Primary Energy and Environmental Benefits of Natural Gas Direct Use in Buildings

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2014 International Gas Union Research Conference – Copenhagen, DM

Abstract

This paper summarizes the significant primary energy and environmental benefits of selecting high efficiency natural gas equipment instead of electric equipment in residential and commercial markets. Benefits are calculated using "full-fuel-cycle" average and non-baseload source energy and CO_2e emissions factors (including carbon dioxide, methane, and nitrous oxide) for the U.S. power generation mix. Factors for calculating primary energy consumption and related emissions include eGRID sub-region and U.S. average for electricity for all power plants. Factors for non-baseload power plants include eGRID sub-region and U.S. levels. U.S. average factors are provided for natural gas. Sample calculations illustrate the compelling primary energy and emission reduction benefits (>50% in many cases) of selecting high efficiency natural gas equipment instead of electric resistance equipment in buildings.

Introduction

According to the U.S. Energy Information Administration (EIA), residential and commercial buildings were responsible for over 40% of U.S. primary energy use, 74% of electricity consumption, and 38% of CO_2 emissions in 2013 (EIA 2014). Total use of primary energy in U.S. buildings in 2013 was 39 quadrillion Btu's (Quads). Of this amount, electricity production and delivery losses were 19 Quads of energy – an amount equal to the total site energy demand. Electricity generation and transportation vehicles are by far the major sources of CO_2 emissions in the U.S. (Figure 1). In the power sector, coal and relatively high energy losses in power generation are the dominant factors. In the transportation sector, petroleum and relatively inefficient drivetrains are the primary causes. Increases in U.S. CO_2 emissions in the residential and commercial sectors continue to be driven by increased electricity usage, a trend that is projected to continue well into the future (Figure 2). The short-term reduction in electricity CO_2 emissions from 2010 through 2017 reflects the recent shift from coal-fired power generation to natural gas power generation (Figure 3). Projected growth in power demand in the buildings sector combined with nuclear power plant retirements reverse the short-term trend by 2018.

Electricity generation trends indicate an opportunity for future full-fuel-cycle energy efficiency and CO_2 emission reduction initiatives that leverage improvements in natural gas appliance efficiency through increased direct use of natural gas in buildings. Direct use refers to natural gas consumed directly in appliances for space conditioning, water heating, cooking, and clothes-drying. In contrast, some consumers use natural gas indirectly by consuming electricity generated with natural gas. However, generally the natural gas distribution system is considerably more efficient than electricity since it avoids the significant losses associated with electricity generation, transmission, and distribution.

The direct use of natural gas provides a cost-effective and resource-efficient choice for consumers and offers one more option in the suite of greenhouse gas (GHG) emissions reduction strategies. And direct use makes financial sense as a consumer fuel choice. A household with natural gas usually spends less on heating, cooking, and drying than one using any other fuel. A recent AGA analysis showed that a household with natural gas for these appliances on average spends almost 30 percent less than a household with all-electric appliances, and leads to 37 percent lower GHG emissions (AGA 2009).

