UNITED STATES OF AMERICA
BEFORE THE
FEDERAL ENERGY REGULATORY COMMISSION

Electrification and the Grid of the Future	)))	Docket No. AD21-12-000

INITIAL COMMENTS OF THE
AMERICAN PUBLIC GAS ASSOCIATION

Pursuant to notice of the Federal Energy Regulatory Commission (FERC or Commission) to hold a technical conference to discuss electrification,[1] and the subsequent notice inviting comments,[2] the American Public Gas Association (APGA) files these initial comments:

I. COMMUNICATIONS

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[1] Electrification and the Grid of the Future; Notice of Technical Conference, FERC (Mar. 2, 2021). Electrification and the Grid of the Future; Supplemental Notice of Technical Conference, 86 FR 20677 (Apr. 21, 2021).

[2] Electrification and the Grid of the Future; Notice Inviting Post-Technical Conference Comments, 86 FR 27843 (May 24, 2021).

II. STATEMENT OF INTEREST

APGA is the national, non-profit association of publicly-owned natural gas distribution systems, with over 735 members in 38 states. Overall, there are approximately 1,000 community-owned systems in the United States. Publicly-owned gas systems are not-for-profit retail distribution entities that are owned by, and accountable to, the citizens they serve. They include municipal gas distribution systems, public utility districts, county districts, and other public agencies that have natural gas distribution facilities.

Public gas systems provide safe, reliable, and affordable energy to their customers and support their communities by delivering fuel to be used for cooking, clothes drying, and space and water heating, as well as for various commercial and industrial applications. A not-for-profit public gas system gives a community local control over how energy is provided to homes and businesses. Decisions are made at the community-level through citizen participation by people who appreciate local issues and who are primarily focused on service, safety, reliability, and costs. Accordingly, community aid and quality service are the mandates for these utilities.

To serve the communities that govern them, APGA members purchase interstate natural gas transportation services from pipelines at rates and under terms and conditions that are regulated by the Commission. While the above referenced technical conference focused on electrification and "how to prepare for an increasingly electrified future," natural gas plays a significant role in these discussions. Because approximately 40 percent of electricity generation is from natural gas-fired power plants, any significant changes to the electrical grid and generation infrastructure will have significant impacts on the natural gas industry. Due to this interwoven nature of the electric and gas markets, public gas systems and their communities are critical stakeholders in this proceeding.

III. COMMENTS

American public gas systems engage with their communities in a number of different ways, such as working collaboratively to further sustainability goals.[3] Our members are committed to providing reliable and affordable energy, while protecting the environment and with minimal disruption to consumer choice. APGA members are good stewards of the environment and communities they serve, evidenced by the way they maintain and operate their utilities, and they recognize that natural gas can provide energy affordably and reliably to all Americans, in addition to proven environmental benefits. Natural gas has been a big driver behind our country's declines in carbon emissions, and America's gas utilities have added 30 million residential customers since 1970 with virtually no increases in emissions. Accordingly, the existing pipeline infrastructure should continue to play an integral role in reducing greenhouse gas emissions.[4]

APGA supports goals to reduce greenhouse gas emissions in the United States. However, in reaching these ambitious targets, we caution against misguided electrification proposals that put all of our "eggs in one basket" by eliminating Americans' ability to choose the energy source best fit for their needs and budget. A policy-driven

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[3] "APGA Sustainability Report," American Public Gas Association (2020), available at https://higherlogicdownload.s3.amazonaws.com/APGA/aba5f6fa-5356-422b-8a3a-fb663df47b2a/UploadedFiles/wR9lTSiXQPDQH5v9nola_2020SustainabilityReport_Final.pdf.

[4] American Gas Association, "Implications of Policy-Driven Residential Electrification," https://www.aga.org/research/reports/implications-of-policy-driven-residential-electrification.

electrification model could increase average residential household energy-related costs by between $750 and $910 per year, or about 38 to 46 percent — a large financial burden for many who already struggle to pay their bills each month. Public natural gas utilities provide equitable energy access in our communities by delivering natural gas at an affordable price to their customers every day — some of whom are among our most vulnerable citizens, including older Americans and low-income families. Proposals to reduce emissions should preserve Americans' ability to access the reliable, affordable energy of natural gas that public gas utilities deliver through the nation's resilient gas distribution system.As FERC continues to explore the issues raised during the technical conference, APGA encourages the Commissioners and FERC staff to review and incorporate findings from existing sources and tools. For instance, the Gas Technology Institute (GTI) released a report detailing case studies of future residential natural gas and electrification scenarios in leading low-carbon regions that will be informative to the Commission's efforts in this area.[5] Additionally, GTI has made available an Energy Planning Analysis Tool that "evaluates the potential implications of energy and technology choices in residential applications," taking into account the energy, environmental, and economic impacts of utilizing varying technologies in place of alternatives.[6] Other studies have also been conducted on the implications of certain electrification policies[7] - APGA

[5] Liss, el al., "Case Studies of Future Residential Natural Gas and Electrification Scenarios in Leading Low-Carbon Regions" (attached for reference). Additional analyses are available online at https://www.gti.energy/analyzing-residential-greenhouse-gas-ghg-emission-reductions/.

[6] "Energy Planning Analysis Tool," Gas Technology Institute, http://epat.gastechnology.org/.

[7] *See, e.g.,* Home Innovation Research Labs, "Cost and Other Implications of Electrification Policies of Residential Construction," Prepared for National Association of Home Builders (Feb. 2021) (attached for reference); *see also* online studies and resources from the American Gas Association pertaining to impacts of electrification, available at https://www.aga.org/research/reports/implications-of-policy-driven-residential-electrification/.

asks that FERC also take into account the findings of these reports as it moves forward with shaping its own rules and policies.

Natural gas continues to be a resilient, reliable, clean, and affordable fuel for not only electricity generation but also for direct use in homes and businesses. Consequently, it plays a critical role in the nation's climate solution. Energy availability is not negotiable, especially considering the importance of home heat during severe winter weather, such as February's Winter Storm Uri that devastated many in the central U.S. APGA members supply to Americans the energy they need, and the robust gas distribution network and existing fuel delivery infrastructure can and should be leveraged to help meet our country's decarbonization goals. Accordingly, APGA asks FERC to better engage and include perspectives from the natural gas industry as it continues to explore potential paths forward.

IV. CONCLUSION

APGA thanks the Commission for considering these comments as it continues exploring how best to move towards a low-carbon future, and we look forward to being a collaborative stakeholder for any future discussion regarding potential changes that may impact the natural gas industry and public gas utilities.

Respectfully submitted,

AMERICAN PUBLIC GAS ASSOCIATION

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Session Title: Strategy: 1. (II) Gas, Energy Source for the Future

Title: Case Studies of Future Residential Natural Gas and Electrification Scenarios in Leading Low-Carbon Regions

Introduction and Background

There is active worldwide dialogue and action on policies aiming to reduce greenhouse gas (GHG) emissions as a means of alleviating potential future global warming effects. This is particularly advanced in several developed economies, such as Germany and the United Kingdom (U.K.). In the United States (U.S.), there are no comprehensive federal policies to reduce GHG emissions, though strides in reducing carbon dioxide (CO_2) emissions have occurred in the past decade – stemming mainly from natural gas displacing coal power generation.

Some U.S. states have established or are formulating more aggressive low-carbon emission policies. These state-level policies generally start with a supply-based policy requiring, and often subsidizing, low or zero-carbon power generation sources. Further consideration is underway on demand-side policies such as using electricity to displace traditional fossil fuel applications. Examples include electric vehicles – in place of traditional liquid fuels – or using electricity for space and water heating in homes and businesses – in lieu of natural gas.

Within the U.S., California and New York are two U.S. states on the forefront of GHG reduction policies. Notably, these two states are major economic entities, ranked first and third in U.S. state-level gross domestic product (GDP). California's GDP is nearly comparable to the U.K., while New York's GDP is similar to Canada's. Table 1 provides comparative electricity information on two European countries and these two U.S. states.

Table 1: Comparison of Electricity Use and Emissions Rates in Select European Countries and U.S. States (2016)

	Electricity Use (billion kWh)	Average Electricity Emission Rate (g CO2/kWh)	Average Residential Electricity Price (/kWh)
Germany	481	474	$0.368 (U.S. $)
United Kingdom	304	243	$0.242 (U.S. $)
California	257	239	$0.1739 (U.S. $)
New York	197	233	$0.1758 (U.S. $)
U.S. Average	--	484	$0.1255 (U.S. $)

Sources: US Department of Energy, Energy Information Administration (DOE EIA); UK.GOV; Climate Transparency: Brown to Green: The G20 Transition To A Low-Carbon Economy (2017; Germany)

California and New York have low power generation sector CO_2 emission rates – about half of the average U.S. – due in part to legacy nuclear and hydroelectric power generation plants and more recent construction of wind, solar, and natural gas power capacity. Notably, California and New York have largely eliminated in-state coal-fired power generation. The UK has CO_2 emission rates similar to California and New York, while Germany's emission rates are conspicuously higher – mainly due to continued reliance on coal for power generation. Like Germany, California and New York have policies to reduce the role of nuclear power; currently, nuclear generation comprises about 9% of California's and 30% of New York's electricity needs.

Generally, higher electricity prices are seen in regions aggressively transitioning toward low-carbon power generation. Residential electricity prices in California and New York are about 35-40% more than the U.S. average; in the UK and Germany, home electricity prices are 93% and 193% higher than average U.S. residential electricity prices. Figure 1 shows trends in Europe, with a correlation between higher per-capita use of wind and solar resulting in higher electricity prices in Germany, Denmark, and Spain. A downward trend in wind and solar prices may help to lower future electricity price impacts. Electricity prices are often lower where legacy low-carbon hydropower or nuclear generation plants constitute a large portion of the electricity supply, such as Norway and France.

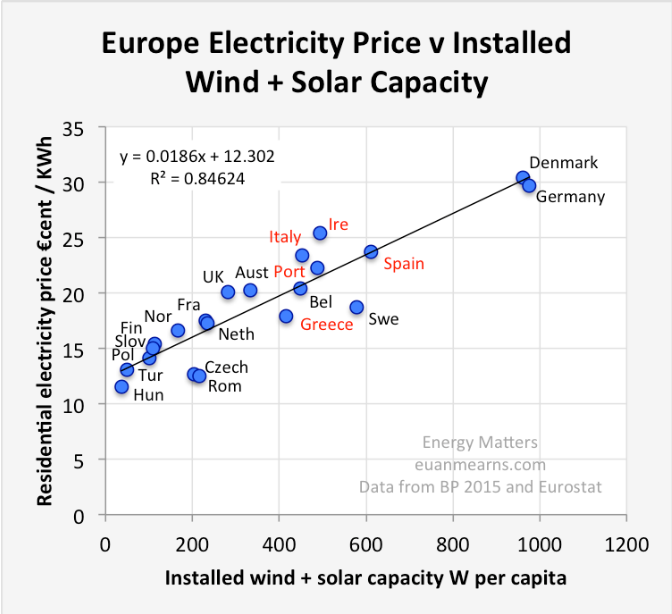

Figure 1: European Trends for Wind and Solar Per Capita Use and Electricity Prices

Carbon abatement cost analyses – that is, costs per unit of CO_2 equivalent (CO_2e) emission reduction – are often used as policy tools to assess greenhouse gas emission reduction options. These are costs society or consumers pay when GHG reduction policies are implemented. As shown in Figure 2, these costs presently range up to \$15-\$30/metric ton of CO_2 reduced in leading countries such as the U.K. and Germany.

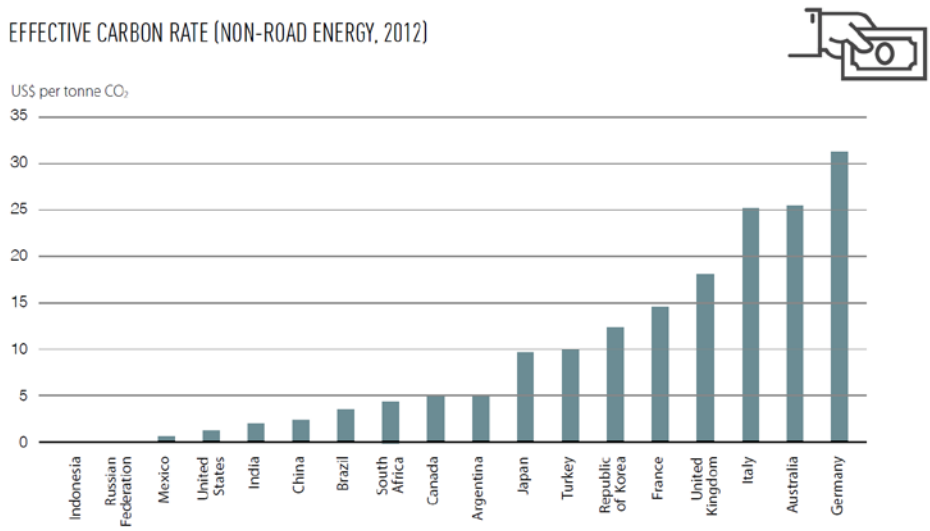

Figure 2: Effective Carbon Abatement Cost of Public Policies in Different Countries (Source: Climate Transparency)

Objectives

This research is intended to quantify the energy use, environmental impact, and cost-trade-offs of potential governmental policy scenarios for residential energy use in California and New York. Specifically, the analysis focuses on the role of natural gas and electricity in traditional home applications: space heating, water heating, cooking, and clothes drying. In these energy use scenarios, we explore the potential implications for consumers and society, with an emphasis on the cost and constraints of residential electrification.

The analysis explores in additional implications and considerations associated with electric space heating. Understanding peak energy use, particularly during severe cold temperature periods, is an important consideration for a major transition from an established energy model (i.e., using natural gas pipelines with large-scale natural gas storage) to a potential new scenario that significantly increases seasonal electricity use. The paper highlights real-world performance of cold climate electric heat pumps, distributed home solar PV systems during winter months, and issues associated with large-scale energy storage.

Cost metrics used in this analysis include annual consumer energy costs, installed capital cost for home appliances, and carbon abatement cost (in \$/CO_2e metric ton). Energy use includes site and total primary energy. Along with various GHG emissions such carbon dioxide and methane, the analysis software includes conventional emissions on a site and source basis (e.g., NO_x, SO_x, and particulate matter).

Methods

In 2017, GTI developed an analytical software platform called the Energy Planning and Analysis Tool (EPAT). The publicly available EPAT software (epat.gastechnology.org) provides regional U.S. estimates of site and full-cycle energy consumption, capital, and operating costs for several residential energy applications (e.g., space heating, water heating, cooking, clothes drying, and other home energy uses). The software allows the user to select a wide range of residential technologies for a pair-wise comparison of two home energy use scenarios: baseline and alternative. The pair-wise analysis can be repeated with different assumptions to craft a range of scenarios.

The EPAT software uses a library of information from published and publicly available data sources pertaining to typical residential energy equipment and appliances (e.g., capital cost and efficiency). Default values can be modified to support specific equipment analyses. EPAT also includes published regional residential energy prices (e.g., for natural gas, electricity, propane, etc.) or energy costs can be specified by the user. Home energy use attributes built into EPAT are mainly derived from the U.S. Department of Energy's Residential Energy Consumption Survey. The software strives to represent real-world operating attributes, such as the seasonal performance of air-source electric heat pumps.

A key EPAT software feature is the use of full-fuel-cycle, or primary, energy consumption and emissions. For example, state-level (or local) power generation characteristics are based on real-world operating plants in different regions of the U.S. The software can be customized to enable scenarios with modified electricity generation portfolios. Full-fuel-cycle emissions of natural gas are also included, capturing upstream energy used to produce and deliver natural gas to homes as well as full-fuel-cycle emissions such as methane.

This analysis includes a baseline scenario using current residential natural gas consumption in California and New York along with alternative energy use scenarios. The baseline scenario uses a proxy estimation of the homes in these two states currently using natural gas (Table 2). Total state-level residential natural gas use and CO_2 emissions, available from DOE EIA, were used to calibrate the baseline home population.

Table 2: Baseline Scenario Home Natural Gas Populations for California and New York

	California	**New York**
Single Family Detached Homes	7,200,000	2,200,000
Single-Family Attached Homes	750,000	340,000
Multi-Family (2-4 units)	800,000	950,000
Multi-Family (5+ units)	2,200,000	1,750,000
Total Residential Gas Use	432 TJ (409 bcf)	443 TJ (420 bcf)
Total CO_2 Site Emissions	24 MMT	25 MMT

Table 3 shows key attributes used in the baseline and alternative scenarios for space and water heating; these are the largest natural gas uses in homes. Equipment options are standard baseline Energy Star equipment for space and water heating, while cooking and clothes drying were conventional minimum efficiency natural gas or electric appliances. For the next-generation natural gas energy efficiency option in California, we selected a combination natural gas heat pump device that meets both space and water heating needs. This system was suitable due to the lower space heating requirements in California compared to New York homes and matches the efficiency performance attributes but with lower costs than two separate gas heat pump space heating and water heating devices used in New York.

Table 3: Residential Energy Use Scenarios

	Space Heating	Water Heating
Baseline Natural Gas Options	80% efficiency non-condensing furnace	Conventional storage water heater (Energy Factor, EF, 0.62)
Electric Energy Efficiency Options	HSPF 8.4 electric heat pump	Electric heat pump water heater (EF 2.0)
Mature Natural Gas Energy Efficiency Options	96% efficiency condensing furnace	95% efficiency tankless (EF 0.95)
Next-Generation Natural Gas Energy Efficiency	New York: 140% efficiency gas absorption heat pump (COP 1.4)	New York: 130% efficiency gas absorption heat pump (EF 1.3)
	California: 140% efficiency combination space and water heating gas absorption heat pump (COP 1.4)	

For both the mature and next-generation natural gas efficiency scenarios, we use a complementary scenario of 15% renewable natural gas (RNG, or bio-methane) blended with conventional natural gas. RNG provides a 15% CO_2 emission reduction, with higher natural gas cost. The RNG commodity energy cost was \$10/MMBtu (\$9.48/GJ) – over twice the commodity cost of conventional U.S. natural gas – plus delivery charges.

For the theoretical electrification scenario, the analysis assumes 100% electric heat pumps use for space and water heating in the natural gas homes converted to electricity. In practice, this is an optimistic scenario given that about 30% of U.S. homes currently using electric heating employ heat pumps; further, newer electric heat pump water heaters are an especially small fraction of the market.

The all-electric scenario incorporates a modified power generation mix that reflects future changes in the use of low and zero-carbon power generation sources, while also considering the intense winter-peaking impact of shifting current natural gas space heating loads to electricity (Table 4). Most of the new peak electric load (65%) occurs only during winter months and would be met by non-baseload generators, assumed to be primarily dispatchable natural gas power generation. With this real-world consideration, the future power generation mix shown in Table 4 was used to supply the new electric loads. This future mix has similar CO_2e emission rates to the existing mix in these two states (the California data factor in the planned shutdown of California's last nuclear power plant and in both states reflect a large winter seasonal demand mainly met by natural gas power generation).

Table 4: Current and Future Scenario California and New York Power Generation Mix

	Current Power Generation	Future Power Generation
California	Natural gas: 60.4% Coal: 0.4% Nuclear: 8.8% Hydro: 8.7% Non-Hydro Renewable: 21.7%	Natural gas: 59.5% Hydro: 16.8% Non-Hydro Renewable: 23.7%
New York	Natural gas: 25.9% Oil, Coal: 6.1% Nuclear: 30.6% Hydro: 30.4% Non-Hydro Renewable: 7%	Natural gas: 60% Nuclear/Hydro: 20% Non-Hydro Renewable: 20%

Idealized scenarios using 100% baseload wind and solar power generation are largely impractical in meeting the severe shorter-duration winter space heating demand, especially given the low output from solar PV systems in winter months.

Results

Energy and Environmental Comparison of Residential Natural Gas and Electric Scenarios

Table 5 and Table 6 show the results of the natural gas and electricity scenarios in California and New York State, respectively. These results show significant annual energy costs increases if policy mandated a switch from the current natural gas appliances to an all-electric home. Annual energy costs for California energy consumers would go up at least 45%, while New York energy consumers would see their energy bills increase by 90%. In practice, energy costs could be higher because not all homes switched from natural gas to electricity will use electric heat pumps due to their high first cost. Further, higher peak electric demand would likely require system-wide investments that could increase electricity prices.

