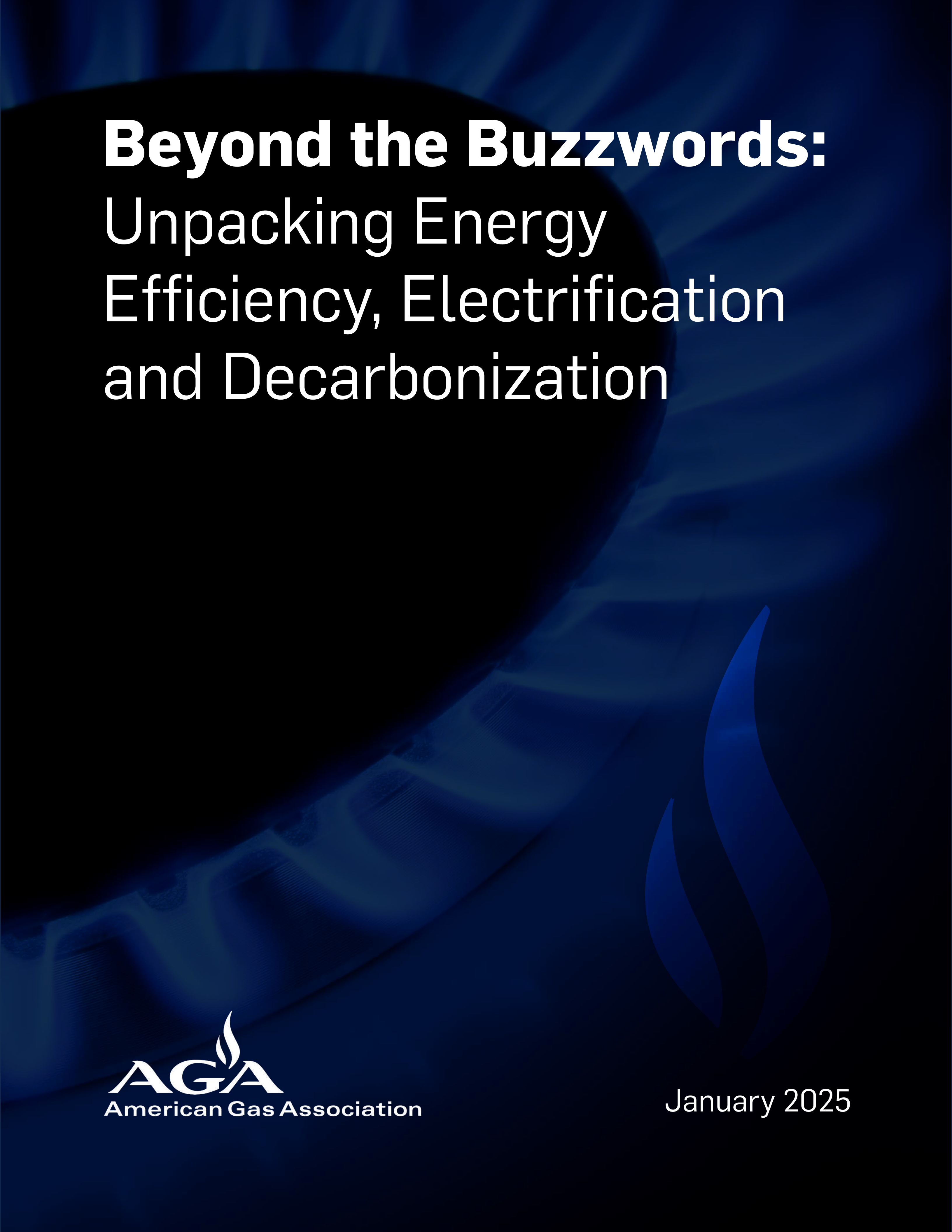

Beyond the Buzzwords: Unpacking Energy Efficiency, Electrification and Decarbonization

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Introduction

In the past decade, efforts to mitigate climate change have intensified, focusing on the need to reduce greenhouse gas emissions across every sector of the economy. Achieving meaningful progress will require an all-of-the-above energy strategy that focuses on maintaining safe, reliable and affordable energy for all consumers while advancing innovation that incorporates lower-carbon solutions at scale.