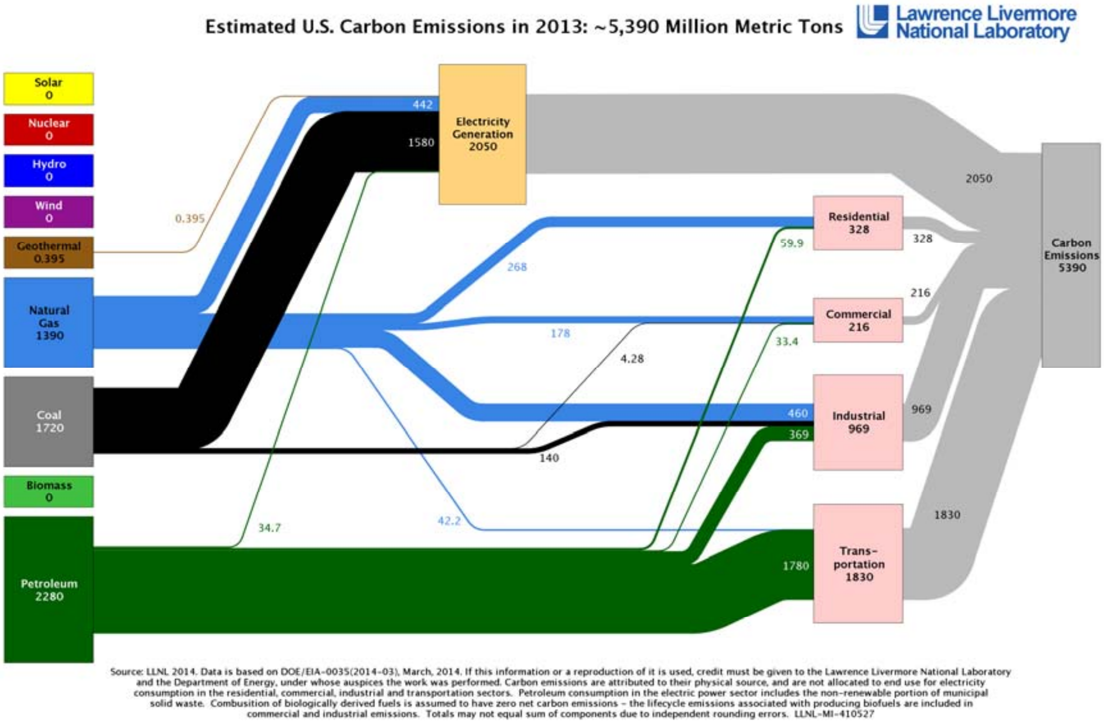

Figure 1 – U.S. CO_2 Emissions Profile 2013

Source: Lawrence Livermore National Laboratory 2014

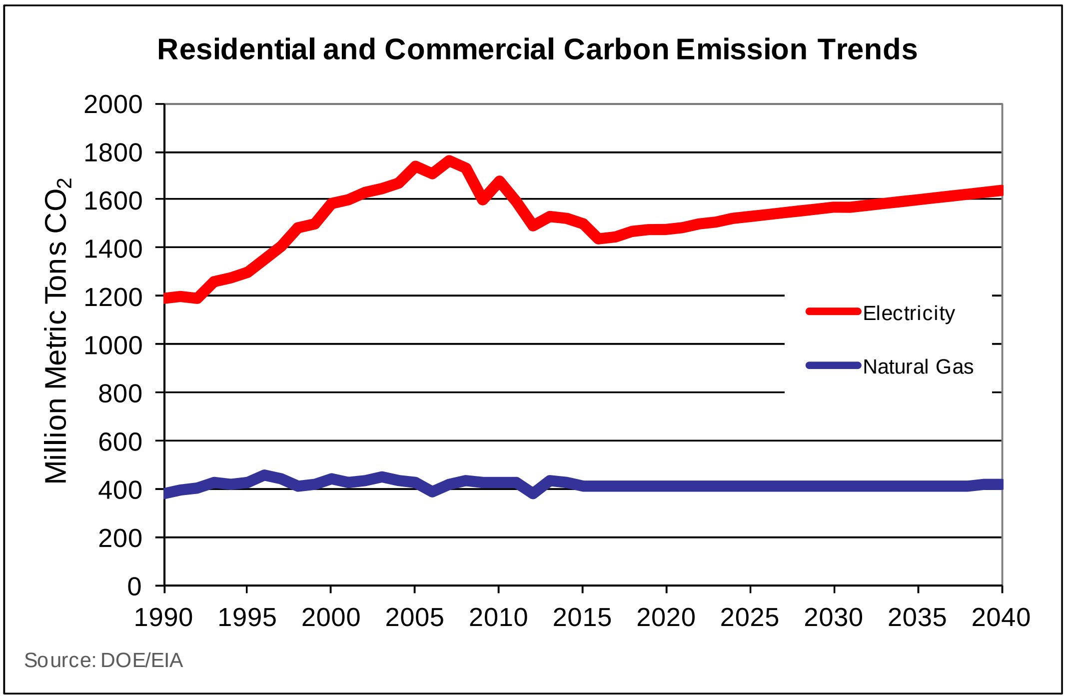

Figure 2 – Gas and Electric CO_2 Emission Trends for Residential and Commercial Sectors