The all-electric residential scenario could achieve CO_2e emissions reductions, but the consumer and societal costs are high. The carbon abatement costs are about $200/metric ton CO_2e in California and an especially high $434/metric ton CO_2e in New York, compared to the current natural gas baseline. These are nearly ten times greater than typical CO_2e emission abatement costs shown in Figure 2. The carbon abatement costs through electrification would be even higher if (1) electricity prices go up or (2) if electric heat pumps are not used in 100% of the converted homes. Because of the appreciably higher annual energy costs, the all-electric scenarios have negative benefit cost ratios of -1.96 in California and -7.89 in New York. There is never a payback for energy consumers in an all-electric scenario, with the consumer cost implications increasing substantially in cold-weather regions.

Table 5: California Home Natural Gas and Electricity Scenarios

	Current Natural Gas Baseline	All Electric Heat Pump Scenario (Future Mix)	Using Mature Natural Gas Technologies	Mature Gas Technologies & 15% RNG	Next-Generation Gas Heat Pumps	Natural Gas Heat Pumps & 15% RNG
Annual Energy Costs ($, billion/yr)	$4.95	$7.20	$3.81	$4.03	$3.21	$3.40
Annual Source Energy (Trillion Btu/yr)	464	512	354	354	290	290
Annual CO_2 Emissions (MMT/yr)	24.7	12.9	18.6	15.8	14.4	12.3
Annual CO_2e Emissions (MMT/yr)	28.0	14.2	21.0	17.9	16.3	13.8
Equipment Capital Cost ($, billion)	$48.76	$56.3	$62.2	$62.2	$90.0	$90.0
Annual Capital Cost ($, billion/yr); 15 Year Simple Amortization	$3.25	$3.75	$4.15	$4.15	$6.00	$6.00
$/metric ton CO_2e	--	$199	-$35	-$2	$87	$85
Benefit/Cost Ratio (ΔEnergy/Annualized Capital Costs)	--	-1.96	1.28	1.02	0.63	0.56
Simple Payback (Years)	--	Never	11.8	14.6	23.7	26.6

Table 6: New York State Home Natural Gas and Electricity Scenarios

	Current Natural Gas Baseline	All Electric Heat Pump Scenario (Future Mix)	Using Mature Natural Gas Technologies	Mature Gas Technologies & 15% RNG	Next-Generation Gas Heat Pumps	Natural Gas Heat Pumps & 15% RNG
Annual Energy Costs ($, billion/yr)	$5.36	$10.17	$4.29	$4.49	$3.41	$3.57
Annual Source Energy (Trillion Btu/yr)	462	443	366	366	277	277
Annual CO_2 Emissions (MMT/yr)	24.9	14.3	19.7	16.7	14.4	12.2
Annual CO_2e Emissions (MMT/yr)	28.2	15.7	22.2	18.9	16.3	13.8
Equipment Capital Cost ($, billion)	$25.2	$34.4	$33.6	$33.6	$61.2	$61.2
Annual Capital Cost ($, billion/yr); 15 Year Simple Amortization	$1.68	$2.29	$2.24	$2.24	$4.08	$4.08
$/metric ton CO_2e	--	$434	-$88	-$35	$37	$42
Benefit/Cost Ratio (ΔEnergy/Capital Costs)	--	-7.89	1.91	1.55	0.81	0.75
Simple Payback (Years)	--	Never	7.9	9.7	18.5	20.1

Natural gas pathways can offer appreciable CO_2e emission reductions with lower costs to consumers and society – including being on par with electrification scenarios in terms of percent CO_2e emission decreased. Wider adoption of mature natural gas energy efficiency products could reduce consumer natural gas costs by 20-25%, with a net negative CO_2e abatement cost of -$35/metric ton in California to -$88/metric ton in New York. Net negative CO_2e abatement costs are net benefits to consumers and society. Mature natural gas energy efficiency products have positive benefit/cost ratios of 1.28 in California and 1.91 in New York. Using 15% RNG with mature high-efficiency natural gas products results in emission levels that begin to approach electric conversion scenarios, but at more attractive societal costs of -$2 to -$35/metric ton CO_2e in California and New York, respectively.

In the longer term, natural gas heat pumps and 15% RNG can achieve comparable CO_2e reductions to electricity, with lower societal costs ($35-$85/metric ton CO_2e). Next-generation natural gas heat pumps have positive benefit/cost ratios, but their values fall below 1.0 – indicative of longer payback periods. This reflects the current high equipment costs, typical of early market entry pricing for emerging technologies.

Figure 3 illustrates the findings. Near-term low-risk, less-costly carbon emission reductions of 20-35% are possible using available natural gas energy efficiency products in homes; the upper range is achieved by blending RNG. All-electric homes in California and New York could reduce CO_2e emissions by 40-50%, but only if heat pumps are used in all households. This pathway has high societal costs of $200/metric ton CO_2e in California to over $400/metric ton CO_2e in New York. Comparable levels of CO_2e emission reduction (40-50%) are possible with next-generation natural gas heat pumps. Maximum reductions are achieved by blending RNG and using natural gas heat pumps.

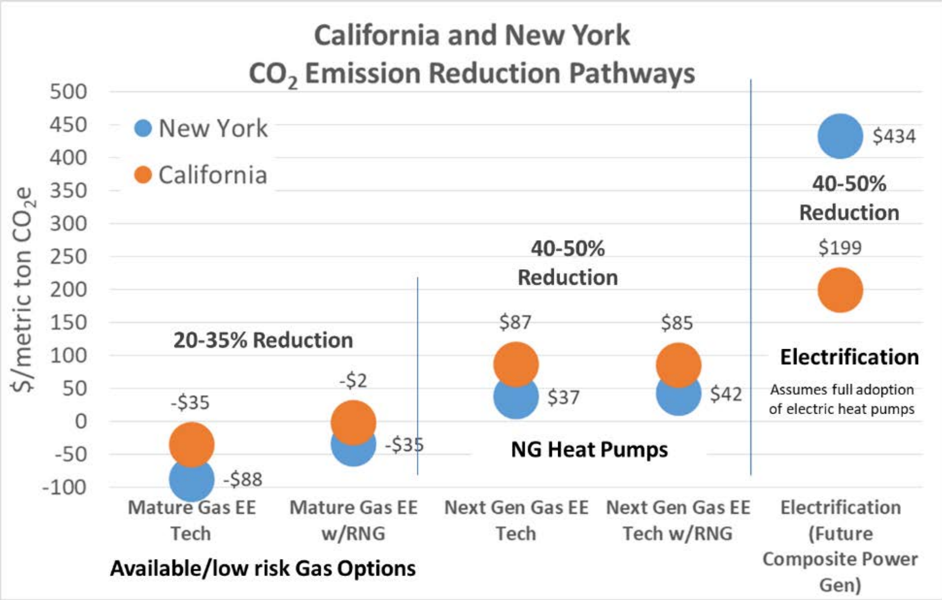

Figure 3: Natural Gas and Electric Residential Carbon Abatement Costs

Operational Considerations Of An All-Electric Home Scenario

There are a significant issues and real-world limitations when considering a large-scale shift from residential natural gas use to electricity, including:

- What are the implications to the electric generation, transmission, and distribution system when heating-dominated natural gas loads are electrified? What is the magnitude of the peak day electricity demand increase? What are the potential electric price impacts?
- What is the real-world performance of air source electric heat pumps in cold temperatures? How would electric heat pumps impact consumer energy costs and comfort, particularly in severely cold temperatures?
- How do home solar PV systems perform during winter months?
- What are the energy storage considerations of an all-electric scenario?

In the following, we touch on several of these questions.

In terms of electric heat pumps and cold weather conditions, Figure 4 illustrates the significant sensible space conditioning differences between cold weather heating loads and summer cooling loads. The temperature differential for heating, particularly in northern climates, is substantially larger than required for cooling.

Figure 4: Graphical Comparison of Heating and Cooling Energy Requirements

Beyond temperature differential, power demand requirements for electric space heating are more challenging due to the diminishing cold-temperature performance and heat-delivery capacity of electric heat pumps. Figure 5 shows the precipitous drop in electric heat pump efficiency during cold weather. In addition, snow accumulation and periodic defrosting of heat pump coils can impact electric heat pump performance and efficiency (Figure 6). Water condensing from the outdoor ambient air and freezing on electric heat pump outdoor coils is a common winter occurrence, particular in regions with higher humidity levels. Defrosting cycles typically use electric resistance heating or reverse operation that further diminishes real-world electric heat pump performance and efficiency at cold temperatures.

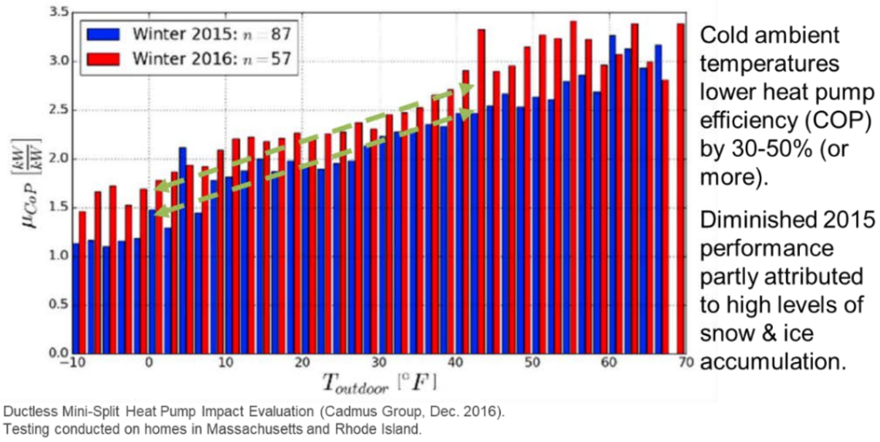

Figure 5: Cold Climate Electric Heat Pump Performance

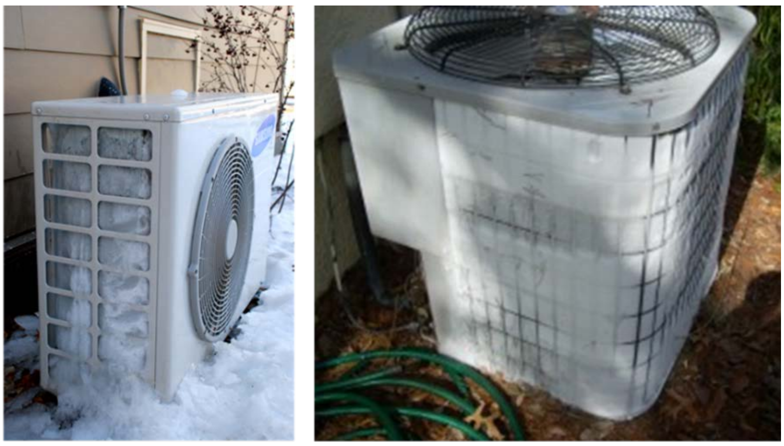

Figure 6: Impact of Snow Accumulation (left) and Ice Formation (right) on Electric Heat Pumps

Shifting from natural gas to electric space heating results in dramatic increases in residential peak electricity use and is highly concentrated during the winter. This is a major technical and economic challenge. Figure 7 and Figure 8 show changes in monthly residential electricity use with residential electrification in California and New York. This is based on recent monthly data on current residential electricity use (shown in orange) along with the additional monthly electricity required if all current California or New York residential gas use were shifted to electricity (darker blue). These figures also show the additional electricity use if only 50% of homes used electric heat pumps and 50% used electric resistance heating (this incremental electricity use is shown in light blue).

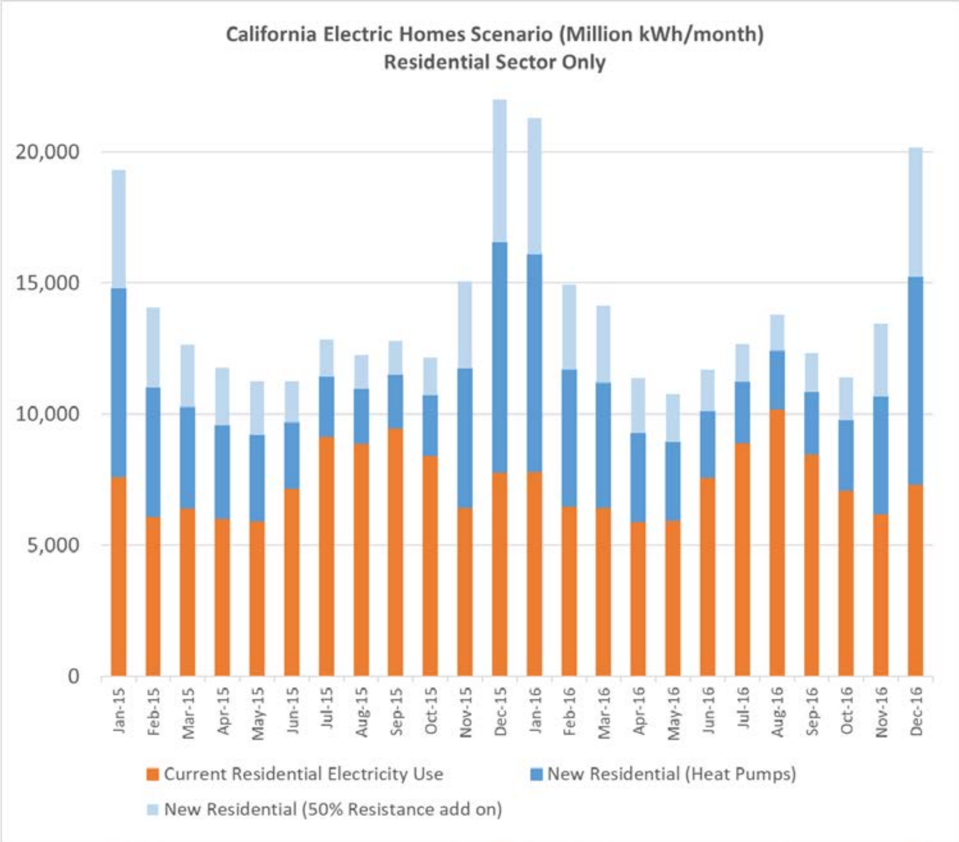

Figure 7: Impact On California Monthly Residential Electricity Use

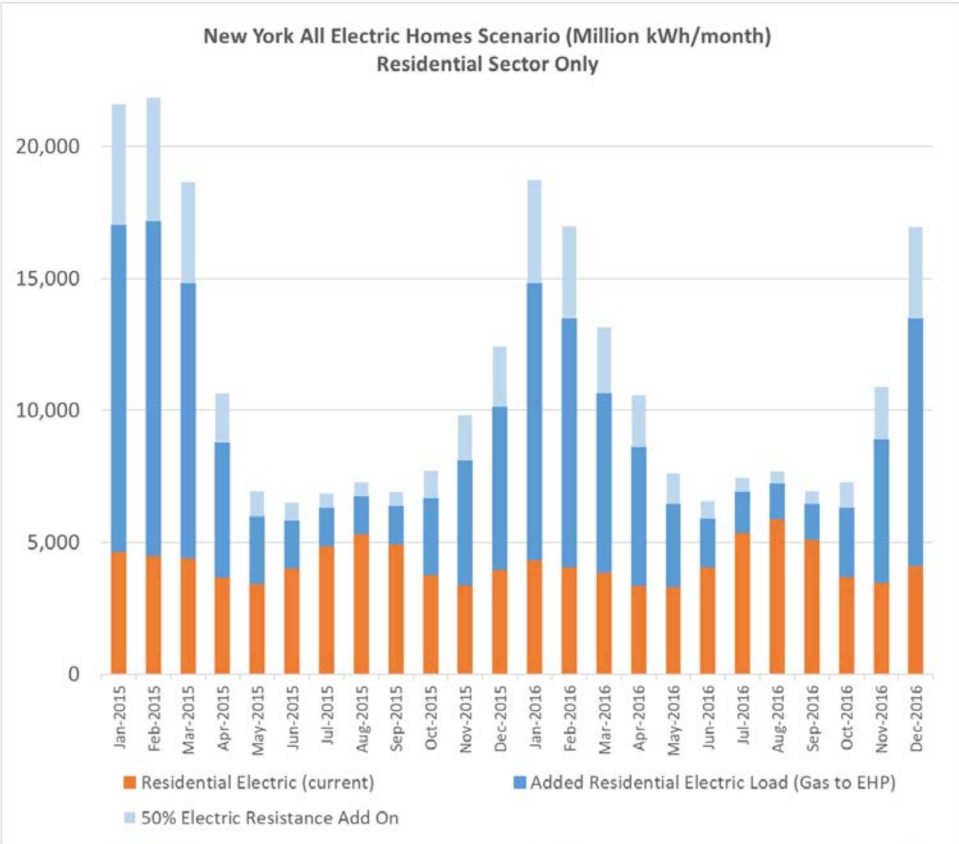

Figure 8: Impact On New York Monthly Residential Electricity Use

On a peak day or hourly basis during the coldest times of the year, the relative increases in peak electricity demand would be even greater than illustrated in these graphs. Figure 9 shows results from GTI's building simulation of electric space heating in two different homes with varying building envelope construction. The figure illustrates the effect of declining electric heat pump efficiency at colder temperatures. Older homes built to less-stringent building codes would require substantially more electricity to meet peaking heating loads. The figure overlays the performance of solar PV systems in southern and northern climates. In colder northern regions, residential solar PV systems would rarely meet the hourly power demands for space heating, much less other home loads or produce adequate excess power to recharge battery storage systems.

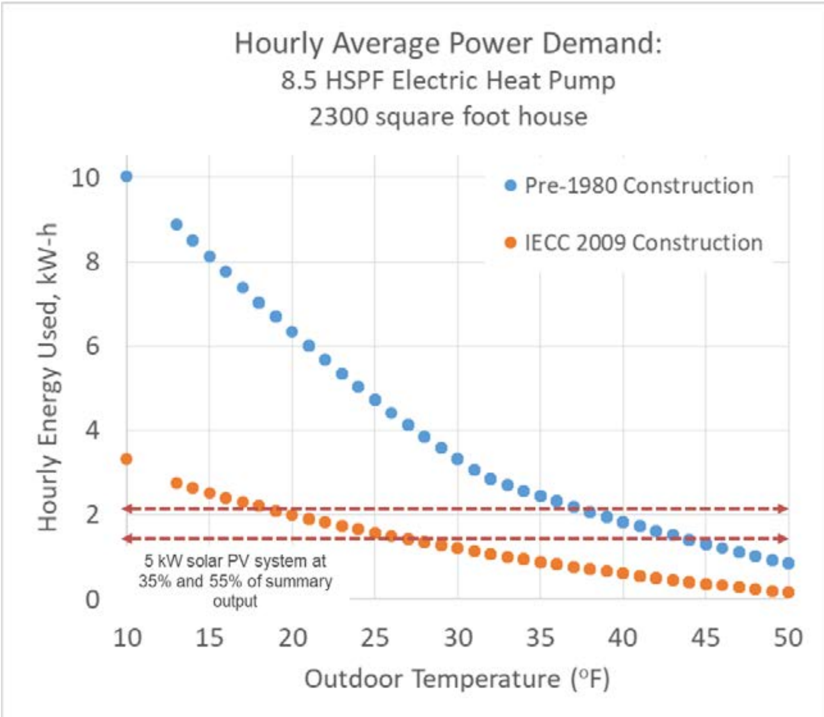

Figure 9: Example Impact of Temperature On Home Electric Heating Power Requirements for Older and Newer Homes

Electrification policies often include the notion of using solar photovoltaic (PV) systems – particularly at the home level. The challenge of shifting from natural gas heating to solar PV is the notably diminished performance of solar systems during the winter months. Figure 10 shows data from NASA on solar PV systems in different U.S. locations during each month of the year. In southern regions during winter months, solar PV systems produce about 50-55% of their summer output; in northern zones, wintertime solar PV output can drop to 30-35% of summer levels. The drop in solar PV performance during winter months is due to shorter days and typically greater cloud coverage; snow accumulation on solar PV systems can further diminish performance.