These efforts have led to a prevailing but inaccurate assumption that **electrification**—shifting from fossil fuel use to electricity for residential, commercial, industrial and transportation applications—equates to **decarbonization** and, by extension, contributes to climate change mitigation. This false belief rests on the notion that converting fossil-fuel-based energy loads and appliances to electricity will significantly reduce greenhouse gas emissions as the electrical grid incorporates more renewable sources. Consequently, terms like "electrification," "decarbonization" and even "energy efficiency" (or energy conservation) have become interchangeable in policy discussions.

While the concepts of "electrification," "decarbonization" and "energy efficiency" may be interconnected, they are not synonymous and have conflicting and contradictory meanings. Each represents a distinct goal, which may not be aligned. For example, in many locations in the United States, the use of electric applications as a substitute for other fuels may result in higher emissions or require greater energy use. Therefore, "electrification" as a policy objective would conflict with decarbonization or energy efficiency goals. Overlooking these distinctions can lead to policies that focus solely on advancing electrification without adequately considering emissions reductions or energy efficiency improvements.

This paper examines the distinct roles of energy efficiency, electrification and decarbonization in pursuing climate goals and challenges the assumption that electrification alone ensures emissions reductions. By disentangling these concepts, a wider array of policy solutions aimed at sensible emissions reductions can be explored. In this context, a holistic approach to emissions reduction that combines the direct use of natural gas, integration of renewable sources and implementation of efficient technologies emerges as the most effective way to reduce greenhouse gases while maintaining safe, reliable, resilient and affordable energy service choices for consumers.

Key Terms:

Decarbonization is the process of reducing greenhouse gas emissions across energy end-uses or sectors of the economy.
Electrification refers to the replacement of direct fuel use with electric end-uses.
Energy efficiency refers to using less energy to perform the same task or produce the same outcome.

Defining Energy Efficiency

Energy efficiency refers to using less energy to perform the same task or produce the same outcome. Efficiency is achieved through various mechanisms, including, but not limited to, advanced technology, process optimization and behavioral changes. Energy efficiency measures are critical for reducing energy consumption to lower consumer costs, among many other ancillary benefits.

Utility energy efficiency programs are designed as a set of initiatives and strategies that promote the efficient use of energy among residential, commercial and industrial customers. These programs are organized around the primary goal of reducing energy use. As a result of the energy saved, there can be many resulting benefits, including 1) cost savings in the form of lower utility bills, 2) enhanced customer comfort and safety, 3) energy security and reliability, 4) job creation and market growth and 5) emission reductions.

While energy efficiency is crucial for reducing overall energy use and lowering costs, it is not synonymous with decarbonization or electrification for several reasons:

1. Distinct End-Goals

Energy efficiency aims to reduce energy consumption and costs. While energy efficiency can contribute to emissions reductions, the primary focus is conservation. As such, energy efficiency does not inherently target carbon emissions, but it is a critical component of sustainability and environmental goals.

2. Energy Source Matters: Considering the Full Fuel Cycle

Energy efficiency does not address the energy source or emissions associated with its use. A full-fuel-cycle (FFC), also known as a lifecycle approach, is necessary to measure true energy requirements. A full-fuel-cycle measure also captures emissions produced at every stage of the energy lifecycle, from production, transportation, generation and distribution. There is further discussion on the full-fuel cycle below.

3. Manufacturing Emissions
Thoughtful decarbonization policy should consider the emissions associated with manufacturing, transportation and disposal of products and processes. For instance, producing more energy-efficient appliances or vehicles can involve carbon-intensive manufacturing processes that must be accounted for in decarbonization strategies.

4. The Need to Align Policy and Market Mechanisms with Cost and Emissions Goals
Cost savings and market mechanisms can drive energy efficiency without necessarily reducing carbon emissions, especially if the efficiency policy induces fuel switching to an energy source that leads to higher emissions. As such, decarbonization often requires complementary policies, regulations and incentives designed to lower carbon emissions.

