Environmentally Beneficial Electrification: Electricity as the End-Use Option

For decades, policymakers have viewed appliances that are fueled 'on site' by natural gas as environmentally preferable to electric appliances that rely on electricity generated at an off-site 'source,' such as at a coal or natural gas power plant. Several trends in energy generation and end-use technology, however, are changing the environmental value of using electric appliances to produce heat and hot water in buildings, requiring a more systems-based approach to energy efficiency tools and revisions to the methodology for calculating 'source' energy metrics.

Keith Dennis

Keith Dennis *is Senior Principal of End-Use Solutions and Standards at the National Rural Electric Cooperative Association (NRECA) in Arlington, VA. He has previously worked at the US DOE, White House Council on Environmental Quality, and in the private sector as a third-party verifier of energy projects. He holds an A.B. in Engineering and Environmental Sciences from Dartmouth College, a Bachelor of Engineering and Master of Engineering Management from the Thayer School of Engineering at Dartmouth College, and a Master of Studies in Environmental Law,* summa cum laude, *from Vermont Law School. He is a licensed professional engineer.*

This article and the opinions within are the responsibility of the author and do not represent the opinion of NRECA nor its members. The author thanks Chuck Foster for his significant contributions to the ideas contained in this article.

I. Introduction

Electrification changed the landscape of America, boosting the nation's economy and the quality of life. The National Academy of Engineers lists electrification as the most significant engineering achievement of all time.[1] Historical data from research by the World Bank demonstrates that access to electricity is one of the most powerful economic development multipliers, enabling people around the world to break free from subsistence and prosper.[2] Now, more than a century after the first poles and wires went up, the electric power

 1040-6190/ http://dx.doi.org/10.1016/j.tej.2015.09.019

industry is undergoing a second revolution as the industry dramatically alters not only the fuel mix behind the electric grid but also the electric distribution system itself. Some federal, state, and local energy policies have not kept up with these changes, however. In fact, policies intended to promote efficiency and energy security could prove to be a hindrance to both those goals by failing to keep pace with grid modernization.

For decades, policymakers have viewed appliances that are fueled ''on-site'' – for example, natural gas-powered water heaters – as environmentally preferable to electric appliances that rely on electricity generated at an off-site ''source,'' such as at a coal or natural-gas-fired power plant. Historically, the amount of energy lost in generation and transmission has given electricity a negative reputation among environmentalists. Over the years, this view hardened into conventional wisdom. Trends in energy generation and end-use technology, however, are changing the environmental value of using electric appliances to produce heat and hot water in buildings. In fact, many experts now believe we are approaching a tipping point: we cannot meet the nation's CO_2 reduction goals if we continue to promote burning fossil fuel on-site in millions of homes across the country. The strategy of pursuing environmentally beneficial electrification has been suggested by the likes of Energy and Environmental Economics (E3)[3] and Lawrence Berkeley National Lab (LBNL)[4] in their assessments of how California will meet its aggressive climate goal, and by other experts in their solutions to address the issue of climate change on a more global scale.[5]

In order to better align energy policies with the optimal economic and environmental outcomes, industry and policymakers need to take a hard look at the discipline of energy efficiency and, more specifically, the technical analyses of the relative ''performance'' of end-use fuels underlying many efficiency standards.

Historically, the amount of energy lost in generation and transmission has given electricity a negative reputation among environmentalists.

This article examines the trends that are creating a landscape in which electric end-use is more and more *the* environmentally beneficial end-use option. It also identifies some technical practices in the energy efficiency field that must be modified in order to better achieve optimal economic and environmental policy objectives.

II. Revisiting Conventional Wisdom on Efficient Energy End Use

For decades, conventional wisdom has held that if consumers in the United States have access to natural gas, it should be their preferred choice for end-use space and water heating if their goal is to conserve energy resources.[6] This idea is based on the relatively inefficient conversion of fossil fuel (primarily coal and natural gas) to electricity in traditional electric generation facilities and delivery to load.

Take, for example, the use of electricity to heat water in a home using an electric resistance water heater with a standard efficiency of 90 percent. If natural gas is burned in a power plant that is 40 percent efficient at converting the fossil fuel energy to electricity, and some of that electricity is lost in transit on power lines, the overall efficiency of converting that fossil fuel to hot water is somewhere around 33 percent. By comparison, the efficiency of a standard 50-gallon natural gas water heater is 58 percent.[7] Since burning a unit of natural gas emits the same amount of carbon dioxide emissions no matter where it is burned, it follows that burning the fuel on-site rather than at a power plant

1040-6190/ http://dx.doi.org/10.1016/j.tej.2015.09.019

would result in lower emissions.[8]

Yet this simple example does not take into account key trends occurring in the electric system:

1) Not all electricity comes from vintage fossil fuel power plants and emissions rates associated with grid supplied electricity are declining;

2) End-use electric appliances have capabilities that are critical to integrating more renewable sources into the grid—they can help match energy load to variable renewable energy supply; and

3) Common heat pump technology can heat space and water with efficiencies of 200–300 percent.

All three of these new developments render the old conventional wisdom obsolete.

These trends need to be accounted for in energy efficiency tools widely used by consumers, contractors, and governmental organizations. A prime example of the lag in the energy efficiency industry is the ''source'' energy metric embedded in many prominent software tools and building codes. Tools that incorporate the source energy metric are designed to help consumers gauge and improve the relative energy efficiency of their buildings. However, this metric accounts for electricity from the grid as if it is less than one-third as efficient as on-site natural gas. As will be discussed later in this article, the source energy metric must be updated to align with policy objectives as our conventional wisdom on this issue changes.