Source: EIA Monthly Energy Review March 2014; Annual Energy Outlook 2014

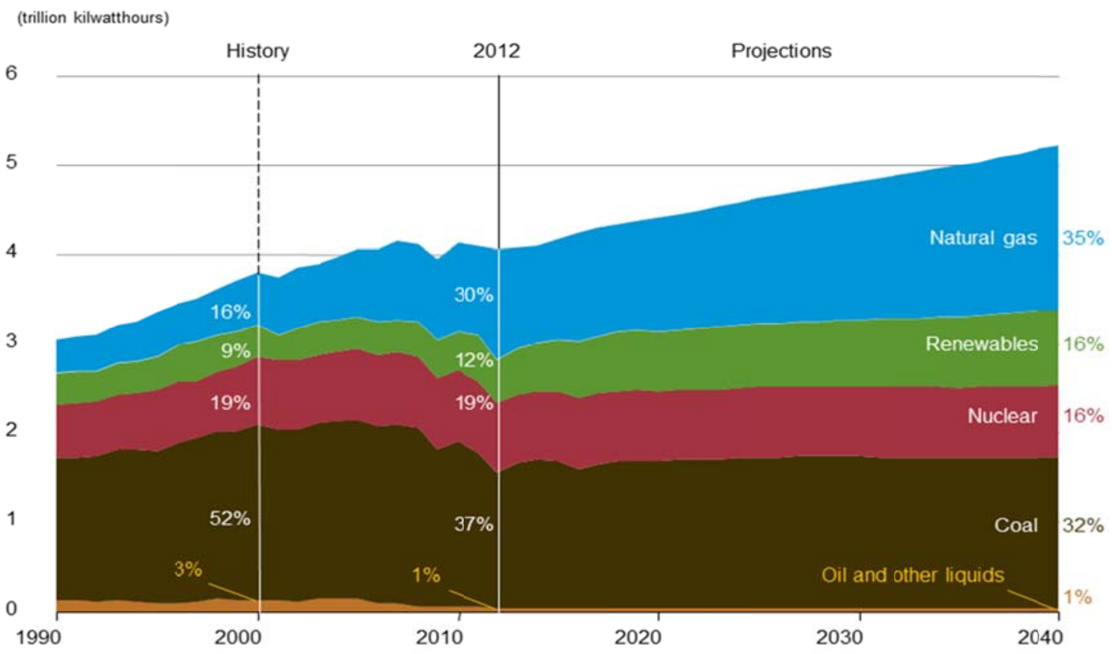

Figure 3 – U.S. Electricity Generation Mix - EIA Forecast through 2040

Source: EIA Annual Energy Outlook 2014

Potential benefits of natural gas direct use include:

- Lower consumer energy bills
- Increased productivity of energy supplies
- Reduced energy imports
- Fewer pollutants and GHG emissions
- Reduced new electric power requirements
- Enhanced domestic energy security
- Safe and reliable performance

Use of natural gas appliances in place of electric resistance appliances has the potential to reduce carbon emissions by 55 percent or more on a full-fuel-cycle basis (Figure 4). Current CO_2 emission recommendations from the electric industry target nuclear power, renewable energy, and carbon capture and sequestration, without any consideration of the benefits of switching to natural gas appliances. Given its abundance and environmental benefits, retaining and expanding natural gas use in buildings can provide substantial societal and consumer benefits.

In spite of the significant benefits of direct natural gas use based on its technical merits, market share erosion to electric products continues to be a challenge, especially in the water heater market (Figure 5). One reason for this market impact is regulatory and voluntary initiatives that treat electric resistance appliances that have higher full-fuel-cycle energy consumption and GHG emissions than their natural gas competitor as if they are equally efficient when they are not. Information on societal benefits of natural gas direct use provides an opportunity to educate outside stakeholders, resulting in more equitable initiatives over time. It also helps ensure fair treatment of current and emerging strategic technologies such as gas heat pumps and combined heat and power systems developed through industry funding.