5. Regulatory Mechanisms Encourage Energy Efficiency
Energy efficiency programs are funded through various mechanisms to leverage public and private sector resources. One primary funding source comes from utility customers, where small fees on customer bills support broader energy efficiency initiatives to help consumers reduce energy consumption and lower overall utility bills. Utility efficiency programs provide rebates for energy-efficient appliances, weatherization assistance, educational outreach and other activities and services. Government grants and incentives are also crucial in financing energy efficiency efforts. At the federal, state and local levels, governments provide financial support in the form of grants, subsidies, or tax incentives to encourage the adoption of energy-efficient technologies and practices. These funds bolster the implementation of projects that enhance building efficiency, upgrade industrial processes and enhance energy security.

Better Understanding Full-Fuel Cycle (FFC) Analysis

The concept of full-fuel-cycle (FFC) analysis is crucial for distinguishing the environmental benefits of energy efficiency versus electrification because it provides a comprehensive view of emissions across the entire energy lifecycle. The definition of FFC energy used throughout this paper is as follows: **Full-fuel-cycle energy is the energy consumed by an appliance, system, or building as measured at the building site plus the energy consumed in the extraction, processing and transport of primary energy forms such as coal, oil, natural gas, biomass and nuclear fuel; energy consumed in conversion to electricity in power-generation plants; and energy consumed in transmission and distribution to the building site.**

The energy and environmental benefits of different policies or strategies cannot be accurately measured without considering FFC analysis, which accounts for the emissions from every stage of the energy process—from raw material extraction and processing to fuel transportation, electricity generation and end-use.

For example, electrifying heating systems may reduce site emissions but can result in higher emissions upstream if the electricity is sourced from fossil-fuel-dominated grids. On the other hand, energy efficiency measures often reduce emissions without depending on the source mix, as they reduce energy consumption at all stages.
Without FFC analysis, policymakers may overlook the upstream emissions associated with electrification, particularly in regions with carbon-intensive electricity grids, potentially overestimating its environmental benefits. By applying FFC analysis, they can better understand how energy efficiency and electrification compare in terms of total emissions and can design policies that target meaningful emissions reductions across the entire energy lifecycle. This approach ensures that efforts to decarbonize are rooted in comprehensive emissions data, leading to more effective and intentional environmental outcomes.

The U.S. Department of Energy (DOE) addressed the importance of FFC in its 2011 policy statement on Full Fuel Cycle analyses. The DOE highlighted that relying solely on site-based emissions can result in an incomplete or misleading understanding of the environmental impacts of energy use. DOE's policy encourages using FFC metrics, particularly when comparing energy sources with distinct upstream and transmission impacts, to accurately represent total emissions.

Understanding FFC versus site and source emissions is critical for policymakers and stakeholders. Without such insight, policies aimed at emissions reduction might unintentionally favor energy solutions with lower site emissions but higher full-fuel-cycle emissions, leading to unintended environmental impacts. By integrating FFC into energy policy assessments, policymakers can better align decisions with overarching climate goals, supporting policies that address immediate site-based and broader lifecycle emissions.[1]

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[1] https://www.federalregister.gov/documents/2011/08/18/2011-21078/energy-conservation-program-for-consumer-products-and-certain-commercial-and-industrial-equipment

Electrification ≠ Decarbonization

Electrification refers to the process of replacing technologies and systems that use fuels directly with electricity as their primary energy source. Electrification can apply to many economic sectors, including transportation, heating and industrial processes.

Policy-driven building electrification refers to direct or indirect regulatory or legislative actions that incentivize or require the elimination of natural gas, propane and fuel oil as options for space heating, water heating and other uses in favor of electric applications. Policy-driven building electrification assumes that the electricity grid will become less carbon-intensive over time, resulting in significant greenhouse gas emissions reductions across electrified end-uses.

While electrification may be a component of strategies that reduce greenhouse gas emissions, it does not inherently guarantee reductions in greenhouse gas emissions or improved energy efficiency. The environmental benefits of electrification depend on the electricity sources and the electric systems' overall energy efficiency compared to the fossil fuel systems they replace. Further, electrification is not inherently synonymous with decarbonization or energy efficiency for the following reasons:

1. The source (full-fuel-cycle) of electricity end-uses matters.
The environmental impact of electrification depends significantly on how the electricity is generated and the fuels that are replaced or reduced. If electricity comes from carbon-intensive sources, the reduction of emissions may be minimal or emissions may increase compared to using direct fossil fuel applications.

