Building Electrification in Arlington County

WHITEPAPER

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Purpose

Since its adoption by the Arlington County Board in 1999, the County's voluntary Green Building Incentive Policy (GBIP) has been one of its primary tools to lower carbon emissions and reduce environmental impact in the private building sector. The GBIP has been highly valued and utilized by developers in Arlington. The first site plan under the GBIP was approved in 2001, and since then more than one hundred site plans have opted into the policy to receive bonus density (FAR) in exchange for meeting stringent green building requirements.

The County periodically evaluates the efficacy of the GBIP and makes updates to the program to align with current market conditions and maximize the benefits of the program. County staff within the Arlington Initiative to Rethink Energy (AIRE) are currently conducting comprehensive stakeholder engagement as part of the 2025 update, the seventh update to the policy since its inception. During the public engagement period for the 2020 policy, as well as the current proposed policy for 2025, environmental advocates in Arlington County have called for requiring full building electrification in order receive bonus density, or other proposed incentive under the voluntary policy.

Prior to the County Board's adoption of the 2020 policy, Steven Winter Associates (SWA) published a report for the County regarding the state of building electrification. This Cadmus report is intended to update and expand upon the key findings in the SWA report, as well as evaluate the role of building electrification in the current policy update. To provide stakeholders with information about the current state of electrification, this report details common commercially available technology options for electrification, the benefits of electrification including impacts on greenhouse gas (GHG) emissions, and outlines challenges that need to be addressed to implement electrification at scale across the County.

Executive Summary

Under the 2019 Community Energy Plan (CEP), Arlington County has set a path to achieve its 2050 GHG emissions reduction target for carbon neutrality. To meet this target, the County will need to rely heavily on reducing GHG emissions from energy use by buildings in the private sector. When new buildings are built, there is a critical opportunity to minimize the carbon footprint of heating, cooling, and other building systems by using efficient design and equipment. The County established its Green Building Incentive Policy (GBIP) more than 25 years ago to take advantage of this opportunity. This program provides incentives for building owners and developers to pursue higher levels of energy efficiency than are strictly required by the building code when constructing new buildings.

Switching from technology that uses fossil fuels on site, such as natural gas-fired furnaces and cookstoves, to electric sources of energy, such as heat pumps and induction cookstoves, is known as building electrification.

As the County considers the evolution of the GBIP, the primary initiative by which it engages building owners in promoting sustainable design principles, it must consider building electrification in addition to energy efficiency standards. Although energy efficiency initiatives have been highly successful in reducing the energy use in buildings, and thus reducing GHG emissions, buildings will continue to contribute to GHG emissions as long as they use energy generated from burning fossil fuels.

Electrification can reduce GHG emissions in energy efficient buildings beyond what efficiency measures alone can accomplish, provided that the electricity is generated from sources of zero-emission energy, such as renewables. Paired with zero-emission electricity generation, electrification can be the most impactful step toward decarbonization that a building can take, and deep decarbonization of the building sector will require substantially more buildings, including existing buildings, to become all electric. Electrification also brings additional advantages. For example, replacing on-site fuel combustion (such as gas stoves) with electric technologies can reduce indoor air pollution, leading to heathier indoor environments. Finally, although upfront costs vary significantly, fully electrified buildings in regions with affordable electricity rates may have lower annual utility costs.

However, electrification at scale also presents certain challenges to developers and building owners and will require changes to cost distribution, contractor education, and policy incentives before electrification can truly be deployed at scale. This whitepaper provides an overview of available technologies for electrification of new building construction and retrofits of existing buildings as well as barriers that will need to be addressed. In most cases, the focus of building electrification is on space heating and HVAC systems, domestic hot water (DHW), and cooking. While many of the technologies needed to fully electrify the predominant building types in the County (office buildings and multifamily housing) are mature, commercially available technologies, voluntary electrification of buildings will require addressing a few key barriers to their implementation.

While this paper does not make direct recommendations regarding changes to Arlington County's policies or programs, it does offer a few key takeaways which are generally applicable to building electrification in the County:

- Electrification is technically possible for a wide range of building types, although system improvements and upgrades are often necessary to convert existing buildings.

- The specific project costs and feasibility of installation are highly site dependent and vary based on building age and construction, existing system type and layout, and building use and occupancy patterns.
- Electrifying existing buildings can generally be expected to incur a cost premium as compared to the installation of fossil fuel fired technologies but *may* result in reduced operational costs.
- Electrification reduces overall emissions, but uncertainty about future load growth and the pace of deployment of new, non-emitting generating assets will impact the scale of the associated GHG emissions reductions.

Building owners must overcome significant upfront costs and, often, complexity. There are three major cost elements associated with building electrification to be considered: 1) capital costs, 2) implementation/integration costs, and 3) operational costs. While cost can be highly variable, electrification in both new construction and existing buildings is generally likely to incur an equipment and installation premium relative to installing or replacing a boiler or furnace. Most electrified space and hot water heating equipment have physical and operating characteristics that differ from the fossil fuel systems they replace. While heat pumps can sometimes be “drop in” replacements for fossil fuel systems, in many cases, modifications to the existing system are necessary. This can add both cost and complexity to prospective projects. The operational costs of a system can be difficult to predict; on the one hand, electric technologies usually operate more efficiently than fossil fuel fired systems, and on the other, natural gas in Virginia is typically cheaper than electricity on a delivered energy content basis. Overcoming cost barriers will require innovative approaches to financing projects and incentives as well as targeted investment in disadvantaged communities.

Electric distribution infrastructure may require upgrades. Both building and utility distribution infrastructure must accommodate the higher loads associated with building electrification. Many buildings have their electrical infrastructure designed to accommodate loads associated with cooling (air conditioning) needs. Adding electrification of space heating and hot water production increases the building’s overall electricity use. As a result, the transformers, conductors, and switch gear to supply energy to the building may need to be upgraded, and the project construction may require increased coordination with the distribution utility, adding time and cost to the project. Long lead times for procuring distribution scale transformers and aligning electrification project delivery with the utility’s construction timeline could discourage building owners from pursuing electrification. Building-sited transformers and switchgear are costs that are appropriately allocated to the building owner. However, the costs of upgrading utility-owned and -sited equipment on the distribution feeder or at the substation can be disproportionately borne by the building owner, despite having the potential to benefit many customers on the grid. While not limited to building electrification alone, the allocation of costs associated with serving growing electric demand is a complex issue, and adopting alternative cost models requires policy changes at the state level.

Equipment replacements should be aligned with building system lifecycles. Heating/cooling and hot water systems are typically foundational systems within a building, and it can be both complicated and expensive to change the system type or configuration in an occupied building. Such systems are typically expected to have a useful life of 20 or more years and are not frequently replaced prior to reaching the end of their expected useful life. As a result, among existing buildings, only a relatively small proportion of the total stock would be likely to be considered for a major capital project to install a new system in any given year. This will require planning from building owners and managers to strategically implement system upgrades. Contractor education plays a vital role in ensuring that building owners are able to effectively plan and understand options for electrification.

Investments in electrification reduce emissions. To assess the potential benefits, this whitepaper presents representative energy savings and GHG reduction metrics from implementing selected electric space heating, water heating, and cooking technologies in reference to office and multifamily buildings. We find that investments in building electrification, particularly space heating, have the potential to reduce overall building energy consumption by 17-23% in existing buildings, with smaller reductions for water heating and cooking electrification. We also estimate that space heating electrification has the potential to reduce greenhouse gas emissions by 12-16%[1]. While the GHG reductions resulting from electrification may change over time as the proportion of renewable energy on the grid increases, an important finding was that electrification *does* result in an overall reduction in GHG emissions even if the exact trajectory is uncertain.

GHG emissions impacts depend on future grid electricity generation sources. Building electrification has the potential to reduce a building's site emissions to zero by eliminating onsite fossil fuel combustion. However, emissions associated with generating the electricity a building uses are still attributed to that building, and therefore an electrified building's emissions profile will depend on the source of electricity. Both nationally and in Virginia there is a trend toward an increasing proportion of non-GHG emitting energy sources in the generation mix. The pace of this transition over the next several decades will influence the degree to which building electrification translates to building decarbonization.

These logistical and financial barriers may present challenges for building owners pursuing electrification when they are replacing major systems. While building electrification represents an important strategy for decarbonizing Arlington County's building stock, achieving electrification at the necessary scale will require policy support. that includes existing (and potentially expanded) incentive programs, continued outreach and education among building owners and operators, developers, and engineers, and the use of innovative financing such as the County's C-PACE program.

[1] These values will be described in greater detail in the section on "Technology Overview and Analysis"

Background and Context

Reducing GHG emissions from the built environment is a key element of Arlington County's decarbonization goals. Deep decarbonization of the building sector requires using less energy and energy that is less carbon-intensive, which building electrification will help achieve. Electrification refers to the transition from equipment that uses fossil fuels to technologies that use electricity to achieve the same end uses, with an emphasis on space and water heating and cooking.

With this consideration in mind, Arlington County requested that Cadmus complete an assessment of opportunities, challenges, and costs associated with full electrification of commercial new construction, existing buildings, and building conversions, which we provide in this whitepaper. We also have provided an updated analysis on the impact that selected electrification technologies have on building energy consumption and GHG emissions.

Electrification alone does not ensure decarbonization, and there are several factors that must be considered with evaluating the costs and benefits of electrification. While electrification is typically the most impactful step that building owners can take to facilitate the reduction of direct carbon emissions from buildings, an additional, parallel process of electricity decarbonization must also occur to ensure that the electricity consumed by the built environment is not a source of GHG emissions.

In this whitepaper, we provide context on the state and local policy landscape, an overview of the different technologies that can be used to electrify a building, and the associated challenges and opportunities for implementation. We also discuss the current and projected emissions from electricity generation for Virginia to provide a better understanding of emissions associated with electrified buildings compared with on-site fossil fuel usage.

Virginia Climate Policies and Goals

The Commonwealth of Virginia has established climate goals and has adopted several pieces of legislation in recent years to identify potential solutions to the state's most significant climate issues.

In 2020, the General Assembly of Virginia passed the Virginia Clean Economy Act (HB1526) (VCEA) which established the state's first clean energy standard and identified a renewable energy target for utilities: a 100% clean electric grid by 2050. In addition, the legislation sets energy resource targets for solar, offshore wind, and battery storage, as well as specific requirements for Virginia's largest utilities. Dominion Energy, which serves Arlington County, must rely entirely on renewable energy by 2045 while maintaining grid reliability. This should lead to less carbon-intensive electricity being delivered to buildings in the County, so electricity use will create less GHG emissions over time. If Dominion is unable to meet this target, it must purchase renewable energy credits (RECs) or pay a deficiency payment, which will fund job training and renewable energy programs in historically economically disadvantaged communities, energy efficiency measures, and administrative costs.[2]

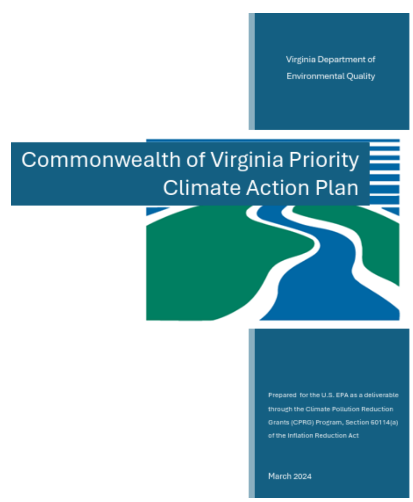

Figure 1: Commonwealth of Virginia Priority Climate Action Plan

[2] Virginia Code § 56-585.5 (2025). Retrieved from https://law.lis.virginia.gov/vacode/title56/chapter23/section56-585.5/

In March of 2024, the Virginia Department of Environmental Quality (DEQ), with funding from a Climate Pollution Reduction Grant (CPRG) through the Inflation Reduction Act (IRA), published the Commonwealth of Virginia Priority Climate Action Plan (PCAP) to identify climate issues and possible solutions in the state. The PCAP establishes priority GHG reduction measures, which specifically identify the need to increase building energy efficiency and reduce GHG emissions from both buildings and the electric power sector.

Several local jurisdictions in Virginia have enacted climate policies focused on green buildings.