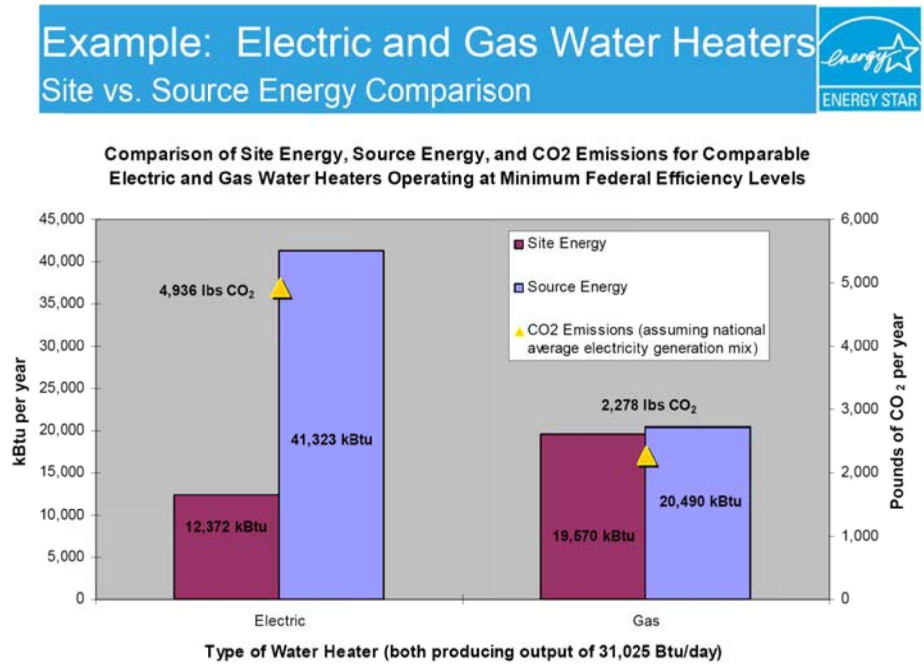

Figure 4 – Site Energy, Source Energy, and CO_2 Emissions for Comparable Water Heaters