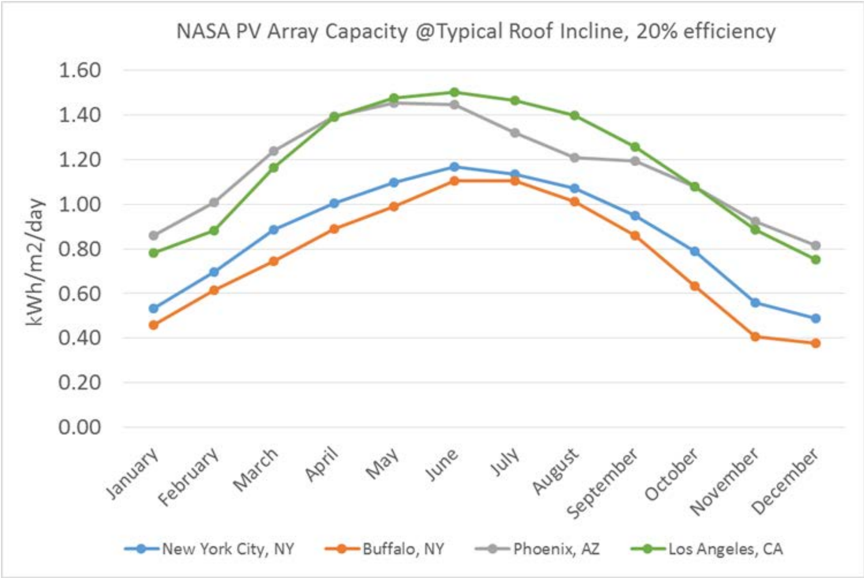

Figure 10: Comparison of Monthly Solar PV System Output

Energy storage is a major area of differentiation between natural gas and electricity use. In the U.S., there are extensive natural gas storage infrastructure, mainly in underground formations. The U.S. natural gas industry uses off-peak periods of April-October to store natural gas in these large-volume storage locations, with the objective of withdrawing massive natural gas volumes during peak cold periods. Figure 11 shows U.S. DOE EIA data on natural gas underground storage, highlighting weekly amounts injected or withdrawn. Recent years have seen two incidents of record levels of natural gas storage used during extreme cold periods – 288 bcf (304 TJ) in January 2014 and 359 bcf (379 TJ) in January 2018. This represents massive amounts of energy available over a short period of time. In context, delivering 359 bcf from natural gas storage in one week is equal to about 638 GW. In contrast, total U.S. electric energy storage capacity is about 24 GW, mostly large pumped hydro facilities.

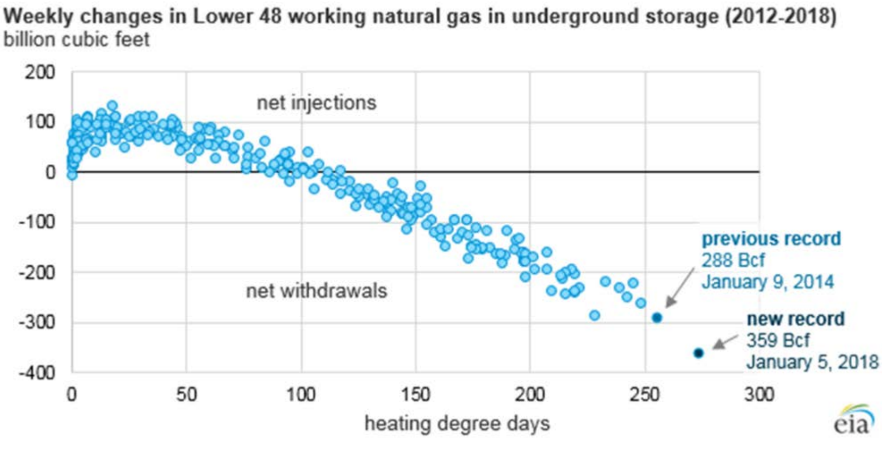

Figure 11: Impact of Heat Degree Day on Gas Storage Usage

The notion of battery energy storage is gaining traction in some regions. The idealized view of battery energy storage often differs from the reality of the cost, performance limitations, and material intensity of batteries. Figure 12 shows one example of a large-scale battery energy storage facility. While batteries are seen as viable options for providing ancillary grid services such as frequency regulation, their cost-effectiveness as bulk energy storage systems is not established. Relying on batteries to deliver bulk electricity during extreme cold periods, when battery performance declines, seems an unlikely alternative to proven, cost-effective large-scale natural gas storage.

Figure 12: Example Large-Scale Battery Energy Storage System

Conclusions

There are growing efforts to explore options to reduce GHG emissions as a means of avoiding potential future global warming impacts. Some policymakers are advocating expanded use of low- or zero-carbon emission power generation sources, coupled with using electricity to displace traditional fossil fuel uses such as liquid fuels for vehicles and natural gas for home space heating, water heating, cooking, and drying.

Using a comprehensive analytical software called the Energy Planning Analysis Tool (EPAT), GTI examined potential future scenarios of high-efficiency natural gas equipment and renewable natural gas along with electrification in two leading low-carbon power generation regions of the United States – California and New York State.

As summarized in Table 7, the findings show all-electric homes are a much more expensive carbon abatement approach – from \$200 to over \$400/metric ton of CO_2e emissions reduction in California and New York, respectively. The benefit/cost ratio of all-electric homes are negative, due to the large increase in annual consumer energy costs through electrification. The economics are even less favorable if electric heat pumps are not adopted in 100% of homes or if electric price increases are required to finance major power generation, transmission, and distribution system upgrades. Home electrification is particularly costly in cold weather regions such as New York.

Table 7: Current and Future Scenario California and New York Power Generation Mix

	All-Electric Heat Pump Scenario	**Mature Natural Gas Scenario**	**Next-Generation Natural Gas Scenario**
California			
% CO_2e Reduction	-49%	-25% (-36% RNG)	-42% (-51% RNG)
CO_2e/metric ton Cost	\$199	-\$35 (-\$2 RNG)	\$87 (\$85 RNG)
Benefit/Cost Ratio	-1.96	1.28 (1.02 RNG)	0.63 (0.56 RNG)
New York			
% CO_2e Reduction	-44%	-21% (-33% RNG)	-42% (-51% RNG)
CO_2e/metric ton Cost	\$434	-\$88 (-\$35 RNG)	\$37 (\$42 RNG)
Benefit/Cost Ratio	-7.89	1.91 (1.55 RNG)	0.81 (0.75 RNG)

In contrast, the direct use of natural gas offers several cost-effective scenarios for appreciable reductions in CO_2e emissions by (1) expanding the market penetration of mature natural gas energy efficiency equipment, (2) developing and deploying natural gas heat pumps for space and water heating, and (3) blending renewable natural gas with conventional natural gas to reduce the carbon intensity of natural gas supply.

This analysis highlights several limitations with implementing an all-electric home scenario, particularly in cold climates. These include the diminishing performance of electric heat pumps at cold temperatures, the substantial decline in home solar PV system output during winter months (which is exacerbated in northern regions), and the severe increase in peak electric demand that would come about with an electrification scenario. In terms of meeting peak space heating demand, system-level natural gas storage is substantially more cost-effective than electricity storage with batteries.

Acknowledgements

GTI expresses its appreciation to the American Gas Association, the American Public Gas Association, and the National Propane Gas Association for their support of the EPAT software program and to the members of the Utilization Technology Development organization for their support of the underlying Source Energy and Emissions Analysis Tool.

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New York State Energy Research and Development Authority (NYSERDA) Solar PV Data Base: http://dataint.cdhenergy.com/nyserda_chp/Monthly_data_summary_all_sites.csv

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U.S.DOE-EIA Natural Gas Price Data: https://www.eia.gov/naturalgas/data.php#prices

U.S.DOE-EIA Electricity Use Data: https://www.eia.gov/electricity/data/browser/

U.S.DOE-EIA Electricity Price Data: https://www.eia.gov/electricity/data.php#sales

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Home Innovation
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Cost and Other Implications of Electrification Policies on Residential Construction

Prepared For

National Association of Home Builders

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EXECUTIVE SUMMARY

Building electrification is an effort to substitute fuel-burning equipment and appliances with their electric counterparts including heat pumps, heat pump water heaters, and electric appliances for cooking and clothes drying. Electrification is often presented as a strategy for reducing carbon emissions and can be complementary to policies focused on renewable energy generation and storage, electric vehicles, grid-interactive technologies, etc.

This study evaluated the cost impact of electrification strategies on new and existing single-family homes. All-electric houses were compared to houses with natural gas equipment and appliances. Construction costs and energy use costs were estimated for a "Reference House" with multiple equipment configurations and in multiple locations. These costs provided the basis for the comparisons presented in this report.

A baseline single-family, new construction reference house using natural gas for heating, water heating, cooking, and clothes drying was established for four locations selected based on consideration of climate zone and fuel costs. The baseline reference houses were then re-designed to include all-electric equipment using several combinations of electrification options for each location. Construction costs and energy use costs were estimated for the gas and electric houses and used to compare electric houses to gas houses.

In addition, the retrofit cost of electrification for an existing baseline gas house was developed and compared to the retrofit cost of installing replacement gas equipment and appliances. Also investigated were equipment life expectancies and consumer perceptions of electric equipment and appliances.

The table below summarizes the range of electrification costs for an electric house with high efficiency equipment compared to a baseline gas house. The heat pump row takes into account the cost difference between the baseline gas house and the minimum efficiency electric house. For heat pumps, the low and high costs are based on systems that are considered appropriate for the climate zone, and the range includes a ductless heat pump option (heat pump types and efficiencies are discussed further below). For heat pump water heaters, the low cost is for the 50-gallon, 3.25 UEF model in Houston and Baltimore and the 80-gallon, 3.25 UEF model in Denver and Minneapolis, and the high cost is for the 80-gallon, 3.75 UEF model. Although an electrical service upgrade was deemed to be not required for the reference house configurations with a single electric vehicle (EV) charger, the table includes a placeholder for cost where a service upgrade or additional community electrical infrastructure cost may be required. For the EV charger circuits, the low cost is for a single circuit, and the high cost is for two circuits and adding a second electrical panel. Adding EV charging may require upgrading the electrical service from the street to the house. These costs vary by utility territory and can be substantial but are not part of this study. There are potential cost savings for not installating gas infrastructure to the development. These costs also vary by utility and may be typically paid for by the utility or developer.

Range of Construction Costs of Electrification relative to a Baseline Gas Reference House, $

Electric Reference House Component	Houston		Baltimore		Denver		Minneapolis	
	Low	High	Low	High	Low	High	Low	High
Heat Pump	2,114	5,528	1,901	8,655	8,259	9,088	7,866	8,655
Heat Pump Water Heater	1,257	2,632	1,295	2,711	2,516	2,791	2,397	2,658
Electric Vehicle charger circuit(s)	617	2,040	635	2,102	65	2,163	623	2,060
Induction cooktop range	0	997	0	1,027	0	1,057	0	1,007
Total added construction cost, $	**3,988**	**11,196**	**3,832**	**14,495**	**11,430**	**15,100**	**10,886**	**14,381**
Electrical service upgrade or community electrical infrastructure	Varies by Utility Territory							
Community gas infrastructure cost savings	Varies by Utility Territory							

Key findings based on the estimated construction costs and annual energy costs developed for the Reference House configurations and selected locations are summarized here:

- The overall range of estimated electrification costs for an electric reference house compared to a baseline gas reference house is between $3,988 and $11,196 in a warm climate (Houston), $3,832 and $14,495 in a mixed climate (Baltimore), and $10,866 and $15,100 in a cold climate (Denver and Minneapolis). On the low end of the range, these costs include a heat pump, heat pump water heater, and a single EV charger circuit. On the high end of the range, the costs also include a cold-cimate heat pump upgrade, second EV charger circuit, a second electrical panel (required for a second EV circuit), and an induction cooktop (induction cookware is not included). Further costs can include a fee for upgrading electric service and community electric infrastructure, which can be substantial. There is a potential cost savings for not providing community gas infrastructure.
- The upfront additional cost of an electric house with a high efficiency 2-stage heat pump (non-inverter type, 18 SEER/9.3 HSPF) and 80-gallon heat pump water heater (3.75 UEF) compared to a baseline gas house (minimum efficiency natural gas equipment) is $4,745 in a warm climate (Houston) and $4,613 in a mixed climate (Baltimore).
- The upfront additional cost of an electric house with a high efficiency inverter heat pump and 80-gallon heat pump water heater (3.75 UEF) compared to a baseline gas house (minimum efficiency natural gas equipment) is $8,160 in a warm climate (Houston) and $8,131 in a mixed climate (Baltimore) (warm and mixed climates based on a 19 SEER/10 HSPF inverter heat pump system rated down to 7°F); for a cold climate, the additional cost ranges from $10,524 (19 SEER/10 HSPF inverter heat pump system rated down to -13°F) to $11,803 (20 SEER/13 HSPF inverter heat pump system). The higher costs in colder, heating dominated climates are due to the higher cost of heat pumps rated to operate in colder temperatures.
- In the colder climates (Denver and Minneapolis), the more expensive electric equipment also results in higher energy use costs by $84 to $404 annually compared to a baseline gas house, and by $238 to $650 annually compared to a gas house with high efficiency equipment. Therefore, in colder climates the consumer will be faced with higher upfront construction costs and higher operating costs throughout the life of the equipment.

- In the cooling dominated climate (Houston), the annual energy use cost for the electric house with a high efficiency heat pump and 80-gallon heat pump water heater (3.75 UEF) can be reduced by $154 (18 SEER/9.3 HSPF 2-stage heat pump) to $264 (19 SEER/10 HSPF inverter heat pump) compared to a baseline gas house, with simple payback of 27 years to 64 years. Compared to a gas house with high efficiency equipment, the annual energy cost ranges from an increase of $18 (18 SEER/9.3 HSPF 2-stage heat pump) to a savings of $85 (19 SEER/10 HSPF inverter heat pump), with simple payback of up to 93 years.
- In the mixed climate (Baltimore), the annual energy use cost for the electric house with a high efficiency heat pump and 80-gallon heat pump water heater (3.75 UEF) ranges from a savings of $77 (18 SEER/9.3 HSPF 2-stage heat pump) to $184 (19 SEER/10 HSPF inverter heat pump) compared to a gas baseline house, with simple payback of 44 years to 60 years; however, when compared to a gas house with high efficiency gas equipment, the consumer is again faced with higher upfront construction cost and higher energy use cost.
- The incremental costs for high efficiency gas equipment options relative to a gas baseline are consistent across climates ranging between $892 and $2,140; the differences are due to house layout and cost adjustments by location; most payback periods are 10 years or less.
- The retrofit cost of electrification for an exisiting baseline gas house ranges between $24,282 and $28,491, not including the additional cost to substitute an induction cooktop ($1,091-1,157), install an electric vehicle charger circuit ($1,266-1,343), or install an electrical service upgrade (a potential substantial additonal cost in some cases). By comparison, the retrofit cost of gas equipment and applicances for an exisiting baseline gas house ranges between $9,767 and $10,359 using standard efficiency equipment, and between $12,658 and $13,425 using high efficiency equipment.
- The ratio of electricity price to natural gas price (each converted to $/Btu) is a significant factor for comparing the impact of electrification between locations with similar climatic characteristics. The higher the electric-to-gas price ratio, the more expensive it will be to operate electric equipment versus gas equipment.
- The median life expectancy of most gas equipment tends to be longer than electric counterparts: gas furnace (20 years) versus heat pump (15 years); tankless gas water heater (20 years) versus heat pump water heater (12 years); conventional gas and electric storage-type water heaters have about the same life expectancy (10-13 years).

ACRONYMS, ABBREVIATIONS, AND DEFINITIONS

AC	Air Conditioner
AFUE	Annual Fuel Utilization Efficiency
COP	Coefficient of Performance
CZ	Climate Zone
EA	Each
ERI	Energy Rating Index
GF	Gas Furnace
HP	Heat Pump
HPWH	Heat Pump Water Heater
HSPF	Heating Seasonal Performance Factor
IECC	International Energy Conservation Code
IRC	International Residential Code
LF	Linear Feet
NAHB	National Association of Home Builders
O&P	Overhead and Profit
SEER	Seasonal Energy Efficiency Ratio
SF	Square Feet
UEF	Uniform Energy Factor

BACKGROUND

Building electrification is an effort to substitute fuel-burning equipment and appliances with their electric counterparts including heat pumps, heat pump water heaters[1], electric clothes dryers, and electric cooking appliances including induction cooktops. Building electrification is often presented as a strategy for reducing carbon emissions and can be complementary to policies focusing on electric vehicles, demand management, grid-interactive technologies, renewable energy generation and storage, etc.

To evaluate the cost impact of building electrification strategies, Home Innovation Research Labs determined construction costs and energy use costs using a “Reference House” with multiple equipment configurations and multiple locations. These costs provided a basis for comparing all-electric houses to houses with gas equipment and appliances. Additionally, Home Innovation investigated equipment life expectancies and consumer perceptions regarding electric equipment and appliances.

METHODOLOGY

Project Approach

The primary tasks for this effort were:

- Establish baseline performance levels in accordance with the 2018 IECC and 2021 IECC.
- Establish a baseline single-family Reference House for each performance level using natural gas equipment and appliances for four locations selected based on considerations of climate zone and difference in fuel costs.
- Re-design the Reference Houses to all-electric houses using several possible combinations of features for each house, including optional infrastructure for electric vehicle (EV) charging.
- Evaluate the differences in the cost of construction for gas houses versus electric houses, including any cost to the builder related to upgrading the electrical service.
- Evaluate the cost of energy to operate gas houses versus electric houses.
- Document, based on available literature, performance considerations and consumer preferences for electric equipment such as heat pumps, heat pump water heaters, instantaneous electric water heaters, and electric cooktops.
- Evaluate the cost of retrofitting an existing gas Reference House to add electrification features, including optional EV charging infrastructure.

Reference House

The characteristics of the Reference House were defined for a representative single-family home. The features and representative locations of the Reference House are shown below; additional construction details and basis for selection are provided in Appendix D.

[1] Traditional electric-resistance storage water heaters are generally not included in electrification strategies.

Reference House features:

- 2-story, 4-bedroom, vented attic, attached 2-car garage
- Slab-on-grade foundation (Climate Zone 2) or basement foundation (Climate Zones 4-6)
- 2,600 square feet (SF) conditioned floor area above grade:
    - First floor: 1,080 SF with 9-foot ceilings
    - Second floor: 1,520 SF with 8-foot ceilings
    - Basement: 1,080 SF for houses with basements (3,680 SF total)

Reference House locations:

- Houston, TX; Climate Zone 2
- Baltimore, MD; Climate Zone 4
- Denver, CO; Climate Zone 5
- Minneapolis, MN; Climate Zone 6

Reference House configurations:

- There are 8 unique "baseline" configurations (4 locations, 2 performance levels, gas fuel)
- Performance level: each baseline house is constructed to the prescriptive thermal envelope requirements of the 2018 IECC or the 2021 IECC; thermal envelope measures remain constant for all analyzed scenarios
- Fuel type: electric houses have all-electric appliances and equipment; gas houses use natural gas for heating, hot water, cooking, and clothes drying

Equipment and Appliance Selection

The baseline gas houses, and minimum efficiency electric houses, utilize federal minimum efficiency HVAC systems and water heaters. Electrification equipment choices were identified, based on manufacturer product data and feedback from builders, to represent options that would be considered commonly available and suitable for the different climates. A range of high efficiency equipment combinations was modeled for each location to evaluate the relationship between upfront costs and annual energy cost savings for various scenarios.

This study evaluated "air source" heat pumps (i.e., not ground source or geothermal heat pumps). Heat pumps, except ductless heat pumps, utilize electric only backup/supplemental heat (i.e., electric resistance heating elements installed within the air handler, and not a supplemental gas furnace or standalone unit heater). Typically, ductless heat pumps are sized to handle the heating load and do not include supplemental resistance heaters. Houses with ductless heat pumps in colder climates commonly include a supplemental heat source, such as a gas heater, pellet stove, or electric baseboard convectors; for this project, the cost of ductless heat pumps did not include any cost for supplemental heat and the energy model relied only on the capacity of the ductless heat pump to produce heat.

The minimum efficiency heat pump utilizes a single-stage compressor. A system with a two-stage compressor represents the next higher efficiency level. Systems with variable speed compressors ("inverter" drive compressors that provide variable refrigerant flow) provide the highest efficiency ratings; the inverter systems are more suitable for colder climates because these can ramp up to provide higher heating capacities at lower temperatures compared to typical single-stage or two-stage equipment. Climate-appropriate heat pump options were evaluated based on criteria from various cold climate heat pump programs[2]. Selection of heat pumps in mixed climates will be driven by customer preferences. To continue to meet performance expectations of those homeowners who are used to gas furnace heating, the more expensive inverter heat pumps will be needed. In this study, both types of heat pump equipment are evaluated for Baltimore to provide a range of costs for plausible scenarios based on consumer preferences.

