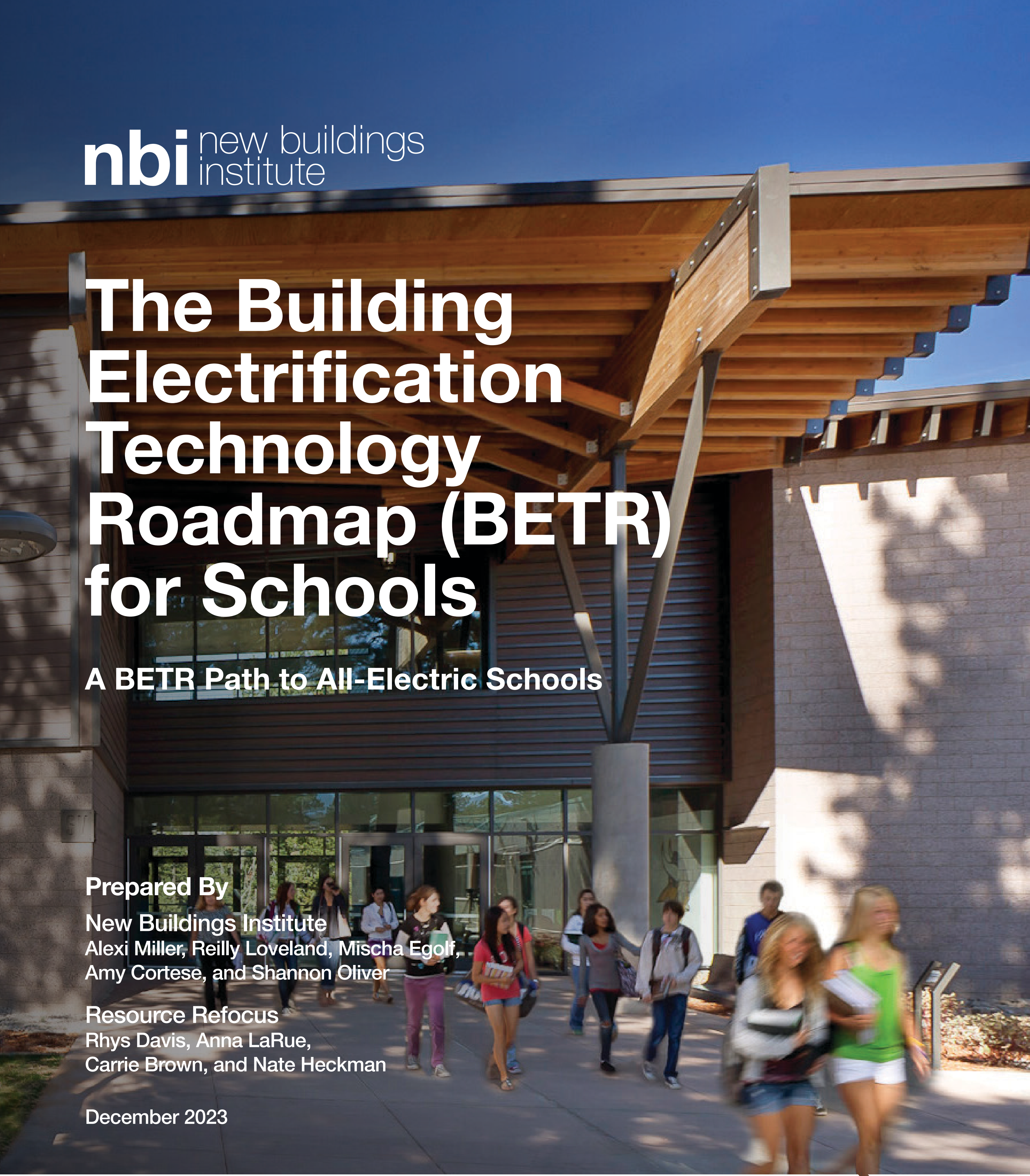

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The Building Electrification Technology Roadmap (BETR) for Schools

A BETR Path to All-Electric Schools

Prepared By

New Buildings Institute
Alexi Miller, Reilly Loveland, Mischa Egolf, Amy Cortese, and Shannon Oliver

Resource Refocus
Rhys Davis, Anna LaRue, Carrie Brown, and Nate Heckman

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South Tahoe High School | South Lake Tahoe, CA
Photo Credit: LPA Architects

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Authors and Acknowledgements

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Authors

The report was written by New Buildings Institute staff members.

Amy Cortese, Program Director

Mischa Egolf, Technical Associate

Reilly Loveland, Associate Director

Alexi Miller, PE, Director of Building Innovation

Shannon Oliver, Senior Project Manager

Contributors

This report was prepared with contributions from Resource Refocus staff members.

Rhys Davis, Technical Consultant

Anna LaRue, Principal

Dr. Carrie Brown, Director

Nate Heckman, Associate Technical Consultant

St. James Intermediate School | Myrtle Beach, SC
Photo Credit: SfL+a Architect

1. Introduction

The *Building Electrification Technology Roadmap (BETR) for Schools* provides high-level guidance for school districts who are considering electrifying school buildings and educational facilities. Crafted for school district decision makers, *BETR for Schools* provides relative cost analysis for a comprehensive set of technologies that can replace traditional equipment used commonly in schools nationwide for a wide variety of replacement scenarios (emergency replacement, lifecycle replacement, or planned upgrade or renovation).

For each building specific replacement scenario presented in this report, the team studied installation challenges, assessed maintenance difficulty, evaluated the upfront and operational costs associated with the replacement technology, as well as the indoor air quality (IAQ) and greenhouse gas (GHG) emissions impacts associated with the respective electrification technologies.

BETR for schools summarizes a comprehensive set of electrification technologies that can replace traditional fuel-fired equipment (typically natural gas or propane) in buildings. This aims to assist school districts as they consider electrification of their facilities. The consolidated analysis includes the upfront equipment costs of selected electrification upgrades, including building mechanical equipment and electric vehicle charging. While the scenarios presented are comprehensive and include common replacement options for school buildings, it is not an exhaustive list as many energy efficiency measures that optimize performance are not included. The example scenarios also do not address energy generation and storage options such as solar photovoltaic and batteries. It is also important to note that costs do not account for incentives, tax credits, and other financing that may be available to districts to reduce upfront costs, as these incentives can vary nationwide.

1.1 Why Should Schools Electrify?

Electrifying school buildings and educational facilities not only presents an opportunity to stabilize operating costs and lower GHG emissions, but also improves the health, wellness, and resilience potential of entire school communities. Old or aging equipment may fail unexpectedly, which can create difficulties in operating budgets and result in reactive replacement projects. Running electric equipment in schools can reduce direct GHG emissions from onsite combustion of fossil fuels in fuel-burning equipment. Finally, fuel-fired equipment poses indoor air quality (IAQ) challenges from leaking source fuels (such as methane or propane) and combustion by-products (such as carbon monoxide). These challenges can be eliminated with the removal of fuel burning equipment within school buildings. **Figure 1** shows an example of how districts might consider developing a roadmap for long term planning to electrify school buildings and portfolios.

