So, the team could not estimate an NEI value specific to propane stovetops. However, according to the U.S. Environmental Protection Agency's (EPA's) AP-42: Compilation of Air Emissions Factors,[25] emissions factors of $PM_{2.5}$ and volatile organic compounds (VOCs) for propane are the same as those for natural gas for residential fuel combustion. However, NO_x emissions are approximately 50% higher from combustion of propane than natural gas. Sulfur dioxide (SO_2) emissions from propane are nearly double those from natural gas. **The higher emissions rates of NO_x and SO_2 from combustion of propane compared to natural gas suggest that the health benefits from the conversion of propane stovetops to induction stovetops would potentially be higher than those from the conversion of natural gas stovetops to induction stovetops.** Therefore, the asthma-related NEIs shown in Table 3, should be viewed as conservative estimates of the asthma-related NEIs from replacing propane stovetops with induction stovetops.

[25] https://www3.epa.gov/ttnchie1/conference/ei12/area/haneke.pdf

2.2 OTHER HEALTH NEIS

The team compiled and reviewed academic literature, governmental reports, and evaluation materials to describe the relationships between:

1) gas stovetops and non-asthma health impacts
2) gas stovetops and premature death
3) gas stovetops and indoor air pollutants (IAP)
4) IAP and the aforementioned health issues and premature death

The literature on these topics is broad and complex, but the team attempted to highlight key articles and studies along with the level of evidence for each potential pathway from gas stovetops to poor health and mortality.

2.2.1 Methods

Table 5 shows the search engines, search terms, and the number of articles pulled from each of the search engines and search term combinations. Five search engines were used to find literature on the topics of non-asthma respiratory health such as chronic obstructive pulmonary disease (COPD) and premature death. The literature review primarily examined links to $PM_{2.5}$, though it also explored NO_2 and CO. The team also performed a brief search on attention deficit hyperactivity disorder (ADHD) due to prior research presenting evidence of a connection with gas stovetops. In all cases, both "gas stove" and "gas cooker" were used for each topic, as the term "gas cooker" is common in Europe and the United Kingdom as a synonym for "gas stove."[26]

The team also reviewed some articles that were referenced in the literature; 11 reviewed articles came from the reference section of articles found during the search rather than through the search terms listed below. An additional five articles came from previous research or were sent to the team via email.

Table 5: IAQ, Premature Death, and Non-Asthma Health Literature Search Method

Database	Search Term	Number of Articles Pulled Based on Title
Boston College Libraries	"gas stove" AND "COPD"	0
Boston College Libraries	"gas cooker" AND "COPD"	0
Boston College Libraries	"gas stove" AND "respiratory" NOT "asthma"	0
Boston College Libraries	"gas cooker" AND "respiratory" NOT "asthma"	0

[26] For a limited number of searches, the team appended "NOT liquefied" due to a plethora of non-applicable literature on converting wood or coal stoves to liquefied petroleum gas cookers in developing countries. In every case that specifies "NOT liquefied," the search term was first attempted without "NOT liquefied" to attempt to capture relevant literature in the US or Europe.

Database	Search Term	Number of Articles Pulled Based on Title
Boston College Libraries	"gas stove" AND "infection" NOT "asthma"	0
Google Scholar	"gas stove" AND "COPD"	2
Google Scholar	"gas cooker" AND "COPD"	3
Google Scholar	"gas stove" AND "respiratory" NOT "asthma"	1
Google Scholar	"gas cooker" AND "respiratory" NOT "asthma"	1
Google Scholar	"gas stove" AND "infection" NOT "asthma"	0
Google Scholar	"gas stove" AND premature mortality	1
Google Scholar	“gas stove” AND ADHD	2
Google Scholar	“gas stove” AND premature death	8
Google Scholar	NO2 AND premature death	3
Google Scholar	NO2 AND premature death	2
PubMed	"gas cooker" AND "COPD"	0
PubMed	"gas cooker" AND "respiratory" NOT "asthma"	4
PubMed	"gas stove" AND "COPD"	0
PubMed	"gas stove" AND "infection" NOT "asthma"	1
PubMed	"gas stove" AND "respiratory" NOT "asthma"	2
UT-Knoxville Libraries	"gas stove" AND mortality	0
UT-Knoxville Libraries	"gas cooker" AND mortality	3
UT-Knoxville Libraries	"gas stove" AND "particulate matter"	7
UT-Knoxville Libraries	"gas cooker" AND "particulate matter"	0
UT-Knoxville Libraries	"gas stove" AND premature death NOT liquefied	5
UT-Knoxville Libraries	"gas cooker" AND premature death NOT liquefied	0

Database	Search Term	Number of Articles Pulled Based on Title
UT-Knoxville Libraries	"gas stove" AND respiratory NOT liquefied	4
UT-Knoxville Libraries	"gas cooker" AND respiratory NOT liquefied	0

2.2.2 Articles Reviewed

Table 6 provides the counts of articles reviewed related to IAQ, premature death, and health impacts other than asthma.

Table 6: Number of IAQ, Premature Death, and Non-Asthma Health Articles Reviewed

Status	Number of Articles
Total number of articles pulled based on title	48
Number of articles rejected based on abstract	23
Number of articles kept and reviewed	25
Articles reviewed from reference sections	11
Articles reviewed from previous research	5

The team kept articles that presented useful data for one of the four relationships outlined in the introduction to Section 2.2. The team considers as implementable data metrics such as specific odds ratios or risk ratios for the health impacts of a gas stovetop in the home or measured concentrations of NO2 or PM2.5 in kitchens where a gas stovetop is in use. The team rejected articles if, after an initial review, they did not provide implementable data, the results could not be tied to monetizable outcomes (e.g., healthcare incident), or the study lacked a sufficient sample size (i.e., anecdotal rather than experimental).

The team kept 41 articles for informing monetization algorithms in Task 3. Brief summaries of each of the articles can be found in Appendix A. The following section provides a higher-level overview of the literature review findings and the implications for monetization.

2.2.3 Summary of IAQ and Non-Asthma Health Risk Literature

Overall, this study finds that the NEI evidence is strongest for the impacts of gas stovetops on respiratory infections, COPD exacerbations, and cardiovascular diseases. Articles studied the health impacts of the presence or absence of a gas stovetop as well as the impacts of air pollutants known to be emitted by gas stovetops. The four sections below summarize the lines of evidence and potential monetization pathways for each of the four categories of evidence outlined in the tables above.

Evidence for a Link between Gas Stoves and Direct Health Impacts

One line of evidence links the presence of a gas stovetop in the home to increased risk of respiratory symptoms and infections, particularly for children, women, and those with a pre-existing respiratory condition such as COPD or bronchopulmonary dysplasia. Equation 1 demonstrates a potential monetization pathway for respiratory infections, which typically require a doctor visit and prescription medications for treatment. Exacerbations of bronchopulmonary dysplasia in infants could potentially also be monetized, though due to the relative rareness of the disease, the team does not expect it would produce more than a few cents in annual NEIs per stove. (The condition affects about 400 infants per 100,000 births.)

Equation 1: Example Algorithm to Monetize Reductions in Respiratory Infections

*Monetized value of reduced respiratory infections ($) = % reduction in respiratory infections resulting from removal of gas stove * Average cost ($) of care for respiratory infection (doctor's office visit + medication) * % paid out of pocket*

The team found a small amount of evidence for a link between gas stoves and ADHD, partly due to the limited scale of the search as outlined in the scope of work. The research team does not currently recommend monetization for ADHD-related impacts.

Evidence for a Link between Gas Stoves and IAP

The link between gas stoves and indoor NO_2 is well established. Multiple studies have published estimates of the degree to which gas stoves elevate NO_2 concentrations both in the kitchen and throughout the home, though estimates range broadly depending on the location of measurement (e.g., kitchen versus other rooms) and length of measurement period (pollutant levels reach their peak during cooking and then taper off in the hours after cooking is complete). However, even one or two hours of exposure to very high levels can have a detrimental effect on health, and in most cases, NO_2 appeared to exceed the recommended threshold for acute exposure during the cooking period.

A strong line of evidence also connects gas stoves to particulate matter, particularly $PM_{2.5}$ as well as a high concentration of ultra-fine particles (UFP), which have been found to have more severe health effects than particles with larger diameters (e.g., PM_{10}). Emission rates and indoor concentrations are well documented across a range of cooking scenarios for both gas and electric stoves, allowing for comparison between the two stove types.

Gas stoves have also been linked to elevated CO concentrations in the kitchen. Previous research indicates that gas stoves can lead to CO poisoning, though additional evidence would need to be reviewed to quantify and monetize these impacts.

Evidence for a Link between IAP and Health Impacts

Like gas stoves, a moderately strong line of evidence connects NO_2 to respiratory infection and illness as well as exacerbations for those with COPD, which is also impacted by $PM_{2.5}$. Equation 2 and Equation 3 show potential monetization pathways for NO_2 and $PM_{2.5}$ from reductions in hospitalization for those with COPD. Equation 4 shows the potential monetization of the savings of avoiding a missed day of school for children due to reduced colds and respiratory symptoms.

Equation 2: Example Algorithm to Monetize Reductions in COPD Hospitalizations (NO_2)

*Monetized value of reduced COPD hospitalizations ($) = % reduction in COPD-related hospitalizations resulting from removal of gas stove (based on reductions in 1-hour and 24-hour average NO_2 ppb) * Average cost ($) of hospitalization for COPD * % paid out of pocket*

Equation 3: Example Algorithm to Monetize Reductions in COPD Hospitalizations ($PM_{2.5}$)

*Monetized value of reduced COPD hospitalizations ($) = % reduction in COPD-related hospitalizations resulting from removal of gas stove (based on reductions in 1-hour and 24-hour average $PM_{2.5}$ μg/m^3) * Average cost ($) of hospitalization for COPD * % paid out of pocket*

Equation 4: Example Algorithm to Monetize Reductions in Missed Days of School

*Monetized value of fewer missed days of school ($) = % reduction in missed days of school resulting from removal of gas stove (based on reductions in maximum 1-hour NO_2 ppb) * Average cost ($) of one missed day of school (based on a previously published methodology estimating the cost of childcare and missed work for the parent or guardian)*[27]

Evidence also exists that links indoor particulate matter to respiratory infections; however, the team recommends monetizing this NEI using the literature that links gas stoves directly to respiratory infections, if possible, rather than using a less direct air pollution pathway. It may also be possible to monetize particulate matter's impact on cardiovascular disease (CVD) through cost estimates of the medical care needed for strokes and heart attacks, as shown in Equation 5. However, it will be important to avoid double counting between CVD and premature death, as some studies use CVD prevalence in estimating premature death.[28, 29, 30, 31]

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[27] Nurmagambetov, T., Kuwahara, R., & Garbe, P. (2018). The Economic Burden of Asthma in the United States, 2008-2013. Annals of the American Thoracic Society, 15(3), 348–356.

