Induction Cooking Market Transformation Initiative

Appendix C: Product Assessment Report

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Contents

List of Abbreviations

Abbreviation	Definition
AC	Air-Conditioning
ACC	Avoided Cost Calculator
ADA	Americans with Disabilities Act
AQMD	Air Quality Management District
CA	California
CalMTA	California Market Transformation Administrator
CARB	California Air Resources Board
CARE	California Alternate Rates for Energy
CE	Capture Efficiency
CEC	California Energy Code
CFM	Cubic Feet Per Minute
CFR	Code of Federal Regulations
CPUC	California Public Utilities Commission
DOE	Department of Energy
EPA	Environmental Protection Agency
EPCA	Energy Policy and Conservation Act
EPRI	Electrical Power Research Institute
ESJ	Environmental and Social Justice
ETLP	Low-Power-Mode Energy Consumption
eTRM	California Electronic Technical Reference Manual
EUL	Expected Useful Life
GHG	Greenhouse Gas
HEA	Home Energy Analytics
HENGH	Healthy Efficient New Gas Homes
HVAC	Heating, Ventilation, and Air Conditioning
IAEC	Integrated Annual Energy Consumption
IAQ	Indoor Air Quality
IEC	International Electrotechnical Commission
IOU	Investor-Owned Utility
IRA	Inflation Reduction Act
LBNL	Lawrence Berkeley National Laboratory
LiFePO4	Lithium Iron Phosphate
LSC	Long-Term System Cost
MF	Multifamily
MTI	Market Transformation Initiative
NEC	National Electric Code
NO2	Nitrogen Dioxide
PG&E	Pacific Gas and Electric
SCE	Request for Ideas
SDG&E	San Diego Gas and Electric
SF	Single-Family
SMUD	Sacramento Municipal Utility District
TDV	Time-Dependent Valuation
TOU	Time of Use
Zero-NOx	Zero Nitric Oxide and Nitric Dioxide

1. Executive summary

1.1. Document purpose and scope

This Product Assessment Report discusses the key findings of CalMTA's product and technical research into induction cooking products, including product features, limitations, and technical considerations for their use in California. The main product assessment activities informing this report were a review of existing literature, review of available products, discussions with manufacturers, and energy modeling. Those activities and this report will inform a forthcoming Market Transformation Initiative (MTI) Plan. The full MTI Plan will include a more comprehensive explanation of the benefits of the initiative for Californians and a complete program logic for transforming the induction cooking market.

Induction cooking appliances provide an efficient solution to electrified cooking in multifamily and single-family homes in California, and also provide indoor air quality (IAQ) and safety benefits. Since the cooking efficiency of induction appliances is higher than incumbent gas and resistance cooking products, they can replace these technologies while simultaneously providing a reduction in greenhouse gas (GHG) emissions and a superior cooking experience. Here, we review the currently available products, applicable codes and regulations, as well as product gaps related to the needs of the California market. We then use energy modeling to estimate the potential of energy savings, avoided cost benefits, and bill impacts for both single- and multifamily buildings across California's investor-owned utilities (IOUs). The findings from this report will then be used to inform how the MTI Plan addresses barriers, interventions, and outcomes.

The Product Assessment Report covers induction and ENERGY STAR certified radiant cooktops and ranges that are permanently installed, whether they are 120V, 240V, or 120V battery-equipped products.[1] Cooktops are rectangular surfaces that drop in to an existing countertop, up to a certain depth. Ranges are cooktops with an integrated electric resistance oven below them in the same chassis. Most modern cooktops and ranges plug into a dedicated 240V circuit. However, there are 120V cooktops, and 120V battery-equipped cooktops and ranges that are powered by a more common 120V wall outlet. These products are all designed for use in a home kitchen, whether inset into a counter like a cooktop or standing on their own like a range. The form factor of these products is most identical with incumbent gas cooking appliances, where the variations for consumer decision points include a standardized product width, often 24'', 30'', 36'', or wider, and the choice between a range or a cooktop. Similarities with gas cooking end at the form factor, however. Induction cooking technology is over twice as energy efficient as gas, and functions by inducing an electrical current in the cookware itself rather than combusting a fuel to heat the cooking vessel.

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[1] For this MTI, "permanently installed" refers to cooktop models that do not sit on the countertop and are installed into it with the intention of remaining stationary.

The document is organized by first providing an overview of induction and ENERGY STAR radiant cooking products, their limitations, and possible technical barriers. Then it surveys the competitive landscape and current codes and standards. Following this review, it uses energy modeling to examine product performance, bill impacts, avoided costs, technical potential, and product plan actions. The report closes with a risk assessment of possible threats to the product plan. The following Executive Summary provides an overview of the report's main findings.

1.2. A note on product naming conventions

This MTI is titled "Induction Cooking" because it focuses on electric cooking products that utilize induction heating technology. The MTI includes induction cooktops and ranges; however, our MTI also incorporates ENERGY STAR certified radiant cooking products. While the MTI prioritizes induction cooking ranges and cooktops, we recognize that many of the same benefits can be achieved with high-efficiency radiant cooking products (i.e., ENERGY STAR certified). In the product assessment report, we use the term "electric cooking" to refer to the collection of products targeted in the MTI, including ENERGY STAR radiant. This collective nomenclature choice is meant for better readability. For any discussion specific to a product, we will use the particular name of the that product type (i.e., induction range or radiant cooktop). Additionally, we will use the term "cooktop" to refer to the heating surface, "oven" for the cavity below, and "range" for the appliances that include both a cooktop and oven.

1.3. Main product assessment findings

Finding 1: Electric cooking is more energy efficient than gas cooking and the avoided GHG emissions more than offset the additional demand on the electricity grid.
The California electronic Technical Resource Manual (eTRM), the California Public Utilities Commission (CPUC) energy efficiency database of record,[2] and laboratory testing have deemed induction technology to be over twice as efficient as gas cooking. The eTRM indicates thermal efficiency for induction, resistance, and gas cooking appliances at 84%, 74%, and 40%, respectively.[3] In a laboratory setting, the measured efficiency for induction, resistance, and gas cooking appliances was found to be 84.8%, 77.4%, and 31.9%, respectively.[4]

Table 1 below shows how avoided costs change when converting to induction cooking from gas and radiant ranges and cooktops. IOUs' avoided cost benefits can be separated into three categories: energy, GHG emissions, and grid costs. A key finding is that in all scenarios that involve substituting an existing gas cooktop or range with either induction or resistance, the grid impacts would be negative due to the added electrical load on the grid. However, this change reduces GHG emissions and increases the overall benefit. Another key finding is that the negative

[2] https://www.caetrm.com/.
[3] https://www.caetrm.com/measure/SWAP013/03/.
[4] Frontier Energy, Residential Cooktop Study, 2019.

grid impacts are reduced or eliminated when using a battery-equipped 120V induction product. Lastly, in all scenarios, the negative grid and/or energy avoided cost impacts of electrification are completely off set by positive GHG impacts.

Table 1: Calculated avoided costs for each cooking electrification scenario by IOUs San Diego Gas and Electric (SDG&E), Southern California Edison (SCE), and Pacific Gas and Electric (PG&E)

	Scenario # - IOU	Avoided cost benefit, energy	Avoided cost benefit, grid	Avoided cost benefit, GHG	Avoided cost benefit, total
Electric resistance coil cooktop to induction cooktop scenario	1-SDG&E	$7.51	$8.52	$6.38	$22.41
	1-SCE	$7.51	$7.54	$6.38	$21.42
	1-PG&E	$8.01	$8.05	$6.99	$23.05
Gas cooktop to induction cooktop scenario	2-SDG&E	$4.75	$(63.71)	$176.44	$117.47
	2-SCE	$5.11	$(66.34)	$176.44	$115.21
	2-PG&E	$(0.69)	$(54.68)	$168.55	$113.18
Electric resistance coil range to induction range scenario	3- SDG&E	$7.50	$8.52	$6.37	$22.39
	3-SCE	$7.50	$7.53	$6.37	$21.40
	3-PG&E	$8.00	$8.05	$6.98	$23.03
Gas range to induction range scenario	4-SDG&E	$(37.88)	$(198.37)	$355.50	$119.24
	4-SCE	$(37.07)	$(197.90)	$355.50	$120.52
	4-PG&E	$(53.35)	$(175.02)	$333.82	$105.45
Electric resistance coil range to 120V battery-equipped induction range scenario	5-SDG&E	$174.09	$300.77	$236.21	$711.07
	5-SCE	$174.09	$(13.32)	$236.21	$396.98
	5-PG&E	$164.19	$249.58	$222.59	$ 636.36
Gas range to 120V battery-equipped induction range scenario	6-SDG&E	$128.70	$93.88	$585.33	$807.92
	6-SCE	$129.52	$(218.75)	$585.33	$496.09
	6-PG&E	$102.83	$66.51	$549.42	$718.77

Finding 2: Substituting cooking fuels will improve indoor air quality for Californians and reduce the negative public health impact of respiratory diseases, cancers, and other conditions directly related to indoor gas cooking.

Research consistently shows that gas cooking has negative health impacts. The by-products of gas combustion contain chemicals that contribute to an increased risk of asthma and leukemia, amongst other conditions. A 2013 meta-analysis found that children living in homes with gas cooking had a 42% increased risk of developing asthma than their peers without gas cooking.[5] This increased risk disappears with the adoption of electric cooking and is a major benefit for the development of this MTI.

Natural gas cooking poses risks even when the appliance is unused, as the gas can leak from the infrastructure in the home. This leakage exposes residents to natural gas contaminants such as benzene, which has a growing body of evidence tying it to childhood leukemia. A 2010 study notes, "There is probably no safe level of exposure to benzene, and all exposure constitutes some risk."[6] Electric cooking appliances do not risk exposure to harmful contaminants in this way.

It is important to recognize that the IAQ benefits of cooking electrification are magnified in environmental and social justice (ESJ) communities. These communities are frequently housed in multifamily buildings and/or older buildings with less mechanical ventilation. Multifamily buildings in particular benefit from cooking electrification. Due to the building geometry creating close proximity between dwelling units and smaller room size, the IAQ issues associated with gas cooking can affect more than one family even when they don't use their gas cooking appliance. Contaminants in smaller homes can become more concentrated, and they can infiltrate adjacent units through common hallways and walls.

Finding 3: Most Californians cook with gas and existing electrical infrastructure in homes is a barrier to the adoption of electric cooking.

Almost 70% of California households cook using natural gas fuel.[7] While this is an excellent market opportunity for electric cooking, cooking electrification barriers are significant. Most California homes with gas cooking do not have dedicated 240V kitchen circuits, which are required for most of the currently available electric cooking products. However, modern natural gas products use electric ignition, which requires a 120V outlet behind the appliance, creating an opportunity for the conversion to 120V cooking products without the need for potentially costly and complicated 240V electrification upgrades. Research shows that most California homes have sufficient panel capacity for a 120V cooking appliance, an additional 1,800W of power, without expensive hardware upgrades (see Figure 1). Accessing this available power will require electrical infrastructure optimizations in many homes, such as smart circuit splitters, which are significantly less costly than hardware upgrades.

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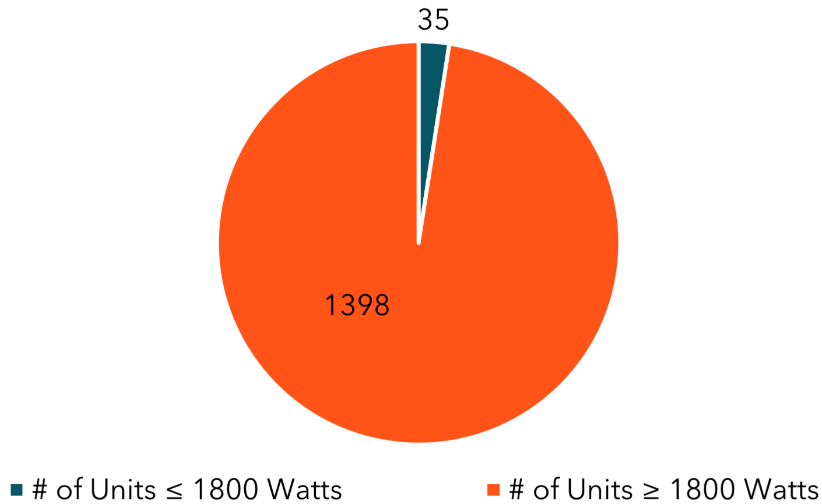
[5] Lin W, Brunekreef B, Gehring U. Meta-analysis of the effects of indoor nitrogen dioxide and gas cooking on asthma and wheeze in children. Int J Epidemiol. 2013 Dec;42(6):1724-37. doi: 10.1093/ije/dyt150. Epub 2013 Aug 20. PMID: 23962958.

[6] Smith MT. Advances in understanding benzene health effects and susceptibility. Annu Rev Public Health. 2010; 31:133-48 2 p following 148. doi: 10.1146/annurev.publhealth.012809.103646. PMID: 20070208; PMCID: PMC4360999.

[7] Highlights for appliances in U.S. homes by state, 2020. Energy Information Agency. Released March 2023. https://www.eia.gov/consumption/residential/data/2020/state/pdf/State%20Appliances.pdf.

Figure 1. Home Energy Analytics (HEA) study participants with less than 1,800W available for a 15A, 120V appliance



A potential solution to the electrification barriers would be 120V cooking products, but research has yet to be completed for the consumer acceptance of cooking performance on a 120V range (including the oven) when limited to 15A@ 120V, or 1,800W of power. While many 120V cooktop solutions are available on the market, there are no 120V ranges manufactured today, likely due to this performance gap.

240V cooking electrification has the largest market share of available products as it is the incumbent approach for most Californians, and so these barriers must be understood. Notably, Title 24 has adopted electric readiness requirements that mandate the installation of 240V circuits into the kitchen of every newly constructed residential dwelling unit in California, regardless of the intention to install gas or electric cooking appliances.

Estimates from CPUC research show that 27% to 41% of existing residential building electric panels would require upgrades to support electrification, with a further 19% to 27% requiring electrical optimization services on the existing panel. This research determined that, in the best case, 46% of residential buildings in California will require upgrades or optimization services. The adoption of electric cooking does not solely rely on the product, technology, or their features, but it will depend on whether these external barriers are also addressed in tandem.

Finding 4: Battery-equipped, 120V products are entering the market to address electrification barriers, but the up-front cost of batteries requires compromise and prioritization for buildings owners looking to electrify cooking.

Given the electrical infrastructure upgrades required for 240V electrification, several start-up manufacturers have identified opportunities for 120V battery-equipped induction cooking products. These products are designed to compete with the performance level of 240V induction cooking products while simultaneously eliminating the potential cost, time, and complexity required for electrical upgrades or optimization.

The trade-off for the simplicity of adopting these battery-equipped products is cost. Currently, the cost of batteries and the associated technologies designed for use in these appliances are significant.

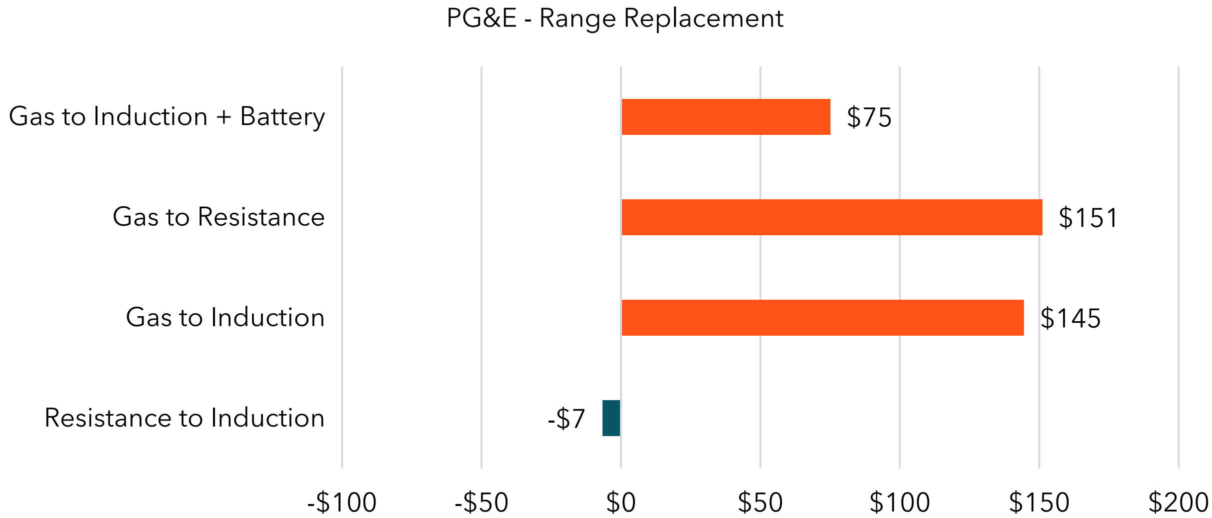
To determine if this new product category is the right choice, building owners must have estimates for the cost of building electrification and the 240V product of choice to compare with the cost of these 120V battery-equipped products. They must also have information about incentives, rebates, and credits available for each to make an accurate financial comparison between each decision tree.

120V battery-equipped products will not be the best choice for building owners who are cost sensitive or, assuming all costs are equal, would prefer to permanently upgrade the building instead of purchasing a battery-equipped product with an end-of-life. However, these 120V battery-equipped products enable distinct benefits and features that will be well-suited for a significant market in California, including blackout resiliency and demand flexibility.

Finding 5: Electric cooking is twice as efficient as gas but, because the cost of natural gas in California is lower than the cost of electricity, consumer bills will increase when electrifying cooking. Although this impact depends on the exact rates of each utility, all IOUs show a negative bill impact with current rates.

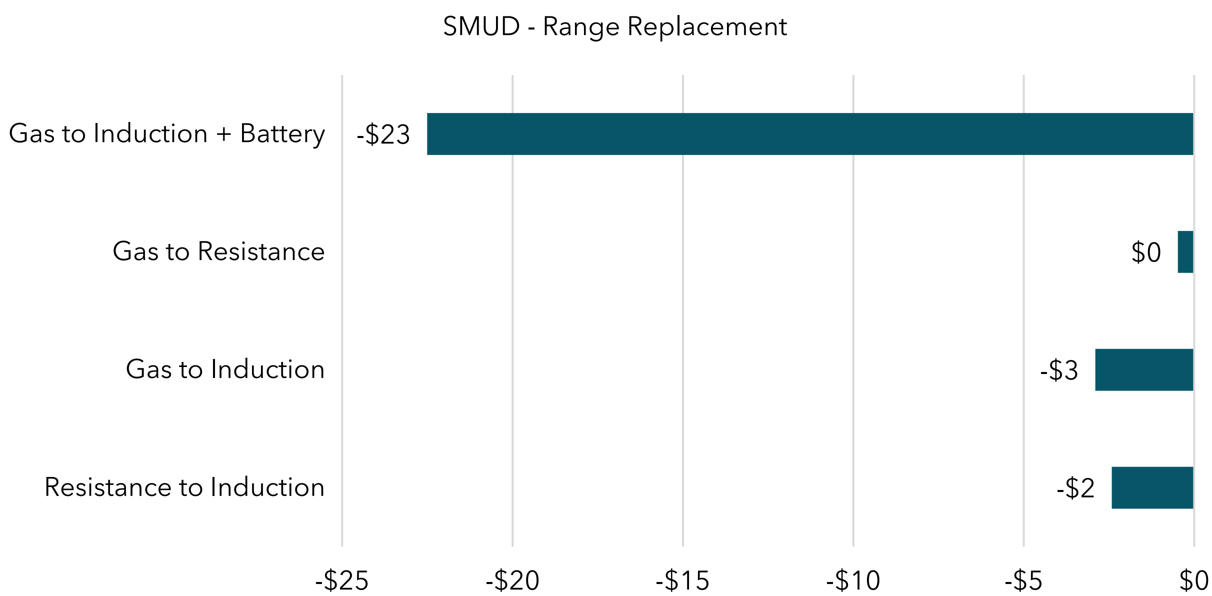
Changing from gas to electric cooking means increased energy efficiency and fewer emissions. However, rates for gas and electricity per unit energy vary significantly in California. At the time of this report, gas is less expensive than electricity such that electrifying cooking end uses will still result in negative bill impacts. More specifically, IOU ratepayers will pay more to cook with induction compared to gas. Bill impacts for cooking electrification are highly dependent on the specific rate of gas, but also the time-of-use rates of electricity. Cooking is typically performed during peak electricity demand hours and is charged at peak demand rates. This exacerbates the issue of cooking electrification bill impacts.

Figure 2. Projected annual bill impact for Pacific Gas & Electric (PG&E) residential customers



Certain municipal district electricity rates are more favorable to electrification, creating the potential for neutral or positive bill impacts. Sacramento Municipal Utility District (SMUD) maintains relatively low per-kWh rates by including a relatively high fixed monthly charge compared to most IOUs. This shift to a higher fixed charge favors electrification by reducing the cost to consume more electricity compared to gas, which is the primary driver of electrification bill impacts.

Figure 3. Projected annual bill impact for SMUD electric/PG&E gas customers



Finding 6: Induction cooking technology provides a superior cooking experience against both gas and conventional electric resistance cooking appliances.
Gas cooking has benefits like immediate temperature response when adjusting the controls and a visual indicator of heat output according to the size of the flame. However, gas cooking has detrimental IAQ, dangerous flames and hot surfaces, and imprecise temperature control.

Conventional electric resistance cooking does not have a reputation for high quality cooking experiences, and its cooking experience benefits over gas is limited to increased IAQ. Resistance cooking is slow to respond to control inputs, has imprecise temperature settings, uses a dangerously high temperature cooking surface, and can overcook food left on the surface when the heat is turned off.

Induction cooking demonstrates superiority over incumbent gas appliances with improved IAQ and precise temperature setpoints. The technology also exceeds the temperature response speed of conventional electric resistance appliances. Notably, induction cooking appliances are superior to both incumbent technologies by enabling high-precision temperature setpoints, the fastest temperature response, and safer cooking surface temperatures. Induction magnifies many of the benefits of incumbent cooking technologies while minimizing or completely removing the negatives of gas and conventional resistance. Induction technology can decarbonize gas cooking and increase IAQ while providing a superior cooking experience over electric cooking.

2.Product overview

2.1. Product definition

Overview

Modern, efficient electric cooking appliances offer improved IAQ, cooking performance, energy savings, and emissions reductions compared to natural gas and propane cooktops, ovens, and ranges found in most California homes and apartments. Electromagnetic induction is the principal technological advancement enabling modern electric cooking appliances to meet and exceed the performance of gas cooking appliances, potentially driving higher rates of adoption of all types of clean, efficient all-electric cooking appliances, including cooktops, wall ovens, and ranges that combine cooktops and oven in one unit.

This MTI will focus on **electric cooktops and all-electric ranges** using either induction or radiant electric technology. Cooktops and ranges that use radiant technology must be certified to the current version[8] of the ENERGY STAR specification.

[8] At the time of publication, products must meet the requirements of ENERGY STAR 1.0 for Residential Electric Cooking Products to achieve ENERGY STAR certification and labeling. "Residential Electric Cooking Products

This definition includes **freestanding electric ranges**, which can be installed between cabinets, or stand alone as well as **slide-in electric ranges**, which can only be installed between cabinets. Freestanding ranges typically locate cooking controls in an elevated panel at the back of the appliance, whereas slide-in ranges typically put controls in the front. Pictures of each type of range are shown in Figure 4.

This definition also includes 240V standalone electric cooktops designed for permanent installation in a countertop, as seen in Figure 5.

Figure 4: Slide-in range (left) and freestanding range (right)

Photos credit: https://www.whirlpool.com/blog/kitchen/slide-in-vs-freestanding-range.html.

Version 1." Accessed July 31, 2024.
https://www.energystar.gov/products/residential_electric_cooking_products_version_1.

Figure 5: 240V 5-burner Miele radiant cooktop (left) and 240V 6-burner Viking cooktop (right)

Photos credit: https://hintex.com/products/miele-km5627-electric-cooktop-240v and https://www.vikingrange.com/consumer/category/products/cooking/cooktops.

240V products – and new 120V induction cooktops and ranges that are battery-enabled, as shown in Figure 6 – are part of the product definition, but cooktops and ranges with coil-style heating elements are excluded, as are standalone wall ovens. Notably, 120V products without batteries are also excluded.

