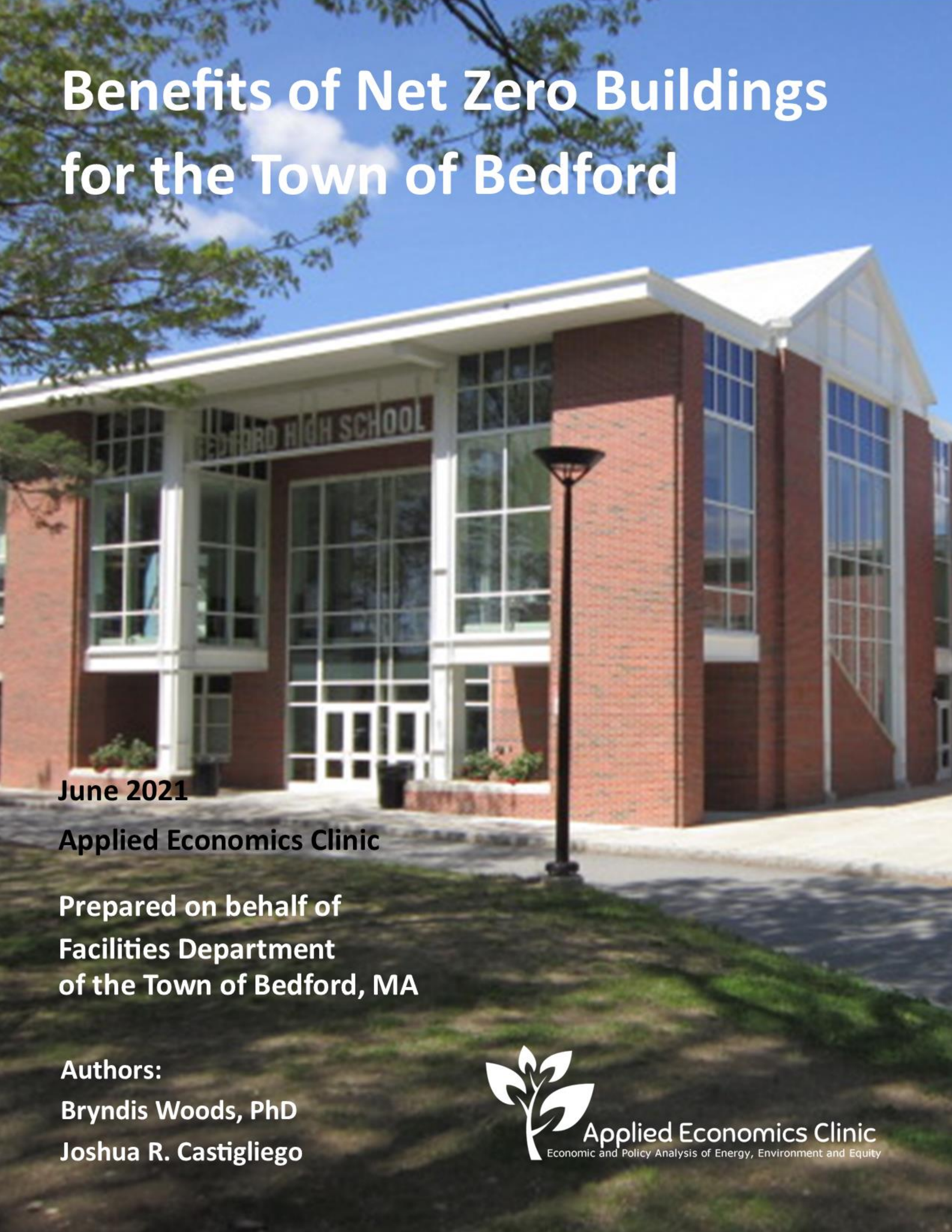


Benefits of Net Zero Buildings for the Town of Bedford

June 2021

Applied Economics Clinic

Prepared on behalf of Facilities Department of the Town of Bedford, MA

Authors:

Bryndis Woods, PhD

Joshua R. Castigliego

Applied Economics Clinic

Economic and Policy Analysis of Energy, Environment and Equity

Executive Summary

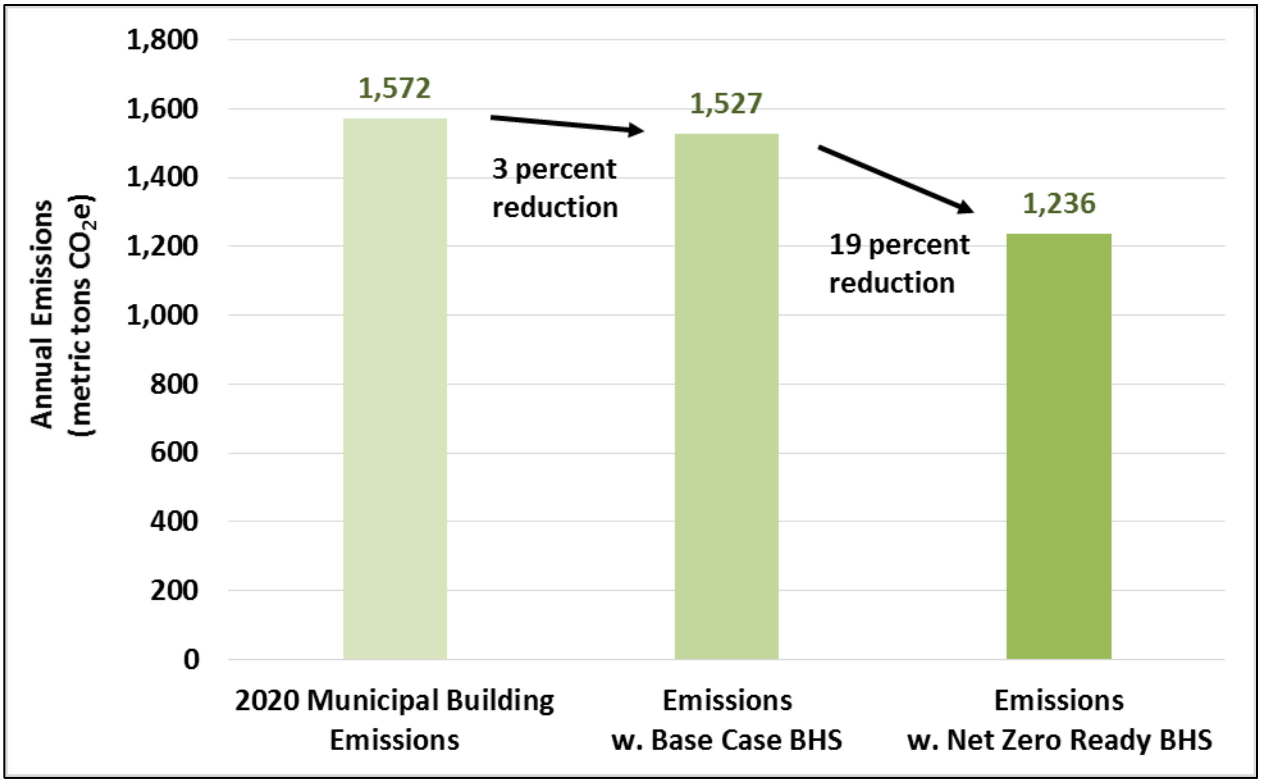
This Applied Economics Clinic report—prepared on behalf of the Facilities Department of the Town of Bedford—outlines the Town's climate and energy goals and how investments in Net Zero buildings can contribute to the Town's climate and energy goals and provide additional health, comfort, cost savings, resiliency and safety benefits. As of 2019, Bedford's emissions totaled 151,000 metric tons of carbon dioxide equivalent (CO_2e), equal to a 40 percent reduction from the Town's estimated 1990 emissions of 250,000 metric tons CO_2e. The emission reductions achieved by the Town so far are the result of: creating a town-wide energy inventory, procuring renewable electricity for municipal buildings, and establishing community choice aggregation for residents and businesses that includes 50 and 100 percent renewable electricity options.

To achieve the Town's goal of net zero energy use in all municipal buildings by 2030 will require investments in "Net Zero" buildings—which generate at least as much renewable energy in a year as they consume—and "Net Zero Ready" buildings—which reduce building energy and fossil fuel use to the point that any remaining emissions could be offset with purchases of carbon offset credits. Across Massachusetts, there are at least twenty-five Net Zero and Net Zero Ready K-12 schools that report energy savings, water savings, emissions reductions, sustainability improvements, better learning conditions, greener campuses, and cost benefits. Net Zero and Net Zero Ready schools are characterized by:

- **Passive design features**, like the water harvesting systems at Fales Elementary School in Westborough;
- **Energy-tight building shells**, like the energy saving windows at Winchester High School;
- **Energy efficient design, lighting and appliances**, like the smart lighting at Somerville High School;
- **Installing systems that run on electricity instead of fossil fuels**, like the geothermal and air-source heat pumps at Belmont High School and Lincoln Elementary School; and
- **Using renewable energy sources**, like the rooftop solar panels at Lunenburg Middle-High School.

As the Town of Bedford considers its next capital funding plan, it is faced with replacing Bedford High School's heating and cooling system. Bedford could choose to replace the existing gas-fired boiler on a one-for-one basis with window air conditioning units ("Base Case"), or it could choose to make the high school Net Zero Ready by replacing the gas-fired boiler with electricity-powered air-source heat pumps and a biomass-powered wood pellet boiler ("Net Zero Ready Case"). AEC's analysis finds that the Base Case is about $2.9 million less expensive than the Net Zero Ready Case over the 20-year lifetime of the boiler equipment. However, for every "extra" thousand dollars invested in the Net Zero Ready Case, the Town of Bedford realizes 2 metric tons of carbon dioxide emissions reduction benefit over the equipment lifetime. Importantly, while the Net Zero Ready Case reduces Bedford High School's emissions substantially, it does not eliminate them. On an annual basis, investing in a Net Zero Ready Bedford High School would reduce the Town's total emissions from municipal buildings by more than 20 percent (see Figure ES-1 below).

Figure ES-1. Town of Bedford municipal buildings' annual emissions



Investing in a Net Zero Ready Bedford High School sets the Town of Bedford up for success in meeting its climate and energy goals and collecting additional health, comfort, cost savings, resiliency and safety benefits.