Source: EPA Presentation to National Academy of Sciences February 2008

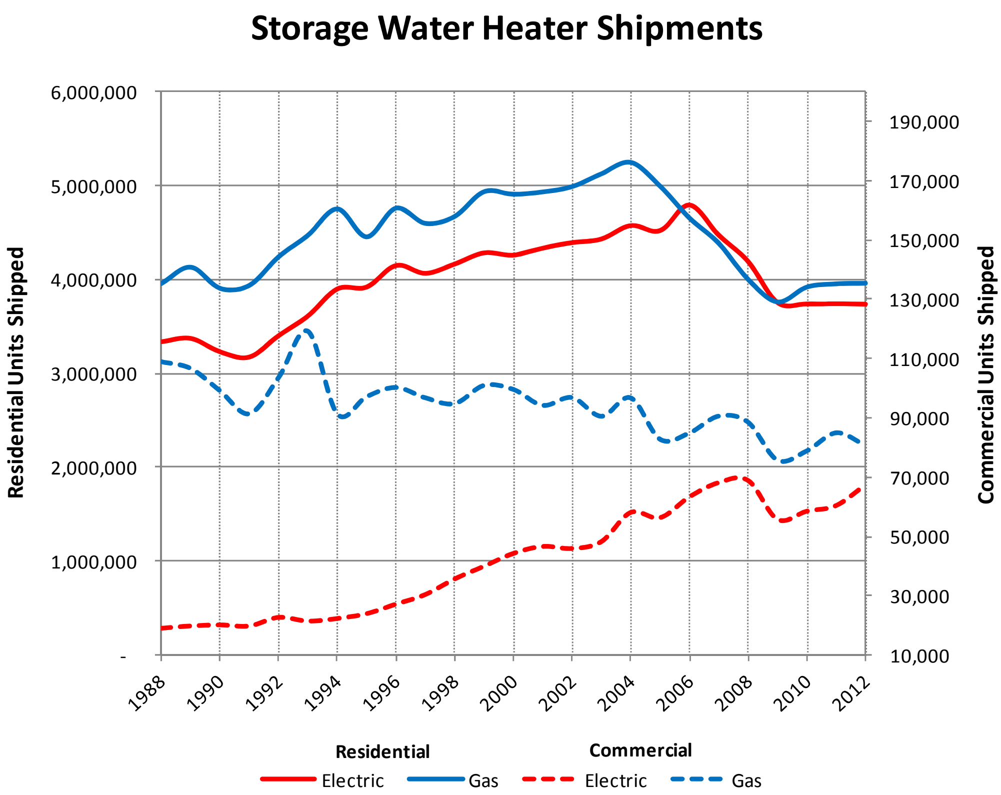

Figure 5 – Residential and Commercial Storage Water Heater Shipments

Source: AHRI

Metrics and Methodologies

To achieve the primary intent of any energy efficiency or environmental initiative (code, standard, legislation, or voluntary program) with minimum adverse or counteracting effects, its provisions must select the correct metric for the primary intent of the initiative and then implement that metric appropriately by using technically robust and unbiased algorithms and methodologies. Any other combination of metrics and implementation procedures will inevitably result in adverse effects (Figure 6). This includes selecting the wrong metric, whether or not it is implemented using the correct methodology, or implementing the correct metric using a flawed methodology. The right metric applied incorrectly is just a new number; it retains the inequitable "separate but equal" bias impacts of a multiple baseline implementation approach. The wrong metric (e.g., site energy consumption) applied correctly (with a single baseline) has the worst impact, because it always rewards the wrong metric. The wrong metric applied incorrectly (two wrongs try to make it right) uses strategies such as "separate but equal" biases in an attempt to neutralize the impact of the wrong metric, and results in many unintended consequences. Finally, the right metric applied correctly provides the best impact because it rewards the right metric the right way to meet the primary intent of the initiative.

Figure 6 – Right Metric and Right Approach Required for Equitable Provisions

Selecting the Correct Metrics

Several factors must be considered when selecting the correct metric for measuring and comparing building energy performance (Figure 7). Site energy is needed for measuring and monitoring, and is the essential starting point for converting to energy costs, primary energy, and GHG emissions attributable to design options or building operation. It is not technically valid or equitable to convert and combine different energy forms into a single common site energy metric for use in building energy performance targets, ratings, or comparisons, irrespective of the goal(s) of the initiative. Site energy must never be used whenever more than one energy form is involved in the comparison (such as for a comparison of electric water heaters and gas water heaters or an all-electric building and a mixed fuel building) given inherent differences in the production, processing, and transportation of fuels prior to end use consumption. In such comparisons, a conversion to the relevant metric of interest is required, either energy cost or primary energy-based metrics depending on the primary intent of the comparison. When the comparison focuses on economic objectives, energy cost provides the most useful metric, not site energy or primary energy. When the comparison focuses on non-economic objectives (such as on natural resources, the environment, or other societal impacts of energy use), primary energy-based metrics are the most suitable as the comparison metric, not site energy or energy cost. Environmental impact metrics require factors that convert site energy to primary energy and associated GHG emissions or other impacts. ASHRAE Standard 105-2014 provides further technical information and compliance options when applying these metrics (ASHRAE 2014).