Figure 6: Impulse Labs cooktop (left) and Channing Street Copper Range (right), both battery-enabled

Photos credit: https://shop.impulselabs.com/products/impulse-induction-cooktop-deposits and https://copperhome.com/products/charlie.

The CalMTA research team expanded the current definition for this MTI to include all induction products and any radiant products that meet the current ENERGY STAR 1.0 specification. This deviation from the Advancement Plan is to provide a broader selection of affordable electrification options. As the ENERGY STAR specification for efficiency ratchets down in future versions, we expect that most of the products that meet that spec will be induction technology.

2.2. Technical definitions and distinctions

Cooking appliances have traditionally been grouped into cooktops, ovens, and ranges. Products that combine an oven and cooktop into a single appliance are commonly referred to as "ranges." Importantly, induction and radiant ranges only differ in the technology used on the cooktop portion, as all electric ovens use resistance technology.

The U.S. Department of Energy (DOE) defines these consumer cooking products as follows. The Code of Federal Regulations (CFR) reference follows each definition:[9]

Conventional oven: "household cooking appliances consisting of one or more compartments intended for the cooking or heating of food by means of either a gas flame or electric resistance heating. It does not include portable or countertop ovens which use electric resistance heating for the cooking or heating of food and are designed for an electrical supply of approximately 120 volts" (10 CFR 430.2).

Portable cooktops: "conventional cooking top designed for indoor use and to be moved from place to place" (10 CFR 430.2).

Conventional Cooktops: "household cooking appliances consisting of a horizontal surface containing one or more surface units which utilize a gas flame, electric resistance heating, or electric inductive heating" (10 CFR 430.2).[10]

Different cooktop technologies can be best understood by their respective modes of heat transfer as described below.

Electric resistance

Heat is generated by running an electric current through a metal wire with high electrical resistance and thermally conductive properties. The metal wire becomes hot and emits heat which is transferred to the cooking vessel primarily through conduction or radiation, depending on the type of resistance cooking product. Electric resistance ranges and cooktops can be classified into two general categories:

Electric resistance coils, which is when the heating element is encased in a coiled metal or ceramic sleeve and conductive heat transfer is the primary means of cooking.

Smooth-top, infrared, radiant, and ceramic cooktops are the same products. They use a heating element encased beneath a glass and/or ceramic top and heat cookware primarily through radiant heating effects. The term radiant will be used to describe these products for the purpose of this report, although common naming practice can vary by region and manufacturer.

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[9] U.S. Department of Energy. "Consumer Conventional Cooking Products." Accessed July 31, 2024. https://www.energy.gov/eere/buildings/consumer-conventional-cooking-products.

[10] California Energy Commission. "Plug Load and Lighting Modeling." June 2016. Accessed July 31, 2024. https://www.caetrm.com/media/reference-documents/2016_T24CASE_Report_-_Plug_Load_and_Ltg_Modeling_-_June_2016.pdf.

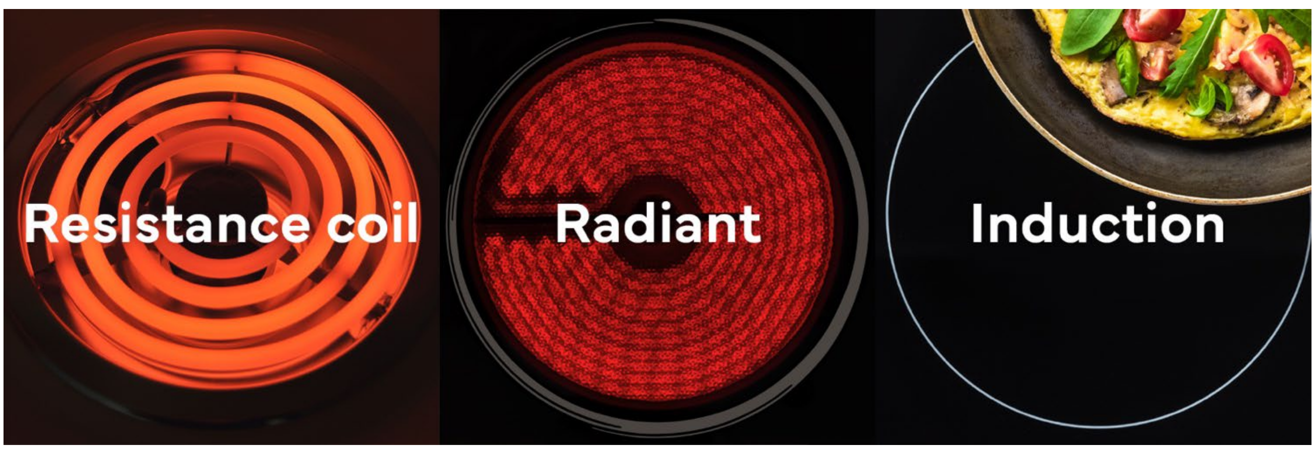
Electric resistance cooktops and ranges are typically more energy-efficient and easier to clean than gas appliances but take longer to reach desired temperatures.

Electric Induction

Heat is generated by allowing a high frequency, alternating current to flow through a tightly wound coil of wire which generates a rapidly changing magnetic field at the surface of the cooktop. The resulting heat is only generated in a pot or pan containing ferromagnetic material. Since non-magnetic materials do not respond to the magnetic fields, nearly all energy generated is transferred to the cooking vessel. This technology eliminates the need for an open flame or exposed heating elements, making it a safer and more energy-efficient option. Induction stoves and cooktops offer precision controls and are faster at reaching desired temperatures than electric resistance or gas appliances but require compatible cookware.

A visual comparison between different electric cooking technologies can be found below in Figure 7.

Figure 7: Visual comparison between resistance coil, radiant, and induction cooktop heating zones



Natural gas

Heat is transferred to the cooking vessel via an open flame which is fueled by natural gas that is piped into the dwelling unit. While the cooking vessel receives some energy from the open flame, most is lost to the surrounding space. Gas stoves and ranges require additional ventilation to remove exhaust gases but can be more versatile than non-induction electric resistance due to their ability to adjust heat levels quickly. Although induction can adjust temperatures even more quickly than gas, once cookware loses contact with the surface, heat transfer ceases. This can be problematic and require adjustment for wok cooking, which involves modulating heat by elevating the wok above the gas flame.

2.3. Product features

Induction cooktops provide precise temperature control, faster boiling times, and unique safety features that can prevent the types of household injuries caused by traditional cooking technologies. Induction appliances have also been shown to improve IAQ by eliminating the combustion of natural gas that is not directly vented to the outside, which simultaneously allows for a reduction in ventilation needs and the associated fan noise. Due to the efficiency of the technology, significantly less waste heat is released into the kitchen. This can increase occupant comfort during extreme weather conditions, warmer seasons, and reduce the cooling energy required to maintain occupant comfort. The IAQ benefits of induction technology will be discussed in greater detail in Section 6.6.

Superior features inherent to induction technology

Induction cooktops typically have a smooth glass cooking surface just like many incumbent radiant cooktops. Unlike a conventional radiant cooking surface, an induction cooktop does not become dangerously hot to the touch. This safety benefit also is a maintenance benefit, as the surface does not burn food onto the surface at high temperature and increase the difficulty of wipe downs and cleaning. Additionally, small children cannot unintentionally burn themselves on the cooktop surface and the elderly will not be in danger if they accidentally leave the appliance on.

The same phenomenon that increases safety and decreases maintenance also increases cooking performance. Thermal mass will be discussed in a later section, but this is a key attribute of cooking products that plays a major role in the heat up and cool down duration of the cooktop. This can have a significant impact on the cooking experience.

Most modern induction cooking products leverage their sophisticated power electronics to provide "PowerBoost" features. This feature name can vary across manufacturers. Essentially, it moves power away from unused heating zones to the heating zone currently in use. This can dramatically increase heat output, and therefore decrease time needed to boil liquids. This feature is not possible with gas or radiant technologies.

New features to enhance user experience

While many induction products available today have basic functionality, manufacturers are providing increasingly feature-rich offerings aimed at improving user experience. These are features that might be included on premium products and not required as part of the specification. However, these features could increase the cost of purchase for these appliances. Not every induction product needs these features, but they are beneficial in creating a diverse marketplace of products. Specific temperature set points, automated range hood syncing and activation, and remote cooktop control via Wi-Fi are found in mid to high-end induction products.

Temperature set point specification is a particularly unique feature of induction technology that can potentially change the way consumers interact with recipes and cook their food. A consumer setting their cookware to a specific temperature requires less guessing and variability between cooking events when compared to gas or radiant cooking. However, more research is needed to understand the impact of these features on product adoption.

Pan presence detection is another important feature in modern induction cooktops, as it ensures optimal cooking performance and efficiency. The system detects the presence of compatible cookware with a flat bottom surface containing iron. If an incompatible pan is detected, the cooktop will prevent inefficient operation that would have occurred without this technology. Conversely, when a compatible pan is present the cooktop will turn on and adjust its power output according to the indicated setting, which provides precise heating control and minimizes energy consumption.

2.4. Product barriers

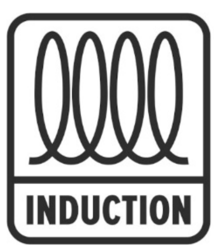
Although induction cooktops and ranges have greater energy efficiency, lower GHG emissions, and an enhanced cooking experience compared to both gas and radiant electric cooktops/ranges, there are barriers with the current market offerings that inhibit their widespread adoption at this time.

Upfront cost

The upfront cost of induction appliances is higher than both gas and electric equivalents for the following reasons:

- The more advanced power electronics required to generate the magnetic field at each hob (burner) increases manufacturing costs.
- Although induction cooking is a proven technology, it holds a smaller market share that typically means a higher purchase price until volume sales can be achieved.
- Due to the premium product features described above, induction products are currently being sold at higher price points.
- Induction cooktops may require the purchase of new, induction-compatible (ferromagnetic) cookware, which can be an additional expense for consumers. The standard symbol for this compatible cookware is found below in Figure 8.

Figure 8: The standard symbol for induction compatible cookware[11]



[11] https://www.beko.co.uk/support/faqs/hobs/which-pans-to-use-on-induction-hob.

Reliability and cost to repair/replace

Induction cooktops are known to have general reliability on par with gas and electric counterparts, but their glass top surface remains vulnerable to impact damage (similar to radiant electric cooktops). If damaged, these glass tops are expensive to replace, often a significant percentage of the cost of the entire cooktop. There are also open questions pertaining to the technology's sensitivity to home voltage fluctuations, which is discussed further in Section 6.

Given concerns with induction appliance repair costs, product warranties are important. Without decades of data to support the lifespan of a product, it is essential for manufacturers to ship induction appliances with robust warranties. Currently, most induction product warranties are 1-2 years for parts and/or labor. However, the internal components of these products are not time-tested, and stronger warranties are necessary to protect consumers and increase adoption.

Confusing controls on some models

Based on anecdotal reports, in contrast to the simple dial controls common on most gas ranges and cooktops, some induction cooktops have touch controls that are not intuitive or self-explanatory.

Visual cues

One aspect that consumers might take for granted is the reliance on visual cues to gauge temperature and heat output. The size of the flame serves as a clear indicator of the heat level, making it easy for cooks to adjust their technique accordingly. Even those who rely primarily on knob settings may double-check the flame to ensure it's at the right intensity.

In contrast, electric radiant cooktops lack a clear visual cue, with only a red glow appearing at higher temperatures. However, even this indication can be inconsistent due to the power cycling nature of many radiant cooktops. This absence of a clear temperature indicator on electric radiant cooktops can lead to confusion and increased risk of overcooking or undercooking food.

Induction cooking presents other visual challenges. The primary safety feature of induction cooking – a surface that doesn't become dangerously hot – can be a drawback for cooks who rely on even the limited visual cues of radiant cooking, much less the size of a gas flame. Induction cooktops lack a flame, red glow, or any visual indicators of heat output, instead relying on the position of the controls and the appearance of the food itself.

This can be particularly problematic for individuals who rely heavily on visual indicators to cook their food. Some manufacturers have begun addressing this issue by introducing features such as an LED ring of lights around the cooking zone that correspond with the heat output of the inductive coil. Samsung's "Virtual Flame Technology" is one example, claiming to provide a clear visual cue similar to gas cooking.[12]

While there is currently no publicly available data on consumer behavior surrounding this issue, it is likely that manufacturers will continue to develop features that address the reliance on visual cues in cooking. As electric and induction cooking technologies fill the electrification space, manufacturers must prioritize user experience and safety by providing clear temperature indicators and other visual cues that help cooks navigate these new cooking methods with confidence.

3. Technical barriers

3.1. Electrification barriers to fuel substitution

A recent California-based study found that upgrading to 240V induction appliances would require panel optimization or upgrades in 38% of multifamily units, and over 30% of single-family homes, assuming no circuit sharing.[13] Additionally, even if there is sufficient current capacity to support the required 30-50A, at least two circuits need to be available to maintain an existing panel. An Electric Power Research Institute (EPRI) survey noted 44% of households nationwide and 52% of households in the Western US had two or fewer open breaker slots.

Another study estimates around 3% of single-family properties and 10% of multifamily properties in California require electrical panel upgrades for comprehensive electrification.[14] Furthermore, the study estimated that 32% of single-family housing units and 59% of multifamily units in California have electric panels of intermediate capacity (100 amps or less) that require load management systems for electrification. Electrical panel service upgrades for single-family properties may average between $2,500 to $5,000 according to recent estimates from State incentive programs.[15] In multifamily housing, two recent studies estimate the cost of electrical

[12] https://www.samsung.com/us/business/builder/our-appliances/ranges/electric/ne58k9560ws-5-8-cu-ft-slide-in-induction-range-with-virtual-flame-ne58k9560ws-aa/.
[13] Opinion Dynamics. 2024. *Fuel Substitution Behind the Meter Infrastructure Market Study: Equity Segment DRAFT REPORT*. May 8. https://pda.energydataweb.com/api/view/3967/Fuel%20Substitution%20Behind%20the%20Meter%20Infrastructure%20Market%20Study%20Equity%20Segment%20DRAFT%202024-05-08.pdf.
[14] Eric Daniel Fournier, Robert Cudd, Samantha Smithies, Stephanie Pincetl, Quantifying the electric service panel capacities of California's residential buildings, Energy Policy, Volume 192, 2024, 114238, ISSN 0301-4215. https://www.sciencedirect.com/science/article/pii/S0301421524002581?ref=pdf_download&fr=RR-2&rr=8b700107cba43087.
[15] TECH Clean California. TECH Working Data Set - Heat Pump Data. Accessed August 23, 2024. https://techcleanca.com/heat-pump-data/download-data/.

panel upgrades for smaller properties at $12K to $89K and $179K to $281K for larger properties.[16,17]

The California census provides data on housing occupancy. In 2020, 3.8 million multifamily dwelling units and 7.8 million single-family dwelling units were occupied in California. Using the study data from above, 234,461 single-family homes and 382,951 multifamily dwelling units would require electrical panel upgrade services for comprehensive electrification. Furthermore, 2.5 million single-family and 2.3 million multifamily dwelling units would require load management systems to enable comprehensive electrification. The breakdown of data from the above study and the needs of California housing stock is tabulated below in Table 2.

Table 2: Upgrade and optimization needs for comprehensive electrification in California by housing type

	Minimum % requiring load management optimization	Minimum # of CA homes requiring load management optimization	Minimum % requiring upgrades	Minimum # of CA homes requiring upgrades	Estimated cost range for upgrades
Single-family	32%	2.5 million	3%	235,000	$2,500 - $5,000
Multifamily	59%	2.3 million	10%	383,000	$12,000 - $281,000

The CPUC has funded a program to provide a tool for helping building owners and residents identify if panel upgrades are required to support additional electrical appliances.[18]

Importantly, as consumers try to electrify their cooking from gas to 240V electric, both induction and radiant cooking products face the same electrical infrastructural challenges. Ranges and cooktops requiring 240V hookups, whether radiant or induction, still require the same electrical input that potentially require upgrades and/or optimization to existing electrical infrastructure in the home and on the grid.

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[16] Jones, Betony. June 15, 2021. "Los Angeles Building Decarbonization: Community Concerns, Employment Impacts, and Opportunities." Inclusive Economics, Oakland. CA. https://www.nrdc.org/sites/default/files/los-angeles-building-decarbonization-jobs-impacts-report-20211208.pdf.

[17] Stop Waste and Association for Energy Affordability (AEA). "Accelerating Electrification of California's Multifamily Buildings. Policy Consideration and Technical Guidelines." May 2021. https://www.stopwaste.org/accelerating-electrification-of-california%E2%80%99s-multifamily-buildings.

[18] Opinion Dynamics and Guidehouse. 2024. "CPUC Fuel Substitution Infrastructure Market Study - Data Tool Analysis Methods." Memorandum from to the California Public Utilities Commission.

Panel capacity observations

Home Energy Analytics (HEA) performed a study in 2022 to determine available panel capacity for California homes.[19] A subset of those results is shown in Figure 1, which displays the study participants with or without a minimum of 1,800W of electrical capacity available on existing electric panels. This data has relevant implications for 120V products, as 1,800W is the power constraint for 15A, 120V circuits found in many single and multifamily buildings. Although panel replacement is expensive and often impractical, many homes have the potential to optimize electric panels and create a dedicated circuit for an additional 120V appliance. As such, 120V plug-and-play induction cooking products have the potential to address the significant barrier of panel upgrades with the 240V product. The 120V products will be discussed in greater detail in the following sections.

Panel capacity single-family versus multifamily

The panel capacity dynamics between single family and multifamily buildings are distinct, each posing a unique set of challenges. Most single-family homes have one electric panel, with all electric end-uses and sub panels connected to this single source. If the home has a gas meter, there is a higher chance that the electric panel is smaller in size, on average. If the home has no gas hookup, the likelihood is that the panel is larger. Changes to single family electrical circuits and their panels are generally easier to understand due to the relative consistency across this building type compared to multifamily buildings.

Multifamily buildings have a wide variety of configurations for electric panels, end-uses, and tenants. Central systems, in-unit systems, direct metering, master metering, and potential tenant gas hookups all influence the electrification solutions that are most cost-effective for that building. This creates a greater level of complexity for electrification in multifamily buildings than single family homes.

If there are no central systems or gas meters in a multifamily building, the likelihood of a sufficiently large electric panel in each unit is higher. However, this best-case scenario is found infrequently in California. End-uses are often divided between gas and electric fuel, whether central or unitized, meaning that the typical in-unit electric panel for the building is too small to fully electrify the unit. However, if both domestic hot water and heating, ventilation, and air conditioning (HVAC) are centralized, and each unit already has electric cooking, building electrification is solely dependent on the central systems. This configuration is typically the more cost-effective electrification pathway for multifamily buildings. If the building uses central systems, but each unit has gas provided for cooking only, then electrification becomes more complicated due to panel size and gas infrastructure decommissioning. Even still, this configuration has cost-effective electrification solutions available through the adoption of 120V battery-equipped

[19] Home Energy Analytics publishes a number of their studies on their website, organized by date, including the November 2022 study cited here: https://corp.hea.com/about.

induction cooking products. These are discussed more thoroughly in the 120V battery-equipped ranges and cooktops section.

If a multifamily building has significant electrical infrastructure upgrades needed to substitute fuels for gas end-uses, then there are upstream barriers that must be considered as well. These issues around building service and grid transformers are discussed in the following section.

Panel/service/local transformers

A building owner has many issues to navigate when choosing to electrify. First, the electric panel must have sufficient current capacity and breaker slots, unless novel circuit sharing solutions are implemented. Second, if a panel upgrade is necessary, the building service must be upgraded to provide additional capacity to the new panel if it was previously insufficient. This must be coordinated with the local utility. Finally, if the building service requires upgrading, the utility must confirm that the local distribution infrastructure has sufficient capacity to support it. If the local infrastructure is insufficient, it typically means a nearby transformer must be upgraded. This final step is one of the biggest bottlenecks to full electrification efforts, as transformers have highly skilled labor requirements and sometimes lengthy manufacturer lead times, with many larger units requiring years of waiting before delivery.

Poor coordination between building owners, electricians, utilities, mechanical engineers, and other stakeholders can create headaches for fuel substitution retrofits. If this coordination is not smooth and affordable, then these barriers will inhibit gas-to-electric cooking retrofits and building electrification more broadly. The difficulty facing such coordination can create major motivation to implement creative solutions to electrify buildings without forcing a panel upgrade.

3.2. Performance limitations of 120V products

Tradeoffs and compromises

Manufacturers have not yet developed 120V range products for a good reason. Range products include an oven and if manufacturers were to develop this product, selecting a 120V induction range over a 240V induction range would involve a tradeoff between performance and electrical infrastructure upgrades. One of the key performance limitations of 120V products is their reduced power output. While conventional electric 240V induction range products can require close to 12,000W of power, the maximum power draw of a 120V induction range is significantly lower, at around 2,400W on a 20A circuit or 1,800W on a 15A circuit, as seen in Table 3 below.

Table 3: Displays the electrical performance characteristics

	Conventional induction range	Proposed 120V induction range
Circuit Voltage (Volts)	240	120
Max Current (Amps)	30 - 50	15 - 20
Max Power (Watts)	7,200 – 12,000	1,800 – 2,400

This performance gap between 120V and 240V products would be challenging for consumers. In the best-case scenario, the maximum power output of a 120V appliance on a 20A circuit is approximately 33% of the total power output available to a 30A 240V circuit. However, even this relatively high-power output is still significantly lower than what a conventional electric 240V induction range product can provide. For consumers who cook frequently or for large groups, a 120V induction range would not be sufficient to meet their needs. In contrast, 240V induction range products offer an uncompromising cooking experience with maximum performance.

One potential solution to the performance limitations of 120V products is to add a battery. By incorporating energy storage into a 120V induction range or cooktop, manufacturers could mitigate the power output issue while avoiding significant electrical infrastructure upgrades. However, the addition of a battery increases the cost significantly.

Ultimately, the decision to adopt a 120V induction cooking product over a 240V induction product depends on a careful evaluation of performance requirements, infrastructure upgrade considerations, and budget constraints. CalMTA, regulators, manufacturers, tradesmen, and consumers need to weigh the pros and cons of each product category when determining what the optimal electrification solution is. Currently, there are no 120V induction ranges (without a battery) available on the market, so the decision to adopt a lower performing range is unavailable to consumers who would consider this approach. However, battery-enabled solutions that solve for these performance limitations and infrastructural needs are entering the market, which will be discussed in the 120V battery-equipped ranges and cooktops section.

Available panel utilization data for cooking events

There are no available datasets for induction cooking appliance power draw behaviors. However, a Redwood Energy study created a dataset of electric resistance cooktop power draw data to determine how upgrading to more efficient induction technology would alleviate potential power/panel constraints for consumers.[20] The study indicates that, for this set of participants, induction cooktop technology can leverage its higher efficiency to meet most cooking needs for those currently using resistance cooking products. It determined that an1,800W induction heating coil could meet the peak cooking power demands of 85% of cooking sessions, and the average cooking power demands of 95% of cooking sessions. These results point to the possibility that lower power 120V induction cooktops can provide adequate cooktop performance for consumers.

120V battery-equipped ranges and cooktops

For consumers who are hesitant to invest in the electrification of their home kitchen due to the high costs and complexities involved, a viable alternative exists. Modern gas cooktops use electronic ignition systems that are powered by a standard 120V circuit, which means that these

[20]Xu, Ruoming and Ian Ira, Joshua (University of California at Davis). 2022. *Retrofit Ready Induction Stove*.

appliances can be easily converted to a new category of battery-equipped 120V cooking appliances.

These battery-equipped products have the potential to provide similar cooking performance benefits as conventional 240V appliances, despite being limited by the maximum power output of a typical 15A 120V circuit.

The first-to-market example, Channing Street Copper's "Charlie" stove, provides up to 3,200W of power output on a single inductive coil, with a peak battery power output of 10,000W. The inclusion of a battery removes the typical constraint of 1,800W of power provided directly by a 15A 120V circuit.

The battery-equipped products could offer several advantages, including reduced complexity associated with 240V cooking electrification, a single decision and purchase point, and additional functionality related to load-shifting, demand response, and resiliency. This product's battery provides resiliency by allowing cooking during power outages, similar to gas appliances, and has the potential to allow other electronic devices to plug in and use as backup power for more than cooking.