FIGURE 1. PREPARING A DECARBONIZATION ROADMAP

A decarbonization roadmap identifies cost-effective strategies and approaches to reduce greenhouse gas emissions across a portfolio of buildings over time. A roadmap lays out a vision of how a school district will transition buildings in their portfolio to be healthy and efficient while eliminating carbon and greenhouse emissions emitted from gas-burning equipment on site. By outlining long-term goals, setting interim targets, and considering strategies in advance, the roadmap outlines how decarbonization will be achieved in a cost-effective way by leveraging projects as they happen over time.

1.2 Things to Consider when Planning to Electrify

There are many variables and diverse stakeholders involved in facility improvement projects—budgets, design and construction, code compliance, educational needs, district goals and priorities, among many more. Successful electrification projects will utilize a structured process and ensure the appropriate stakeholders are involved.

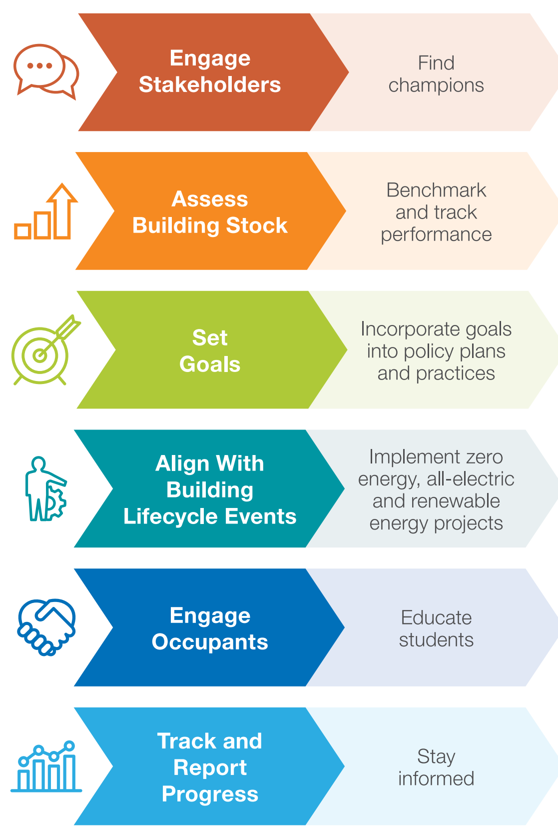
As the team is assembled and districts consider which electrification projects are prioritized, here are some questions to keep in mind:

- What impact will this have on student learning and occupant health?
- What stakeholders will need to be engaged and how?
- What are the new electrical infrastructure upgrade needs?
- What is the remaining equipment useful life?
- Will this require review from a local agency such as California's Division of the State Architect?
- How will funding be secured for projects?

The [Decarbonization Roadmap Guide for School Building Decision Makers] and associated resources provide common actions, examples, and templates to help decision makers take on decarbonization projects. Figure 2 shows the common approaches laid out in the Decarbonization Roadmap Guide for School Building Decision Makers that schools can take to develop their own roadmap. NBI's [Energy, Ventilation and Emissions Checklist] also provides a comprehensive list of questions for districts to consider.

Electrification projects in schools and districts will likely be tied to specific life cycle events or facility upgrades. Life cycle events are further explained in the scenarios next section but are crucial times in which key building components will be improved. They provide a unique opportunity to transition equipment, operational practices, and employee training toward a decarbonized future state, through the path of electrification.

FIGURE 2. DECARBONIZATION ROADMAP APPROACHES FOR SCHOOLS



2. Scenarios: What Might a School Electrification Project Look Like?

Opportunities for school electrification generally fall into one of the four categories below and align with life cycle events that occur as equipment and systems age, as well as during planned facility improvements. These are generally ranked from simplest to most complex, not necessarily in order of priority or preference. For example, emergency replacements, while simple, are usually not the best decarbonization pathway. The available electrification options for any project will depend on the available funding, goals, existing equipment, and facility needs.

2.1 Emergency Replacement (ER)

Decision making priorities in this scenario: minimal upfront costs, non-invasive installation, readily available equipment

This scenario refers to swift and unplanned replacement of existing equipment and assumes the selection of electric equipment that is the most like-for-like replacement to the existing equipment. ER is a common replacement scenario and prioritizes solutions with minimal upfront costs, non-invasive installation, and that provide readily available equipment. If the existing space or water heating equipment is a complex, centralized system, immediate and full electrification may be challenging and expensive. In these cases, it is important to develop multi-phase strategic electrification plans to achieve zero carbon over time. Hot water heating and commercial kitchen replacements are the most likely electrification options in an emergency situation, and may be a good opportunity to introduce maintenance and kitchen staff to new equipment and technology.

2.2 Planned/Routine Capital Improvement and Deferred Maintenance (PC)

Decision making priorities in this scenario: minimal upfront costs, non-invasive installation, some lead time and planning for improved air quality

This scenario applies to planned upgrades, as opposed to time-sensitive, emergency situations. In this scenario, energy reduction goals are not the primary consideration, instead equipment replacement is driven by timing and budget. This scenario provides more flexibility to include measures like duct sealing and economizer replacements in addition to the equipment upgrade itself, and the ability to replace complex central systems. It does not include deep retrofits. All technologies discussed in this report may be good electrification options in a PC scenario. One key factor for successful PC electrification projects is to ensure any staff that will maintain and operate the new equipment or technology have the opportunity to tour (even if virtually) an existing facility with similar equipment in operation (e.g., heat pump water heater) and speak with the operations and maintenance staff.

2.3 Efficiency & Cost Savings Project (Deep Efficiency Retrofit) (DE)

Decision making priorities in this scenario: lifecycle cost savings on utility bills and maintenance

This scenario provides the opportunity to not only electrify equipment, but also to incorporate energy efficiency measures such as improvements to the building envelope, lighting upgrades, improved control systems, and resiliency measures such as energy storage. When it is feasible, investing in these energy efficiency measures can reduce the overall heating and cooling needs of the building, which helps to reduce capital (and operating) costs for mechanical equipment. This scenario may also be an opportunity to consider other decarbonization measures such as electric vehicle charging infrastructure, especially if equipment electrification will trigger the need for electrical service upgrades. For schools and districts with existing net zero energy, renewable energy, and/or energy storage goals, DE electrification projects are crucial before planning and design for these projects, as the efficiency gains from the DE electrification project and electric load additions will greatly impact the sizing of renewable/storage systems.