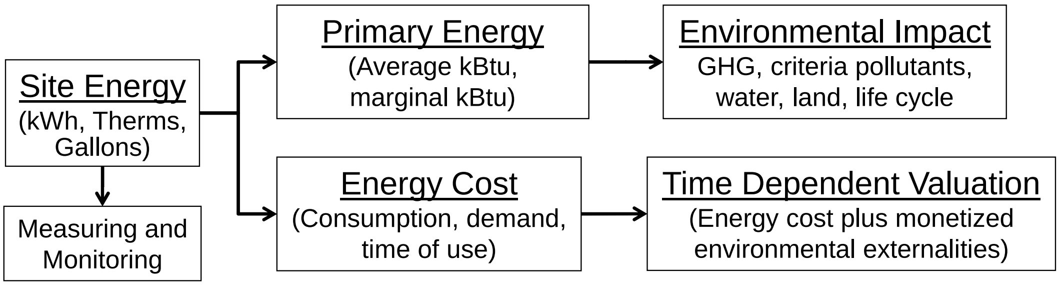

Figure 7 – Different Metrics and Methods Depending on Primary Intent

Selecting the Correct Methodologies

Methodologies for analysis involve options for the baseline (single or multiple baselines), aggregation level (local, regional, national, or international), and type of impact (average or marginal). The multiple baseline methodology is likely to be fuel-biased, whereas a single baseline methodology is technology-blind and fuel-blind. For example, multiple baselines for natural gas and electric water heater categories in the ASHRAE Standard 90.1-2013 prescriptive tables are fuel-biased and technology-biased. The tables treat electric resistance appliances that have higher energy cost and primary energy consumption than their natural gas competitor as if they are equivalent by using a less stringent baseline for the electric option than for the natural gas option. This creates an unearned market advantage for these appliances. On the other hand, the EPA Portfolio Manager® methodology is a fuel-blind single baseline for all building comparisons based on a source energy use index. This approach is indifferent to how the source energy target is met, which provides equitable consideration of all technology and fuel options.

The aggregation level and type of impact compared in the analysis will also affect the results whenever there are significant regional variations in performance. This is especially important for the U.S. electric grid because it is not a national grid, but rather is a set of interconnected regional grids that have different regional generation mixes. National average data provides a simple primary energy and GHG emissions conversion factor. The consistency provided by use of national average factors sends a strong signal regarding primary energy efficiency and its impact on GHG emissions, and does not reward or penalize a building based on its location.

In some cases a national average calculation may distort the actual primary energy or GHG emissions associated with specific buildings in different regions, especially for electricity. Use of regional values has the potential to reflect more accurately the actual primary energy use and environmental impact of the building stock for inventory or benchmarking due to the regional nature of the power grid. However, regional average factors do not reflect the impact of incremental investment and energy consumption decisions and can be even more misleading than national average factors in some situations such as power exported from one country, region, or state to another (Leslie et. al. 2014).

Both national and regional average generation analysis methodologies may be appropriate for inventory and benchmarking purposes, but are less useful when making comparisons for design or investment decisions. Marginal calculation methodologies are more appropriate than either national or regional average calculations for evaluating the impacts of incremental changes in electricity consumption, such as comparing new building energy efficiency design options or evaluating competing retrofit measures. Marginal calculation methodologies are not useful for benchmarking or inventory purposes because they consider the incremental impact of investment decisions by an individual building, not the aggregated status of all comparable buildings.

Full-Fuel-Cycle Energy Analysis Tool

Once the primary intent of the initiative is well understood, the correct metric and implementation methodology can be identified and selected. The next hurdle is to identify and use a suitable calculation tool for the analysis.

AGA has compiled an extensive set of data using publicly available sources to support calculation of the full-fuel-cycle energy consumption and associated pollutant emissions for electricity generation and fossil fuel energy use (AGA 2014). The factors for calculating full-fuel-cycle energy consumption and related emissions were developed at the state, eGRID sub-region, NERC region, and U.S. average level for electricity for all power plants. Factors for non-baseload power plants were developed at the eGRID sub-region and U.S. average levels. Factors for fossil fuels were developed at the U.S. average level.

Site energy consumption by fuel type also provides input data for a full-fuel-cycle calculation tool for primary energy and GHG emissions (Leslie et. al. 2010) that can be used in average and marginal analyses and related factors such as those developed in this paper. The tool uses current government data sources to determine primary energy and related GHG emissions for selected fossil fuels and electric energy consumed at a site. The Source Energy and Emissions Analysis Tool (SEEAT) is currently implemented as a free public domain web tool located at www.cmictools.com.

SEEAT calculates full-fuel-cycle energy consumption and selected air emissions including GHG emissions associated with annual site energy consumption by purchased fuel type of baseline and alternative applications as defined by user-selectable and default inputs. SEEAT also provides estimates of annual site energy use based on a user-selected location.

Default power plant efficiency, fuel mix, and emissions data contained in the current and previous eGRID databases allow the user to determine source energy consumption and GHG emissions (as well as SO_2, NO_x, and Hg) associated with annual site electricity consumption at national, NERC region, eGRID sub-region, and state levels as well as for non-baseload (marginal) generation mixes. Energy consumption and emissions associated with extraction, processing, transportation, and distribution are also determined for electricity and other energy forms based on government data sources.