However, the tradeoff for this approach is a meaningful consideration. The cost of energy storage batteries contributes to product costs in this appliance category and comes with related safety risks that require market-ready solutions. Currently, "Charlie" mitigates both of these concerns by leveraging Lithium Iron Phosphate (LiFePO4) batteries, which have limited fire risk and are well-suited to load-shifting peak power demand, which creates opportunities for avoided costs for consumers on time of use (TOU) electricity rates.

4. Competitive landscape

Here we summarize a SWOT analysis, examining the Strengths, Weaknesses, Opportunities, and Threats of the MTI technologies and competing products. An objective and thorough SWOT analysis can reveal insights as to a future product strategy and help identify key barriers to overcome. The comprehensive SWOT is found in Table 4 and Table 5. Items in **bold** have dedicated subsections with additional details and supporting data. See footnotes for relevant section numbers.

4.1. Key strengths

One of the primary strengths of induction cooking products is their IAQ benefits. Compared to incumbent gas cooking, induction cooking has improved IAQ and a meaningful reduction in negative health impacts associated with combustion by-products, contaminants, and particulates. Induction cooking's improved IAQ will benefit the health of families, children, and ESJ communities in particular. Induction cooking technology also provides a higher performance cooking experience. Heat output is precise and immediate, and no heat is wasted on the thermal mass of the appliance, which simultaneously provides safety benefits as well.

4.2. Key weaknesses

Despite the improved IAQ and superior cooking experience of induction technology, these products face barriers with the electrical infrastructure of most California homes. Most homes with existing gas cooking products require some degree of modification to the electrical system to accommodate the more common 240V induction cooking products. 240V electrical infrastructure upgrades are often cost-prohibitive for building owners, which makes the adoption of induction cooking sensitive to factors external to the products themselves.

4.3. Key opportunities

240V induction cooking products have two powerful market opportunities. The first is in new construction homes, where Title 24 Electric Ready Requirements mandate that all new homes are constructed with 240V circuits in the kitchen, even if the builder is installing a gas cooking appliance. This means that any newly constructed home going forward will more easily adopt induction cooking by avoiding potentially cost-prohibitive electrical system upgrades. Secondly, induction cooking technology is a far superior cooking experience than incumbent electric resistance cooking products. Reduced thermal mass, precise temperature setpoints, and higher safety mean that any existing home with electric resistance cooking will be incentivized to upgrade their cooking experience if there is a market of affordable induction appliances for them to select from.

4.4. Key threats

Moving to electric cooking using the electricity rates of today will typically lead to increased bills. Although less efficient, gas is a cheaper fuel to cook with than electricity. TOU rates amplify this by increasing the cost to cook dinner at the exact time most of California cooks dinner. Gas cooking does not suffer from this threat.

Table 4: Competitive landscape for MTI cooking products, including strengths, weaknesses, opportunities, and threats

Product	Strengths	Weaknesses
MTI Product – 240V Induction Range	IAQ benefits[21] Fastest boiling times[22] High performance cooking experience Safe surface temperatures Easy to clean Lower emissions fuel supply Lower ventilation requirements Decreased peak cooling loads	The oven part of induction ranges have limited opportunity for efficiency improvements and still use electric resistance heating **Electrification barriers when substituting fuels**[23] **Reduced reliability**[24] Steeper learning curve for cooking experience Need for specialized cookware Unable to cook during power outage events Higher purchase price than incumbent technologies
MTI Product – 240V Induction Cooktop	Relatively easy do-it-yourself installation (excluding potential electrical work) **IAQ benefits** **Fastest boiling times** High performance cooking experience Safe surface temperatures Easy to clean Lower emissions fuel supply Lower ventilation requirements Decreased peak cooling loads	**Expensive, on average, even relative to 240V Induction Range products that include an oven**[25] **Electrification barriers when substituting fuels** **Reduced reliability** Steeper learning curve for cooking experience Need for specialized cookware Unable to cook during power outage events Higher purchase price than incumbent technologies

[21] See Section 4.1
[22] See Section 4.4
[23] See Section 4.2
[24] See Section 4.3
[25] See Section 4.5

Product	Strengths	Weaknesses
MTI Product – 240V Radiant Range	Easier to repair than induction[26] More affordable Familiar, if lower performing, cooking experience Fully mature technology Lower ventilation requirements No need for specialized cookware Lower emissions fuel supply	Overshoot/thermal mass affects cooking performance[27] Electrification barriers when substituting fuels Hot surface is less safe than induction Hard to clean Unable to cook during power outage events
MTI Product – 240V Radiant Cooktop	Easier to repair than induction More affordable Familiar, if lower performing, cooking experience Fully mature technology Lower ventilation requirements No need for specialized cookware Lower emissions fuel supply	Overshoot/thermal mass negatively affects cooking performance Electrification barriers when substituting fuels Hot surface is less safe than induction Hard to clean Unable to cook during power outage events
MTI Product – 120V Battery-Equipped Induction Range	Load shifting opportunities, lower peak demand bill contribution[28] IAQ benefits Fastest boiling times[29] Battery provides cooking performance of higher voltage products	Battery fire risk perception[30] Battery cost[31] Potential fire code compliance issues Consumer understanding to cook with a battery Time constraint on battery-assisted performance Need for specialized cookware

[26] See Section 4.6
[27] See Section 4.7
[28] See Section 6.3
[29] Battery-equipped 120V induction cooking products are comparable to 240V induction cooking boiling times only when the battery contains enough charge to provide this level of performance.
[30] See Section 8.4
[31] See Section 8.3

Product	Strengths	Weaknesses
	Increased resiliency with blackout battery backup Fewest electrification barriers for panel upgrades by plugging into existing 120V outlet Lower emissions fuel supply Lower ventilation requirements Decreased peak cooling loads	
MTI Product – 120V Battery-Equipped Induction Cooktop	**Load shifting opportunities, lower peak demand bill contribution** **IAQ benefits** **Fastest boiling times** Battery provides cooking performance of higher voltage products Increased resiliency with blackout battery backup Fewest electrification barriers when plugging into existing 120V outlet Lower emissions fuel supply Lower ventilation requirements Decreased peak cooling loads	**Battery fire risk perception** **Battery cost** Potential fire code compliance issues Consumer understanding to cook with a battery Time constraint on battery-assisted performance boost Need for specialized cookware

Product	Opportunities	Threats
MTI Product – 240V Induction Range	Offer a higher performing product to consumers with coil-type resistance ranges Leverage existing consumers with coil-type resistance ranges to bypass electrification barriers Minor bill savings for consumers upgrading from resistance tech	Resistance ovens have little room for improvements in efficiency TOU rates amplify bill impacts of fuel substitution due to typical cooking hours, which are further exacerbated by range products due to oven fuel substitution and the limited efficiency opportunities for them

Product	Opportunities	Threats
	Can transform market perception of electric cooking experience quality New construction codes requiring installation of 240V outlet even if builder is installing gas	Lack of electrical panel capacity prevents consumers from moving to electrical cooking Need for specialized cookware Premium features bloat prices and suppress demand
MTI Product – 240V Induction Cooktop	Offer a higher performing product to consumers with coil-type resistance ranges Leverage existing consumers with coil-type resistance ranges to bypass electrification barriers Minor bill savings for consumers moving from resistance tech Can transform market perception of electric cooking experience quality New construction codes requiring installation of 240V outlet even if builder is installing gas	240V cooktops face additional barrier through National Electric Code (NEC) requirement for dedicated wall oven circuit TOU rates amplify bill impacts of fuel substitution due to typical cooking hours Lack of electrical panel capacity prevents consumers from moving to electrical cooking Need for specialized cookware Premium features bloat prices and suppress demand
MTI Product – 240V Radiant Range	Radiant cooking technology could offer a lower cost alternative compared to induction for consumers looking to electrify New construction codes requiring installation of 240V outlet even if builder is installing gas New ENERGY STAR specification certifies radiant products, which helps promote the appliance	TOU rates amplify bill impacts of fuel substitution due to typical cooking hours, which are further exacerbated by range products due to oven fuel substitution and the limited efficiency opportunities for them Perception issues around poor radiant electric cooking experience Manufacturers potentially unwilling to engage until consumer acceptance data is comprehensive Overshoot and high thermal mass in some radiant products may sour consumers to all electrical cooking including induction
MTI Product – 240V Radiant Cooktop	Radiant cooking technology could offer a lower cost alternative compared to induction for consumers looking to electrify New construction codes requiring installation of 240V outlet even if builder is installing gas	TOU rates amplify bill impacts of fuel substitution due to typical cooking hours 240V cooktops face additional barrier through NEC requirement for dedicated wall oven circuit

Product	Opportunities	Threats
	New ENERGY STAR specification certifies radiant products, which helps promote the appliance	Perception issues around poor radiant electric cooking experience Manufacturers potentially unwilling to engage until consumer acceptance data is comprehensive Overshoot and high thermal mass in some radiant products may sour consumers to all electrical cooking including induction
MTI Product – 120V Battery-Equipped Induction Range	120V battery-equipped appliances can have a lower cost to electrify compared to 240V products while still offering all induction benefits Consumers in hot climates may be encouraged to move from gas due to kitchen heating Eliminates need for added air ventilation requirements which add costs to use of gas products Opportunity to pool consumers into virtual power plants for demand side management programs Ability to continue to cook during power outages Leverage improved IAQ over gas	Consumers still perceive gas cooking as the ultimate experience, unmatched by electric cooking Culture-based preferences make some customers resistant to substituting cooking fuels Gas industry increases PR investments for gas cooking, obstructs regulation and legislation to eliminate it Battery life degradation Fire code compliance Battery costs and relative uncertainty in future battery supply chains Inconsistent performance and associated consumer education
MTI Product – 120V Battery-Equipped Induction Cooktop	120V battery-equipped appliances can have a lower cost to electrify compared to 240V products while still offering all induction benefits Consumers in hot climates may be encouraged to move from gas due to kitchen heating Eliminates need for added air ventilation requirements which add costs to use of gas products	Consumers still perceive gas cooking as the ultimate experience, unmatched by electric cooking Culture-based preferences make some customers resistant to substituting fuels Gas industry increases PR investments for gas cooking, obstructs regulation and legislation to eliminate it Battery life degradation Fire code compliance

Product	Opportunities	Threats
	Opportunity to pool consumers into virtual power plants for demand side management programs Ability to continue to cook during power outages Leverage improved IAQ over gas	Battery costs and relative uncertainty in future battery supply chains Inconsistent performance and associated consumer education

Table 5: Competitive landscape for incumbent cooking products, including strengths and weaknesses

Product	Strengths	Weaknesses
Incumbent Technology – Gas Range	High performing, intuitive cooking experience Easy to repair Allows for consumers to continue to cook during power outage High control cooking experience	Negative IAQ, affecting health and safety Higher greenhouse gas emissions Higher ventilation requirements Increases peak cooling loads Increased energy waste due to ~34% thermal efficiency
Incumbent Technology – 240V Resistance Coil Range/Cooktop	IAQ benefits Lower emissions fuel supply Fully mature technology, reliable Affordable	**Overshoot/thermal mass negatively affects cooking performance** Uneven coil surface, can be difficult to cook and clean Hot surface safety Unable to cook during power outage events

5. Codes & standards

5.1. Federal standards

Cooktops, ovens, and ranges are regulated under federal appliance efficiency standards. For gas cooking those standards prohibit gas cooktops and gas ovens from being equipped with a constant burning pilot light.[32] There are no standards for electric cooktops or ovens currently in effect. In 2024, the U.S. DOE issued a direct final rule[33] establishing a maximum integrated annual energy consumption (IAEC) for both gas and electric cooktops and the cooktops on ranges that are manufactured on or after January 31, 2028:

Table 6: Energy conservation standards for consumer conventional cooktops manufactured on or after January 31, 2028

Product class	Maximum IAEC
Electric smooth element standalone cooktops	207 kWh/year
Electric smooth element cooktops component of a range	207 kWh/year
Gas standalone cooktops	1,770 kBTU/year
Gas cooktop component of a range	1,770 kBTU/year

IAEC is a combined measure that includes the average burner energy consumption and the standby power energy consumption, calculated over a year.

The rule would continue to prohibit gas ovens from having a constant burning pilot, and it would prohibit both gas and electric ovens from being equipped with a linear power supply for products manufactured on or after January 31, 2028. Neither portable cooking products nor electric coil cooktops are subject to any efficiency standards. Induction cooktops are a type of "Electric Smooth Element Cooktop," which also includes smooth top electric resistance cooking tops but does not include electric coil cooking tops.

Based on testing conducted during the rulemaking,[34] the proposed standards would eliminate:

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[32] 10 C.F.R § 430.32(j)(1) and (j)(2).

[33] 89 Fed. Reg. 11434 (Feb. 13, 2024). A direct final rule is typically effective 120 days after its issuance unless it is withdrawn. In this case, the direct final rule took effect June 13, 2024.

[34] Technical Support Document, Tables 5.5.7 (Test Results for Electric Smooth Element Cooking Tops), 5.5.8 (Expanded Test Results for Electric Smooth Element Cooking Tops), 5.5.9 (Test Results for Gas Cooking Tops), and 5.5.10 (Expanded Test Results for Gas Cooking Tops).

8 out of the 70 tested electric smooth cooktops (11%), including both some electric resistance and some induction models.

2 of the 57 tested gas cooktops (4%).

Federal appliance standards are required to establish separate product classes based on certain performance characteristics, including type of fuel used.[35] DOE is further prohibited from establishing an efficiency standard that would eliminate a product feature, including fuel type, that is widely available in the market today.[36] All federal appliance standards divide product classes into gas and electric types. The corresponding efficiency levels are based solely on the technological feasibility and economic justification of comparing the efficiencies within a fuel type, not between fuel types. As a result, DOE is unlikely to develop a standard that prohibits a gas cooktop, oven, or range, although DOE has adopted standards that could result in fuel-substitution between products, such as for water heaters or furnaces, by adopting levels of stringency for gas that are feasible but more costly than moving to an electric alternative.

U.S. Environmental Protection Agency's (EPA) ENERGY STAR program has a voluntary specification that establishes maximum IAEC levels for electric cooktops and a dual-metric of IAEC and annual combined standby power energy ($E_{TLP,O}$) for the oven portion of an electric range.[37] There is no ENERGY STAR specification for gas cooking tops or ranges. The maximum energy consumption for electric cooking tops is:

Table 7: Energy use requirements for ENERGY STAR electric cooktops

Product class	Maximum energy consumption
Electric cooktop	195 kWh/year IAEC
Electric range	195 kWh/year IAEC
	7 kWh/year $E_{TLP,O}$

As of October 18, 2024, 20 cooktops and 62 ranges have been certified to meet the ENERGY STAR requirements. Of these, 39 use induction technologies and 32 use electric resistance (radiant).[38]

As this is the first ENERGY STAR specification for cooking products, more appliances may continue to qualify for this list. The development of this spec was accelerated to ensure

[35] 42 U.S.C. § 6295(q)(1).
[36] 42 U.S.C. § 6295(o)(4).
[37] ENERGY STAR Program Requirements for Residential Electric Cooking Products Version 1.0 (Oct. 2023). https://www.energystar.gov/products/electric_cooking_products/residential_electric_cooking_products_version_1.
[38] ENERGY STAR Certified Residential Electric Cooing Products dataset, last updated October 18, 2024. https://data.energystar.gov/Active-Specifications/ENERGY-STAR-Certified-Residential-Electric-Cooking/m6gi-ng33/about_data.

consumers could use it as a tool to receive Inflation Reduction Act (IRA) incentives. Manufacturers will continue adapting to these requirements in anticipation of the availability of these funds.

National Electric Code

The National Electric Code is what licensed electricians follow in their trade. While most of this code does not specifically influence cooking appliance technologies, there is at least one nuance that should be noted here. When a 240V wall oven is installed, it is required to have a dedicated 240V circuit. Whether the kitchen cooktop is gas or even 240V electric, the wall oven must have a separate circuit. This code can potentially increase costs for single family home electrification where separate wall ovens and cooktops are more common.

5.2. Federal test procedures

DOE established performance test procedures for gas and electric cooktops in 2022[39] and ENERGY STAR has incorporated the electric federal test procedure into its voluntary specification.[40] The test procedure for cooktops is 10 C.F.R. Part 430, Appendix I1 to Subpart B, and is based on International Electrotechnical Commission (IEC) 60350-2 (active mode test for cooking products) and IEC 62301 (standby mode test). It can be found in Attachment 2 of this document. Manufacturers are required to begin testing using this test procedure when they certify their cooking products for compliance with the federal standards for products manufactured on or after January 1, 2028. They must also use this test procedure before 2028 if they certify their products to the ENERGY STAR program or if they make any public representations about the energy use of the product.

The federal test procedure contains the following key elements:

- Overshoot test: Used to calculate the turndown temperature to bring water down to a simmer.
- Simmer test: Measures the energy use while the water is turned up to and then held at a simmer.
- Standby mode test: Measures the energy use while the cooking zones are not being used.
- Test of each cooking zone (excluding specialty cooking zones).

The federal test procedure excludes specialty cooking zones from the test, so energy consumption from these elements is not counted towards meeting the standard levels.

[39] 87 Fed. Reg. 51492 (Aug. 22, 2022), https://www.regulations.gov/document/EERE-2021-BT-TP-0023-0024.
[40] ENERGY STAR Program Requirement for Residential Electric Cooking Products Version 1.0 (Oct. 2023), section 4: Test Requirements.

5.3. California standards

State appliance standards

California does not directly regulate residential cooking products. The State's appliance efficiency regulations incorporate the current federal design standards (prohibiting a constant burning pilot) for residential gas cooktops and ovens.[41] It is expected that the California Energy Commission will eventually incorporate the federal performance standards, establishing maximum IAEC levels for both gas and electric cooktops and ovens, in a future rulemaking to align the state and federal requirements. These state standards would only take effect if the federal standards were repealed.[42] However, the California Energy Code (CEC) may eventually require that cooktops, ovens, and ranges report their IAEC levels into the California database of products to be sold in the state.

State building codes

California's CEC, Title 24, Part 6, does not contain any direct regulation of residential cooking products. Like plug-loads, residential cooking products are considered an "unregulated" energy end use.[43] The CEC has long avoided incorporating moveable appliances into the building code out of concerns for persistence (whether the appliance will stay with the building for 30 years to achieve the expected energy savings).

Title 24 does, however, contain three key indirect regulations related to cooking products that push a builder toward electric cooktops and ovens to avoid additional compliance costs from installing gas cooking products. These include:

Code compliance "incentives" for all-electric buildings

Electric-readiness requirements for kitchens

Additional range hood requirements for gas cooktops

Incentivizing all-electric buildings

Both the prescriptive and performance paths in the California Energy Code contain provisions that incentivize builders to build all-electric buildings. For example, the prescriptive pathway largely requires heat pump technologies for space- and water-heating, and the home must be "electric-ready" (described further below) and have solar photovoltaic panels. Gas technologies are prescriptively permitted only in a few climate zones and special situations in newly constructed buildings (with this list of exceptions decreasing each code cycle). Similarly, under the performance pathway, the baseline building is modeled after one relying on heat pump

[41] Cal. Code Regs., tit. 20, §§ 1601-1608.

[42] Cal. Code Regs., tit. 20, § 1605(a)(2).

[43] See California Energy Commission, 2023. 2023 Single-Family Residential Alternative Calculation Method Reference Manual for the 2022 Building Energy Efficiency Standards, at p. 2 (June 2023). Available at: https://www.energy.ca.gov/sites/default/files/2023-07/CEC-400-2022-008-CMF-REV2_0.pdf.

technologies. This requires a builder interested in using gas to identify other efficiency improvements to offset the energy cost associated with the use of gas.

All-electric buildings are also mildly incentivized by CEC's use of a Long-Term System Cost (LSC) metric to evaluate the cost-effectiveness of the code and to set the energy budget for the performance approach. LSC replaces time-dependent valuation (TDV) for the 2025 Energy Code. Like TDV, LSC considers long-term, energy-system costs, including costs of transmission and distribution, capacity, emissions, and other factors that vary by hour and day of the year. LSC also incorporates these costs but shifts the valuation to value energy savings in the heating season while placing less value on peak cooling savings. LSC tends to encourage envelope improvements for compliance, which leaves less additional efficiency available for a gas building to select offsetting the higher energy cost of gas relative to an electric building.

Electrification readiness requirements

Title 24 has been updated to include electrification readiness requirements for cooking. Specifically, Title 24, Part 6, Section 150.0 (u) requires that systems using gas or propane cooktop to serve individual dwelling units shall include:

1) A dedicated 240V branch circuit wiring within 3 feet from the cooktop and accessible to the cooktop with no obstructions. The branch circuit conductors shall be rated at 50 amps minimum. The blank cover shall be identified as "240V ready." All electrical components shall be installed in accordance with the California Electrical Code.
2) The main electrical service panel shall have a reserved space to allow for the installation of a double pole circuit breaker for a future electric cooktop installation. The reserved space shall be permanently marked as "For Future 240V use."

This will allow any new single-family or multifamily building permitted under this requirement to be capable of electrifying cooking eventually, even if a gas cooking appliance is initially installed. For a builder deciding between gas and electric, the electric-readiness requirements may drive the builder to choose an electric cooktop or range to avoid the added costs of plumbing and installing a gas cooktop in addition to the electrical outlets and panel requirements.

Additional requirements for gas cooktops to manage indoor air quality

Title 24 contains requirements for range ventilation hoods that require higher cubic feet per minute (CFM) for homes and apartments with gas cooktops due to the increased indoor pollutants. The smaller the home or apartment, the bigger the range ventilation hood needs to be, since the reduced air volume of a small home is more easily contaminated (on a percentage basis) with gas combustion by-products.

Table 8: Title 24, Section 150.0-G Kitchen Range Hood Airflow Rates (cubic feet per minute, cfm) and ASTM E3087 Capture Efficiency (CE) Ratings According to Dwelling Unit Floor Area and Kitchen Range Fuel Type

Dwelling unit floor area (ft^2)	Hood over electric range	Hood over natural gas range
>1500	50% CE or 110 cfm	70% CE or 180 cfm
1000 - 1500	50% CE or 110 cfm	80% CE or 250 cfm
750 - 1000	55% CE or 130 cfm	85% CE or 280 cfm
<750	65% CE or 160 cfm	85% CE or 280 cfm

The requirement for a higher airflow kitchen range hood when installing a gas cooktop creates a small incentive to install instead an electric cooktop with a lower cost range hood.

Local building codes

In California, local jurisdictions may adopt their own "reach codes" that exceed the requirements of the state building energy code. One initial example of such a reach code was to prohibit gas use in newly constructed buildings, such as in the City of Berkeley, or to require all-electric buildings, such as in the City of Santa Clara. These codes would have effectively required new buildings to use electric cooking products. However, *California Restaurant Association v. City of Berkeley*[44] found that Berkeley's ordinance was preempted by the federal appliance standards. Many local jurisdictions with similar ordinances or with all-electric building ordinances have since revised or amended their standards to avoid legal issues.

More recently, the City of Berkeley has proposed a new initiative to create a natural gas tax.[45] Berkeley voters will determine if this $2.96 per therm tax will be enacted for non-rent-controlled buildings, single-family homes, or buildings under 15,000 square feet. This tax would not be paid by the occupants who use the gas, only the owners of the building in which it is consumed. To protect tenants, this initiative would make it illegal for building owners to raise rent in order to offset this tax.

Local jurisdictions are exploring and advancing decarbonization in other ways, including using a source energy approach similar to the California Energy Code to reflect the full costs of natural gas, resulting in:

[44] 89 F.4th 1094 (9th Cir. 2023).

[45] Borenstein, Severin. 2024. "Berkeley Makes Another Run at Natural Gas." Energy Institute Blog. August 19, 2024. https://energyathaas.wordpress.com/2024/08/19/berkeley-makes-another-run-at-natural-gas/.

Making gas-fueled buildings more expensive to build[46]

Developing additional electric-readiness requirements that make it costlier for a builder to install both electric hookups as required and include gas appliances that are not required[47]

Imposing a carbon tax on buildings that use natural gas on site[48]

All of these would further incentivize the installation of electric cooking products.