[28] Grieshop, A. P., Marshall, J. D., & Kandlikar, M. (2011). Health and climate benefits of cookstove replacement options. *Energy Policy*, *39*(12), 7530–7542. https://doi.org/10.1016/j.enpol.2011.03.024

[29] Christidis, T., Erickson, A. C., Pappin, A. J., Crouse, D. L., Pinault, L. L., Weichenthal, S. A., Brook, J. R., van Donkelaar, A., Hystad, P., Martin, R. V., Tjepkema, M., Burnett, R. T., & Brauer, M. (2019). Low concentrations of fine particle air pollution and mortality in the Canadian Community Health Survey cohort. *Environmental Health*, *18*(1), 84. https://doi.org/10.1186/s12940-019-0518-y

[30] Faustini, A., Rapp, R., & Forastiere, F. (2014). Nitrogen dioxide and mortality: Review and meta-analysis of long-term studies. *European Respiratory Journal*, *44*(3), 744–753. https://doi.org/10.1183/09031936.00114713

[31] Brook, R. D., Rajagopalan, S., Pope, C. A., Brook, J. R., Bhatnagar, A., Diez-Roux, A. V., Holguin, F., Hong, Y., Luepker, R. V., Mittleman, M. A., Peters, A., Siscovick, D., Smith, S. C., Whitsel, L., & Kaufman, J. D. (2010). Particulate Matter Air Pollution and Cardiovascular Disease. *Circulation*, *121*(21), 2331–2378. https://doi.org/10.1161/CIR.0b013e3181dbece1

Equation 5: Example Algorithm to Monetize Reductions in Strokes and Heart Attacks

Monetized value of reduced strokes and heart attacks ($) = reduction in $PM_{2.5}$ (μg/m^3) resulting from removal of gas stove / 10 μg/m^3 *$PM_{2.5}$ * % reduction in risk of heart attack or stroke due to PM2.5 exposure * Average cost ($) of care for heart attack or stroke * % paid out of pocket*

While one article indicated a link between ambient air pollution and diabetes [46], more research is needed to quantify any potential relationship between indoor air pollution and diabetes.

Evidence for a Link between IAP and Premature Death

The literature on air pollution and premature death is complicated by the fact that most of the studies reviewed used data on outdoor or "ambient" air pollution over longer periods of time (between a period of days to years), whereas indoor exposures caused by gas stoves occur most intensely for one or two hours while cooking, during which time concentrations of pollutants often far exceed outdoor levels. However, evidence indicates that NO_2, $PM_{2.5}$, and CO levels also remain elevated over the longer term in homes with gas stoves, which may be more comparable to studies on ambient pollution and premature death. Using evidence on long-term elevated levels of indoor pollutants, Equation 6 demonstrates a potential monetization pathway for premature death.

Equation 6: Example Algorithm to Monetize Reductions in Mortality

*Monetized value of reduced mortality ($) = reduction in average $PM_{2.5}$ (μg/m^3) resulting from removal of gas stove * reduction in risk of mortality per unit of $PM_{2.5}$ reduction * Value of statistical life (VSL)*

Section 3 Fire Risk

3.1 Induction Fire Risk Research Compared to Traditional Electric and Gas/Propane Stoves

One of the potential benefits of switching to induction stovetops is their potential to decrease the risk of kitchen fires. In Massachusetts, electric and gas stovetops caused over 1,800 home fire-related incidents between 2018 and 2020, pointing towards a substantial potential reduction in preventable injuries, casualties, and property damage. It is often cited that induction stovetops reduce fire risk due to their lack of an open flame, and because the stovetop does not generate any heat without the presence of cookware on the surface of the stovetop. The team reviewed literature from secondary sources to explore whether induction stovetops may reduce the risk of fires that is associated with both gas and electric resistance stovetops.

3.1.1 Methods

Table 7 shows the search engines, search terms, and the number of articles pulled from each of the search engines and terms. Four search terms were searched on three different search engines; 12 searches in total were performed.

Table 7: Induction Fire Risk Literature Search Method

Database	Search Term	Number of Articles Pulled Based on Title
Google Search	Induction stovetops fire risk	7
	Induction cooker fire risk	0
	Induction stoves kitchen fires	0
	Induction cooktops fire risk	0
Google Scholar	Induction stovetops fire risk	2
	Induction cooker fire risk	3
	Induction stoves kitchen fires	1
	Induction cooktops fire risk	2
Boston College Libraries	Induction stovetops fire risk	1
	Induction cooker fire risk	1
	Induction stoves kitchen fires	1
	Induction cooktops fire risk	0

3.1.2 Articles Reviewed

Table 8 provides the counts of articles reviewed related to fire-related impacts.

Table 8: Number of Fire Risk-Related Articles Reviewed

Status	Number of Articles
Total number of articles pulled based on title	17
Number of articles rejected based on abstract	11
Number of articles kept and reviewed	6

The team kept six articles for informing monetization algorithms in Task 3. Brief summaries for each article can be found in Appendix A.2 (see Table 25).

3.1.3 Summary of Fire Risk Literature

Overall, while the research suggests that fire risks from induction stovetops can be lower compared to electric resistance and gas stovetops, the unique ways in which induction stovetops operate pose distinct dangers that may increase fire risk. Outside of studies focused on finding the failure points of induction stovetops, most of the evidence available about the fire risks of induction stovetops is anecdotal or simply concludes that induction stovetops are safer due to a lack of a flame. The National Fire Incident Reporting System (NFIRS) dataset used in Section 3.2 does not list induction stovetops as a stove type, making observing fire risk reduction very challenging. The studies reviewed here do not offer a direct comparison between the fire risk of induction stovetops and electric resistance and gas stovetops. However, the literature reviewed indicates that certain distinct features of induction stovetops may pose other fire risks not seen in electric resistance or gas stoves. These features include quick heating speeds, faulty safety mechanisms, cookware compatibility constraints, and potentially difficult operation. Induction stovetops do not have a flame and a constant heat source, which may lower the fire risk. However, because of their unique design features, further research is needed to establish whether induction stoves have a lower overall fire risk compared to electric resistance and gas stovetops.

Because there is insufficient evidence in the literature regarding whether induction stoves reduce (or increase) fire risk relative to traditional electric and gas stovetops, the team does not recommend monetizing an avoided fires NEI. This recommendation should be revisited as the related literature is expected to grow as the penetration of induction stovetops increases.

3.2 Fire Risk Assessment for Gas and Electric Stoves

Overall, the evaluation team found that electric stovetops cause more than four times as many fires as gas stovetops, significantly higher rates of injuries, and nearly four times as much damage to property in home fires. In Section 2.1, the team discussed whether induction stovetops could reduce the number of home fires caused by kitchen stovetops. In this section,

the team used secondary data and available literature to explore the differences between the fire risks associated with gas and electric stovetops.

3.2.1 Assessment of the Reliability of Secondary Data

After review, the team determined that the NFIRS dataset's equipment power source label can be used to determine a stovetop's fuel type, and therefore it can be used to assess the fire risk of gas and electric stovetops. The team assessed the NFIRS public fire dataset to distinguish between fires caused by gas stovetops from those caused by electric stovetops in Massachusetts.[32] The team compiled datasets from 2018 to 2020 to build a three-year average in fire incidents. Based on prior experience, the team noticed that a piece of equipment's power source as listed in the NFIRS data does not necessarily constitute its fuel source. For example, a stovetop's power source may be listed as electric line voltage, but it may actually be a gas stovetop. Therefore, the team conducted additional analysis to determine how reliable the electric or gas power source label is at capturing the true power sources of stovetop equipment. However, the team notes there is some uncertainty in the data due to unknown fire causes and the occasional mislabeling of equipment power sources.

The team took several steps to assess the NFIRS data, and while it was determined the NFIRS data could be used to estimate fire-related incidents, the data did not distinguish between electric resistance and induction stovetops. This may be due to very low penetration of induction stovetops during the data period. The team's first step was to determine if any distinctions could be made between electric and gas stovetop fire incidents, whether through the heat source that caused ignition, or the type of material first ignited. The second step was to determine approximately what percentage of stovetops have an accurately labeled power source type by research the model numbers of both gas and electric stovetops. The third step was to apply the fire-incidence data, by stovetop fuel-type, to the estimated saturation of gas and electric stovetops in Massachusetts.[33] Finally, the team applied the per-home fire incidence rate caused by stovetops to the property damage, injury, and fatality data that is recorded in the NFIRS data. Additional results from the fire risk analysis are presented in Section 7.

3.2.2 Summary of Fire Incident Data

Of the 1,405 stovetop-ignited residential fires that were reported through NFIRS between 2018 and 2020 in Massachusetts, 1,139 (81%) were caused by electric stoves, compared to 246 (18%) caused by gas stoves. Table 9 shows each stovetop fuel type and how often incidents were caused by them. The table also shows the incidence rate for each stovetop type, which represents the probability that a fire will occur in a home with one of the two types of stoves. Between 2018 and 2020, 0.0222% of homes with electric stovetops in Massachusetts had a fire

[32] NFIRS public datasets can be found at https://www.fema.gov/about/openfema/data-sets/fema-usfa-nfirs-annual-data.
[33] The team estimated the saturation gas and electric stoves in Massachusetts using the Energy Information Administration's 2020 Residential Energy Consumption Survey (RECS) state-level data. https://www.eia.gov/consumption/residential/data/2020/state/pdf/State%20Appliances.pdf

incident, compared to 0.0068% of homes with gas stovetops in the same period.[34] As noted above, the data did not distinguish between electric resistance and induction stovetop types.

Table 9: Prevalence of Fire-Related Incidents Caused by Stoves in Massachusetts (2018 to 2020)

Stove Type	Total Fire-related Incidents (2018 to 2020)	Incidents (3-Year Average)	Percent of Incidents	Total Number of Homes with Stove Type in Massachusetts[35]	Incident Rate per Home (based on 3-year average number of incidents)
Electric	1,139	380	81.1%	1,710,000	0.0222%
Gas	246	82	17.5%	1,200,000	0.0068%
Other	20	7	1.4%	-	-
Total	***1,405***	***469***	***100%***	***2,710,000***	***0.0173%***

Fires ignited by radiated and conducted heat is the most frequent cause of fires associated with both electric- and gas stovetops, but this type of heat source causes a higher percentage of fires when electric stovetops are involved. Table 10 shows the difference between fires ignited by four different heat sources in stovetop-caused fire incidents. Fires ignited by sparks and embers cause a much higher proportion of fires when gas stovetops are involved than electric stovetops.

Table 10: Percentage of Fires Caused by Electric and Gas Stoves by Heat Source

Heat Source	Electric Stoves	Gas Stoves
Spark, ember, or flame from operating equipment	2%	20%
Radiated, conducted heat from operating equipment	52%	31%
Arcing	3%	2%
Heat from powered equipment, other	35%	25%

Overall, electric stovetops caused substantially higher rates of injuries and deaths than gas stoves did during this period. Table 11 shows the percentage of homes in Massachusetts that experienced four different levels of injuries and deaths between 2018 and 2020. The most notable difference is present for the rate of moderate injuries (i.e., little danger of death, but quick medical care is required), which is nearly five times higher for electric stovetops. However, the rates of deaths for the two different stove types are much closer than any of the other injury types.

[34] For reference, 63% of homes in New England (1.71 million homes in Massachusetts) have electric stoves, compared to 44% of homes (1.2 million) with fossil fuel stoves.
[35] https://www.eia.gov/consumption/residential/data/2020/state/pdf/State%20Appliances.pdf

The team notes that it is likely that most of the minor injuries caused by stoves (i.e., burns) are not caused during home fires but occur during periods of normal use and go unreported.