2.4 Addition to Existing Building (AD)

Decision making priorities in this scenario: minimal upfront cost, lifecycle cost savings, improved air quality, fewer concerns of physical space or panel sizing, fitting in with existing systems

This scenario addresses building additions or major alteration projects. These are similar to deep efficiency retrofit projects but reduce the complexity of working around existing physical or electrical constraints. In this scenario, equipment can be electrified and included in a suite of optimization measures, while also including energy efficiency measures and consideration of decarbonization strategies such as electric vehicle charging infrastructure.

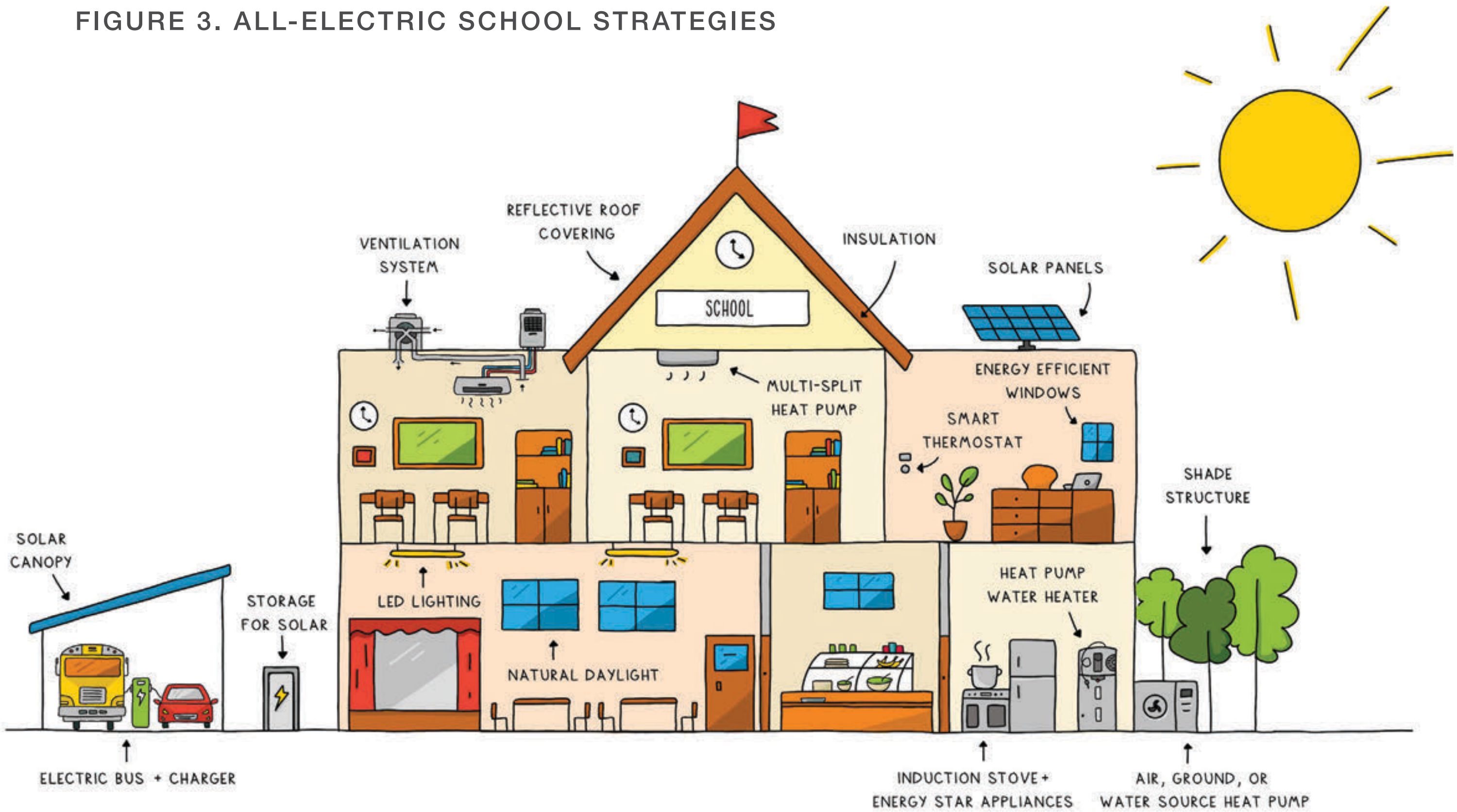
Like PC electrification projects, all technologies discussed in this report may be good electrification options in an AD scenario. Integrating new equipment and systems into existing controls and infrastructure is particularly important in these projects. For example, new central systems (for space and water heating) should tie into existing ducting or piping.

Playa Vista Elementary | Los Angeles, CA
Photo Credit: NAC Architecture

3. Technology: What Equipment in Schools Can Be Electrified?

School buildings and educational facilities are rife with opportunities to replace antiquated technologies with more efficient options. This section will present details of electric replacement options for different energy-using equipment and systems in schools, as well as cost and operational considerations and environmental impacts of switching out the most common appliances and technologies in a variety of replacement scenarios. Figure 3 below showcases a series of electrification approaches. Some of these approaches are either related strategies such as shade structure, insulation, etc. or they are the technologies that can be electrified. The technologies described in the section below are not exhaustive but rather are the recommended electrification replacement option for each of the scenarios presented. Electric replacement technologies are compared to baseline equipment with similar operating characteristics to provide the closest like-for-like replacement scenario.

FIGURE 3. ALL-ELECTRIC SCHOOL STRATEGIES



Artwork by Nicole Kelner

3.1 Space Conditioning and Ventilation

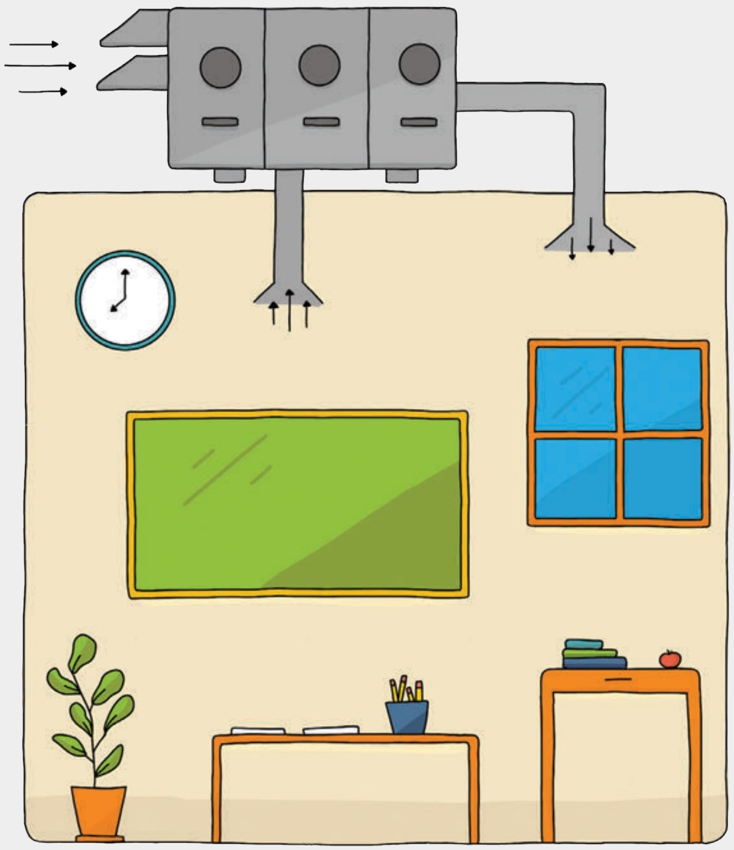
The heating, ventilation, and air conditioning (HVAC) system in a school is directly related to indoor air quality (and thus student health) and occupant comfort.[1] For the typical school, space heating, cooling, and ventilation make up over 50% of the annual energy use, so selecting equipment that minimizes energy use can result in significant annual carbon emission reductions. In all scenarios, heat pumps should be prioritized, and electric resistance equipment avoided. Heat pumps eliminate the need for separate space heating and cooling equipment. While converting a gas furnace to use electric resistance is technically electrification, this should not be prioritized due to the low efficiency of electric resistance heating; heat pumps cut electricity use by 50% when compared with electric resistance heating in most climates.[i]