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I. Introduction

Incorporated in 1729, the Town of Bedford is located in Massachusetts' Middlesex County, about fifteen miles northwest of Boston. In 2019, the Town was home to about 14,000 people across 5,300 households.[1] Bedford has undertaken a number of actions to combat climate change and enhance sustainability, including: becoming a Green Community under the Green Communities Division, which provides financial and technical assistance to help municipalities reduce energy use and develop clean energy resources;[2] establishing an Energy and Sustainability Committee[3] and Net Zero Advisory Council[4] to assist the Town in reaching its climate and energy goals; and producing annual energy reports made publicly available on the Town website.[5]

This Applied Economics Clinic report—prepared on behalf of the Town of Bedford—outlines the Town's climate and energy goals and emissions profile; discusses how Net Zero buildings can contribute to the Town's climate and energy goals and provide additional benefits; presents examples of Net Zero schools across the Commonwealth; summarizes plans for a Net Zero Ready Bedford High School; and discusses how these investments set Bedford up for success in meeting its climate and energy goals and reaping additional health, comfort, cost savings, resiliency and safety benefits.

II. Bedford's Climate and Energy Goals

In November 2017, the Town of Bedford voted to align with the Global Warming Solutions Act (GWSA) goal of achieving an 80 percent reduction in greenhouse gas emissions town-wide by 2050.[6] The GWSA was signed into law in August 2008, and established the state's long-term climate goals and set targets for emission reductions (see Figure 1 below for a timeline of Massachusetts and Town of Bedford climate actions). The GWSA set an economy-wide greenhouse gas emission reduction pathway with an ultimate

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[1] U.S. Census Bureau. 2019. *American Community Survey 5-Year Estimates [Table]*. ACS Demographic and Housing Estimates (Table ID: DP05). Available at: https://data.census.gov/cedsci/table?q=population&g=0600000US2501704615&tid=ACSDP5Y2019.DP05&moe=false&hidePreview=true

[2] M.A. Department of Energy Resources. January 21, 2020. "GCS and Grant Summaries". Available at: https://www.mass.gov/doc/map-of-271-gcs-and-grant-summaries/download.

[3] Bedford, Massachusetts. No date. "Energy and Sustainability Committee". Available at: https://www.bedfordma.gov/energy-and-sustainability-committee#:~:text=The%20Energy%20and%20Sustainability%20Committee,reduce%20community%20greenhouse%20gas%20emissions.

[4] Bedford, Massachusetts. October 22, 2019. "Net Zero Report". Available at: https://www.bedfordma.gov/energy-and-sustainability-committee/news/net-zero-report.

[5] Bedford, Massachusetts. 2020. "Bedford Annual Energy Report". Available at: https://www.bedfordma.gov/energy-and-sustainability-committee/pages/bedford-annual-energy-report.

[6] Bedford, Massachusetts. November 6, 2017. "November 6 & 7, 2017 Special Town Meeting". Available at: https://www.bedfordma.gov/town-manager/town-meeting/pages/november-6-7-2017-special-town-meeting

goal of achieving reductions of at least 80 percent below 1990 levels by 2050.[7] Many cities and towns throughout the Commonwealth—including Bedford—have since established their own climate and energy goals to align with, and in some cases go above and beyond, the statewide climate goals outlined in the GWSA. In April 2020, Massachusetts strengthened its long-term climate goals by setting a target of achieving net-zero greenhouse gas emissions by 2050, which includes an emissions reduction of at least 85 percent from 1990 levels.[8] As the Commonwealth doubles down on its climate goals, many municipalities—including Bedford—might consider realigning themselves with the state's more stringent emission reduction targets.

In November 2018, the Town of Bedford released its town-wide energy inventory, which was conducted by Peregrine Energy Group to establish baseline greenhouse gas emissions for the Town.[9] The energy inventory revealed that greenhouse gas emissions in non-municipal buildings increased between 2013 and 2016, which was attributed to an increase in the emissions factor of electricity (as the result of nuclear plant retirements) as well as electric usage by commercial and industrial customers.[10]

In 2019, the Town of Bedford established a Net Zero Advisory Council to develop a plan for reducing greenhouse gas emissions in its municipal, residential, and commercial buildings. In June 2019, the Net Zero Advisory Council presented their recommendations on how to move the Town toward achieving its long-term climate goals over the next decade.[11] The *Bedford Net Zero Final Report* (Net Zero Report), released in October 2019, provides an overview of current energy use and greenhouse gas emissions in Bedford as well as summarizes the recommendations of the Advisory Council.[12]

To date, Bedford has initiated a number of the Advisory Council's recommendations, including:

- Setting a net zero energy goal for all municipal buildings by 2030 (according to the Facilities Department commitment in the Net Zero Report and based on the Town's capital program),
- Procuring renewable electricity for municipal buildings in July 2019, and
- Establishing community choice aggregation for residents with an option to "opt-up" to 50 and 100 percent renewable energy in August 2019.[13] The new contract is up for renewal in December 2021.

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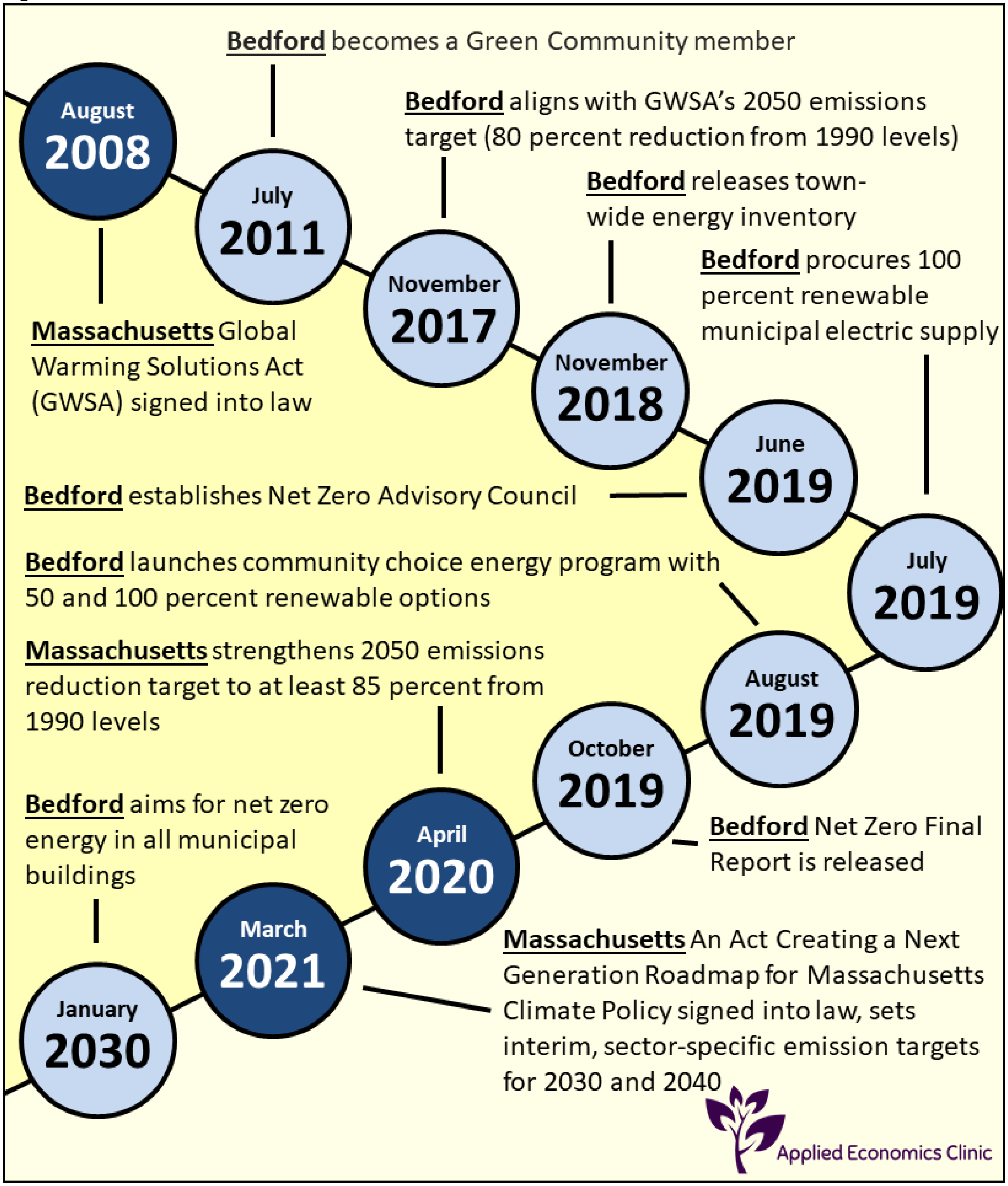
[7] The 192nd General Court of the Commonwealth of Massachusetts. August 7, 2008. *An Act Establishing The Global Warming Solutions Act*. Chapter 298. Available at: https://malegislature.gov/Laws/SessionLaws/Acts/2008/Chapter298
[8] The Commonwealth of Massachusetts Executive Office of Energy and Environmental Affairs. April 22, 2020. "Determination of Statewide Emissions Limit for 2050". Available at: https://www.mass.gov/doc/finalsigned-letter-of-determination-for-2050-emissions-limit/download
[9] Peregrine Energy Group. November 2018. *Energy Inventory*. Prepared for the Bedford Selectmen. Available at: https://www.bedfordma.gov/energy-and-sustainability-committee/news/bedford-energy-inventory
[10] Peregrine Energy Group. November 2018. *Energy Inventory*. Prepared for the Bedford Selectmen. p.11. Available at: https://www.bedfordma.gov/energy-and-sustainability-committee/news/bedford-energy-inventory
[11] Bedford, Massachusetts. June 11, 2019. *Bedford Net Zero Advisory Council Executive Summary*. Available at: https://www.bedfordma.gov/sites/g/files/vyhlif2781/f/news/bedford_net_zero_execsummary.doc.pdf
[12] Peregrine Energy Group. October 2019. *Bedford Net Zero Final Report*. Prepared for the Bedford Selectmen. Available at: https://www.bedfordma.gov/energy-and-sustainability-committee/news/net-zero-report
[13] Bedford, Massachusetts. No date. "Program Details". Available at: https://bedfordcca.com/

Figure 1. A timeline of Massachusetts and Town of Bedford climate action



Sources: Appendix A.