Federal preemption barriers

The Energy Policy and Conservation Act (EPCA), 42 U.S.C. sections 6291 and following, requires DOE to adopt federal appliance standards. This law preempts states and local governments from:
Requiring testing or reporting that are inconsistent with the federal test procedure

Requiring labeling that is inconsistent with federal labeling

Applying standards to federally covered appliances[49]

The building code exception to preemption allows state and local building codes to regulate covered appliances as long as those codes meet seven criteria.[50] This exception still requires that the code provide at least one pathway for minimally compliant federally regulated appliances to be installed.

In *California Restaurant Association v. City of Berkeley*, the court read EPCA's preemption provisions broadly to, in non-legal terms, disallow any regulation, including a building code, that has the effect of prohibiting an appliance that complies with the federal appliance law when the law is based on regulating the energy of the appliance.

For cooking appliances, states and local governments are preempted from:
Directly regulating the energy use or energy efficiency of a cooktop, range, or oven

Banning a type of cooktop, range, or oven because it uses natural gas

Adopting building codes that prohibit the installation of a gas cooktop, range, or oven

Part of the building code exception to preemption allows for efficiency credits for higher-than-minimum-efficiency appliances if provided on a "one-for-one equivalent energy use or equivalent

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[46] City of San Jose, Ordinance No. 30950, effective October 27, 2023, available at https://efiling.energy.ca.gov/GetDocument.aspx?tn=253580-5&DocumentContentId=88813.
[47] See potential resources for this measure at https://localenergycodes.com/content/reach-codes/electric-ready?rid=1208.
[48] Fossil Free Berkeley, Ballot Measure Text, available at https://fossilfreeberkeley.org/ballot-text-large-buildings-fossil-fuel-emissions-tax/.
[49] 42 U.S.C. § 6297(a)-(c).
[50] 42 U.S.C. § 6297(f)(3).

cost basis." One way that some states (i.e., Washington) have done this is to calculate the efficiency of a minimum efficiency gas appliance compared with the efficiency of a minimum efficiency electric appliance, usually by converting to BTUs. Because gas products are often less efficient than heat pump or high-efficiency electric products, the state can then require that the builder identify other efficiency improvements to couple with the gas product to make it equally efficient to the electric product. Because these additional efficiency improvements often add significant cost to the builder, this can drive the builder to choose to install just the electric product to keep costs down.

In order for this approach to incentivize installation of induction cooktops, the cost to install an induction cooktop needs to be less than the cost to install a gas cooktop plus additional efficiency measures.

5.4. Non-energy regulations

The California Air Resources Board (CARB) is currently developing and proposing zero-emission GHG standards for new space and water heaters sold in California as part of the 2022 State Strategy for the State Implementation Plan. The focus is on reducing the "carbon dioxide equivalent" emissions which include carbon dioxide, nitrous oxide, and methane. CARB intends for the regulation to take effect in 2030 and has stated that they also may explore including cooking appliances but have not proposed to include them so far in the rulemaking. CARB is primarily focused on outdoor emissions and will be unlikely to consider gas stoves in homes until later this decade.

Assembly Bill 2513, passed by the California Assembly and now waiting for its third hearing before the Senate Committee, would require on or after January 1, 2025, that all gas stoves sold in the state have a label about air pollutants and their potential health hazards. The bill was passed by the Assembly and was heard in the Senate committee on Environmental Quality on June 5. While it did not pass, it was sent back for "reconsideration" at the time of this report. Having a label about the negative health impacts of natural gas stoves could educate consumers to choose electric cooktops, increasing the market for these products.

6. Product performance

Product performance for modern electric cooking products (such as induction cooktops) can be evaluated and understood relative to two baselines:
Gas cooking products

Conventional, inefficient electric resistance cooking products

Although ovens (when part of a range) are included in the product definition, the most significant differences in product performance are related to the fuel source and technology used in cooktops.

As such, this section is focused on differences in cooktop performance, which can be sorted into two primary categories, with some overlap between the two:

Performance as it relates to energy efficiency and emissions reductions

Performance as it relates to cooking (user) experience

Since all types of electric cooktops are inherently more efficient than gas cooktops (per unit of energy input), product performance features that improve the user (i.e., cooking) experience – and have the potential to increase the rate of adoption – are of particular importance for cooking appliances.

6.1. Efficiencies of different cooktop technologies

Different programs and resources use slightly different definitions of energy efficiency for cooking products, as well as different methods for assessing efficiency. These are described below.

CA eTRM: According to the California Electronic Technical Reference Manual (CA eTRM), cooking efficiency is calculated as the ratio of thermal energy absorbed by the food divided by the energy consumed by the device as it is heating the food. CA eTRM assumes the following efficiencies for gas, resistance, and induction cooktops.[51]

Gas: 40%

Resistance: 74%

Induction: 84%

ENERGY STAR: EPA's ENERGY STAR for cooking appliances uses a standardized test procedure to allow direct comparison between different products and technologies.[52, 53] Although real world cooking activities and energy efficiency will inherently deviate from the findings of the test procedure, it offers a standardized set of parameters by which to measure and understand the efficiency of different products.

The current version and test method for ENERGY STAR cooking appliances sets a threshold for maximum IAEC of 195 kWh/year, which reflects energy used by the cooktop, whether standalone or part of a range.

According to the EPA,[54] ENERGY STAR certified residential electric cooking products under the Version 1 specification will offer users, on average, energy savings of approximately

[51] The CA eTRM uses these deemed efficiency values as references for program calculations, and they do not reflect the performance of every product in each category. These values were finalized using data from a study performed by Frontier Energy and the 2014 ACEEE Summer Study.

[52] ENERGY STAR. 2023. "ENERGY STAR® Program Requirements for Residential Electric Cooking Products Partner Commitments Rev. October 2023."

[53] Code of Federal Regulations. Appendix I1 to Subpart B of Part 430 – Uniform Test Method for Measuring the Energy Consumption of Conventional Cooking Products.

[54] United States Environmental Protection Agency. "ENERGY STAR Residential Electric Cooking Products Manufacturers and Other Interested Stakeholders" Letter from S. Leybourn and T. Crk. September 25, 2023.

18% from standard electric units. However, it does not define or describe efficiency as a ratio or percentage.

Due to the inherent inefficiencies and negative externalities (i.e., IAQ impacts) of gas cooktops ENERGY STAR does not offer a path for their certification.[55]

A dataset of cooking appliances was collected for this MTI. It includes gas, radiant, and induction cooktop and range products in both 120V and 240V. The data was collected by hand to provide a comprehensive perspective of both induction and radiant products offered today, with a smaller emphasis on available gas cooking products. The dataset contained both ENERGY STAR certified and non-ENERGY STAR certified products. Relatively few products have undergone the certification process to date, in part because the Environmental Protection Agency recently introduced ENERGY STAR for cooking appliances, and that standard is restrictive with respect to currently available induction cooking products. 120V and portable induction cooking products have become more commonplace but are not eligible for ENERGY STAR. However, the number of induction cooking products that are certified are likely to increase as more time passes and the market continues to develop. It should be noted that all products currently listed as ENERGY STAR certified are produced by major manufacturers, who may be more sophisticated and well-funded than smaller companies, allowing them to navigate and complete the certification process. This does not necessarily mean that more affordable products from smaller manufacturers are less efficient.

Tested annual energy consumption

DOE, the Association of Home Appliances Manufacturers, and Pacific Gas and Electric (PG&E) performed tests on 75 electric cooktops and ranges. The data from this was published in a 2023 DOE Technical Support Document and was used in an analysis for ENERGY STAR product criteria for both induction and radiant cooktops.[56]

The range of IAEC values was close to 40 kWh/year across each technology, but no radiant products consumed less than 186 kWh/year while many induction products tested below that. The most notable takeaway from this data was the spread of magnitude in standby power consumption across products within and without each technology and form factor. Figure 9 below displays mean and median annual combined low-power-mode energy consumption (ETLP) for induction and resistance cooktops and ranges from the 2023 DOE Technical Support Document above. Notably, the mean ETLP for induction cooktops and ranges are considerably higher than the median for each. This indicates a wide spread of ETLP values for these products relative to the smaller delta between average ETLP values for resistance cooktops and ranges. Also important is

[55] Energy Star. "Electric Cooking Products." Accessed July 31, 2024. https://www.energystar.gov/products/electric_cooking_products.

[56] Energy Efficiency and Renewable Energy Office. 2023. "Updated Cooking Top Test Sample, Energy Conservation Program for Consumer Products and Commercial and Industrial Equipment, Conventional Cooking Products, August 2023." July 31, 2023. https://www.regulations.gov/document/EERE-2014-BT-STD-0005-10090.

the larger ETLP for range products, which is due to the contribution of low-power-mode energy consumption of the oven in addition to the cooktop.

Figure 10 displays mean and median IAEC values from the same data set. Range IAEC values are marginally higher than cooktop IAEC due to the low-power consumption contribution of the oven, as ETLP is a component of IAEC. Interestingly, the median induction range IAEC is lower than the mean IAEC, while the median resistance range IAEC is higher than the corresponding mean IAEC. This indicates more induction products tested at higher IAEC values than the average resistance range product, but the most efficient products tested were induction. This trend is not present for the cooktop form factor, where induction cooktop mean IAEC is lower than the median IAEC. This indicates that for induction cooktop technology, there are more outliers at the higher end of energy consumption with respect to the other categories. This is a statistical trend that is not unexpected for a technology that is both less mature, and a form factor that does not incorporate the average energy consumption of an electric resistance oven.

Figure 9: Total ETLP for induction and resistance cooktops and ranges (ETLP in kWh/year)

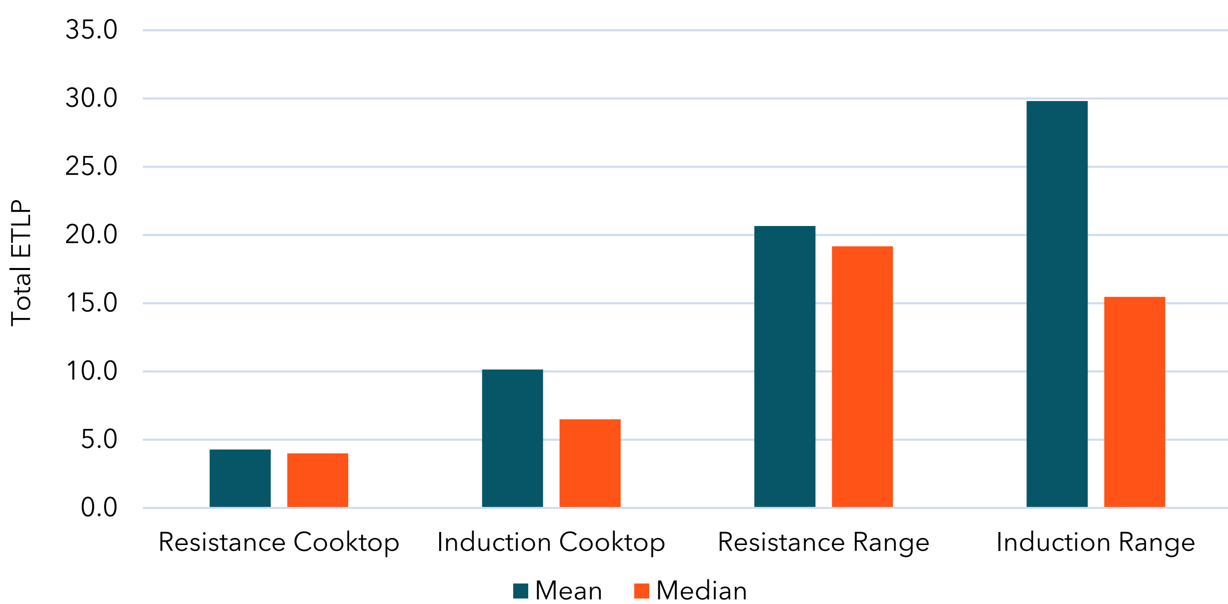
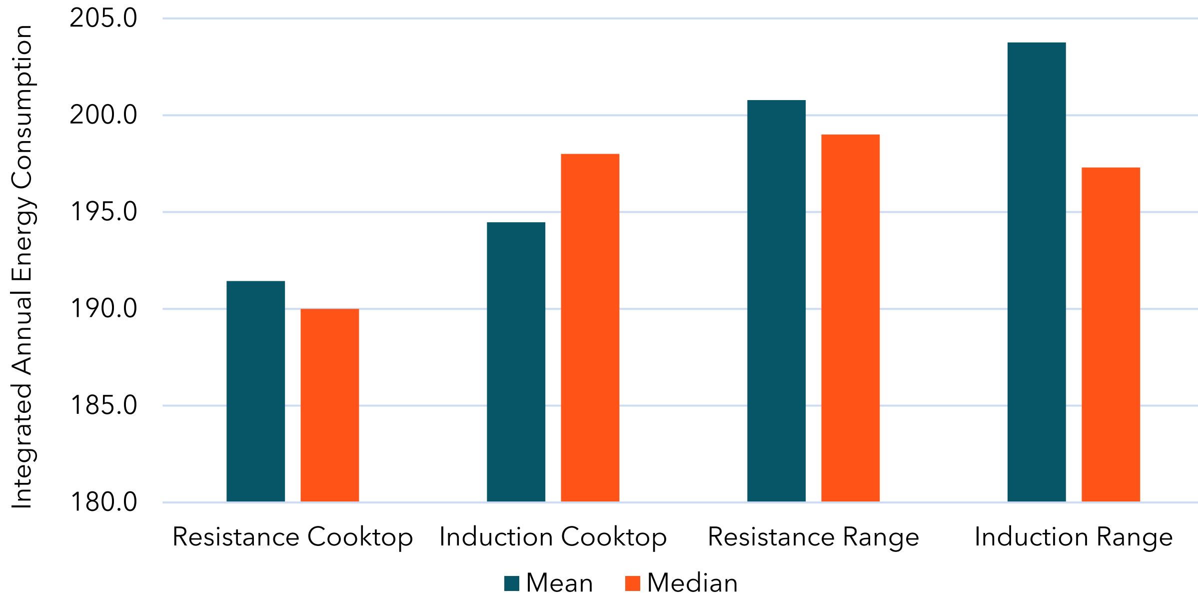


Figure 10: Integrated annual energy consumption for induction and resistance cooktops and ranges (IAEC in kWh/year)



Technical differences that affect efficiency

The efficiency of each cooking technology is influenced by unique factors, including convective heating losses and thermal boundary layer geometry. Electric resistance and gas appliances use convective heating, which heats the air mass below and around the cookware, creating a thermal boundary layer that, in part, determines overall efficiency. Smaller cookware sizes lead to thicker thermal boundary layers, resulting in wasted heat energy. Conversely, larger cookware has more surface area for heat transfer to occur, minimizing the thermal boundary layer and increasing efficiency.

In electric resistance cooking, the heating zone diameter remains constant regardless of heat output settings, whereas gas cooking allows for adjustable flame size to accommodate different cookware sizes. The conductive/radiant heating at the edge of an electric resistance heating zone primarily heats air mass, contributing little to cookware heating and thickening the thermal boundary layer, which decreases overall system efficiency.

A paper published in the 2014 ACEEE Summer Study on Energy Efficiency in Buildings highlights the impact of cookware size on efficiency.[57] Conventional electric technology showed higher

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[57] Sweeney, M., J. Dols, B. Fortenbery, and F. Sharp (EPRI). 2014. "Induction Cooking Technology Design and Assessment." *Proceedings of the 2014 ACEEE Summer Study on Energy Efficiency in Buildings, 9-370.* Washington, DC: American Council for an Energy Efficiency Economy (ACEEE).

efficiency (83%) when tested with large cookware, while induction cooking maintained a relatively consistent efficiency regardless of cookware size. However, conventional electric technology's efficiency fell to 42% when used with small cookware, emphasizing the importance of considering cookware size in evaluating energy efficiency in cooking technologies. The ENERGY STAR test procedure does not currently account for cookware size in the values published, which creates a potentially hidden bill impact and performance benefit for conventional resistance cooking using larger cookware.

Uniquely, induction cooking technology efficiency is also partly determined by heat buildup in the power electronics control board and the transistors that make induction work. This heat is regulated by an internal fan and/or heat sink ubiquitous to induction heating appliances. There are no equivalent comparisons for internal heat gains/waste heat in gas or resistance appliances.

Frontier Energy conducted research in 2019 demonstrating the efficiency of all three cooking technologies across six different appliances.[58] Table 9 displays the measured thermal efficiency of each appliance tested by Frontier Energy.

Table 9: Selected test results from the 2019 Residential Cooktop Performance and Energy Comparison Study by Frontier Energy

Cooktop	Induction A (Frigidaire)	Induction B (GE)	Induction C (Samsung)	Resistance Ceramic (Whirlpool)	Resistance Coil (Frigidaire)	Gas Burner (Samsung)
Large Hob Input Rate	3.6 kW	3.7 kW	3.3 kW	2.5 kW	2.4 kW	17 kBTU/h
Equivalent kBTU/h	12.3	12.6	11.3	8.5	8.2	17
12-lb water heat up time (min.)	9.8	9.3	11.6	17.8	15.5	18.6
Efficiency	85.2%	86.1%	83%	75.5%	79.3%	31.9%
Total Energy Per Year	252 kWh	259 kWh	263 kWh	273 kWh	282 kWh	21.2 therms

Induction cooking appliances were measured to be 5-15% more efficient than electric resistance products. The gas-powered appliance was measured between 8-9% less efficient than the California eTRM deemed efficiency values. Notably, this efficiency does not include the difference in ventilation energy required between each technology. These efficiencies are likely conservative and would further favor induction cooking when viewed through a holistic building systems lens.

[58] Livchak, D., R. Hedrick, and R. Young (Frontier Energy). 2019. *Residential Cooktop Performance and Energy Comparison Study*. Prepared for the Sacramento Municipal Utilities District (SMUD). Frontier Energy Report #510318071-R0.

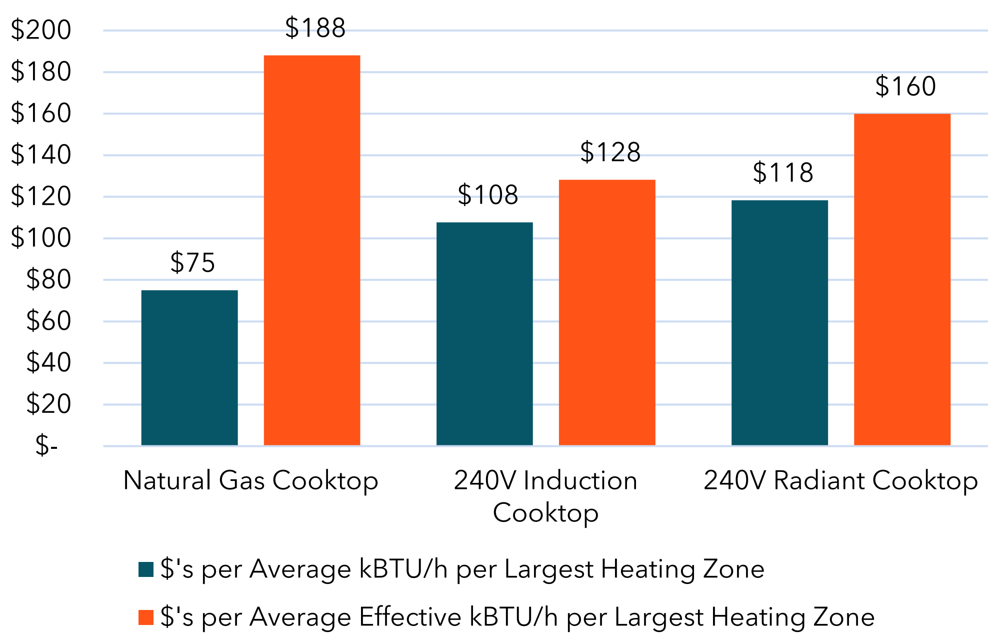
Price per effective kBTU/h of heating output

One of the advantages of induction cooking is that there is less wasted heat relative to natural gas and radiant cooking. The team wanted to understand if considering the product's cost relative to its thermal efficiency would make induction products appear more cost competitive. To this end, the team calculated what we refer to as an "effective kBTU/h" which represents the performance-weighted cost of each product category. This effective kBTU/h reflects the heat that actually cooks food, rather than being wasted due to inefficiencies.

For each product category (segmented by fuel type and gas/induction/radiant), the power output of the largest heating zone was averaged. That value was divided into the median price of the product category, and the resulting value then weighted by the thermal efficiency of each product category.

One set of findings are presented in Figure 11 below. The first bar in each series shows the price per average kBTU/h based on the rated power output while the second bar shows the price per *effective* kBTU/h, which factors in the thermal efficiency. Natural gas cooktops are clearly the lowest price product as shown in the first series, since the thermal efficiency is excluded from the metric. However, when these efficiency losses are factored into the price, induction cooktops are the best value, as shown in the second series. This trend was observed across different form factors and product sizes.

Figure 11: Compares price per effective kBTU/h for cooktops with 4 heating zones



A more comprehensive explanation of the methodology used to determine Figure 11 above is provided in Attachment 1.

If a consumer compares a gas cooktop that is $X, and an induction cooktop that is >$X, they might be inclined to purchase the lower priced option. However, if a consumer leveraged this methodology to calculate "$'s per heat that actually heats your food", then that consumer would know that the gas cooktop costs $Y per effective BTU/h, and the induction cooktop costs <$Y per effective BTU/h. While this effective BTU/h value does not incorporate operational costs, it has the potential to inform consumers of the first cost performance value of the appliances considered for purchase.

New cooktop features for induction technology

Pan size detection

Many modern induction cooktops feature advanced pan size detection capabilities, which enable them to adapt the size of the inductive field to match the diameter of the cookware. This is achieved using multiple "rings" of inductive coils, arranged concentrically around the cooking surface. As the cookware is placed on the cooktop, the system detects its diameter and adjusts the heat flux accordingly. If smaller cookware is used, only the inner coil activates, ensuring optimal heating performance while minimizing energy waste.

Standby power consumption

Standby power refers to the energy consumed by an appliance when it is not actively cooking. Historically, gas cooktops with pilot lights resulted in standby losses due to continuous gas consumption to maintain the pilot flame. However, modern natural gas cooktops typically rely on electrical ignition and no longer incur gas standby losses, except for potential gas leaks from infrastructure. In contrast, resistance and induction cooking appliances are powered by electricity, which is generally a more efficient fuel source than gas. Nonetheless, these devices still experience standby losses due to the ongoing operation of their electronic circuits, particularly in models featuring clocks, Wi-Fi chips, or other more complex electronic components. ENERGY STAR qualified cooking appliances for residential use exhibit cooktop standby losses that are remarkably low, accounting for less than 3% of their total annual energy consumption. Additionally, separate measurements are taken for both the cooktop and oven low-power modes, with average oven values contributing even less than 3% to the overall rated annual energy consumption.

6.2. Boiling times

Gas cooking appliances are measured and rated in British Thermal Units per hour (BTU/h). Electric resistance and induction cooking appliances are measured and rated in kilowatts (kW). These power ratings are the primary driver of boiling times and reflect the following differences:

- Gas cooktop BTU/h output is simply determined by the volume of gas flowing through the burner to be combusted.
- Radiant resistance cooktops' maximum power/heat output is primarily limited by the gauge of the wire providing electric current to the resistance heating element. Each heating element has a maximum heat output determined by the size of the element and the gauge of the wire.

- Induction cooktops have more dynamic power control electronics. This means that the maximum heat output for a given inductive coil is not primarily determined by wire gauge or inductor size, although these characteristics still influence heat output. Instead, 240V induction cooktops with PowerBoost/RapidBoil/PowerBoil or equivalent functionality can "share" power between heating elements under certain conditions. This means that when only a single heating element is active, most of the cooktop's rated power can flow through that single element, leading to significantly reduced boiling times (up to 50% faster compared to radiant cooktops with the same nominal power per element).

Table 9 above illustrates the range of water heat up times across select induction, resistance, and gas products. The induction products tested have the fastest boiling times, ranging from 9.3 to 11.6 minutes, while the electric resistance and gas products had the slowest boiling times, ranging from 15.5 to 18.6 minutes.