Policy updates of this kind are not easy. Not only is it difficult to explain the technical workings of these tools, but the bureaucratic process of making changes can also be tedious. However, a failure to take on this challenge will have significant environmental consequences. The chairman of the American Gas Association still asserts that ''natural gas is three times as efficient as electricity, so we ought to be looking at policies that say that, that promote that, that encourage that.''[9] Yet LBNL simultaneously asserts that ''moving away from oil and natural gas and towards electricity is a key decarbonization strategy.''[10] Technical flaws in the current source metric produce tools that favor on-site fossil fuel by more than three to one over electricity. Those flaws should be corrected to level the playing field for electric end use so that technologies are evaluated on their real environmental and consumer merits, not outdated rules of thumb and outdated common wisdom. Use of this metric has led to policies such as California's Title 24, which creates a framework where on-site natural gas is given strong preference for water heating in homes, especially in replacement situations where the code's ''prescriptive path'' is unworkable for electric water heating.[11] If the source metric is not updated, Americans who depend on the government to provide objective and accurate efficiency tools to make environmentally sound decisions at their homes and businesses will be unwittingly making long-term investments in a more carbon-intensive energy future.

Not only is it difficult to explain the technical workings of these tools, but the bureaucratic process of making changes can also be tedious.

III. Trends Making Electricity *the* Environmental Choice

Technological trends, driven in part by policy trends, are creating a situation in which engineering-based analysis demonstrates that electric end use is the environmentally superior choice over on-site fossil fuel use for space and water heating, vehicles, and other equipment.[12] These trends include a long-term reduction in greenhouse gas intensity of the electric grid, increased efficiency of electric end-use appliances, and the increased need to manage

 1040-6190/ http://dx.doi.org/10.1016/j.tej.2015.09.019

end-use electric load to help integrate variable renewable resources. As these trends continue to develop, electricity will only increase in environmental performance while on-site fossil fuel use has reached the virtual limits of its efficiency.

A. Electric grid emissions trends and establishment of climate goals

Federal and state energy policies, combined with technology changes, have lowered the carbon intensity of the electric system. U.S. Energy Information Administration (EIA) data shows that in the decade between 2005 and 2014, carbon dioxide emissions per megawatt-hour declined by about 16 percent.[13] Non-carbon dioxide emitting sources currently make up more than 30 percent of the overall fuel mix powering the electric grid.[14] Regions that have historically been heavily dependent on coal are adding natural gas and renewables to their fuel mixes, a shift that will result in lowered GHG emissions. In January through May 2015, over 65 percent of electric generation capacity brought on line nationwide derived from non-emitting sources and the other 35 percent was natural gas.[15]

The EIA predicts that about 13 GW of coal-fired power plants will be retired by the end of 2015, and replaced with more than 13 GW of zero-emission wind, solar, and nuclear power plants by the end of this year.[16] EIA also projects that 60 gigawatts of coal-fired capacity will retire between 2012 and 2020, with 90 percent of the retirements happening by 2016.[17] The Environmental Protection Agency (EPA) estimates that coal-based generation will decline 20–22

percent in 2020 and 25–27 percent in 2030.[18]

Greenhouse gas emission reduction goals have been established on local, state, national and international levels. Some notable goals include the U.S. goal to reduce greenhouse gas emissions in the range of 17 percent below 2005 levels by 2020,[19] Minnesota's goal to reduce emissions 30 percent below 2005 emissions by 2025 and 80 percent below 2005 emissions by 2050,[20] and California's goal to reduce GHG emissions by approximately 30 percent by 2020 and 80 percent by 2050.[21] Also of significance, EPA's 2015 Clean Power Plan is projected to achieve a 32 percent cut from 2005 emissions nationwide by 2030.[22] Renewable energy policies are similarly aggressive, with 37 states having adopted binding targets or voluntary goals, and the U.S. recently setting a goal of 20 percent non-hydro renewables by 2030, which would be up from 7 percent in 2014.[23] These goals will have an increasing and lasting impact on the carbon dioxide emission profile of the grid.

In designing policies for end-use equipment, it is important to consider both the grid as it operates today and longer-term trends due to the life expectancy of end-use equipment. For example, DOE estimates the average lifespan of a residential furnace is 22 years[24] and residential water heater is 13 years.[25] **Figure 1** shows the emissions profile of GHG emission rates of electric generation in the U.S. and the trend per federal policy goals through 2030, a timeframe within which most space and heating equipment purchased today will remain in operation. *Investments in a new end-use appliance that burns natural gas or other fossil fuel on-site will lock emissions from that source into future decades*. In contrast, the environmental performance of electric equipment will improve over the life of the product as the emissions from a changing power generation fuel mix decrease. Over their life, electric products can support the integration of renewable energy generators, could be powered by on-site