III. Bedford's Emissions Profile

Bedford's Net Zero Report uses 1990 as a baseline year to align with the GWSA and other towns across the Commonwealth. However, Bedford and most other towns do not have inventories of town-wide greenhouse gas emissions that date back to 1990. Due to these data gaps, the Net Zero Report uses Massachusetts' statewide greenhouse gas emissions inventory to estimate Bedford's 1990 greenhouse gas emissions to be around 250,000 metric tons of carbon dioxide equivalents (CO_2e).[14] The Town of Bedford must limit its town-wide greenhouse gas emissions to roughly 50,000 metric tons CO_2e by 2050 to reach its long-term goal of an 80 percent emissions reduction. The Town must address energy use in its municipal, residential, and non-residential buildings to achieve the reduction in greenhouse gas emissions necessary to meet its climate goals.

Bedford's Residential, Commercial, and Industrial Buildings

Bedford's residential buildings account for approximately 24 percent of the town's building-related greenhouse gas emissions, while commercial and industrial buildings (i.e., non-residential) account for 73 percent.[15] In total, the energy usage from Bedford's non-municipal buildings (i.e., residential, commercial, and industrial) in 2019 resulted in approximately 151,000 metric tons CO_2e.

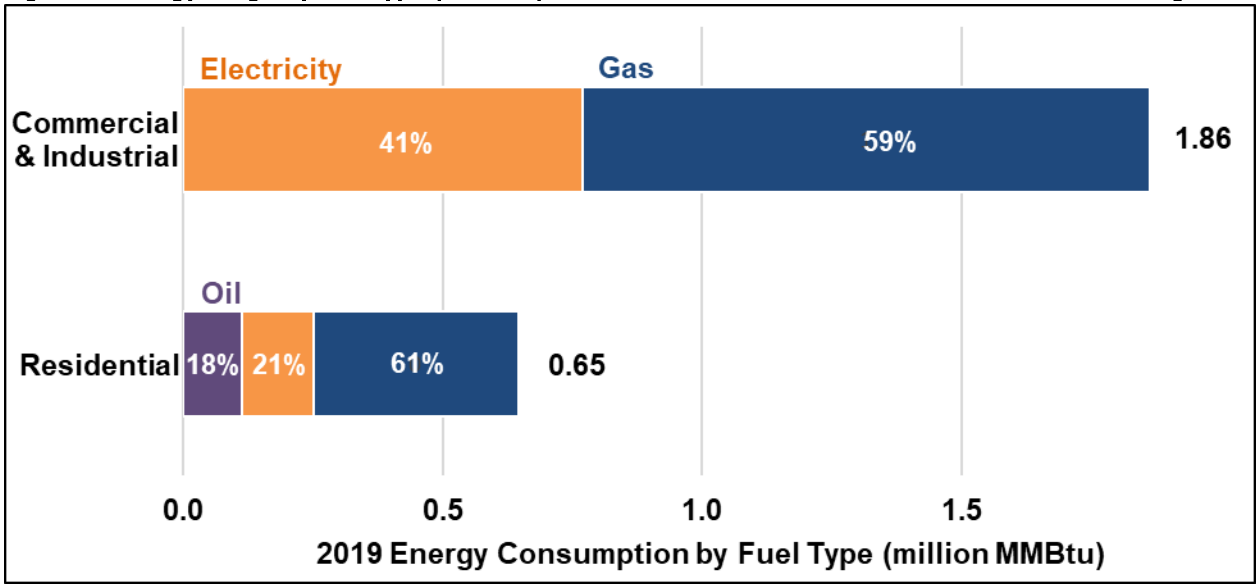
Bedford's residential and non-residential buildings use electricity, gas, and heating oil to meet their energy needs (see Figure 2). In 2019, Bedford's residential and non-residential buildings consumed 265,400 MWh (0.9 million MMBtu) of electricity, 14.9 million therms (1.5 million MMBtu) of gas, and 830,000 gallons (0.1 million MMBtu) of heating oil.[16] Fossil fuels (i.e., gas and heating oil) account for 59 and 79 percent of total energy usage in non-residential and residential buildings, respectively. As the Town moves toward achieving its 2050 climate goals, Bedford's residents and businesses that currently use fossil fuels will need to transition to clean energy sources—such as electricity from renewable generation—to meet their energy needs.

[14] Peregrine Energy Group. October 2019. *Bedford Net Zero Final Report*. Prepared for the Bedford Selectmen. Available at: https://www.bedfordma.gov/energy-and-sustainability-committee/news/net-zero-report pp.5-6

[15] Peregrine Energy Group. October 2019. *Bedford Net Zero Final Report*. Prepared for the Bedford Selectmen. Available at: https://www.bedfordma.gov/energy-and-sustainability-committee/news/net-zero-report p.5

[16] Heating oil usage in this report was derived from Bedford's *2018 Energy Inventory*, which estimates that Bedford's residential buildings use approximately 830,000 gallons of heating oil per year, accounting for roughly 5 percent of greenhouse gas emissions from Bedford's non-municipal buildings (i.e., residential, commercial, and industrial buildings). Peregrine Energy Group. November 2018. *Energy Inventory*. Prepared for the Bedford Selectmen. p. 9-10. Available at: https://www.bedfordma.gov/energy-and-sustainability-committee/news/bedford-energy-inventory

Figure 2. Energy usage by fuel type (MMBtu) in Bedford's residential and non-residential buildings



Source: Mass Save. March 2021. 2019 Geographic Report: Electric and Gas Usage Data. Available at: https://www.masssavedata.com/Public/GeographicSavings?view=C; Peregrine Energy Group. November 2018. Energy Inventory. *Prepared for the Bedford Selectmen. Available at: https://www.bedfordma.gov/energy-and-sustainability-committee/news/bedford-energy-inventory*

The Net Zero Advisory Council has outlined an action plan with strategies for residential and non-residential buildings to achieve emission reductions over the next ten years (see

Table 1). These initiatives are aimed at transitioning the Town's residents and businesses away from emissions-intensive energy sources (i.e., fossil fuels) by increasing the share of renewable electricity received by customers through community choice aggregation and renewable power purchases as well as incentivizing the adoption of clean energy technologies. Energy efficiency initiatives are also a crucial strategy; these measures achieve emission reductions while reducing customers total energy use.

Table 1. Emission reduction initiatives for Bedford's residential and non-residential buildings

RESIDENTIAL INITIATIVES	DESCRIPTION
Community Choice Aggregation (CCA)	Increase share of renewable energy supplied by Bedford's CCA program to at least 50 percent by 2030 and 100 percent by 2050.
Participation in energy efficiency programs	Increase participation in ultility sponsored MassSave energy efficiency programs in order to achieve an additional 10 percent reduction in Bedford's residential energy use by 2030 as compared to the state average.
Adoption of clean energy technology	Encourage residents to install solar PV and to consider energy storage, heat pumps, and electric vehicle charging.
COMMERCIAL & INDUSTRIAL INITIATIVES	**DESCRIPTION**
Document and publicize progress to date	The Town will identify and publicize businesses in Bedford that have already implemented energy efficiency and green power purchase initiatives to inspire others.
Renewable power purchases	Achieve a 20 percent share of electricity usage by commercial customers to be supplied by renewable energy by 2030.
Building Energy Use Disclosure Bylaw	Adopt a Building Energy Use Disclosure Bylaw requiring commercial customers to report their energy use to the Town.
Incentivize energy efficiency and solar	Use the special permit process to encourage the implementation of energy efficiency and solar in new buildings.
Strategic plan development	Develop a strategic plan to help commercial customers reduce energy usage and greenhouse gas emissions.

Source: Peregrine Energy Group. October 2019. Bedford Net Zero Final Report. Prepared for the Bedford Selectmen. p.8-10. Available at: https://www.bedfordma.gov/energy-and-sustainability-committee/news/net-zero-report.

Bedford's Municipal Buildings

The Town of Bedford's municipal buildings include the town's schools (i.e., Bedford High School, John Glenn Middle School, Davis Elementary School, Lane Elementary School), Town Center, Town Hall, Department of Public Works, the public library, the police and fire stations, and a few others. Although Bedford's municipal buildings account for the smallest share—roughly 3 percent[17]—of building-related greenhouse gas emissions in the town, these buildings represent opportunities where the Town can lead by example when it comes to achieving its long-term climate and energy goals.

[17] Peregrine Energy Group. October 2019. *Bedford Net Zero Final Report*. Prepared for the Bedford Selectmen. p. 5. Available at: https://www.bedfordma.gov/energy-and-sustainability-committee/news/net-zero-report

On July 1, 2019, the Town entered into a three-year contract for 100 percent renewable electricity in all municipal buildings, which results in zero greenhouse gas emissions from electric use (note that direct fossil fuel use for space and water heating in municipal buildings still results in greenhouse gas emissions). In addition to making renewable electricity purchases, the Net Zero Advisory Council has identified a number of initiatives for Bedford's municipal buildings to achieve emissions reductions (see Table 2). Many of these initiatives call on the Town to set an example for its residents and businesses in prioritizing sustainability in the operation and design of its municipal buildings. The Net Zero Advisory Council's recommended initiatives also include investigating the feasibility of adopting clean energy technologies and developing a microgrid for municipal buildings. After the Town of Bedford applied for a microgrid feasibility study and schematic design grant, GE Energy Consulting and Nexant announced in March 2021 that the Massachusetts Clean Energy Center's Clean Energy and Resiliency Program had provided funding for a microgrid feasibility study in Bedford.[18] To ensure that the Town stays on track to achieving its energy and climate goals, there are also initiatives to develop a 10-year energy plan to detail emission reduction and sustainability efforts, voluntarily disclose the energy use of municipal buildings, and hire a sustainability manager to oversee the Town's efforts.

Table 2. Emission reduction initiatives for Bedford's municipal buildings

MUNICIPAL INITIATIVES	DESCRIPTION
Renewable electricity purchases	The Town has entered into a 3-year contract for 100 percent renewable electricity on July 1, 2019, and intends on continuing these procurements into the future.
New buildings and major renovations	Adopt a goal of achieving net-zero energy use and zero fossil fuel energy use in all new buildings and renovation projects.
Municipal sustainability coordinator	Hire a Sustainability Coordinator to oversee the Town's sustainability efforts.
Publish a 10-Year Energy Plan	Produce a 10-year energy plan that integrates emission reductions and sustainability in the Town's capital planning process.
Town microgrid	Explore the feasibility of developing a microgrid for municipal buildings.
Building energy use disclosure	Voluntarily report the energy use of municipal buildings as would be required by such a Building Energy Use Disclosure Bylaw for commercial customers.