In addition to Arlington County's Green Building Incentive Policy (GBIP), **Fairfax County**[1], the **City of Alexandria**[1], and the **City of Charlottesville**[1] have adopted green building policies requiring certification through green building rating systems, benchmarking, and other local climate goals. The City of Fairfax expects to adopt its draft green building policy in 2025.[1]

Measure 4 of the PCAP, "Increase residential and commercial building energy efficiency and identify and implement GHG emission reduction solutions at homes, businesses, and institutions," identifies Virginia Energy, Virginia Department of Housing and Community Development (DHCD), Virginia Property Assessed Clean Energy Authority (PACE), state universities, utilities, local governments, and building owners as potential implementing agencies and partners. The PCAP's suggested local government involvement toward meeting Measure 4 includes implementing and operating voluntary programs which support efficiency and GHG reduction. This strategy is in line with Arlington County's current operation of voluntary programs such as the Green Building Incentive Policy (GBIP).

Meanwhile, Measure 6, "Reduce GHG emissions from the electric power sector and improve grid reliability and security," places responsibility on utilities such as Dominion to provide or procure cleaner generation resources and assets, and to comply with legislative requirements. In addition, the measure names the Virginia State Corporation Commission, Virginia Energy, the Virginia Solar Energy Development and Energy Storage Authority, the Virginia Offshore Wind Development Authority, and the Virginia Nuclear Energy Consortium Authority as key implementing agencies and partners.[3]

The Commonwealth has also adopted legislation to establish GHG reduction goals for the state. In particular, the Commonwealth Energy Policy, updated through Senate Bill 94 in 2020, introduced greenhouse gas emissions reduction goals for Virginia's economy. Notably, the bill requires: "Establishing greenhouse gas emissions reduction goals across Virginia's economy that reach net-zero emissions by 2045," and "Developing the carbon-free energy resources required to fully decarbonize the electric power supply of the Commonwealth including deployment of 30 percent renewables by 2030 and realizing 100 percent carbon-free electric power by 2040."[4]

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[3] Virginia Department of Environmental Quality. (2024). *Commonwealth of Virginia Priority Climate Action Plan*. U.S. Environmental Protection Agency. Retrieved from https://www.epa.gov/system/files/documents/2024-03/commonwealth-of-virginia-priority-climate-action-plan.pdf

[4] Virginia Code § 45.2-1706.1 (2025). Retrieved from https://law.lis.virginia.gov/vacode/title45.2/chapter17/section45.2-1706.1/

Arlington County Climate Policies and Goals

As the first LEED Platinum Community in the country, Arlington County has long been dedicated to establishing and achieving ambitious climate and sustainability goals. Arlington's Initiative to Rethink Energy (AIRE), within the Department of Environmental Services in the Office of Sustainability and Environmental Management, has adopted a variety of workplans identifying short- and long-term climate goals and coordinates closely with the County's Climate Policy Office (CPO). AIRE serves as Arlington County's lead for climate mitigation, adaptation, resilience, and implementation of energy programs designed to:

- "Reduce greenhouse gas emissions from County government operations,
- Encourage, assist, and recognize businesses that join the County in reducing emissions from their activities,
- Inform and encourage residents to reduce their own emissions,
- Engage other localities and regional organizations in a broader effort, and
- Execute its Community Energy Plan (CEP), with a goal of setting mid- and long-term targets for emissions reductions in the County as a whole."[5]

Dillon Rule

Virginia is one of 14 states that operates entirely under Dillon Rule, which places restrictions on the agency of local governments to mandate policy beyond state law. This results in limitations on the ability of municipal governments in Virginia to require benchmarking and building performance standards, for example.[11]

The Community Energy Plan, updated most recently in 2019, establishes steps to achieve carbon neutrality in Arlington by 2050. Specifically, the plan identified a target for County government operations to be supplied by 100% renewable electricity by 2025—which was achieved early in January 2023[6]—and for 100% of Arlington's community-wide electricity to be from renewable sources by 2035.

To accompany the Community Energy Plan, the County developed a Carbon Roadmap[7] to outline specific implementation strategies, timelines, and responsibilities by sector. The most recent version of the Roadmap, published in October 2024, identifies steps that Arlington County plans to take from 2024-2026 to continue to make progress towards the County's carbon neutrality and renewable energy goals.

Green Building Incentive Policy

Arlington County's Green Building Incentive Policy (GBIP) is a voluntary initiative targeting sustainability for new construction activities in the private sector, namely commercial office buildings, multifamily apartments, mixed use developments, and hotels. The GBIP was first introduced as a pilot program in October 1999, allowing commercial office properties up to .25 floor area ratio (FAR) bonus density in exchange for earning LEED Silver certification. FAR is the ratio of a building's usable floor area to the size of the lot on which it is built. Since then, the policy has been amended six (6) times to broaden the scope of eligible property types, introduce greater bonus density allowances for meeting higher levels of

[5] Arlington County Government. "Arlington Initiative to Rethink Energy (AIRE)." Arlington County Virginia Government, https://www.arlingtonva.us/Government/Programs/Office-of-Sustainability-and-Environment/AIRE.

[6] Arlington County Government. (2023). "County Operations Now Run Entirely on Renewable Electricity." Arlington County Virginia Government, https://www.arlingtonva.us/About-Arlington/Newsroom/Articles/2023/County-Operations-Now-Run-Entirely-on-Renewable-Electricity.

[7] Arlington County. (2024). *Carbon Roadmap Years 3 to 5*. Arlington County, Virginia. Retrieved from https://www.arlingtonva.us/files/sharedassets/public/v/1/carbon-roadmap-years-3-to-5-final_1.pdf

LEED certification and optimized energy performance improvement, require energy benchmarking, and incorporate an ENERGY STAR certification requirement to monitor actual building performance.[8] The GBIP has since led to the development of more than 95 LEED certified commercial, multifamily, and hotel properties in Arlington County, encouraging green building in the private sector.[9]

Arlington's Building Context

Building energy usage comprises the largest share—over 60%—of energy consumption in Arlington County, which is roughly split between the commercial and residential sectors.[10] Within the residential sector, roughly half of residential building energy consumption is attributable to multifamily housing and buildings, and the rest to single-family homes (shown in Figure 2). Within the commercial sector, large and small office buildings account for a significant majority of the total square footage. As a result, efforts to reduce fossil fuel emissions from buildings within the county should focus on electrifying fossil fuel end-uses in large office and multifamily buildings.

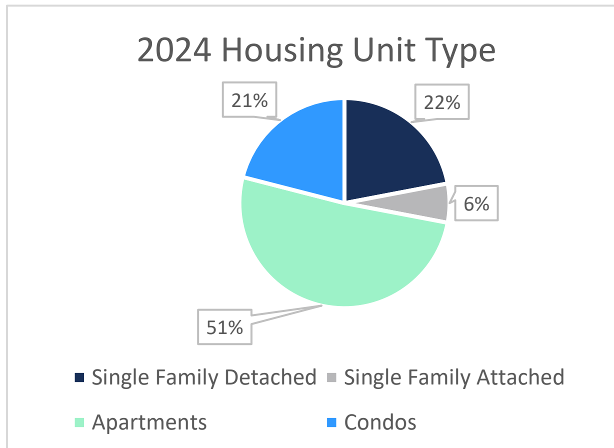

Figure 2: Residential Sector by Housing Type

In 2012, a study of Arlington County's building stock found that commercial and residential buildings each accounted for about half of overall site energy usage. Within each sector, "commercial building energy usage was primarily electricity (81%), where residential buildings used electricity and natural gas in a 52% to 48% split. The overall fuel split for both sectors was 66% for electricity and 34% for natural gas."[11]

Furthermore, analysis of GHG emissions by sector in 2023 found that residential and commercial buildings accounted for a collective 53% of total emissions, reinforcing the focus on office and multifamily buildings for decarbonization efforts.[12]

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[8] Arlington County Government. (2020). "Board Report 35." Arlington County Virginia Government, https://www.arlingtonva.us/files/sharedassets/public/v/1/environment/documents/board_report_35-final.pdf.

[9] Arlington County Government. "Green Building Incentive Policy." Arlington County Virginia Government, https://www.arlingtonva.us/Government/Programs/Office-of-Sustainability-and-Environment/AIRE/Buildings/Green-Building-Incentive-Policy.

[10] Arlington County Government. (2019, October). *Community Energy Plan*. Arlington County Government. https://arlingtonva.s3.amazonaws.com/wp-content/uploads/sites/13/2019/10/Final-CEP-CLEAN-003.pdf

[11] Arlington County, Virginia. "Key Revisions to Arlington's Green Building Incentive Policy." *Office of Sustainability and Environmental Management, Department of Environmental Services*, December 1, 2020. Arlington County, https://arlington.granicus.com/MetaViewer.php?view_id=44&clip_id=3833&meta_id=199521.

[12] Arlington County Government. (2025, March). *Arlington County 2023 Greenhouse Gas Inventory*. Arlington County Government. https://www.arlingtonva.us/files/sharedassets/public/v/2/departments/documents/aire/arlington-county-cy2023-ghg-inventory-report.pdf.

The 2015 Arlington County Building Energy Study, developed by Leidos, estimated that there were 108,100 housing units, of which 68,600 were multifamily units, representing over 63% of the total.[13] Arlington County's 2024 Profile report estimated that there are 123,700 housing units in the County, 72% of which are multifamily units, including both apartment buildings and condos. This marks an increase of approximately 15,600 housing units over a roughly 9-year timeframe. The report also estimates that over the next 25 years, an additional 38,100 housing units will need to be built in the County based on population and development forecasts.[14] Increases in multifamily housing will inevitably result in an increase in residential energy demand, and reducing or removing fossil fuel combustion from multifamily buildings is a key pathway for the County to reduce its carbon footprint. Figure 3 shows the end uses for energy in multifamily buildings.[15]

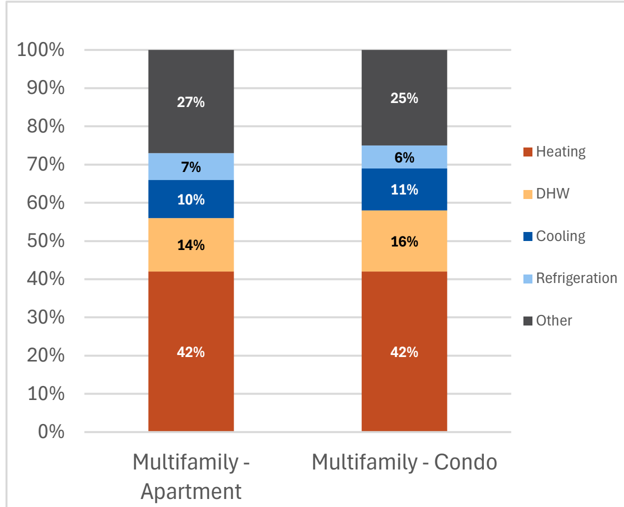

Figure 3: Multifamily Segment Energy Shares by End Use

The commercial sector in Arlington County is dominated by large offices, at just over 50% of the estimated 66 million square feet of floor space, according to the 2015 Arlington County Building Energy Study. Small offices contribute nearly 5.8 million square feet (9%), and lodging contributes a smaller, but significant, proportion of nearly 7.2 million square feet (11%).

Space heating and domestic hot water needs are lower in offices than residential buildings (see Figure 4).[16] As a result, fossil fuel consumption is a lower portion of total energy use in office buildings.