  http://dx.doi.org/10.1016/j.tej.2015.09.019

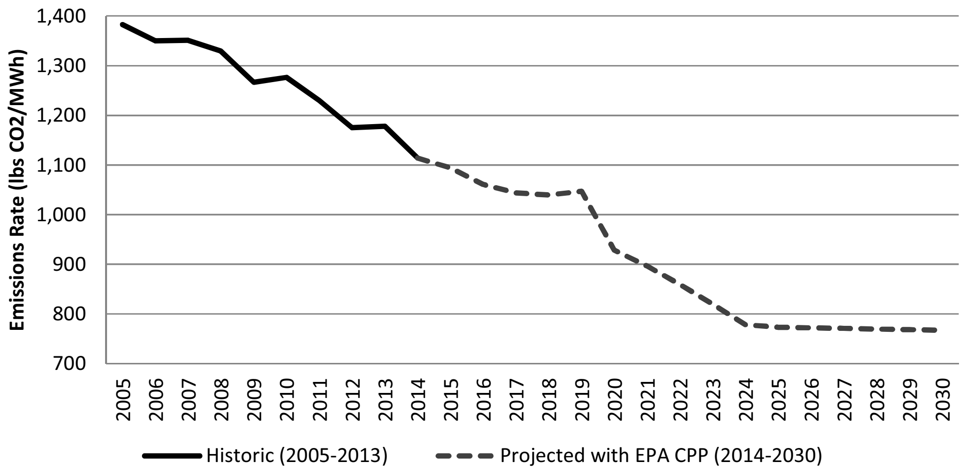

Figure 1: Carbon Intensity of US Electric Generation 2005–2030

renewable generation that has not yet been installed, and can participate in thermal storage programs. The same cannot be said of appliances that will require fossil fuel on-site through the duration of their useful life.

B. Increased availability and adoption of heat pump technology

As an example of key beneficial electrification potential, rapid advances and adoption of electric heat pump technology provide an important opportunity to reduce energy consumption in homes and businesses and to lower greenhouse gas emissions. Common air source heat pump space and water heating systems, which use a refrigeration cycle to extract heat from the air, are 200 to 300 percent efficient. In other words, for every unit of power used, the heat pump produces two or three times that amount by taking heat out of ambient air.[26] Using these systems cuts energy use and associated emissions of the system by a factor of two or three.[27] This heat pump technology is increasing in adoption. In 2014 air source heat pump space heating systems shipments were the highest on record with about 2.4 million shipments, up from 1.7 million in 2012.[28]

Heat pumps have been criticized for poor performance in cold climate conditions. However, cold climate technology is improving and some new systems can operate effectively at subzero temperatures without the need for any backup resistance or fossil fuel heating.[29] Additionally, dual fuel heat pump technology has advanced in popularity and provides a solution with multiple benefits. These dual fuel systems switch to a fossil fuel, such as propane or natural gas, when the temperature is too cold to operate the heat pump effectively or when the overall electric system has high demand. This switching capability can make the best use of the heat pump technology to lower energy use, and also avoids creating a system peak where electricity may have to be generated using less efficient power generators. While electric heat pumps have greater potential for efficiency gains as the technology advances, fossil fuel end-use products are more limited with no path towards efficiencies of 100 percent or above. Energy Star gas water heaters systems, for example, are only 67 percent efficient whereas their electric counterparts are 200 percent efficient on-site.[30]

With heat pump technology, the old rule of thumb is now obsolete. The onsite unit efficiency of over 200 percent negates any efficiency that would be achieved by combusting fossil fuel on-site rather than at a fossil-fuel-based electric generator providing remote electrification to the unit. For example, analysis from the Vermont Public Interest Research Group (VPIRG) shows

  http://dx.doi.org/10.1016/j.tej.2015.09.019

Baseline Fuel	New Heating Fuel	
	Natural Gas	Electric Heat Pump
Oil	27%	34%
Propane	16%	26%

Figure 2: Carbon Emission Reductions from Fuel Switching to Gas or Cold Climate Heat Pump in Vermont
Note: Chris Neme, Supra note 32 at 7.

''a fuel switch to a cold climate ductless heat pump would also result in greater carbon dioxide emission reductions than a fuel switch to natural gas.''[31] The analysis, the results of which are shown in Figure 2, shows that using an electric heat pump reduces carbon dioxide emissions more than a high-efficiency natural gas system in Vermont. These findings incorporate the current marginal emission profile of electric power in Vermont; it does not account for future changes and probable emission reductions resulting from new federal policies and technology developments.[32] Similar studies by non-profit groups such as Environment Northeast show similar results. As emissions in the grid decline in the future, the case will only be more compelling all across the country.[33]

C. The need to manage electric end-use load to fit the supply availability of renewable energy

Traditionally, utilities have used a combination of baseload, intermediate, and peaking power plants to supply the necessary electrical power at the time it is needed. Traditional electric power can be scheduled. In order to integrate variable renewable electricity generation, utilities must find a way to integrate that power when it is available, which often does not coincide with periods of greatest end-use demand. Utilities need to manage load to meet available energy supply, creating a paradigm shift for the industry. Matching energy demand to energy supply can be assisted greatly by an often forgotten thermal storage device that is located in every home in the country – the water heater.[34] Energy storage is traditionally related with high-tech, expensive, and exciting battery technology. However, the simple technology of water heaters offers tremendous value through the ability to store energy taken from the grid at times when overall energy demand is low and energy is readily available and cheap—including energy generated by intermittent renewable resources, such as wind, solar, and hydro.[35]

Over 250 electric cooperatives in 34 states conduct demand response programs using electric resistance water heaters that are able to lower system peaks by over 500 MW.[36] While traditional end-use demand response simply lowers energy demand in times of short energy supply through load shedding, the thermal storage properties of water heaters enable both the demand reduction and the ability to increase load during times of excess energy supply. Such oversupply situations occur when the wind is blowing at night while people are sleeping, or when the sun is shining in the day while people are at work. This is the difference between load shedding and intelligent load control shown in Figure 3. Since a water heater can store energy until it is needed for a shower or dish or hand washing, consumers' hot water service will not be affected by delay in time between when the water is heated and subsequently used. The benefits of this ''electric thermal storage'' technology enabled by residential electric storage water heaters includes improved grid efficiency, reduced operating costs, and cost savings to consumers.[37]