High efficiency water heating options for electric houses consist of heat pump water heaters: 50-gallon and 80-gallon capacities were selected for evaluation. Heat pump water heaters operating in heat pump only mode have a slower recovery than standard electric water heaters, so these are normally operated in "hybrid mode" that allows supplemental electric resistance heaters to operate as needed to maintain water temperature within the tank. The Uniform Energy Factor (UEF)[3] efficiency rating for heat pump water heaters is determined based on the default operational mode as defined by the manufacturer in its product literature; for the heat pump water heaters in this study, hybrid mode is the default mode, so using the UEF in the energy software in effect models the heat pump water heaters in hybrid mode.

Even in hybrid mode, with a tank temperature setpoint of 125°F, the modeling software indicated "unmet showers" for both capacities, indicating the heat pump water heater would run out of hot water before showering needs were met for a typical demand schedule. When set to 140°F, there were unmet showers for the 50-gallon model in colder climates, but there were no unmet showers for the 80-gallon model; the modeling results for unmet showers are provided in Appendix D. To minimize unmet showers, heat pump water heaters were modeled at a tank temperature of 140°F, and construction costs include a mixing valve to temper the water temperature leaving the tank. Further, based on builder feedback that any number of unmet showers may be considered unacceptable, the 80-gallon model was selected for comparison analysis in the Results section.

Higher efficiency gas equipment options also were analyzed to provide a full picture of equipment options available to builders for improving energy performance of homes. In those markets where higher efficiency gas equipment is the prevalent choice, it was also used as a comparative baseline for evaluation of electrification costs.

The selected equipment options and associated efficiencies that were used to develop construction costs and annual energy costs are shown in Table 1.

[2] E.g., Northeast Energy Efficiency Partnerships (NEEP), Minnesota Center for Energy & Environment (MNCEE)

[3] UEF is the current measure of water heater overall efficiency; the higher the UEF value, the more efficient the water heater; UEF is determined by the Department of Energy's test method outlined in 10 CFR Part 430, Subpart B, Appendix E.

Table 1. Equipment Options

Reference House	Equipment
Gas Baseline	Gas Furnace (GF): 80 AFUE
	Air Conditioner (AC): 13 SEER (14 SEER in CZ2&4)
	Water Heater (WH): 50 gal, natural draft, 0.58 UEF
Gas Equipment Options	50 gal, natural draft, 0.64 UEF
	Tankless, direct vent, 0.82 UEF
	Tankless, condensing direct vent, 0.93 UEF
	96 AFUE GF
	96 AFUE GF + 16 SEER AC
	97 AFUE modulating GF + 16 SEER AC
Electric Minimum Efficiency	Heat Pump (HP): 14 SEER/8.2 HSPF
	Water Heater (WH): 50 gal, 0.92 UEF
Electrification Equipment Options	2-stage HP, 18 SEER/9.3 HSPF
	Inverter HP, 19 SEER/10 HSPF rated to 7°F (CZ2&4) or -13°F (CZ5&6)
	Inverter HP, 20 SEER/13 HSPF
	Ductless inverter HP, 19 SEER/11 HSPF
	50 gal Heat Pump Water Heater (HPWH), 3.25 UEF
	80 gal HPWH, 3.25 UEF
	80 gal HPWH, 3.75 UEF

Construction Costs

Construction costs were developed using RSMeans[4] 2020 Residential Cost Data and RSMeans 2020 Residential Repair & Remodeling Cost Data. Costs for mechanical equipment were sourced from distributor web sites. Construction costs are summarized in the Results section; construction cost details are provided in Appendix A.

Appendix A costs are reported as both total to the builder and total to consumer. The total cost to builder includes overhead and profit (designated in the tables as "w/O&P") applied to individual component costs (materials and labor) to represent the cost charged by the sub-contractor. The total cost to consumer is based on applying a builder's markup of 18.9% to the builder's total cost[5]. For remodeling costs, a markup of 30.1% is applied to the remodeler's total cost to determine the total cost to consumer[6]. These represent national average costs, which were made specific for each home by applying a location adjustment; selected location adjustment factors from RSMeans are listed in Appendix C. For alternative house locations, the Appendix A costs could be modified by applying the appropriate location adjustment factor. The Results section reports total cost to consumer, adjusted for location.

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[4] RSMeans, https://www.rsmeans.com/

[5] As reported in the NAHB Cost of Doing Business Study, 2016 Edition. https://www.builderbooks.com/cost-of-doing-business-study--2016-edition-products-9780867187472.php

[6] As reported in the NAHB Remodeler's Cost of Doing Business Study, 2020 Edition. http://nahbnow.com/2020/05/how-much-does-it-cost-remodelers-to-do-business

Construction costs for this study are based on the following:

- Costs include equipment, associated electrical circuits and gas piping, and installation labor; equipment includes HVAC systems, water heaters, cooking ranges, and clothes dryers.
- Costs for air distribution ducts, water distribution piping, and refrigerant and condensate piping are not included because these would be the same for gas and electric houses (except for the ductless heat pump comparison where the cost of the ducts is subtracted from the system costs and the incremental costs for refrigerant and condensate piping are added to the system costs).
- Costs do not include ducting for heat pump water heaters; for the Reference Houses, water heaters are installed in the attic or basement and ducting is assumed to be not required. Costs would be greater where heat pump water heaters installed in closets or mechanical rooms require ducting.
- Electric houses include a basic electric range with exposed heating elements. Induction cooktop costs are also evaluated. Gas houses include a gas range; in single family detached houses started in 2019 that use natural gas as the primary heating fuel, 90% have a natural gas range or cooktop[7].
- Gas houses include a gas clothes dryer; in single family detached houses started in 2019 that use natural gas as the primary heating fuel, 40% have a natural gas dryer[8].
- For gas houses, the construction cost includes gas piping from the street to the house and interior gas piping. Costs for gas infrastructure to the development, which may be paid for by the utility or developer is reported separately as potential cost savings based on estimates developed by others.
- Reference Houses are assumed to have a 200-amp electrical service and panel. Based on an electrical load calculation performed in accordance with the National Electrical Code[9], a 200-amp service is sufficient for an electric Reference House with a finished basement and one electric vehicle (EV) charger circuit; the electrical load calculation is provided in Appendix D. The design electrical loads for the reference house are within about 11 percent of the panel capacity. An electrical service upgrade would be required for a second EV charger circuit and at some point, for a larger house or a house with additional electric loads such as a well, swimming pool, or electric baseboard heaters. If the existing electrical service from the street is sufficient, the electrical upgrade would normally consist of adding a second electrical panel; upgrading the service from the street, if required, would add significant cost. Any cost to upgrade the electrical service or panel is not included in this report and should be a subject of a follow-up study.
- The same construction cost is used for the 2018 IECC and 2021 IECC Reference Houses in the same location using the same fuel.

[7] 46% of all homes had a natural gas range or cooktop; 51% of all homes used natural gas as the primary heating fuel. Home Innovation: 2020 Annual Builder Practices Survey

[8] 20% of all dryers are natural gas dryers, eia.gov and 51% of new homes in 2019 used natural gas as the primary heating fuel

[9] National Electrical Code: NFPA 70. https://catalog.nfpa.org/NFPA-70-National-Electrical-Code-NEC-C4022.aspx

- Construction costs are developed based on new construction data except for the retrofit of an existing gas house for electrification that includes remodeling cost data.

Energy Use Costs

Annual energy use costs were developed using BEopt[10] 2.8.0.0 hourly simulation software and energy prices from the U.S. Energy Information Agency[11]. The natural gas and electricity prices are average annual 2018 residential prices in the state (2019 prices were not yet available during the analysis period of this study).

The energy prices used for this study are shown in Table 2. The table also shows prices for other example locations within the same Climate Zone, and a calculated ratio of electricity price to natural gas price for each location. This ratio is an important indicator for energy cost comparisons for locations with similar climate conditions – the higher the ratio, the more expensive it will be to operate electric equipment versus gas equipment.

Table 2. Energy Prices (source: eia.gov)

	CZ 2	**CZ 4**	**CZ 5**	**CZ 6**	
Fuel	**Houston**	**Baltimore**	**Denver**	**Minneapolis**	National Ave
Electricity, $/kWh	**0.1120**	**0.1330**	**0.1215**	**0.1314**	0.1287
Nat Gas, $/therm	**1.142**	**1.179**	**0.772**	**0.869**	1.050
Elec to Gas Price Ratio*	**3.0**	**3.4**	**4.8**	**4.6**	3.7
	Examples of energy prices in different locations within the same climate zone**				
	Phoenix	New York	Boston	Helena	
Electricity, $/kWh	0.1277	0.1852	0.2161	0.1096	
Nat Gas, $/therm	1.535	1.237	1.547	0.732	
Elec to Gas Price Ratio*	2.5	4.6	4.3	4.6	
	Tampa	Portland	Chicago	Burlington	
Electricity, $/kWh	0.1154	0.1098	0.1277	0.1802	
Nat Gas, $/therm	2.134	1.065	0.815	1.365	
Elec to Gas Price Ratio*	1.6	3.1	4.8	4.0	

*Calculated by converting fuel prices to $/Btu, based on 104 kBtu/therm for gas and 3,414 Btu/kWh for electric

** These additional locations are shown for the purpose of demonstrating the range of price ratios and were not used for energy modeling or separate cost analysis except on a limited basis to compare New York to Baltimore to illustrate the impact of different price ratios within the same climate zone.

[10] BEopt (Building Energy Optimization Tool) software: https://beopt.nrel.gov/home

[11] Energy Information Agency: https://www.eia.gov/

RESULTS

Construction Costs

Construction costs for various equipment options are summarized in Table 3 for gas houses and Table 4 for electric houses. Cost details are provided in Appendix A. Table 3 shows the baseline cost for gas houses and the incremental cost of gas equipment options. Table 4 shows the incremental cost of electrification equipment options relative to electric houses with federal minimum efficiency equipment.

Table 3. Construction Costs for Gas Houses

	Gas Construction Cost, $			
Gas Reference House Configuration	**Houston**	**Baltimore**	**Denver**	**Minneapolis**
Baseline, total cost	11,132	11,746	11,913	11,345
Gas equipment options, incremental cost:				
50 gal WH, 0.64 UEF	182	188	193	184
Tankless WH, 0.82 UEF	728	750	772	735
Tankless condensing WH, 0.93 UEF	1,106	1,139	1,173	1,117
96 AFUE GF	1,147	1,106	1,138	1,084
96 AFUE GF + 16 SEER AC	1,317	1,161	1,497	1,426
97 AFUE modulating GF + 16 SEER AC	2,367	2,243	2,611	2,486
Adjust if installing 90+ GF AND tankless WH (metal chimney vent no longer required)	(283)	(1,019)	(1,049)	(999)

Table 4. Construction Costs for Electric Houses

	Electric Construction Cost, $			
Electric Reference House Configuration	**Houston**	**Baltimore**	**Denver**	**Minneapolis**
Electrification equipment options, incremental cost relative to federal minimum efficiency electric systems:				
50 gal HPWH*, 3.25 UEF	1,257	1,295	1,333	1,270
80 gal HPWH, 3.25 UEF	2,373	2,445	2,516	2,397
80 gal HPWH, 3.75 UEF	2,632	2,711	2,791	2,658
18 SEER/9.3 HSPF 2-stage HP	2,041	2,102**	N/A	N/A
19 SEER/10 HSPF inverter HP, rated to 7°F (CZ2&4) or -13°F (CZ5&6)	5,455	5,620	8,288	7,893
20 SEER/13 HSPF inverter HP	8,524	8,782	9,040	8,610
19 SEER/11 HSPF ductless HP***	3,894	8,856	9,117	8,683
Option: Electric Vehicle (EV) charger circuit	617	635	654	623
Option: Substitute induction cooktop range	997	1,027	1,057	1,007

*The 50 gallon HPWH set to 140°F may provide sufficient hot water in Climate Zones 2 & 4 (Houston and Baltimore)

** Standard heat pump may or may not be acceptable to occupants in this climate zone during the heating season.

*** The cost includes savings for not installing ductwork; the Houston system is less expensive due to one less "head" (wall mounted air handler) because there is no basement, lower overall capacity, and does not include cold climate technology.

Gas Infrastructure Cost

For gas houses, the construction cost in Table 3 includes gas piping from the street to the house and interior gas piping, but it does not include gas infrastructure to the development, which may be paid for by the utility or developer. The cost of community gas infrastructure to the builder can range from zero to thousands of dollars per house; some reports show an average cost of approximately $1,400[12].

Energy Use Costs

The modeled annual energy costs are shown in Table 5 for gas houses and Table 6 for electric houses. Table 5 shows energy costs for baseline houses and for baseline houses with individual gas equipment options. Table 6 shows energy costs for minimum efficiency electric houses and for individual electrification equipment options. Both tables show results for houses constructed in accordance with the prescriptive building thermal envelope requirements for the 2018 IECC and 2021 IECC.

The 2021 IECC also requires selecting an additional energy savings package (options are defined in the 2021 IECC). This requirement is met for the reference houses in Baltimore, Denver, and Minneapolis because the HVAC ducts are 100% inside conditioned space (one of the prescribed options for 2021). For Houston, the 2021 houses were modeled with a tighter building enclosure and ERV installed (also a prescribed option for 2021).

Efficiency ratings for heat pumps are normally based on the system operating in "efficiency mode" although systems are commonly set up in "comfort mode". System efficiency is lower than rated when operating in comfort mode (lower COP ratings by outdoor temperatures). For this analysis, the energy model is based on the rated efficiencies (in efficiency mode). Energy use would be higher where systems are set up in comfort mode.

For the 13 HSPF heat pump option (HVAC3), manufacturer product data was used for the software inputs for variable speed (inverter).

Heat pump water heaters were modeled in "hybrid mode" (supplemental elecric resistance heaters operate as needed to maintain tank water temperature) and at a set point of 140°F to minimize "unmet showers" (running out of hot water before showering needs are met for a typical demand schedule, as indicated by the modeling software).

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[12] California Building Industry Association (CBIA) survey showed $1,424; Green Builder article from Oct 2020 reported approximately $1,400 per single family detached house; Energy Logic presentation showed $1,300-$1,500, Green Builder webinar: https://www.greenbuildermedia.com/impact-series-archive-home/the-electrification-wave-implications-for-builders-and-others

Table 5. Annual Energy Costs for Gas Houses

	Gas House Annual Energy Cost, $/yr							
	Houston		Baltimore		Denver		Minneapolis	
Gas Reference House Configuration	2018	2021	2018	2021	2018	2021	2018	2021
Baseline	1,501	1,466	1,814	1,756	1,477	1,422	1,893	1,881
w/ 50 gal WH, 0.64 UEF	1,484	1,448	1,797	1,739	1,465	1,410	1,881	1,869
w/ Tankless WH, 0.82 UEF	1,454	1,418	1,769	1,711	1,445	1,390	1,861	1,849
w/ Tankless condensing WH, 0.93 UEF	1,440	1,405	1,750	1,691	1,431	1,376	1,843	1,831
w/ 96 AFUE GF	1,467	1,439	1,727	1,677	1,410	1,362	1,775	1,764
w/ 96 AFUE GF/16 SEER AC	1,392	1,369	1,694	1,647	1,371	1,326	1,730	1,720
w/ 97 AFUE modulating GF/16 SEER AC	1,391	1,367	1,689	1,643	1,368	1,323	1,723	1,713
w/ 96 AFUE GF/16 SEER AC & 0.82 UEF tankless WH	1,328	1,308	1,627	1,580	1,326	1,281	1,664	1,654
w/ 96 AFUE GF/16 SEER AC & 0.93 UEF tankless condensing WH	1,315	1,294	1,607	1,560	1,312	1,267	1,647	1,637

Table 6. Annual Energy Costs for Electric Houses

	Electric House Annual Energy Cost, $/yr							
	Houston		Baltimore		Denver		Minneapolis	
Electric Reference House Configuration	2018	2021	2018	2021	2018	2021	2018	2021
Minimum efficiency	1,617	1,595	2,118	2,054	NA	NA	NA	NA
w/ 50 gal HPWH set to 140°F, 3.25 UEF	1,468	1,448	1,919	1,854	1,858	1,791	2,628	2,611
w/ 80 gal HPWH set to 140°F, 3.25 UEF	1,454	1,433	1,846	1,781	1,782	1,715	2,536	2,515
w/ 80 gal HPWH set to 140°F, 3.75 UEF	1,444	1,424	1,828	1,763	1,764	1,697	2,518	2,498
w/ 18 SEER/9.3 HSPF 2-stage HP	1,500	1,486	2,025	1,971	NA	NA	NA	NA
w/ 19 SEER/10 HSPF inverter HP, rated to 7°F (CZ2&4) or -13°F (CZ5&6)	1,413	1,404	1,925	1,880	1,859	1,812	2,614	2,598
w/ 20 SEER/13 HSPF inverter HP	NA	NA	NA	NA	1,825	1,782	2,552	2,536
w/ 19 SEER/11 HSPF ductless HP	1,397	1,408	1,888	1,852	1,852	1,814	2,571	2,559
w/ 18 SEER/9.3 HSPF HP & 80 gal 3.75 UEF HPWH set to 140°F	1,325	1,312	1,734	1,679	NA	NA	NA	NA
w/ 19 SEER/10 HSPF HP & 80 gal 3.75 UEF HPWH set to 140°F	1,237	1,229	1,630	1,585	1,586	1,538	2,297	2,280
w/ 20 SEER/13 HSPF HP & 80 gal 3.75 UEF HPWH set to 140°F	NA	NA	NA	NA	1,550	1,506	2,230	2,215
w/ 19 SEER/11 HSPF ductless HP & 80 gal 3.75 UEF HPWH set to 140°F	1,230	1,242	1,712	1,675	1,720	1,682	2,277	2,266

Comparative Analysis

The estimated construction costs and modeled annual energy use costs provide the basis to compare electric houses and gas houses. Table 7 compares an electrified house, with selected combinations of equipment options, to a baseline gas house with minimum federal efficiency equipment, for the 2018

IECC performance level. Table 8 makes the same comparisons for the 2021 IECC performance level. The tables show the additional construction cost, annual energy savings (shown as a negative value where there are energy cost increases), and simple payback for the electric house relative to the gas house. Table 9 and Table 10 make similar comparisons except electric houses are compared to gas houses with selected higher efficiency equipment.

Note that other combinations of equipment could be compared using the estimated construction costs and annual energy costs.