Table 11: Casualty Rates per Home for Electric and Gas Stoves

Stove Type	Incident Rate per Home	Percent of homes with Minor Injuries	Percent of Homes with Moderate Injuries	Percent of Homes with Severe Injuries	Percent of Homes with Deaths
All Stoves average	0.0173%	0.000443%	0.000209%	0.000025%	0.000074%
Electric power source	0.0222%	0.000507%	0.000273%	0.000039%	0.000078%
Gas power source	0.0068%	0.000278%	0.000056%	0%	0.000056%

Overall, fires caused by electric stovetops cause more expensive fire incidents than gas stovetops. In terms of property loss, gas stovetop fires cost about 19 cents per home in Massachusetts, while electric stovetop fires cost about 88 cents per home, over four times higher. In terms of content loss, electric stoves cost about 30 cents per home, compared to seven cents per home for gas stoves, which is just over four times higher as well (Table 12). The value columns represent the average value per home involved in each fire incident, per year, multiplied by the incidence rate for that specific stovetop type. The loss columns represent the average losses per home, per year, multiplied by the incidence rate for that specific stovetop type. As noted above, due to the data not distinguishing between electric resistance and electric induction stoves, this category could contain both types of stovetops—though the team notes it is likely these are predominately electric resistance stoves.[36]

Table 12: Property Values, Content Values, Property Losses, and Content Losses per Home (dollars)

Stovetop Type	Incident Rate per Home	Property Value per Home	Content Value per Home	Property Loss per Home	Content Loss per Home
All stovetops average	0.0173%	$37.32	$2.32	$0.65	$0.22
Electric power source	0.0222%	$55.83	$3.16	$0.88	$0.30
Gas power source	0.0068%	$4.15	$0.58	$0.19	$0.07

[36] According to the data from EIA's 2020 RECS, 63% of homes in Massachusetts have electric stovetops but only 2.9% of households reported having induction stovetops.

3.3 BURNS

A potential positive NEI of switching to induction stovetops is the reduction of burn injuries in the home. It is often cited that induction stovetops reduce burn risk due to their lack of an open flame, and because the stovetop does not generate any heat without the presence of cookware on the surface of the stovetop.[37] The team conducted a multi-step analysis to assess whether these claims are valid.

3.3.1 Methods

The team assessed the potential reduction in burn injuries with a two-part approach. The first part was an assessment of the risk of burns from existing gas and electric stovetops, which was completed via an analysis of data from the National Electronic Injury Surveillance System (NEISS) pertaining to burn injuries caused by electric and gas stovetops.[38] The second part was a scan of existing literature concerning the reduction in the risk of burns by installing an induction cooktop.

Table 13 shows the search engines, search terms, and the number of articles pulled from each of the search engines and search terms. Five search terms were searched on three different search engines; 15 searches in total were performed.

Table 13: Induction Stove Burn Risk Search Method

Database	Search Term	Number of Articles Pulled Based on Title
PubMed	"induction stove" AND "burn risk"	0
PubMed	"induction cooker" AND "burn risk"	0
PubMed	"induction stove" AND "burns"	1
PubMed	"induction cooktop" AND "burns"	0
PubMed	"Induction cooker" AND "burn injury"	0
Google Scholar	"induction stove" AND "burn risk"	1
Google Scholar	"induction cooker" AND "burn risk"	2
Google Scholar	"induction stove" AND "burns"	1
Google Scholar	"induction cooktop" AND "burns"	0
Google Scholar	"Induction cooker" AND "burn injury"	1
Boston College Libraries	"induction stove" AND "burn risk"	0
Boston College Libraries	"induction cooker" AND "burn risk"	2
Boston College Libraries	"induction stove" AND "burns"	2
Boston College Libraries	"induction cooktop" AND "burns"	1

[37] https://kitchenni.com/can-induction-cooktops-cause-fire/
[38] NEISS datasets can be accessed here: https://www.cpsc.gov/cgibin/NEISSQuery/home.aspx

Database	Search Term	Number of Articles Pulled Based on Title
Boston College Libraries	"Induction cooker" AND "burn injury"	0

3.3.2 Summary of Burn Risk Data

NEISS data are collected from 100 participating hospitals across the United States and are meant to serve as a nationally representative sample of injuries caused by a wide range of consumer products. The team used NEISS data from 2021, the most recent complete year of data, for this analysis. Stovetop fuel types were grouped by their equipment name in the dataset; data on induction stovetops were not collected by the NEISS for 2021.

Table 14 shows the rate of burn injuries for gas and electric stovetops per 100 hospitals in the United States, the rate of burn injuries adjusted for the number of hospitals in Massachusetts, and the rate of burn injuries per Massachusetts household. The team found that electric stovetops caused more than twice as many burn injuries as gas stovetops, representing more than 70% of all stovetop-related burns in the NEISS data. The low incidence rates overall may be the result of a lack of reporting: NEISS data are collected at hospitals, and it is likely that most burns that are not severe are treated at home and therefore not reported.

Table 14: Rate of Burn Injuries for Electric and Gas Stovetops

Injury Type	Stove Fuel Type	Total Number of Burn Incidents (per 100 hospitals, nationwide)[39]	Number of Burn Incidents per Fuel Type (per 100 hospitals, nationwide)	Percentage of Burn Incidents	MA total Incidents[40]	MA Incidents per Fuel Type	Incidents per Fuel Type per MA Household
Burn	Electric	78	55	70.5%	47.58	33.5439	0.0000122
Burn	Gas	78	23	29.5%	47.58	14.0361	0.0000051

Overall, although electric stoves cause a substantially higher number of burn injuries than gas stovetops, the severity of burns caused by gas stovetops appears to be higher. Table 15 provides a more detailed look into the severity of burn injuries caused by gas and electric stovetops, grouping the rate of burn injuries at national and Massachusetts levels by the patients' disposition at the time of treatment. For both gas and electric stovetops, patients were most commonly released from the hospital after being examined and/or treated. This occurred in 60

[39] More than half of the stoves that were reported to cause injuries in the NEISS were of an unspecified fuel type. These stoves were excluded from the analysis.
[40] NEISS data provide the rate of injuries per 100 hospitals. Massachusetts has 61 hospitals, so the team multiplied the rate of injuries by 0.61 to approximate the rate of injuries in MA. https://www.chiamass.gov/massachusetts-acute-hospital-profiles/

out of the 78 stove-caused burns in the dataset. Patients were hospitalized, or were transferred to another hospital, for equal numbers of both gas and electric stove-caused burns incidents. However, it is important to note that even though the number of burns caused by gas stoves is much lower than those caused by electric stoves, 34.8% of all burn incidents caused by gas stoves resulted in hospitalizations, compared to 14.5% of burn incidents caused by electric stoves.

Table 15: Rate of Burn Injuries for Electric and Gas Stovetops, by Patient Disposition

Injury Type	Patient Disposition	Stovetop Fuel Type	Total Number of Burn Incidents by Disposition Level (per 100 hospitals, nationwide)	Number of Burn Incidents by Disposition Level per Fuel Type (per 100 hospitals, nationwide)	Percent of Burn Incidents	MA Total Incidents	MA Incidents per Fuel and Injury Type	Incidents per Fuel Type per MA Household
Burn	Left without being seen	Electric	2	2	3.6%	1.22	1.22	0.0000 0044
Burn	Treated and admitted for hospitalization	Electric	12	6	10.9%	7.32	3.66	0.0000 0133
Burn	Treated and transferred to another hospital	Electric	4	2	3.6%	2.44	1.22	0.0000 0044
Burn	Treated/ Examined and released	Electric	60	45	81.8%	36.6	27.45	0.0000 0998
Burn	Treated and admitted for hospitalization	Gas	12	6	26.1%	7.32	3.66	0.0000 0133
Burn	Treated and transferred to another hospital	Gas	4	2	8.7%	2.44	1.22	0.0000 0044
Burn	Treated/ Examined and released	Gas	60	15	65.2%	36.6	9.15	0.0000 0333

3.3.3 Articles Reviewed

The second step in this assessment was to review literature to determine whether induction stovetops can reduce the risk of burn injuries caused by kitchen stovetops. Table 16 provides the counts of articles reviewed related to fire-related impacts. The team kept no articles because none assessed the burn risk of induction stovetops on an empirical basis.

Table 16: Number of Burn Risk-Related Articles Reviewed

Status	Number of Articles
Total number of articles pulled based on title	11
Number of articles rejected based on abstract	11
Number of articles kept and reviewed	0

3.3.4 Summary of Secondary Burn Risk Literature

Because of a lack of empirical evidence in the literature about the relative risk of burns from induction stovetops vs. traditional (resistance) electric and gas stovetops and in the NEISS data, the team does not recommend monetizing an avoided burns NEI at this point. This recommendation should be revisited since the related literature is expected to grow as the penetration of induction stovetops increases.

Overall, the literature found during the search did not uncover any clear evidence that induction stovetops reduce the risk of burn injuries. All articles made the same claim: since induction stovetops neither produce a flame nor produce heat once the cookware is removed from the cooking surface, the risk of burn injuries should be minimal.[41] [42] [43] None of the articles empirically tested this claim.

[41] https://doi.org/10.3390/su9091546
[42] https://go.gale.com/ps/i.do?p=ITOF&u=mlin_m_bostcoll&id=GALE%7CA673863958&v=2.1&it=r
[43] https://ieeexplore.ieee.org/abstract/document/9656856

Section 4 Induction Stovetops and Pacemakers

4.1 Risk of Impacts of Induction Stoves on Individuals with Pacemakers

One potential negative NEI of switching to induction stovetops is the risk that they may pose to individuals with pacemakers. Manufacturers of induction stoves publish warnings regarding the impacts their devices may have, as the magnetic fields they emit may cause electromagnetic interference (EMI) in sensitive electronics such as pacemakers.[44] The team assessed available literature on the extent to which the EMI risk of induction stoves may affect individuals with cardiac health problems (e.g., pacemakers).

4.1.1 Search Terms Used for Pacemaker Risk Literature Review

Table 17 shows the search engine databases, search terms, and the number of articles pulled from each search. Five search terms were searched on three different search engines; 15 searches in total were performed. A total of 26 articles were pulled for further review.

Table 17: Pacemakers Literature Search Method

Database	Search Term	Number of Articles Pulled Based on Title
ScienceDirect	induction cooktops pacemaker	1
	induction ovens[45] pacemaker	0
	induction cooktops cardiac health	0
	induction stove pacemaker risk	0
	induction cooktop impact on pacemaker	0
Google Scholar	induction cooktops pacemaker	5
	induction ovens pacemaker	3
	induction cooktops cardiac health	2
	induction stove pacemaker risk	5
	induction cooktop impact on pacemaker	1
Boston College Libraries	induction cooktops pacemaker	2

[44] https://products.geappliances.com/appliance/gea-support-search-content?contentId=18986

[45] The team used the search term “induction oven” to capture a broader array of studies on the impact of induction stovetops on individuals with pacemakers. These studies use the term “induction oven” in the same way as the phrase “induction cooktop” is used throughout this report.

Database	Search Term	Number of Articles Pulled Based on Title
	induction ovens pacemaker	4
	induction cooktops cardiac health	1
	induction stove pacemaker risk	1
	induction cooktop impact on pacemaker	1

4.1.2 Articles Reviewed

Table 18 includes the number of articles pulled based on the search criteria described above. The team found 26 articles during the initial literature scan, but only found eight to be relevant to pacemaker impacts and induction stoves. Brief summaries of these eight articles can be found in Appendix A, Section A.3, Table 26.