2. Electrification may lead to greater energy consumption.
Electrification does not automatically lead to increased energy efficiency. Many electric systems are less efficient than their direct fuel counterparts. For example, electric resistance heating requires significantly more energy for the same services than a natural gas furnace, as measured on a full-fuel-cycle basis.

3. Infrastructure build-out and grid management must be considered.
Widespread electrification may require substantial upgrades to electric generation, transmission and distribution systems. Residential or commercial electrification may also require electrical upgrades in new and existing homes and buildings. A widespread shift to electric heating, including the use of more efficient heat pump technology, could drive significant increases in peak electric loads and shift the electric grid to winter peaking in many locations, which can increase the challenges associated with decarbonizing the electric grid using variable renewable sources.

4. Reliability and Resilience Impacts must also be considered.
The current energy system, served by natural gas infrastructure and end uses, provides reliable and resilient services to natural gas consumers and other parts of the system. Replacing this system with largely electric end-uses served by increasing amounts of variable renewable resources could create new challenges to overall energy system reliability and resilience.

Leveraging the Direct Use of Natural Gas for Efficiency Gains & Emissions Reductions

In 2024, the American Gas Association published a report titled *Building for Efficiency: Home Appliance Cost & Emissions Comparison*, which compares natural gas and electric appliances in terms of their associated greenhouse gas emissions and cost. Among its key findings, the study shows that natural gas provides significant annual cost savings for new homes, with advanced gas setups saving even more than electric heat pumps. Most new homes prefer high-efficiency gas furnaces, especially in colder climates and advanced gas systems can achieve comparable or greater emissions reductions than all-electric homes.

Additionally, the study examines scenarios where electrification does not yield comparable efficiency or environmental benefits, providing evidence-based insights that underscore natural gas's advantages in specific applications.

Natural Gas Water Heaters vs. Standard Electric Water Heaters

Water heating significantly contributes to residential and commercial energy consumption, representing up to 20% of energy usage in some households. The choice of water heating technology directly impacts energy efficiency and emissions.

Data from AGA's Building for Efficiency Report highlights the substantial efficiency and emissions advantages of natural gas water heaters over standard electric water heaters. It's useful to examine the site and full-fuel-cycle efficiencies of different end-use equipment. In this case, we use a full-fuel-cycle multiplier for natural gas of 0.92 and 0.39, per data available from the GTI Energy, Energy Planning Analysis Tool.

Efficiency Comparison:

- **Natural Gas Water Heaters**: These systems typically operate at a site efficiency rate of 62 - 95% Energy Factor (EF), implying a full-fuel-cycle efficiency of 57 – 88%. The use of natural gas water heaters often translates to lower energy consumption per unit of heat produced. The direct combustion of natural gas means more of the energy input is converted into usable heat, with less loss.
- **Standard Electric Water Heaters:** Operating at an average site efficiency of 90 to 99% EF, implying a full-fuel-cycle efficiency of 35 – 38%. Therefore, standard electric water heaters consume significantly more energy to produce the same level of hot water. Electric resistance heating, common in standard electric water heaters, inherently suffers from conversion losses at power plants, further reducing overall system efficiency.

Emissions Impact:

The shift from a natural gas water heater to an electric model can increase carbon emissions for households and businesses reliant on electricity from a fossil-fuel-heavy grid. AGA's report indicates that natural gas water heaters emit approximately 30-40% less CO_2 compared to their electric counterparts on average, depending on regional electricity sources. In regions where coal or natural gas predominates in power generation, electric water heating may lead to a net increase in emissions.

Natural Gas Furnaces vs. Electric Heat Pumps in Cold Midwest States

Heating in colder climates poses distinct energy challenges. This example compares natural gas furnaces to electric heat pumps in a cold Midwest state, where winter temperatures can frequently drop below freezing. In such environments, electric heat pumps may struggle to maintain efficiency and low emissions levels, making natural gas furnaces a more practical solution.