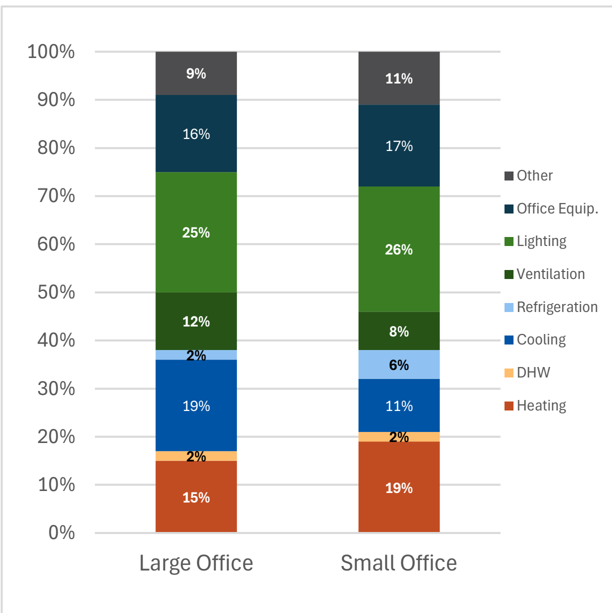

Figure 4: Selected Commercial Energy Shares by End Use

[13] Arlington County, Virginia. "Arlington County Building Energy Study: Energy End Use Analysis of Key Building Segments in the Commercial and Residential Building Sectors." *Prepared by Leidos Inc.*, March 26, 2015. Arlington County, https://www.arlingtonva.us/files/sharedassets/public/v/1/environment/documents/arlington-county-building-energy-study.pdf.

[14] Arlington County, Virginia. "Profile 2024: Annual Statistical Factbook." *Department of Community Planning, Housing, and Development*, April 3, 2024. Arlington County, https://www.arlingtonva.us/files/sharedassets/public/v/3/projects/documents/data-and-research/profile/profile_report_2024_final_4_3_24.pdf.

[15] Arlington County, Virginia. "Arlington County Building Energy Study: Energy End Use Analysis of Key Building Segments in the Commercial and Residential Building Sectors." *Prepared by Leidos Inc.*, March 26, 2015. Arlington County, https://www.arlingtonva.us/files/sharedassets/public/v/1/environment/documents/arlington-county-building-energy-study.pdf.

[16] Ibid.

However, further electrifying office space in Arlington is still impactful because they are typically large buildings, and the built environment in the County is dominated by this building type.[17]

[17] Arlington County, Virginia. "Arlington County Building Energy Study: Energy End Use Analysis of Key Building Segments in the Commercial and Residential Building Sectors."

Benefits of Electrification

Energy Efficiency and GHG Reductions

The benefits of electrification are considerable and are primarily related to improved energy efficiency and emissions reductions associated with reduced fossil fuel consumption.

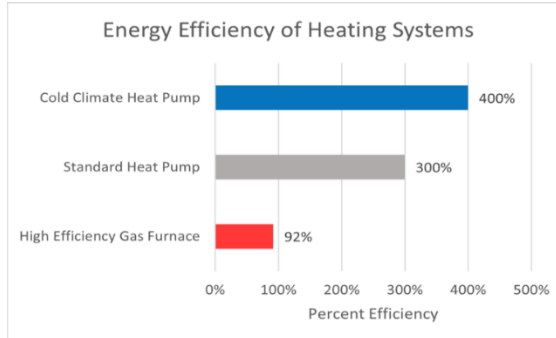

Figure 5: Efficiency of Heating Systems

Compared to combustion, the vapor compression cycle is an inherently more efficient method of space and water heating. In a combustion-based system, all the heat energy released is contained in the fuel and as a result, the efficiency of a combustion-based system cannot exceed 100%. While modern condensing boilers and furnaces can achieve efficiencies of 95% or more, these systems are less common in large offices and multifamily buildings and actual efficiencies are typically much lower. For example, Virginia's 2021 Energy Conservation Code section on commercial energy efficiency only mandates an efficiency of 80% for most equipment applications.[18] In contrast, the vapor compression cycle that underpins heat pump technologies *transfers* energy between two spaces (frequently from outside air to indoor air or a water loop). Under most operating conditions, it is capable of *moving* more energy across the system per unit of energy than is input into the system. Put more simply, for every kWh of energy used to run a heat pump, it can transfer between 2 and 4 kWh of equivalent of heat energy from outside to inside.

The specific emissions impacts related to Dominion's energy mix are discussed in more detail later in this paper, but in general terms, electrification enables a reduction in greenhouse gas emissions associated with fossil fuel combustion. While a significant proportion of electricity is generated with natural gas (and a smaller proportion from coal), much of the electricity on the modern-day grid comes from non-emitting sources such as nuclear, solar, and wind. It is this proportion of non-emitting generation technologies in the mix of "grid" energy, coupled with the much higher efficiencies of heat pump technologies, that enables reduced overall emissions.

Building Operations and Costs

Building electrification may have benefits related to the operation and conditioning of interior spaces. Depending on equipment and HVAC system configuration, heat pump-based systems are often capable of providing simultaneous heating and cooling. That is, one or more zones may be operating in heating mode while others are operating in cooling mode. This can be contrasted with some traditional systems that can only provide either heating *or* cooling to every zone, or configurations which may allow parallel systems to be heating and cooling the same zone at the same time.

Because they typically provide both heating and cooling, heat pump-based HVAC systems can also simplify the mechanical systems present in a building and reduce maintenance costs in new construction. In existing buildings, the impacts could vary based on the existing equipment and remaining equipment useful life. As discussed later in this paper, operational cost savings relative to fossil fuels depend on numerous factors including both energy and fuel costs and electricity tariff structure (especially the impact

[18] 2021 Energy Conservation Code. https://codes.iccsafe.org/content/VAECC2021P1/chapter-4-ce-commercial-energy-efficiency#VAECC2021P1_CE_Ch04_SecC403

of demand charges). As a result, while building electrification *may* reduce overall operational energy costs, this may not be the case for all conditions and configurations.

Health Impacts

While the specific health benefits related to indoor air quality resulting from electrifying natural gas cookstoves are addressed in a subsequent section, there are also more generalized health benefits of large-scale building electrification. An analysis from Rewiring America calculated the impacts of pollutants associated with fossil fuel combustion from household boilers and furnaces, clothes dryers, and water heaters. It found that household electrification nationwide would result in 3,400 fewer premature deaths,1,300 fewer hospital admissions and ER visits, 220,000 fewer asthma attacks, and 670,000 fewer days of reduced or missed work *every year*. The total value associated with avoiding these outcomes through electrification is estimated at $40 billion per year.[19] While this assessment is national in scale and focused on the residential sector, the benefits of electrification in the commercial sector are analogous, with similar reductions in ultrafine particulate matter, ammonia, nitrogen oxides, and organic compounds.

[19] Kanj, Wael, et al. (December 2024) “Breathe Easy” Rewiring America. https://www.rewiringamerica.org/research/home-electrification-health-benefits

Technology Overview & Analysis

The primary end-uses in buildings addressed when considering electrification include heating & cooling, domestic hot water production, and cooking. Below, we identify technologies and configurations that are commonly installed in commercial and multifamily buildings, which are aligned with those described in the 2020 Arlington County Building Electrification Report, prepared by Steven Winter Associates.

These are as follows:

- **Space heating:** variable refrigerant flow (VRF), split air-source heat pump (ASHP), packaged terminal heat pump (PTHP) and central heat pump and ground source heat pump (GSHP) systems, both with hydronic loops
- **Domestic hot water:** Centralized & decentralized domestic hot water (DHW) systems
- **Induction cooking:** Cookstoves that use direct electrical induction heating of cookware

We have estimated the impact of installing these heat pump-based heating systems, domestic hot water systems, and induction cookstove technologies, as compared to a natural-gas fired system. We estimated the impact on building site energy use and GHG emissions based on models and research of building systems operating in Arlington County's climate zone (IECC climate zone 4A). To do so, we used Cadmus' analysis of field studies and laboratory testing data to arrive at coefficients of performance (COP)[20] for both existing fossil fuel technologies and heat pump technologies in Arlington's climate zone.

We also draw on the proportions of energy consumption in the building stock which were calculated in the Arlington County Building Energy Study 2015. While some of the data used for this study is dated, we believe that the long effective life of building stock in the County and the relative infrequency of major building renovations and upgrades means that these findings should still be valid, especially when used for the directional purposes outlined in this paper. A full evaluation and description of the technologies in Table 1 is located in the Appendix.

As noted in the above section, it is challenging to provide accurate information with regard to the installation costs and operational costs of heat pump systems, which are highly variable, and we have not attempted to do so. Instead, we have reiterated the relative "low/medium/high" gradations used by Steven Winter Associates in their analysis, reflecting their assessment of new construction costs. For context, in a retrofit application, they estimate costs in the range of $20/square foot for mini split and VRF systems to be reflective of a mid-range cost scenario.[21] We have also provided a subjective assessment of technical feasibility in terms of "low, medium, and high" to provide a general indication of the relative ease of retrofitting an existing building with each system from a technical standpoint. While this broadly corresponds to costs, it also reflects the complexity of retrofitting certain systems in existing buildings.

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[20] The coefficient of performance (COP) is the ratio of useful heat output to the heat energy input. For example, a COP of 1.0 corresponds to and efficiency of 100% and a COP of 2.0 corresponds to a system efficiency of 200%.

[21] Steven Winters Associates, Inc. (2020, October). Arlington County Building Electrification Report. https://arlington.granicus.com/MetaViewer.php?view_id=44&clip_id=3833&meta_id=199521

Table 1: Summary of Electrification Impacts

Electrification Technology Type	VRF		Split ASHP		PTHP		Central HP w/ hydronic loop		GSHP w/ hydronic loop		Centralized DHW		Decentralized DHW		Induction cooking	
End Use	Space Heating		Space Heating		Space Heating		Space Heating		Space Heating		DHW		DHW		Cooking	
Technology Availability	Established		Established		Established		Established		Established		Developing		Developing		Established	
Building Type	Office	MF	Office	MF	Office	MF	Office	MF	Office	MF	Office	MF	Office	MF	Office	MF
Est. EUI Reduction	19.8%	17.1%	21.3%	18.4%	21.1%	18.3%	20.6%	17.8%	22.9%	19.8%	2.6%	5.7%	2.9%	6.2%	0.1%	0.4%
Est. GHG Reduction[1]	13.4%	11.6%	15.0%	13.0%	14.8%	12.9%	14.3%	12.4%	16.8%	14.6%	1.8%	3.9%	2.1%	4.4%	0.1%	0.2%
Cost	$$$		$$		$		$$$		$$$		$$		$		$	
Technical Feasibility (Retrofit)	Med		High		High		Med		Low		Med		Med		High	

Table 2: Reference Performance Assumptions for Selected Technologies

Technology	VRF	Split ASHP	PTHP	Central HP w/ hydronic loop	GSHP w/ hydronic loop	Centralized DHW	Decentralized DHW	Gas-fired heating (space and water)	Gas-fired cooking	Induction cooking
COP	2.51	2.95	2.88	2.73	3.63	2.60	3.20	0.85	0.40	0.90

The electrification of fossil fuel-fired technologies with the technologies outlined above results in a range of energy efficiency and greenhouse gas emission improvements relative to the baseline conditions. We assume 85% efficiency for natural gas fired space and water heating systems, and 40% efficiency for natural gas fired cooking.[22]

In the case of space heating technologies, electrification generally reduces site energy use intensity (EUI) by roughly 20%, with a range of 17-23%.[23] The impact on offices and multifamily buildings is similar. The reduction in GHG emissions from electrification is less than the impact on energy consumption as an overall percentage, ranging from 12-17%. The shift to all-electric buildings still has GHG emissions associated with electricity generation, but those are anticipated to fall as the generation portfolio decarbonizes. The magnitude of the GHG reduction from building electrification efforts depends both on the specific technology installed as well as the GHG intensity of the grid. A more detailed discussion of the current and future grid emissions is included later in this paper, under the section on “Regional Energy Characteristics and Impacts of Electrification.”

The numbers in Table 1 reflect the GHG emissions reductions relative to the estimated grid emissions in 2030. Because Dominion forecasts that its grid electricity will have reduced emissions over time, electrification investments will have a smaller emission impact in the near term, and a greater impact in

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[22] The 2015 Federal Standard sets the minimum gas-fired equipment annual fuel utilization efficiency (AFUE) at 80% The 2021 Virginia Energy Conservation Code also proscribes a minimum efficiency of 80%. The value of 85% follows the assumption from the SWA paper which we build upon and reflects the fact that there are many higher efficiency appliances on the market, likely lifting the average efficiency of installed equipment.

[23] EUI represents the total energy consumed within a building on an annual basis, divided by the square footage of the building and enables comparisons of energy consumption across building of different sizes and system types.

the later years of Dominion's IRP forecast period. However, it is important to note that all the technologies considered in this white paper result in reduced GHG emissions *regardless of when they are installed*; there was no scenario in which electrification resulted in an increase in emissions.