Table 18: Number of Pacemakers/ICDs-Related Articles Reviewed

Status	Number of Articles
Total number of articles pulled based on title	26
Number of articles rejected based on abstract	13
Number of articles kept and reviewed	8

4.1.3 Summary of Secondary Data

Overall, the evidence suggests that the risk posed by induction stovetops on individuals with pacemakers is minimal. In all the studies reviewed, there is no evidence of any long-term health impacts, injuries, or death caused by induction stovetops on individuals with pacemakers. The most severe consequence appears to be a temporary interruption of pacemaker service, which is quickly corrected by the pacemaker itself. One study which was referenced by most of the other studies developed a specific "worst case scenario" for induction stovetop impacts: the pacemaker is of the unipolar, left-sided variety; the individual stands as close as possible to induction stovetop (closer than 34 cm); the cookware is not concentric with the induction coil; the individual touches the pot for long period of time; metal cooking utensils are used for a long period of time; finally, the individual is not pacemaker-dependent.[63] [46]

These similar criteria are echoed in the studies where researchers were able to affect a pacemaker with an induction stovetop. Most of the studies found that only in extreme or unrealistic situations could they cause any interruptions in pacemaker operations. Induction stovetops were also found to be safer than other common devices that emit magnetic fields, such as welding machines and EAS gates, which are commonly found at retail stores. One important note about these articles is that many were written more than a decade ago, so they do not account for any

[46] Irnich and Bernstein, "Do Induction Cooktops Interfere with Cardiac Pacemakers?," 383.

potential technological developments that may have been made to advance protecting pacemaker patients from EMI.[47]

The team does not recommend monetizing the risk of induction stovetops on individuals with pacemakers. There is no clear pathway to monetize these potential negative impacts given the evidence that the risk posed by induction stovetops on individuals with pacemakers is minimal.

[47] Currently, pacemakers are constructed to minimize the risk of EMI. Pacemaker implants are encased in a metallic can which protects them from high-frequency electromagnetic radiation above 10 kHz. The induction stove studies reviewed by the team all estimated induction cooking frequencies to lie within the 15-50 kHz range, meaning that pacemakers encased in metal cans should be protected from EMI.
https://academic.oup.com/eurheartj/article/36/28/1798/2398060?login=true

Section 5 Methane Leaks

Methane (CH_4), which is the primary component of natural gas, is a very potent greenhouse gas (GHG) – up to 84 times more powerful than carbon dioxide (CO_2) in the first 20 years it is released into the atmosphere. Natural gas stovetops in homes can release methane through post-meter leaks and incomplete combustion. **Recent research found that natural gas stoves (i.e., stovetops and ovens combined) emit 0.8 − 1.3% of the gas they use as unburned methane and more than three-quarters of methane emissions the study measured originated while the stove was shut off.**[48] The study estimated that an average natural gas stove emitted 649 grams of CH_4 per year. Excluding the methane emissions associated with ovens, which was 11% of total emissions from stoves measured in the study, an average natural gas stovetop would emit 577 grams of CH_4 per year.

The social cost of CH_4 is not as well established as the social cost of CO_2 in the literature. It is common to estimate the social costs of non-CO_2 GHGs by multiplying their global warming potential (GWP) for a given time horizon (often 100 years) by the social cost of CO_2. This approach, however, mischaracterizes the relationship between the time a specific greenhouse gas stays in the atmosphere and the time profile of discounted future damages. In February 2021, the federal government's Interagency Working Group (IWG) on the Social Cost of Greenhouse Gases provided updated values and technical guidance on the social cost of carbon, methane, and nitrous oxides.[49] The social cost of methane is an estimate of the economic costs, or damages, of emitting one additional ton of methane into the atmosphere, and thus the benefits of reducing methane emissions. Since these economic costs from emissions are the total costs borne globally, not just locally, monetizing the emissions reduction impacts using the social cost of methane would capture the total societal impacts. For the 2022 – 2024 Three-Year Plan, the Department of Public Utilities (DPU) directed the Massachusetts Program Administrators to calculate the BCR for each measure with and without the societal value of GHG emissions reductions in the BCR screening model.[50]

The societal impacts associated with GHGs are out of scope for the NEI studies because they are being covered as part of the AESC 2021 Study.[51] Therefore, the team does not recommend monetizing avoided GHG emissions as part of this study. However, the team quantified and documented methane emissions associated with gas stoves here because the team believes that the AESC study did not account for such emissions.[52] The team recommends that PAs include

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[48] Eric D. Lebel, Colin J. Finnegan, Zutao Ouyang, and Robert B. Jackson. "Methane and NOx Emissions from Natural Gas Stoves, Cooktops, and Ovens in Residential Homes." Environmental Science & Technology 2022 56 (4), 2529-2539 DOI: 10.1021/acs.est.1c04707

[49] https://www.whitehouse.gov/wp-content/uploads/2021/02/TechnicalSupportDocument_SocialCostofCarbonMethaneNitrousOxide.pdf

[50] D.P.U. 20-150-A at 7 n.6. https://www.mass.gov/doc/dpu-20-150-a-order-approving-revised-energy-efficiency-guidelines/download

[51] https://www.synapse-energy.com/project/aesc-2021-materials

[52] Footnote 221 on page 185 of the 2021 AESC notes that the study excludes emissions from pipeline leaks. The team believes that the AESC similarity ignores leaks from gas stoves.

the uncombusted methane emissions from stovetops in future studies involving societal impacts from GHG emissions.

As presented in the IAQ section, a recent study[53] documented the presence of VOCs, including benzene, a known carcinogen,[54] in natural gas at the point of end use. By using previous natural gas leakage data, the authors estimated that 120 – 356 kg of annual natural gas benzene emissions throughout Greater Boston are not currently accounted for in emissions inventories, along with an unaccounted-for indoor portion. This implies that indoor natural gas leakage is a source of not only CH_4 but also associated VOCs, with potential health impacts for occupants.

We also ignore emission reductions associated with pipeline leakage, as these emissions are not considered elsewhere in the AESC study.
https://www.synapse-energy.com/sites/default/files/AESC%202021_20-068.pdf

[53] Drew R. Michanowicz, Archana Dayalu, Curtis L. Nordgaard, Jonathan J. Buonocore, Molly W. Fairchild, Robert Ackley, Jessica E. Schiff, Abbie Liu, Nathan G. Phillips, Audrey Schulman, Zeyneb Magavi, and John D. Spengler "Home is Where the Pipeline Ends: Characterization of Volatile Organic Compounds Present in Natural Gas at the Point of the Residential End User." Environmental Science & Technology 2022 56 (14), 10258-10268
DOI: 10.1021/acs.est.1c08298

[54] https://emergency.cdc.gov/agent/benzene/basics/facts.asp#:~:text=The%20Department%20of%20Health%20and,of%20the%20blood%2Dforming%20organs.

Section 6 Incremental Costs

The team also explored other costs associated with installing induction stovetops that may be incurred by participants. These include costs associated with upgrades to electrical equipment, frequency of repairs, and costs for repairs.

The team is currently conducting targeted web research and reviewing literature to estimate average costs of purchasing new cookware for induction stovetops and to estimate the percentage of households that also need to purchase new cookware because their existing cookware is not compatible with induction stovetops (Task 2). The findings from this cookware cost research will be incorporated into the final study report.

6.1 Operating and Maintenance Costs

Ultimately, the team did not uncover evidence on the frequency of repairs and maintenance and the associated costs for induction stovetops. The team reviewed secondary data for information on the frequency with which induction stovetops need repair and receive maintenance, and the associated costs, to compare to propane and gas stovetops. This included a review of five technical resource manuals (TRMs) to search for information on the operation and maintenance costs of induction stovetops (Table 19).[55,56,57,58,59] The team scanned the articles that were reviewed for the other NEIs presented in this report for information on repair frequencies, costs, and details on electrical system upgrades. In addition, the team conducted a limited search to identify articles that documented the frequency in which induction stovetops need repair.

Table 19: TRM Review of Induction Stove Measures

TRM	Induction Cooktop Measure	Operation and Maintenance Costs	Additional Cost Information
Massachusetts	Yes, for replacement of propane stovetops	N/A	$681 incremental cost above a gas/propane stovetop and a $992 incremental cost above an electric resistance stovetop
Vermont	Yes, fossil fuel stovetops only	N/A	Measure Costs: $115 to $1,844, averaging $594; assumes full retrofit cost

[55] Massachusetts 2022-2024 TRM. https://fileservice.eea.comacloud.net/FileService.Api/file/FileRoom/14154670
[56] Illinois TRM Version 11.0 (Draft). https://ilsag.s3.amazonaws.com/IL-TRM_Effective_010123_v11.0_Vol_3_Res_06242022_DRAFT.docx
[57] Vermont Act 56 Tier III Technical Advisory Group 2021 Annual Report. Submitted to the Public Utility Commission on behalf of the Technical Advisory Group by VEIC.
[58] New York Version 9.0 TRM. https://www3.dps.ny.gov/W/PSCWeb.nsf/96f0fec0b45a3c6485257688006a701a/72c23decff52920a85257f1100671bdd/$FILE/NYS%20TRM%20V9.pdf
[59] Pennsylvania Phase IV TRM, Volume 2: Residential Measures. https://www.puc.pa.gov/pcdocs/1692531.docx

TRM	Induction Cooktop Measure	Operation and Maintenance Costs	Additional Cost Information
Illinois	Yes, replacement for electric, natural gas, and propane	N/A	Incremental equipment cost: $1,200 Estimated labor (electric baseline): $100 for increase power requirements. Estimated labor (gas baseline): $200, includes capping gas line.
New York	N/A	N/A	N/A
Pennsylvania	N/A	N/A	N/A

6.2 Costs of Electrical Upgrades for Induction Stovetop Installation

The cost associated with upgrading electrical capacity in homes that install induction stovetops should be treated as an incremental cost rather than an NEI. The team looked for evidence on the rate at which homes need electric upgrades to enable installing an induction cooktop, and any costs associated with these upgrades. The evidence base suggests that some homes may not have the power requirements to install an induction stovetop without electrical upgrades. However, the team did not find evidence of how frequently these upgrades are required for installing induction stovetops. In addition, there are some instances of online sources, such as media articles and technology blogs, that provide anecdotal details on the costs of upgrading the electric system for installing induction stovetops, but the team was unable to find any academic research or evaluations that systematically detailed either costs or frequencies of electric upgrades. The Illinois TRM includes $100 for additional labor to upgrade electrical power requirements and $200 additional labor to convert gas stovetops to electrical, including capping off the gas line; however, the TRM notes that these values are estimated. It should be noted that many existing homes will require electric panel upgrades for heat pumps or EV charging as electrification becomes more widespread, so the cost for electrical panel upgrades for induction cooking is not an isolated incremental cost.

The PAs could consider collecting data from initial program participants to determine the frequency with which electric upgrades are required and the costs associated with these upgrades to inform incremental costs. This could inform whether these electric upgrades are more common in certain baseline scenarios (i.e., replacing gas stovetop vs. electric resistance stovetops with induction stovetops).

Section 7 Recommendations

Recommendation. The team recommends applying on an interim basis the NEI values detailed in Table 20 to induction stovetops that replace propane or natural gas stovetops. The values we recommend are based on adjustments to NEI values that were originally developed in the RNC NEI Quick Hit Assessment study for electric stoves (both stovetop and ovens). The team adjusted them to reflect the values for stovetops only and made several other adjustments to incorporate the new data sources identified, as discussed in Section 2.1.

Table 20: Asthma-Related NEIs from Replacing Propane or Natural Gas Stovetops with Induction Stovetops in Existing Homes (2020 $)

Non-Energy Impact	Value Suggested
Childhood asthma prevention, occupant lifetime	$4.73 per home per year
Childhood asthma symptom reduction	$51.45 per home per year
Adult asthma symptom reduction	$49.77 per home per year
Total	**$105.95per home per year**

Appendix A Literature Review Summaries

A.1 Indoor Air Quality

The reviewed articles are summarized in four tables reflecting the four relationships or pathways explored in Section 1.2. Table 21 summarizes articles related to non-asthma health impacts. The team acknowledges that some articles in the table are older and therefore we included publication years for reference. However, these articles provide important lines of evidence.