The average life cycle of space conditioning equipment is 10-20 years, so it is often a key system to consider for electrification due to the environmental and health impacts. Table 1 summarizes common all-electric technologies that can replace existing space heating systems.

FIGURE 4. HEAT PUMPS AND REFRIGERANTS

Heat pumps pull heat from a source (usually the outside air, or sometimes ground or water) and use a vapor-compression cycle to heat or cool the space. An air source heat pump is basically a reversible air conditioner, and like air conditioners, heat pumps require refrigerants to transfer heat and condition spaces.

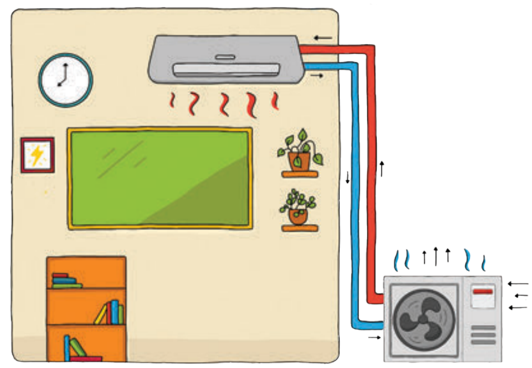
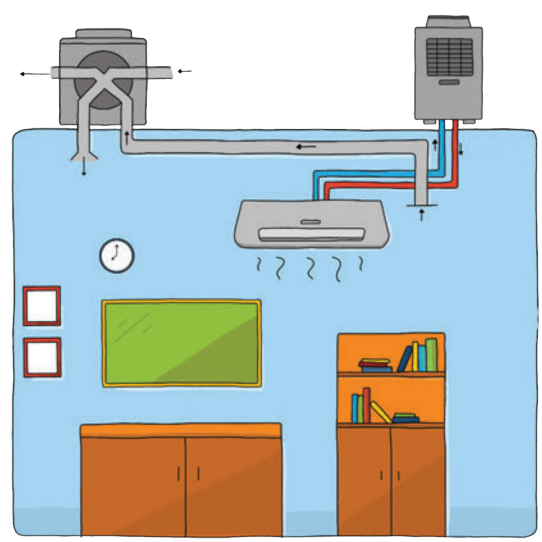
Refrigerants can be very potent greenhouse gases (GHGs). Refrigerant leakage or improper end-of-life disposal can cause significant emissions. Global warming potential (GWP) quantifies this emissions potential, with lower numbers being more desirable. Very-low-GWP equipment (refrigerant GWP<150) options are emerging, but few models are available today. However, as more units become available, lower-GWP options will help minimize GHG footprints.



Ducted air source heat pump. Artwork by Nicole Kelner

1 See "Key Messages for Communicating About Carbon Neutral Schools" for quantitative information. https://newbuildings.org/resource/key-messages-for-communicating-about-carbon-neutral-schools/

TABLE 1. COMMON SPACE CONDITIONING AND VENTILATION ELECTRIC REPLACEMENT OPTIONS

BASELINE	ELECTRIC REPLACEMENT OPTIONS
Ducted Heating	**240V Air Source Heat Pump (ASHP)—Split System or Packaged Rooftop Unit (RTU)** Packaged systems installed on the roof have all key components in one “box.” Split systems have an outdoor unit and an air handling unit inside, just like air conditioners.
Ductless Heating (wall furnace, space heaters)	**Packaged Terminal Heat Pump** Small capacity units can heat and cool one specific room. Inserted into a slot in the wall, these units require no external piping or ducts. All components are included in the housing. **Ductless ASHP Split System (“mini-split”)** Small indoor air handlers are connected to the outdoor unit via refrigerant lines to precisely heat and cool specific rooms or zones. These systems can use either 240V or 120V power. The lower-voltage systems can avoid the cost of electrical upgrades.  Mini-split air source heat pump. Artwork by Nicole Kelner
Central Boiler Heating	**Variable Refrigerant Flow (VRF)** VRF systems use refrigerant lines to cool or heat air throughout a series of small air handlers (mini-splits) located throughout the building, instead of using ducts. System efficiencies are often very high due to the system’s inherent heat recovery capability, but the large amount of refrigerant in the lines and components means refrigerant leaks can be a significant concern.  VRF System (optional DOAS unit also shown at top left). Artwork by Nicole Kelner **Water Source/Ground Source Heat Pump** These systems use ground or water loops as the heat sink/source, which is more efficient than using ambient air in cold and hot weather. Significant site work is needed: either drilling or excavating. Schools often choose to locate their ground loops under parking lots or sports fields. **Air to Water Heat Pump** Air to water systems pull heat from the air but use a hydronic distribution system to deliver heating and cooling. These systems can be configured as combination systems that also provide domestic hot water (see Water Heating section).

Other considerations in space conditioning and ventilation:

- The heating capacity and efficiency of standard air source heat pumps decreases when the outside air temperature is low (that is, roughly below freezing), so districts in high mountain, desert, or other locations with low wintertime outside air temperatures should specify cold-climate heat pumps. Cold-climate heat pumps typically are rated to run at full heating capacity down to 5°F,[ii] and still offer roughly double the rated efficiency of a gas burning system down to -22°F.[iii]
- There are several measures that should be included where possible to improve the performance of HVAC systems and have an impact on indoor air quality, including:
  - » **MERV 13 filters:** Filters with a Minimum Efficiency Reporting Value (MERV) rating of 13 or higher are better at capturing airborne contaminants than traditional filters. However, they can reduce airflow and increase fan load if the system is not designed for this type of filter.
  - » **Dedicated outdoor air system (DOAS):** Provides 100% outdoor air to increase ventilation efficiency as well as dehumidification benefits. These systems also typically include a heat recovery ventilator (HRV) or energy recovery ventilator (ERV) from the exhaust air to improve system performance.
  - » **Protect and filter outdoor air intakes:** The location and orientation of outdoor air intakes should meet the requirements of ASHRAE 62.1[2] to ensure they are an adequate distance from pollutant sources. If needed, the intakes should be moved. In all cases, the mesh filters should be inspected and cleaned regularly.
  - » **Duct sealing:** Well-sealed ducts greatly improve system efficiency by mitigating leaks through holes, cracks, and seams by mitigating leaks through holes, cracks, and seams.
- Districts should ensure that HVAC controls are grid interactive. This means that equipment can take an electrical pulse or other signals from the utility or a third party and automatically adjust. This can be done by specifying smart thermostats, building management systems, or other grid connectivity controls compliant with OpenADR 2.0b or 3.0 specifications.[3] This will help schools be more prepared for changes in electric rate structures (such as time-of-use rates and demand charges) and enable participation in demand response programs, which can deliver utility cost rebates/savings.