Another consideration with respect to emissions from grid electricity is the transmission and distribution losses (T&D losses, or "grid" losses). These are terms for the resistive and inductive losses of energy that occur in the conductors, substations, and transformers in the transmission and distribution system as electricity travels from the point of generation to the end-user. While they vary based on individual transmission and distribution systems, they are generally assumed to be around 5%. That is, more energy must be *generated*—with associated emissions—than is ultimately delivered to end-use customers. The values in Table 1 reflect "source" GHG emissions, which are the emissions associated with the generation of electricity at the generating unit and therefore include the emissions associated with T&D losses.

With respect to domestic water heating electrification, the expected EUI reductions are lower for office buildings which have a proportionally smaller amount of water heating, and higher for multifamily and lodging types with greater hot water demand for showering and dish and clothes washing. Cooking electrification has a relatively small impact on both EUI and GHG reduction due to the small contribution it makes to the overall energy consumption of these three building types.

As will be discussed further, the energy and emissions reductions outlined in the table above are representative and rely on average performance metrics and building characteristics. The actual performance of any system will depend on a variety of factors, some of which are discussed in greater detail in the sections below, and include the age and condition of the building, especially the integrity of the building envelope, the characteristics and configuration of the actual equipment installed, and the usage patterns associated with the building. Additionally, the metrics in the table above should not be interpreted as recommendations, but rather the relative potential of different technologies when installed in idealized cases, holding a host of external factors constant.

Costs are difficult to estimate accurately. Many of the cost studies which have been conducted on heat pumps and building electrification have been focused on the residential sector, and specifically, on single family homes. Residential installation programs, often state- and utility- led programs, have similar equipment specifications and residential conditions that are broadly consistent across a large number of projects. On the commercial side, buildings are not as standardized or consistent, and the picture of the total costs and unit cost of building electrification efforts in larger multifamily buildings are less clear.

Conversely, the commercial sector has had a smaller volume of building electrification projects overall, and the applications and configurations of both space heating and water heating systems exhibit a broader range of system sizes that are more likely to involve custom solutions engineered for specific buildings loads and characteristics. Additionally, the layout of existing systems and the location, size, and condition of in-place electrical, plumbing, and other HVAC infrastructure can impact the electrification options available to a building owner as well as the cost of retrofitting an existing building.

Considerations and Challenges

Capital and Operational Costs

One of the primary considerations for building electrification is the potential for increased costs. Particularly when existing buildings are retrofitted, installing an all-electric HVAC system is likely to cost more than a comparable fossil-fueled system, in terms of installed capital cost.

While energy prices can fluctuate and customer rate structures vary considerably, electricity in Arlington County costs roughly twice as much as natural gas on a delivered MMBtu basis, which can result in increased operational costs. However, when accounting for the improved energy efficiency of electric heating equipment, switching from natural gas to heat pumps has the potential to result in both operational energy *and* cost savings if energy savings outweigh the increase in cost per MMBtu of energy delivered.

Installation costs can be difficult to estimate precisely, especially outside of the single-family market where equipment specifications and use-cases tend to fall into a few common archetypes. In contrast, there is a great degree of variability in equipment needs for multifamily and commercial buildings.

Installation costs can also vary considerably based on the existing electrical and plumbing infrastructure available in the building. For example, a 2019 NRDC report on multifamily electrification retrofits estimated that replacement equipment for a building served by a hot water boiler costs $1.80/ft^2, while electrifying the system with central heat pumps could cost $5/ft^2. These costs do not account for labor, which has substantial regional variation, nor does it consider longer term operational costs.[24]

In new construction, the costs associated with electrification can be lower because there are no existing systems to be removed or integrated, and the building can be designed to optimize both the

FINDINGS FROM 2020 BUILDING ELECTRIFICATION REPORT

Arlington's 2020 report on building electrification offered the following findings for new construction in Arlington to prioritize, based on GHG impact and availability of technology:

1. Heating & Cooling Systems
   a. Constitutes the largest end uses in Arlington's buildings, with the highest potential for GHG reductions.
   b. Equipment cost savings can be achieved by serving heating and cooling with one technology.
   c. The technology is readily available, along with qualified, experienced installers and vendors.
2. Central Ventilation Systems
   a. Should be designed together with heating & cooling systems to ensure equipment is sized appropriately. These systems impact heating and cooling loads and may be required to condition outdoor air.
3. DHW Systems
   a. Smaller load than heating & cooling.
   b. Can be incorporated more easily, with less disruption to building design.
   c. Technology is still in development for more effective, affordable large-scale options.
4. Cooking
   a. Cooking is a small percentage of energy use in multifamily buildings.
   b. Technology is available.
   c. Health benefits are well-documented, but user adoption may be slow.

[24] Steven Winter Associates. Heat Pump Retrofit Strategies for Multifamily Buildings. Natural Resources Defense Council, April 2019. Accessed at: https://www.nrdc.org/sites/default/files/heat-pump-retrofit-strategies-report-05082019.pdf

performance and equipment locations of electric space and water heating equipment. For example, a study on the impact of zero energy building (ZEB) code compliance in New York estimated that the incremental costs associated with construction of a 50,000 ft^2 "medium" office building were slightly negative with respect to the installation of all-electric HVAC and DWH systems, relative to a code compliant building with fossil fuel fired systems[25]

Industry and Supply Chain Familiarity

Fossil fuel-fired systems represent a well-understood technology with a robust network of equipment suppliers and operations and maintenance staff, as well as an established network of service technicians familiar with the equipment and how to install it. This is especially true for systems in existing buildings. Even though many existing fossil fuel systems are oversized and may not deliver optimal performance from either a cost, occupant comfort, or maintenance standpoint, owners and maintenance staff generally understand their capabilities and limitations and are comfortable with them. Investing in a new system utilizing different technology represents a potential risk and may have a learning curve from an operations and maintenance standpoint. The uncertainty in how a new system will perform in a specific building with existing occupants and operational requirements can dissuade building owners from electrifying equipment when it needs to be replaced, so a knowledgeable contractor base is critical to successful electrification at scale.

Aligning electrification and energy efficiency investments over time

Improving the energy efficiency of a building often represents a good investment regardless of the heating technology and fuel source utilized and can reduce energy and maintenance costs and improve occupant comfort. In the case of heat electrification, improving the building envelope, specifically by improving insulation and air-sealing, can be critical in ensuring that investments in heat pumps and related upgrades are able to perform as expected while also keeping equipment and operating costs to a minimum. In existing buildings, retro-commissioning can identify potential areas of improvement for energy performance, for example through duct leakage repairs or operational efficiencies.

A recent playbook by NYSERDA and New Building Institute on the potential for electrification of multifamily buildings notes that "because the building envelope plays such a critical role in heating demand and overall comfort, additional wall and roof insulation, improvements to airtightness, and the introduction of high-performance windows have the greatest impact on energy use, utility cost, and carbon emission reductions."[26] Alignment of efficiency measures with electrification investments enables HVAC equipment to be "right-sized" which can reduce the capital and equipment costs associated with the retrofit, as well as minimizing energy costs associated with the operation of that equipment.

Many commercial property owners have muti-year capital plans that consider the expected useful life of the equipment and mechanical systems. If an existing system was recently installed, or if major components were recently replaced, they may not be scheduled to be replaced for many years.

In many cases, if a building owner is planning to electrify an existing building, it may make sense to develop a phased plan to upgrade elements of an HVAC system. Even if the primary fossil fuel

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[25] Denniston, Sean et al. "Cost Study of the Building Decarbonization Code" Mew Buildings Institute 2022. https://newbuildings.org/wp-content/uploads/2022/04/BuildingDecarbCostStudy.pdf

[26] BE-EX, NYSERDA, & Steven Winters Association, Inc. (2020, November). Low Carbon Multifamily Retrofits: Post-1980 8+ Stories. https://be-exchange.org/wp-content/uploads/2021/03/Post-80-High-Full-playbook.pdf

consuming boiler or furnace is not due to be replaced right away, interim investments in the building and system can be made which facilitate the electrification of the system when equipment reaches the end of its useful life.

Split incentives and Shifting of Fossil Fuel Heating Costs

In many commercial office situations, the tenant is usually responsible for all monthly utilities. Building owners or managers are responsible for investments in equipment upgrades that impact utility costs, which create a financial split of the cost and benefits. However, in multifamily buildings there are often more complicated utility arrangements. For example, in many apartments and in some condominiums, the operational costs of central heating systems are typically paid by the landlord or building owner and embedded in rents. Electricity is most often metered at the unit level and the utility costs are typically paid by the tenants.

In multifamily electrification scenarios in which heat pumps are installed and tied into the electrical service of each unit, the electrification of heat in those units may transfer the operational heating costs from the landlord to the tenants. It may be possible for landlords to pass their operational cost savings to their tenants in the form of reduced rent (or smaller increase), but this is by no means assured. In such situations, it can be difficult to invest in electrification and allocate costs in a way that fairly allocates costs and savings. Innovative leasing models, such as green leases, which incorporate sustainable building practices into lease agreements, can be used to distribute costs. While a detailed description is beyond the scope of this paper, green leases can enable the costs of capital investments for energy efficiency and other operating cost-reducing investments to be amortized and passed through from the landlord to the tenant in a manner that does not increase overall costs for the tenant.

Space considerations

While not a major consideration for new buildings, the available space within existing buildings can present a barrier to electrifying existing systems, particularly if equipment needs to be sited in residential units or other occupied parts of the building. Retrofits involving mini-split and multi-split systems typically have smaller system components, and may be able to be grouped, or installed in banks, either on available roof space, or potentially mounted on exterior walls. However, depending on the vintage and layout of the building, outdoor surfaces and structures may not be large enough or available for the installation of HVAC equipment. Additionally, roofs may be already in use for patio space, solar panels or other equipment.

For electrification investments which require upgrades to utility infrastructure and electrical supply equipment, such as larger transformers and switchgear, the availability of space in utility rooms and vaults can be a further constraint in the densely built development corridors within Arlington County. Indoor space is extremely valuable and outdoor space, if it is available at all, is frequently in use for other purposes and may not be suitable for electrical infrastructure.

Electrical Capacity

Electrical services in existing buildings are designed around building cooling loads and may need to be upgraded to accommodate higher electrical loads associated with heat and hot water electrification. Depending on the size and scale of the upgrade, both customer- and utility-side upgrades may be necessary to electrify. Electrical panels and switchgear on the customer side, and transformers and new services typically are available in established increments, loads that push a building into the next capacity tier can impact costs.

Especially in older buildings, which may have been designed for smaller electric loads than those commonly encountered today, the increased power requirements for winter heating may exceed the capacity of the panel or subpanel within the building and may require a new electric service and panel upgrades. For example, retrofitting heat pumps in older multifamily buildings that have smaller electrical service panels for each unit may require substantial electrical work to upgrade services and run new circuits to each unit. However, in units with adequate capacity, installations may be more straightforward.

When upgrading electrical service, there are two broad types of costs that may be incurred because of projects: customer-sited upgrades, and utility-sited upgrades. Customer-sited equipment is that which is typically owned by the customer, sited on the property, and exists for the direct benefit of the customer. In some cases, the utility may determine that grid upgrades—enhancement to the feeder or substation—are necessary to accommodate an individual request for service. While these upgrades may be triggered by a specific project, the investments result in the installation of equipment that may not be located on the building site, are owned by the utility, and have the potential to benefit multiple customers on the broader distribution network. In some cases, the costs of these utility upgrades may be charged entirely to the building owner triggering the project. These costs can be significant and could make projects infeasible from a financial standpoint. New policies could be adopted that more equitably allocate the costs for expansion and upgrades to the electrical distribution system.

Balancing of heating and cooling loads

In buildings with fossil fuel fired heating systems, the cooling loads are typically handled by separate, electrically driven air-conditioners or chillers. As a result, the separate heating and cooling loads can be accommodated by independently sizing each component.