Table 21: Articles that Studied Links from Gas Stoves to Non-Asthma Health

Article	Gas Stove Risk-Related Summary
A Cross Sectional Analysis of Behaviors Related to Operating Gas Stoves and Pneumonia in U.S. Children Under the Age Of Five (2015) [9][60]	The article examined the respiratory health impacts of ventilation when using a gas stove for cooking or for heating. The study used ventilated gas cooking as the baseline or reference point but did not examine ventilated gas cooking compared to electric or induction cooking. Compared to ventilated gas cooking, unventilated gas cooking did not significantly increase the odds of bronchitis or cough, while unventilated use of either the gas stovetop or oven for heating was associated with higher odds of both cough and bronchitis.
Air Pollution and Infection in Respiratory Illness (2003) [7]	This review article summarized multiple studies. One found that the presence of a gas stove in the home appeared to increase the risk of wheezing bronchitis for children, specifically girls but not boys. Another study indicated that gas stoves were associated with lower respiratory tract symptoms (odds ratio (OR) = 1.23).
Association of Early-life Exposure to Household Gas Appliances and Indoor Nitrogen Dioxide With Cognition and Attention Behavior in Preschoolers (2009) [38]	Both the use of gas appliances and increases in NO_2 concentrations were associated with lower outcomes for general cognition and inattention symptoms. The abstract and results include extensive details on the beta coefficients and odds ratios for these risks.
Impact of Environmental Factors on Lung Defences (2005) [43]	This review article summarized multiple studies. One study found that children exposed to a long- term increase in NO_2 equivalent to having a gas cooker had a 29% increase in their risk of respiratory illness. A second study demonstrated that hospital admissions for asthma and COPD increased by 1.0% per 10 $\mu g\ m^{-3}$ PM_{10}, though gas stoves typically emit $PM_{2.5}$ or smaller.
Indoor Air Pollution Sources and Respiratory Symptoms in Bronchopulmonary Dysplasia (2020) [47]	Gas stoves were not studied separately from other sources of combustion in the home, but the presence of at least one combustion source was associated with increased hospitalizations for infants with Bronchopulmonary Dysplasia on home respiratory support ($p = 0.04$) and possibly for those infants with Bronchopulmonary Dysplasia but not on home respiratory support ($p = 0.06$). Gas stoves were present in 50.2% of homes.

[60] Numbers in brackets refer to the corresponding article citation in "References" section (Appendix D).

Article	Gas Stove Risk-Related Summary
Inflammatory Markers and Lung Function in Relation to Indoor and Ambient Air Pollution (2022) [33]	The article indicated that forced expiratory volume (FEV1) declined with exposure to NO_2, (−0,83% per 10 µg/m^3) and to gas cookers without hoods (−0.89%). FEV1 is a common clinical measurement of respiratory health; for people with asthma or COPD, FEV1 can be correlated with disease severity and mortality.
Prenatal Exposure to Cooking Gas and Respiratory Health in Infants is Modified by Tobacco Smoke Exposure and Diet in the INMA Birth Cohort Study (2013) [14]	Prenatal exposure to gas cooking in homes was not associated with lower respiratory tract infection (LRTI), wheezing, persistent cough, chestiness or otitis for infants.
Respiratory Symptoms in Older People and Use of Domestic Gas Appliances (1999) [13]	Only weak and non-significant associations were found with use of gas appliances and exercise induced breathlessness, wheeze, or chest tightness; wheeze; morning phlegm; and daytime breathlessness at rest. The risks associated with use of a gas hob tended to be higher in women; the odds ratio for wheeze was small but statistically significant while morning chest tightness was not statistically significant.
The Prevalence of Respiratory Symptoms in South Australian Preschool children. II. Factors Associated with Indoor Air Quality (1995) [54]	The article found that having a natural gas stove compared to an electric stove was significantly associated with increased prevalence rates in preschool children for: "(i) asthma (odds ratio [OR] 1.24); (ii) wheezing in the preceding 12 months (OR 1.16); excessive colds (OR 1.14); and hay fever (OR 1.13)."

Table 22 summarizes the literature on emissions rates, indoor pollutant concentrations, and personal exposures resulting from the use of gas stoves.

Table 22: Articles that Studied Links from Gas Stoves to IAP

Article	Gas Stove Risk-Related Summary
24-h Nitrogen Dioxide Concentration is Associated with Cooking Behaviors and an Increase in Rescue Medication Use in Children with Asthma (2017) [45]	"Each hour of kitchen appliance use was associated with an 18 ppb increase in 24-h NO_2 concentration."
Compilation of Published PM2.5 Emission Rates for Cooking, Candles and Incense for Use in	"The goal of this study was to produce a database of pollutant emission rates associated with cooking and the burning of candles and incense." Table 3 reports average $PM_{2.5}$ emission rates for gas (3.8E+04 mg/hr) versus electric (1.1E+04 mg/hr) ranges/ovens.

Article	Gas Stove Risk-Related Summary
Modeling of Exposures in Residences (2012) [23]	
Contribution of Gas and Electric Stoves to Residential Ultrafine Particle Concentrations Between 2 and 64 nm: Size Distributions and Emission and Coagulation Rates (2008) [56]	Boiling water on gas stoves resulted in peak concentrations of ultrafine particles (UFP) ranging from 430,000 to 680,000 particles/cm^3 in the kitchen and 27,000 to 47,000 particles/cm^3 in the master bedroom.
Contribution of Solid Fuel, Gas Combustion or Tobacco Smoke to Indoor Air Pollutant Concentrations in Irish and Scottish Homes (2012) [49]	The geometric mean of the 24-hour time-weighted-average $PM_{2.5}$ concentration in homes with gas cookers was 7 µg/m^3. The article additionally notes, "Airborne endotoxin, CO, CO_2 and NO_2 concentrations were generally within indoor air quality guidance levels."
Gas Stoves: Health and Air Quality Impacts and Solutions (2020) [16]	Exhibit 1 outlines the types of pollutants emitted by gas stoves and notes, "Although cooking food emits $PM_{2.5}$, tests show $PM_{2.5}$ emissions from gas stoves can be two times higher than from electric stoves."
Home Interventions are Effective at Decreasing Indoor Nitrogen Dioxide Concentrations (2014) [44]	"[Gas] stove replacement resulted in a 51% and 42% decrease in median NO_2 concentration at 3 months of follow-up in the kitchen and bedroom, respectively (P = 0.01, P = 0.01)." The article also notes that installing a ventilation hood did not significantly change NO_2 concentrations in the kitchen and bedroom.
Home is Where the Pipeline Ends: Characterization of Volatile Organic Compounds Present in Natural Gas at the Point of the Residential End User (2022) [37]	"Results revealed 296 unique nonmethane volatile organic compounds (NMVOC) constituents in end use [natural gas] of which 21 (or approximately 7%) were designated as hazardous air pollutants… Natural gas odorant content (tert-butyl mercaptan and isopropyl mercaptan) was used to estimate that a mean NG-CH_4 concentration of 21.3 (95% CI: 16.7–25.9) parts per million by volume (ppmv) could persist undetected in ambient air given known odor detection thresholds. This implies that indoor natural gas leakage may be an underappreciated source of both CH_4 and associated VOCs." Further study is needed to assess whether the hazardous air pollutants discovered in the end-use natural gas were concentrated enough to produce adverse health effects.
Indoor Exposure to Selected Air Pollutants in the Home Environment: A Systematic Review (2020) [25]	This article summarizes results from multiple studies. Highlights are quoted below. Additionally, the article notes the World Health Order (WHO) guidelines for acute and chronic NO_2 exposure are 200 µg/m^3 and 40 µg/m^3, respectively.

Article	Gas Stove Risk-Related Summary
	"NO_2 concentrations were higher in all rooms in houses in the UK [58] and Germany [59] where gas cookers were used. NO_2 levels in kitchens with a gas cooker in the UK were twice as high as in those with an electric cooker during winter [58]. Nitrogen oxides (NO_x) and NO_2 were higher in homes with cooktop pilot burners, relative to gas cooking without pilots. In homes in California, USA, where residents cooked 4 hours or more per day with gas, self-reported use of kitchen exhaust fans was associated with lower NOx and NO_2 exposure [60]." "Overall, the most important predictors of indoor NO_2 concentrations were gas cooker use, followed by ventilation and outdoor NO_2 levels." "Relatively high CO concentrations (max 8 hour mean 2.5 mg/m3) were recorded in kitchens with gas cookers in California, USA [60]."
Indoor $PM_{2.5}$ Characteristics and CO Concentration Related to Water-Based and Oil-Based Cooking Emissions Using a Gas Stove (2011) [24]	The article measured $PM_{2.5}$ and CO emissions from cooking tofu or chicken on a gas stove. Table 1 reports the resulting $PM_{2.5}$ indoor concentrations and indoor-outdoor ratios. Figure 5 shows the temporal variation in $PM_{2.5}$ throughout the cooking period. Table 2 summarizes the relationship between $PM_{2.5}$ in the kitchen and concentrations in an adjoining room. Figure 7 summarizes the CO concentrations during cooking.
Investigating Measurements of Fine Particle ($PM_{2.5}$) Emissions from the Cooking of Meals and Mitigating Exposure Using a Cooker Hood (2019) [42]	$PM_{2.5}$ emission rates for a gas stove were measured while cooking four different meals. "Mean emission rates and source strengths varied between 0.54-3.7 mg/min and 15-68 mg, respectively, with 95% confidence. Using a cooker hood (apparent capture efficiency > 90%) and frying in non-stick pans were found to significantly reduce emissions."
Methane and NO_x Emissions from Natural Gas Stoves, Cooktops, and Ovens in Residential Homes	NO_x (NO and NO_2) emissions were linearly related to the amount of natural gas burned. Emissions averaged 21.7 ng NOx J^{-1}, comprised of 7.8 ng NO_2 J^{-1} and 14.0 ng NO J^{-1}. Without a range hood, NO_2 concentrations can surpass the 1-hour national standard (100 ppb) within a few minutes of stove usage.
Particle Exposures and Infections (2014) [31]	The article notes that particulate matter concentrations from gas cooking have been found to be as high as 380 mg /m^3 but are usually lower. It places the particle burden in the tens of mg/m^3.
Personal Exposure to Ultrafine Particles (2011) [55]	The article measured personal exposure to particulate matter from a number of sources and found cooking on a gas stove to be one of the greatest sources of UFP. Tables 1 and 2 summarize concentrations and emission rates in a laboratory setting, while Table 3 summarizes the personal exposures recorded in California homes.
Pollutant Exposures from Natural Gas Cooking Burners: A Simulation-	"The simulation model estimated that--in homes using natural gas cooking burners (NGCBs) without coincident use of venting range hoods--62%, 9%, and 53% of occupants are routinely exposed to NO_2, CO, and HCHO

Article	Gas Stove Risk-Related Summary
Based Assessment for Southern California (2014) [35]	(formaldehyde) levels that exceed acute health-based standards and guidelines. NGCB use increased the sample median of the highest simulated 1-hour indoor concentrations by 100, 3,000, and 20 ppb for NO_2, CO, and HCHO, respectively."
Predictors of Concentrations of Nitrogen Dioxide, Fine Particulate Matter, and Particle Constituents Inside of Lower Socioeconomic Status Urban Homes (2007) [3]	In a sample of low socioeconomic status homes in Boston, cooking with a gas stove was found to increase indoor NO_2 by 5.7 ppb.
Results of the California Healthy Homes Indoor Air Quality Study of 2011–2013: impact of natural gas appliances on air pollutant concentrations (2016) [40]	The article indicates that cooking with a gas stove elevated peak 1-hour CO concentration in the kitchen by 3.1 ppm compared an electric stove. Indoor-attributed bedroom NOx increased 31.4 ppb, and indoor-attributed bedroom NO_2 increased 6.2 ppb on average.
The Benefit of Kitchen Exhaust Fan Use After Cooking - An Experimental Assessment (2018) [12]	This article provides extensive data on UFP, $PM_{2.5}$, NO and NO_2 concentrations in the kitchen before, during and after cooking with a gas stove under various types of ventilation (or lack thereof).