While electric water heaters have long been a key asset for demand response programs, the technology is positioned for even greater value as the renewables market continues to mature. Using water heaters to store renewable energy can prevent it from being curtailed or spilled to maintain system reliability during periods of low load. This is one of the strategies put forth by the Regulatory Assistance Project (RAP) in its

  http://dx.doi.org/10.1016/j.tej.2015.09.019

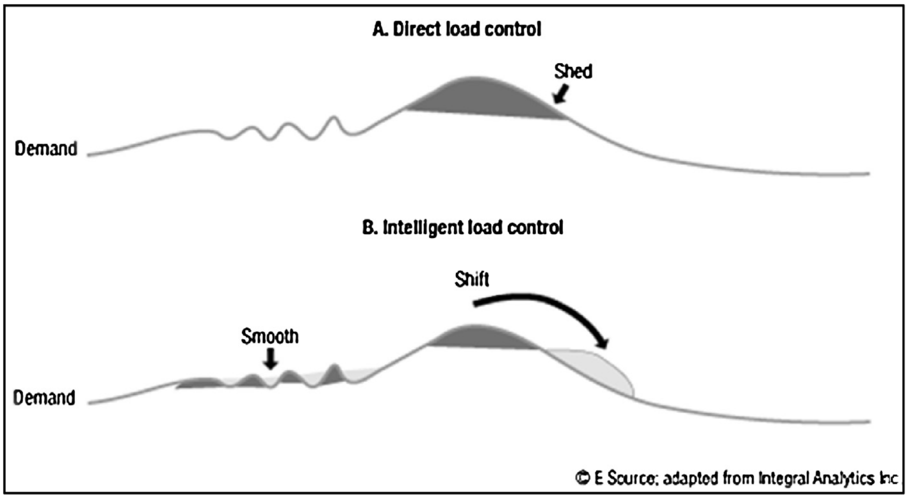

Figure 3: Using Water Heaters for Intelligent Load Control (David Podorson. 2014. Battery Killers: How Water Heaters Have Evolved into Grid-Scale Energy-Storage Devices) **Note:** An E Source White Paper.

paper ''Teaching the Duck to Fly''[38] to help solve the challenges faced in California as solar ramps up and down daily on its grid, a phenomenon illustrated by the rather infamous ''Duck Curve.'' According to RAP's analysis, implementation of water heater controls on 100,000 electric water heaters would enable the utility to add about 450 MW at any single hour, and to shift a total of about 1,000 MWh of energy between periods of the day.[39] PJM has found that water heaters are the most cost-effective form of energy storage available and a resource with a combined energy storage capacity on par with today's pumped storage hydro fleet.[40]

IV. Policy Considerations

Effectively implementing energy policy can be challenging, especially when the policies rely on consumers to make certain choices. Policymakers often provide consumers with tools and incentives to help them make choices that align with policy goals. These tools range from direct rebate incentives on certain equipment, minimum appliance standards, energy ''scores'' that rate the performance of their home, or Energy Star labels. These tools depend on technical analysis that must be periodically updated as technology changes or the policies incentivize the wrong choices, leading to sub-optimal outcomes. A period of rapid technology change makes updating these tools all the more urgent.

A. Revisiting the 'source' energy metric

The use of ''source'' energy estimates in expressing the relative energy performance of buildings and homes has become a practice in some programs and policies aimed at reducing end-use energy consumption, improving energy security, and reducing pollution. The idea behind the ''source'' energy metric is to represent the total amount of raw fuel that is required to operate the building. It incorporates all transmission, delivery, and production losses associated with energy use in buildings, as illustrated in Figure 4.

Among the high-profile programs that use source estimates are the EPA-DOE Energy Star program, DOE's Home Energy Score and Commercial Building Asset Rating programs, and DOE's proposed rules on reducing fossil fuel use at federal buildings.[41] Table 1 presents a

Table 1: Use of Flawed Source Energy Metric in Building Codes and Standards.

US EPA Energy Star for Commercial Buildings (Portfolio Manager)
US DOE Appliance Standards Program
California Title 24 Compliance Procedure
US DOE Home Energy Score
2012 International Green Construction Code
2012 International Energy Conservation Code
ASHRAE Standards
US Green Building Council LEED® 2014
Legislated Benchmarking and Reporting Requirements such as New York City Local Law 84
Federal building energy reporting requirements
DOE's Definition of Zero Energy Buildings