Source: Peregrine Energy Group. October 2019. Bedford Net Zero Final Report. Prepared for the Bedford Selectmen. p.8-9. Available at: https://www.bedfordma.gov/energy-and-sustainability-committee/news/net-zero-report

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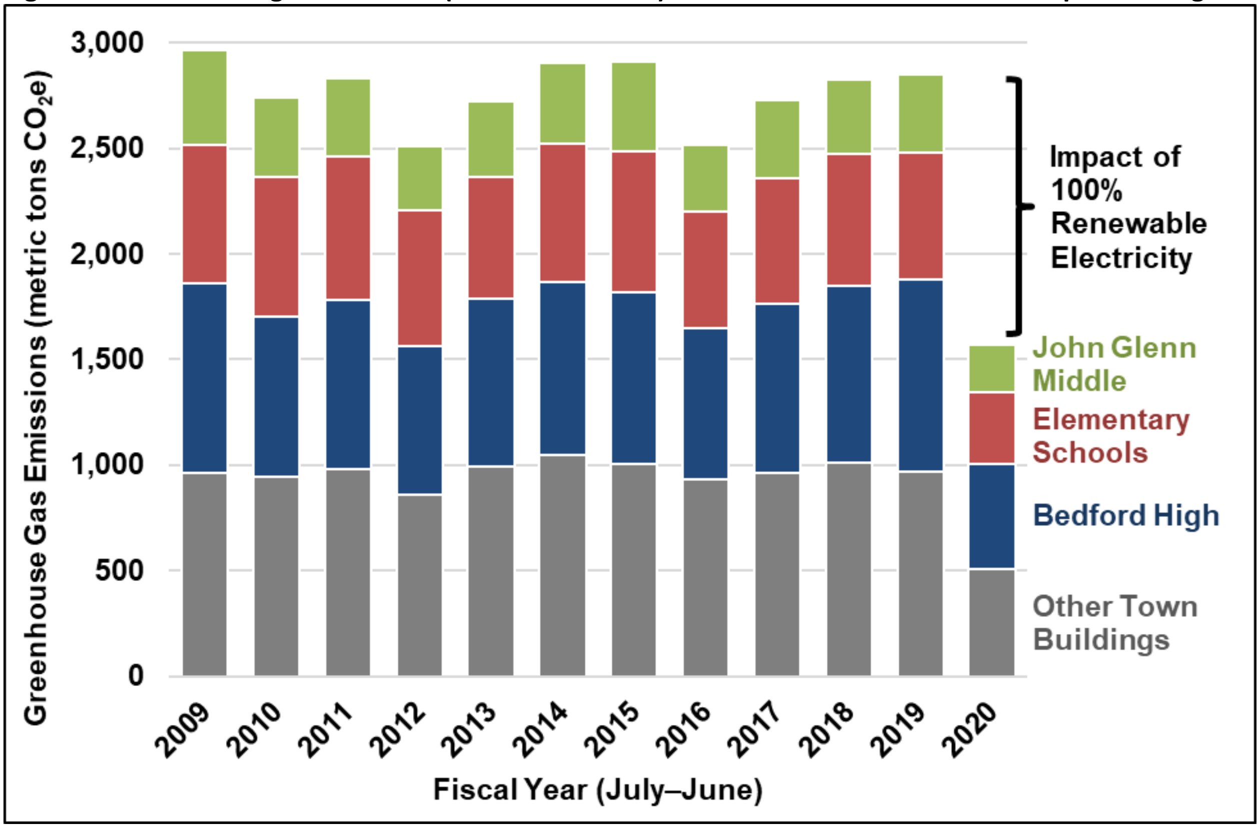
[18] GE. March 16, 2021. "GE Energy Consulting begins Microgrid Study for Town of Bedford, MA". Available at: https://www.ge.com/news/press-releases/ge-energy-consulting-begins-microgrid-study-for-town-of-bedford-ma.

Over the past decade or so, Bedford's municipal buildings have consistently emitted between 2,500 and 3,000 metric tons CO_2e per year, with more than half of those emissions coming from the Town's school buildings (see Figure 3). With the procurement of 100 percent renewable electricity that began in July 2019, the Town's municipal buildings experienced an emissions reduction of 46 percent (722 metric tons CO_2e) between the fiscal years (FY) of 2019 and 2020.[19]

Figure 3. Greenhouse gas emissions (metric tons CO_2e) in the Town of Bedford's municipal buildings

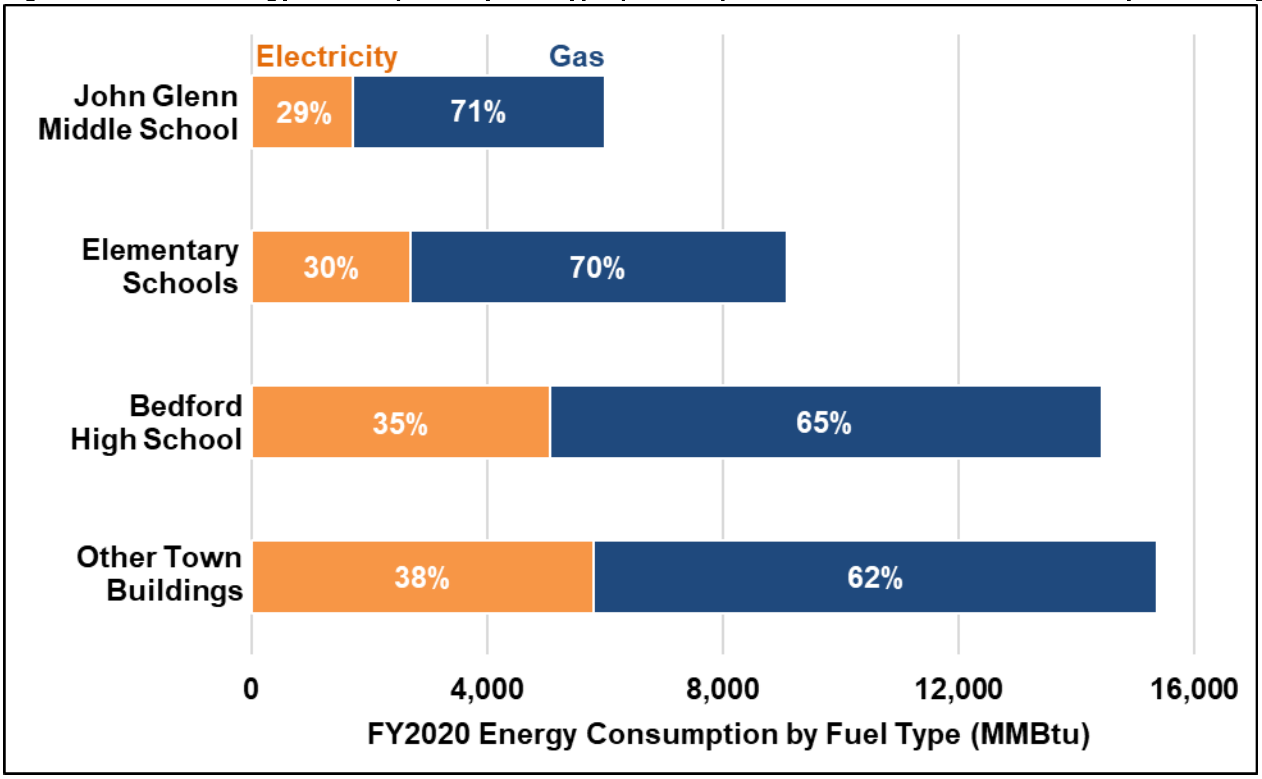


Source: Town of Bedford. Green Community Annual Reports for FY2017 through FY2020.

In FY2020, electricity accounted for 29 to 38 percent of Bedford's energy consumption across its municipal buildings, while gas accounted for 62 to 71 percent (see Figure 4). Despite procuring renewable electricity for its municipal buildings, the Town will need to explore other initiatives, such as energy efficiency and electrification, to continue to make progress towards its net zero by 2030 and longer-term climate goals, and lead by example for its residents and businesses.

[19] The Town of Bedford's fiscal years run between July and June (e.g., FY2020 ran from July 2019 through June 2020).

Figure 4. FY2020 energy consumption by fuel type (MMBtu) in the Town of Bedford's municipal buildings



Source: Town of Bedford. Green Community Annual Reports for FY2017 through FY2020.

IV. Design and Benefits of Net Zero and Net Zero Ready Buildings

There are different varieties of 'Net Zero' and 'Net Zero Ready' buildings:

- **Net Zero** buildings generate at least as much renewable energy in a year as they consume.[20]
    - Some Net Zero buildings may be **Positive Energy** buildings that generate more energy than they use in a year.
- **Net Zero Ready** buildings substantially reduce building energy and fossil fuel use through efficiency and fuel-switching measures to the point that any remaining emissions could be offset with purchases of carbon offset credits, which pay for someone else, somewhere else to remove a given quantity of greenhouse gases from the atmosphere by, for example, planting trees or financing renewable energy development.[21]

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[20] Woods, B and Tavares, E. January 2020. "Benefits of Net Zero Buildings: Comfort, Safety, Value, Climate." Applied Economics Clinic. Available at: https://aeclinic.org/publicationpages/2020/1/13/benefits-of-net-zero-buildings-comfort-safety-value-climate.

[21] USGBC Massachusetts. 2019. *Zero Energy Buildings in Massachusetts: Saving Money from the Start.* Available at: https://builtenvironmentplus.org/wp-content/uploads/2019/09/ZeroEnergyBldgMA2019.pdf.

- Some Net Zero Ready buildings may be **Zero Emissions/Fossil Fuel Free** buildings that generate and/or purchase enough renewable energy to offset any emissions produced by the building in a year.