Outdoor air intake. Image by Stefan Schweihofer

2 ASHRAE Standard 62.1 specified minimum ventilation rates and other measures that ensure indoor air quality minimizes negative health effects and meets the needs of occupants. More information can be found on the ASHRAE website: https://www.ashrae.org/technical-resources/bookstore/standards-62-1-62-2

3 OpenADR provides a standardized way for devices to communicate the with utility. Devices that meet specifications 2.0b and 3.0 conform to all of the requirements to participate in demand response programs. More information can be found here: https://www.openadr.org/

TABLE 2. COMPARISON OF ELECTRIFICATION TECHNOLOGIES FOR HVAC EQUIPMENT

To provide decision makers with a holistic view of electrification impacts, Table 2 presents the cost and environmental impacts of selected electric HVAC equipment technologies that are most applicable to schools. Each row represents one equipment option. The most appropriate project type (scenario) and building type for each technology are noted. Section 4 summarizes key assumptions and methodology for the metrics, and a legend is provided below.

	UPFRONT COST RANGE ($/SF)		SCENARIO				BUILDING TYPES			UTILITY COST IMPACT		BENEFITS				
TECHNOLOGY	Low	High	Emergency Replacement	Planned Capital Improvement	Deep Efficiency Retrofit	Addition to Existing Building	Small	Large	Relocatable	Lower or similar utility costs	Likely to increase utility costs	Ease of Maintenance	Ease of Install	IAQ improvement potential	GHG emission reduction	Low GWP Refrigerant Option
Packaged Terminal Heat Pump	$1.03	$1.48	✔						✔	✔		●	●	-	○	✔
Single-Zone Ducted Package ASHP + MERV 13	$9.90	$34.38	✔	✔		✔	✔		✔	✔		○	●	○	◒	
Single-Zone Non-Ducted Minisplit ASHP w/ DOAS	$11.90	$17.47		✔	✔	✔	✔		✔	✔		◒	◒	●	●	✔
Multi-Zone Ducted ASHP + MERV 13	$8.10	$18.15	✔	✔		✔	✔	✔		✔		○	●	○	◒	
Multi-Zone Multi-split ASHP w/ DOAS	$10.82	$25.27			✔		✔	✔		✔		◒	◒	●	●	✔
Air-to-Water Hydronic Heat Pump	$4.09	$8.40		✔	✔	✔		✔			✔	○	○	-	◒	

Key: ○ Low ◒ Medium ● High Full circles are most desirable.

Cost ranges are determined from RS Means 2023 where possible, with other sources including government cost reporting, cost studies, and manufacturer data also utilized. See ***Appendix A*** *for full table with all end-uses and* ***Appendix B*** *for sources. Costs include both labor and equipment that will be needed to install the electrification solutions but not additional components used by both the gas baseline and electrification systems such as ducting and piping. Costs are adjusted to match 2023 Southern California costs, and, where necessary, the systems are normalized using typical capacity per area factors for similar building types and climate zones.*

3.2 Water Heating

Water heating is a relatively low contributor to overall energy use in schools, but a reliable hot water supply is important in school kitchens and bathrooms. Heat pump water heaters (HPWHs) offer significant efficiency gains over electric resistance and fossil fuel options and should be deployed wherever possible. When replacing unitary water heaters, it is usually best to install a larger-tank HPWH than the baseline system (e.g., from a 50-gallon to a 65-gallon tank) to maximize the use of the heat pump and minimize the use of the backup resistance elements.

TABLE 3. COMMON ELECTRIC WATER HEATING REPLACEMENT OPTIONS

BASELINE	ELECTRIC REPLACEMENT OPTIONS
Instantaneous Gas Water Heaters	**Electric Resistance Tankless Water Heaters** For emergency replacement situations, electric resistance tankless units can decarbonize this water heating type, if sufficient electrical capacity is available. This technology is best suited for short-duration and low-volume applications like isolated restrooms. **Unitary Tank Heat Pump Water Heater (HPWH)** In some cases, it may be possible to replace a tankless water heating system with a tank-type HPWH. These are much more efficient than tankless options. See below.
Unitary Tank-Type Electric Resistance or Gas Burning Water Heaters	**240V Heat Pump Water Heater (HPWH)** Typically, three times as efficient as traditional gas or electric resistance tank type water heaters, offered in 50-80 gallon storage capacities. **120V Heat Pump Water Heater (HPWH)** Lower voltage and amperage than traditional 240V HPWH, these units offer 50-80 gallons of hot water storage and plug into a standard outlet, facilitating retrofit projects by avoiding rewiring, panel upgrade, and other installation costs. **120-Gallon Heat Pump Water Heater (HPWH)** These units also run on 240V and provide a solution for situations where a hot water storage capacity greater than 80 gallons is needed. For buildings where a central HPWH system is not feasible, multiple 120-gallon units plumbed in parallel can be a good design option.  120V plug-in heat pump water heater. Artwork by Nicole Kelner
Central Domestic Hot Water (DHW) Boiler	**Central/Commercial Heat Pump Water Heater** For buildings with a central water heating plant, heat pump(s) can be paired with large hot water storage tanks. Skid-mounted "plug and play" systems are coming to market that decrease the design and installation complexity of this solution. Central HPWH systems can deliver substantial grid integration capacity if designed with demand flexibility and connectivity in mind. Space constraints and electrical capacity can be a challenge. **Air to Water Heat Pump** As described in the Space Conditioning section, these systems can be configured as combination systems that also provide domestic hot water.