No literature was found linking gas stoves directly to premature death or cardiovascular disease (CVD), which is one of the primary causes of premature death associated with air pollution. Therefore, Table 23 below summarizes the literature linking air pollutants to premature death and cardiovascular which may be used in conjunction with the articles above detailing emission rates and pollutant concentrations associated with gas stoves.

Table 23: Articles that Studied Links from Air Pollution to Premature Death

Article	Gas Stove Risk-Related Summary
A Framework for Estimating the US Mortality Burden of Fine Particulate Matter Exposure Attributable to Indoor and Outdoor Microenvironments (2020) [2]	The article estimated that U.S. mortality associated with total $PM_{2.5}$ exposure in the year 2012 ranged from ~230,000 to ~300,000 deaths. Residential exposure to indoor $PM_{2.5}$ sources was one of the greatest contributors to mortality, accounting for an estimated 19-37% of the deaths (see page 277). The article estimates that ~72,000 premature deaths in the U.S. were due to residential exposure to indoor sources of $PM_{2.5}$. In a second scenario, the article estimates 5,500 premature deaths in New England specifically due to residential exposure to indoor sources of $PM_{2.5}$.

Article	Gas Stove Risk-Related Summary
Air Pollution and Mortality in the Medicare Population (2017) [10]	"Increases of 10 µg per cubic meter in $PM_{2.5}$ were associated with increases in all-cause mortality of 7.3% (95% confidence interval [CI], 7.1 to 7.5) and 1.1% (95% CI, 1.0 to 1.2), respectively. When the analysis was restricted to person-years with exposure to $PM_{2.5}$ of less than 12 µg per cubic meter and ozone of less than 50 ppb, the same increases in $PM_{2.5}$ and ozone were associated with increases in the risk of death of 13.6% (95% CI, 13.1 to 14.1) and 1.0% (95% CI, 0.9 to 1.1), respectively. For $PM_{2.5}$, the risk of death among men, blacks, and people with Medicaid eligibility was higher than that in the rest of the population."
Health and Climate Benefits of Cookstove Replacement Options (2011) [19]	This article indicates that the mortality dose–response for $PM_{2.5}$ can be modeled as a linear relationship when considering only ambient concentrations of ~5 to ~30 µg m^{-3}. The article presents a methodology that may be useful for estimating the health and mortality impacts of replacing gas stoves.
Low Concentrations of Fine Particle Air Pollution And Mortality in the Canadian Community Health Survey Cohort (2019) [8]	The article reports similar findings to the above for low ambient concentrations of $PM_{2.5}$ in the 0 to 20 µg m^{-3} range, though it finds the relationship may be somewhat supralinear[61] (a gently curved line where the interior of the curve faces down and to the right) rather than purely linear.
Nitrogen Dioxide and Mortality: Review and Meta-Analysis of Long-Term Studies (2014) [15]	The article found that an increase of 10 µg·m^{-3} in annual, ambient NO_2 concentration was associated with a risk ratio of 1.04 for all-cause mortality. The same increase in PM2.5 was associated with a 1.05 risk ratio for all-cause mortality. The effect on cardiovascular mortality was 1.13 for NO_2 and 1.20 for $PM_{2.5}$. The effect on respiratory mortality was 1.03 for NO_2 and 1.05 for $PM_{2.5}$.
Particulate Matter Air Pollution and Cardiovascular Disease (2010) [6]	The article reviewed all new literature since the previous version of the report and found strong evidence for a link between $PM_{2.5}$ and cardiovascular morbidity and mortality for exposures as short as a few days or as long as years. Reductions in ambient $PM_{2.5}$ can lower mortality rates within the timeframe of a few years. The article notes, "Time-series studies estimate that a 10-g/m3 increase in mean 24-hour $PM_{2.5}$ concentration increases the relative risk (RR) for daily cardiovascular mortality by approximately 0.4% to 1.0%... A 10-g/m3 increase during the preceding day contributes on average to the premature death of approximately 1 susceptible person per day in a region of 5 million people (based on annual US death rates in 2005)."
Particulate Matter Air Pollution: Effects on the Cardiovascular System (2018) [20]	The article reviews epidemiology on outdoor particulate matter. The studies reviewed indicated that a 10 µg/cm3 increase in $PM_{2.5}$ concentration was associated with a 1.04% increase in all-cause mortality
Pollution and the Heart (2022) [46]	The article confirms that the relationship between $PM_{2.5}$ and mortality is linear at low concentrations and begins to flatten out at higher concentrations. Other findings are quoted below.

[61] https://www.briangwilliams.us/nuclear-energy-3/the-shape-of-the-doseresponse-curve-alternative-models.html

Article	Gas Stove Risk-Related Summary
	"Short-term variation in $PM_{2.5}$ levels (from hours to days) is associated with increased risks of myocardial infarction, stroke, and death from cardiovascular disease. The risk of these events increases by 0.1 to 1.0% for each short-term increment of 10 µg per cubic millimeter in the $PM_{2.5}$ level. In some analyses, dose-related increases in risk have also been reported with NO_x and sulfur oxides." "Globally, airborne $PM_{2.5}$ pollution is estimated to contribute to about 3.2 million incident cases of diabetes each year and to 196,792 deaths from diabetes."
Premature Adult Death and Equity Impact of a Reduction of NO2, PM10, and PM2.5 Levels in Paris—A Health Impact Assessment Study Conducted at the Census Block Level (2019) [29]	The article uses published hazard ratios to quantify the risk of premature death due to ambient NO_2 and $PM_{2.5}$ for ten different levels of socioeconomic status. Hazard ratios ranged from 1.36 – 1.013 for NO_2 and 1.05 – 1.018 for $PM_{2.5,}$ with lower socioeconomic status communities generally at higher risk. The article estimates that between 17.5-48.9 deaths per 100,000 can be attributed to ambient NO_2 while 17.2-54.0 deaths per 100,000 can be attributed to ambient $PM_{2.5}$, depending on socioeconomic status.

Table 24 summarizes literature that links air pollutant to health effects other than premature death, such as non-asthma respiratory health, cardiovascular disease, and ADHD.

Table 24: Articles that Studied Links from Air Pollution to Other Non-Asthma Health Impacts

Article	Gas Stove Risk-Related Summary
Air Pollution and Infection In Respiratory Illness (2003) [7]	The authors of this article performed a systematic review of literature on air pollution and respiratory illness. One study examined specifically short-term indoor NO_2 exposures at school and in the home and found that "exposure to NO_2 at hourly peak levels of the order of <160 µg/m3 compared with background levels of 40 $\mu g/m^3$ was associated with a significant increase in sore throat, colds and absences from school, although infection was not confirmed" and that "significant dose–response relationships were demonstrated for these four measures with increasing levels of NO2 exposure." A second study found that "an increase in daily maximum 1-hour concentration of NO_2 and particulate [matter] was associated with a 4.60% and 3.01% increase, respectively in admissions for COPD in Sydney."
Association Between Ambient Gaseous and Particulate Air Pollutants and Attention Deficit Hyperactivity Disorder (ADHD) in Children; A Systematic Review (2019) [1]	This systematic review of literature on air pollution and risk of ADHD found an association between particulate matter and incidence of ADHD. The article notes, "The number of studies reporting an association between air pollution and increased risk of ADHD is relatively higher compared to the number of studies reporting no association. However, the findings of the studies provided limited evidence to support the idea that exposure to air pollution may be linked to increased risk of ADHD."
Association of Early-life Exposure to Household Gas Appliances and Indoor Nitrogen Dioxide With Cognition and	Both the use of gas appliances and increases in NO_2 concentrations were associated with lower outcomes for general cognition and inattention symptoms. The abstract and results include extensive details on the beta coefficients and odds ratios for these risks.

Article	Gas Stove Risk-Related Summary
Attention Behavior in Preschoolers (2009) [38]	
Indoor Air Pollution, Related Human Diseases, and Recent Trends in the Control and Improvement of Indoor Air Quality (2020) [52]	The article provides a broad overview of indoor air pollutants and their impacts on health, including respiratory infection, pulmonary diseases (including COPD and lung cancer), and cardiovascular diseases. However, it does not provide specific measures of risk. With more time, following up on some of the references and footnotes included could lead to additional helpful details on respiratory health and cardiovascular disease. The article notes, "Exposure to $PM_{2.5}$ increases the incidences of specific acute CVDs, such as ischemic stroke, myocardial infarction, cardiac arrhythmia, heart failure, and atrial fibrillation."
Indoor Particulate Matter (2014) [53]	The article notes, "Exposure to inhalable particles can affect both your lungs and your heart… People with heart or lung diseases such as coronary artery disease, congestive heart failure, and asthma or chronic obstructive pulmonary disease (COPD), children and older adults may be at greater risk from PM exposure."
Pulmonary, Inflammatory, and Oxidative Effects of Indoor Nitrogen Dioxide Exposure in Veterans with Chronic Obstructive Pulmonary Disease (COPD) (2021) [36]	In a study in the homes of 144 patients with COPD, the median concentration of indoor NO_2 was found to be 9.4 ppb. The article found a potential association between indoor NO_2 and reductions in FEV1 and FVC – two indicators of disease severity and mortality risk -- in patients with more severe COPD.
The Health Effects of Nonindustrial Indoor Air Pollution (2008) [4]	The article reviewed literature on indoor air pollution and health and found associations between particulate matter and respiratory infections. Aside from the well-established relationships between NO_2 and asthma, the evidence linking NO_2 to other respiratory outcomes was weaker but indicated certain vulnerable populations may be at higher risk, including adult women and children who already have asthma.
WHO Guidelines for Indoor Air Quality: Selected Pollutants [57]	These guidelines present a "comprehensive review and evaluation of the accumulated scientific evidence by a multidisciplinary group of experts studying the toxic properties and health effects of these pollutants." The guidelines cover health impacts of indoor NO_2 and CO at different concentrations and for differing populations. The guidelines further present summaries of what is known about the level of health risks and exposure-response relationships, though they lack exact specifications for quantifying many of the risks and responses.

A.2 Fire Risk

The team kept articles if researchers collected evidence about induction stovetop fire hazards from experimental results, or if the enhancements to home fire safety resulting from induction stovetops were assessed empirically. The team rejected articles if they only provided anecdotal evidence supporting their conclusions (i.e., if they concluded without presenting evidence that induction stovetops are safer than gas or electric stovetops because they do not have an open flame, nor do they emit heat without a piece of cookware resting on top). However, many of the articles we reviewed tested this assumption as part of their experimental process. Table 25 summarizes articles related to the unique fire risks of induction stovetops.