A 2019 report by the U.S. Green Building Council Massachusetts Chapter found that Net Zero buildings are "possible today with no added upfront cost and make for smart investments."[22] Net Zero and Net Zero Ready buildings are characterized by six primary elements (see Figure 5 below):

1. **Passive design features** that serve to minimize a building's energy needs. For example, orienting a building to maximize rooftop solar potential,[23] adjusting the building layout and window placement to maximize natural sunlight, [24] and stabilizing temperature shifts within a building through the use of products like concrete, stone and brick that can absorb and store heat energy.[25]
2. **Building shell** that minimizes heat loss in the winter and heat gain in the summer[26] through insulation, sealing and extra thick windows. Ventilators ensure indoor air is fresh and minimize indoor air pollution.
3. **Energy efficiency** through efficient lighting, electronics and appliances. An abundance of natural sunlight (per passive design) also reduces the building's need for artificial lighting. Occupancy sensors can further reduce energy use by adjusting heating, cooling and lighting based on whether or not a room is in use.[27]
4. **Electrification** is the process of replacing fossil-fuel powered systems to run on electricity. End uses such as space heating, water heating, and cooking commonly rely on direct fossil fuel use, like oil and gas.[28] As the electric grid is powered by greater and greater amounts of renewable energy, switching these systems to run on electricity will entail greater and greater emission reductions.
5. **Renewable energy** eliminates the need to rely on polluting fossil fuels (and their price volatility) to provide power to a building. Increasing the market penetration of Net Zero buildings helps towns and cities meet their climate goals while building a more resilient and energy-secure building stock.
6. **Energy audits** provide helpful information and monitoring services to building occupants that can be used to maximize efficiency at the lowest cost. For example, auditors can help identify the most

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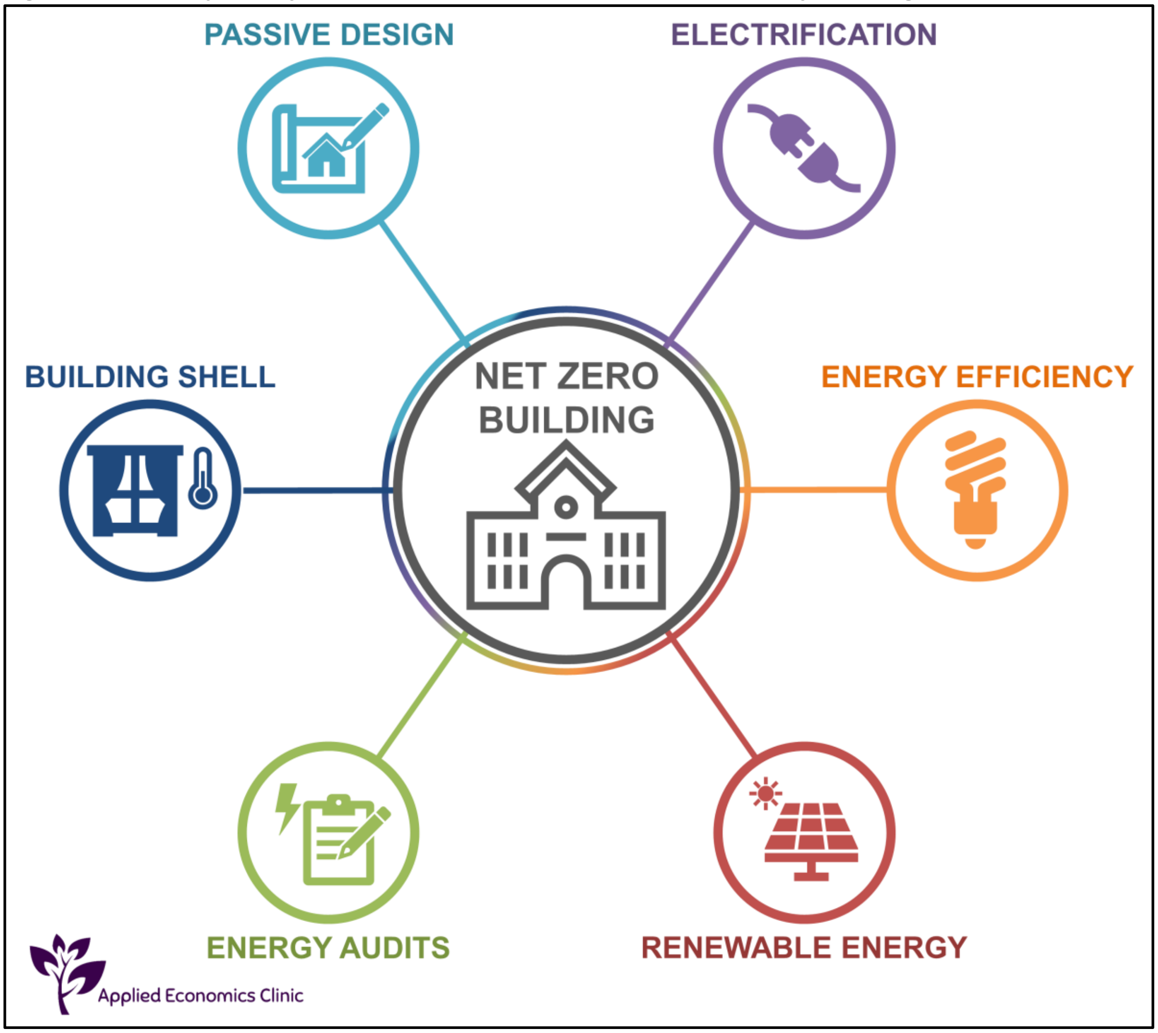
[22] U.S. Green Building Council – MA Chapter. 2019. "Zero Energy Buildings in Massachusetts: Saving Money from the Start." Available at: https://usgbcma.org/wpcontent/uploads/2019/09/ZeroEnergyBldgMA2019.pdf. p.5.
[23] Green Building Program. No date. "232 Highland Street". Available at: http://www.epositiveboston.org/marcella-street/.
[24] PHIUS. No date. "Passive House Principles". Available at: https://www.phius.org/what-is-passive-building/passive-house-principles.
[25] Fox Blocks. No date. "Essential Elements of Passive House Design ". Available at: https://www.foxblocks.com/blog/passive-house-design.
[26] Leonard N. September 30, 2019. "Best Practices in Net-Zero House Design". High Performing Buildings. Available at: https://www.hpbmagazine.org/best-practices-in-net-zero-house-design/.
[27] AMVIC Building System. No date. "The Five Essential Components of Net Zero Homes". Available at: https://www.amvicsystem.com/blog/the-five-essential-components-of-net-zero-homes/.
[28] Environment Massachusetts. No date. "Building electrification." Available at: https://environmentmassachusetts.org/energy-101/building-electrification

affordable materials to use, balance design elements, and perform efficiency tests.[29]

Figure 5. The six primary elements of Net Zero and Net Zero Ready buildings



Not only do Net Zero and Net Zero Ready buildings enhance sustainability by reducing or eliminating reliance on fossil fuel-powered energy, but they also provide numerous additional benefits, such as:

Health and Comfort

- **Less indoor air pollution** due to advanced ventilation and filtration systems
- **Comfortable indoor temperatures** due to high-performing building shells
- **Less noise** due to thicker walls and windows
- **More sunshine** due to passive design features that maximize natural light

[29] AMVIC Building System. No date. “The Five Essential Components of Net Zero Homes.” Available at: https://www.amvicsystem.com/blog/the-five-essential-components-of-net-zero-homes/

- **Healthy, high-performing learning environments** that give students the best foundation for learning[30]

Savings

- **Lower utility bills** due to self-generated energy (and potentially energy storage) that is unaffected by rising utility energy prices
- **Potential net energy producer** when buildings generate more energy than they need
- **Enhanced building value** due to the building's durability, efficiency and advanced technologies
- **Sound fiscal management of community resources** that reduce exposure to energy price volatility and lower energy costs due to increased efficiency, freeing up funds for other town priorities[31]

Resiliency and Safety

- **Weather resiliency** due to the ability to produce energy during power outage events and extreme heat and cold conditions—can serve as a refuge for town residents in emergencies
- **Better materials** provide increased durability, comfort and safety and resilience against extreme conditions
- **No risk of explosion** when fossil fuel use is eliminated, and reduced risk when fossil fuel use is minimized

Climate

- **Clean energy and net zero or reduced emissions** by reducing or eliminating the need to rely on polluting fossil fuels
- **Climate goal progress** by reducing emissions and making progress towards emission reduction goals and demonstrating leadership in environmental stewardship

By pursuing Net Zero and/or Net Zero Ready municipal buildings, the Town of Bedford is not only taking important action to achieve its climate goals, but will also achieve important health, comfort, cost, resiliency and safety benefits for its residents and businesses.[32]

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[30] Torcellini P. et al. August 2019. *A Guide to Zero Energy and Zero Energy Ready K–12 Schools*. NREL. Available at: https://betterbuildingssolutioncenter.energy.gov/sites/default/files/attachments/NREL_ZE_K12_Study.pdf.
[31] Torcellini P. et al. August 2019. *A Guide to Zero Energy and Zero Energy Ready K–12 Schools*. NREL. Available at: https://betterbuildingssolutioncenter.energy.gov/sites/default/files/attachments/NREL_ZE_K12_Study.pdf.
[32] U.S. Census Bureau. 2019. *QuickFacts: Bedford, MA*. Available at: https://www.census.gov/quickfacts/fact/table/bedfordtownmiddlesexcountymassachusetts/RHI225219.

V. Net Zero and Net Zero Ready Schools in Massachusetts

Net Zero and Net Zero Ready schools are common across the Commonwealth: there are at least twenty-five such K-12 schools complete and in progress throughout the Commonwealth, in communities from Cambridge to Springfield. Table 3 shows the result of AEC's review of 35 publicly available sources regarding Net Zero and Net Zero Ready schools across the Commonwealth. Note that this list may not be exhaustive, and includes only elementary, middle and high schools (not colleges or universities).