  http://dx.doi.org/10.1016/j.tej.2015.09.019

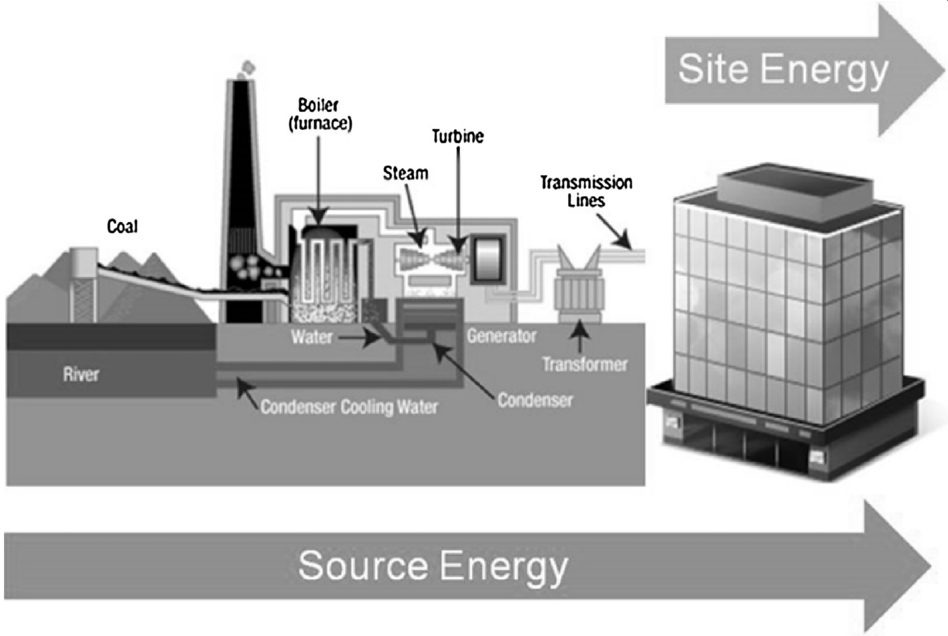

Figure 4: The Concept of 'Site' and 'Source' Energy Metrics
Note: www.energystar.gov

Table 2: EPA and DOE Source-Site Ratios[a]

Energy Type	U.S. Ratio
Electricity (Grid Purchase)	3.14
Electricity (on-Site Solar or Wind Installation)	1.00
Natural Gas	1.05
Fuel Oil	1.01
Propane & Liquid Propane	1.01

[a] For basic information, see: https://portfoliomanager.energystar.gov/pdf/reference/Source%20Energy.pdf

partial list of programs and policies inappropriately affected by the use of this metric.

With so much at stake, society needs and deserves estimates based on a technically sound and accurate methodology. The methodology used to calculate the source energy conversion lumps non-fossil electric generation in with fossil-fuel based generation, ignoring the fact that more than 30 percent of electric power is generated using non-emitting power sources. As a result, EPA, DOE and others treat electricity delivered to a home as if it is less than one-third as efficient as fossil fuel delivered to a home or business, which is technically unsound and ultimately leads to sub-optimal environmental end-use energy decisions. Correcting the flaws in the source energy metric is a priority on which environmental advocates and the electric industry can agree. Notably, in comments on a DOE appliance standard, the National Resource Defense Council (NRDC) commented ''the source conversion factors that EIA adopts have serious deficiencies for the purpose of setting a product standard; they're simply not the right numbers to inform good standards decisions.''[42]

The source-site ratios used by DOE, EPA and others are presented in Table 2. In order to calculate the ''source'' energy use of a building or home, EPA and DOE tools convert the energy delivered to the site into ''source'' energy using these ratios. For a home that receives electrical, natural gas, and propane service, for example, electricity use in British thermal units (Btu)[43] will be multiplied by 3.14, natural gas by 1.05, propane by 1.01. These values will be added together to determine overall ''source'' energy use for the building.

The ''source'' energy metrics used to gauge the relative performance of electric generation are based on EIA methodologies established before reducing carbon dioxide emissions was a policy objective and before renewable energy generation was a significant contribution to the electric grid. As NREL notes in their report of source energy metrics, the source-site ratios are ''based on the assumption that most of the electricity was produced from thermal electric power plants. The result tells nothing of the fuel types consumed or the emissions from the electricity production.''[44] This means that before even taking into account the efficiency of an electric appliance itself, the electricity from the grid used to power the device has already been determined by energy efficiency tools and policies to be less than one-third as efficient as on-site fossil fuel, no matter how it was generated.

  http://dx.doi.org/10.1016/j.tej.2015.09.019

Table 3: Approximate Heat Rates for Electricity New Generation Calculations Used by EIA in Energy Flow.

		Approx Heat Rates
Fossil Fuels	Coal	10,498
	Petroleum	10,991
	Natural Gas	8,039
	Total Fossil Fuel	9,516
Non-Emitting Generation	Nuclear	10,479
	Noncombustable Renewable Energy	9,516

The EIA Electricity Flow chart (**Figure 5**), upon which the source energy metric is based, is designed to illustrate the relative contribution of energy by fuel type into the electrical system. In order to illustrate the relative portion of non-fossil fuel in the grid, an artificial conversion for electricity generated by non-fossil fuels is used. For renewable energy, for example, a fossil fuel heat rate above the average for natural gas plants is used, as shown in **Table 3**. However, those artificial conversions are not appropriate for the purposes of illustrating relative resource efficiency or environmental performance of the various non-fossil fuels. The conversions are not based on any practical science and are contradictory to the policy objectives that the source energy metric is designed to address.

Using these heat rates to calculate source-site energy ratios makes the ratio insensitive to changes in the grid mix. In fact, adding renewable energy generation to the electric grid would have the same effect on the ratio as adding the average fossil fuel generation using EIA's methodology. Adding nuclear generation would actually increase the source-site ratio for electricity, which would signal consumers to invest in more on-site fossil fuel combustion as the grid lowers emissions. This is the opposite of policy objectives, is not understood by even the most informed consumers,[45] and is likely an unintended flaw in the methodology of the ratio that is just coming to light as use of the metric increases.