One of the benefits of heat pump systems is that they can provide *both* heating and cooling to a building, usually with one type of equipment. However, this makes it more important to consider both heating and cooling needs when designing systems and specifying equipment. For example, many office buildings have larger annual cooling loads than heating loads—sizing equipment for the heating load would result in insufficient capacity to provide cooling during summer months. Conversely, sizing equipment for cooling loads would result in excess heating capacity, which can result in inefficient performance and equipment cycling. As a result, evaluating the total heating and cooling needs of a building and considering the role of and potential for auxiliary heating and cooling equipment is often an important consideration when electrifying HVAC systems.

Improvements in cold-climate performance

Heat pump efficiency has improved over the years, which has also resulted in improvements in cold-climate performance. Technological advancements in heat pump components have aided in these efficiency improvements. For example, the increased use of variable speed compressors and fans allows the compressor speed to adjust as needed instead of operating at full capacity and cycling on and off. Other improvements such as enhanced vapor injection, which improves low-temperature performance, electronic expansion valves, which modulate refrigerant flow through the system, as well as sensor and control improvements, have contributed to increasing low temperature efficiency.

Currently, cold-climate heat pumps can provide reliable heating in temperatures as low as 15-20°F, with some models operating as low as -20°F.[27] Performance at these temperatures is crucial to building

[27] Cox, Vivian (2024, May). *The history of heat pumps: Technology advances to meet the cold-climate challenge*. Regulatory Assistance Project. https://www.raponline.org/blog/the-history-of-heat-pumps-technology-advances-to-meet-the-cold-climate-challenge/

consumer and installer confidence that full electrification is possible without maintaining existing fossil fuel equipment as "back-up" or for cold days. While there are situations for which hybrid solutions may be appropriate, for many space heating applications the technology exists to accommodate the temperature ranges found in Arlington County.[28]

For example, in 2024 the DOE concluded a Residential Cold Climate Heat Pump Challenge in which eight participating manufacturers developed heat pumps with improved energy efficiency and performance in cold weather. The manufacturers completed rigorous testing with some results meeting energy efficiency requirements in temperatures as low as -15°F. The DOE is currently working with nine manufacturers to improve rooftop units for commercial buildings through the new Commercial Building Heat Pump Accelerator Challenge.[29]

On-site Renewable Electricity

The installation of on-site renewable energy generation, typically solar photovoltaic systems, is often considered in the context of energy efficiency and electrification projects and in relation to sustainability efforts generally. In Arlington County, rooftop installations are likely to be used in more cases than ground-mounted systems due to the high land values and a lack of available space. Larger-scale solar facilities are generally infeasible to build within County boundaries. Rooftop systems can be paired with energy efficiency measures to reduce the demand for grid electricity and should be factored into cost analyses when considering building electrification. Space constraints must be considered for solar installations alongside other uses for rooftop area such as green roofs or building amenities.

Impact of Refrigerants

Heat pump technologies utilize compounds called *refrigerants* in the vapor compression cycle to move heat from the evaporator to the condenser. The properties of the selected refrigerant impact the efficiency and operating characteristics of the design of the heat pump system. There are tradeoffs between the performance, safety, and environmental impacts of each refrigerant. Historically, many refrigerants were non-toxic and non-flammable but had high ozone depleting potential (ODP). The Montreal Protocol and subsequent phase-out of many of these refrigerants saw them replaced with compounds with low ODP but relatively high greenhouse warming potential (GWP).

Under normal operation, refrigerants are contained in a closed system and are not exposed to the environment. As heat pump market penetration grows, the utilization of refrigerant containing equipment will increase as well. Refrigerant leaks can occur during installation, maintenance and replacement, especially for systems which are field-installed and charged with refrigerant, the correct installation and assembly, and dismantling of system components is crucial to limit the uncontrolled venting of refrigerants.

As a result of the increased deployment of heat pumps, without significant changes to the makeup of refrigerants, the climate impacts of potential leaks have the potential to become a significant contributor to the County's overall GHG footprint. The County's 2023 GHG Inventory indicated that as much as 7% of

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[28] SEDAC. (2023, November). *Cold Climate Heat pumps work!*. https://smartenergy.illinois.edu/cold-climate-heat-pumps-work/

[29] DOE. (2024, October). DOE Efforts Send New and Improved Cold-Climate Heat Pumps to the Market. https://www.energy.gov/eere/buildings/articles/doe-efforts-send-new-and-improved-cold-climate-heat-pumps-market

total County emissions resulted from the leakage of hydrofluorocarbons (HFCs), the class of chemicals to which most commercially available refrigerants belong.[30]

There are many commercially available and utilized refrigerants, and it is beyond the scope of this paper to summarize the pros and cons of each one, nor do we attempt to make recommendations as to what refrigerant is most appropriate in any circumstance. However, many heat pumps currently on the market utilize R410a and increasingly, R32 and R454B.[31,32]

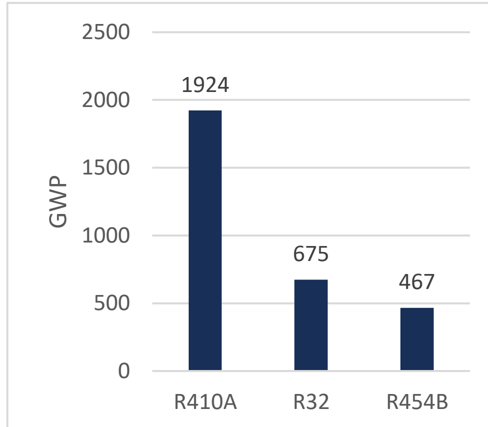

Figure 6: GWP of selected Refrigerants

New regulations set by the EPA are aimed at phasing out certain refrigerants with high GWP potential. The regulation states that, "starting January 1, 2025, the manufacturing or importing of any product in specified sectors that uses a regulated substance with a global warming potential of 700 or greater is prohibited".[33] This includes R410a which is the most widely used refrigerant for HVAC systems. R410a is classified as an A1 refrigerant, which means that it is both non-flammable and non-toxic. Increasingly, A2L refrigerants such as R32 and R454B are being utilized in new heat pump systems and while they can burn, they are not seen as posing a significant safety risk in most residential and commercial applications.

R32 performs similarly to R410A but it has approximately a third the GWP and is more efficient in transferring heat. R454B is relatively new and has around one quarter the GWP of R410A, one of the lowest on the market. It is also energy efficient and is likely to comply with future environmental regulations. R454B also has comparable pressures and temperatures to R410A, allowing for similar system designs.[34]

Lastly, R744 is the refrigerant designation for carbon dioxide (CO_2) which has a GWP of 1, among the lowest of any refrigerant. Additionally, carbon dioxide is energy efficient as a refrigerant, inexpensive, non-toxic, and non-flammable. A potential downside of R744 is that it needs to operate at a much higher pressure than many of the previously referenced refrigerants in order to meet operating requirements. As a result of these higher pressures, existing equipment designs require significant reworking to accommodate CO_2 as components may need to be made more robust.[35]

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[30] Arlington Initiative to Rethink Energy. *2023 Greenhouse Gas Inventory*. Arlington County. https://www.arlingtonva.us/Government/Programs/Sustainability/AIRE/Greenhouse-Gas-Inventory

[31] Johnson Controls. (n.d.). *Navigating the refrigerant transition*. https://www.johnsoncontrols.com/navigating-the-refrigerant-transition

[32] Trane. (n.d). *A Complete Guide to HVAC Refrigerants*. https://www.trane.com/residential/en/resources/blog/a-complete-guide-to-hvac-refrigerants/

[33] Environmental Protection Agency. *Technology Transitions HFC Restrictions by Sector*. https://www.epa.gov/climate-hfcs-reduction/technology-transitions-hfc-restrictions-sector

[34] Johnson Controls. (n.d.). *Navigating the R-454B refrigerant transition*. https://www.johnsoncontrols.com/navigating-the-refrigerant-transition

[35] Parr, R. (2020, October). What are the Pro's and Con's of CO2 (R744) as a Refrigerant? https://climadesign.co.uk/what-are-the-pros-and-cons-of-co2-r744-as-a-refrigerant/

Regional Energy Characteristics and Impacts of Electrification

Arlington County is served by Virginia Electric and Power Company, a subsidiary of Dominion Energy (referred to as “Dominion” in this whitepaper), a vertically integrated power company which owns and operates generation, transmission and distribution assets. Regionally, Dominion is part of the PJM Interconnection, a regional transmission operator (RTO) which operates wholesale energy and capacity markets and coordinates the transmission of wholesale electricity among 13 states and the District of Columbia in the south, mid-Atlantic, and midwestern regions of the United States.[36]

Dominion is regulated by the State Corporation Commission (SCC) which is responsible for ensuring that the utility provides safe, reliable, and affordable electricity to its customers. The SCC is an independent department of the state government and is led by three commissioners elected by the General Assembly of Virginia.[37]

Dominion must ensure that it has sufficient capacity to meet current and future loads and once operational, it operates its generation assets to meet real time load subject to economic, technical, operational, and weather-related constraints. This is satisfied by filing annual Integrated Resource Plans (IRPs) which outline short- and long-term load forecasts, regional PJM market developments, transmission and generation needs considerations, distribution assets, renewable energy opportunities, and adequacy of resources, among other topics.

With respect to renewable energy generation, the IRP includes numerous investments required by the VCEA including offshore wind, solar, and storage. Specifically, it declares large amounts of new renewable energy generations “to be in the public interest,” facilitating the regulatory and permitting review of such investments. It then requires Dominion Energy to pursue development of at least 5,200 MW of offshore wind. and construct or acquire 2,700 megawatts of energy storage capacity by 2035.[38]

In this section, we briefly summarize the three elements of:

- *Load growth*: estimates of how peak load—the highest amount of simultaneous capacity, or power it will need to supply to customers—will grow over time,
- *Generation:* the existing and planned assets it will utilize or invest in to ensure that it can meet its forecasted load and energy requirements, and
- *Transmission infrastructure*: the high voltage infrastructure to transport bulk power over longer distances, from generators to load centers and distribution substations where energy can be distributed to customers.

[36] PJM Interconnection. (n.d.). *Who we are*. PJM Interconnection. https://www.pjm.com/about-pjm/who-we-are

[37] Virginia State Corporation Commission. "About the SCC." Virginia SCC, https://www.scc.virginia.gov/about-the-scc/. Accessed 17 Jan. 2025.; Virginia State Corporation Commission. "About the Commissioners." Virginia SCC, https://www.scc.virginia.gov/about-the-scc/about-the-commissioners/. Accessed 17 Jan. 2025.

[38] Virginia General Assembly. (2020). *House Bill 1526 Summary*.

Drivers of load growth

In its IRP filing, Dominion provides future load forecasts which amount to 5.5% annual growth over the next decade, one of the highest in the nation.[39,40] Within Dominion's Virginia service territory and within Northern Virginia specifically, there are several drivers of load growth: including a growing population and increased development, building and vehicle electrification.[41] However, by far the greatest contributor to load growth in Northern Virginia is the pace of development of data centers—both expansions of existing facilities and new facilities—many of which have not yet been built but are proposed. In its IRP, Dominion notes that "since 2013, the Company has averaged around 15 data center connections (*i.e.*, data center campuses) per year."[42] Dominion notes that data centers are responsible for "migration to the cloud as businesses outsource information technology functions, smartphone technology and apps, 5G technology, digitization of data, and artificial intelligence," and are key to economic growth and development.[43]

Prior to Dominion's filing of the 2024 IRP in October, the SCC ordered that the utility submit supplementary filings to show how the growth in electricity consumption of data centers' impact on energy and capacity forecasts, as well as the resulting investment plans for both new generation and transmission assets which Dominion deems necessary for meeting them.[44]

The impacts are significant. According to Dominion's supplemental filing, electrical consumption is forecasted to grow by 76% and peak demand is forecasted to increase by 53% from 2024 through 2039. Without the impact of data center load growth, the forecasts are much lower: energy consumption only increases by 10% and peak load only increases by 7% by the end of the forecast period.[45]

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[39] Virginia State Corporation Commission. SCC Seeks Public Comments of Dominion Energy Virginia's Integrated Resource Plan. November 20 2024. https://www.scc.virginia.gov/about-the-scc/newsreleases/release/comments-sought-on-dev-integrated-resource-plan/comments-sought-on-dev-integrated-resource-plan.html

[40] Utility Dive. (2025, January 22). *Federal policy rollbacks, electricity demand growth, data center EV*. Utility Dive. https://www.utilitydive.com/news/federal-policy-rollbacks-electricity-demand-growth-data-center-EV/737456/

[41] Virginia Electric and Power Company. "Virginia Electric and Power Company's Report of Its 2024 Integrated Resource Plan."(2024, October, p. 36). https://www.dominionenergy.com/-/media/pdfs/global/company/irp/2024-irp-w_o-appendices.pdf?rev=c03a36c512024003ae9606a6b6a239f3.