The calculation methodology allows application of the full-fuel-cycle energy boundary condition to a variety of analyses, including average energy performance and GHG emissions calculations using national and regional default factors, average and marginal calculations based on user-specified values for regional or national power generation mix and efficiency, and regional marginal generation analysis for eGRID sub-regions based on the EPA non-baseload power generation database contained in eGRID 2014 (EPA 2014). Analysis results summarized in this paper used SEEAT Version 6.1 for all calculations.

Storage Water Heater Case Study

Using SEEAT, a parametric case study compared a 0.62 EF natural gas storage water heater to a 0.95 EF electric resistance storage water heater using U.S. national data and eGRID sub-region electricity generation data. Cases were run for each sub-region using average grid mix and non-baseload power plants to evaluate the differences in source energy consumption and GHG emissions with fixed annual site consumption of 3,330 kWh for the electric water heater and 174 therms for the natural gas water heater. For all locations and all marginal and average cases, site energy use was 17.4 MMBtu for the natural gas water heater and 11.4 MMBtu for the electric water heater. The natural gas primary energy conversion factor for all cases was 1.09, and the CO_2e emission factor was 147 lb/MMBtu. The electricity factors varied based on the location and power plant methodology (average or non-baseload).

Primary Energy Savings

Table 1 shows the primary energy savings results for eGRID sub-regions and national average using the non-baseload and average generation mix. Marginal and average results were significantly different in regions with a large fraction of hydropower generation such as the AKMS and NWPP sub-regions. This illustrates the importance of choosing the correct calculation methodology to match the purpose of the analysis. For benchmarking purposes, Alaska and Washington State would be able show good progress in improving the electricity grid in their region, with lower overall contributions to total primary energy consumption. On the other hand, it would not be beneficial to invest in more electricity technologies in those areas because of the negative marginal impact on the interconnected grid and resulting increased primary energy consumption. Using the regional average generation mix for decisions would result in poor investments that would not achieve the expected level of primary energy consumption reduction.

Table 1 – Natural Gas Water Heater Primary Energy Annual Savings Summary

eGRID 2014 Sub-region Acronym	eGRID 2014 Sub-region Name	Non-Baseload Primary Energy Savings MBtu (%)	Average Primary Energy Savings MBtu (%)
AKGD	ASCC Alaska Grid	19.5 (50%)	18.5 (49%)
AKMS	ASCC Miscellaneous	17.0 (47%)	1.9 (9%)
ERCT	ERCOT All	15.0 (44%)	16.8 (47%)
FRCC	FRCC All	14.4 (43%)	15.4 (45%)
HIMS	HICC Miscellaneous	21.7 (53%)	25.0 (57%)
HIOA	HICC Oahu	20.4 (52%)	18.6 (49%)
MROE	MRO East	17.8 (48%)	18.5 (49%)
MROW	MRO West	21.8 (53%)	20.0 (51%)
NYLI	NPCC Long Island	25.7 (57%)	20.8 (52%)
NEWE	NPCC New England	13.1 (41%)	14.4 (43%)
NYCW	NPCC NYC/Westchester	16.0 (46%)	16.2 (46%)
NYUP	NPCC Upstate NY	12.8 (40%)	10.3 (35%)
RFCE	RFC East	17.4 (48%)	17.9 (48%)
RFCM	RFC Michigan	16.9 (47%)	18.4 (49%)
RFCW	RFC West	18.5 (49%)	18.3 (49%)
SRMW	SERC Midwest	18.9 (50%)	19.0 (50%)
SRMV	SERC Mississippi Valley	17.4 (48%)	16.7 (47%)
SRSO	SERC South	15.6 (45%)	16.1 (46%)
SRTV	SERC Tennessee Valley	17.9 (48%)	16.7 (47%)
SRVC	SERC Virginia/Carolina	16.6 (47%)	17.6 (48%)
SPNO	SPP North	21.9 (53%)	21.7 (53%)
SPSO	SPP South	18.7 (49%)	17.8 (48%)
CAMX	WECC California	12.2 (39%)	12.9 (40%)
NWPP	WECC Northwest	14.8 (44%)	8.4 (30%)
RMPA	WECC Rockies	20.5 (52%)	20.7 (52%)
AZNM	WECC Southwest	14.0 (42%)	16.7 (47%)
US Average		**NA**	**16.7 (47%)**