A Power Systems Engineering study replicating the EIA's methodology under various hypothetical scenarios demonstrates the flaws in the way the source energy metric is

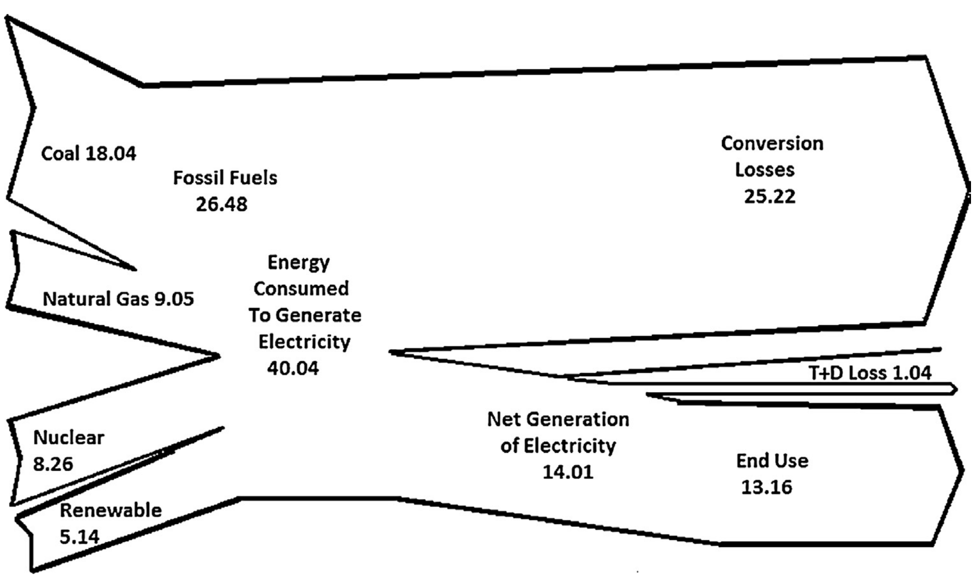

Figure 5: 2011 Electricity Flow (in Quadrillion Btu)
Note: EIA. Electricity Flow 2011. Modified for better display.

  http://dx.doi.org/10.1016/j.tej.2015.09.019

Table 4: Source-Site Ratios Using EPA/DOE Methodology[a]

	Source-Site Ratio
All Coal Switched to Gas	2.81
All Coal Switched to Renewable	2.99

[a] David Williams. 2014. *Source-Site Ratios.* Power Systems Engineering. http://www.nreca.coop/wp-content/uploads/2015/04/sourcesite_ratios_final_022015.pdf

Table 5: Sample Calculation of a 'Fossil Source' Energy Metric.

Sample Calculation of Current ''Source'' Energy Conversion Factor Using 2011 Data

Energy Consumed to Generated Electricity/(Gross Generation of Electricity − T&D Losses)=
40.04/(14.01 − 1.04) = **3.09**

Sample Calculation of Proposed ''Fossil Source'' Energy Conversion Factor Using 2011 Data

Fossil Fuels/(Gross Generation of Electricity − T&D Losses)=
26.48/(14.01 − 1.04) = **2.04**

currently calculated. The analysis shows that a switch of all coal-fired power in the country to renewable energy would result in a source-site ratio of 2.99 (Table 4). Under this scenario, despite using non-emitting sources to provide 71 percent of the grid's power, consumers would still be incentivized three to one to have gas end uses rather than electric.

Of critical concern, and driving the need to fix this metric, is that a myriad of energy policy tools are built on this flawed source energy metric. Output from these policy tools, for example, forms the basis for deciding whether homeowners and businesses should be provided or denied incentives based on the energy performance of their homes and buildings. These consumers are given inaccurate signals from the government and are improperly incentivized due to the flaws in this metric. This is in contrast to the intent of the tools, which is to help consumers to be better informed market participants.[46]

As the nation moves forward in an effort to curb carbon dioxide emissions, use of this metric in policy runs counter to those goals – especially in the context of EPA's Clean Power Plan (CPP). Under the CPP or other policies that cap emissions in the electric sector, there could be a significant and unintended incentive to switch consumers from a more environmentally beneficial electric system to one that burns fossil fuel on-site. The emissions from this one-site combustion would not be subject to the electric sector cap, so the switch from electricity to on-site gas would simply shift the emissions to sectors not covered under the cap. Use of source metrics in combination with other climate policies could thus lead to compliance of the electric-sector GHG rules while simultaneously significantly increasing GHG emissions of the country overall.

With new grid-connected combined cycle natural gas plants that are over 60 percent efficient, increasing new renewable electric generation on the grid, and large contributions of non-fossil hydro and nuclear power, it is inaccurate and inappropriate to characterize electricity as one-third as efficient as site-delivered fossil fuel. Since these metrics are subject to debate in many forums, from code hearings and appliance standards proceedings to legislation, there is an opportunity for utilities, environmental advocates, and policy makers to work to fix this issue. One proposal would be to simply replace the current ''source'' energy metric with a ''fossil source'' energy metric using data from the same EIA chart. A sample calculation with this simple change to the calculation used to derive the current metric is presented in Table 5.[47] This solution would better align the source energy metric with its intent of reducing primary fossil fuel use and its associated emissions. In addition to correcting the flawed treatment of renewable resources, NRDC's comments to DOE also include a proposal to use a ''marginal source'' value to better reflect the types of generation that power new appliances.[48]