6.3. Bill impacts

This section presents the findings from a bill impact analysis comparing the customer utility bill impacts between induction (both 240V and battery-equipped 120V), radiant, and gas technologies. This analysis focuses on gas ranges, which include both cooktop and oven. Cost impacts will be similar for customers who replace both their gas cooktop and gas wall oven with the electric version of each. However, customers who electrify only their cooktop will see a smaller impact.

An analysis was completed in each investor-owned utility service territory, as well as SMUD electrical territory. The results represent customers with the following utility service(s):
Customers with PG&E service for both gas and electricity[59]

Customers with SCE electricity service and SoCalGas natural gas service[60]

Customers with SDG&E service for both gas and electricity[61]

Customers with SMUD electricity service and PG&E natural gas service[62]

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[59] PG&E Residential rate plan pricing, effective July 1st, 2024:
https://www.pge.com/assets/pge/docs/account/rate-plans/residential-electric-rate-plan-pricing.pdf. PG&E residential average gas rate, July 2024 forecast: https://www.pge.com/assets/rates/tariffs/Residential.pdf
[60] SCE Time-of-use residential rate plans, effective 6/01/2024; https://www.sce.com/residential/rates/Time-Of-Use-Residential-Rate-Plans and SoCalGas Rate Alert for January 2024.
https://www.socalgas.com/sites/default/files/2024-01/SoCalGas_GasRateAlert_January2024.pdf
[61] SDG&E Time of Use Plans. https://www.sdge.com/residential/pricing-plans/about-our-pricing-plans/whenmatters#DR1. And the Natural Gas Rate Change Alert for January 2024.
[62] SMUD Residential Rates; https://www.smud.org/Rate-Information/Residential-rates; and PG&E residential average gas rate, July 2024 forecast https://www.pge.com/assets/rates/tariffs/Residential.pdf.

The sections below summarize previous analysis (literature review), methods and assumptions, and key findings.

Previous energy cost analysis

Frontier's 2019 report includes an energy cost modeling analysis of three different induction cooktop products, two electric resistance cooktops, and one gas cooktop. Estimated annual costs to operate the gas cooktop was $33.06, while annual cost to operate induction and resistance products ranged from $40.55 to $45.48, an annual operating cost difference of about $1 a month to substitute fuel from gas to electric cooktop.

However, Frontier's 2019 analysis did not account for the cost to operate a gas oven, or the incremental cost to operate the electric oven that is included in induction ranges, which is higher than the annual energy consumed by the cooktop. Furthermore, the analysis used an electricity cost of $0.16/kWh, which represents a "normalized average of SMUD 2019 Time-of-Use summer and winter rates, with the assumption that summer cooking occurs on peak with weekly cooking during 3 weekdays and 2 weekend days," and a per therm cost of $1.56 to represent gas prices for customers SMUD's electric service territory.

Although natural gas prices have also increased significantly since 2019, today's per-kWh IOU electricity rates are far higher than the SMUD 2019 rates used in Frontier's analysis, requiring a revised analysis to understand bill impacts associated with adoption of electric induction cooktops and ranges.

Furthermore, Frontier's analysis did not include the relationship between when customers use their cooktops and TOU rates. This approach masks the negative bill impact of using electricity for cooking during daily TOU peak periods and does not quantify the benefit of using a battery-equipped range to shift cooking electricity consumption from TOU peak periods to TOU off-peak periods.

Methods and assumptions

To provide an updated and more precise assessment of bill impact associated with adoption of 240V induction and 120V battery-equipped induction ranges, the team used present-day TOU electricity rates published by California's three electric investor-owned utilities (IOUs) and SMUD. These daily TOU electricity rates were paired with the same annual and hourly cooking electricity consumption estimates (load shapes) used to calculate the technical potential[63] for induction cooking products.

The team used average per therm cost estimates published by the three natural gas IOUs to establish baseline annual cost to operate a natural gas range in each of the four scenarios. PG&E

[63] See the "Modeling methodology and data sources" subsection in the Technical Potential section of this report.

gas rates were used for customers in SMUD territory, and SoCalGas rates for those in SCE territory.

For each utility territory with multiple TOU rate options, the team selected a TOU rate with no usage tiers, and which included a significant differential between peak and off-peak rates, representing a trend towards TOU rates that are more reflective of wholesale power costs. Each electricity rate plan also has a fixed monthly charge ranging from $24.80 (SMUD) to $12.00 (SCE). However, the analysis assumes the customer already pays for electrical service from the utility, so the monthly charge does not factor into the incremental cost of electrifying cooking appliances and was omitted from the analysis. Monthly fixed gas service charges were not considered, since eliminating the monthly charge requires full electrification of the customer's home. However, it should be noted that customers who chose that path could save $60/year or more in fixed charges, helping to offset increases in electricity bills.

Table 10 below shows the rate plans and specific TOU rates associated with each plan, as well as annual average per therm costs for natural gas. It is important to note that although SMUD's per-kWh rates are lower than the IOUs overall, SMUD's summer peak TOU rate is 2.5 times their summer off-peak, enabling customers to save money through load shifting. It should also be noted that customers who are eligible for California Alternate Rates for Energy (CARE) receive a discount of approximately 35% per kWh and 20% per therm, lessening the impact of electrification. Bill impacts for CARE customers, however, are not represented in the table.

Table 10: Rate plans and pricing used for billing impact analysis

PG&E Electric Home Rate Plan (Peak 4-9pm every day)	**Summer peak**	**Summer mid-peak**	**Summer off-peak**	**Winter peak**	**Winter mid-peak**	**Winter off-peak**		
Electricity rate (kWh)	$ 0.60	$ 0.44	$ 0.38	$ 0.37	$ 0.35	$ 0.33		
Natural gas rate (Therm)	$ 2.50	$ 2.50	$ 2.50	$ 2.50	$ 2.50	$ 2.50		
CARE Electricity rate (kWh	$ 0.39	$ 0.29	$ 0.25	$ 0.24	$ 0.23	$ 0.21		
CARE Natural Gas rate (Therm)	$ 2.00	$ 2.00	$ 2.00	$ 2.00	$ 2.00	$ 2.00		
SCE TOU-D Prime Rate Plan (Peak 4-9pm every day)	**Weekday summer peak**	**Weekday summer off-peak**	**Weekday winter peak**	**Weekday winter off-peak**	**Weekend summer peak**	**Weekend summer off-peak**	**Weekend winter peak**	**Weekend winter off-peak**
Electricity rate (kWh)	$ 0.61	$ 0.25	$ 0.58	$ 0.23	$ 0.38	$ 0.25	$ 0.58	$ 0.23
Natural gas rate (Therm)	$ 1.90	$ 1.90	$ 1.90	$ 1.90	$ 1.90	$ 1.90	$ 1.90	$ 1.90
CARE Electricity rate (kWh	$ 0.40	$ 0.16	$ 0.38	$ 0.15	$ 0.25	$ 0.16	$ 0.38	$ 0.15
CARE Natural Gas rate (Therm)	$ 1.52	$ 1.52	$ 1.52	$ 1.52	$ 1.52	$ 1.52	$ 1.52	$ 1.52
SDG&E TOU-ELEC Pricing Plan (Peak 4-9pm every day)	**Summer peak**	**Summer off-peak**	**Summer super-off-peak**	**Winter Peak**	**Winter off-peak**	**Winter super-off-peak**		
Electricity rate (kWh)	$ 0.60	$ 0.33	$ 0.30	$ 0.60	$ 0.33	$ 0.30		
Natural gas rate (Therm)	$ 2.10	$ 2.10	$ 2.10	$ 2.10	$ 2.10	$ 2.10		
CARE Electricity rate (kWh	$ 0.39	$ 0.22	$ 0.19	$ 0.39	$ 0.22	$ 0.19		
CARE Natural Gas rate (Therm)	$ 1.68	$ 1.68	$ 1.68	$ 1.68	$ 1.68	$ 1.68		
SMUD Residential TOU Rate (Peak 5-8 pm every day)	**Summer peak**	**Summer mid-peak**	**Summer off-peak**	**Winter peak**	**Winter off-peak**			
Electricity rate (kWh)	$ 0.35	$ 0.20	$ 0.14	$ 0.16	$ 0.12			
Natural gas rate (Therm)	$ 2.50	$ 2.50	$ 2.50	$ 2.50	$ 2.50			

Annual operating cost impact versus cooking with natural gas today

Given today's prices for gas and electricity in California, customers substituting fuels from gas to a 240V electric induction range or a 240V radiant range would see bill increases in all three IOU electric service territories. The improved efficiency of induction cooktops (relative to electric resistance cooktops) helps to mitigate the bill impacts of cooking electrification — but only slightly. Those who adopt induction ranges will save between $6 and $7 a year compared to those who chose conventional radiant electric ranges — a small fraction of the total bill increases for IOU customers adopting either type of 240V electric range. As shown in Figure 2, Figure 12, and Figure 13, the annual bill impacts for IOU customers who replace a gas range with a 240V electric induction range are projected to see bill increases ranging from $145/year (PG&E territory) to $174/year (SDG&E territory) – although these impacts would vary with different TOU rate plans. Given that improved efficiency of induction only mitigates bill impact of electrification by about 4% in the IOU electric territories, consumers that choose induction over radiant cooktops would do so for reasons other than bill savings.

Annual operating cost impact versus cooking with natural gas in the future

Any reduction in the gap between gas and electricity prices per kWh in California will reduce the bill impacts of electrifying cooking appliances, and naturally make induction appliances more attractive to consumers. Although it is difficult to forecast long-term trends in gas prices, there are several potential policy mechanisms that could drive up the price of natural gas in the next decade, such as GHG emission offset penalties imposed by CARB or other regulations.

Cost for 120V battery-equipped versus 240V induction

240V induction appliances consume much of their energy during evening TOU peak periods, which directly align with the time when many Californians prepare dinner, resulting in a magnified cost impact for those moving from natural gas. In contrast, battery-equipped cooking appliances are designed to operate entirely on direct current (battery) power while cooking and can be programed to recharge during one or more off-peak period throughout each night/day, allowing the appliance to replenish any lost charge from both morning and evening cooking events. Although savings is attributable to this load shift in all three IOU electricity service territories, the impact is most substantial for SCE customers, who can use battery-equipped ranges to reduce the amount of the bill increase from electrification by almost $100/year ($57 increase for battery-equipped induction vs. $152 annual increase for 240V induction). This suggests that as the difference between peak and off-peak TOU rates grows, the savings potential for battery-equipped appliances will become more valuable.

Figure 12: Projected annual utility bill impact for SCE + SoCalGas residential customers

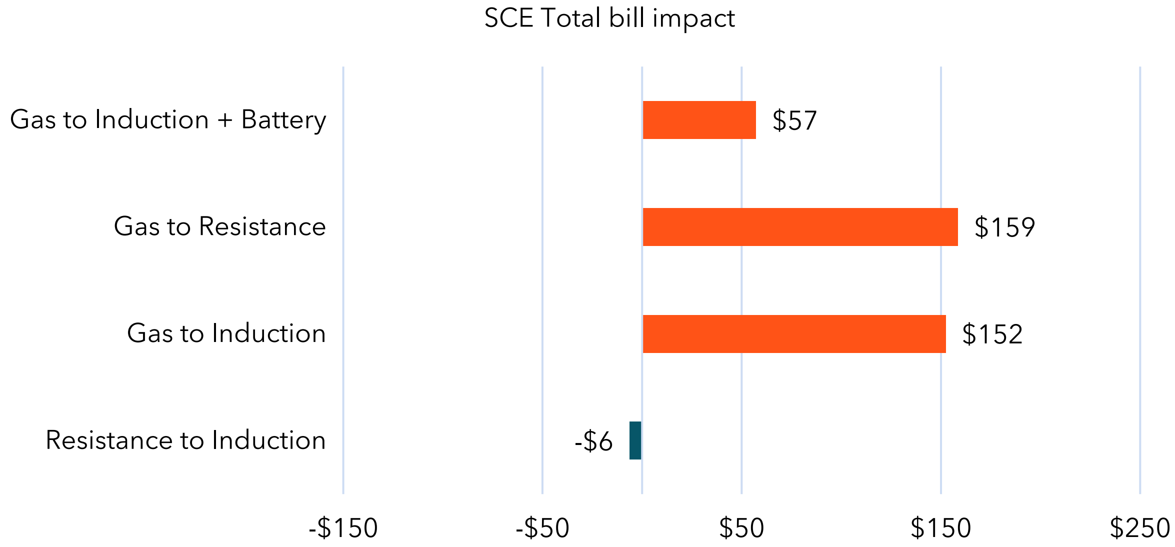
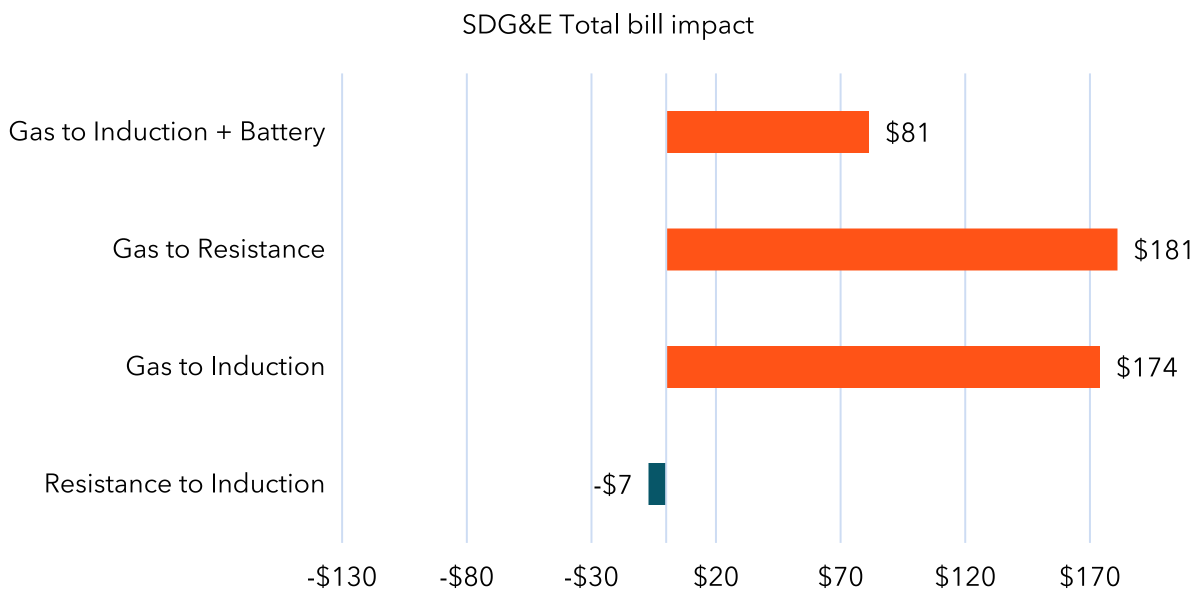


Figure 13: Projected annual utility bill impact for SDG&E residential customers



As shown in Figure 3 earlier in this report, SMUD's low per-kWh rates allow customers to electrify cooking without any increase in annual bills, showing slight savings in every category of electric cooking appliance versus using a gas range fueled by PG&E natural gas. Furthermore, SMUD's aggressive TOU rates allow customers to generate annual cost savings of approximately $23 by replacing a gas range with a battery-equipped induction range.

One of the reasons SMUD can maintain relatively low per-kWh rates is by including a relatively high fixed monthly charge of $24.15, which is considerably higher than the fixed monthly charges for most IOU rate plans offered today. By shifting more cost to a fixed charge, electric utilities can support electrification by offering lower per-kWh rates, resulting in lower incremental bill impact for those moving from gas to electric appliances.

In recognition of the potential for higher fixed charges to support electrification, in May 2024 the CPUC approved a proposal to increase the fixed monthly charge[64] in all three electric IOUs, matching SMUD's monthly charge of $24.15. When this monthly charge takes effect in late 2025 or early 2026 it should be accompanied by a reduction in per-kWh rates, reducing the cost to electrify cooking and other appliances. While any decrease will be welcomed, per-kWh IOU rates will likely remain higher than those offered by SMUD and other municipal utilities.

6.4. Product reliability and repair costs

Reliability versus other technologies

Reliability is a critical consideration when evaluating induction cooking technology against other alternatives. While the underlying principles of induction have been well-established for decades, its application to residential appliances is relatively recent. Unfortunately, data on the long-term lifespan and reliability of modern induction cooktops is scarce due to their limited market share.

The main problems noted, generally, with induction ranges are cooktops not sensing pans correctly, physical damage to the glass top, voltage issues, and loud internal cooling fans.

However, evidence from Yale Appliance,[65,66] suggests that there has been a significant improvement in reliability between 2020 and 2024. In 2020, the warranty period service call ratio for induction products was 25%, compared to 12% in 2024. The breakdown by brand can be seen below in Table 11 and Table 12. This trend of improvement is potentially attributed to manufacturers addressing home voltage spike-related issues that seem to be more prevalent in induction products, according to Yale Appliance. More data is needed to determine feasibility of additional reliability improvements surrounding this issue, but generally speaking, repair rates decrease as products mature in the market.

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[64] CPUC Energy Division AB 205 Fact Sheet, May 2024. https://www.cpuc.ca.gov/-/media/cpuc-website/divisions/energy-division/documents/demand-response/demand-flexibility-oir/ab205_factsheet_050824.pdf.
[65] Yale Appliance. "Best Electric & Induction Range Deals." Accessed July 31, 2024. https://blog.yaleappliance.com/best-electric-induction-range-deals.
[66] Yale Appliance. "Most Reliable Induction Ranges." Accessed July 31, 2024. https://blog.yaleappliance.com/most-reliable-induction-ranges.

Table 11: Yale Appliance 2020 and 2024 service records for induction ranges[67]

Appliance brand	2020 Service QTY	2020 Shipped QTY	2020 Service rate	2024 Service rate
Jenn-Air	58	135	43%	-
KitchenAid	5	14	36%	-
Fisher & Paykel	4	12	33%	14%
Café Appliances	5	15	33%	11%
Wolf	16	71	23%	-
Bosch Benchmark	4	23	17%	15%
Miele	3	18	17%	-
Bosch Appliances	5	38	13%	9%
GE Profile	2	25	8%	11%
Samsung	2	67	7%	-
LG	-	-	-	5%
Beko	-	-	-	21%
Grand Total	**104**	**418**	**25%**	**12%**

For comparison, electric resistance and gas cooktops have much simpler designs and mature supply chains which do not require the same coordination for the sophisticated power control electronics and coils present in induction cooktops. These components are key factors to consider for lifetime optimization and the reliability of induction cooking technology. Yale Appliance[51] reported a service call ratio of 5% for electric resistance cooktops in 2020, as seen below in Table 12.

Table 12: Yale Appliance 2020 service records for resistance ranges

Appliance brand	Service Qty	Shipped Qty	Service rate
Jenn-Air	28	63	44%
KitchenAid	31	89	35%
GE Profile	2	18	11%
Café Appliances	3	28	11%
Bosch Appliances	10	154	6%
Samsung	27	754	4%
Whirlpool	12	1269	1%
LG Electronics	0	62	0%

[67] The original data from Yale Appliance has been rounded to the nearest whole number for Table 11 and Table 12.

Appliance brand	Service Qty	Shipped Qty	Service rate
Premier	0	19	0%
Blomberg	0	17	0%
Avanti	0	17	0%
Grand Total	**113**	**2490**	**5%**

Other reliability data sources, such as *Consumer Reports* and Angi.com, suggest that the most frequent repair request for installed electric cooking appliances is the smooth glass top.[68] Heavy and/or inconsiderate usage of this component can lead to scrapes, scratches, chips, and breakage. In this sense, the reliability of induction and resistance products are similar, as they both use almost the same glass top products. Angi.com provides average repair costs ranging from $150 to $600. However, they note that replacing the smooth glass top on resistance and induction appliances can cost around $600 on average. Notably, Angi.com does not distinguish between induction and resistance cooktops in their repair cost data, suggesting that the costs are likely similar for both technologies.

It's also worth noting that consumer confusion between induction and resistance products is a relevant issue. The similarity in appearance due to the smooth glass top can lead to consumers to mistakenly identify one technology type over the other. This confusion can result in unnecessary difficulties with products usage and understanding, which can further impact reliability data when consumers provide incorrect product identification to sources like *Consumer Reports* or Angi.com. Additionally, Consumer Reports did not make any claims as to the relative reliability of the three types of cooktops/ranges included in their survey, further obfuscating their reliability data.

Induction cooking appliances are constructed using more components than incumbent products. The power control electronics and the inductive coils are considerably more complex, energy-intensive, and in-demand than the equivalent components in electric resistance (and gas) products. While the trade-off of this sophistication is a superior cooking experience compared to resistance products, the systemic complexity and its consequences remain relevant for discussions surrounding product reliability.

Repair costs versus other technologies

The cost to repair each cooking technology can vary. Different materials, skilled labor requirements, and supply chains can influence the cost of repairing each cooking technology type. While long-term data sources for repair costs are lacking, gas cooktops are currently cheaper to repair than radiant and induction cooktops. According to *Consumer Reports*, the

[68] Angi. "How Much Does Oven Repair Cost?" Accessed July 31, 2024. https://www.angi.com/articles/how-much-does-oven-repair-cost.htm.

median repair cost for gas cooktops is $153, while radiant and induction cooktops average $192 and $536, respectively.[69] The induction cooktop repair premium is driven by its relatively high component cost (notably the glass top, which suffered damage for 11% of all survey respondents and costs upwards of $600 on average to replace) and the need for specialized labor to perform most repairs (compared to gas/electric resistance cooktops which have more do-it-yourself repair potential).

It's essential to note that these figures only account for instances where a repair was attempted or completed. In reality, when repair costs approach the purchase price of the appliance, it may be more cost-effective for consumers to replace their cooktop altogether. This is particularly relevant for induction cooktops, which tend to have higher repair costs.[70]

A closer examination of the component pricing for a mid-tier induction cooktop[71] reveals that the glass top is not necessarily the most expensive component. In fact, several other components on this particular model have prices near or above $900, with many additional parts priced in the lower hundreds.

Table 13: Distributor component pricing for a mid-range induction cooktop

Product component	Distributor component price
Right generator board	$1,108
Filter board	$1,004
Heat shield kit	$890
Touch board	$847
Left generator board	$649
Wiring kit	$624

Though these prices are for materials only and do not include the cost of labor, they highlight the complexity of induction cooktops and the potential for higher repair costs compared to other cooking technologies.

Expected lifespan versus other technologies

California programs rely on deemed expected useful life (EUL) values for each of these products to make savings calculations and perform programmatic accounting. The eTRM contains multiple

[69] Consumer Reports. "Should You Repair or Replace Your Broken Cooktop?" Accessed July 31, 2024. https://www.consumerreports.org/appliances/cooktops/should-you-repair-or-replace-your-broken-cooktop-a6490859316/.

[70] Consumer Reports. "Should You Repair or Replace Your Broken Cooktop?" Accessed July 31, 2024. https://www.consumerreports.org/appliances/cooktops/should-you-repair-or-replace-your-broken-cooktop-a6490859316/.

[71] DEY Appliance Parts. "Replacement Parts for Appliance Model." Accessed July 31, 2024. https://www.deyparts.com/lookup/211626/1442884#diagram.

expected useful life (EUL) numbers. A 2016 eTRM life cycle cost analysis deems all electric cooking products, whether resistance or induction, to have an EUL of 17.89 years. The same source deems gas cooktops to have an EUL of 14.42 years. These values are not based on specific consumer data, and the relative magnitude of each seems to conflict with recurring anecdotes regarding the lifespan of gas versus resistance appliances, specifically. For the purposes of the calculations within this report, an EUL of 16 years will be used for induction cooking appliances.[72]

The real lifespan of cooking appliances, like many consumer products, depends on factors such as consumer behavior and manufacturer quality. Manufacturers design these appliances with a planned lifespan in mind, typically 10,000 hours of usage. The frequency of meals cooked, input power quality, presence of self-cleaning technology, and other factors all contribute to an individual product's lifespan. Budget model gas and radiant cooktops have relatively simple designs, fewer components, and established do-it-yourself repair guidelines, making them less prone to irreparable or complex failures.