Other electric water heating considerations:

- Most unitary HPWHs nationwide (including, legally, all those sold in California, Oregon, and Washington), are grid-connective (i.e., able to communicate with the utility) out of the box. The most common grid connectivity hardware is the EcoPort (aka CTA-2045). Where possible, install HPWHs compliant with communication protocol CTA-2045b Level 2, OpenADR 2.0b, or OpenADR 3.0 to enable participation in utility demand response programs.[4]
- Heat pump water heaters expel cool, dry air into the space which can impact the performance of the water heater if the space becomes overcooled. Ensuring there is an appropriate amount of air volume will mitigate this.
- Heat pump water heaters produce a small amount of condensate water, much like a dehumidifier, which needs to be plumbed into a sink or drain.
- Because heat pump water heaters have a compressor, they will make some noise (up to 60 decibels, usually similar to a refrigerator). Care should be taken to ensure this does not disrupt student learning, preferably by installing the equipment away from classrooms.
- Insulating hot water storage tanks and pipes and optimizing recirculation in hot water systems helps reduce energy loss and saves energy.

St. James Intermediate School | Myrtle Beach, SC
Photo Credit: SfL+a Architect

4 EcoPort is the brand name for products certified to the CTA-2045 standard. This standard establishes hardware specifications and communication protocols required for devices to communicate with the utility. The communication protocols described here (CTA-2045b Level 2, OpenADR 2.0b, and OpenADR 3.0) are used by utility companies to deploy demand response programs. More information can be found here: https://www.openadr.org/ecoport-info

TABLE 4. COMPARISON OF ELECTRIFICATION TECHNOLOGIES FOR WATER HEATING EQUIPMENT

To provide decision makers with a holistic view of electrification impacts, Table 4 presents the cost and environmental impacts of selected electric water heating technologies that are most applicable to schools. Each row represents one equipment option. The most appropriate project type (scenario) and building type for each technology are noted. Section 4 summarizes key assumptions and methodology for the metrics, and a legend is provided below.

TECHNOLOGY	UPFRONT COST RANGE ($/SF)		SCENARIO				BUILDING TYPES			UTILITY COST IMPACT		BENEFITS				
	Low	High	Emergency Replacement	Planned Capital Improvement	Deep Efficiency Retrofit	Addition to Existing Building	Small	Large	Relocatable	Lower or similar utility costs	Likely to increase utility costs	Ease of Maintenance	Ease of Install	IAQ improvement potential	GHG emission reduction	Low GWP Refrigerant Option
Electric resistance tankless WH	$0.28	$1.80	✔				✔		✔		✔	●	●		○	
120V HPWH (<80 gallons)	$1.23	$2.04	✔	✔			✔		✔	✔		●	●		●	
240V HPWH (<80 gallons)	$1.27	$2.54		✔	✔	✔	✔		✔	✔		●	◒		◒	✔
Central HPWH (>80 gallons)	$0.36	$1.43		✔	✔	✔	✔	✔		✔		◒	○		◒	✔

Key: ○ Low ◒ Medium ● High Full circles are most desirable.

Cost ranges are determined from RS Means 2023 where possible, with other sources including government cost reporting, cost studies, and manufacturer data also utilized. See Appendix A for full table with all end-uses and Appendix B for sources. Costs include both labor and equipment that will be needed to install the electrification solutions but not additional components used by both the gas baseline and electrification systems such as ducting and piping. Costs are adjusted to match 2023 Southern California costs, and, where necessary, the systems are normalized using typical capacity per area factors for similar building types and climate zones.

3.3 Commercial Kitchens and Cooking

Most school facilities include some commercial kitchen equipment. This may be as simple as a warming oven to reheat food from a central district kitchen or a full suite of equipment for preparing meals onsite. In all cases, kitchen equipment should be replaced with ENERGY STAR® certified electric options where available. Equipment is generally split into smaller, "residential-grade" and commercial/restaurant-grade.

Induction cooktops are a key technology. These ranges use an electromagnetic field to directly heat the cooking pan or pot itself, rather than heating its underside like a gas flame or electric resistance hob. Induction technology results in a near complete energy transfer to the cooking vessel, making induction cooktops incredibly energy efficient relative to other modes of cooking. And, since there is no open flame or hot element on an induction range top, there is no chance of a burn injury or igniting a stray potholder or paper towel that might be on or near the range top. This technology can fully replace a free-standing range or be implemented in the plug-in countertop variety. Additionally, removing all fuel combustion sources from a kitchen may significantly reduce code requirements for ventilation and allow for downsizing or removing make-up air units and exhaust fans. These actions can lower energy and equipment costs, and provide the opportunity to manage thermal comfort more efficiently and consistently for kitchen staff.

When it comes to commercial-grade equipment, a wide range of electrically powered appliances are available. Commercial/restaurant-grade induction cooktops are also a key technology here, with glowing reviews from chefs and other users. Electric options such as griddles, fryers, deck and warming ovens are well-established and widely available, with performance usually equal to or better than gas options. Other technology options are also critical, such as the combination (combi) oven, which can replace both a steam cooker and an oven in a single device. In large central kitchens, electrical constraints (wiring, panel capacity, etc.) may be a barrier and should be evaluated before beginning projects. If dishwashing equipment requires a booster water heater to meet temperature for health code or operator preference, aging gas-fired booster heaters should be replaced with high efficiency electric resistance options. These come in 240V and 208V varieties, and should be sized properly for the volumetric flow and target hot water temperature requirements of each kitchen.

Induction cooktop. Artwork by Nicole Kelner

TABLE 5. COMPARISON OF ELECTRIFICATION TECHNOLOGIES FOR KITCHEN EQUIPMENT

Table 5 presents the cost, environmental impacts, and other considerations of both full electrification of commercial kitchen equipment and smaller-scale countertop kitchen equipment. Section 4 summarizes key assumptions and methodology for the metrics, and a legend is provided below.

TECHNOLOGY	UPFRONT COST RANGE		SCENARIO				BUILDING TYPES			UTILITY COST IMPACT		BENEFITS			
	Low	High	Emergency Replacement	Planned Capital Improvement	Deep Efficiency Retrofit	Addition to Existing Building	Small	Large	Relocatable	Lower or similar utility costs	Likely to increase utility costs	Ease of Maintenance	Ease of Install	IAQ improvement potential	GHG emission reduction
Full Electric Commercial Kitchen Equipment (total kitchen cost)	$14,265	$63,873		✔	✔	✔	✔	✔			✔	◒	◒	●	○
Electric Small Countertop Kitchen Equipment (total kitchen cost)	$489	$5,787	✔	✔	✔	✔	✔		✔	✔		●	●	○	○

Key: ○ Low ◒ Medium ● High Full circles are most desirable.

Cost ranges are determined from RS Means 2023 where possible, with other sources including government cost reporting, cost studies, and manufacturer data also utilized. See Appendix A for full table with all end-uses and Appendix B for sources. Costs include both labor and equipment that will be needed to install the electrification solutions but not additional components used by both the gas baseline and electrification systems such as ducting and piping. Costs are adjusted to match 2023 Southern California costs, and, where necessary, the systems are normalized using typical capacity per area factors for similar building types and climate zones.