[42] Ibid., 14.

[43] Ibid., 14, 15.

[44] Virginia Mercury. (2024, October 28). *Once again, Dominion's energy plan falls short. This time, the SCC isn't having it*. Virginia Mercury. https://virginiamercury.com/2024/10/28/once-again-dominions-energy-plan-falls-short-this-time-the-scc-isnt-having-it/

[45] Virgina Electric and Power Company's SCC Directed 2024 IRP Supplement. November 15, 2025. Case # PUR-2024-00184 https://www.scc.virginia.gov/docketsearch/DOCS/82l101!.PDF

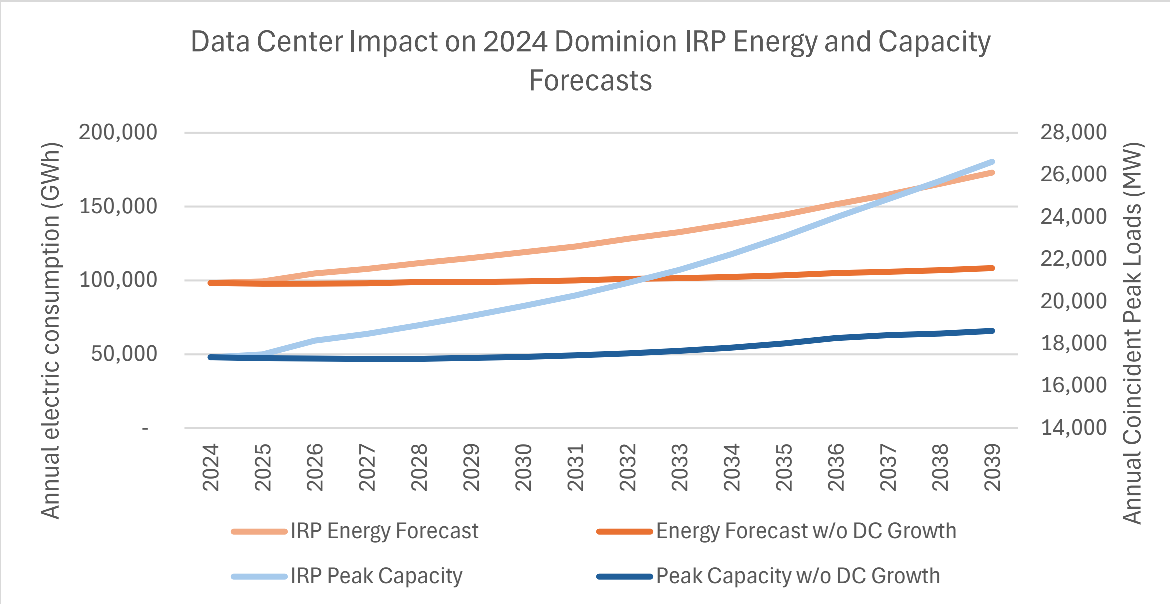

Figure 7: Dominion IRP Energy and Demand Forecast

These forecasts matter for two main reasons: cost and generation mix. While assessing relative cost impacts is beyond the scope of this paper, the incremental cost of such a rapid buildout in both generation and transmission assets would be substantial and would likely be passed on in large part to all ratepayers. More relevant to the second impact is the amount and technology of new generation capacity that Dominion estimates will require to serve this new load, which is discussed in the subsequent section.

A 2024 study by E3, commissioned by the Joint Legislative Audit and Review Commission, assessed the impact of data center growth in Virginia and made several recommendations regarding the improvement of retail rate design to address cost concerns. Some of these include the consideration of a separate rate class for data centers, new methods to allocate costs, and for frequent rate adjustments, to promote the equitable allocation of system costs.[46]

[46] Virginia Joint Legislative Audit and Review Commission. Data Centers in Virginia—Commission Briefing. December 9, 2024. https://jlarc.virginia.gov/pdfs/presentations/Rpt598Pres-1.pdf

Generation Mix and GHG Implications

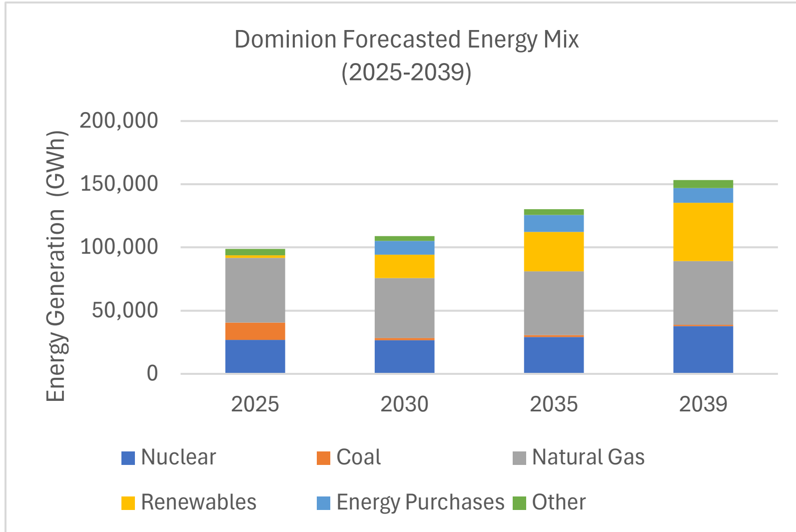

Figure 8: Energy Forecasts by Generation Type

Dominion Energy's generation mix is made up of a variety of resource types. According to Dominion's 2024 IRP, the utility has made changes to its generation mix which has improved environmental performance. This has meant the retirement of some coal-fired facilities, the conversion of other plants to be able to burn multiple fuels, including biomass, fuel oil and natural gas. It has also invested in technologies to reduce the amount of nitrogen oxides and particulate matter released from combustion.[47] The IRP notes that these changes have resulted in reductions in CO_2 emissions intensity, which is the quantity of emissions per MWh delivered to customers. The result of this shift in generation technologies results in roughly a 50% decrease in the emissions intensity of Dominion's electricity by 2039.

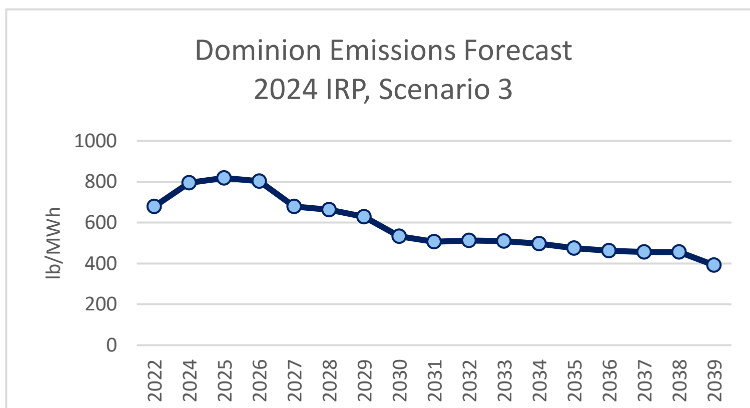

Figure 9: Emissions Forecast

In the 2024 IRP, Dominion provides four different scenarios for investments in different generation technologies over the 15-year IRP planning horizon, which considers the impact of the Virginia Clean Energy Act (VCEA) as well as the implementation of a set of EPA regulations which primarily impact coal generation assets. For clarity and consistency with the IRP, in this whitepaper and supporting analysis, we consider the impacts of Scenario 3, which assumes implementation of and compliance with both the VCEA and EPA regulations.[48]

In 2023, Dominion generated over one third of the energy it delivered to customers from natural gas and just under a third of its power from nuclear power plants. Nearly a quarter was purchased from other power producers via the PJM wholesale markets, and of the remainder, roughly 5% was from coal generation and 5% was from renewable resources. However, over the next 15 years in the IRP forecast period, Dominion plans to significantly increase the proportion of renewable generation in its portfolio,

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[47] Virginia Electric and Power Company. "Virginia Electric and Power Company's Report of Its 2024 Integrated Resource Plan." (2024, October, p. 55).

[48] Virginia Electric and Power Company. "Virginia Electric and Power Company's Report of Its 2024 Integrated Resource Plan."(2024, October).

both through direct ownership and contracted purchases with independent generators. As noted above, many of the increases in renewable generation are directly attributable to Dominion's compliance with the requirements of VCEA legislation.

In order to meet this increased load, Dominion proposes to build and purchase over 12,000 MW of solar generation, nearly 3,500 MW of wind generation, and 4,100 MW of storage. They also propose to construct almost 6,000 MW of natural gas generation and 1,300 of new nuclear capacity, while continuing to make approximately 3,000 MW in capacity purchases per year. It is important to note that these values and forecasts reflect the underlying generation assets and technologies, and do not consider ownership or purchases of renewable energy certificates.

Given the rapid increase in the pace of forecasted load growth, coupled with retirement of many older, higher-emitting generation assets, there is considerable uncertainty regarding the long-term demand for data center energy consumption. There are concerns about both Dominion's ability to meet the loads implied by the forecasts and especially their ability and intent to do so with renewable energy and other zero-emissions resources. Specifically, stakeholders have raised concerns that forecasted near-term capacity shortfall in available generation capacity in the PJM territory will result in the rapid construction of fossil fuel resources rather than renewable energy and other non-emitting resources and a heavy reliance on REC purchases to comply with the requirements of the VCEA.

To determine the GHG impacts of the current and future emissions of the electricity provided by Dominion, Cadmus relied on their recent 2024 IRP filing, specifically the values in Appendix 3B-7, which provides actual and projected energy generation by technology types. We applied technology-specific emission factors to fossil fuel generation utilizing the 2022 eGrid values specific to the SRVC subregion for all years of the IRP forecast. That is, we used unique *metric ton of CO_2 equivalent per MWh of generation* factors each for natural gas, coal, and oil-fired generation, but did not assume that emissions factors would change on a per MWh basis for each technology.[49] Changes to the overall mix were driven entirely by changes in the relative proportions of generation technologies dispatched to supply power to Dominion's customers. Additionally, while the generation technologies associated with power purchased from the PJM market are unknown and variable, we applied the SRVC average emission factor for 2022 to those energy purchases as a simplifying assumption.

In forecasting the emissions associated with Dominion's IRP, we ignored the impact of renewable energy certificates (RECs) when determining the annual emissions factors. The emissions profiles associated with Dominion's energy mix are based on the *technical characteristics* of the generation assets used to generate the energy consumed by Dominion's customers and do not consider purchased environmental attributes from other technologies, which are decoupled from energy generation. Whether such a strategy complies with the letter or spirit of the VCEA is beyond the scope of this paper to address.

While this paper focuses on the technical characteristics of Dominion's generating assets to determine emission rates, the County is evaluating market-based options for achieving 100% renewable electricity community-wide by 2035, in line with the goal established in the 2019 CEP. County actions to reach 100% renewable electricity do not significantly change the generation makeup of the larger grid, but they would seek to match all electricity demand within the County with zero-emission sources through contractual arrangements. Once the County achieves its 100% renewable electricity goal, fully electrified buildings would not produce any greenhouse emissions from their energy consumption when accounting

[49] CO_2 equivalence included the global warming potential of carbon dioxide (CO_2), nitrous oxide (N_20), and methane (CH_4).

for these market-based renewable electricity purchases but would continue to rely on the grid carbon intensity when accounting for location-based emissions.[50] A detailed analysis of the impacts of market-based renewable purchases is outside the scope of this paper.

Transmission Implications

Utility-scale transmission planning is less directly relevant to the ability of any building or group of buildings to electrify and is distinct from the distribution infrastructure that utilities typically invest in to bring power from substations to end-use customers.