Efficiency and Performance Comparison:

- **Natural Gas Furnaces:** Modern natural gas furnaces achieve site efficiencies of up to 98% (Annual Fuel Utilization Efficiency, AFUE), implying a full-fuel-cycle efficiency of 90%. Natural gas furnaces deliver consistent heating performance even in extreme cold. The high efficiency minimizes energy consumption and reduces the carbon footprint associated with space heating.
- **Electric Heat Pumps:** While heat pumps can be efficient in mild temperatures, their efficiency and output can decline significantly as temperatures drop. A minimum efficiency pump is rated at 2.2 COP (7.5 HSPF2), implying a full-fuel-cycle efficiency of 85%. However, at temperatures below 20°F, electric heat pumps will operate at lower site efficiency and lower output capacity and thus require supplemental electric resistance heating to maintain indoor comfort, which can increase energy use substantially. This leads to higher energy consumption in cold Midwest states compared to natural gas furnaces, especially during prolonged cold spells.

Emissions Impact:

The report's data shows that electric heat pumps can produce higher emissions than natural gas furnaces due to the fuel mix used to generate electricity and the additional energy required to satisfy heating loads in colder climates. In states where electricity is generated primarily from coal or natural gas, the increase in electricity demand during cold periods translates to higher greenhouse gas emissions.

These examples illustrate that, in many cases, the direct use of natural gas in residential and commercial settings offers clear advantages for energy efficiency and emissions reduction, especially when compared to standard electric options. Water heating and space heating applications highlight areas where natural gas meets and exceeds efficiency and environmental standards. Conversely, using electric alternatives, particularly in regions with colder climates or a fossil-fuel-dominated electric grid, can result in higher energy consumption and emissions. Tailoring energy solutions to specific regional and application based requirements is essential for energy efficiency and emissions reduction.

Conclusion

Decarbonization requires a multifaceted approach that includes accurately accounting for and reducing full-fuel-cycle (FFC) energy and emissions, alongside implementing targeted policies to lower carbon emissions. This involves managing energy demand, promoting emerging technologies, utilizing renewable and low-carbon fuels and integrating negative emissions technologies.

Policymakers and stakeholders should consider the following strategies to craft effective and balanced energy policies that address climate goals while maintaining affordability and reliability:

- **Adopt a Holistic Approach to Decarbonization:** Avoid one-size-fits-all policies. Utilize FFC metrics to assess total emissions and energy impacts of various energy sources and technologies.
- **Promote Energy Efficiency as a Standalone Objective:** Expand energy efficiency programs and regulatory frameworks that incentivize efficiency improvements across the energy lifecycle.
- **Utilize the Full-Fuel-Cycle:** Use full-fuel-cycle (FFC) measures of energy use and emissions, rather than the primary (or site) energy measures.
- **Leverage Natural Gas's Role in Decarbonization:** Preserve high-efficiency gas systems for cost-effective, low-emission energy solutions and encourage advanced natural gas technologies, including renewable natural gas.
- **Support Integrated Energy Strategies:** Combine renewable energy, direct natural gas use and energy efficiency measures to achieve tailored emissions reductions. Invest in innovative technologies to accelerate progress.
- **Institute Robust Regulatory Frameworks:** Establish clear, measurable goals and ensure transparency through FFC-based data reporting to promote accountability and informed decision-making.
- **Educate and Engage Stakeholders:** Raise public awareness about the distinctions between energy efficiency, electrification and decarbonization. Preserve consumer choice by supporting diverse energy options tailored to specific regional and application needs.

As the energy sector pursues ambitious emissions reduction goals, solutions must be tailored to regional, technological and application-specific contexts. Policymakers should address safety, affordability, feasibility, equity, energy reliability and resilience challenges.

With its high efficiency and lower emissions in key applications such as space and water heating, natural gas is a valuable energy source. Studies show that high-efficiency natural gas appliances often outperform electric alternatives in cost-effectiveness and emissions, particularly where grids rely on fossil fuels. Optimizing FFC emissions from natural gas and other resources can support a pragmatic, balanced decarbonization strategy that maximizes environmental and economic benefits, fostering a more energy-efficient and adaptable transition to a lower-carbon future.