Table 7. Electric House Compared to Baseline Gas House, 2018 IECC Performance Level

Electric House relative to Gas Baseline House (80 AFUE GF, 13/14 SEER AC, 0.58 UEF WH) (2018 IECC)

Electric House Configuration	Houston	Baltimore	Denver	Minneapolis
14 SEER/8.2 HSPF HP & 50 gal 0.92 UEF WH				
Added construction cost, $	73	(201)		
Energy savings, $/yr	(116)	(304)		
Simple payback, yrs	NA	NA		
14 SEER/8.2 HSPF HP & 80 gal 3.75 UEF HPWH set to 140°F				
Added construction cost, $	2,705	2,510		
Energy savings, $/yr	57	(14)		
Simple payback, yrs	47	NA		
18 SEER/9.3 HSPF 2-stage HP & 80 gal 3.75 UEF HPWH set to 140°F				
Added construction cost, $	4,745	4,613		
Energy savings, $/yr	176	80		
Simple payback, yrs	27	58		
19 SEER/10 HSPF inverter HP (equipment rated for 7°F in CZ2&4 or -13°F in CZ5&6) & 80 gal 3.75 UEF HPWH set to 140°F				
Added construction cost, $	8,160	8,131	11,050	10,524
Energy savings, $/yr	264	184	(109)	(404)
Simple payback, yrs	31	44	NA	NA
20 SEER/13 HSPF inverter HP & 80 gal 3.75 UEF HPWH set to 140°F				
Added construction cost, $			11,803	11,241
Energy savings, $/yr			(128)	(337)
Simple payback, yrs			NA	NA

Table 8. Electric House Compared to Baseline Gas House, 2021 IECC Performance Level

Electric House relative to Gas Baseline House (80 AFUE GF, 13/14 SEER AC, 0.58 UEF WH) (2021 IECC)

Electric House Configuration	Houston	Baltimore	Denver	Minneapolis
14 SEER/8.2 HSPF HP & 50 gal 0.92 UEF WH				
Added construction cost, $	73	(201)		
Energy savings, $/yr	(129)	(298)		
Simple payback, yrs	NA	NA		
14 SEER/8.2 HSPF HP & 80 gal 3.75 UEF HPWH set to 140°F				
Added construction cost, $	2,705	2,510		
Energy savings, $/yr	42	(7)		
Simple payback, yrs	64	NA		
18 SEER/9.3 HSPF 2-stage HP & 80 gal 3.75 UEF HPWH set to 140°F				
Added construction cost, $	4,745	4,613		
Energy savings, $/yr	154	77		
Simple payback, yrs	31	60		
19 SEER/10 HSPF inverter HP (rated to 7°F in CZ2&4 or -13°F in CZ5&6) & 80 gal 3.75 UEF HPWH set to 140°F				
Added construction cost, $	8,160	8,131	11,050	10,524
Energy savings, $/yr	237	171	(116)	(399)
Simple payback, yrs	34	48	NA	NA
20 SEER/13 HSPF inverter HP & 80 gal 3.75 UEF HPWH set to 140°F				
Added construction cost, $			11,803	11,241
Energy savings, $/yr			(84)	(334)
Simple payback, yrs			NA	NA

Table 9. Electric House Compared to Higher Efficiency Gas House, 2018 IECC Performance Level

Electric House relative to Gas House with 96 AFUE GF, 16 SEER AC, 0.93 UEF WH (2018 IECC)				
Electric House Configuration	**Houston**	**Baltimore**	**Denver**	**Minneapolis**
18 SEER/9.3 HSPF 2-stage HP & 80 gal 3.75 UEF HPWH set to 140°F				
Added construction cost, $	2,605	3,331		
Energy savings, $/yr	(10)	(127)		
Simple payback, yrs	NA	NA		
19 SEER/10 HSPF inverter HP (rated to 7°F in CZ2&4 or -13°F in CZ5&6) & 80 gal 3.75 UEF HPWH set to 140°F				
Added construction cost, $	6,020	6,849	9,429	8,980
Energy savings, $/yr	78	(23)	(274)	(650)
Simple payback, yrs	77	NA	NA	NA
20 SEER/13 HSPF inverter HP & 80 gal 3.75 UEF HPWH set to 140°F				
Added construction cost, $			10,182	9,697
Energy savings, $/yr			(238)	(583)
Simple payback, yrs			NA	NA
Ductless HP 19 SEER/11 HSPF & 80g 3.75 UEF HPWH set to 140°F				
Added construction cost, $	4,459	10,085	10,258	9,770
Energy savings, $/yr	85	(105)	(408)	(630)
Simple payback, yrs	52	NA	NA	NA

Table 10. Electric House Compared to Higher Efficiency Gas House, 2021 IECC Performance Level

Electric House relative to Gas House with 96 AFUE GF, 16 SEER AC, 0.93 UEF WH (2021 IECC)				
Electric House Configuration	**Houston**	**Baltimore**	**Denver**	**Minneapolis**
18 SEER/9.3 HSPF 2-stage HP & 80 gal 3.75 UEF HPWH set to 140F				
Added construction cost, $	2,605	3,331		
Energy savings, $/yr	(18)	(119)		
Simple payback, yrs	NA	NA		
19 SEER/10 HSPF inverter HP (rated to 7°F in CZ2&4 or -13°F in CZ5&6) & 80 gal 3.75 UEF HPWH set to 140°F				
Added construction cost, $	6,020	6,849	9,429	8,980
Energy savings, $/yr	65	(25)	(271)	(643)
Simple payback, yrs	93	NA	NA	NA
20 SEER/13 HSPF inverter HP & 80 gal 3.75 UEF HPWH set to 140°F				
Added construction cost, $			10,182	9,697
Energy savings, $/yr			(239)	(578)
Simple payback, yrs			NA	NA
Ductless HP 19 SEER/11 HSPF & 80g 3.75 UEF HPWH set to 140°F				
Added construction cost, $	4,459	10,085	10,258	9,770
Energy savings, $/yr	52	(115)	(415)	(629)
Simple payback, yrs	86	NA	NA	NA

As the results in Tables 7 through 10 indicate, the upfront additional cost of an electric house with high efficiency electric heat pump and heat pump water heater ranges between $4,613 and $11,803 compared to a baseline gas house (minimum efficiency natural gas equipment). The higher cost is associated with colder, heating dominated climates due to the higher cost of heat pumps rated to operate in colder temperatures. In colder climates (Denver and Minneapolis), the more expensive electric equipment also results in higher energy use costs than gas equipment. Therefore, in colder climates the consumer will be faced with higher upfront cost and higher operating costs throughout the life of the equipment.

In the cooling dominated climate (Houston), the energy use cost for the electric house with high efficiency equipment can be reduced by $154 to $264 annually compared to a baseline gas house resulting in a simple payback ranging between 27 years and 64 years; compared to a gas house with higher efficiency gas equipment, the change in energy cost ranges from an increase of $18 to a savings of $85 annually, with simple payback of 52 years to 93 years. For the electric house with minimum efficiency equipment compared to the baseline gas house, the energy cost increases by $116 to $129 annually.

In the mixed climate (Baltimore), the energy use cost for the electric house with high efficiency equipment can be reduced by $77 to $184 annually compared to a baseline gas house, with simple paybacks ranging between 44 years and 60 years; compared to a gas house with higher efficiency gas equipment, the consumer is again faced with higher upfront cost and higher annual energy use cost. For the electric house with minimum efficiency equipment compared to the baseline gas house, the energy cost increases by $298 to $304 annually.

Comparison of Gas Equipment Options

The estimated construction costs and modeled annual energy use costs also provide the basis for comparing gas equipment options. Table 11 compares two options for a gas house, with selected combinations of high efficiency equipment, to a baseline gas house with minimum federal efficiency equipment, for the 2018 IECC performance level. Table 12 makes the same comparisons for the 2021 IECC performance level. The tables show the additional construction cost, additional energy cost (shown as a negative value where there are energy savings), and simple payback for the efficient gas house relative to the baseline gas house.

The incremental costs for high efficiency gas equipment options are consistent across climates; the differences are due to house layout and cost adjustments by location; most payback periods are 10 years or less.

Table 11. Gas House Equipment Comparison, 2018 IECC Performance Level

Efficient Gas House relative to Baseline Gas House, 2018 IECC

Gas House Configuration	Houston	Baltimore	Denver	Minneapolis
96 AFUE GF/16 SEER AC & 0.82 UEF WH				
Added construction cost, $	1,762	892	1,220	1,162
Energy savings, $/yr	173	187	151	229
Simple payback, yrs	10	5	8	5
96 AFUE GF/16 SEER AC & 0.93 UEF WH				
Added construction cost, $	2,140	1,282	1,621	1,544
Energy savings, $/yr	186	207	165	246
Simple payback, yrs	12	6	10	6

Table 12. Gas House Equipment Comparison, 2021 IECC Performance Level

Efficient Gas House relative to Baseline Gas House, 2021 IECC

Gas House Configuration	Houston	Baltimore	Denver	Minneapolis
96 AFUE GF/16 SEER AC & 0.82 UEF WH				
Added construction cost, $	$1,762	$892	$1,220	$1,162
Energy savings, $/yr	$158	$176	$141	$227
Simple payback, yrs	11	5	9	5
96 AFUE GF/16 SEER AC & 0.93 UEF WH				
Added construction cost, $	$2,140	$1,282	$1,621	$1,544
Energy savings, $/yr	$172	$196	$155	$244
Simple payback, yrs	12	7	10	6

Impact of Electric to Gas Price Ratio

To illustrate the impact of the electric-to-gas price ratio described in the methodology section, Table 13 compares electric houses, with selected high efficiency options, to baseline gas houses, using the 2021 performance level, for two locations within the same climate zone: Baltimore (3.4 price ratio) and New York (4.6 price ratio). Table 14 compares an electric house to a gas house with selected high efficiency gas options.

The additional energy costs are higher and payback periods, where there are energy savings, are significantly longer for New York compared to Baltimore despite being in the same climate zone. These differences are primarily due to the higher electric-to-gas price ratio.

Table 15 compares a gas house with selected high efficiency equipment options to a baseline gas house. Paybacks are somewhat shorter for New York compared to Baltimore due to higher energy prices in New York.

Table 13. Electric House Relative to Gas Baseline House, 2021 IECC Performance Level

Electric House relative to Gas Baseline House

Electric House Configuration	Baltimore	New York
14 SEER/8.2 HSPF HP & 50 gal 0.92 UEF WH		
Added construction cost, $	(201)	(201)
Energy savings, $/yr	(298)	(689)
Simple payback, yrs	NA	NA
18 SEER/9.3 HSPF 2-stage HP & 80 gal 3.75 UEF HPWH set to 140°F		
Added construction cost, $	4,613	4,613
Energy savings, $/yr	77	(93)
Simple payback, yrs	60	NA
19 SEER/10 HSPF inverter HP & 80 gal 3.75 UEF HPWH set to 140°F		
Added construction cost, $	8,131	8,131
Energy savings, $/yr	171	38
Simple payback, yrs	48	214

Table 14. Electric House Relative to Gas House with High Efficiency Equipment, 2021 IECC Performance Level

Electric House relative to Gas House w/96 AFUE GF, 16 SEER AC, 0.93UEF WH

Electric House Configuration	Baltimore	New York
18 SEER/9.30 HSPF HP & 80 gal 3.75 UEF HPWH		
Added construction cost, $	3,331	3,331
Energy savings, $/yr	(119)	(337)
Simple payback, yrs	NA	NA
19 SEER/10 HSPF HP & 80 gal 3.75 UEF HPWH		
Added construction cost, $	6,849	6,849
Energy savings, $/yr	(25)	(206)
Simple payback, yrs	NA	NA

Table 15. Gas House Equipment Comparison, 2021 IECC

Efficient Gas House relative to Baseline Gas House

Gas House Configuration	Baltimore	New York
96 AFUE GF/16 SEER AC & 0.82 UEF WH		
Added construction cost, $	892	892
Energy savings, $/yr	176	224
Simple payback, yrs	5	4
96 AFUE GF/16 SEER AC & 0.93 UEF WH		
Added construction cost, $	1,282	1,282
Energy savings, $/yr	196	244
Simple payback, yrs	7	5

Electrification Retrofit Costs

The estimated cost of electrification to retrofit an existing gas house is summarized in Table 16; details are provided in Appendix B. The analysis is based on starting with an existing baseline gas house, removing existing gas appliances, capping gas lines and chimney vents and abandoning those in place, installing an electric range, dryer, high efficiency heat pump and heat pump water heater, installing associated electrical wiring, and repairing and painting drywall that was removed to install new wiring.

For comparison purposes, the estimated costs to retrofit an existing gas house with gas equipment is shown in Table 17.

Table 16. Retrofit Cost of Electrification for an Existing Baseline Gas Reference House

	Retrofit Cost of Electrification			
Electrification Equipment Options installed in an Existing Gas Baseline Reference House	**Houston**	**Baltimore**	**Denver**	**Minneapolis**
Install electric range, clothes dryer, 19 SEER/10 HSPF HP, 80 gal 3.75 UEF HPWH	$24,282	$25,017	$28,491	$27,134
Additional incremental cost to substitute a range with an induction cooktop	$1,091	$1,124	$1,157	$1,102
Additional cost to install one electric vehicle (EV) charger circuit	$1,266	$1,305	$1,343	$1,279

Table 17. Retrofit Cost of Gas Equipment and Appliances for an Existing Gas Baseline Reference House

	Retrofit Cost of Gas Equipment and Appliances			
Gas Equipment Options installed in an Existing Gas Baseline Reference House	**Houston**	**Baltimore**	**Denver**	**Minneapolis**
Install gas range, gas dryer, 80 AFUE GF, 14 SEER AC, 50 gal 0.56 UEF WH	$9,767	$10,063	$10,359	$9,866
Install gas range, gas dryer, 96 AFUE GF, 16 SEER AC, tankless condensing 0.93 UEF WH	$12,658	$13,041	$13,425	$12,786

Life Expectancy of Equipment and Appliances

Table 18 shows the approximate life expectancy of HVAC equipment, water heaters, dryers, and ranges as reported by various organizations. Factors that affect life expectancy of equipment include:

- Proper installation and maintenance
- Proper sizing to minimize on-off cycling
- Climate: air conditioners tend to last longer in colder climates; heat pumps tend to wear out sooner in colder climates
- Corrosive environments, indoor and outdoor including coastal environments
- Intensity of use

Table 18. Life Expectancy of Equipment and Appliances

	Life Expectancy: median or range (years)						
Equipment/Appliance	**DOE[13]**	**NAHB[14]**	**Consumer Affairs[15]**	**ASHRAE[16]**	**HVAC.COM[17]**	**Consumer Reports[18]**	**Erie Insurance[19]**
Gas Furnace	20	18; 15-20	15	18	15-25	15-20	
Air Conditioner	16	15; 10-15	15-20	15	12-15	15	
Heat Pump	15	16	10-15	15	16	15	
Ductless Heat Pump	15						
Gas Storage Water Heater	13	10	8-12		10		
Electric Storage Water Heater	13	11	8-15		10		
Tankless Water Heater	20	20	20		20		
Heat Pump Water Heater	12		13-15				
Gas Clothes Dryer		13				10	14
Electric Clothes Dryer		13				10	14
Gas Range		15					19
Electric Range		13					17

[13] U.S. Department of Energy: BEopt software values. https://beopt.nrel.gov/home

[14] National Association of Home Builders: Study of Life Expectancy of Home Components, 2007. https://www.interstatebrick.com/sites/default/files/library/nahb20study.pdf

[15] Consumer Affairs: Central Air Conditioning. https://www.energy.gov/energysaver/central-air-conditioning
Replacing your home's heat pump. https://www.consumeraffairs.com/news/replacing-your-homes-heat-pump-031513.html

[16] American Society of Heating, Refrigeration, and Air Conditioning Engineers: Equipment Life Expectancy Chart. https://hvac-eng.com/hvacr-equipment-life-expectancy/

[17] HVAC.COM, 2017. https://www.hvac.com/faq/life-expectancy-hvac-systems/

[18] Consumer Reports. https://www.consumerreports.org/heat-pumps/most-and-least-reliable-heat-pumps/; https://www.consumerreports.org/central-air-conditioners/most-reliable-central-air-conditioning-systems/; https://www.consumerreports.org/cro/gas-furnaces/buying-guide/index.htm

[19] Erie Insurance. https://www.erieinsurance.com/blog/when-to-replace-appliances

Consumer Perceptions of Electric Appliances

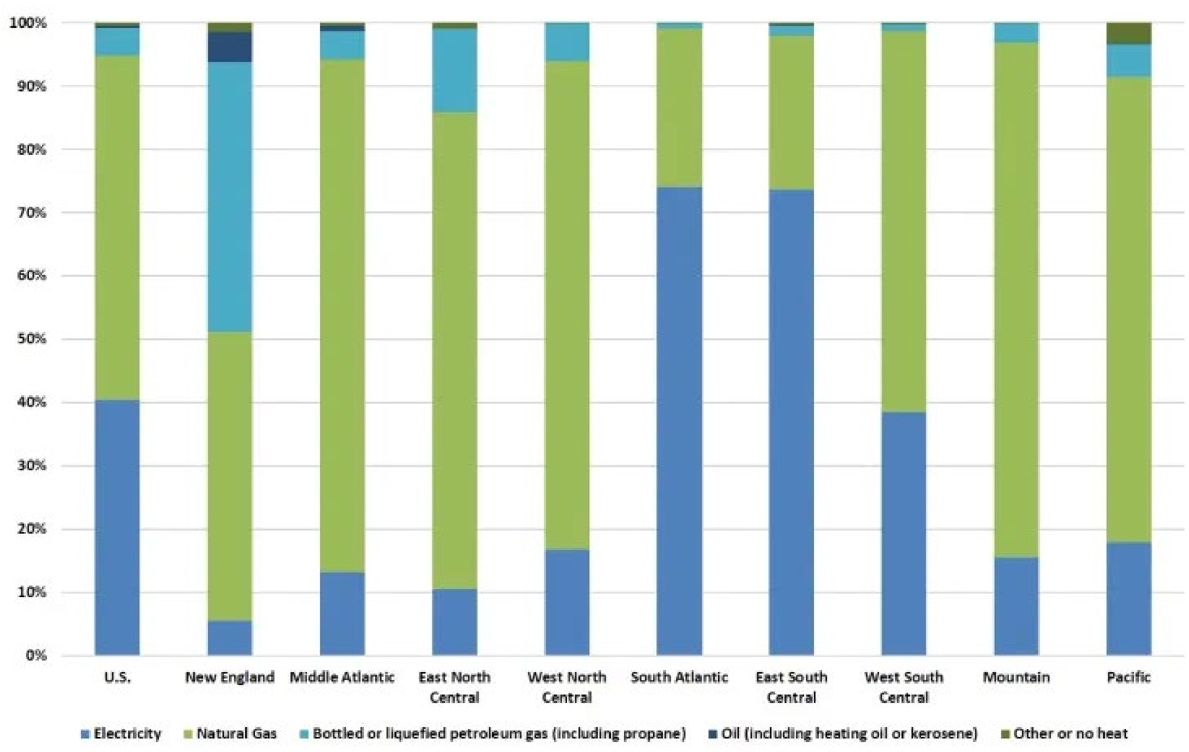
Natural gas is the primary heating fuel for the majority of new homes in the United States, as shown in Table 19[20]. The primary heating fuel varies significantly by region of the country; in colder climates, the share of natural gas heating is over 80 percent (Figure 1). In some of the warmer climates, heat pumps approach an 80 percent market share (Figure 2).

Table 19. Primary Heating Fuel for New Homes (source: NAHB)

Primary Heating Fuel for New Single Family Home Starts

Year	Natural Gas	Electricity
2019	51%	44%
2018	54%	40%
2017	56%	39%
2016	55%	40%
2015	55%	40%

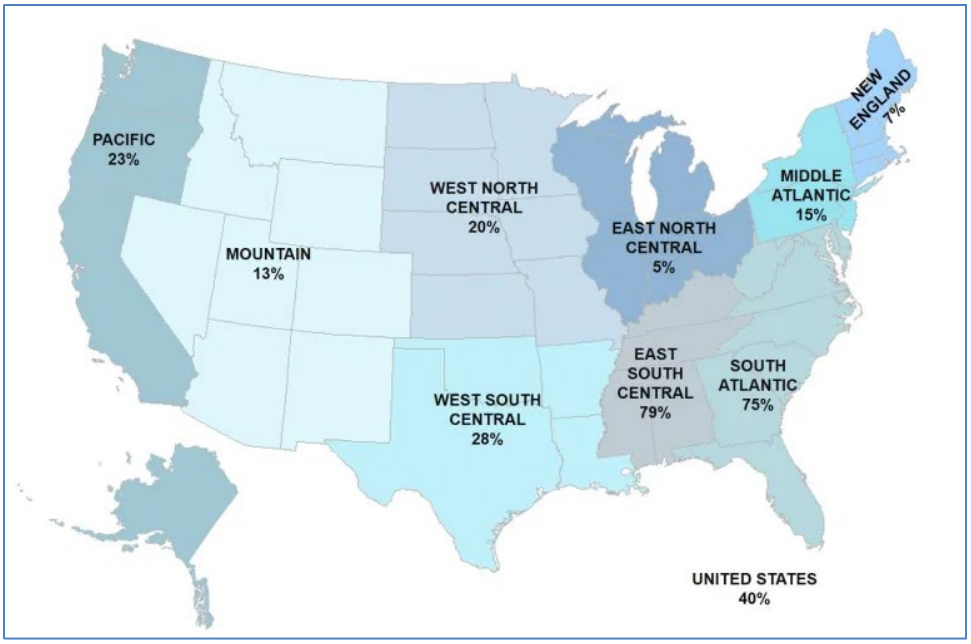
Figure 1. Type of Primary Heating Fuel Used in New Homes Started in 2019 (source: NAHB)



Source: NAHB tabulations of data from the 2019 Survey of Construction. U.S. Census Bureau, partially funded by HUD.