Table 25: Articles that Studied Induction Stovetop Fire Risks

Article	Fire Risk-Related Summary
Home Cooking Fire Mitigation: Technology Assessment. Final Report [11]	Fire Protection Effectiveness (FPE), cost effectiveness, and cooking performance were assessed using a set of equations and methods found in Section 6 of the article. For both electric and gas stove fires, fire prevention strategies reduced 90% of fire losses (Tables 8 and 9). Induction stoves fall within this category. However, they contributed very little to the reduction in fire losses. Results pertaining to induction stoves are shown in Figures 22 and 23. Induction stoves prevent some deaths due to home fires, but do not have a substantial impact on the number of incidents, the number of injuries, and the amount of property damage from home fires. This report uses NFIRS fire data, and the FPE equations to provide a hypothetical analysis of fire prevention performance.
Will the Induction Cooktops Wipe Out Kitchen Fires? [22]	In this blog post, the author argues that induction stoves can make a substantial impact on reducing the number of kitchen stove fires in Finland. The author uses data from the Finnish fire statistics resource to demonstrate the risk of kitchen fires in the country. To show the potential impact of reducing these fires, the author uses one year of induction stove sales data to estimate how quickly older stove types are being replaced by induction stoves. However, the evidence used to suggest that induction stoves are safer than other stove types is anecdotal.
Thermal Characterization of Electric Stoves [27]	Three different types of stovetops (electric coil, electric ceramic, and induction) as well as four different types of cookware (cast iron, carbon steel, aluminum, and an oven tray made from aluminum) were assessed in terms of their maximum temperatures, time to reach these temperatures, and time to cool from these temperatures. All three stoves and all four pan types can reach temperatures exceeding the autoignition temperatures of common cooking oils and solid materials found in kitchens, such as cardboard and paper towels. The danger from induction stoves is that they can heat oil up much more quickly than typical electric stoves, bringing the oil to the flash and flame points more quickly. The article estimates that 22% of new stovetops purchased in the US in 2018 were induction stovetops. However, the data source for this information is behind a paywall. This study suggests that although induction stovetops are safer than electric stovetops when there is not a pot/pan on them because they need to induce the heat, induction stovetops heat up cooking oils in significantly less time when compared

Article	Fire Risk-Related Summary
	to electric stovetops. The tests were not run with any of the oils or other materials in/near the pans.
Introduction of Induction Heating Is Too Late for Older Residents with Difficulty in Handling Fire [28]	Participants were divided into three groups: Healthy (no dementia), CDR 0.5 (slight dementia), and CDR 1+ (dementia). All participants were instructed to boil a kettle of water on an induction stove. If a participant was unable to perform the task, help was provided. Only 15% of the healthy group, 8% of the CDR .5 group, and none of the CDR 1+ group could operate the induction stovetop on their own. When asked, 40% of participants claimed that the stovetop was easy or very easy to use and most participants claimed that they would be comfortable using the device once they took the time to learn how to use it. However, participant concerns included not knowing when the stove was on, not being able to understand how the controls worked, a preference for physical knobs, buttons, and switches over capacitive touch controls, and not being able to distinguish between the various displays.
Experimental Study of Induction Cooker Fire Hazard [30]	The authors explain how induction cookers work, explore the variety of induction stoves available on the market, and assess several properties of induction-compatible cookware, including thermal efficiency, the different patterns on the bottom of cookware, and the temperatures at which different cooking oils can combust. Next, the authors ran an experimental study to test whether induction stoves can heat cooking oil to the oil's smoke point and ignition temperatures, and whether the stoves' safety mechanisms would be able to prevent a fire from occurring. The authors found that induction stove safety devices did not activate until long after the cooking oil was heated to its autoignition temperature. Additionally, the authors found that poor thermal conductivity between the pan and the surface of the stove may not activate the safety systems in time, leading to increased fire risk.
Fire Hazards of Introducing Water and Ice Into Hot Oil in Open Kitchen [34]	This study assessed the grease fire hazards of cooking with an induction stove. In one group of tests, cooking oil was heated until it reached its autoignition temperature, and water and ice were added, resulting in a large explosion. In a second group of tests, cooking oil was heated to a temperature below the autoignition temperature, and when water and ice were added, no fire occurred. Currently, this article is locked, so the study aim and conclusions are unknown.

A.3 INDUCTION STOVETOPS AND PACEMAKERS

The team included articles if they provided empirical evidence from experiments that tested the EMI risk of induction stovetops on individuals with pacemakers or implantable cardioverter-defibrillators (ICDs). The team rejected articles if a different source of electromagnetic interference (EMI) other than induction stoves was studied, if the analysis relied on anecdotal evidence, or if article simply referenced another paper's work without conducting new research. Table 26 summarizes

Table 26: Articles that Studied Pacemaker/ICD Impact

Article	Pacemakers/ICD-Related Summary
Induction Ovens and Electromagnetic Interference: What Is the Risk for Patients with Implantable Cardioverter Defibrillators? [5]	Nineteen human patients with internal defibrillators (ICDs) with both types of sensing[62] were asked to stand near a pot of water on an induction cooktop, at a minimum distance of 25 cm. Patients were asked to touch the handle of the pot for short intervals at different power levels (low, medium, high) and at both leaning and upright body positions. The pot was also adjusted so that it was eccentric to the circular cooking surface, which was identified as a potential cause of risk in the Irnich and Bernstein article. No interference or malfunction was detected in the patients.
Electromagnetic Interference of Implantable Unipolar Cardiac Pacemakers by an Induction Oven [21]	Electromagnetic probes and human body models containing pacemakers were held directly above and directly to the side of a pot of water on an induction stove. The object of the experiment was to determine the maximum distance at which interference would occur in the pacemakers. The first experiment was an inhibition test, in which the EMI would prevent the pacemaker from sending a pacing pulse at the appropriate time. The second test was an asynchronization test, in which the EMI would cause the pacemaker to send a pacing pulse at the wrong time or at the wrong rate. Pacemaker inhibition occurred when the stove was turned on and when a pan was removed from the heating surface, at a maximum distance of 32 cm above the heating surface. Pacemaker asynchronization occurred during pan-detection mode and while the stove was heating up, at a maximum distance of 34 cm above the heating surface. However, interruptions to normal pacemaker function seem to be transient, as the pacemakers tested seem to be able to withstand the EMI.
Do Induction Cooktops Interfere with Cardiac Pacemakers? [26]	This study tested eleven different induction stovetops and 244 different pacemaker devices to assess the level of induced electrical voltages in individuals with pacemakers. The study was carried out using human body models with pacemakers embedded inside. The body models were positioned leaning over the induction stove and moved horizontally and vertically relative to the stove to determine any differences in induced voltages. A pot of water was placed on the stove in either a concentric or

[62] This refers to the two methods in which pacemakers sense when the heart is beating out of tune: bipolar and unipolar sensing. Bipolar pacemakers have electrodes which connect to both halves of the heart, whereas unipolar pacemakers only attach to one half of the heart.

Article	Pacemakers/ICD-Related Summary
	eccentric position. With these variations, the researchers were able to determine a "worst case scenario" for impact: Unipolar, left-sided pacemaker implant location, which is the most common placement for individuals who are not pacemaker-dependent[63]; Person stands as close as possible to induction cooktop (closer than 34 cm); Pot is not concentric with induction coil; Patient touches pot for long period of time (creating a grounding effect), and metal cooking utensils are used for a long period of time.~~.~~ The researchers recommend that individuals with unipolar-sensing pacemakers avoid these worst-case scenario conditions in order to prevent EMI.
Electromagnetic and Radiation Environment Effects on Pacemakers [39]	Human body models were filled with water and several different pacemakers were placed within them. The models were then subjected to a wide range of magnetic fields, including fields oscillating at frequencies similar to those generated by induction stoves. Upon disassembling the pacemakers, the researchers found that certain magnetic field frequencies caused pacemakers to deprogram or stop functioning entirely. It was not named whether induction stoves could cause damage to pacemakers, but caution was advised, nonetheless. This study was focused on EMI from cancer treatment methods. However, it mentions that other electronic devices could cause impacts, such as induction stoves.
Electromagnetic Interference with a Bipolar Pacemaker by an Induction Heating (IH) Rice Cooker [41]	A woman with a bipolar-sensing pacemaker was found to have had 21 instances of EMI recorded on her pacemaker's memory. These instances ranged from 12-75 seconds per instance, and only occurred in the morning and in the evening. Upon consulting with the patient's family, these instances were found to be corresponding with the opening and closing of the patient's induction heating rice cooker. No health symptoms were noted during these instances. Although this is the first recorded instance of an individual with a bipolar-sensing pacemaker facing interference, this has occurred in only one recorded patient, and there were no health side-effects.
Induction Ovens and Electromagnetic Interference: What Is the Risk for Patients with Implanted Pacemakers? [48]	Patients with four different types of pacemakers were asked to lean over a pot of water cooking on an induction stove (about 20 cm away from the cooking surface) as the power level was adjusted up and down, and exposure to the magnetic field was adjusted (by moving a secondary metal pan towards and away from the water pot). Their pacemakers and hearts were monitored to see if there was any interference. The test was run under a normal (pacemaker-maintained) heartrate as well as under an increased heartrate, about 10-15 bpm above the normal rate. There was no evidence of pacemaker malfunction, nor were there any changes in health parameters for the patients.

[63] Individuals who are pacemaker-dependent generally have bipolar-sensing units, which are more resilient to electromagnetic pulses from induction stoves.

Article	Pacemakers/ICD-Related Summary
Protection of Pacemaker Wearers: Effects on Magnetic Fields On The Operation of Implanted Cardiac Pacemakers [50]	The researchers developed an exposure system meant to simulate EMI exposure from a variety of sources found in the real world, and they also tested EMI exposure from an induction cooktop. Patients were asked to stand near an induction cooktop actively heating a pot of water, then touch the pot briefly, and then finally stir the pot of water. These tests were run at three different induction heating power levels. The researchers did not observe any EMI, unless they increased the sensitivity of the pacemaker sensing to beyond what it would be tuned to in a typical patient.
Electromagnetic Interference with Cardiac Pacemakers and Implantable Cardioverter-Defibrillators from Low-Frequency Electromagnetic Fields in Vivo [51]	Eleven human patients with both bipolar and unipolar sensing pacemakers were asked to stand in front of two pots of water on a 4-burner induction cooktop, then asked to hold the handle of one of the pots for a minute, then asked to slide one of the pots to the back of the stove (causing them to lean directly above the active cooktop). In other areas of the study, the same patients were exposed to EMI from a variety of different sources, including an EAS gate (the gates that stores use to prevent shoplifting), a welding machine, and a Helmholtz coil. While one patient was affected by the EAS gate and the welding machine, no patients were affected by the induction stove. However, the authors noted that the experiment was limited in that only one induction cooktop was used, and some of the pacemakers in use by the patients were older models, with newer models having more advanced safety measures built in.

Appendix B Fire Risk Additional Details

This appendix provides additional details on the assessment of the NFIRS data.

Table 27 shows the frequency of fires caused by electric and gas stoves where the type of material first ignited was a fossil fuel of some kind. Though it is not captured in the table, the first item ignited is unknown (or listed as "other") in most fire incidents. Electric stoves rarely ignite fossil fuels, which provides evidence to suggest that the power source may be labeled correctly in the data.

Table 27: Percentage of Fires Caused by Electric and Gas Stoves by Type of Material First Ignited

	Electric Stoves		Gas Stoves	
Type of Material First Ignited	Occurrences	Percent of Occurrences	Occurrences	Percent of Occurrences
Natural gas	3	0.3%	13	5.3%
Flammable or combustible liquid, other	2	0.2%	4	1.6%
LP gas	1	0.1%	2	0.8%
Flammable gas, other	0	0.0%	1	0.4%

Table 28 shows the results from the first round of the model number search. The specific search terms used to find the stoves selected occupy the rightmost column. The first seven stoves are "fully electric": both the power source and the first item ignited are electricity related. A stove that is "incorrectly identified" is one where the listed power source in the dataset does not match with the stove's fuel type in the real world. For example, if a stove's power source is listed as electric, and the model number search finds that it is a propane stove, then the stove's power source would be "incorrectly identified." In this sample of 16 stoves, 75% of stoves were correctly identified, 12.5% of stoves were incorrectly identified, and 12.5% of stoves had an unknown fuel source.

In a random sample of 15 stoves with available model numbers, 73.3% of electric stoves were correctly identified, and 26.7% of stoves were incorrectly identified. On the gas stoves side, in a random sample of 20 stoves with model numbers available, 75% of stoves were correctly identified, and 25% of stoves had an unknown fuel source.