3.4 Laundry

For schools with laundry facilities, large clothes dryers use significant energy to remove water from heavy, wet clothing. Heat pump dryers use about 60% less energy than a standard electric resistance dryer[iv] but take longer (2-4 hours per drying cycle as opposed to ½ to 1 hour).[v] For schools with low or moderate laundry needs, currently available residential grade 120V heat pump clothes dryers can replace gas dryers without needing 240V wiring. Vented and ventless options are available. For commercial-grade laundry needs, larger heat pump dryers have recently become available. ENERGY STAR® certified equipment should be specified where available.

TABLE 6. ELECTRIFICATION TECHNOLOGY FOR LAUNDRY EQUIPMENT

Table 6 presents the costs and impacts of using residential heat pump dryers. Commercial scale heat pump dryers are only recently available and their costs may not have stabilized at the time of writing. Section 4 summarizes key assumptions and methodology for the metrics, and a legend is provided below.

TECHNOLOGY	UPFRONT COST RANGE		SCENARIO				BUILDING TYPES			UTILITY COST IMPACT		BENEFITS			
	Low	High	Emergency Replacement	Planned Capital Improvement	Deep Efficiency Retrofit	Addition to Existing Building	Small	Large	Relocatable	Lower or similar utility costs	Likely to increase utility costs	Ease of Maintenance	Ease of Install	IAQ improvement potential	GHG emission reduction
Heat Pump Dryer (residential)	$435	$2,174	✔	✔	✔	✔	✔	✔	✔	✔		●	●	○	○

Key: ○ Low ◒ Medium ● High Full circles are most desirable.

Cost ranges are determined from RS Means 2023 where possible, with other sources including government cost reporting, cost studies, and manufacturer data also utilized. See Appendix A for full table with all end-uses and Appendix B for sources. Costs include both labor and equipment that will be needed to install the electrification solutions but not additional components used by both the gas baseline and electrification systems such as ducting and piping. Costs are adjusted to match 2023 Southern California costs, and, where necessary, the systems are normalized using typical capacity per area factors for similar building types and climate zones.

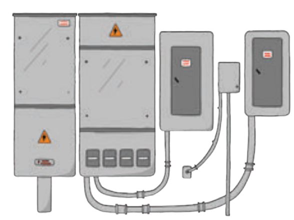
3.5 Transportation

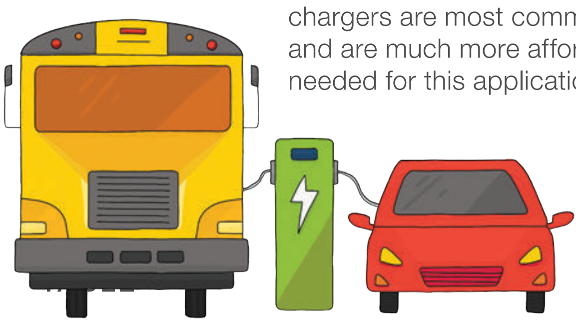
The transition to electric vehicles (EVs) is accelerating in California, with EVs now accounting for more than a quarter of all new vehicle sales.[vi] Per California Air Resources Board regulations, all new passenger and light-duty trucks sold in the state will be zero-emission vehicles by 2035.[vii] In addition to passenger and fleet EVs, electric school buses are also emerging, with substantial federal and state incentives to accelerate deployment. EV charging infrastructure, including chargers and associated equipment (EVSE) will need to be available in school parking lots for staff, students, and visitors and in bus barns for school buses.

Installing EVSE can trigger panel, transformer, or electrical service upgrades due to the high power and current flow through EVSE. Consider including an automated load management system (ALMS) that can actively balance and optimize power flows across multiple chargers. ALMS can help minimize the need for these costly retrofits and improve grid-integration capability.

TABLE 7. ELECTRIC VEHICLE CHARGING INFRASTRUCTURE OPTIONS

To reduce utility costs, futureproof against future rate changes, and improve grid integration, install smart grid-connected EVSE on ENERGY STAR's connected products list[viii] or otherwise compliant with current open communications protocols (e.g., Open Charge Point Protocol[ix] or IEC 63110[x]).

BASELINE	ELECTRIC REPLACEMENT OPTIONS
Passenger and Light-Duty Fleet Vehicles	**Passenger Vehicle Electric Vehicle (EV) Chargers** EV chargers are available at level 1 (120V plug-in), level 2 (208-240V), and level 3 (400V-900V: DC Fast Chargers or Superchargers). Level 2 chargers are the most appropriate choice for light commercial applications like schools. These chargers operate at various levels from 16A to 80A; 40A is the most common in this setting. There are two main connector standards: the J1772/CCS Type 1 connector and the Tesla/NACS connector.[5] It is best to provide some of each connector type for Level 2 chargers serving employee commuters and/or the general public. **Passenger Vehicle Electric Vehicle (EV) Readiness** In some cases, like new construction or parking lot renovations/updates, it can make sense to install conduit, circuits, junction boxes, and panels for future deployment of EVSE while delaying the installation of the chargers and transformer for another phase.  Electrical panel. Artwork by Nicole Kelner
Electric School Buses	**School Bus Electric Vehicle (EV) Chargers** Electric school buses are a recently available technology that can reduce transportation energy costs, cut emissions, and improve local air quality for students, staff, and nearby residents inside and outside the bus. These vehicles require dedicated Level 2 or 3 chargers, which are generally installed at the bus barn. Level 2 chargers are most common because they are usually sufficient for overnight charging and are much more affordable. Level 3 (fast) chargers are an option but usually not needed for this application. Districts should consider standardizing either with the CCS Type 1 or the NACS connector type for EV fleet Level 2 and Level 3 charging stations, to limit operator confusion and simplify the charging portfolio. Installation of school bus EVSE may trigger panel, transformer, or electrical service upgrades.



Electric vehicle supply equipment. Artwork by Nicole Kelner

5 More information about charger speeds and connector types can be found here: https://www.transportation.gov/rural/ev/toolkit/ev-basics/charging-speeds

8. COMPARISON OF ELECTRIFICATION TECHNOLOGIES FOR VEHICLE ELECTRIFICATION AND CHARGING EQUIPMENT

To provide decision makers with a holistic view of electrification impacts, Table 8 presents the cost and environmental impacts of selected transportation electrification technologies that are most applicable to schools. Each row represents one equipment option. The most appropriate project type (scenario) and building type for each technology are noted. Section 4 summarizes key assumptions and methodology for the metrics, and a legend is provided below.