The schools listed in Table 3 use a variety of clean energy, energy efficiency and conservation technologies, including:

- **Geothermal-powered ground source heat pumps**—for example, Belmont Middle and High Schools and Dr. Martin Luther King, Jr. School in Cambridge
- **Electric-powered air source heat pumps**—for example, Hastings School in Lexington and Lincoln Elementary School
- **Rooftop solar panels**—for example, Cunniff Elementary School and Hosmer Elementary School in Watertown and King Open/Cambridge St. Upper School in Cambridge
- **Battery storage systems**—for example, Lincoln K-8 School and Hastings School in Lexington
- **Water harvesting systems**—for example, Fales Elementary School in Westborough and Tobin Montessori and Vassal Lane Schools in Cambridge
- **Energy efficient and 'smart' lighting**—for example, Somerville High School and Lunenburg Middle-High School
- **Energy saving windows**—for example, Winchester High School and Leominster High School

As a result of these investments, schools report energy savings, water savings, emission reductions, sustainability improvements, better learning conditions, greener campuses, and cost benefits. For example, in Harwich, the Monomoy Regional High School saw its energy costs cut by 32 percent.[33] In Springfield, $10 million in project savings from the Roger L. Putnam Vocational Technical Academy were reinvested for the renovation of the Forest Park Middle School.[34] In Lexington, the Hastings School is anticipated to result in a net income to the Town of $30,000 to $100,000 annually.[35] By working towards Net Zero and Net Zero Ready schools, the Town of Bedford stands to join the ranks of dozens of other towns and cities across the Commonwealth that are reaping a variety of benefits from their Net Zero and Net Zero Ready investments.

[33] NEEP. No date. "Monomoy Regional High School". Available at: https://neep.org/sites/default/files/resources/Monomoy%20Case%20Study.pdf.

[34] NEEP. No date. "Roger L. Putnam Vocational Technical Academy". Available at: https://neep.org/sites/default/files/resources/Putnam%20Technical%20Vocational%20HS_FINAL_0.pdf.

[35] Hometown Weekly. June 17, 2020. "On making Dale School a Net Zero building". Available at: http://hometownweekly.net/letters/on-making-dale-school-a-net-zero-building/.

Table 3. Net Zero and Net Zero Ready Schools in Massachusetts

School	City/Town	Type	Net Zero or Net Zero Ready	Status
Arlington High School	Arlington	Retrofit	Net Zero Ready	In progress
Belmont Middle and High School	Belmont	New Construction	Net Zero	Complete
Brookline High School	Brookline	Retrofit + Addition	Net Zero Ready	In progress
Cambridge Rindge and Latin	Cambridge	Retrofit	Net Zero Ready	Complete
Coolidge Corner K-8	Brookline	Retrofit + Addition	Net Zero	In progress
Cunniff Elementary School	Watertown	New Construction	Net Zero Ready	Complete
Dr. Martin Luther King, Jr. School	Cambridge	New Construction	Net Zero	Complete
Fales Elementary School	Westborough	New Construction	Net Zero Ready	In progress
Francis T. Bresnahan Elementary School	Newburyport	Retrofit + Addition	Net Zero Ready	Complete
Hastings School	Lexington	New Construction	Net Zero	Complete
Hosmer Elementary School	Watertown	New Construction	Net Zero Ready	In progress
Howe-Manning Elementary School	Middleton	New Construction	Net Zero Ready	Complete
Hunnewell Elementary School	Wellesley	New Construction	Net Zero Ready	In progress
King Open / Cambridge St Upper School & Community Complex	Cambridge	New Construction	Net Zero	Complete
Leominster High School	Leominster	Retrofit + Addition	Net Zero Ready	Complete
Lincoln K-8 School	Lincoln	Retrofit	Net Zero Ready	In progress
Lunenburg Middle-High School	Lunenburg	New Construction	Net Zero Ready	Complete
Monomoy Regional High School	Harwich	New Construction	Net Zero Ready	Complete
Nelson Place Elementary School	Worcester	New Construction	Net Zero Ready	Complete
Ninth Elementary School	Brookline	New Construction	Net Zero	In progress
Rochester Memorial Elementary School	Rochester	Retrofit	Net Zero Ready	Complete
Roger L. Putnam Vocational Technical Academy	Springfield	New Construction	Net Zero Ready	Complete
Somerville High School	Somerville	Retrofit	Net Zero Ready	In progress
Tobin Montessori and Vassal Lane Schools	Cambridge	New Construction	Net Zero Ready	In progress
Winchester High School	Winchester	Retrofit	Net Zero Ready	Complete

Sources: See Appendix B.

VI. Investing in a Net Zero Ready Bedford High School

As the Town of Bedford works towards its goal of net zero energy use in all municipal buildings by 2030, investment in measures that contribute towards this goal will inevitably be made. In the current capital funding plan for the Town's municipal buildings, multiple such investments are proposed, including:

- Heating, ventilation, and air conditioning (HVAC) replacements, energy efficiency upgrades and solar-ready roof replacements in Bedford's school buildings;
- Building shell improvements at Bedford's library, fire station and town hall; and
- A town-wide energy management system.[36]

Measures like these help the Town of Bedford's municipal buildings move toward Net Zero status by facilitating town-wide energy management, reducing building energy needs, installing more efficient energy systems, and preparing Bedford's schools for rooftop solar panels. Measures like these are also common across the Commonwealth: All of the 25 Net Zero and Net Zero Ready schools identified in Section 0 above undertook building energy efficiency improvements, while at least 17 include solar panels on the roof. Investing in renewable energy and energy efficiency contribute to the Town's net zero energy use goals and provide emission reduction benefits, while also benefiting Bedford as it works to modernize its energy system. For example, Bedford is currently conducting a feasibility study evaluating the potential for a town-wide, renewable energy-powered microgrid that could 'island' itself from the larger electric grid in the case of a power outage. Bedford's microgrid would include the police and fire stations, Town Hall, Town Center, and Bedford High School—which would also house the microgrid control center.[37]

The remainder of this chapter presents the results of a cost and emission analysis for Bedford High School that considers two potential scenarios facing the Town of Bedford as it decides how to replace the school's heating and cooling systems:

- **Base Case:** replace the existing gas-fired boiler on a one-for-one basis to serve the building's heating needs and utilize window air conditioning units for cooling needs. The gas boiler would produce greenhouse gas emissions, while the window A/C units would be emission-free due to Bedford's 100 percent renewable electric supply for its municipally-owned buildings.
- **Net Zero Ready Case:** replace the existing gas-fired boiler with more efficient electric-powered air-source heat pumps and a wood pellet boiler (which shares the same efficiency as a gas-fired boiler). The air-source heat pumps would provide an estimated 80 percent of the heating load with zero greenhouse gas emissions (because of 100 percent renewable electric supply), while the pellet boiler would provide the remaining 20 percent and would entail greenhouse gas emissions. The air-source heat pumps would also provide cooling with zero associated emissions.

[36] Town of Bedford Facilities Department. 2020. Capital Funding for Facilities (2022-2027).
[37] Rosenberg, M. March 25, 2021. "Microgrid Could Provide Uninterrupted Power for Key Town Buildings." *The Bedford Citizen*. Available at: https://www.thebedfordcitizen.org/2021/03/microgrid-could-provide-uninterrupted-power-for-key-town-buildings/.

Table 4 presents the results of AEC's cost and emissions analysis of Bedford High School's Base Case and Net Zero Ready Case. (AEC's analysis builds on the findings of Northeast Engineering and Commissioning Services, Inc.'s "Bedford High School Energy Net Zero Upgrade Cost Comparison" report: see Appendix C for a detailed description of our methodological approach and assumptions.) The results of our analysis demonstrate that the Net Zero Ready Case is more expensive than the Base Case overall, but results in lower emissions, lower operating costs and lower energy consumption than the Base Case. It would be possible for the Base Case to achieve the same emission reductions as the Net Zero Ready Case if the Town purchased carbon offsets equal to 5,806 metric tons of carbon dioxide equivalent over 20 years; those offset purchases would make the Base Case more expensive. Selecting the Net Zero Ready Case would move the Town of Bedford closer to its emission reduction and net zero energy use goals, but does not eliminate greenhouse gas emissions from the High School completely.

Table 4. A comparison between one-for-one replacement and heat pumps plus pellet boiler

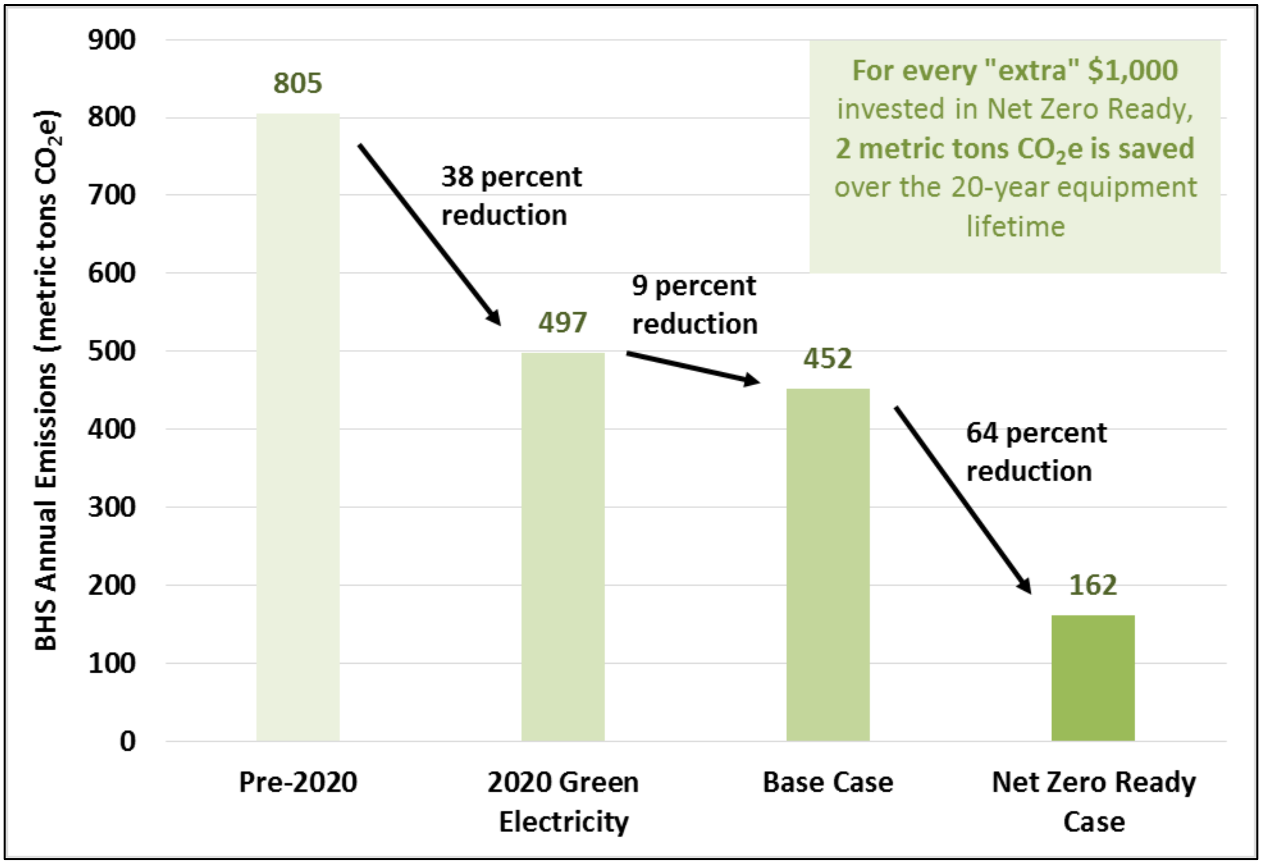
20-YEAR COST SUMMARY	Base Case	Net Zero Ready Case	Difference
Upfront capital costs (2020$, millions)	$4.36	$8.41	-$4.05
Lifetime heating operating costs (2020$, millions)	$2.45	$1.33	$1.12
Lifetime cooling operating costs (2020$, millions)	$0.10	$0.06	$0.04
Total lifetime costs (2020$, millions)	**$6.91**	**$9.80**	**-$2.90**
20-YEAR ENERGY AND EMISSIONS SUMMARY	**Base Case**	**Net Zero Ready Case**	**Difference**
Lifetime energy consumption - Heating (MMBtu)	170,239	74,905	95,334
Lifetime energy consumption - Cooling (MMBtu)	6,448	5,015	1,433
Lifetime emissions (metric tons CO_2e)	**9,042**	**3,236**	**5,806**