B. Applying a systems approach to end-use efficiency

When considering an issue as broad as end-use energy efficiency it is important to take a

  http://dx.doi.org/10.1016/j.tej.2015.09.019

Table 6: Household Site End-Use Consumption by Fuel in the U.S., Averages, 2009[a]

	Electricity	Natural Gas	Propane/LPG	Fuel Oil
Water Heating (Million Btu)	9.1	21.0	18.9	18.6

[a] EIA. 2009. Residential Energy Consumption Survey. Table 4.6.

system-wide approach and viewpoint. This systems approach to efficiency has historically been lacking throughout the end-use efficiency community, but is critical to understanding the topic and implementing environmentally and economically optimal end-use strategies. In order for technology to work, it must be cost-effective. There is no ''one size fits all'' solution to end use and the simple existence of a technology with a higher efficiency rating does not mean that its use will be the optimal or most efficient fit for every application. Maximizing efficiency ratings of end-use appliances does not necessarily maximize the economic or environmental performance of our energy *systems* as a whole.

The optimal end-use energy policy should consider the adoption of heat pump technology as a tool where appropriate to meet goals, but not the whole solution itself. Indeed, there are many cases in which more traditional electric resistance technology is the most beneficial option. Electric resistance space and water heaters have a negative reputation in the efficiency community. However, it must to be recognized that in some cases this technology is the best economic and environmental choice when you take a systems approach. While space and water heating efficiency standards measure the ''energy efficiency factor'' of the specific end-use appliance, they do not capture the whole picture related to the application of the technology within the broader energy system, such as the home or business in which it is operating.

Take, for example, electric resistance water heating. Unlike gas water heaters, electric water heaters are extremely flexible in application because they do not need to be vented to the outside to exhaust combustion fumes. A gas water heater, on the other hand, necessitates the creation of a hole in a home's thermal envelope that would bring in external air at the outdoor temperature, decreasing the efficiency of the home. Electric resistance water heaters come in all shapes and sizes and can be tucked into closets near showers and sinks, reducing piping and distribution system loses. They also are superior products for use in electric thermal storage programs. Similarly, electric resistance space heaters can be used for ''zone'' heating and can be placed in basements and play rooms for use only during cold periods or periods when the area is being used. The flexible nature of electric resistance heating can negate the need to duct a central heating system or to operate a whole house HVAC system just to heat a specific space in a building. This enables overall energy savings in the building. Data collected by the EIA in its 2009 Residential Energy Consumption Survey shows that the *actual, field-observed* efficiency advantage for electric resistance water heaters over fossil-fuel-fired water heaters is dramatic (**Table 6**). The site energy use of an electric water heater in 2009, before the heat pumps would have registered in the survey, shows that an electric resistance water heater uses only 43 percent as much energy on-site as a gas water heater. This in part due to the energy savings associated with the flexibility of locating the electric resistance water heater near the point of water use without the need for long pipes or outdoor air venting, which is not accounted for in ''efficiency'' ratings of the products. However, the savings are confirmed in the surveys of actual installations.

In the final analysis, an environmentally beneficial choice is not always going to be a heat pump or the most ''efficient'' product as indicated by the product's label. Society needs metrics that will incentivize any technology where it makes cost-effective sense and more traditional electric technology where it is the best fit in order to

  http://dx.doi.org/10.1016/j.tej.2015.09.019

maximize the benefits of the decreasing grid emissions moving forward.

V. Conclusion

Incentivizing beneficial electrification with appliances and technologies available today would immediately reduce carbon dioxide emissions. Failure to do so will result in locking in technologies for many years that are net negative relative to greenhouse emissions reduction objectives. Given the current and future policies to lower grid emissions, the increasing popularity of heat pump technology, and the challenge of matching renewable energy supply with demand, end-use electrification will become a more and more attractive and useful option to improve the environmental performance of homes and businesses across the country. Due to the long life of end-use appliances, it is important that we get the policy incentives right now so that the investments made today align with the goals we hope to achieve tomorrow.

Climate goals cannot be met by widespread burning of fossil fuels in home appliances. Cost-effective electrification of end-use of electric appliances and vehicles will need to be a big part of any strategy designed to meet these types of policy objectives. It is now not a matter of whether electrification will be the obvious choice for end-use, it is a matter of when we reach the tipping point where electricity is *the* choice.■

Endnotes:

1. Constable, George; Somerville, Bob. 2003. A Century of Innovation: Twenty Engineering Achievements That Transformed Our Lives.

2. World Bank Independent Evaluation Group. 2008. *The Welfare Impact of Rural Electrification: A Reassessment of the Costs and Benefits.*

3. Amber Mahone et al. 2015. *California PATHWAYS: GHG Scenario Results*. Energy and Environmental Economics.

4. LBNL. 2013. California's Carbon Challenge Phase II Volume I: Non-Electricity Sectors and Overall Scenario

5. For example, Jeffrey Sachs (Five Questions for Jeffrey Sachs On Decarbonizing the Economy. July 15th, 2014) and Bill Nye (Chris Smith. 2015. *Watch Bill Nye Explain Climate Change with Emoji*. BGR News).

6. While it could be argued that the idea that on-site fossil fuel combustion is environmentally preferred to on-site use of electricity has never been accurate in geographic locations where the local grid is supplied by low- or non-carbon dioxide emitting sources such as nuclear or hydro, this idea is quickly becoming outdated throughout the entire nation.

7. 75 FR 20112.