Greenhouse Gas Emissions Savings

Table 2 shows the GHG emissions savings results for eGRID sub-regions and national values using the non-baseload generation mix and the average generation mix. Marginal and average CO_2e emission results were significantly different in many sub-regions, again illustrating the importance of the methodology selected for the analysis. However, unlike the primary energy savings, which were always positive for the natural gas water heater, the average emissions savings would actually be negative in four of the sub-regions. This is a further illustration of the misleading information provided by an average calculation methodology when making investment decisions. Analysts using the average methodology instead of the marginal methodology would incorrectly conclude that investments in natural gas technologies instead of electric technologies would increase GHG emissions in those sub-regions with negative savings on average, when at the margin, the natural gas technology investment is actually beneficial to the environment. In these sub-regions, the choice of methodology would result in opposite investment decisions, one of which would meet the primary intent of reducing GHG emissions, and the other would not.

Table 2 – Natural Gas Water Heater CO_2e Emission Annual Savings Summary

eGRID 2014 Sub-region Acronym	eGRID 2014 Sub-region Name	Non-Baseload CO_2e Emission Savings lb (%)	Average CO_2e Emission Savings lb (%)
AKGD	ASCC Alaska Grid	2,980 (54%)	2,660 (51%)
AKMS	ASCC Miscellaneous	3,310 (56%)	-700 (-38%)
ERCT	ERCOT All	2,660 (51%)	2,330 (48%)
FRCC	FRCC All	2,590 (50%)	2,120 (45%)
HIMS	HICC Miscellaneous	4,180 (62%)	2,990 (54%)
HIOA	HICC Oahu	4,130 (62%)	4,080 (61%)
MROE	MRO East	4,480 (64%)	3,590 (58%)
MROW	MRO West	5,100 (67%)	3,300 (56%)
NYLI	NPCC Long Island	3,480 (58%)	2,980 (54%)
NEWE	NPCC New England	2,100 (45%)	450 (15%)
NYCW	NPCC NYC/Westchester	2,080 (45%)	170 (6%)
NYUP	NPCC Upstate NY	2,500 (49%)	-350 (-16%)
RFCE	RFC East	3,700 (59%)	1,370 (35%)
RFCM	RFC Michigan	4,210 (62%)	3,610 (59%)
RFCW	RFC West	4,910 (66%)	3,100 (55%)
SRMW	SERC Midwest	4,950 (66%)	4,260 (62%)
SRMV	SERC Mississippi Valley	2,530 (50%)	1,610 (39%)
SRSO	SERC South	3,480 (58%)	2,650 (51%)
SRTV	SERC Tennessee Valley	4,630 (64%)	2,680 (51%)
SRVC	SERC Virginia/Carolina	3,630 (59%)	1,570 (38%)
SPNO	SPP North	5,390 (68%)	4,240 (62%)
SPSO	SPP South	3,410 (57%)	3,550 (58%)
CAMX	WECC California	1,380 (35%)	0 (0%)
NWPP	WECC Northwest	2,890 (53%)	690 (21%)
RMPA	WECC Rockies	4,540 (64%)	4,670 (65%)
AZNM	WECC Southwest	2,470 (49%)	2,070 (45%)
US Average		**NA**	**2,250 (47%)**

Conclusions

Application of the full fuel cycle efficiency and GHG emission calculation methodology to a simple water heater example illustrates the significant societal benefit of choosing to invest in direct use of natural gas in buildings rather than the electric alternative. It also illustrates the importance of choosing the correct metrics and methodologies for analysis of the energy and environmental impact of investment decisions along with benchmarking and inventory calculations. Investment in natural gas water heating offers opportunities for reducing primary energy consumption by 39 to 57 percent while reducing GHG emissions by 35 to 68 percent compared to an electric resistance water heater depending on the source of electricity displaced.

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