Sources: 1) Northeast Engineering and Commissioning Services, Inc. October 28, 2020. Bedford High School - Energy Net Zero Upgrade Cost Comparison. Prepared for Town of Bedford. pp. 2-3; 2) US EIA. June 2018. Updated Buildings Sector Appliance and Equipment Costs and Efficiencies. Available at: https://www.eia.gov/analysis/studies/buildings/equipcosts/pdf/full.pdf; 3) US EIA. 2021. Annual Energy Outlook 2021 - Table 3. Energy Prices by Sector and Source. Available at: https://www.eia.gov/outlooks/aeo/data/browser/#/?id=3-AEO2021&region=1-0&cases=ref2021&start=2019&end=2050&f=A&linechart=&map=ref2021-d113020a.4-3-AEO2021.1-0&ctype=linechart&sourcekey=0; 4) U.S. Environmental Protection Agency (EPA). April 2021. "Emission Factors for Greenhouse Gas Inventories." Available at: https://www.epa.gov/sites/production/files/2021-04/documents/emission-factors_apr2021.pdf.

The "extra" investment entailed in the Net Zero Ready Case is not money wasted: for every "extra" thousand dollars invested in the Net Zero Ready Case as compared to the Base Case, Bedford saves 2 metric tons of carbon dioxide equivalent (CO_2e) over the 20-year lifetime of the equipment. A Net Zero Ready

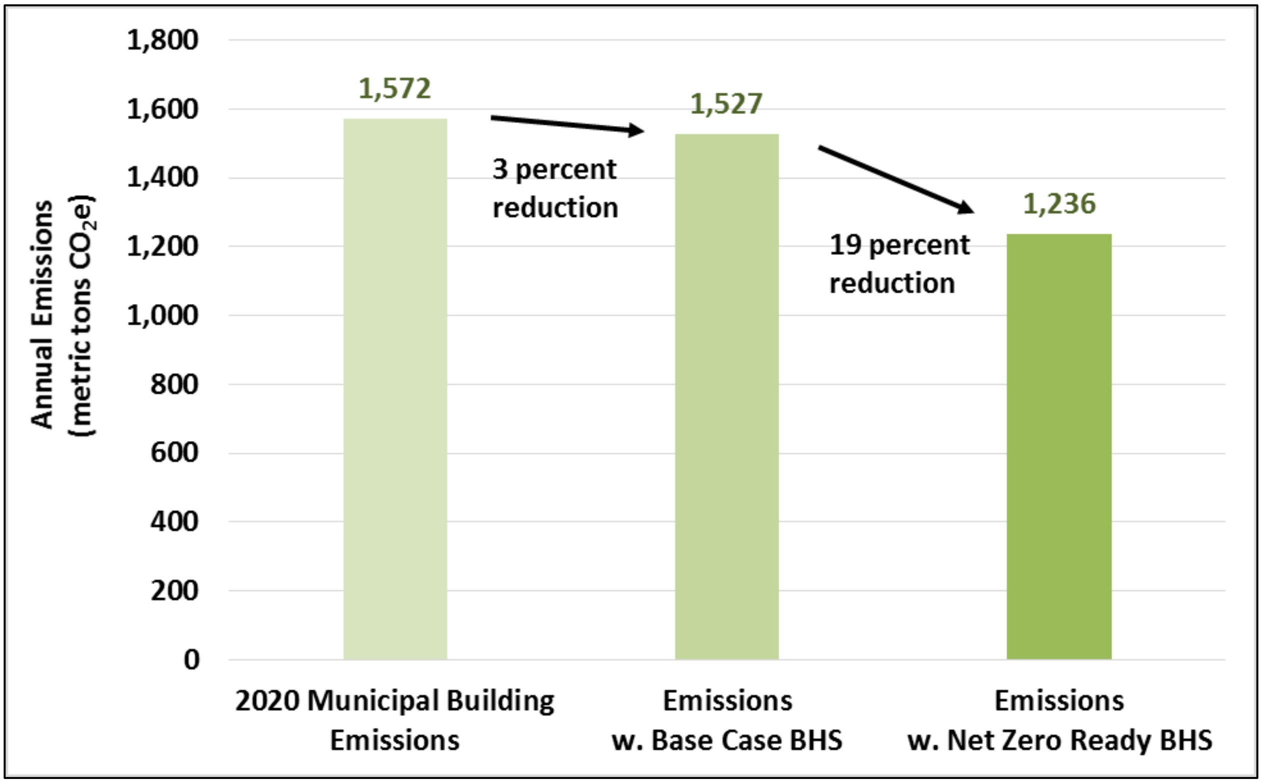
Bedford High School would reduce that building's total 2020 emissions by about two-thirds (see Figure 6) and the Town's total emissions from municipal buildings by more than one-fifth (see Figure 7).

Figure 6. Bedford High School annual emissions



Sources: 1) EPA. April 2021. "Emission Factors for Greenhouse Gas Inventories." Table 1. Available at: https://www.epa.gov/sites/production/files/2021-04/documents/emission-factors_apr2021.pdf; 2) Bedford High School - Energy Net Zero Upgrade Cost Comparison. October 28, 2020. PDF pages 2 and 3; 3) US EIA. June 17, 2020. "What are Ccf, Mcf, Btu, and therms? How do I convert natural gas prices in dollars per Ccf or Mcf to dollars per Btu or therm?". Available at: https://www.eia.gov/tools/faqs/faq.php?id=45&t=8.

Figure 7. Town of Bedford municipal buildings' annual emissions



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A Net Zero Ready Bedford High School also sets Bedford up for the greatest benefits from its potential town-wide microgrid. If Bedford High School were microgrid-connected, the school would continue to have power during blackouts, could serve the majority of its heating needs and all of its cooling needs with renewable energy-powered electricity, and would enhance community resilience and safety by providing a shelter for vulnerable populations that face increased risks from power outages, including populations that that depend on nebulizers, oxygen machines, or refrigerated medicines.

VII. Conclusion

The Town of Bedford has committed to reduce its town-wide greenhouse gas emissions 80 percent by 2050 and achieve net zero energy use in all municipal buildings by 2030. In 2019, 58 percent of Bedford's town-wide emissions came from gas and heating oil use. To work toward its climate goals, Bedford has taken steps that include creating a town-wide energy inventory, procuring renewable electricity for municipal buildings, and establishing community choice aggregation for residents and businesses that includes 50 and

100 percent renewable electricity options. These measures have served to reduce Bedford's town-wide emissions from 250,000 metric tons CO_2e in 1990 down to 151,000 metric tons CO_2e in 2019, a 40 percent reduction. Currently, the Town is considering additional measures to develop renewable energy sources, reduce greenhouse gas emissions, and enhance the reliability and resiliency of the Town's energy supply such as a town-wide microgrid, solar panels on school rooftops and new battery storage capacity.

Achieving the Town's goal of net zero energy use in all municipal buildings by 2030 will require investments in Net Zero and Net Zero Ready buildings. As the Town of Bedford considers its next capital funding plan, it is faced with whether to invest in a Net Zero Ready Bedford High School. There are at least twenty-five Net Zero and Net Zero Ready K-12 schools across the Commonwealth, in communities from Cambridge to Springfield, that report energy savings, water savings, emissions reductions, sustainability improvements, better learning conditions, greener campuses, and cost benefits. Investing in a Net Zero Ready Bedford High School will not only set the Town of Bedford up for success in meeting its climate and energy goals by reducing the high school's 2020 emissions by two-thirds and town-wide 2020 municipal building emissions by more than 20 percent, but will also result in additional health, comfort, cost savings, resiliency and safety benefits for Bedford's residents.

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Appendix C: Methodology for Bedford High School Analysis

To estimate the emission savings per "extra" thousand dollars spent in the Net Zero Ready Case compared to the Base Case, AEC calculated the total costs (upfront capital costs associated with purchasing and installing the equipment as well as annual operating costs for heating and cooling) and greenhouse gas emissions for each of Bedford High School's potential heating and cooling system upgrade options over a 20-year period. The analysis period is based on the assumed 20-year lifetime of the gas-fired and wood pellet boilers and air-source heat pumps.[38]

In this analysis, AEC builds on the results of Northeast Engineering and Commissioning Services, Inc.'s October 2020 "Bedford High School Energy Net Zero Upgrade Cost Comparison" report, which conducted an cost analysis to compare each potential heating and cooling system upgrade for Bedford High School. Northeast Engineering's report estimated the total capital costs for heating and cooling, provided a partial analysis of operating costs for heating (but not for cooling),[39] provided efficiency ratings for heating technologies, and presented fuel costs (gas, electricity, wood pellets). The report did not include information about emissions, operating costs for cooling, efficiency ratings for cooling technologies, or Bedford High School's heating or cooling energy consumption—AEC estimated these variables as described in more detail below.