8. This is a simplified example for illustrative purposes and does not take into account losses in the overall energy system of the house associated with gas systems as discussed in Section IV(b) herein.

9. John Siciliano. Climate Daily News. Gas Utilities To Remain Neutral In 2015 Fight to Impede EPA Climate Rule. Posted: Dec. 19, 2014.

10. LBNL. 2013. *Scenarios for Deep Carbon Emission Reductions from Electricity by 2025 in Western North America Using the Switch Electric Power Sector Planning Model*. California's Carbon Challenge Phase II Volume II.

11. California Energy Commission. Residential Compliance Manual for the 2013 Building Energy Efficiency Standards. June 2014.

12. This article focuses on end-use space and water heating appliances. There are similar opportunities for electrification of vehicles, diesel agricultural pumps, and small internal combustion engines like lawnmowers and commercial blowers.

13. EIA. 2015. Electric Power Monthly. Table 1.1.

14. EIA. 2015. What is U.S. electricity generation by energy source?

15. FERC Office of Energy Projects Energy Infrastructure Update, May 2015.

16. Tim Shear. EIA. 2015. Scheduled 2015 capacity additions mostly wind and natural gas; retirements mostly coal. Today in Energy.

17. EIA. 2014. AEO2014 projects more coal-fired power plant retirements by 2016 than have been scheduled.

18. U.S. EPA. 2014. Regulatory Impact Analysis for the Proposed Carbon Pollution Guidelines for Existing Power Plants and Emission Standards for Modified and Reconstructed Power Plants. pp. 3–26.

 1040-6190/ http://dx.doi.org/10.1016/j.tej.2015.09.019

19. Executive Office of the President. 2013. *The President's Climate Action Plan.*

20. Anne Claflin. 2015. *Greenhouse Gas Emissions Reduction: Biennial Report to the Minnesota Legislature. Minnesota Pollution Control Agency: Minnesota Department of Commerce. p. 1.*

21. California Environmental Protection Agency: Air Resources Board. *Climate Change Programs*. 2015.

22. The White House. 2015. *Fact Sheet: President Obama to Announce Historic Carbon Pollution Standards for Power Plants.*

23. The White House. 2015. *U.S.-Brazil Joint Statement On Climate Change.*

24. 80 FR 13122.

25. 73 FR 20159.

26. Geothermal heat pump systems reach efficiencies of well over 400%, but have less mainstream market potential.

27. US DOE. www.energy.gov

28. AHRI market data.

29. Jack Newsham. 2014. As electricity costs rise, market for heat pumps takes off. The Boston Globe.

30. US EPA ENERGY STAR® Product Specification for Residential Water Heaters V. 3.0.

31. Vermont Public Interest Research Group (VIRG). 2014. *Prefiled Testimony of Chris Neme.* Docket No. 8180. p. 4.

32. Chris Neme, Energy Futures Group.2014. *Comparative Analysis of Fuel-Switching from Oil or Propane to Gas or Advanced Electric Heat Pumps in Vermont Homes*. Docket 8180 Neme Attachment B. p. 8.

33. Environment Northeast Inc. 2014. *An EnergyVision Pathway to a Modern, Sustainable Low Carbon Economic and Environmental Future.*

34. This same strategy can potentially be done in the future with electric vehicles.

35. Alice Clamp. NRECA. Water Heaters for Thermal Storage: Major Cost Benefits but Wider Grid Use Faces Challenges. March 2015.

36. *Id.*

37. In April 2015, with wide-ranging support from efficiency and environmental groups, manufacturers, and utilities, new legislation was signed into law to create a new classification of grid-enabled water heaters, or large electric resistance water heaters designed for use in electric thermal storage programs. Public Law No. 114-11.

38. Jim Lazar. 2014. Teaching the ''Duck'' to Fly. RAP.

39. *Id.*

40. Terry Boston. April 7, 2014. *Urgent Action on Energy Conservation Standards for Residential Water Heaters*. DOE Docket # EERE-2012-BT-STD-0022.

41. DOE Docket # EERE-2010-BT-STD-0031.

42. NRDC Comments to DOE Docket: EERE-2014–BT–STD–0031. July 2015 at 7.

43. The electricity will first be converted to Btu using a value of 3,412 Btu/kWh.

44. M. Deru, P. Torcellini. 2007 Source Energy and Emission Factors for Energy Use in Buildings. NREL. p. 4.

45. For example, BSD-151: Understanding Primary/Source and Site Energy, by Kohta Ueno and John Straube, states: ''Of course, over time, the fraction of renewable energy is expected to increase, making the grid 'greener.' With the retirement of old coal, the addition of wind, high efficiency gas, biomass, tidal, or even nuclear, the carbon intensity of producing electricity will drop, and the source-site ratio will drop.'' The idea put forth by these experts is not accurate as increasing use of these fuels will not significantly affect the source-site ratio. This highlights the level of confusion around the source metric and the technical details of how it is calculated.

46. Dennis, K., 2006. The compatibility of economic theory and proactive energy efficiency policy. Electr. J. 19(7), 61.

47. This would replace the use of the 40.04 quads listed as ''energy consumed to generate electricity'' with the 26.48 quads of fossil fuel used to generate electricity in source calculations. The result would indicate the grid fossil source portion of the electric grid is currently approximately 50 percent, or the ''fossil source-site'' ratio is approximately 2.

48. NRDC Comments to DOE 2015 Supra note 42.

  http://dx.doi.org/10.1016/j.tej.2015.09.019