[20] NAHB Eye on Housing: Air Conditioning and Heating Systems in New Homes, Nov 13, 2020. http://eyeonhousing.org/2020/11/air-conditioning-and-heating-systems-in-new-homes-5/

Figure 2. Share of New Single-Family Homes Started in 2019 with Air or Ground Source Heat Pump (source: NAHB)



Home Innovation reviewed existing literature regarding consumer perceptions of electric appliances. The results are presented here [*added notes are by Home Innovation to expand on specific items*]:

- Heat pumps:
  - Do not provide comfort during the heating season; the supply air temperature does not feel warm[21] [T*he supply air temperature for heat pump systems is typically below 100°F (when the electric supplemental heater is not operating) and can feel uncomfortable particularly compared to a gas furnace with a typical supply air temperature of 105-120°F. Further, the heat pump supply temperature drops as it gets colder outside. For example, manufacturer product data for a conventional heat pump system (non-inverter) typically indicates a supply air temperature of approximately 97°F at 47°F outdoor temperature and 70°F thermostat set point, but supply air temperature drops to 87°F when the outdoor temperature drops to 17°F; inverter heat pump systems designed for cold climates maintain supply air temperature better because these don't lose as much capacity at lower outdoor temperatures, and these also may reduce airflow at the air handler to maintain a target supply air temperature.*]
  - High initial installation cost
  - High operating cost for heating
  - The recovery period, after setting back the thermostat during heating, relies on the electric supplemental heaters to operate which is expensive, so it is more economical to "set-and-forget" the thermostat setting in heating mode. [*Some heat pump thermostats*

[21] Trane: https://www.trane.com/residential/en/resources/heat-pump-vs-furnace-what-heating-system-is-right-for-you/

will increase the set point gradually to minimize electric resistance heating during the recovery period.]

  - Ductless heat pumps may need a supplemental heat source during particularly cold periods
  - Prone to improper installation, e.g., correct air flow and refrigerant charge[22]
  - There are numerous potential mechanical issues[23] [24]
  - Expensive to repair
  - Short life expectancy [*Note: see previous section for equipment life expectancies*]

- Electric water heaters, conventional electric-resistance storage type:
  - Run out of hot water too soon/slow recovery rate [*Note: The first hour rating (FHR) of an electric water heater is lower than a gas water heater with the same size tank; larger capacity tanks are commonly selected to help offset this*]
  - Expensive to operate

- Heat pump water heaters[25] [26]:
  - High potential for energy savings [*Note: COP ratings have increased considerably in recent years; energy modeling for this study confirms significant energy savings compared to standard electric water heaters; savings will be less during heating season where the HPWH is installed in conditioned space because it uses heated house air, so the heating system is also indirectly heating the water, and where the HPWH is installed in unconditioned space with lower ambient temperature.*]
  - High initial cost
  - Run out of hot water too soon/slow recovery rate. [*Note: Heat pump water heaters have a slower recovery than standard electric water heaters, so are typically set to "hybrid" mode that allows the electric resistance heating element to operate as needed. Further, the energy software for this study showed it was necessary to select an 80-gallon capacity and 140F water temperature to avoid "unmet showers"*]
  - Noise can be an issue, depending on location in the dwelling
  - Confusion around best selection of settings: hybrid mode; heat pump only mode; electric element only; high demand mode; vacation mode *[Note: operating in hybrid mode or electric element only mode reduces efficiency compared to heat pump only mode*]

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[22] ACHRNEWS: https://www.achrnews.com/articles/135097-addressing-poor-heat-pump-installations

[23] Carrier: https://www.carrier.com/residential/en/us/products/heat-pumps/heat-pump-troubleshooting/

[24] HVAC.com: https://www.hvac.com/blog/the-most-common-heat-pump-problems-how-to-avoid-them/

[25] As reported in Field Performance of Heat Pump Water Heaters in the Northeast. Shapiro and Puttagunta, Consortium for Advanced Residential Buildings, Feb 2016. https://www.nrel.gov/docs/fy16osti/64904.pdf

[26] Building Green blog: https://www.buildinggreen.com/blog/heat-pump-water-heaters-cold-climates-pros-and-cons

    - Reliability, e.g., compressor failure
    - Additional maintenance: inspecting and clearing the condensate strainer and drain lines; cleaning the air filter and evaporator
- Cooking
    - Historically, many homeowners prefer a gas cooktop: 90% of new homes with natural gas as the primary heating fuel have a natrual gas range or cooktop[27]
    - More recently, some homeowners consider induction cooktops as superior to gas and conventional electric cooktops[28] [*Note: the modeling software for this project predicted an annual energy savings of $4 for an induction cooktop*].
- Clothes Drying[29]
    - Electric dryers have a lower initial cost
    - Gas dryers dry loads in about half the time of electric dryers
    - Gas dryers cost less to operate

[27] Home Innovation 2019 builder practice survey.

[28] Reviewed.com. https://www.reviewed.com/ovens/features/induction-101-better-cooking-through-science

[29] Home Depot. https://www.homedepot.com/c/ab/gas-vs-electric-dryers/9ba683603be9fa5395fab902da8afc8

Summary Construction Costs of Electrification

Table 20 summarizes the range of electrification costs for an electric house with high efficiency equipment compared to a baseline gas house. The heat pump row takes into account the cost difference between the baseline gas house and the minimum efficiency electric house. For heat pumps, the low and high costs are based on systems that are considered appropriate for the climate zone, and the range includes the ductless heat pump option. For heat pump water heaters, the low cost is for the 50-gallon, 3.25 UEF model in Houston and Baltimore and the 80-gallon, 3.25 UEF model in Denver and Minneapolis, and the high cost is for the 80-gallon, 3.75 UEF model. Although an electrical service upgrade was deemed to be not required for the reference house configurations with a single EV charger, the table includes a placeholder for cost where a service upgrade or additional community electrical infrastructure cost may be required. For the EV charger circuits, the low cost is for a single circuit, and the high cost is for two circuits and adding a second electrical panel. Adding EV charging may require upgrading the electrical service from the street to the house; this cost can be substantial but is not included in the table. For gas houses, the construction cost includes gas piping from the street to the house and interior gas piping (these costs are subtracted for electric homes), but it does not account for gas infrastructure to the development, which may be paid for by the utility or developer. The cost of community gas instrastructure to the builder can range from zero to thousands of dollars per house; some reports (developed by others) show an average cost of approximately $1,400.

Table 20. Summary Range of Construction Costs of Electrification

Range of Construction Costs of Electrification relative to a Baseline Gas Reference House, $								
Electric Reference House Component	**Houston**		**Baltimore**		**Denver**		**Minneapolis**	
	Low	**High**	**Low**	**High**	**Low**	**High**	**Low**	**High**
Heat Pump	2,114	5,528	1,901	8,655	8,259	9,088	7,866	8,655
Heat Pump Water Heater	1,257	2,632	1,295	2,711	2,516	2,791	2,397	2,658
Electric Vehicle charger circuit(s)	617	2,040	635	2,102	654	2,163	623	2,060
Induction cooktop range	0	997	0	1,027	0	1,057	0	1,007
Total added construction cost, $	**3,988**	**11,196**	**3,832**	**14,495**	**11,430**	**15,100**	**10,886**	**14,381**
Electrical service upgrade or community electrical infrastructure	Varies by Utility Territory							
Community gas infrastructure cost savings	Varies by Utility Territory							

CONCLUSIONS

Based on the estimated construction costs and annual energy costs developed for the Reference House configurations and selected locations, key findings are summarized here:

- The overall range of estimated electrification costs for an electric reference house compared to a baseline gas reference house is between $3,988 and $11,196 in a warm climate (Houston), $3,832 and $14,495 in a mixed climate (Baltimore), and $10,866 and $15,100 in a cold climate (Denver and Minneapolis). On the low end of the range, these costs include a heat pump, heat pump water heater, and a single EV charger circuit. On the high end of the range, the costs also include a heat pump upgrade, second EV charger circuit, a second electrical panel (required for a second EV circuit), and an induction cooktop (induction cookware is not included). The low-end cost for mixed climates depends on the consumer preference for equipment and can be similar to cold climate costs for those customers who are used to the performance of a gas furnace and expect a simialr level of comfort. Further costs can include a fee for upgrading electric service and community electric infrastructure, which can be substantial. There is a potential cost savings for not providing community gas infrastructure.
- The upfront additional cost of an electric house with a high efficiency 2-stage heat pump (non-inverter type, 18 SEER/9.3 HSPF) and 80-gallon heat pump water heater (3.75 UEF) compared to a baseline gas house (minimum efficiency natural gas equipment) is $4,745 in a warm climate (Houston) and $4,613 in a mixed climate (Baltimore).
- The upfront additional cost of an electric house with a high efficiency inverter heat pump and 80-gallon heat pump water heater (3.75 UEF) compared to a baseline gas house (minimum efficiency natural gas equipment) is $8,160 in a warm climate (Houston) and $8,131 in a mixed climate (Baltimore) (warm and mixed climates based on a 19 SEER/10 HSPF inverter heat pump system rated down to 7°F); for a cold climate, the additional cost ranges from $10,524 (19 SEER/10 HSPF inverter heat pump system rated down to -13°F) to $11,803 (20 SEER/13 HSPF inverter heat pump system). The higher costs in colder, heating dominated climates are due to the higher cost of heat pumps rated to operate in colder temperatures.
- In the colder climates (Denver and Minneapolis), the more expensive electric equipment also results in higher energy use costs by $84 to $404 annually compared to a baseline gas house, and by $238 to $650 annually compared to a gas house with high efficiency equipment. Therefore, in colder climates the consumer will be faced with higher upfront construction costs and higher operating costs throughout the life of the equipment.
- In the cooling dominated climate (Houston), the annual energy use cost for the electric house with a high efficiency heat pump and 80-gallon heat pump water heater (3.75 UEF) can be reduced by $154 (18 SEER/9.3 HSPF 2-stage heat pump) to $264 (19 SEER/10 HSPF inverter heat pump) compared to a baseline gas house, with simple payback of 27 years to 64 years. Compared to a gas house with high efficiency equipment, the annual energy cost ranges from an increase of $18 (18 SEER/9.3 HSPF 2-stage heat pump) to a savings of $85 (19 SEER/10 HSPF inverter heat pump), with simple payback of up to 93 years.
- In the mixed climate (Baltimore), the annual energy use cost for the electric house with a high efficiency heat pump and 80-gallon heat pump water heater (3.75 UEF) ranges from a savings of

$77 (18 SEER/9.3 HSPF 2-stage heat pump) to $184 (19 SEER/10 HSPF inverter heat pump) compared to a gas baseline house, with simple payback of 44 years to 60 years; however, when compared to a gas house with high efficiency gas equipment, the consumer is again faced with higher upfront construction cost and higher energy use cost.

- The incremental costs for high efficiency gas equipment options relative to a gas baseline are consistent across climates ranging between $892 and $2,140; the differences are due to house layout and cost adjustments by location; most payback periods are 10 years or less.
- The retrofit cost of electrification for an exisiting baseline gas house ranges between $24,282 and $28,491, not including the additional cost to substitute an induction cooktop ($1,091-1,157), install an electric vehicle charger circuit ($1,266-1,343), or install an electrical service upgrade (a potential substantial additonal cost in some cases). By comparison, the retrofit cost of gas equipment and applicances for an exisiting baseline gas house ranges between $9,767 and $10,359 using standard efficiency equipment, and between $12,658 and $13,425 using high efficiency equipment.
- The ratio of electricity price to natural gas price (each converted to $/Btu) is a significant factor for comparing the impact of electrification between locations with similar climatic characteristics. The higher the electric-to-gas price ratio, the more expensive it will be to operate electric equipment versus gas equipment.
- The median life expectancy of most gas equipment tends to be longer than electric counterparts: gas furnace (20 years) versus heat pump (15 years); tankless gas water heater (20 years) versus heat pump water heater (12 years); conventional gas and electric storage-type water heaters have about the same life expectancy (10-13 years).

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APPENDIX A: CONSTRUCTION COSTS

Construction costs were developed using RSMeans[30] 2020 Residential Cost Data and RSMeans 2020 Residential Repair & Remodeling Cost Data. Costs for mechanical equipment were sourced from distributor web sites[31].

Baseline Gas House

Component	Unit	Material	Labor	Total	w/O&P	Quantity	Cost
Gas Furnace, 80kBtuh, AFUE 80%	EA	761.00	157.00	918.00	1,092.70	1	1,093
Condenser, 3-ton, 13 SEER	EA	1,085.00	465.00	1,550.00	1,950.52	1	1,951
Evaporator coil	EA	439.00	183.00	622.00	780.82	1	781
Water heater, 50 gal gas, UEF 0.56	EA	559.00	162.00	721.00	878.64	1	879
Gas Chimney Vent, 4" dia.	LF	9.35	8.30	17.65	24.00	35	840
Gas Chimney Vent, 3" dia.	LF	7.60	7.85	15.45	21.50	4	86
Gas piping, 1" main	LF	7.80	6.15	13.95	18.60	25	465
Gas piping, 3/4" range	LF	4.40	5.30	9.70	13.55	20	271
Gas piping, 1/2" dryer, GF, WH	LF	4.03	5.15	9.18	12.90	30	387
Furnace circuit: disconnet, 40' #14/2 NM	EA	57.00	83.50	140.50	199.00	1	199
Wire, add 20' #14/2 NM (furnace)	LF	0.18	1.33	1.51	2.37	20	47
GFCI 15-amp, 1-pole breaker (furnace)	EA	41.99		41.99	46.19	1	46
Condenser circuit: disconnect, 40-amp 2-pole breaker, 40' #8/2 NM	EA	144.00	95.50	239.50	315.00	1	315
GFCI 30-amp 2-pole breaker (AC)	EA	124.99		124.99	137.49	1	137
Standard 30/40-amp 2-pole breaker (AC)	EA	10.65		10.65	11.72	(1)	(12)
Range circuit, 15-amp outlet & wiring	EA	8.90	23.00	31.90	47.50	1	48
Gas Range	EA	542.00	44.50	586.50	669.63	1	670
Gas Dryer	EA	528.00	170.00	698.00	861.30	1	861
Gas piping, street to meter, 1/2 polyethylene	LF	0.49	1.72	2.21	3.36	50	168
Excavate utility trench for gas piping	LF				0.68	50	34
Backfill utility trench for gas piping	LF				0.53	50	27
Gas service tap into main at street	EA				250.00	1	250
Set gas meter, by utility	EA					0	0
Total to Builder							**9,542**
Total to Consumer							**11,345**
Denver						1.05	**11,913**
Minneapolis						1.00	**11,345**

Baseline Gas House adjusted for Baltimore

Component	Unit	Material	Labor	Total	w/O&P	Quantity	Cost
Total to Builder, from above							**9,542**
Condenser, 3-ton, 14 SEER	EA	1,215.00		1,215.00	1,336.50	1	1,337
Condenser, 3-ton, 13 SEER	EA	1,085.00		1,085.00	1,193.50	(1)	(1,194)
Total to Builder							**9,685**
Total to Consumer							**11,515**
Baltimore						1.02	**11,746**

30 RSMeans, https://www.rsmeans.com/

31 Mechanical equipment cost sources include: hvacdirect.com; supplyhouse.com; acwholesalers.com; menards.com

Baseline Gas House adjusted for Houston

Component	Unit	Material	Labor	Total	w/O&P	Quantity	Cost
Total to Builder, from above							**9,542**
Condenser, 3-ton, 14 SEER	EA	1,215.00		1,215.00	1,336.50	1	1,337
Condenser, 3-ton, 13 SEER	EA	1,085.00		1,085.00	1,193.50	(1)	(1,194)
Gas Chimney Vent, 4" dia.	LF	9.35	8.30	17.65	24.00	10	240
Gas Chimney Vent, 4" dia.	LF	9.35	8.30	17.65	24.00	(35)	(840)
Gas piping, 1" main	LF	7.80	6.15	13.95	18.60	45	837
Gas piping, 1" main	LF	7.80	6.15	13.95	18.60	(25)	(465)
Total to Builder							**9,457**
Total to Consumer							**11,244**
Houston						0.99	**11,132**

Substitute 50-gallon gas natural draft water heater, 0.64 UEF

Component	Unit	Material	Labor	Total	w/O&P	Quantity	Cost
50 gal gas nat draft water heater, UEF 0.56	SF	559.00		559.00	614.90	(1)	(615)
50 gal gas nat draft water heater, UEF 0.64	SF	699.84		699.84	769.82	1	770
Total to Builder							**155**
Total to Consumer							**184**
Houston						0.99	**182**
Baltimore						1.02	**188**
Denver						1.05	**193**
Minneapolis						1.00	**184**

Substitute tankless gas direct vent water heater, 0.82 UEF

Component	Unit	Material	Labor	Total	w/O&P	Quantity	Cost
50 gal gas water heater, 0.56 UEF	EA	559.00	162.00	721.00	878.64	(1)	(879)
Tankless gas water heater, 0.82 UEF	EA	799.00	171.00	970.00	1,157.29	1	1,157
Concentric vent wall termination kit	EA	90.00		90.00	99.00	1	99
Concentric vent 39" extension	EA	37.59		37.59	41.35	1	41
Gas Chimney Vent, 3" dia. (WH connector)	LF	7.60	7.85	15.45	21.50	(4)	(86)
Gas piping, 1/2"	LF	2.16	5.15	7.31	12.90	(7)	(90)
Gas piping, 1"	LF	7.80	6.15	13.95	18.60	7	130
15-amp circuit, toggle, 40' #14/2 NM	EA	57.00	83.50	140.50	199.00	1	199
GFCI 15-amp, 1-pole breaker	EA	41.99		41.99	46.19	1	46
Total to Builder							**618**
Total to Consumer							**735**
Houston						0.99	**728**
Baltimore						1.02	**750**
Denver						1.05	**772**
Minneapolis						1.00	**735**

Substitute tankless gas direct vent condensing water heater, 0.93 UEF

Component	Unit	Material	Labor	Total	w/O&P	Quantity	Cost
50 gal gas water heater, 0.56 UEF	EA	559.00	162.00	721.00	878.64	(1)	(879)
Tankless gas water heater, 0.93 UEF	EA	1,039.00	171.00	1,210.00	1,421.29	1	1,421
Vent piping, PVC, 2" dia.	LF	3.45	2.97	6.42	8.65	20	173
2" PVC concentric vent kit	EA	22.49		22.49	24.74	1	25
Gas Chimney Vent, 3" dia. (WH connector)	LF	7.60	7.85	15.45	21.50	(4)	(86)
Gas piping, 1/2"	LF	2.16	5.15	7.31	12.90	(7)	(90)
Gas piping, 1"	LF	7.80	6.15	13.95	18.60	7	130
15-amp circuit, toggle, 40' #14/2 NM	EA	57.00	83.50	140.50	199.00	1	199
GFCI 15-amp, 1-pole breaker	EA	41.99		41.99	46.19	1	46
Total to Builder							**939**
Total to Consumer							**1,117**
Houston						0.99	**1,106**
Baltimore						1.02	**1,139**
Denver						1.05	**1,173**
Minneapolis						1.00	**1,117**

Substitute 96% AFUE gas furnace

Component	Unit	Material	Labor	Total	w/O&P	Quantity	Cost
Gas furnace, 80kBtuh, AFUE 80%	EA	761.00		761.00	837.10	(1)	(837)
Gas Chimney Vent, 4" dia.	LF	9.35	8.30	17.65	24.00	(35)	(840)
Gas Chimney Vent, 3" dia. (water heater)	LF	7.60	7.85	15.45	21.50	35	753
Gas furnace, 80kBtuh, AFUE 96%	EA	1,295.00		1,295.00	1,424.50	1	1,425
Vent piping, PVC, 2" dia.	LF	3.45	2.97	6.42	8.65	40	346
2" concentric vent kit	EA	59.95		59.95	65.95	1	66
Total to Builder							**912**
Total to Consumer							**1,084**
Baltimore						1.02	**1,106**
Denver						1.05	**1,138**
Minneapolis						1.00	**1,084**

Substitute 96% AFUE gas furnace adjusted for Houston

Component	Unit	Material	Labor	Total	w/O&P	Quantity	Cost
Gas furnace, 80kBtuh, AFUE 80%	EA	761.00		761.00	837.10	(1)	(837)
Gas Chimney Vent, 4" dia.	LF	9.35	8.30	17.65	24.00	(10)	(240)
Gas Chimney Vent, 3" dia. (water heater)	LF	7.60	7.85	15.45	21.50	10	215
Gas furnace, 80kBtuh, AFUE 96%	EA	1,295.00		1,295.00	1,424.50	1	1,425
Vent piping, PVC, 2" dia.	LF	3.45	2.97	6.42	8.65	40	346
2" concentric vent kit	EA	59.95		59.95	65.95	1	66
Total to Builder							**974**
Total to Consumer							**1,158**
Houston						0.99	**1,147**