Given the less than 4% national market share of induction appliances,[73] there is limited long-term usage data available for this technology. As a result, the consequences of its complex features and electronics on lifespan and reliability cannot be known with certainty until it gains further adoption over time.

A comparable trend can be seen in the refrigerator appliance space. In recent years, refrigerators have become increasingly complex, with manufacturers adding advanced features such as high-definition screens, Wi-Fi chips, sensors, cameras, and more. While these features may provide luxury benefits to customers, they also introduce new points of failure that can lead to premature malfunctions. In fact, some refrigerator models are notorious for malfunctioning early in their projected lifespan, requiring expensive repairs that can approach the initial purchase price of the appliance itself. This trend could translate into electric cooking appliance technologies as they grow in market share and adopt similar advanced features. While gas cooktops remain relatively simple and unaffected by this trend, manufacturers are slowly introducing more advanced features to radiant cooktops. Induction appliances are following suit as the technology matures, further increasing the risk of complex failures and premature malfunctions.

6.5. Non-energy benefits

240V induction cooking products offer several significant non-energy benefits compared to incumbent technologies. The most notable advantage is safety, as induction cooking appliance do not heat up like conventional gas or radiant cooktops. This reduces the risk of burns and other injuries associated with hot surfaces.

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[72] https://www.caetrm.com/measure/SWAP015/03/.

[73] Mordor Intelligence. "U.S. Induction Cookware Market." Accessed July 31, 2024. https://www.mordorintelligence.com/industry-reports/us-induction-cookware-market.

Induction cooking also eliminates IAQ issues present in gas cooking, where combustion byproducts can release pollutants into the air. By using electromagnetic energy instead of flames, induction cooking provides a cleaner and healthier cooking experience. Reference the following section for more detail on IAQ benefits.

Gas cooking appliances generate significant waste heat into the living space, which can create extreme discomfort for residents without adequate conditioning or ventilation in the space. Induction cooking is drastically more efficient, and by generating less waste heat into occupant spaces there are legitimate comfort benefits realized from the technology.

In terms of cooking performance, 240V induction appliances offer several advantages over traditional technologies. They can often share power between heating zones and allow for the rapid boiling of water, a feature often referred to as PowerBoil or RapidBoil. This feature allows for significantly faster water boiling times, enabling more than twice the boiling speed of incumbent technologies.

Induction cooking also provides immediate, precise, and accurate temperature control, which is superior to traditional gas cooking technology in some ways. Compared to radiant cooktops, the induction cooking experience is superior, offering faster heating, more precise temperature control, and improved safety features.

6.6. Indoor air quality advantages

Improved IAQ is a competitive advantage for induction cooking that is potentially compelling enough to entice consumers to purchase induction products, bringing energy savings and GHG emissions along in the process.

A 2013 meta-analysis found that children living in homes with gas cooking had a significant increased risk of developing asthma, with a 42% greater chance than their peers without gas.[74] This finding has been reinforced by more recent studies, including a 2023 analysis that attributed approximately 12.7% of childhood asthma cases across the nation to gas cooking.[75] The same study found that the proportion of childhood asthma that could be theoretically prevented if gas cooking were not present in California to be 20.1%. This translates to millions of children and families being disproportionally affected by poor IAQ due to gas cooking appliances.

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[74] 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.

[75] Gruenwald, Talor, Brady A. Seals, Luke D. Knibbs, and H. Dean Hosgood, III. 2023. "Population Attributable Fraction of Gas Stoves and Childhood Asthma in the United States" *International Journal of Environmental Research and Public Health* 20, no. 1: 75. https://doi.org/10.3390/ijerph20010075.

In California alone, where about 65%[76] of homes have gas cooking appliances, we can estimate a significant number of individuals at risk. Assuming the same risk level applies to both single family and multifamily homes, we can approximate that 25 million Californians use gas cooking appliances. Since children under the age of 18 account for about 22% of California's population, this translates to around 5.5 million children with a 42% increased risk of asthma compared to their peers without gas cooking. Furthermore, negative IAQ is generally inversely proportional to the size of the dwelling unit, meaning that smaller homes are at risk of bigger impacts. This is particularly relevant for multifamily dwelling units, which also suffer from shared exposure from others cooking with gas in the building. These physics convey an additional IAQ burden for ESJ communities in multifamily units. This estimate contains many conservative assumptions but gives an idea of the magnitude of the potential impacts.

A study from Stanford University[77] found that long-term exposure to Nitrogen Dioxide (NO2) may contribute to an additional 50,000 cases of pediatric asthma each year. Additionally, the full spectrum of pollutants from gas cooking appliances are potentially responsible for up to 200,000 cases of pediatric asthma nationally. By making a conservative, proportional comparison for California by population, up to 20,000 children in the State are diagnosed with pediatric asthma due to gas cooking appliances in the home. This number is likely higher for California, as the state has a higher percentage of gas cooking appliances than every state but Illinois. The report authors make a point to note that NO2 is not the sole pollutant from gas cooking affecting health, and that other pollutants resulting from gas cooking play an additive role in respiratory conditions, cancers, and more.

Another recent study made compelling findings about the use of induction cooking products to reduce indoor air pollution.[78] When compared to the baseline gas cooking group, the induction cooking group had a 56% reduction in mean daily NO2 concentrations.

These findings demonstrate the importance of substituting fuels used in cooking appliances not just for climate change mitigation, but safety and the health of families and children.

Exposure to contaminants

IAQ can be compromised when using natural gas or propane-powered cooking appliances. These fuels, which are gaseous, permeable, and combustible, contain chemicals like Benzene,

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[76] The CalMTA Market Characterization report contained an analysis of 2020 RECS data with a breakdown of gas cooking appliance usage in California by housing type, between 60% to 70%.

[77] Yannai Kashtan et al. Nitrogen dioxide exposure, health outcomes, and associated demographic disparities due to gas and propane combustion by U.S. stoves. Sci. Adv.10, eadm8680 (2024). DOI: 10.1126/sciadv.adm8680.

[78] Misbath Daouda, Annie Carforo, Heather Miller, Jennifer Ventrella, Yu Ann Tan, Michelle Feliciano, Jessica Tryner, Andrew Hallward-Driemeier, Steve Chillrud, Roisin Commane, Diana Hernández, Michael Johnson, Darby Jack, Out of Gas, In with Justice: Findings from a gas-to-induction pilot in low-income housing in NYC, Energy Research & Social Science, Volume 116, 2024, 103662, ISSN 2214-6296, https://doi.org/10.1016/j.erss.2024.103662.

nitric oxide, and nitrogen dioxide that can seep into living spaces even when the appliance is not in use. This slow leakage poses risks of explosion or exposure to harmful chemicals. Furthermore, when these fuels are burned, unventilated exhaust gases can fill a household with small airborne particulates, leading to dirt and grime buildup, respiratory issues, and ground-level ozone generation.

Benzene is particularly worrying for public health. Benzene has been shown to cause cancers like leukemia, with growing evidence for an association with childhood leukemia.[79] A 2010 study on the health effects of benzene states, "There is probably no safe level of exposure to benzene, and all exposure constitutes some risk."[80] Exposure to benzene is an inevitable consequence for families in homes with natural gas infrastructure, and this exposure alone provides a significant incentive to move to electric cooking fuel.

Risks to multifamily versus single-family occupants

The negative IAQ impacts from both un-combusted gas and the combustion biproducts of gas ovens and cooktops tend to be more severe in multifamily buildings and small single-family homes, as well as older residential buildings of both types. This is because the concentration of IAQ contaminants is inversely proportional to the volume of a space, and generally higher in multifamily buildings, since many walls are shared with other occupied space. Older buildings are less likely to have a functional mechanical ventilation of any type, including quiet, correctly sized range hoods ducted outdoors. Due to the vintage and building geometry of more affordable housing stock in California, it is reasonable to conclude that a higher ratio of the 5.5 million children with a higher risk of asthma described above are within ESJ communities.

Relationship between IAQ and ventilation

As noted in Lawrence Berkeley National Laboratory's (LBNL) Healthy Efficient New Gas Homes (HENGH) study, when properly sized, designed, and installed, range hoods can mitigate most of the active emissions generated by gas cooktops while cooking.[81] The important word is "properly." Frequently, homes with gas cooking products and range hoods are not properly set up to adequately ventilate gas cooking contaminants from the home. The report notes the significant difference in hood capture efficiency[82] between the front and rear burners, for example. Rear burners are much more likely to have gasses from combustion ventilated up through the hood, while front burner cooking is less likely. This was especially true at lower flow

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[79] D'Andrea MA, Reddy GK. Health Risks Associated with Benzene Exposure in Children: A Systematic Review. Global Pediatric Health. 2018;5. doi:10.1177/2333794X18789275.

[80] Smith MT. Advances in understanding benzene health effects and susceptibility. Annu Rev Public Health. 2010; 31:133-48 2 p following 148. doi: 10.1146/annurev.publhealth.012809.103646. PMID: 20070208; PMCID: PMC4360999.

[81] Chan, W.R., Y-S. Kim, B.D Less, B.C Singer, Walker, I. 2020. (Lawrence Berkely National Laboratory). *Ventilation and Indoor Air Quality in New California Homes with Gas Appliances and Mechanical Ventilation*. LBNL-2001200RI.

[82] Capture Efficiency (CE) is the fraction of pollutants released at cooktop or oven that are removed before mixing into home.

rates, as measured in the study. Furthermore, many homes in California have recirculating range hoods installed. These product types do not ventilate exhaust gasses to the outside and do little to combat the IAQ issues outlined here.

The HENGH study discovered that noise and perceived effectiveness were factors in a consumer's decision to use the range hood. If the ventilation hood is louder than what the consumer can tolerate, they may forego using it. Perceived effectiveness played a major role in behavior as well. LBNL found that respondents who believed their ventilation hood to be more effective than participants who believed it was less effective, tended to use the product more.

The study also obtained real data from range hood use for homes and low-income apartments in Southern California and found that most homes used a range hood for fewer than half of cooking events. However, there was evidence that longer cooking events prompted a higher percentage of ventilation hood use by participants.

Lower noise levels associated with ventilation

Induction cooking's reduced waste heat and minimal airborne particulates result in significantly less ventilation requirements compared to gas cooking products. This reduction in ventilation needs translates to smaller fans operating at lower speeds, which has a direct impact on noise levels within the home. The resulting lower noise levels contribute to higher consumer comfort and satisfaction, making induction cooking a more appealing option for homeowners seeking a peaceful cooking experience.

6.7. User experience

ADA accessibility

As consumer products become increasingly complex and technologically advanced, ensuring accessibility is critical. The Americans with Disabilities Act (ADA) provides vital protections to individuals with disabilities, and manufacturers are often incentivized to comply with these regulations when designing cooking products. Not all products must comply with these ADA guidelines, but doing so creates a broader market reach within a single product and allows manufacturers to optimize fewer designs.

For cooking ranges and cooktops, the ADA sets guidelines for accessibility:[83]

Maximum reach: Controls and operating mechanisms must be accessible from a maximum height of 48 inches, while the lowest point should not exceed 15 inches. The location of controls shall not require reaching across heating zones.

[83] GE Appliances. "ADA Compliant Appliances: ADA Range Requirements." Accessed July 31, 2024. https://www.geappliances.com/ge/ada-compliant/#ada-range-requirements.

One-handed operation: Controls should be operable with one hand without requiring tight grasping, pinching, or twisting of the wrist. The force needed to activate controls must be no more than 5 pounds.

Knee space protection: If a cooking appliance has a knee space underneath, it must be insulated or protected from burns, abrasions, or electrical shock.

These requirements can significantly alter product design, but they are crucial for ensuring that individuals with differing abilities can safely and easily use cooking products. In fact, some of the safety benefits of induction cooking – such as a surface that doesn't become dangerously hot – are directly aligned with the ADA's accessibility requirements. This redundancy in safety measures is a significant advantage for consumers and manufacturers alike, as it enhances overall user experience and confidence when using these products.

Temperature control

The traditional method of controlling temperature on gas cooking appliances has been to turn a control knob until it aligns with the desired flame size. While this technique has been used for decades, it's relatively imprecise and not ideal for modern cooking needs.

Radiant cooking products offer little to no feedback for temperature control beyond limited visual cues. This makes them difficult to use and unpopular among consumers. One of the main reasons for their unpopularity is the long heat-up and cool down times caused by their high thermal mass. This means that it takes a lot of time to reach the desired temperature, which can be frustrating for cooks desiring precision.

In contrast, induction cooking products offer a significantly better user experience when it comes to temperature control. Induction technology allows for extremely accurate and precise temperature control, with many products featuring easy to read digital displays that allow consumers to select specific temperatures for each cooking event. This level of control is attractive to cooks who value consistency and precision. Induction cooking is also more precise because of its ability to respond immediately to changes in input. The power output of inductive coils adjusts quickly to temperature changes, and the cookware itself generates and contains most of the heat. This is a radically different paradigm from traditional gas and radiant products, often requiring longer periods of time to reach the initially desired temperatures due to thermal efficiency and thermal mass, respectively.

Overshoot/thermal mass

The thermal mass of an appliance refers to its tendency to absorb and store heat energy, which affects its thermal behavior and response to changes in temperature. Each cooking technology applies heat to thermal mass through varying mechanisms, with fossil-fueled (natural gas/propane) and electric resistance appliances wasting heat through radiation and convection. These technologies apply heat to a larger thermal mass than induction cooking appliances.

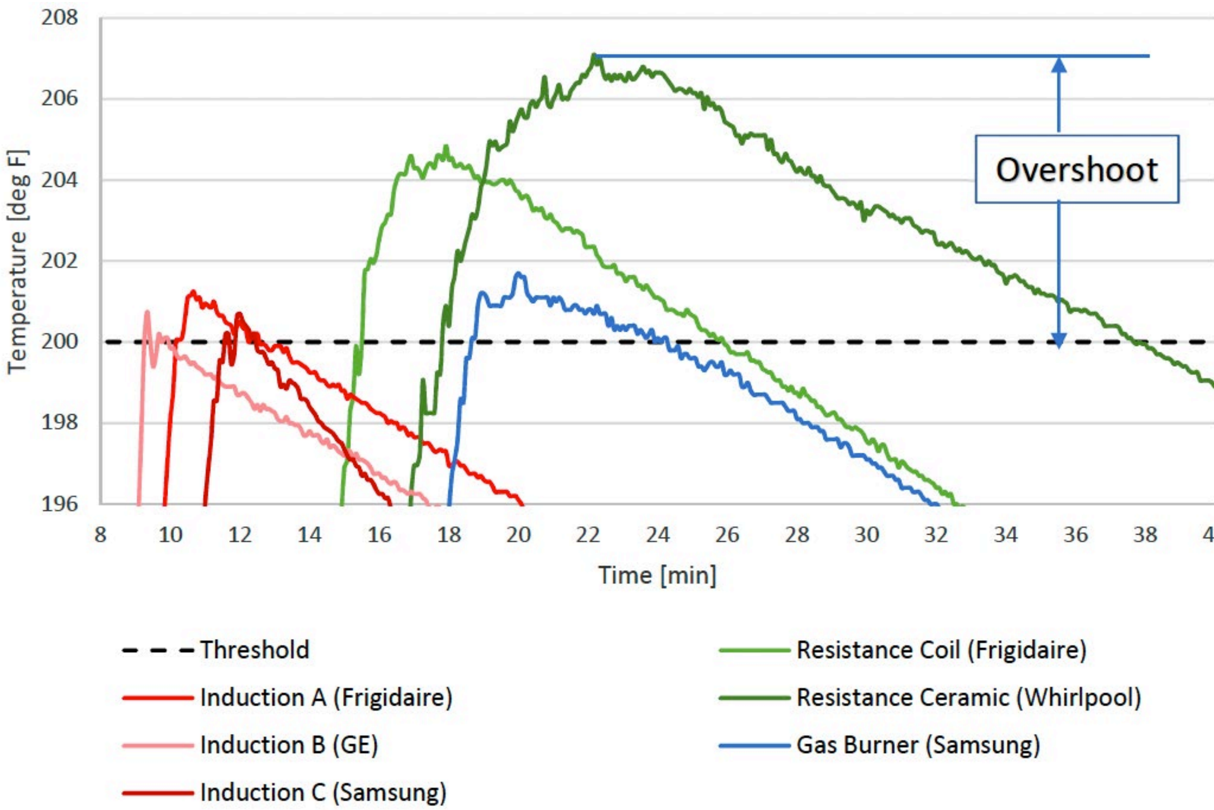
Temperature overshoot refers to the fact that thermal inertia or "momentum" in certain cooking products causes them to temporarily exceed the target temperature. The glass top on a radiant appliance can be particularly problematic in this regard. Its thickness and material properties determine how much heat it absorbs, which can lead to prolonged heating and cooling times. When the power is turned off, the trapped heat continues to transfer into the cookware, causing the food to continue cooking until temperature equilibrium is reached.

Thermal inertia is a significant factor in the perceived quality of the electric cooking experience for consumers. It's not as prevalent in gas cooking and mostly absent in induction cooking, which are both more direct in their heat application methods, even if gas isn't nearly as efficient. Minimal heat travels via convection or radiation when using induction cooking products.

Testing overshoot

When testing temperature response times for various cooking appliance technologies, Frontier Energy measured overshoot as how much residual heat was transferred to the water after reaching 200°F, the temperature threshold signaling the end of the test, and how fast the water then cooled down to 190°F. Satisfactory temperature response is characterized by a minimal temperature overshoot and faster cooldown time. Frontier Energy recorded this data in Figure 14 below.

Figure 14: Overshoot testing results from Frontier Energy's 2019 residential cooktop performance and energy comparison study



'calculated based on a single high-input element or burner heating 12 lb of water from 70 to 200F in an 8 qt pot

Source: https://www.caetrm.com/media/reference-documents/Induction-Range-Final-Report-July-2019.pdf, p. 16.

As shown in Figure 14 above, induction cooking experiences minimal overshoot in comparison to a conventional electric resistance ceramic cooktop. This measurement is key to understanding the difference in cooking experience between these technologies. Relative to the resistance cooktops, the induction cooktops in this test exhibited an average 27-49% improvement in cool-down time, which means less overcooking when cookware is left on the heating zone.

7. Product plan

7.1. Objectives

As a mature technology that is available from multiple manufacturers, the highest priority product development objectives for induction cooking products are focused on features that address specific barriers to increase market adoption, most of which are unlikely to be addressed without intervention from CalMTA and/or others.

There are secondary objectives focused on increasing overall consumer satisfaction with induction cooking products, leading to wider market adoption. However, the market may organically address some of these deficiencies as consumers share explicit feedback through online reviews and implicit feedback via their purchase decisions.

Short-term objectives

In the short term (1-3 years), the MTI will seek to engage in the following areas:

Work with manufactures to bring a greater variety of 120V range and cooktop products to the market, with a primary focus on driving down cost for battery-equipped 120V products.

Work with manufactures to develop 24" induction ranges, including 120V versions, to ensure access to the technology in single-room-occupancy and other low-income housing.

Engage with manufacturers to improve the efficiency of induction products through the inclusion of features such as pan size and pan presence detection.

Long-term objectives

Work with manufactures to understand tradeoffs between product performance and electrical capacity and evaluate opportunities to drive down cost while retaining a sufficient level of performance.

Evaluate tradeoffs between energy consuming features that increase market adoption and help displace gas cooking, vs the additional electricity consumed to support these features.

Evaluate the impact of product attributes including noise and simple vs. complex user interfaces to determine whether future intervention is needed to ensure consumer satisfaction.

Investigate reliability and repair cost concerns to determine whether market intervention is needed to improve customer satisfaction and broad perception of induction products.

7.2. Product plan actions

Potential improvements to electric cooking products can be grouped into three broad categories, with some overlap between each. Although many of the barriers addressed through these improvements are broadly related to all electric cooking technologies, interventions will focus exclusively on improvements to induction products:

Improvements that address market or technical barriers to adoption of electric appliances

Improvements that increase energy efficiency and/or demand flexibility

Improvements that increase consumer interest and/or satisfaction with electric cooking appliances

In the US, the market for electric cooktops, ovens, and ranges is quite mature, with diverse product offerings from many different manufacturers, creating a competitive environment that, in theory, should drive innovation and investment in new product functions and features. However, the large national and multinational manufacturers typically develop products that meet the needs and market conditions for the US as a whole, not specific regions. So, although these large manufacturers have continually improved and enhanced their products over the years, most of those improvements have failed to address the unique market needs and opportunities of California. More specifically, California's insufficient existing 240V electrical infrastructure, inadequate panel capacity, and lack of consumer familiarity with electric cooking appliances and/or preference for gas cooktops are not necessarily barriers being prioritized by these manufacturers. It is unlikely that they will focus on product improvements to address those specific needs without intervention from groups like CalMTA.

Although overlooked by the major manufacturers, two California-based startups – Channing Street Copper and Impulse Labs – have identified an opportunity to address the needs of consumers in California and other regions historically dominated by gas cooking appliances. The first-generation products from these manufacturers can help address the gap in products designed for homes without capacity for 240V power. However, both manufacturers have initially focused on high-end, no-compromise products that match or exceed the performance of 240V products. Targeting this high-end market and high level of performance means their products also carry some of the highest price tags – improvements to the next-generation of these products will also need to focus on reducing cost to consumers and building owners.

Product development actions

Improvements that address market or technical barriers to adoption

Most of the potential improvements within this category address the lack of 240V electrical infrastructure in California homes and buildings. Even in cases where it is possible to provide a 240V circuit for a new electric cooking appliance, improvements that allow induction products to use existing 120V circuits may provide the lowest overall cost to convert homes from gas to electric cooking. These include:

- 120V battery-powered cooktops and ranges that can provide the same cooking experience as a 240V product, allow use of the product during power outages, and shift the cooking electricity load away from daily grid peaks.
- Products that can be manually or automatically adjusted to match available amperage on a circuit, ensuring the best possible cooking experience (fastest heating times), without the risk of exceeding the capacity of a circuit (tripping a breaker).
- Lower cost 120V cooktops and ranges with reduced (but still acceptable) performance relative to 240V products.

Potential strategies include:

- Leveraging two 120V receptacles, each on a different circuit.
- Operating the oven on a 120V AC and the cooktop on battery (direct current) to reduce the coincident peak power demand on the circuit.

- Advanced strategies for balancing the allocation of power among heating zones, and/or between the oven and heating zones.
- Reducing oven volume, increasing insulation, or other strategies to reduce oven power demand.
- Reducing the power and/or performance of the cooktop and/or oven, along with a smaller battery, or potentially without a battery, limiting overall power to 1800 W.

Manufacturers report that adding a battery significantly increases the cost of 120V products, and although the cost for battery-equipped products is expected to decline, they will always cost more than the equivalent product without a battery. Since this can avoid the need for expensive electrical upgrades, the overall cost to consumers who are able to afford electrification may be the same or lower than buying a 240V stove and upgrading circuitry and/or electrical panel. However, today's 120V products with battery backup are still far out of reach for most potential buyers, including the multifamily sector, where electrical infrastructure upgrades are often not a viable option.

As such, the most important product improvement needed at this time is a low-cost 120V range with acceptable performance. It is unclear whether it is possible to manufacture a (lower cost) 120V induction range that will meet the needs and expectations of consumers without using a battery, or with a smaller battery than currently offered.

Improvements that increase energy efficiency and/or demand flexibility

On a BTU-normalized basis, all radiant and induction cooktops are more than twice as efficient as the most efficient gas cooktops. Simply moving from a gas to electric cooktop offers significant energy savings and on-site emissions reductions. Relative to radiant cooktops, induction is inherently more efficient. However, there are additional variables and factors that allow some radiant cooktops to meet ENERGY STAR certification requirements, exceeding the performance of some induction cooktops. Likewise, there are additional enhancements to induction products that provide incremental gains in efficiency.

Most of the potential efficiency improvements for cooktops are already available in some products. They include:
Pan size detection

Pan presence detection

Reduced standby or ancillary energy consumption (from lights, clocks, onboard circuitry, etc.)

The two California-based startups mentioned in Product Plan Actions are the only manufacturers that currently produce full-scale (i.e., four or more burners) 120V induction products – and in both cases they use batteries to allow the product to exceed the power available from a 120V circuit (typically 15A or 20A). Although the primary purpose of adding a battery is purely functional, by designing these products to operate entirely on battery power when in use (and recharging when not in use), these products also dramatically reduce the impact of electric cooking appliances on peak demand and provide power for cooking and/or to charge small electronics during power outages.