Due to the projected load growth needed to support the development of additional data centers, the SCC directed Dominion to "identify whether the need for the transmission project is primarily being driven by data center load growth" in their request for the utility to file a supplementary IRP. Dominion responded with an updated appendix that was originally included in the 2024 IRP to indicate whether a transmission expansion project was primarily driven by data center needs. Projects were considered to be driven by data centers if it was indicated that a transmission project would specifically support a data center load, or if a new transmission project corrects overload from existing data centers. Of the almost 200 transmission projects identified in the planning period, with target dates ranging from August 2024 through October 2031, 89 were indicated to be driven entirely by forecasted data center growth—roughly 44%.[51]

[50] Arlington County estimates both location-based and market-based emissions as part of its greenhouse gas emissions inventory in accordance with the Greenhouse Gas Protocol Global Protocol for Community-Scale Greenhouse Gas Inventories.

[51] Clean Virginia "2024 Dominion Energy's Integrated Resource Plan." Issue Alert. https://www.cleanvirginia.org/wp-content/uploads/2025/01/2024-Dominion-IRP-Issue-Alert.pdf

Key Points and Takeaways

This paper has presented an overview of building electrification within Arlington County with a specific focus on two of the predominant building types, offices and multifamily buildings. It presents an overview of selected technologies which facilitate building electrification, emphasizing space heating and hot water heating equipment and estimates their energy and greenhouse gas impacts relative to representative building types. It also assesses the impacts of the current and future emissions scenarios of the electric grid, relying primarily on Dominion's recent IRP filings.

While this paper does not make recommendations with respect to Arlington County's policies or programs, there are a few key takeaways which are generally applicable to building electrification in the County:

- Electrifying existing buildings and building new fully electrified buildings can generally be expected to incur a cost premium as compared to the replacement or installation of fossil fuel fired technologies. It *may* result in reduced operational costs, but the extent to which this can be expected depends on both the specific electric rates and the existing efficiency of the building. Improvements to the insulation and airtightness of a building can reduce operational costs and improve overall comfort but can also increase project costs and complexity. This results in uncertainty in estimating return on investments in electrification upgrades.
- The specific project costs and feasibility of installation are highly site dependent and vary based on building age and construction, existing system type and layout, and building use and occupancy patterns.
- Electrification is technically possible for a wide range of building types, although system improvements and upgrades are likely necessary. The technology largely exists and is commercially available for most space and hot water heating and cooking electrification projects. However, its installation will likely need to be aligned with capital planning and equipment replacement schedules, and efforts to expand designer and contractor technology understanding is needed.
- While electrification will reduce overall emissions, uncertainty around future load growth and the pace of deployment of new, non-emitting generating assets will impact the scale of the associated GHG emissions reductions.

Appendix: Common Types of Building Electrification Technologies

As introduced in the main text of the whitepaper, the primary end-uses in buildings which are commonly considered when addressing electrification include heating & cooling, domestic hot water production, and cooking. In this appendix, we expand on the technologies, providing a general taxonomy of common systems and configurations. The following sections provide greater detail on the three end uses commonly targeted for electrification: space heating, water heating, and cooking. While not exhaustive, we describe equipment and system configurations and along with some of the specific applications and considerations for each. We have also reiterated the EUI and GHG impacts estimates resulting from the installation of a reference building with natural gas-fired equipment.

Space Heating

Heat pump technologies utilize an electrically driven compressor to drive a working fluid (refrigerant) through a thermodynamic process to transfer heat from a heat source to a heat sink. Air conditioners use this technology to move heat outdoors, lowering the indoor air temperature. While these systems are only capable of moving heat in one direction, heat pumps use a reversing valve to switch the direction of refrigerant flow, enabling them to both heat and cool.

It is also worth noting that in most buildings, cooling is already provided by electrically driven processes, whether by large, central chillers, by roof-top units (RTUs), or by window air conditioners. However, the adoption of electric technologies for both heating and cooling as part of an integrated system may have the potential to simplify HVAC systems by streamlining the amount of equipment required to condition a space.

Besides being electrically driven and not producing direct operational GHG emissions, a benefit to heat pumps is their high efficiency when compared to fossil fuel systems. Because heat pumps move heat, rather than create it, they are capable of exceeding efficiencies of 100% (equivalent to a coefficient of performance, or COP, of 1.0). Electric resistance heating operates at 100% efficiency, and most commercial boilers and furnaces operate at efficiencies between 80-90%.

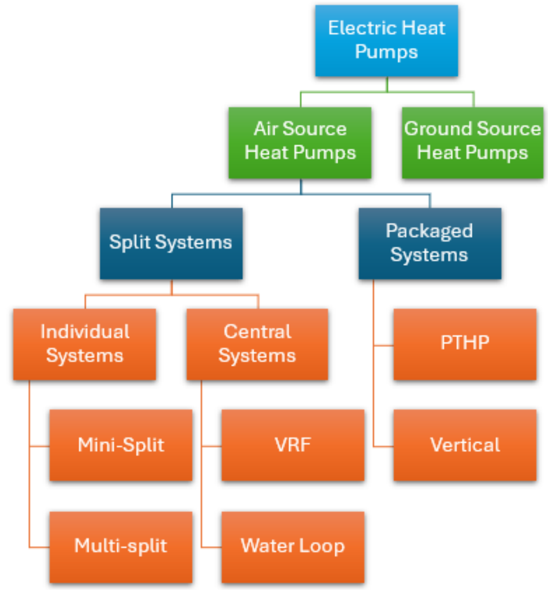
The Northeast Energy Efficiency Partnership (NEEP) has worked with state partners from New England to Maryland and the District of Columbia to develop and maintain the Cold Climate Air-source Heat Pump (ccASHP) specification and the associated product list. More information available at: https://neep.org/heating-electrification/ccashp-specification-product-list

Air-source heat pump efficiency decreases as temperatures drop. As the outdoor air gets colder, the temperature difference between the indoor setpoint and the outdoor air temperatures increases. As a result, heat pumps must work harder to push heat indoors and it uses more energy. The same thing happens in cooling mode as outdoor temperatures increase. But in relative terms, heat pumps are always more efficient than conventional gas-fired equipment or electric resistance.

As noted above, efficiency decreases as the outdoor temperature differential increases, but many newer systems are specifically designed for cold climates (ccASHPs). As a result, while their efficiency decreases, it may only decrease slightly, from a coefficient of performance (COP) of 2.7-3.3 at 17ºF to a

COP of 2.2-3.0 at 5ºF.[52] As long as heat pump systems are designed and specified properly for the operating conditions and installed correctly, they deliver heating and cooling more efficiently than conventional systems in Arlington County's climate.

Figure 10: Simplified Taxonomy of Heat Pump Systems



General Types and Configurations of Heat Pump Systems for Heating

There are numerous configurations of heat pump systems for heating and cooling, and it is beyond the scope of this paper to describe each one in detail. Broadly speaking, heat pumps fall into two categories based on their "source" of heat: air source systems and ground source systems. Air source systems are further broken down into "split" and "packaged" distinctions, which describe the relative locations of their components. Split systems are further divided into "individual" and "central" systems which describe the scale and configuration of the distribution system. This taxonomy is summarized in general terms in Figure 10.[53] These systems are described in greater detail below, along with some of the pros and cons associated with their characteristics and use, as well as considerations as to how they are commonly used. The observations below are general and cannot incorporate the variety of use-cases for which heat pumps may of may not be appropriate; they should not be intrepreted as recommendations.

Air Source vs. Ground Source

Overview

As the names suggest, ground source systems use the ground as a source of heat, typically through deep wells, or boreholes, through which water is pumped in pipes. Because the ground generally remains at a constant temperature year-round which is quite close to "room temperature," ground source systems can often achieve very high overall system efficiencies. However, the design and cost of drilling wells and installing piping can make up a significant proportion of the overall cost. Space is also a consideration: adjacent fields or parking lots are often used, and the building's footprint can also be used, though typically only in new construction applications. Another consideration is the composition of the ground. The geology of the site needs to be conducive to drilling and installing the wells, and not all sites will have the right characteristics. Additionally, in more densely populated areas such as much of Arlington County, underground infrastructure, such as utility conduits and vaults, walkways, and transportation infrastructure, such as WMATA tunnels, access points, and ventilation shafts, may limit the available space in ways that make ground source systems infeasible. In some cases, innovative drilling techniques may be able to mitigate some space constraints but potentially at increased cost.

[52] MD cold climate heat pump fact sheet, need citation.
[53] U.S. Department of Energy. (2021). *New frontier: Electrification of multifamily housing* [Slides]. Better Buildings Solution Center. https://betterbuildingssolutioncenter.energy.gov/sites/default/files/slides/2021Summit-New_Frontier_Electrification_Multifamilty_Housing-Slides.pdf

Air-source systems use ambient air as a heat source. They typically require much less capital investment as compared to ground-source systems, but they are subject to seasonal and daily variations in outdoor air temperature which often varies significantly from the required indoor temperature. As a result, their overall system efficiencies are typically lower because the system needs to “work harder” to transfer heat against a larger temperature differential. The outdoor unit of an air source heat pump, because it is exposed to the elements, can also require periodic maintenance to ensure that it is functioning properly, is kept clear of snow, ice, and leaf build-up, and has not experienced degradation on pipe insulation or fittings.

Considerations and Applications

A primary benefit of air source systems is their lower installed cost and greater flexibility of installation—they can be installed in numerous configurations as will be described in greater detail below.

In commercial settings, ground-source systems are more commonly installed in new buildings when the bore field can be designed around the system requirements and design of the building. However, they can be retrofitted to existing buildings where space and existing HVAC system configurations allow.

Table A1: Estimated EUI & GHG Emissions Reductions from GSHP w/ Hydronic Loop

Building Type	Office	MF
Est. EUI Reduction	22.9%	19.8%
Est. GHG Reduction	16.8%	14.6%

Split System vs. Packaged Systems

Overview

A heat pump works by using an electrically-driven compressor to push a refrigerant through a vapor compression cycle, transferring heat from a low temperature space (via a heat exchanger called an evaporator) to a relatively higher temperature space (via a heat exchanger called a condenser)—against the “normal” flow of heat. In “packaged” system, the evaporator and condenser are in the same enclosure and typically break the envelope of the building. Examples of packaged systems include the packaged terminal heat pump or a traditional window air-conditioner.

In a split system, the two heat exchangers are in separate enclosures and are typically connected by runs of refrigerant lines. In many air-source configurations, one of the heat exchangers is located outside where it can take in heat from or reject heat to the ambient air. Examples of “split” systems include a frequently installed configuration called a “mini split” system, in which a single outdoor unit is connected to a single indoor cassette, typically mounted on an interior wall near the ceiling—these are often used in residential and some multi-family applications. Multi-split split systems retain this basic form but may have increased size and distributional complexity, enabling control over multiple zones.

Considerations and Applications

Packaged terminal heat pumps are commonly found in hotels and lodging applications when there are multiple spaces that need to have independent heating and cooling control. They are distinguished from “packaged terminal air-conditioners” (PTACs) which often utilize an electric resistance element to provide heating. The heat pump versions typically provide both heating and cooling and may eliminate the electric heating element entirely. As a "packaged" unit, the compressor is located in the enclosure and increases ambient noise when the unit is in operation.

PTHPs are commonly installed "through the wall" and require a large penetration in the building envelope. They are less common in new buildings but in buildings that currently utilize PTACs, they can provide a more efficient alternative to systems which may rely to a significant degree on electrical resistance heating in the winter.[54]

Table A2: Estimated EUI & GHG Emissions Reductions from PTHP

Building Type	*Office*	*MF*
Est. EUI Reduction	21.1%	18.3%
Est. GHG Reduction	14.8%	12.9%

Individual vs. Central Systems

Overview

Split systems can be further divided into individual systems and central systems although at the commercial scale, the definitions can be somewhat blurred.

The individual systems defined by the mini- and multi-split configurations are distinguished by the fact that the conditioned air enters the occupied space directly from the heat exchanger (typically a wall or ceiling mounted cassette). Conversely, a central system uses a heat pump to heat or cool indoor spaces through a distribution system. The system may be pipes and convectors in a hydronic system, or it may be ductwork in a forced-air system.