Substitute 96% AFUE gas furnace and 16 SEER air conditioner

Component	Unit	Material	Labor	Total	w/O&P	Quantity	Cost
Gas furnace, 80kBtuh, AFUE 80%	EA	761.00		761.00	837.10	(1)	(837)
Gas Chimney Vent, 4" dia.	LF	9.35	8.30	17.65	24.00	(35)	(840)
Gas Chimney Vent, 3" dia. (water heater)	LF	7.60	7.85	15.45	21.50	35	753
Gas furnace, 80kBtuh, AFUE 96%	EA	1,295.00		1,295.00	1,424.50	1	1,425
Vent piping, PVC, 2" dia.	LF	3.45	2.97	6.42	8.65	40	346
2" concentric vent kit	EA	59.95		59.95	65.95	1	66
Condenser, 3 ton, 13 SEER	EA	1,085.00		1,085.00	1,193.50	(1)	(1,194)
Condenser, 3 ton, 16 SEER	EA	1,346.00		1,346.00	1,480.60	1	1,481
Total to Builder							**1,199**
Total to Consumer							**1,426**
Baltimore (adjusted for 14 SEER to 16 SEER)						1.02	**1,161**
Denver						1.05	**1,497**
Minneapolis						1.00	**1,426**

Substitute 96% AFUE gas furnace and 16 SEER air conditioner adjusted for Houston

Component	Unit	Material	Labor	Total	w/O&P	Quantity	Cost
Gas furnace, 80kBtuh, AFUE 80%	EA	761.00		761.00	837.10	(1)	(837)
Gas Chimney Vent, 4" dia.	LF	9.35	8.30	17.65	24.00	(10)	(240)
Gas Chimney Vent, 3" dia. (water heater)	LF	7.60	7.85	15.45	21.50	10	215
Gas furnace, 80kBtuh, AFUE 96%	EA	1,295.00		1,295.00	1,424.50	1	1,425
Vent piping, PVC, 2" dia.	LF	3.45	2.97	6.42	8.65	40	346
2" concentric vent kit	EA	59.95		59.95	65.95	1	66
Condenser, 3 ton, 14 SEER	EA	1,215.00		1,215.00	1,336.50	(1)	(1,337)
Condenser, 3 ton, 16 SEER	EA	1,346.00		1,346.00	1,480.60	1	1,481
Total to Builder							**1,118**
Total to Consumer							**1,330**
Houston						0.99	**1,317**

Substitute 97% AFUE modulating gas furnace and 16 SEER air conditioner

Component	Unit	Material	Labor	Total	w/O&P	Quantity	Cost
Gas furnace, 80kBtuh, AFUE 80%	EA	761.00		761.00	837.10	(1)	(837)
Gas Chimney Vent, 4" dia.	LF	9.35	8.30	17.65	24.00	(35)	(840)
Gas Chimney Vent, 3" dia. (water heater)	LF	7.60	7.85	15.45	21.50	35	753
Gas furnace, 80kBtuh, AFUE 97	EA	2,106.00		2,106.00	2,316.60	1	2,317
Vent piping, PVC, 2" dia.	LF	3.45	2.97	6.42	8.65	40	346
2" concentric vent kit	EA	59.95		59.95	65.95	1	66
Condenser, 3 ton, 13 SEER	EA	1,085.00		1,085.00	1,193.50	(1)	(1,194)
Condenser, 3 ton, 16 SEER	EA	1,346.00		1,346.00	1,480.60	1	1,481
Total to Builder							**2,091**
Total to Consumer							**2,486**
Baltimore (adjusted for 14 SEER to 16 SEER)						1.02	**2,243**
Denver						1.05	**2,611**
Minneapolis						1.00	**2,486**

Substitute 97% AFUE modulating gas furnace and 16 SEER air conditioner adjusted for Houston

Component	Unit	Material	Labor	Total	w/O&P	Quantity	Cost
Gas furnace, 80kBtuh, AFUE 80%	EA	761.00		761.00	837.10	(1)	(837)
Gas Chimney Vent, 4" dia.	LF	9.35	8.30	17.65	24.00	(10)	(240)
Gas Chimney Vent, 3" dia. (water heater)	LF	7.60	7.85	15.45	21.50	10	215
Gas furnace, 80kBtuh, AFUE 96%	EA	2,106.00		2,106.00	2,316.60	1	2,317
Vent piping, PVC, 2" dia.	LF	3.45	2.97	6.42	8.65	40	346
2" concentric vent kit	EA	59.95		59.95	65.95	1	66
Condenser, 3 ton, 14 SEER	EA	1,215.00		1,215.00	1,336.50	(1)	(1,337)
Condenser, 3 ton, 16 SEER	EA	1,346.00		1,346.00	1,480.60	1	1,481
Total to Builder							**2,011**
Total to Consumer							**2,391**
Houston						0.99	**2,367**

Adjustment for installing a gas tankless water heater AND a 90+ AFUE furnace

Component	Unit	Material	Labor	Total	w/O&P	Quantity	Cost
Gas Chimney Vent, 4" dia. (furnace)	LF	9.35	8.30	17.65	24.00	(35)	(840)
Total to Builder							**(840)**
Total to Consumer							**(999)**
Baltimore						1.02	**(1,019)**
Denver						1.05	**(1,049)**
Minneapolis						1.00	**(999)**

Adjustment for installing a gas tankless water heater AND a 90+ AFUE furnace for Houston

Component	Unit	Material	Labor	Total	w/O&P	Quantity	Cost
Gas Chimney Vent, 4" dia. (furnace)	LF	9.35	8.30	17.65	24.00	(10)	(240)
Total to Builder							**(240)**
Total to Consumer							**(285)**
Houston						0.99	**(283)**

Electric Minimum Efficiency House

Component	Unit	Material	Labor	Total	w/O&P	Quantity	Cost
Heat Pump, 3-ton, 14 SEER 8.2 HSPF	EA	1,629.00	527.50	2,156.50	2,650.67	1	2,651
Air Handler, matching	EA	988.00	195.00	1,183.00	1,404.26	1	1,404
Air Handler electric heat, 15 kW	EA	164.00	42.00	206.00	248.78	1	249
Water Heater, 50 gal elec	EA	419.00	162.00	581.00	728.20	1	728
Heat Pump circuits: 40A & 100A breakers, disconnects, 40' #8/2 & 30' #3/2 NM	EA	520.00	257.00	777.00	995.00	1	995
Wire, add 30' #3/2 NM (AH)	LF	3.20	3.18	6.38	8.70	30	261
GFCI 30-amp 2-pole breaker (HP & AH)	EA	124.99		124.99	137.49	2	275
Standard 30/40-amp 2-pole breaker (HP)	EA	10.65		10.65	11.72	(1)	(12)
GFCI 50/60-amp 2-pole breaker (AH)	EA	149.00		149.00	163.90	1	164
Water Heater circuit: breaker, disconnect, 20' #10/2 NM	EA	29.00	66.50	95.50	141.00	1	141
Wire, add 40' #10/2 NM (WH)	LF	0.45	1.67	2.12	3.20	40	128
GFCI 30-amp 2-pole breaker (WH)	EA	124.99		124.99	137.49	1	137
Standard 30/40-amp 2-pole breaker (WH)	EA	10.65		10.65	11.72	(1)	(12)
Range circuit, 50-amp recep., 30' #8/3 NM	EA	82.50	79.00	161.50	220.00	1	220
Wire, add 30' #8/3 NM (range)	LF	1.17	2.57	3.74	5.45	30	164
GFCI 50/60-amp 2-pole breaker (range)	EA	149.00		149.00	163.90	1	164
Dryer circuit: 30-amp recep., breaker, 20' #10/3 NM	EA	54.50	52.00	106.50	145.00	1	145
Wire, add 40' #10/3 NM (dryer)	LF	0.66	2.38	3.04	4.61	40	184
GFCI 30-amp 2-pole breaker (dryer)	EA	124.99		124.99	137.49	1	137
Standard 30/40-amp 2-pole breaker (dryer)	EA	10.65		10.65	11.72	(1)	(12)
Electric Range, 30", freestanding, min.	EA	529.00	44.50	573.50	655.33	1	655
Electric Dryer, front load, energy-star, min.	EA	428.00	170.00	598.00	751.30	1	751
Total to Builder							**9,519**
Total to Consumer							**11,318**
Houston						0.99	**11,205**
Baltimore						1.02	**11,545**
Denver						1.05	**11,884**
Minneapolis						1.00	**11,318**

Substitute 50-gallon heat pump water heater, 3.25 UEF

Component	Unit	Material	Labor	Total	w/O&P	Quantity	Cost
50 gal electric water heater	EA	419.00	162.00	581.00	728.20	(1)	(728)
Heat pump water heater, 50 gal, 3.25 UEF	EA	1,199.00	162.00	1,361.00	1,586.20	1	1,586
Mixing valve	EA	167	16.25	183.25	210	1	210
Total to Builder							**1,068**
Total to Consumer							**1,270**
Houston						0.99	**1,257**
Baltimore						1.02	**1,295**
Denver						1.05	**1,333**
Minneapolis						1.00	**1,270**

Substitute 80-gallon heat pump water heater, 3.25 UEF

Component	Unit	Material	Labor	Total	w/O&P	Quantity	Cost
50 gal electric water heater	EA	419.00	162.00	581.00	728.20	(1)	(728)
Heat pump water heater, 80 gal, 3.25 UEF	EA	1,999.00	203.00	2,202.00	2,533.85	1	2,534
Mixing valve	EA	167	16.25	183.25	210	1	210
Total to Builder							**2,016**
Total to Consumer							**2,397**
Houston						0.99	**2,373**
Baltimore						1.02	**2,445**
Denver						1.05	**2,516**
Minneapolis						1.00	**2,397**

Substitute 80-gallon heat pump water heater, 3.75 UEF

Component	Unit	Material	Labor	Total	w/O&P	Quantity	Cost
50 gal electric water heater	EA	419.00	162.00	581.00	728.20	(1)	(728)
Heat pump water heater, 80 gal, 3.75 UEF	EA	2,199.00	203.00	2,402.00	2,753.85	1	2,754
Mixing valve	EA	167	16.25	183.25	210	1	210
Total to Builder							**2,236**
Total to Consumer							**2,658**
Houston						0.99	**2,632**
Baltimore						1.02	**2,711**
Denver						1.05	**2,791**
Minneapolis						1.00	**2,658**

Substitute heat pump system with two-stage compressor, 18 SEER, 9.3 HSPF

Component	Unit	Material	Labor	Total	w/O&P	Quantity	Cost
Heat Pump, 14 SEER 8.2 HSPF	EA	1,629.00		1,629.00	1,791.90	(1)	(1,792)
Air Handler, matching	EA	988.00		988.00	1,086.80	(1)	(1,087)
Heat Pump 2-stage 18 SEER 9.3 HSPF	EA	2,994.00		2,994.00	3,293.40	1	3,293
Air Handler, matching	EA	1,199.00		1,199.00	1,318.90	1	1,319
Total to Builder							**1,734**
Total to Consumer							**2,061**
Houston						0.99	**2,041**
Baltimore						1.02	**2,102**
Denver						1.05	**2,164**
Minneapolis						1.00	**2,061**

Substitute heat pump system with variable speed inverter compressor, rated to 7°F, 19 SEER, 10 HSPF

Component	Unit	Material	Labor	Total	w/O&P	Quantity	Cost
Heat Pump, 14 SEER 8.2 HSPF	EA	1,629.00		1,629.00	1,791.90	(1)	(1,792)
Air Handler, matching	EA	988.00		988.00	1,086.80	(1)	(1,087)
Heat Pump inverter system, rated down to 7°F, 19 SEER 10 HSPF	EA	6,830.00		6,830.00	7,513.00	1	7,513
Total to Builder							**4,634**
Total to Consumer							**5,510**
Houston						0.99	**5,455**
Baltimore						1.02	**5,620**
Denver						1.05	**5,786**
Minneapolis						1.00	**5,510**

Substitute heat pump system with variable speed inverter compressor, rated to -13°F, 19 SEER, 10 HSPF

Component	Unit	Material	Labor	Total	w/O&P	Quantity	Cost
Heat Pump, 14 SEER 8.2 HSPF	EA	1,629.00		1,629.00	1,791.90	(1)	(1,792)
Air Handler, matching	EA	988.00		988.00	1,086.80	(1)	(1,087)
Heat Pump inverter system, rated down to -13°F, 19 SEER 10 HSPF	EA	8,652.00		8,652.00	9,517.20	1	9,517
Total to Builder							**6,639**
Total to Consumer							**7,893**
Houston						0.99	**7,814**
Baltimore						1.02	**8,051**
Denver						1.05	**8,288**
Minneapolis						1.00	**7,893**

Substitute heat pump system with variable speed inverter compressor, 20 SEER, 13 HSPF

Component	Unit	Material	Labor	Total	w/O&P	Quantity	Cost
Heat Pump 3-ton 14 SEER 8.2 HSPF	EA	1,629.00		1,629.00	1,791.90	(1)	(1,792)
Air Handler, matching	EA	988.00		988.00	1,086.80	(1)	(1,087)
Heat Pump system 20 SEER 13 HSPF, est.	EA	8,700.00		8,700.00	9,570.00	1	9,570
Heat Pump required controller, est.	EA	500.00		500.00	550.00	1	550
Total to Builder							**7,241**
Total to Consumer							**8,610**
Houston						0.99	**8,524**
Baltimore						1.02	**8,782**
Denver						1.05	**9,040**
Minneapolis						1.00	**8,610**

Construction Cost for Electric Vehicle (EV) Charger Circuit

Component	Unit	Material	Labor	Total	w/O&P	Quantity	Cost
40-amp circuit, breaker, disconnect, 40' #8/2	EA	144.00	95.50		315.00	1	315
GFCI 40-amp 2-pole breaker	EA	124.99			137.49	1	137
Standard 40-amp 2-pole breaker	EA	10.87			11.96	(1)	(12)
Receptacle, NEMA 6-50	EA	13.34			14.67	1	15
Weatherproof while-in-use cover	EA	12.98			14.28	1	14
Wire, #8/2, additional	LF	1.17	2.57		5.45	10	55
Total to Builder							**524**
Total to Consumer							**623**
Houston						0.99	**617**
Baltimore						1.02	**635**
Denver						1.05	**654**
Minneapolis						1.00	**623**

Construction Cost for Adding a 100-amp Electric Panel

Component	Unit	Material	Labor	Total	w/O&P	Quantity	Cost
100-amp load center with 8 1-pole breakers	EA	164.00	244.00	408.00	575.00	1	575
15/20-amp 1-pole breakers	EA	8.88			9.77	(8)	(78)
100-amp 2-pole breaker	EA	86.50	57.00	143.50	188.00	1	188
Total to Builder							**685**
Total to Consumer							**814**
Houston						0.99	**806**
Baltimore						1.02	**831**
Denver						1.05	**855**
Minneapolis						1.00	**814**

Construction Cost to Substitute an Electric Range with an Induction Cooktop

Component	Unit	Material	Labor	Total	w/O&P	Quantity	Cost
Electric Range, standard	EA	529.00		529.00	581.90	(1)	(582)
Electric Range, with induction cooktop	EA	1,299.00		1,299.00	1,428.90	1	1,429
Total to Remodeler							**847**
Total to Consumer							**1,007**
Houston						0.99	**997**
Baltimore						1.02	**1,027**
Denver						1.05	**1,057**
Minneapolis						1.00	**1,007**

Substitute ductless cold climate heat pump for Climate Zones 4-6:
6-head system (4 on second floor, 1 on first floor, 1 in basement), 19 SEER 11 HSPF

Component	Unit	Material	Labor	Total	w/O&P	Quantity	Cost
Heat Pump, 3-ton, SEER 14	EA	1,629.00	527.50	2,156.50	2,650.67	(1)	(2,651)
Air Handler, 3-ton coil	EA	988.00	195.00	1,183.00	1,404.26	(1)	(1,404)
Air Handler electric heat, 15 kW	EA	164.00	42.00	206.00	248.78	(1)	(249)
Refrigerant piping	EA	204.00	21.50	225.50	261.00	(1)	(261)
Duct distribution system, all metal	LB	0.54	3.45	3.99	6.30	(702)	(4,423)
Registers	EA	17.20	12.10	29.30	39.00	(16)	(624)
Grilles	EA	43.50	17.45	60.95	77.00	(3)	(231)
Ductless 4-zone system 19 SEER 11 HSPF	EA	5,644.00		5,644.00	6,208.40	1	6,208
Ductless 2-zone system	EA	4,466.00		4,466.00	4,912.60	1	4,913
Ductless, installation	EA	50.00	355.00	405.00	632.94	6	3,798
Ductless refrigerant piping/wiring kit	EA	279.50	30.00	309.50	356.29	6	2,138
Condensate piping, 3/4 PVC	LF	1.30	2.54	3.84	5.60	120	672
Heat Pump circuits: 40A & 100A breakers, disconnects, 40' #8/2 & 30' #3/2 NM	EA	520.00	257.00	777.00	995.00	(1)	(995)
Wire, add 30' #3/2 NM (AH)	LF	3.20	3.18	6.38	8.70	(30)	(261)
GFCI 30-amp 2-pole breaker (HP & AH)	EA	124.99		124.99	137.49	(2)	(275)
Standard 30/40-amp 2-pole breaker (HP)	EA	10.65		10.65	11.72	1	12
GFCI 50/60-amp 2-pole breaker (AH)	EA	149.00		149.00	163.90	(1)	(164)
Condenser circuit: disconnect, 40-amp 2-pole breaker, 40' #8/2 NM	EA	144.00	95.50	239.50	315.00	2	630
GFCI 30/40amp 2-pole breaker	EA	124.99		124.99	137.49	2	275
Standard 30/40-amp 2-pole breaker	EA	10.65		10.65	11.72	(2)	(23)
Wire, add #8/2 NM for HP	LF	1.17	2.57	3.74	5.45	40	218
	LF						
Total to Builder							**7,302**
Total to Consumer							**8,683**
Houston						0	**0**
Baltimore						1.02	**8,856**
Denver						1.05	**9,117**
Minneapolis						1.00	**8,683**

Substitute ductless heat pump for Climate Zone 2 (slab-on-grade foundation): 5-head system (4 on second floor, 1 on first floor), 19 SEER 11 HSPF

Component	Unit	Material	Labor	Total	w/O&P	Quantity	Cost
Total to builder cost from above							7,302
Ducts, all metal	LB	0.54	3.45	3.99	6.30	702	4,423
Duct board plenums & junction boxes	SF	3.82	4.43	8.25	11.65	(54)	(629)
Supply branch flex duct	LF	3.61	2.17	5.78	7.55	(300)	(2,265)
Supply & return trunk flex duct	LF	6.05	5.65	11.70	16.05	(70)	(1,124)
Ductless 4-zone cold climate	EA	5,644.00		5,644.00	6,208.40	(1)	(6,208)
Ductless 4-zone	EA	4,772.00		4,772.00	5,249.20	1	5,249
Ductless 2-zone cold climate	EA	4,466.00		4,466.00	4,912.60	(1)	(4,913)
Ductless 1-zone	EA	2,289.00		2,289.00	2,517.90	1	2,518
Ductless, labor, 3/4 ton wall mount	EA	50.00	355.00	405.00	632.94	(1)	(633)
Ductless refrigerant piping/wiring kit	EA	279.50	30.00	309.50	356.29	(1)	(356)
Condensate piping, 3/4 PVC	LF	1.30	2.54	3.84	5.60	(10)	(56)
Total to Builder							**3,308**
Total to Consumer							**3,934**
Houston						0.99	**3,894**

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APPENDIX B: ELECTRIFICATION RETROFIT COSTS

Retrofit Cost of Electrification for an Existing Gas Baseline House – Climate Zones 2 & 4