To ensure that more Californians can benefit from battery-equipped induction products, CalMTA can influence large national and multinational appliance manufacturers to develop lower-cost versions of those products. The economies of scale these large manufacturers already enjoy may allow them to produce and market battery-equipped products at a much lower price point than the two startups. In the case of induction manufacturers like LG and Samsung that already produce batteries and numerous other products with integrated batteries, there may be additional efficiencies that allow them to further reduce cost and bring battery-equipped induction products to market quickly (relative to large appliance manufacturers like Frigidaire that do not currently produce batteries or battery-equipped products). Furthermore, by promoting battery-equipped induction products that visually coordinate with other appliances from the same manufacturer, CalMTA can potentially help increase adoption of induction cooking in the kitchen remodel market.

Finally, to ensure that pan detection and other efficiency features become more widespread, over time CalMTA could develop additional product specifications including these features, engage with manufacturers, provide midstream incentives, and/or coordinate with ENERGY STAR to drive these features into more products.

Improvements that increase consumer interest and/or satisfaction with electric cooking appliances

Induction cooking products already offer significant advantages over both gas and electric resistance cooking appliances, and manufacturers will continue to make updates and add features to increase the appeal of their products. However, for induction to gain a lasting foothold in the California market, products will need to appeal specifically to customers who are accustomed to cooking with gas and may have certain negative perceptions about electric cooking and/or the superiority of cooking with gas.

For example, a New York Times Wirecutter article[84] says a key reason that induction is still so uncommon is that “induction cooktops look like conventional electric cooktops [...] And those basic electric models are not especially well liked.” Potential improvements that can help address consumer attachment to gas and/or negative associations with electric resistance include:

- New design aesthetics that distinguish induction from conventional electric resistance products, such as the unique look employed by Impulse Labs.
- Visual cues that help users transition from gas cooktops, such as LED lights that emulate the look and intensity of a gas flame.

[84] The New York Times Wirecutter. “Why Don’t People Use Induction Cooktops?” Accessed July 31, 2024. https://www.nytimes.com/wirecutter/blog/why-dont-people-use-induction-cooktops/.

- Incorporation of a universally compatible resistance heating area (alongside several induction zones) to ease customer concerns about compatible cookware and allow more flexibility with use of existing cookware.
- Control and digital temperature displays that allow the user to set and hold specific temperatures for each heating zone.
- Further improvements to limit temperature overshoot and increase the precision of induction cooktops.
- Improvements to induction cooking products to address perceived and actual reliability issues, as seen in Table 11 and Table 12 from Yale Appliance detailing the variation in service calls for resistance and induction range appliances in 2020.
- Development of new products like induction woks and tortilla makers that serve specific culturally important food needs.

Technology actions

As a mature market with multiple, competing manufacturers, industry-funded R&D will likely address many of the minor improvements identified above. However, as of today the only manufacturers producing 120V battery-equipped induction products are focused almost entirely on high-end products for relatively affluent consumers. It is unclear whether either of those two manufacturers will shift their focus to lower-cost products, nor is it clear whether they are positioned to achieve the economies of scale and cost reductions attainable by major national and multinational brands.

To entice more manufacturers to enter the market for 120V battery-equipped induction products, it may be necessary for CalMTA (or other public-benefit organizations) to fund research that proves the viability and/or identifies methods to reduce the cost of 120V products. Research is needed to understand:

- Consumer cooking behaviors that will inform the level of performance needed in a 120V product.
- Cost drivers and potential engineering solutions that can reduce the price of 120V products while still meeting consumer expectations and needs.
- Cost sensitivity and willingness to pay for 120V induction products with reduced performance relative to 240V, particularly for multifamily owners and managers.

Code improvements

Federal appliance standards

DOE is required to review and, if necessary, update its test procedures every 5 to 7 years, and its standards every 6 to 8 years.[85] For cooking products, DOE will begin proceedings to review the test

[85] 42 U.S.C. §§ 6293(b) (test procedures), 6295(m) (standards).

procedures in 2027 and make any changes by 2029. DOE will review its standards in 2028, with a final rule by 2030. Standards would typically take effect three years after the final rule, in 2033.[86] Depending on the data available at the time the standard is under consideration, a future federal appliance standard could set efficiency levels for electric cooktops that are only achievable by induction technologies. The information from the most recent rulemaking showed that this was not cost-effective today, as the costs of induction cooktops were too high compared to their relative energy savings. A future federal appliance standard is very unlikely to eliminate gas cooktops or cause significant fuel-substitution, absent a change in the federal appliance statute.

State building codes

Although state building codes have long excluded consumer "white good" appliances, certain residential products, like cooktops, ranges, ovens, and dishwashers, are nearly always installed before the owner moves in, making them good candidates for the development of new code requirements, potentially expanding the scope of Title 24, Part 6 building codes. Since induction cooktops reduce the amount of waste heat absorbed into the living space, (creating a secondary impact on whole-home energy use) cooking appliances are a logical initial target for a Title 24 code proposal targeting white goods. These potential code requirements could look similar to requirements for heat pumps in both the prescriptive and performance pathways and create large incentives for a builder to include an electric cooktop. Although various groups have suggested this type of regulation as a logical next step for Title 24, no such code measure has yet been formally proposed to the CEC, so this is likely to be a long-term play targeting the 2031 code cycle or beyond.

There may also be opportunities to expand and leverage the range hood requirements described in the Codes and Standards section to encourage adoption of induction cooking products in existing residential buildings. Although code enforcement is inconsistent in existing buildings, homes and apartment buildings undergoing kitchen renovations trigger the same range hood requirements that apply to new construction – gas cooking appliances require larger, more expensive, and noisier range hoods – and the size is inversely proportional to the size of the dwelling unit. If the code compliance and enforcement process for range hoods were improved, it could create significant incentives and awareness for homeowners and multifamily building owners to reconsider their choice of cooking appliances during a kitchen remodel – the added cost and noise of a code-compliant range hood for a gas cooktop could help steer homeowners towards electric cooking products.

Local building codes

One avenue for codes is to have more local jurisdictions adopt reach codes that go beyond the state energy code in pushing newly constructed buildings towards electric cooking products. This effort is likely to continue ramping up over the next several years as local jurisdictions look to building codes as a way to meet their climate action plans.

[86] 42 U.S.C. § 6295(m)(4)(A)(i). The only reason this 3-year timeline would not apply is if a rule is negotiated that results in a different effective date, as occurred with the 2024 Direct Final Rule.

Zero emission standards

A final opportunity to drive electric cooking in regulatory requirement in the medium-term is to advocate to air districts (like Bay Area Air Quality Management District or South Coast Air Quality Management District) to adopt zero-nitric oxide and nitric dioxide (zero-NOx) standards for gas cooking products. These air districts have already adopted zero-NOx requirements for certain space- and water-heating.[87] To also address cooking, these agencies would need data to support making a case that the NOx emissions from cooking products are creating a significant impact on local air pollution levels that put the air district out of attainment with its Clean Air Act requirements.

7.3. Technical solutions (non-product)

Smart panels

Smart panels are a solution to many home electrification barriers. These products replace conventional electric panels, providing the same functions regarding fire prevention and circuit organization, with the added ability of Wi-Fi energy monitoring and some degree of control over where energy flows in the home. Smart panels become more effective with added components like solar PV, whole-home battery backup, and Internet of Things smart devices. They are generally oriented around energy management and power control, which is a new frontier for most consumers.

While smart panels offer several advantages, including enhanced control over energy use, increased efficiency through optimized energy allocation, and advanced monitoring capabilities, they also have some limitations. These products are typically more expensive than conventional electric panels, and as a relatively new technology category, their longevity and reliability may be unknown compared to traditional breaker boxes. Additionally, for consumers who need to run a new 240V circuit to electrify gas cooking, there is a landscape of electrification solutions in homes where the electric panel itself does not need to be replaced or upgraded.

Circuit sharing devices

Circuit sharing devices offer a cost-effective solution for consumers who need to electrify their kitchens but lack sufficient capacity or space on their electrical panel. This can overcome the challenge and expense of needing a new circuit run back to the panel, the installation of a sub-panel, or a panel upgrade if there is insufficient capacity. In such cases, sharing an existing 240V circuit, like one for a 240V electric clothes dryer, might be the cheapest option.

Circuit sharing devices allow multiple high current devices to share the same wire branch and panel breaker, with only one device powered at any given time. These devices are specifically designed to prioritize which appliance has access to the full current capacity of the circuit, preventing other appliances from drawing power and risking an overload. The NeoCharge Smart Splitter is an example of such a product, which enables multiple 240V appliances to share the

[87] Bay Area Air Quality Management District, Regulation 9, Rules 4 and 6; South Coast Air Quality Management District, Rules 1146.2, 111, and 1121.

same circuit even when it lacks sufficient capacity to support all appliances simultaneously. These devices are a potentially valuable tool for electrifying cooking.

8. Technical potential

According to the CPUC, "Technical potential is defined as the amount of energy savings that would be possible if the highest level of efficiency for all technically applicable opportunities to improve energy efficiency were taken, including retrofit measures, replace-on-burnout measures, and new construction measures."[88] Although CalMTA did not perform a formal technical potential study, the team used available data to estimate unit-scale energy consumption for baseline and target technologies. The team then leveraged existing data sources to determine the quantity of existing cooking appliances in residential buildings and estimate statewide technical potential.

The following section outlines the methodology and data sources used to estimate energy consumption for both baseline and target technologies.

8.1 Technical/market baseline

Technical potential is calculated based on the quantity of existing appliances in California residential buildings. It does not account for changes in the market over time, Baseline Market Adoption for the target technology, or market factors limiting adoption – it is simply the maximum potential impact of the technology if it were adopted in 100% of California dwelling units.

As described in the Market Assessment section, the California residential market is currently dominated by products using natural gas, but also includes a handful of different electric resistance technologies, as well as induction. Many high-end ranges are mixed-fuel models, with gas cooktops and electric ovens. Likewise, standalone wall ovens tend to use electricity, even in homes where the cooktop is fueled by gas. As such, most of the potential energy and emissions reductions will be attributable to the replacement of gas[89] cooking appliances, including both gas cooktops and gas ranges.

Baseline energy and emissions

To establish baseline energy consumption and emissions, the team leveraged existing data sources to model a natural gas range and an inefficient electric resistance range, which were then compared to a model representing induction appliances, the proposed technology.

Proposed/target technology energy and emissions

Since the product definition includes both *efficient* radiant and induction electric cooking appliances per the ENERGY STAR specification, the proposed design used for the calculation

[88] https://www.cpuc.ca.gov/-/media/cpuc-website/divisions/energy-division/documents/energy-efficiency/2025-potential-goals-study/draft-2025-pg-study-work-plan.pdf.

[89] Many homes in rural communities rely on propane as a fuel source for cooking, but for the purposes of this plan those appliances will be grouped together with natural gas appliances.

represents a level of performance consistent with most electric induction ranges as well as the best-in-class radiant electric range (i.e., those capable of achieving ENERGY STAR certification). In other words, gas appliances only represent a baseline technology, and induction appliances only represent the target technology, but electric resistance products can represent either the baseline (inefficient resistance) or the target (efficient resistance cooktop).

Modeling methodology and data sources

Annual energy consumption for both baseline and target technologies was estimated based on results from Residential Building Stock Assessment EPRI load shape.[90] This load shape was then scaled to the IAEC for each appliance type provided by DOE in a recent life-cycle cost and payback analysis.[91]

Table 14: The assumed energy consumption values for each appliance type for these modeling scenarios

Appliance type	Annual kWh consumption assumed	Annual therm consumption assumed
Electric induction cooktop	192.5	0
Electric resistance cooktop	207	0
Gas cooktop	0	15.81
Electric induction range	528.67	0
Electric resistance range	543.56	0
Gas range	0	35.51

Estimating avoided costs

Adoption of efficient electric cooking appliances can be considered an efficiency measure and/or a fuel substitution measure, depending on the baseline. As an efficiency measure (relative to conventional electric resistance cooktops), kWh savings can be calculated. However, as a fuel substitution measure, adoption of induction cooking includes both the elimination of gas consumption (therms) and the addition of electrical load (kWh. The CPUC's Avoided Cost Calculator (ACC)[92] provides a robust framework for evaluating the impact of fuel substitution measures, like electrification of cooking. Since the calculator can convert both gas and electricity consumption/savings to dollars of avoided cost, it provides a metric to calculate the impact of both fuel substitution measures as well as pure efficiency measures. The team used the CPUC's

[90] Electric Power Research Institute. "Residential Building Stock Assessment (RBSA)." https://loadshape.epri.com/rbsa.
[91] https://www.regulations.gov/document/EERE-2014-BT-STD-0005-12820.
[92] Per the CPUC, "The primary benefits of demand-side resources are the avoided costs related to generation and distribution of energy. The avoided costs of electricity are modeled based on the following components: generation energy, generation capacity, ancillary services, transmission and distribution capacity, and decarbonization policy compliance. The ACC was established in 2005 and is updated biennially to improve the accuracy of how the benefits of demand-side resources are calculated."

Avoided Cost Calculator (ACC) from 2024 to convert baseline gas and baseline electricity use to dollars (cost). The team then calculated the dollar value for annual operation (electricity use) of the target technology and subtracted the target value from the baseline value to calculate the avoided costs for adoption of one unit. These unit-scale calculations were then used to estimate Total System Benefit, as described in the Market Forecasting Appendix, and to develop the statewide Technical Potential estimates provided in Section of this report.

Modeling approach

Consumption for each baseline was converted from therms or kWh to dollars using the respective ACC workbook and the assumed values in Table 14. The ACC includes unique factors and cost calculations for each year covering a 30-year period beginning in 2024. Since the technical potential assumes 100% adoption but does not account for the rate of adoption or when the technical potential will be reached, the avoided costs values were determined for a 16-year EUL starting in 2024. The statewide technical potential represents the annual avoided cost resulting from 100% adoption of induction technology between starting in 2024.

Assumptions and results

The team calculated avoided costs in each of three electric IOU territories: PG&E, SCE, and SDG&E. For each IOU territory avoided costs were calculated for two scenarios, each of which represented adoption in multifamily (MF) and/or single family (SF) housing, resulting in a total of eight scenarios found in below.

The avoided cost values for each of the three IOU territories were averaged together to develop average Annual Avoided Cost per Unit, assuming one range or cooktop per dwelling unit.

Statewide technical potential

The total technical potential is based on the entire market adopting the MTI technology and avoided costs over the expected useful life the product. The total avoided costs were calculated in net present value for each electrification scenario and then summed. As shown in Table 15, annual technical potential is $1.15 billion with $315 million in multifamily and $835 million in single-family homes.

Existing single family and multifamily dwelling units were estimated using 2022 American Consumer Survey data. The details of this data can be found in Appendix D.

Table 15: The total technical potential of the Induction Cooking MTI

Savings Shape # - Market Segment	Baseline	Proposed	Total units (thousands)	Avoided cost per unit ($)	Statewide avoided cost (millions of $)
1 - SF	Electric Resistance Cooktop	Electric Induction Cooktop	358	$22.29	$7.98
2 - SF	Gas Cooktop	Electric Induction Cooktop	1,477	$115.29	$170.31
3 - SF	Electric Resistance Range	Electric Induction Range	1,314	$22.27	$29.26
4 - SF	Gas Range	Electric Induction Range	5,452	$115.07	$627.36
1 - MF	Electric Resistance Cooktop	Electric Induction Cooktop	65	$22.29	$1.45
2 - MF	Gas Cooktop	Electric Induction Cooktop	109	$115.29	$12.53
3 - MF	Electric Resistance Range	Electric Induction Range	1,766	$22.27	$39.34
4 - MF	Gas Range	Electric Induction Range	2,272	$115.07	$261.46
Total	-	**Electric Induction Cooking**	**12,813**	**-**	**$1,149.69**

Table 1 from the Executive Summary displays the calculated avoided costs for each proposed cooking electrification scenario, broken out by IOU. The results demonstrate a trend of greater avoided GHG costs for ranges, while cooktops are balanced by greater avoided costs in energy and grid impacts. Given the large contribution of energy consumption by ovens, it follows that electrifying both an oven and a cooktop would yield higher avoided GHG costs, and lower avoided grid and energy impacts compared to a cooktop alone. Finally, there are significant avoided costs available for battery-equipped products that can load-shift their cooking demand to off-peak hours, capturing additional grid benefits.

Additional factors not included in initial calculation

Impacts on heating and cooling loads

Dinnertime and the associated cooking activities for many consumers fall squarely within California's daily electricity peak (4:00 – 9:00) PM), meaning that the electrification of cooking can add load at a time when the grid is already strained. The impact of this added load is already accounted for by the hourly load shapes used to develop the avoided cost model.

However, gas cooking generates more than twice as much waste heat as induction cooktops, creating additional electrical cooling load to manage this excess heat. Therefore, moving from gas to induction can reduce peak HVAC electricity demand from California households, and partially offset overall peak demand on the grid. This factor was not accounted for in our avoided cost model or assessment of Technical Potential but should be evaluated to determine the overall potential benefit of replacing gas stoves with induction.

The team will account for the bill impacts and avoided costs of the reduced heat input into the home upon moving from gas to induction appliances using the following methodology.

Leverage existing energy models for representative single-family and multifamily homes in each climate zone of interest.

Assume that homes with gas appliances use gas for heating. Assume these base cases benefit from waste heat in the heating season and are harmed by waste heat in the cooling season.

Extract energy use for heating from the baseline energy model. Identify times when the heat is in use with a Boolean flag for nonzero heating energy expenditure.

Extract energy use for cooling from the baseline energy model. Identify times when the AC is in use with a Boolean flag for nonzero cooling energy expenditure.

Identify the waste heat (versus time for the whole year) based on the cooking load shape and an assumed efficiency for the gas cooktop/oven.

Modify the heating load in the heating season by adding the value of the waste heat from the gas appliance, which will no longer be present after moving to induction. Use an assumed efficiency value (i.e., 81% for a gas furnace) to turn this heat load into energy load used for heating.

Modify the cooling load in the cooling season by subtracting the value of the waste heat from the gas appliance, which will no longer be present after moving to induction. Use an assumed coefficient of performance value (i.e., 3 for a central AC) to turn this reduced heat load into energy saved by not cooling.

Re-run the energy model to determine avoided costs and bill impacts based on the modified annual energy usage for heating and cooling.

We did not run full energy models due to the complexity with ventilation in the context of single source heating events in the kitchen and the associated airflow modeling. However, when we ran our analysis, we determined that HVAC savings were on the order of ~8%.

Impacts on leakage from gas infrastructure

In many homes and buildings, cooking appliances may be the last end-use that consumers electrify, enabling disconnection from the gas grid. If done strategically, this can enable decommissioning of portions of the natural gas grid, reducing emissions and waste from methane leakage. Although it is difficult to determine how much of a role cooking electrification has in full electrification of homes and apartments, or in the subsequent gas decommissioning of the gas distribution system, it is a factor that should be considered.

Since cooking is often described as the most challenging and final energy end use to be electrified in homes and apartments, increasing adoption of induction cooktops and ranges can play a critical, lynchpin role enabling full electrification and gas decommissioning. Future work includes an environmental and economic analysis of gas infrastructure strategic decommissioning, as well monitoring current legislation addressing it. As induction cooking is a "keystone" measure for residential electrification in California, this analysis will contextualize the importance of these products within the broader gas decommissioning and decarbonization effort in the State.

8.2 Methodology/Approach

Using the avoided cost model, we obtained the grid emissions intensity for each hour from 2025-2052 by utility and climate zone. We then constructed a continuous time-series of this grid intensity (in units of tons CO2 / kWh). For standard induction and resistance appliances, we multiplied the hourly usage (in kWh) by this grid intensity to get total emissions over this 28-year period, dividing by 28 at the end to get the annual emissions impact in tons. For the gas baseline, we multiplied annual usage in therms by emissions intensity of natural gas (5.3 kg CO2/therm). Taking the difference of these emissions values produced our estimates of emissions reductions for moving from gas appliances to standard induction or efficient radiant resistant units.

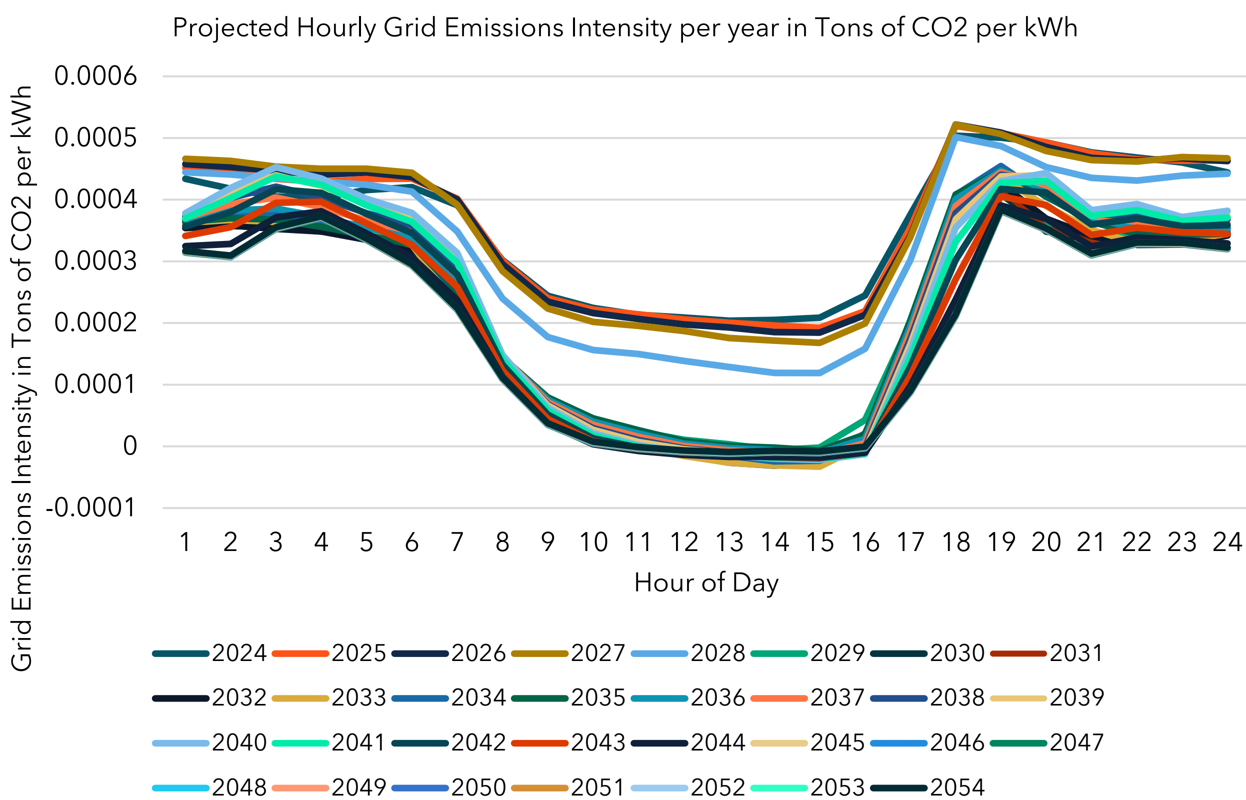
8.3 Energy consumption/peak electrical

For battery equipped induction appliances, more substantial modeling was required to estimate the GHG emission impact. We constructed an optimized load shape for these appliances, which concentrated charging events (in other words, grid energy usage) in times of minimum grid intensity throughout the day. After analyzing the grid intensity profiles, we determined the optimal hour of the day to be 2pm from 2025-2043, and 11am from 2044-2052. The total daily usage for induction appliances was thus transferred to this single hour of the day each day for the 28-year period that we analyzed and scaled up to account for the assumed 85% round-trip efficiency for charging and discharging the battery. After constructing this modified (shifted) load shape, we could multiply each hourly value by the grid emissions intensity for that hour as described for the other types of appliances. Taking the difference of total annual emissions between the different technologies (i.e., gas ranges vs. battery equipped induction ranges), we calculated the annual emissions reductions summarized in the following section.