Table 28: Model Number Search, Selected Qualities

Power Source	Heat Source	First Item Ignited	Type of Material First Ignited	Correctly Identified ?	Search Tags
Electrical line voltage (>= 50 volts)	Arcing	Electrical wire, cable insulation	Plastic	yes	Item first ignited: electrical

Power Source	Heat Source	First Item Ignited	Type of Material First Ignited	Correctly Identified ?	Search Tags
Electrical line voltage (>= 50 volts)	Arcing	Electrical wire, cable insulation	Material compounded with oil, other	yes	wires only
Electrical line voltage (>= 50 volts)	Arcing	Electrical wire, cable insulation	Multiple types of material	yes	
Electrical line voltage (>= 50 volts)	Heat from powered equipment, other	Electrical wire, cable insulation	Cooking oil, transformer or lubricating oil	no	
Electrical line voltage (>= 50 volts)	Arcing	Electrical wire, cable insulation	Type of material first ignited, other	unknown	
Electrical line voltage (>= 50 volts)	Arcing	Electrical wire, cable insulation	Type of material first ignited, other	yes	
Electrical line voltage (>= 50 volts)	Arcing	Electrical wire, cable insulation	Plastic	unknown	
Electrical line voltage (>= 50 volts)	Heat from powered equipment, other	Pipe, duct, conduit or hose	Undetermined	yes	Item first ignited: fossil fuel-related items only
Electrical, other	Heat from powered equipment, other	Flammable liquid/gas in container or pipe	Natural gas	no	
Electrical, other	Radiated, conducted heat from operating equipment	Liquids, piping, filters, other	Polish, paraffin, wax	yes	
Electrical, other	Spark, ember or flame from operating equipment	Cooking materials, including edible materials	Type of material first ignited, other	yes	Heat source: spark, ember
Electrical line voltage (>= 50 volts)	Spark, ember or flame from operating equipment	Appliance housing or casing	Plastic	yes	
Electric power source	Radiated, conducted heat from operating equipment	Undetermined	Plastic	yes	Heat source: radiated/ conducted heat; type of material first ignited: plastic
Electric power source	Radiated, conducted heat from operating equipment	Item First Ignited, Other	Plastic	yes	
Electric power source	Radiated, conducted heat from operating equipment	Decoration	Plastic	yes	
Electric power source	Radiated, conducted heat from operating equipment	Household utensils	Plastic	yes	

Appendix C Algorithms for Asthma-Related NEIs

The algorithms presented below are adopted from the RNC NEI Quick Hit Assessment study (MA 20X14-RNCNEI). They calculate the asthma-related NEIs from eliminating combustion stovetops from homes, i.e., from a 100% reduction to combustion byproducts from gas stovetops. The NEIs presented below include both avoided healthcare costs and productivity losses.

Table 29: Electric Induction Stovetop – Childhood Asthma Prevention, Annualized Occupant Lifetime Benefit

(Healthcare Care and Productivity Losses)

Input		Value	Source
a	Lifetime medical expenses (2010$) for asthma with onset age 0-5[2]	$16,200.00	Belova et al. [1]
b	Inflation Adjustment (2020$), medical expenses	$19,286.00	CPI Calculator[3]
c	Cost of Living Adjustment (MA), medical expenses	$20,636.02	Regional Price Parities[4]
d	Lifetime productivity loses (2010$) for asthma with onset age 0-5[2]	$31,800.00	Belova et al. [1]
e	Inflation Adjustment (2020$), productivity losses	$37,859.00	CPI Calculator[3]
f	Cost of Living Adjustment (MA), productivity losses	$40,509.13	Regional Price Parities[4]
g	OOP medical costs	11%	MEPS
h	OOP medical cost of asthma – lifetime	$2,194.75	c * g
i	Childhood asthma prevalence rate, MA	12.9%	Massachusetts Government Asthma Statistics[5]
j	Adulthood asthma prevalence rate, MA	10.2%	
k	Population of children without asthma	87.1%	1- i
l	Increased risk of Asthma due to gas combustion stove	1.36	Lin et al.[6]
m	2019 MA incidence of asthma, ages 0-14	38,644	Global Health Data Exchange[7]
n	2019 MA asthma eligible population, ages 0-14	963,053	Massachusetts under 14 population, U.S. Census[8] * (k)
o	MA asthma incidence rate, ages 0-14	4.0%	m / n
p	Estimated asthma incidence rate, gas stoves	5.5%	l * o

Input		Value	Source
q	Estimated asthma incidence count of children based on gas stove rate, annual	52,556	n * p
r	Estimated increase in asthma incidence due to gas stoves	26.5%	(q – m) / q
s	MA average number of children age 0-14 per home	0.42	Extrapolated from MA-specific U.S. Census population and occupied housing data
t	Portion of stovetops in total annual energy usage for stoves	40%	See Section 2.1 for details
u	Induction stove measure life	16 years	MA TRM[9]
NEI Value			
v	Value of avoided all-setting healthcare costs and productivity losses of asthma due to prevented cases of childhood asthma, MA, annualized lifetime benefit	**$4.73**	((h + f) * o * r * s * t) / u

[1] Belova, A., Fann, N., Haskell, J., Hubbell, B., & Narayan, T. (2020). Estimating Lifetime Cost of Illness. An Application to Asthma, 2020. Annals of the American Thoracic Society.
[2] Average age of asthma onset is five years old. Asthma Among Children in Massachusetts, Commonwealth of Massachusetts Department of Public Health, January 2017. Retrieved from https://www.mass.gov/doc/pediatric-asthma-data-bulletin-0/download
[3] https://www.bls.gov/data/inflation_calculator.htm
[4] https://apps.bea.gov/iTable/iTable.cfm?reqid=70&step=1&isuri=1&acrdn=8#reqid=70&step=1&isuri=1
[5] https://www.mass.gov/service-details/statistics-about-asthma
[6] Lin W, Brunekreef B, Gehring U. Meta-analysis of the effects of indoor nitrogen dioxide and gas cooking on asthma and wheeze in children. Int J Epidemiol. 2013 Dec;42(6):1724-37. doi: 10.1093/ije/dyt150. Epub 2013 Aug 20. PMID: 23962958.
[7] http://ghdx.healthdata.org/gbd-results-tool
[8] https://data.census.gov/mdat/#/
[9] https://fileservice.eea.comacloud.net/FileService.Api/file/FileRoom/14154670

Table 30: Electric Induction Stovetop – Reduced Childhood Asthma Symptoms

(Healthcare costs and Productivity Losses)

Input		Value	Source
a	Increase in childhood asthma symptoms attributable to gas stoves	42%	Lin et al.[1]
b	Ratio of healthcare costs and productivity losses to symptoms	100%	Evaluation team assumption[2]
c	Incremental annual healthcare costs associated with childhood asthma, adj. for MA (2010$)	$800.00	Belova et al.[3]
d	Inflation adjustment (2020$), healthcare costs	$952.42	CPI Calculator[4]
e	Cost of living adjustment (MA), healthcare costs	$1,019.09	Regional Price Parities[5]
f	Incremental annual productivity losses associated with childhood asthma (2010$)	$3,500	Belova et al.[3]
g	Inflation adjustment (2020$), productivity losses	$4,166.83	CPI Calculator[4]
h	Cost of living adjustment (MA), productivity losses	$4,458.51	Regional Price Parities[5]
i	Estimated annual healthcare cost with exposure to gas stove in home, MA (2020$)	$1,447.11	e * (1 + a)
j	Estimated annual productivity losses with exposure to gas stove in home, MA (2020$)	6,331.08	h * (1 + a)
k	OOP medical costs	11%	MEPS
l	Estimated annual incremental OOP healthcare costs associated with exposure to gas stove	$45.52	(i – e) * k
m	Estimated annual incremental productivity losses avoided from reduced symptoms	$1,872.57	j - h
n	MA childhood current asthma rate	12.9%	Massachusetts Government Asthma Statistics[6]
o	MA average number of children under 18 per home	0.52	Massachusetts under 18 population in occupied homes, U.S. Census[7]
p	Portion of stovetops in total annual energy usage for stoves	40%	See Section 2.1 for details
NEI Value			
q	Value of avoided all-setting healthcare costs and productivity losses of child asthma due to reduced symptoms, MA, annual	**$51.45**	b * (l + m) * n * o * p

[1] Lin, W., Brunekreef, B., Gehring, U. (2013). Meta-analysis of the effects of indoor nitrogen dioxide and gas cooking on asthma and wheeze in children. International Journal of Epidemiology, 42(6), 1724-1737.

Input	Value	Source

[2] While the reviewed studies indicated that costs of asthma increase with asthma severity (See P. Godard, P. Chanez, L. Siraudin, N. Nicoloyannis, G. Duru (2002)) and lower asthma control (See Lai, C. K. W., Kuo, S.-H., de Guia, T., Lloyd, A., Williams, A. E., & Spencer, M. D. (2006)), they did not include data on the relationship between changes in symptoms and changes in medical costs or productivity losses. The evaluation 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.
[3] Belova, A., Fann, N., Haskell, J., Hubbell, B., & Narayan, T. (2020). Estimating Lifetime Cost of Illness. An Application to Asthma, 2020. Annals of the American Thoracic Society.
[4] https://www.bls.gov/data/inflation_calculator.htm
[5] https://apps.bea.gov/iTable/iTable.cfm?reqid=70&step=1&isuri=1&acrdn=8#reqid=70&step=1&isuri=1
[6] https://www.mass.gov/service-details/statistics-about-asthma
[7] https://www.census.gov/programs-surveys/acs

Table 31: Electric Induction Stovetop – Reduced Adult Asthma Symptoms

(Healthcare Costs and Productivity Losses)

Input		Value	Source
a	Increase in childhood asthma symptoms attributable to gas stoves	42%	Lin et al.[1]
b	Ratio of healthcare costs and productivity losses to symptoms	100%	Evaluation team assumption[2]
c	Incremental annual healthcare costs associated with adult asthma (2010$)	$1,600.00	Belova et al.[3]
d	Inflation adjustment (2020$), healthcare costs	$1,904.84	CPI Calculator[4]
e	Cost of living adjustment (MA), healthcare costs	$2,038.18	Regional Price Parities[5]
f	Incremental annual productivity losses associated with adult asthma (2010$)	$900.00	Belova et al.[3]
g	Inflation adjustment (2020$), productivity losses	$1,071.47	CPI Calculator[4]
h	Cost of living adjustment (MA), productivity losses	$1,146.47	Regional Price Parities[5]
i	Estimated annual healthcare cost with exposure to gas stove in home, MA (2020$)	$2,894.21	**e** * (1 + **a**)
j	Estimated annual productivity losses with exposure to gas stove in home, MA (2020$)	$1,627.99	**h** * (1 + **a**)
k	OOP medical costs	11%	MEPS
l	Estimated annual incremental OOP healthcare costs associated with exposure to gas stove	$91.04	(**i** – **e**) * **k**
m	Estimated annual incremental productivity losses avoided from reduced symptoms	$481.52	**j** - **h**
n	MA adult current asthma rate	10.2%	Massachusetts Government

Input		Value	Source
			Asthma Statistics[6]
o	MA average number of adults per home	2.1	Massachusetts over 18 population in occupied homes, U.S. Census
p	Portion of stovetops in total annual energy usage for stoves	40%	See Section 2.1 for details
NEI Value			
q	Value of avoided all-setting healthcare costs and productivity losses of adult asthma due to reduced symptoms, MA, annual	**$49.77**	b * (l + m) * n * o * p

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