Component	Unit	Material	Labor	Total	w/O&P	Quantity	Cost
Demo gas furnace	EA		141.00	141.00	234.00	1	234
Demo condenser & coil	EA		300.00	300.00	495.00	1	495
Remove refrigerant from system	LB		8.40	8.40	13.75	5	69
Demo gas water heater	EA		124.00	124.00	204.00	1	204
Heat Pump system 19 SEER 10 HSPF rated 7F	EA	6,830.00		6,830.00	7,513.00	1	7,513
Heat Pump, Labor	EA		500.00	500.00	825.00	1	825
Air Handler, Labor	EA		461.00	461.00	760.00	1	760
Air Handler electric heat, 15 kW	EA	164.00	42.00	206.00	248.78	1	249
Refrigerant piping	EA	204.00	21.50	225.50	261.00	1	261
Heat pump misc materials, est.	EA	200.00		200.00	220.00	1	220
Heat pump water heater, 80 gal, 3.75 UEF	EA	2,199.00		2,199.00	2,418.90	1	2,419
Heat pump water heater labor	EA		200.00	200.00	330.00	1	330
Water heater, mixing valve	EA	167.00	16.25	183.25	210.00	1	210
Water heater misc materials, est.	EA	100.00		100.00	110.00	1	110
Heat pump/air handler circuits: 40A/100A breakers, disconnects, 40' #8/2, 30' #3/2 NM	EA	520.00	257.00	777.00	995.00	1	995
Condenser circuit: disconnect, 40-amp 2-pole breaker, 40' #8/2 NM	EA	144.00	95.50	239.50	315.00	(1)	(315)
Air handler wire, add 30' #3/2 NM	LF	3.20	3.18	6.38	8.70	30	261
Air handler GFCI 30-amp 2-pole breaker	EA	124.99		124.99	137.49	1	137
Air handler GFCI 50/60-amp 2-pole breaker	EA	149.00		149.00	163.90	1	164
Water Heater circuit: breaker, disconnect, 20' #10/2 NM	EA	29.00	66.50	95.50	141.00	1	141
Water heater wire, add 40' #10/2 NM	LF	0.45	1.67	2.12	3.20	40	128
Water heater GFCI 30-amp 2-pole breaker	EA	124.99		124.99	137.49	1	137
Water heater standard 30-amp 2-pole breaker	EA	10.65		10.65	11.72	(1)	(12)
Range circuit, 50-amp recep., 30' #8/3 NM	EA	82.50	79.00	161.50	220.00	1	220
Range, wire, add 30' #8/3 NM	LF	1.17	2.57	3.74	5.45	30	164
Range GFCI 50/60-amp 2-pole breaker	EA	149.00		149.00	163.90	1	164
Dryer circuit: 30-amp recep., breaker, 20' #10/3 NM	EA	54.50	52.00	106.50	145.00	1	145
Dryer, wire, add 40' #10/3 NM	LF	0.66	2.38	3.04	4.61	40	184
Dryer, GFCI 30-amp 2-pole breaker	EA	124.99		124.99	137.49	1	137
Dryer, standard 30/40-amp 2-pole breaker	EA	10.65		10.65	11.72	(1)	(12)
Electric Range, 30", standard, remove/install	EA	529.00	67.00	596.00	692.45	1	692
Electric Dryer, standard, remove/install	EA	428.00	181.00	609.00	769.45	1	769
Drywall repair, 1 SF area patch, labor & material	EA				65.52	10	655.20
Drywall paint, minimum charge	EA				197.00	1	197.00
Total to Remodeler							**18,852**
Total to Consumer							**24,527**
Houston						0.99	**24,282**
Baltimore						1.02	**25,017**

Retrofit Cost of Electrification for an Existing Gas Baseline House – Climate Zones 5 & 6

Component	Unit	Material	Labor	Total	w/O&P	Quantity	Cost
Total to builder, from table above							18,852
Heat Pump system 19 SEER 10 HSPF rated 7F	EA	6,830.00		6,830.00	7,513.00	(1)	(7,513)
Heat Pump system 19 SEER 10 HSPF rated -13F	EA	8,652.00		8,652.00	9,517.20	1	9,517
Total to Remodeler							**20,856**
Total to Consumer							**27,134**
Denver						1.05	**28,491**
Minneapolis						1.00	**27,134**

Retrofit Cost to Install an Electric Vehicle (EV) Charger Circuit

Component	Unit	Material	Labor	Total	w/O&P	Quantity	Cost
40-amp circuit, breaker, disconnect, 40' #8/2	EA	144.00	95.50		315.00	1	315
GFCI 40-amp 2-pole breaker	EA	124.99			137.49	1	137
Standard 40-amp 2-pole breaker	EA	10.87			11.96	(1)	(12)
Receptacle, NEMA 6-50	EA	13.34			14.67	1	15
Weatherproof while-in-use cover	EA	12.98			14.28	1	14
Wire, #8/2, additional	LF	1.17	2.57		5.45	10	55
Drywall repair, 1 SF area patch, labor & material	EA				65.52	4	262
Drywall paint, minimum charge	EA				197.00	1	197
Total to Remodeler							**983**
Total to Consumer							**1,279**
Houston						0.99	**1,266**
Baltimore						1.02	**1,305**
Denver						1.05	**1,343**
Minneapolis						1.00	**1,279**

Retrofit Incremental Cost to Substitute an Electric Range with Induction Cooktop

Component	Unit	Material	Labor	Total	w/O&P	Quantity	Cost
Electric Range, standard	EA	529.00		529.00	581.90	(1)	(582)
Electric Range, with induction cooktop	EA	1,299.00		1,299.00	1,428.90	1	1,429
Total to Remodeler							**847**
Total to Consumer							**1,102**
Houston						0.99	**1,091**
Baltimore						1.02	**1,124**
Denver						1.05	**1,157**
Minneapolis						1.00	**1,102**

Retrofit Cost of Gas Equipment and Appliances for an Existing Gas Baseline House: 80 AFUE GF; 14 SEER AC; 50 gal 0.56 UEF WH

Component	Unit	Material	Labor	Total	w/O&P	Quantity	Cost
Demo and Install GF, labor	EA				377.00	1	377
Demo and Install AC system, labor	EA				943.00	1	943
Demo and Install WH, labor	EA				499.00	1	499
Reclaim old refrigerant	LB		8.40	8.40	13.75	5	69
Install new Refrigerant piping	EA	204.00	21.50	225.50	261.00	1	261
GF materials, est.	EA	200.00		200.00	220.00	1	220
AC materials, est.	EA	200.00		200.00	220.00	1	220
WH materials, est.	EA	100.00		100.00	110.00	1	110
80 AFUE GF	EA	761.00		761.00	837.10	1	837
14 SEER AC	EA	1,215.00		1,215.00	1,336.50	1	1,337
Coil	EA	439.00		439.00	482.90	1	483
50 gal gas 0.56 UEF WH	EA	559.00		559.00	614.90	1	615
Remove and install range, labor	EA				138.00	1	138
Remove and install dyer, labor	EA				297.90	1	298
Gas Range	EA	542.00		542.00	596.20	1	596
Gas Dryer	EA	528.00		528.00	580.80	1	581
Total to Remodeler							**7,583**
Total to Consumer							**9,866**
Houston						0.99	**9,767**
Baltimore						1.02	**10,063**
Denver						1.05	**10,359**
Minneapolis						1.00	**9,866**

Retrofit Cost of Gas Equipment and Appliances for an Existing Gas Baseline House:
96 AFUE GF; 16 SEER AC; Tankless Condensing 0.93 UEF WH

Component	Unit	Material	Labor	Total	w/O&P	Quantity	Cost
Demo and Install GF, labor	EA				377.00	1	377
Demo and Install AC system, labor	EA				943.00	1	943
Demo and Install WH, labor	EA				499.00	1	499
Reclaim old refrigerant	LB		8.40	8.40	13.75	5	69
Install new Refrigerant piping	EA	204.00	21.50	225.50	261.00	1	261
GF materials, est.	EA	200.00		200.00	220.00	1	220
AC materials, est.	EA	200.00		200.00	220.00	1	220
WH materials, est.	EA	100.00		100.00	110.00	1	110
96 AFUE GF	EA	1,295.00		1,295.00	1,424.50	1	1,425
GF Vent piping, PVC, 2" dia.	LF	3.45	2.97	6.42	8.65	40	346
GF 2" concentric vent kit	EA	59.95		59.95	65.95	1	66
16 SEER AC	EA	1,346.00		1,346.00	1,480.60	1	1,481
Coil	EA	439.00		439.00	482.90	1	483
Tankless condensing 0.93 UEF WH	EA	1,039.00		1,039.00	1,142.90	1	1,143
WH Vent piping, PVC, 2" dia.	LF	3.45	2.97	6.42	8.65	20	173
WH 2" PVC concentric vent kit	EA	22.49		22.49	24.74	1	25
WH Gas piping, 1"	LF	7.80	6.15	13.95	18.60	7	130
WH 15-amp circuit, toggle, 40' #14/2 NM	EA	57.00	83.50	140.50	199.00	1	199
WH GFCI 15-amp, 1-pole breaker	EA	41.99		41.99	46.19	1	46
Remove and install range, labor	EA				138.00	1	138
Remove and install dyer, labor	EA				297.90	1	298
Gas Range	EA	542.00		542.00	596.20	1	596
Gas Dryer	EA	528.00		528.00	580.80	1	581
Total to Remodeler							**9,828**
Total to Consumer							**12,786**
Houston						0.99	**12,658**
Baltimore						1.02	**13,041**
Denver						1.05	**13,425**
Minneapolis						1.00	**12,786**

APPENDIX C: LOCATION ADJUSTMENT FACTORS

State	City	Cost Adjustment Factor	State	City	Cost Adjustment Factor
Alabama	Birmingham	0.96	Montana	Billings	1.01
Alabama	Mobile	0.94	Nebraska	Omaha	0.99
Alaska	Fairbanks	1.29	Nevada	Las Vegas	1.00
Arizona	Phoenix	0.99	New Hampshire	Portsmouth	0.93
Arizona	Tucson	0.96	New Jersey	Jersey City	0.95
Arkansas	Little Rock	0.96	New Mexico	Albuquerque	1.00
California	Alhambra	1.00	New York	Long Island City	1.02
California	Los Angeles	0.99	New York	Syracuse	0.99
California	Riverside	0.98	North Carolina	Charlotte	0.97
California	Stockton	1.00	North Carolina	Hickory	0.93
Colorado	Boulder	1.04	North Carolina	Raleigh	0.96
Colorado	Colorado Springs	1.00	North Dakota	Fargo	0.99
Colorado	Denver	1.05	Ohio	Columbus	0.99
Connecticut	New Haven	1.01	Oklahoma	Oklahoma City	0.97
Delaware	Dover	0.97	Oklahoma	Tulsa	0.98
District of Columbia	Washington, D.C.	0.99	Oregon	Bend	1.03
Florida	Fort Meyers	0.92	Pennsylvania	Norristown	0.90
Florida	Miami	0.96	Pennsylvania	State College	0.92
Florida	Orlando	0.97	Rhode Island	Providence	0.99
Florida	Tampa	0.95	South Carolina	Greenville	0.93
Georgia	Atlanta	0.98	South Dakota	Sioux Falls	0.99
Hawaii	Honolulu	1.19	Tennessee	Memphis	0.99
Idaho	Boise	0.98	Texas	Austin	0.95
Illinois	Chicago	1.00	Texas	Dallas	0.98
Indiana	Indianapolis	1.00	Texas	Houston	0.99
Iowa	Des Moines	0.96	Texas	San Antonio	0.98
Kansas	Wichita	0.98	Utah	Ogden	0.95
Kentucky	Louisville	0.94	Utah	Provo	0.97
Louisiana	Baton Rouge	0.99	Utah	Salt Lake City	0.98
Maine	Portland	0.99	Vermont	Burlington	1.01
Maryland	Baltimore	1.02	Virginia	Fairfax	0.94
Massachusetts	Boston	1.02	Virginia	Winchester	0.94
Michigan	Ann Arbor	0.96	Washington	Tacoma	1.02
Minnesota	Minneapolis	1.00	West Virginia	Charleston	0.96
Mississippi	Biloxi	0.98	Wisconsin	La Crosse	0.93
Missouri	Springfield	0.95	Wyoming	Casper	1.00
*Source: RSMeans *Residential Cost Data 2020*. Sample cities are listed in this table; check RSMeans for additional locations.					

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APPENDIX D: REFERENCE HOUSE

Reference House Characteristics

The Reference House for this study is based on similar reference houses and site locations that were initially defined in a report by Home Innovation titled "Estimated Costs of the 2015 Code Changes"[32]; additional details from this report are provided below in the section Reference House Characteristics – Previous Studies.

The features and construction details of the standard Reference House for this study are shown in the tables below.

Reference House Features

Reference House Construction	Feature
Stories above grade	2
Bedrooms	4
Conditioned floor area, slab-on-grade houses, SF	2,600
Conditioned floor area, basement houses, SF	3,680
1st floor area: 40' wide x 38' deep - (20'x22' garage)	1,080
2nd floor area: 40' wide x 38' deep	1,520
Ceiling height, first floor, ft.	9
Ceiling height, second floor, ft.	8
Walls, gross area above grade excluding rim and gable, SF	2,652
Window area, SF (model 90 SF per side)	360
Foundation, slab-on-grade	CZ 2
Foundation, basement	CZ 4-6
Foundation perimeter, LF	156
Attic, below 7:12 slope roof	Vented

Reference House Construction Details

	CZ 2 Houston		CZ 4 Baltimore		CZ 5 Denver		CZ 6 Minneapolis	
Reference House Modeling Inputs	**2018 IECC**	**2021 IECC***	**2018 IECC**	**2021 IECC***	**2018 IECC**	**2021 IECC***	**2018 IECC**	**2021 IECC***
Walls: 2x4-16oc (CZ2-5); 2x6-16oc (CZ6)	R13		R13+5	R13+10	R13+5	R13+10	R20+5	
Slab-on-grade (CZ2)	R0		na		na		na	
Basement walls, 8' high, 1' above grade	na		R13		R19		R19	
Ceiling, plus radiant barrier in CZ2	R38	R49	R49	R60	R49	R60	R49	R60
Floors over garage	R13		R19		R30		R30	
Windows, U-factor	0.40		0.32		0.30		0.30	
Windows, SHGC (where NR, use 0.40)	0.25		0.40		NR	0.40	NR	
Interior shade fraction: 0.92-(0.21*SHGC)	0.87		0.84		0.84		0.84	
External shading	none		none		none		none	
House tightness, ACH50	5		3		3		3	
Ducts, furnace, WH location	attic		basement		basement		basement	
Ducts in attic, % (where in attic)	70		na		na		na	
Duct leakage, CFM25/100sf	4		4		4		4	
Mechanical ventilation, CFM	64		75		75		75	
Thermostat set points, heating/cooling	72/75		72/75		72/75		72/75	
*2021 IECC value is shown only where different than the 2018 IECC value								

[32] Estimated Costs of the 2015 Code Changes, Home Innovation Research Labs. https://www.homeinnovation.com/trends_and_reports/featured_reports/estimated_costs_of_the_2015_irc_code_changes

Modeling Results of Unmet Showers for Heat Pump Water Heaters

Heat Pump Water Heater	Unmet Showers per Beopt software			
	Houston	Baltimore	Denver	Minneapolis
50 gal at 125F	4.5%	9.5%	11.0%	13.0%
50 gal at 140F	0.0%	0.0%	0.9%	2.0%
80 gal at 125F	0.0%	1.2%	2.0%	3.2%
80 gal at 140F	0.0%	0.0%	0.0%	0.0%

The Reference Houses are assumed to have a 200-amp electrical service and panel. To determine if adding one electric vehicle (EV) charger circuit would drive the need to upgrade the electrical service, a load calculation was performed on an all-electric Reference House with a finished basement. The calculation is shown in the table below. The result shows that an electrical service upgrade is not required for adding one 40-amp EV charger circuit. Further, the 200-amp service could accommodate one 50-amp EV charger circuit, or a 20 kW supplemental heater for the heat pump system (the Reference House utilizes a 15 kW supplemental heater), but not both. An electrical service upgrade would be required for a second EV charger circuit and at some point, for a larger house or a house with additional electric loads such as a well, swimming pool, or electric baseboard heaters.

Electric Service Load for an Electric Reference House

Electrical Service Load Calculation, 2017 NEC 220.82

Electrical Load Component	kVA
Lighting & general use, 0.003kVA/SF floor area including basement	11.0
Small appliance circuits	3.0
Laundry circuit	1.5
Range (oven and cooktop)	10.0
Water heater	4.5
Dishwasher	1.2
Dryer	5.0
Refrigerator	1.5
Sub-total	**37.7**
100% of first 10 kVA	10.00
40% of balance	11.08
Heat Pump & Air Handler, manufacturer product data for 3-ton, 14 SEER system	4.22
Supplemental heat, 65% of 15kW	9.75
Total, without electric vehicle (EV) circuit	35.05
EV Charger, Level 2, 40-amp circuit, 6.2-7.6 kW	7.60
Total load (177.7-amps at 240-volts)	**42.65**
Total available (200-amps x 240-volts)	**48.00**

Reference House Characteristics – Previous Studies

For earlier studies by Home Innovation, baseline metrics were defined for four representative single-family houses, built to the IRC, to determine the cost impact of any code changes. The Reference Houses and their site locations were initially defined in a report titled "Estimated Costs of the 2015 Code Changes" prepared by Home Innovation for NAHB. These single-family houses were selected for their similarity to new home offerings in the six metropolitan areas selected as site locations – Miami, Dallas, Los Angeles, Seattle, New York, and Chicago, and their size proximity to a national average of 2,607 SF. Features of the Reference Houses are summarized in the next section.

The four residential building designs are based on the data contained in the Census Bureau report, *Characteristics of New Single-Family Construction Completed*[33]. The report provides information about building foundation type and number of stories for new single-family detached construction over the previous nine-year period.

New Construction Foundation Types

Slab	54%
Crawlspace	17%
Basement	30%

New Construction Number of Stories

One-story	53%
Two-story	43%
Three-story	3%

The Census data supports defining the four reference houses as follows to encompass approximately 85% of the last decade's new single-family construction:

- One-story on slab foundation
- Two-story on slab foundation
- One-story on basement foundation
- Two-story on basement foundation

The table below covers the locations where each type of reference house foundation would be pragmatically constructed. All these selected cities, except Chicago, lie within the top ten states for construction starts in 2013.[34] Chicago was selected to represent a Climate Zone 5 house.

Sites for Reference Houses

Reference House	Climate Zone	1	2	3	4
Foundation		Slab	Slab	Basement	Basement
Miami	1	X	X		
Los Angeles	3	X	X		X*
Dallas	3	X	X		X*
Seattle	4	X	X	X	X
New York	4	X	X	X	X
Chicago	5			X	X
Fairbanks	8			X	X

[33] www.census.gov/construction/chars/completed.html

[34] www.census.gov/construction/bps/pdf/2013statepiechart.pdf

Based on the data compiled by Home Innovation from the *2013 Builder Practices Survey* (BPS)[35], a nationwide annual survey, the typical Heating, Ventilation, and Cooling (HVAC) systems used in new houses are summarized in the table below. According to the BPS, 44% of new homes are cooled with a central air conditioner. These results influenced the selection of a gas furnace with central (electric) air conditioner as the HVAC system in each of the reference houses.

Typical HVAC Systems Supplied with New Houses

Feature	% of Stock
Furnace or Boiler, natural gas or propane	48%
Central Air Conditioner, electric	44%
Standard Heat Pump with Backup Heat	41%
Geothermal Heat Pump	4%
Electric furnace, baseboard, or radiant	4%
Furnace or Boiler, oil	2%

The statistics presented in the foregoing tables support defining the features of the Reference Houses as detailed in the table below.

Features of the Reference Houses

Reference House	1	2	3	4
Square Feet	2,607	2,607	2,607	2,607
Foundation	Slab	Slab	Basement	Basement
Number of Stories	1	2	1	2
Number of Bedrooms	3	4	3	4
Number of Bathrooms	2	2.5	2	3
Garage, attached	2-car	2-car	2-car	2-car
Heat, Gas Furnace	Yes	Yes	Yes	Yes
Cooling, (Electric) central air	Yes	Yes	Yes	Yes
Hot Water, Gas 50-gallon tank	Yes	Yes	Yes	Yes
9 ft. Ceilings, 1st	Yes	Yes	Yes	Yes
8 ft. Ceilings, 2nd	n/a	n/a	Yes	Yes
Energy Star appliances	Yes	Yes	Yes	Yes
Laundry Room/Closet	Yes	Yes	Yes	Yes
Walls, 2x4 (Climate Zones 1 & 2)	Yes	Yes	n/a	n/a
Walls, 2x6 (Climate Zones 3 thru 8)	n/a	n/a	Yes	Yes
Basement, Conditioned, Unfinished	n/a	n/a	Yes	Yes
Furnace Location	Attic	Attic	Basement	Basement
Water Heater Location	Interior	Garage	Basement	Basement
Window SF/% gross wall	360/18%	315/12%	360/18%	330/12%
Cladding	Brick, 4 sides	Brick, 4 sides	Brick, 4 sides	Stucco
Roof Pitch	12/12	6/12	9/12	4/12

The furnace location has been designated as a platform in the attic for both slab reference houses, a common practice in mild climates; furnace would be located within conditioned space for cold climates.

[35] www.homeinnovation.com/trends_and_reports/data/new_construction

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