Central HVAC systems with hydronic distribution utilize a "water loop," or circuit of piping, to deliver water at a consistent temperature to the occupied spaces. In each space, or zone, a terminal heat pump utilizes the water loop as a heat source or sink, in order to heat or cool the occupied space or unit. Another key difference for central systems is whether the distribution system bringing heating and cooling to the occupied space utilizes refrigerant or water. In water loop systems, a heat pump may be used to maintain a target temperature, adding or removing heat as required, which flows to the occupied spaces via recirculation pumps.

Variable refrigerant flow heat pumps are a class of split, air-source heat-pumps that are typically differentiated from mini- and multi-split systems by their larger size and by longer and more complicated refrigerant distribution systems. In the context of this taxonomy of heat pumps systems, they can blur the line between multi-split systems and a centralized system: they are split systems, but they are typically configured to handle loads that would be handled by a central system.

Considerations and Applications

Central Hydronic: An advantage of central systems with hydronic loops is the level of control enabled in each unit or zone. Because each terminal heat pump can operate independently, different parts of the same floor or wing of a building may be able to achieve different temperature set-points. This is especially relevant in multifamily buildings where tenants may have different temperature setpoints or occupancy patterns.

[54] Steven Winters Associates, Inc. (2020, October). Arlington County Building Electrification Report. https://arlington.granicus.com/MetaViewer.php?view_id=44&clip_id=3833&meta_id=199521

In a retrofit scenario, one of the advantages of electrifying hydronic systems is that they may be able to take advantage of existing piping and infrastructure,[55] potentially reducing the costs of retrofit as well at the amount of disruption in occupied areas.

Table A3: Estimated EUI & GHG Emissions Reductions from Central HP w/ Hydronic Loop

Building Type	Office	MF
Est. EUI Reduction	20.6%	17.8%
Est. GHG Reduction	14.3%	12.4%

VRF: Heat pump systems installed in large buildings in offices are more likely to be VRF systems which are typically larger, more complicated, and more expensive than multi-split systems. As a result, they can be more difficult to retrofit into existing buildings and are more commonly installed in new construction applications. As compared to multi-split systems, which are typically only capable of operating in heating *or* cooling modes, VRF systems are often configured such that they can operate in simultaneous heating *and* cooling modes, utilizing a digital control system to assess the total heating and cooling requirements of the system and directing refrigerant through branch controller boxes to route refrigerant to the appropriate locations in the system. As a result, VRF systems can transfer heat *within* the building, rather than relying solely on outdoor air as a heat source.

Table 3: Estimated EUI & GHG Emissions Reductions from VRF

Building Type	Office	MF
Est. EUI Reduction	19.8%	17.1%
Est. GHG Reduction	13.4%	11.6%

Mini- and multi-split systems: Both mini-split and multi-split systems are relatively small heat pump systems which can be installed to serve heating and cooling loads. As described in the section above, these systems are typically fairly simple, often consisting of a single outdoor util and between 1 and 4 indoor heat exchangers. They are not typically integrated into ventilation systems and can serve as stand-alone HVAC units.

Small mini-split systems are less likely to be found in large office applications, but they are commonly utilized in retrofits or new construction for multifamily buildings where they are installed in modular configurations with each unit serving the heating and cooling needs of one (or in some cases more) units.

A characteristic of smaller split systems is that they cannot typically accommodate long refrigerant line lengths. The indoor and outdoor units must be located relatively close to each other. For commercial office and multifamily applications, these systems are often installed in retrofit scenarios and may be installed in “banks” or modular arrangements that are located to serve a group of apartments or zones.

[55] The degree to which this is possible depends on several factors, including whether the circulated water temperature is in the same range as the previous equipment

A disadvantage of mini- and multi-split systems stems from their relatively small size and ease of installation, they can be installed in locations and for applications which are not optimal. For example, excessive refrigerant line lengths, insufficient refrigerant line insulation, and bad placement of outdoor units can all contribute to the potential for poor performance of split systems.[56]

Table A4: Estimated EUI & GHG Emissions Reductions from Split ASHP

Building Type	Office	MF
Est. EUI Reduction	21.3%	18.4%
Est. GHG Reduction	15%	13%

Domestic Hot Water

Overview

Domestic hot water (DWH) refers to water which is used primarily for washing and cooking. In fossil fuel-fired applications, this is often provided by a natural gas boiler, though it is also frequently generated with electric resistance heaters. There are two common configurations for providing hot water: through centralized or decentralized systems. In centralized systems, there are usually one or more large boilers and storage tanks which serve the needs of the whole building. In decentralized systems, there may be multiple, smaller water heaters which provide hot water for specific purposes, or to a specific part of the building.

Central systems are more commonly found in larger multifamily buildings where available interior space may make in-unit systems infeasible. Central systems are likely to consist of primary heat pumps and storage tanks and a secondary "maintenance" tank and heat pump to manage heat lost through the recirculation system. While large, central, air-to-water heat pumps exist, for many applications installing multiple split systems to operate in parallel limits equipment size and can provide redundancy if one piece of equipment fails and needs to be repaired.[57]

Considerations and Applications

Electrifying these systems is possible with existing technology and as with space heating, there are many equipment configurations that can be utilized. However, water heating poses some unique challenges to electrification which we addressed briefly. Due to the high specific heat capacity of water and the large temperature differential between supply water and the water provided to the building, heat pumps heat water more slowly when compared to natural gas or electric resistance heating system, though they do so much more efficiently. In applications which require high volumes of hot water, such as in multifamily buildings, it can be challenging to design systems which economically meet hot water demand solely with HP-based systems.

As with heat pumps for space heating, both central and individual systems are available and in most retrofit scenarios equipment would be replaced with a like system. In multifamily buildings that have

[56] Steven Winters Associates, Inc. (2020, October). Arlington County Building Electrification Report. https://arlington.granicus.com/MetaViewer.php?view_id=44&clip_id=3833&meta_id=199521
[57] Perry, C., A. Khanolkar, and H. Bastian. 2021. *Increasing Sustainability of Multifamily Buildings with Heat Pump Water Heaters*. Washington, DC: American Council for an Energy-Efficient Economy. www.aceee.org/research-report/b2101

decentralized, in-unit water heaters, a straight replacement may not always possible because fossil fuel fired water heaters typically have minimal ventilation requirements for air intake and exhausting flue gas. By contrast, heat pump water heaters require a higher volume of air to serve as a heat source and HPWHs that vent cool air into the occupied space increase building heating loads in the winter and may impact occupant comfort. Installing additional venting to accommodate HPWH systems may not be feasible, and the additional noise associated with its operating may cause tenant complaints.

An NBI/ACEEE study on water heating in multifamily buildings found that for larger multifamily buildings, designing central HPWH systems that are cost-effective is challenging absent utility and/or state program support. In jurisdictions that lack these programs, partial electrification of DWH systems may be the most viable option and can result in a system which utilizes a heat pump system for the majority of the building's load and utilizes electric resistance or natural gas-fired unit to meet the remainder. This approach can result in a significant reduction in emissions as well as reducing the capital costs associated with installing heat pumps sufficient to meet the entirety of the heating needs. This is how many residential HWHPs that have a "hybrid" mode operate. During "normal" operation, they utilize the heat pump and when demand exceeds the ability to the system to maintain the required temperature, an electric resistance element provides a temporary boost to the system.[58]

Due to the higher temperatures required of DHW systems relative to space heating needs, HPWH systems also have some limitations which favor some refrigerants over others. R410a, one of the most common refrigerants used in heat pump systems, delivers good performance at low ambient air temperatures, but may struggle to provide water temperatures greater than 125ºF. HPWH technologies are still developing to meet the performance and efficiency objectives of full electrification in commercial applications and is an especially promising application for systems that use CO_2 as a refrigerant. The properties of CO_2 allow systems that use it to deliver both high temperature hot water *and* do so at the low outdoor temperatures found in the winter in Northern Virginia. A disadvantage of CO_2 systems is that they have higher operating pressures as compared to systems using more widely utilized refrigerants and subsequently require more robust components, which increases the cost. However, the environmental and performance benefits of these systems in likely to increase market penetration, potentially reducing overall costs.[59]

In many office buildings, domestic hot water needs are relatively low, and typically only make up a small proportion of the energy use while in multifamily buildings, domestic hot water heating can make up a significant proportion of the overall energy consumption.[60] In many office environments, small commercial unitary systems may be adequate to meet the local hot water needs of bathrooms and the often-limited kitchen facilities which may exist.

Table A5: Estimated EUI & GHG Emissions Reductions from Centralized and Decentralized Domestic Hot Water

	Centralized		**Decentralized**	
Building Type	Office	MF	Office	MF
Est. EUI Reduction	2.6%	5.7%	2.9%	6.2%

58 Perry, C., A. Khanolkar, and H. Bastian. 2021. *Increasing Sustainability of Multifamily Buildings with Heat Pump Water Heaters*.

59 Ibid.

60 Arlington County, Virginia. "Arlington County Building Energy Study: Energy End Use Analysis of Key Building Segments in the Commercial and Residential Building Sectors."

Est. GHG Reduction	1.8%	3.9%	2.1%	4.4%

Cooking

Overview

Natural gas cookstoves, especially those in residential applications, are often unvented or minimally vented and can be a significant contributor to unhealthy and potentially hazardous concentrations of nitrogen oxides (NO_2 and NO) and toxic compounds such as carbon monoxide and formaldehyde which result from combustion. For NO_2 in particular, gas stoves can result in temporarily elevated levels which exceed indoor guidelines and outdoor standards. This repeated temporary exposure to NO_2 is linked with higher rates of asthma in children and can exacerbate respiratory conditions.[61]

Induction cookstoves work by rapidly switching the polarity of an electromagnetic field to directly heat the pan itself. As a result, the heating efficiency of induction ranges is higher than electric resistance ranges, and especially gas ranges, in which as much as 65% of the heat of combustion travels around the pan and does not contribute to cooking.[62]

Considerations and Applications

In multifamily residential settings, there are currently a wide range of induction ranges available on the market. Retrofitting stoves and cooktops is typically a straightforward task for property managers, with the caveat that, like electric resistance ranges, most induction cooktops require a 220V circuit. Depending on the age and design of the electrical system in the building, there may be adequate capacity in the unit's electrical panel to accommodate the larger circuit. If not, larger electrical upgrades may be necessary.

Costs are also higher for induction stoves, though some of that increase may be due to lower market share and sales volumes. In new buildings, the incremental costs of designing and constructing a building with the capacity to accommodate the higher loads are much smaller and may be partially or fully offset by the savings of not having to run gas lines to each unit.[63]

Another major barrier for induction stoves is perception and preference. Many people associate gas with higher-end appliances and the level of control over a gas flame is a selling point for many. Many people are simply unaware of what induction technology is or how it works and while induction stovetops are also capable of a high degree of control and can heat up rapidly, they have different performance characteristics and that alone may be enough to slow adoption.

While the GHG emissions associated with cooking are small, in addition to improved efficiency and indoor air quality, induction stoves are typically easier to clean than gas stoves, due to their smooth glass tops. They can also be safer because, unlike electric resistance and gas stoves, the cooking surface retains very little heat after the heating element is switched, reducing the risk of burns, especially for small children.

Kitchens with cookstoves are not common in office settings and so induction technology is generally less relevant to the building type. In instances where an office has a cafeteria and commercial kitchen or food

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[61] Seals, Brady and Andee Krasner. *Gas Stoves: Health and Air Quality Impacts and Solutions*. 2020. https://rmi.org/insight/gas-stoves-pollution-health

[62] Snell, Essie. *Promoting induction cooking to support residential efficiency and decarbonization.* ESource, 2020. https://www.esource.com/130211s0im/promoting-induction-cooking-support-residential-efficiency-and-decarbonization

[63] Ibid.

preparation facilities, the equipment specifications and ventilation requirements associated with these spaces are different. This is similarly true for mixed-use multifamily buildings which may have restaurants tenants on the ground floor.

Table A6: Estimated EUI & GHG Emissions Reductions from Induction Cooking

Building Type	Office	MF
Est. EUI Reduction	0.1%	0.4%
Est. GHG Reduction	0.1%	0.2%