Capital costs

The total capital costs (for both heating and cooling) estimated by Northeast Engineering and Commissioning Services, Inc. were used directly in AEC's analysis:

- **Base Case:** $4.36 million
- **Net Zero Ready Case:** $8.41 million[40]

Building heating demand

Before estimating the annual operating costs for each heating system upgrade option, AEC had to determine the average annual heating requirement (in MMBtu) of Bedford High School. AEC calculated a 5-year average of Bedford High School's heating demand (8,512 MMBtu) based on the building's annual gas use between 2016 and 2020. AEC back-calculated the building's current annual heating requirement (6,384 MMBtu)—equal to the heating demand less efficiency losses—by multiplying the heating demand (8,512

[38] 1) US EIA. June 2018. *Updated Buildings Sector Appliance and Equipment Costs and Efficiencies*. Available at: https://www.eia.gov/analysis/studies/buildings/equipcosts/pdf/full.pdf. 2) Innovative Natural Resource Solutions LLC and Meister Consultants Group. March 2018. *Forest Opportunity Roadmap / Maine Wood Energy*. Available at: http://formaine.org/wp-content/uploads/2020/09/FOR-Maine-Wood-Energy-final-9-2018.pdf. 3) Whitney, E. December 2017. Heat Pump Technology Briefing. Alaska Center for Energy and Power. Available at: https://acep.uaf.edu/projects-(collection)/heat-pumps-technology-briefing.aspx.

[39] Northeast Engineering and Commissioning Services, Inc. October 28, 2020. Bedford High School – Energy Net Zero Upgrade Cost Comparison. Prepared for Town of Bedford.

[40] All dollar values presented in 2020 dollars, converted (when necessary) using the CPI-U.

MMBtu) by the gas-fired boiler's efficiency of 75 percent, resulting in an annual technology-neutral heating requirement of 6,384 MMBtu.

For the Base Case, the annual energy demand for heating of 8,512 MMBtu is assumed to be constant over the 20-year analysis period. For the Net Zero Ready Case, the annual energy demand for heating is expected to be lower due to the use of a more-efficient air-source heat pump (250 percent efficiency)[41] compared to a gas-fired boiler (75 percent efficiency). The Net Zero Ready Case assumes that 80 percent of the High School's heating requirement will be met by the air-source heat pump with the remaining 20 percent is met by a wood pellet boiler—which has the same 75 percent efficiency as the gas-fired boiler.

To estimate the energy demand for heating under the Net Zero Ready Case, AEC took the 80 percent and 20 percent shares of the average annual heating requirement of 6,384 MMBtu by, respectively, to be the portion of the heating requirement that will be met by the air-source heat pumps and the wood pellet boiler—equal to 5,107 MMBtu and 1,702 MMBtu. AEC accounts for the efficiency of the air-source heat pumps by divided their share of the heating requirement (5,107 MMBtu) by the system efficiency of 250 percent—resulting in an annual energy demand of 2,043 MMBtu. The Net Zero Ready Case total heating demand is 3,745 MMBtu (2,043 MMBtu met by the air-source heat pump and the 1,702 MMBtu met by the wood pellet boiler).

Heating operating costs

To estimate the annual operating costs for each heating system upgrade option, AEC multiplied the energy demand for heating (in MMBtu) of each technology by their respective operating costs (in $ per MMBtu) in each year.[42] To forecast annual operating cost forecasts over the 20-year analysis period, AEC calculated compound annual growth rates over the 20-year period from 2021 to 2040 using U.S. Energy Information Administration's (EIA) energy price forecasts for gas and electricity from the 2021 Annual Energy Outlook (AEO).[43] The calculated growth rates for gas and electricity prices were applied to the annual operating costs (in $ per MMBtu) of the gas-fired boiler and electric-powered air-source heat pumps, respectively (derived from the October 2020 Northeast Engineering and Commissioning Services, Inc. report). In the absence of a publicly available energy price forecast for wood pellets, the operating costs for the wood pellet boiler were assumed to remain constant in real terms over the 20-year analysis period.

In addition to their primary fuel, the gas-fired boiler in the Base Case and the wood pellet boiler in the Net Zero Ready Case require some amount of electricity to operate. The annual electricity consumption of each

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[41] Air-source heat pumps heat and cool a building by using electricity to pump heat either inside or outside the building, which results in the generation of more heating energy than the electric energy that is required to run them. This analysis assumes that air-source heat pumps have an efficiency of 250 percent, which is based on a coefficient of performance of 2.5.

[42] All dollar values presented in 2020 dollars, converted (when necessary) using the CPI-U.

[43] US EIA. 2021. *Annual Energy Outlook 2021 - Table 3. Energy Prices by Sector and Source*. Available at: https://www.eia.gov/outlooks/aeo/data/browser/#/?id=3-AEO2021&region=1-0&cases=ref2021&start=2019&end=2050&f=A&linechart=&map=ref2021-d113020a.4-3-AEO2021.1-0&ctype=linechart&sourcekey=0.

technology was derived from U.S. EIA's *Updated Buildings Sector Appliance and Equipment Costs and Efficiencies*.[44] AEC used U.S. EIA's estimates for residential gas-fired furnace and wood pellet stoves as proxies for the gas-fired boiler and wood pellet boiler in each of the heating system upgrade options. AEC calculated the annual operating costs associated with this electricity draw by multiplying the annual energy consumption (kWh) for each technology by the assumed annual electricity price ($0.19 per kWh per Northeast Engineering's report escalated over the 20-year analysis period using its compound annual growth rate). The total lifetime operating costs for heating for each technology is equal to its fuel operating costs plus its electricity draw operating costs (if applicable) over the 20-year equipment lifetime.

Building cooling demand

AEC estimated Bedford High School's cooling requirement multiplying the building's classroom area (160,300 square feet)[45] by a cooling load factor of 0.007 MMBtu per square foot, which is equal to 1,128 MMBtu. The cooling load factor (0.007 MMBtu per square foot) was calculated by dividing the average annual cooling load for a residential building in Massachusetts (13.1 MMBtu)[46] by the average New England home size (1,861 square feet).[47]

To estimate the energy demand for each cooling system upgrade option, AEC divided the high school's cooling requirement (1,128 MMBtu) by each technology's efficiency: window air conditioners (350 percent efficiency) for the Base Case, and air-source heat pumps (450 percent efficiency) for the Net Zero Ready Case. The efficiency for each cooling technology was calculated by converting each technology's residential Energy Efficiency Rating (EER) for 2020[48]—12.0 Btu per watt-hour (Wh) for window air conditioners and 15.3 Btu per Wh for air source heat pumps—into a Coefficient of Performance (COP) by applying a conversion factor of 3.412 Btu per Wh.

Cooling operating costs

To estimate the annual operating costs for each cooling system upgrade option, AEC multiplied the energy demand for cooling (in MMBtu) of each technology by their respective operating costs (in $ per MMBtu) in each year. AEC estimated the annual operating costs for cooling (in $ per MMBtu) by dividing the assumed electricity price discussed above.

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[44] US EIA. June 2018. *Updated Buildings Sector Appliance and Equipment Costs and Efficiencies*. Available at: https://www.eia.gov/analysis/studies/buildings/equipcosts/pdf/full.pdf.

[45] The classroom area of Bedford High School is assumed to be 70 percent of the building's total area of 229, 000 square feet, which is derived from Northeast Engineering and Commissioning Services, Inc.'s October 2020 report.

[46] Mass Save. May 29, 2020. *Massachusetts Technical Reference Manual for Estimating Savings from Energy Efficiency Measures*. 2019 Plan-Year Report Version. Appendix 3, Technical Reference Manual, D.P.U. 20-50. p.78. Available at: https://fileservice.eea.comacloud.net/FileService.Api/file/FileRoom/12190505.

[47] U.S. EIA. May 2018. *2015 RECS Survey Data*, Table HC10.10. Available at: https://www.eia.gov/consumption/residential/data/2015/hc/hc10.10.xlsx.

[48] The EER is provided as a Combined Energy Efficiency Rating (CEER) for room air conditioners and a Seasonal Energy Efficiency Rating (SEER) for air-source heat pumps. US EIA. June 2018. *Updated Buildings Sector Appliance and Equipment Costs and Efficiencies*. Available at: https://www.eia.gov/analysis/studies/buildings/equipcosts/pdf/full.pdf.

Greenhouse gas emissions

To estimate the annual greenhouse gas emissions for each heating and cooling system upgrade option, AEC multiplied the energy demand for heating (in MMBtu) of each technology by U.S. Environmental Protection Agency's emission factors (kg per MMBtu) associated with each fuel type (i.e., gas for gas-fired boiler, wood and wood residuals for wood pellet boiler) for carbon dioxide (CO_2), methane (CH_4), and nitrous oxide (N_2O).[49] Since the Town of Bedford's electricity is 100 percent renewable, the electricity required to run the window air conditioners and air-source heat pumps—as well as the electricity draw needed to operate the gas-fired boiler and wood pellet boiler—results in zero greenhouse gas emissions. AEC calculated total greenhouse gas emissions in CO_2 equivalents (CO_2e) by multiplying the emissions in kg of CO_2, CH_4, and N_2O by their 100-year global warming potentials of 1, 25, and 298, respectively. AEC multiplied the annual emissions in kg CO_2e by 20 years to calculate the cumulative greenhouse gas emissions for each heating and cooling system upgrade option over the analysis period.

To estimate the emission-savings benefit of the Net Zero Ready Case over the Base Case, AEC divided the difference in cumulative greenhouse gas emissions of 5,806 metric tons CO_2e by the difference in cumulative costs (operating costs plus capital costs) between the Base Case and Net Zero Ready Case, equal to $2.9 million. The emission-savings benefit of the Net Zero Ready Case is estimated to be 2 metric ton CO_2e per "extra" thousand dollars spent over the 20-year period.

[49] U.S. EPA. April 2021. "Emission Factors for Greenhouse Gas Inventories." Available at: https://www.epa.gov/sites/production/files/2021-04/documents/emission-factors_apr2021.pdf.