8.3 Greenhouse gas emissions

In calculating the total GHG emission savings of fuel substitution from gas to induction, we find that although gas ranges use an average of 35.5 therms per year in our model (~188 kg CO_2/year), the net reductions in emissions are substantially lower. This is mostly a function of the carbon intensity of the grid, which varies widely by hour of the day (see Figure 15). The battery-equipped induction appliances allow all energy consumption for the year to be coincident with markedly lower grid emissions intensity observed during peak solar generation periods (i.e., 0.00008 ton CO_2/kWh at 2pm vs. 0.00042 ton CO_2/kWh at 5pm). This dramatically lowers the GHG emissions for battery equipped induction appliances despite the fact that they consume slightly more energy on an annual basis than the baseline induction appliances (after accounting for 85% round-trip efficiency for charging and discharging the battery). This demonstrates significant potential for emissions reductions (and reduced bill impacts) through intelligent load shifting practices.

Figure 15: Hourly grid emissions intensity by hour



9. Risk assessment

In Table 4 and Table 5 of Section 5, the competitive landscape of cooking products is tabulated. Strengths, weaknesses, opportunities, and threats are organized by technology type and form factor. Some of these attributes carry broader risks that may threaten induction cooking technology adoption. This section aims to elaborate on the risks of these specific threats and weaknesses as they pertain to the adoption of 240V and 120V battery-equipped induction cooking products.

9.1. Availability of affordable induction products

At present, the lowest cost electric cooking products use resistance coils. While there are budget friendly radiant cooktops products, there will always be additional costs associated with the glass or ceramic cooktop surface that are not present in the coil-type appliances. Induction cooking product designs also incorporate a smooth glass or ceramic surface, and so the cost add of this component impacts prices on these appliances. In addition, induction cooking products have sophisticated components, as described in a previous section.

For these reasons, current market offerings for permanently installed induction cooking products are costlier to purchase than both incumbent cooking technologies. Unless more affordable permanently installed induction products are introduced into the market, this poses a significant risk to the adoption of the technology in California, particularly with ESJ communities.

9.2. Workforce capacity to upgrade and/or optimize existing electrical panels

240V induction cooking products will frequently require upgrades and/or optimizations to the home electrical infrastructure, as described in this report. While bottlenecks in supply chains are certainly a concern, there is a bigger potential for constraints in workforce availability to perform the labor required if electrification efforts gain significant momentum statewide. Battery-equipped 120V induction cooking products can mitigate this potential risk, but a large number of building owners will opt for 240V cooking electrification and the possibility of labor as the limiting factor remains strong.

9.3. Cost of batteries

While there are risks associated with cooking fuel substitution measures adding more demand to an already strained electricity supply grid, 120V battery-equipped induction cooking appliances can alleviate some of these issues. However, this product class brings a new set of risks, the most notable of which is the current cost of batteries. While the benefits of the battery are numerous, the costs are a significant hurdle as of the writing of this report.

The market for energy storage has grown rapidly in recent years, leading to increased research, development, and deployment of safer and more cost-effective battery technologies. As a result, the prices per kWh have been steadily declining.

During the lifespan of this Market Transformation Initiative, it is expected that the cost of battery storage will continue to drop significantly, with current pricing serving as a worse-case scenario for battery-equipped appliances. This decline in battery costs will likely make 120V induction cooking appliances with batteries more competitive and attractive to consumers, relative to 240V electric cooking solutions and the associated constraints with them, ultimately driving growth and the adoption of electrification solutions.

9.4. Fire code

Incumbent battery chemistries have a documented history of safety issues, including events caused by thermal runaway. Thermal runaway is the uncontrolled and accelerating increase in temperature, which can lead to a catastrophic failure of the battery. This phenomenon occurs due to a combination of factors, such as overcharging, high temperatures, and physical damage. The resulting instance of thermal runaway can cause fires, damage, and injury.

Lithium-ion battery fires in New York City have prompted the city council to propose a bill[93] aimed at requiring stricter quality and safety requirements for lithium-ion batteries used in micromobility applications. The fire department has noted that these types of fires are more intense and require more than just a bit of water to extinguish. Dozens of deaths have been attributed to these fires over the years, and the city is reluctant to promote the installation of significant quantities of lithium-ion batteries in energy storage applications for consumer appliances.

To address these concerns with incumbent batteries, the market has incentivized alternative battery chemistries. Currently, Lithium Iron Phosphate ($LiFePO_4$) batteries are a viable and available alternative to incumbent Lithium-ion chemistries that are susceptible to thermal runaway. While $LiFePO_4$ batteries have a reduced energy density compared to these incumbent chemistries, they are significantly safer, with no susceptibility to thermal runaway. The reduced energy density is only a major factor in certain applications of energy storage, and cooking appliances do not necessarily require a premier level of energy density.

The consequence of rapidly developing battery chemistries is seen in the market, but regulation is slower to recognize these safety claims.

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[93] New York City Council. "Legislation Detail: Local Law to amend the administrative code of the city of New York, in relation to safety standards for powered bicycles and powered mobility devices used for deliveries." Accessed July 31, 2024. https://legistar.council.nyc.gov/LegislationDetail.aspx?ID=6495036&GUID=53BE60CC-CF72-417F-B0A3-FD0D99A991F1.

9.5. Reliability

Induction cooking products are relatively unproven over multiple decades of mass consumer adoption. There is little to no data available about long-term reliability. As such, there remains a risk for the procurement of sophisticated components and the availability of the labor force to repair and install them. Supply chain considerations will be discussed further in the next section.

9.6. Cost of fuel

While the cost of induction appliances themselves are certainly a concern, there lies another risk to the adoption of this cooking technology. The bill impacts of fuel substitution are, generally, not favorable for electrification. The future of gas and electric rates are not a certainty, and so there is risk in the continued uneconomical cost of moving from gas to electric fuel for cooking. The gas industry might promote these costs loudly, and in conjunction with the perception of high-quality gas cooking experiences today, it creates a potential risk for induction cooking adoption over a longer time horizon.

This issue is further magnified by the difference in TOU rates for electricity and gas. Gas rates do not vary by hour, only season. Conversely, electric rates are higher when most Californians are ready to cook their evening meal. This dynamic has a detrimental effect on the cost of fuel substitution for cooking technologies, specifically. The future of peak electrical rates must not rise faster than the increase in gas rates, or the economics of cooking fuel substitution will not become favorable.

9.7. Differentiation between induction and radiant

Induction and radiant cooking are fundamentally different in the way that each cooks food. However, the actual appearance of each product, generally, is quite similar. If Californians have existing bias and a negative perception of electric cooking due to the history of radiant products, there is a risk that the invisible differences in appearance between radiant and induction products might cause potential buyers to delay or refuse adoption of the superior technology.

9.8. Technical supply chain considerations

While an exhaustive investigation into the specific supply chain constraints for induction appliance components is outside the scope of this report, several supply chain comparisons can be made to inform the future of separate market areas for these appliances.

Supply chain for appliances

The existing supply chains for gas and radiant resistance cooking appliances themselves are mature, reflecting the long history of these products. Simple electronics controls, aluminum housings, metal oven racks and grates, resistance heating elements, and gas-rated piping have been manufactured for decades, making procurement relatively straightforward.

In contrast, induction technology is a more recent entry into cooking appliances, with more sophisticated power electronics controls and components. These components are also more sensitive to electrical infrastructure problems than incumbent radiant products, as previously indicated by Yale Appliance. The combination of more sophisticated and sensitive manufacturing processes, as well as the potential for reliability issues related to voltage spikes, mean that the stable adoption of induction cooking appliances faces a potential uphill future in widespread adoption.

New market entries for battery-equipped 120V induction products are further constrained by supply chains. Currently, these products must import batteries from overseas while managing tariffs, shipping, and more. The largest single lever in reducing the costs of these battery-equipped products would be to leverage reliable US-made batteries manufactured locally, with no shipping constraints or tariffs.

Supply chain for external dependencies

Modern gas cooking appliances do not rely on pilot lights, but instead use electronic ignition systems powered by a 15A, 120V circuit. This means that each gas cooktop requires an electrical hookup, although it is still possible to use the appliance without power by manually igniting the gas burners, assuming the flow of gas remains uninterrupted. This setup is common in most households and does not pose a barrier to the use of gas cooking appliances.

In contrast, 240V radiant and induction cooking appliances require significantly more access to electrical capacity than comparable gas cooking products. When electricity cannot be provided to these technologies, no cooking can be performed. As such, resiliency for these cooking methods relies on robust grid infrastructure within the home and on the broader electrical network.

Both radiant and induction cooking technologies have a high potential to necessitate electrical infrastructure upgrades when electrifying cooking from gas appliances. These upgrades may include:
Electrical panel replacements and/or optimizations

Conduit upgrades

Local distribution system upgrades

Transformer upgrades

While there is no definitive data on exactly how many of these types of upgrades will be realized in the future, various scenarios can be described based on existing studies and industry reports. These are critical scenarios to model, as many of these external dependencies have widely known supply chain bottlenecks and can significantly impact CA electrification efforts.

The complexity and sophistication of induction appliance components pose a challenge for the supply chain, particularly when compared to the more established and secure chains for gas and radiant resistance cooktops. Similarly, radiant and induction cooking appliances require electrical supplies that are often a significant bottleneck to electrification efforts. As the market for induction appliances continues to grow, it is essential to track and address these technical supply chain considerations to ensure stable and reliable component procurement and infrastructure development, ultimately supporting the widespread adoption of this technology.

Attachment 1: Cost Per Effective kBTU/h of Heating Output

An analysis comparing the up-front cost of different cooking appliances was developed, and a subset of results were presented in Figure 11, under the Product Performance section of this report.

Gas cooking power uses British Thermal Units per Hour (BTU/h), while electric cooking power uses kilowatts (kW). To simplify this comparison the following analysis methodology was developed.

1) Data Collection: A dataset of over 800 cooking appliances was gathered.
2) Categorization: The appliances were sorted by fuel type (gas, electric), technology type (gas, radiant, induction), and the number of heating zones
3) Median price calculation: The median price for each appliance was gathered, and the average of these median prices was calculated for each product category
4) Power output standardization: The power output of the single largest heating zone for each product was found and averaged across each product in the category
5) Conversion to kBTU/h: Electric cooking appliance power output values were converted to kBTU/h from kW for consistency
6) Weighting by thermal efficiency: Each product category's average median price was divided by the average power output of the largest heating zone, then weighted by the thermal efficiency of each technology:
    a. 40% for gas
    b. 74% for radiant
    c. 84% for induction
7) Calculation of Price per Effective kBTU/h: This resulted in a value representing the performance-weighted cost-effectiveness of each product category, with "Effective kBTU/h" indicating the heat that actually cooks food, rather than being wasted due to inefficiencies.

By comparing the calculated values across different categories, a consistent trend was observed, providing a potential opportunity for a product labeling market intervention.

Attachment 2: Current Test Method for Measuring the Energy Consumption of Conventional Cooking Products

The DOE is enacting energy standards for cooking products beginning in 2028. The following test method is used to generate the results for the standard requirements shown in Table 6, under Section 5 of this report.

3.1.4 ***Per-cooking zone energy consumption test.*** Establish the test conditions set forth in section 2 of this appendix. Turn off the gas flow to the conventional oven(s), if so equipped. The product temperature must meet the specifications in section 2.5 of this appendix.

3.1.4.1 ***Test vessel placement.*** Position the test vessel with water load for the cooking zone under test, selected and prepared as specified in section 3.1.1 of this appendix, in the center of the cooking zone, and as specified in Annex C to IEC 60350-2.

3.1.4.2 ***Overshoot test.*** Use the test methods set forth in Section 7.5.2.1 of IEC 60350-2 to determine the target turndown temperature for each cooking zone, Tc_{target}, in degrees Celsius, as follows.

$Tc_{target} = 93\ °C - (T_{max} - T_{70})$

Where:

T_{max} is highest recorded temperature value, in degrees Celsius; and

T_{70} is the average recorded temperature between the time 10 seconds before the power is turned off and the time 10 seconds after the power is turned off.

If T_{70} is within the tolerance of 70 ± 0.5 °C, the target turndown temperature is the highest of 80 °C and the calculated Tc_{target}, rounded to the nearest integer. If T_{70} is outside of the tolerance, the overshoot test is considered invalid and must be repeated after allowing the product to return to ambient conditions.

3.1.4.3 ***Potential simmering setting pre-selection test.*** The potential simmering setting for each cooking zone may be determined using the potential simmering setting pre-selecting test. If a potential simmering setting is already known, it may be used instead of completing sections 3.1.4.3.1 through 3.1.4.3.4 of this appendix.

3.1.4.3.1 Use the test vessel with water load for the cooking zone under test, selected, prepared, and positioned as specified in sections 3.1.1 and 3.1.4.1 of this appendix. The temperature of the conventional cooking top is not required to meet the specification for the product temperature in section 2.5 of this appendix for the potential simmering setting pre-selection test. Operate the cooking zone under test with the lowest available power setting. Measure the energy consumption for 10 minutes ±2 seconds.

3.1.4.3.2 Calculate the power density of the power setting, j, on a conventional electric cooking top, Qe_j, in watts per square centimeter, as:

$$Qe_j = \frac{6 \times E_j}{a}$$

Where:

a = the surface area of the test vessel bottom, in square centimeters; and
E_j = the electrical energy consumption during the 10-minute test, in Wh.

3.1.4.3.3 Calculate the power density of the power setting, j, on a conventional gas cooking top, Qg_j, in BTU/h per square centimeter, as:

$$Qg_j = \frac{6 \times \left(V_j \times CF \times H + Ee_j \times K_e\right)}{a}$$

Where:

a = the surface area of the test vessel bottom, in square centimeters;

V_j = the volume of gas consumed during the 10-minute test, in cubic feet;

CF = the gas correction factor to standard temperature and pressure, as calculated in section 4.1.1.2.1 of this appendix;

H = either H_n or H_p, the heating value of the gas used in the test as specified in sections 2.2.2.1 and 2.2.2.2 of this appendix, in BTU per standard cubic foot of gas;

Ee_j = the electrical energy consumption of the conventional gas cooking top during the 10-minute test, in Wh; and

K_e = 3.412 BTU/Wh, conversion factor of watt-hours to BTU.

3.1.4.3.4 Repeat the measurement for each successively higher power setting until Qe_j exceeds 0.8 W/cm^2 for conventional electric cooking tops or Qg_j exceeds 4.0 BTU/ h·cm^2 for conventional gas cooking tops.

For conventional cooking tops with rotating knobs for selecting the power setting, the selection knob shall be turned to the maximum power setting in between each test, to avoid hysteresis. The selection knob shall be turned in the direction from higher power to lower power to select the power setting for the test. If the appropriate power setting is passed, the selection knob shall be turned to the maximum power setting again before repeating the power setting selection.

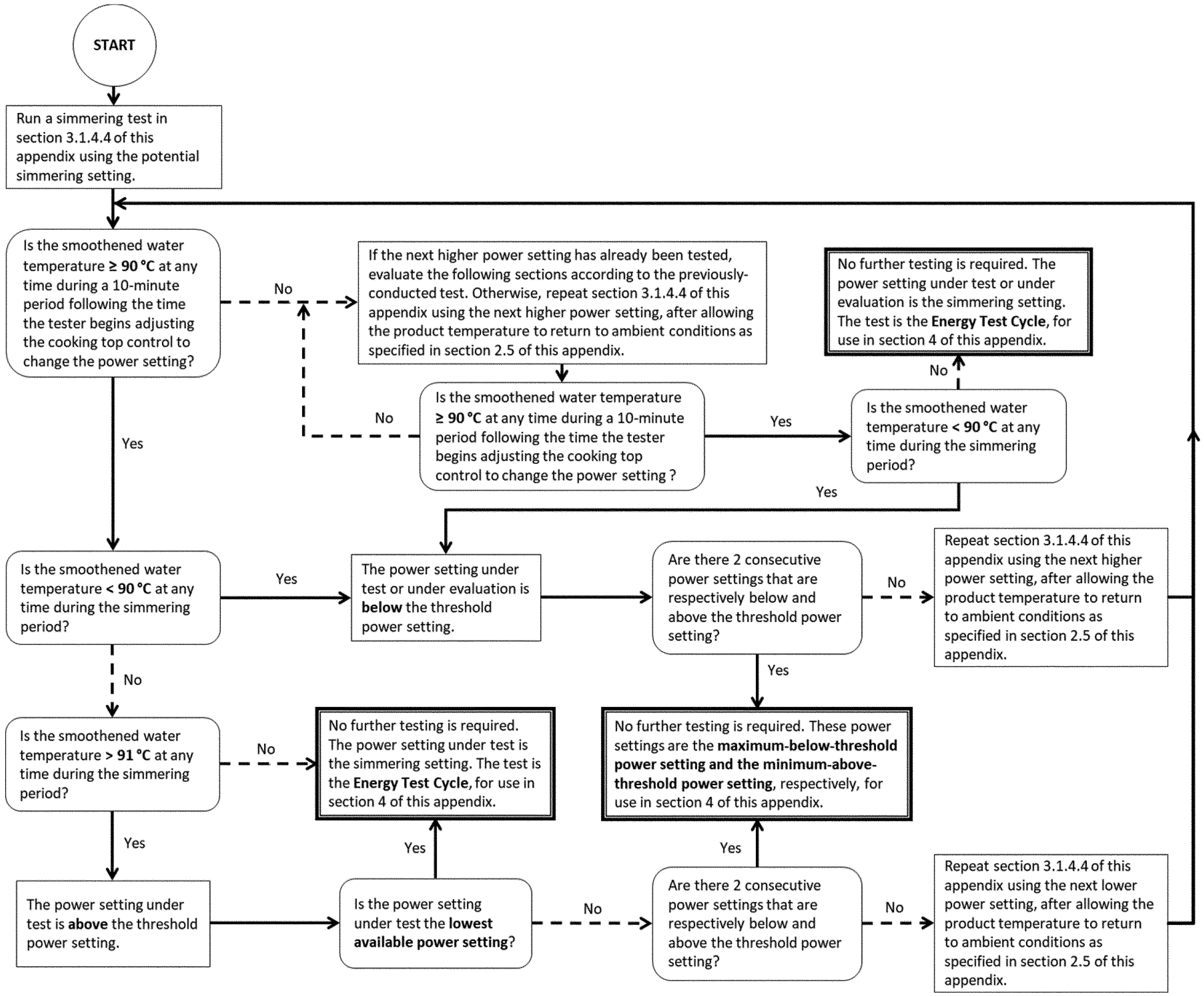
Of the last two power settings tested, the potential simmering setting is the power setting that produces a power density closest to 0.8 W/cm^2 for conventional electric cooking tops or 4.0 BTU/h·cm^2 for conventional gas cooking tops. The closest power density may be higher or lower than the applicable threshold value.

3.1.4.4 ***Simmering test.*** The product temperature must meet the specifications in section 2.5 of this appendix at the start of each simmering test. For each cooking zone, conduct the test method specified in Section 7.5.2 of IEC 60350-2, using the potential simmering setting identified in section 3.1.4.3 of this appendix for the initial simmering setting used in Section 7.5.2.2 of IEC 60350-2.

For conventional cooking tops with rotating knobs for selecting the power setting, the selection knob shall be turned in the direction from higher power to lower power to select the potential simmering setting for the test, to avoid hysteresis. If the appropriate setting is passed, the test is considered invalid and must be repeated after allowing the product to return to ambient conditions.

3.1.4.5 ***Evaluation of the simmering test.*** Evaluate the test conducted under section 3.1.4.4 of this appendix as set forth in Section 7.5.4.1 of IEC 60350-2 according to Figure 3.1.4.5 of this appendix. If the measured turndown temperature, Tc, is not within -0.5 °C and +1 °C of the target turndown temperature, Tc_{target}, the test is considered invalid and must be repeated after allowing the product to return to ambient conditions.

Figure 3.1.4.5 Evaluation of the Simmering Test



3.2 **Standby mode and off mode power.** Establish the standby mode and off mode testing conditions set forth in section 2 of this appendix. For products that take some time to enter a stable state from a higher power state as discussed in Section 5, Paragraph 5.1, Note 1 of IEC 62301 (Second Edition), allow sufficient time for the product to reach the lower power state before proceeding with the test measurement. Follow the test procedure as specified in Section 5, Paragraph 5.3.2 of IEC 62301 (Second Edition) for testing in each possible mode as described in sections 3.2.1 and 3.2.2 of this appendix. For units in which power varies as a function of displayed time in standby mode, set the clock time to 3:23 at the end of an initial stabilization period, as specified in Section 5, Paragraph 5.3 of IEC 62301 (First Edition). After an additional 10-minute stabilization period, measure the power use for a single test period of 10 minutes +0/−2 seconds that starts when the clock time first reads 3:33. Use the average power approach described in Section 5, Paragraph 5.3.2(a) of IEC 62301 (First Edition).

3.2.1 If the product has an inactive mode, as defined in section 1 of this appendix, measure the average inactive mode power, P_{IA}, in watts.

3.2.2 If the product has an off mode, as defined in section 1 of this appendix, measure the average off mode power, P_{OM}, in watts.

3.3 **Recorded values.**

3.3.1 **Active mode.**

3.3.1.1 For a conventional gas cooking top tested with natural gas, record the natural gas higher heating value in BTU per standard cubic foot, H_n, as determined in section 2.2.2.1 of this appendix for the natural gas supply, for each test. For a conventional gas cooking top tested with propane, record the propane higher heating value in BTU per standard cubic foot, H_p, as determined in section 2.2.2.2 of this appendix for the propane supply, for each test.

3.3.1.2 Record the test room temperature in degrees Celsius and relative air pressure in
hectopascals (hPa) during each test.

3.3.1.3 **Per-cooking zone energy consumption test.**

3.3.1.3.1 Record the product temperature in degrees Celsius, T_P, prior to the start of each overshoot test or simmering test, as determined in section 2.5 of this appendix.

3.3.1.3.2 **Overshoot test.** For each cooking zone, record the initial temperature of the water in degrees Celsius, T_i; the average water temperature between the time 10 seconds before the power is turned off and the time 10 seconds after the power is turned off in degrees Celsius, T_{70}; the highest recorded water temperature in degrees Celsius, T_{max}; and the target turndown temperature in degrees Celsius, Tc_{target}.

3.3.1.3.3 **Simmering test.** For each cooking zone, record the temperature of the water throughout the test, in degrees Celsius, and the values in sections 3.3.1.3.3.1 through 3.3.1.3.3.7 of this appendix for the Energy Test Cycle, if an Energy Test Cycle is measured in section 3.1.4.5 of this appendix, otherwise for both the maximum below-threshold power setting and the minimum-above-threshold power setting. Because t_{90} may not be known until completion of the simmering test, water temperature, any electrical energy consumption, and any gas volumetric consumption measurements may be recorded for several minutes after the end of the simmering period to ensure that the full simmering period is recorded.

3.3.1.3.3.1 The power setting under test.

3.3.1.3.3.2 The initial temperature of the water, in degrees Celsius, T_i.

3.3.1.3.3.3 The time at which the tester begins adjusting the cooking top control to change the power setting, to the nearest second, t_c and the turndown temperature, in degrees Celsius, Tc.

3.3.1.3.3.4 The time at which the simmering period starts, to the nearest second, t_{90}.

3.3.1.3.3.5 The time at which the simmering period ends, to the nearest second, t_S and the smoothened water temperature at the end of the simmering period, in degrees Celsius, T_S.

3.3.1.3.3.6 For a conventional electric cooking top, the electrical energy consumption from the start of the test to t_S, E, in watt-hours.

3.3.1.3.3.7 For a conventional gas cooking top, the volume of gas consumed from the start of the test to t_S, V, in cubic feet of gas; and any electrical energy consumption of the cooking top from the start of the test to t_S, E_e, in watt-hours.

3.3.2 **Standby mode and off mode.** Make measurements as specified in section 3.2 of this appendix. If the product is capable of operating in inactive mode, as defined in section 1 of this appendix, record the average inactive mode power, P_{IA}, in watts as specified in section 3.2.1 of this appendix. If the product is capable of operating in off mode, as defined in section 1 of this appendix, record the average off mode power, P_{OM}, in watts as specified in section 3.2.2 of this appendix.

Attachment 3: Unit Energy Savings & Avoided Cost Calculation Methodology

See Appendix B: Market Forecasting and Cost-Effectiveness Modeling Approach for this attachment.