TECHNOLOGY	UPFRONT COST RANGE		SCENARIO				BUILDING TYPES			UTILITY COST IMPACT*		BENEFITS			
	Low	High	Emergency Replacement	Planned Capital Improvement	Deep Efficiency Retrofit	Addition to Existing Building	Small	Large	Relocatable	Lower or similar utility costs	Likely to increase utility costs	Ease of Maintenance	Ease of Install	IAQ improvement potential	GHG emission reduction
EV Chargers for Passenger Vehicles	$3,335	$15,000		✔	✔	✔	✔	✔	✔	✔		●	◒	◒	●
Level 2 EV Charger for School Buses	$3,335	$15,000		✔	✔	✔	✔	✔	✔	✔		●	◒	●	●
Level 3 EV Charger for School Buses	$60,000	$100,000		✔	✔	✔	✔	✔	✔	✔		●	◒	●	●
Electrical Service Panel	$0.14/ft^2	$1.18/ft^2	✔	✔	✔	✔	✔	✔				●	○		
Distribution Transformer	$0.17/ft^2	$1.27/ft^2	✔	✔	✔	✔	✔	✔				●	○		

Key: ○ Low ◒ Medium ● High Full circles are most desirable.

Cost ranges are determined from RS Means 2023 where possible, with other sources including government cost reporting, cost studies, and manufacturer data also utilized. See Appendix A for full table with all end-uses and Appendix B for sources. Costs include both labor and equipment that will be needed to install the electrification solutions but not additional components used by both the gas baseline and electrification systems such as ducting and piping. Costs are adjusted to match 2023 Southern California costs, and, where necessary, the systems are normalized using typical capacity per area factors for similar building types and climate zones.

** EV chargers will increase electrical utility cost, but because the cost of gasoline or diesel fuel is avoided, overall operating cost is generally much lower for EVs compared to internal combustion vehicles.*

4. Understanding Typical Cost Ranges and Other Key Electrification Project Metrics

The tables throughout this document (presented in full in [Appendix A](#)) summarize cost ranges and other key metrics for selected electrification upgrades. This information was gathered from a variety of sources and is summarized below. As a general consideration, organizations should complete a lifecycle cost analysis[6] of any potential electrification project to most clearly depict the financial implications of the project. Upfront costs (as indicated below) and operational costs for an electrification project should be compared to the relative costs for a like-for-like replacement. The incremental costs (costs in excess of the relative like-for-like replacement costs) of the electrification project can then be reviewed for incentive opportunities, alternative funding sources, and to determine if the incremental costs can be justified through utility budget stabilization, to meet organizational goals, or to futureproof against potential code or regulatory requirements that might otherwise require similar equipment.

4.1 Upfront Costs

Upfront cost ranges were developed by referencing several sources including existing published studies on all-electric retrofits, prices on building supply wholesaler or manufacturer websites, and RS Means,[xi] a construction cost estimating software.

Limited data is available for commercial heat pump systems in school electrification retrofits. Along with wide variation in system specifications and installations, this posed challenges to developing cost estimations. Factors impacting heat pump system costs include how the system is installed, the combination of indoor and outdoor units, and system familiarity by installers.[xii] When available, material, labor, and total costs that included overhead and profit for heat pump systems were taken from RS Means regional data set to Riverside, California. Costs from other sources were adjusted to reflect Southern California prices.

Domestic hot water systems and equipment costs were gathered from RS Means, various published case studies, and CASE reports that reported costs for California. These costs were supplemented with online product prices. Appliance costs were gathered from Miele and Redwood Energy's Pocket Guide to All-Electric Commercial Retrofits.

Limited data is available for commercial heat pump systems in school electrification retrofits. Along with wide variation in system specifications and installations, this posed challenges to developing cost estimations. Factors impacting heat pump system costs include how the system is installed, the combination of indoor and outdoor units, and system familiarity by installers. When available, material, labor, and total costs that included overhead and profit for heat pump systems were taken from RS Means regional data set to Riverside, California. Costs from other sources were adjusted to reflect Southern California prices.

6 The Whole Building Design Guide offers a comprehensive summary of lifecycle cost analysis here: https://www.wbdg.org/resources/life-cycle-cost-analysis-lcca

Domestic hot water systems and equipment costs were gathered from RS Means, various published case studies, and CASE reports that reported costs for California. These costs were supplemented with online product prices. Appliance costs were gathered from Miele and Redwood Energy's Pocket Guide to All-Electric Commercial Retrofits.

Cost estimates shown for EVSE are per parking spot. The cost estimates shown here were developed based on a project with 15 dual-head chargers (that is, one charger serving every two parking spots) able to provide EV charging to 30 parking spots. Costs include sitework, conduit, wiring, junction box circuits, panels/subpanels, and a dedicated transformer. The largest component of EVSE costs is not the chargers themselves or the electrical infrastructure but rather the sitework (trenching, etc.), which accounts for about 60% of total estimated costs.

These ranges are meant to provide a general idea of the upfront cost for schools in Southern California, however, actual costs will be dependent on a variety of factors and local conditions.

4.2 Building Types and Scenarios

Building types are simplified into three prototypical categories:

- **large** school buildings (more than 25,000 square feet),
- **small** school buildings (less than 25,000 square feet)
- **relocatable** classroom buildings (typically from 1,000 to 10,000 square feet).

The technologies listed in the charts in Section 3 above, and in Appendix A are not feasible in every scenario, so results are limited to the four difference scenarios described in Section 2.

4.3 Operating Costs

Operating costs can vary greatly depending on utility rates, climate zone, school/district operational characteristics (community use, summer vs school year operations, 4- vs 5-day school weeks, etc.), and the existing building envelope. For this reason, operating cost implications are more generally categorized by how the given technology is likely to change utility costs as compared to the existing system, without any supplementary upgrades.

Yosemite Community College District | Modesto, CA
Photo Credit: Darden Architects

One key consideration related to operational costs and electrification, is the ability for an organization to stabilize its utility costs year-over-year, for ease in budgeting, contracting, and operational cost analyses. High natural gas market volatility[xiii] during the 2022 calendar year stemmed from factors well outside an organization's, or even the regional market's, control. Electrification can help mitigate this volatility, as the electricity grid and associated market increases its resilience and diversifies its source energy to include a greater proportion of renewable energy for base load production.

4.4 Other Metrics

- The maintenance implication scale indicates the degree to which the systems will need to be regularly serviced or will fail quicker if not properly maintained. A low rating would indicate a system that does not need maintenance more often than once every few years, while a high rating would indicate a system that needs maintenance multiple times per year for optimal performance.
- The installation difficulty scale indicates both the degree of labor and of invasiveness required for the equipment installation. A low rating would indicate a system that is mostly self-contained and can be built onto the school without needing to tear into walls or roofs, while a high rating would indicate a system that requires multiple components that require an invasive install in each zone.
- The indoor air quality scale (IAQ) describes the impact of the system on indoor air quality without any supplemental upgrades such as envelope sealing. Some systems will not have any IAQ impact when replacing an existing system. A low rating would indicate a system that could likely bring some harmful IAQ impacts down to the minimum required by law, while a high rating would indicate a system that would minimize the most harmful IAQ impacts.
- The greenhouse gas (GHG) impacts column is determined based on the combination of operational energy savings and the size of existing gas system being displaced. A low rating would indicate a system that marginally improves on GHG emissions for a smaller system, while a high rating would indicate a system that represents the lowest GHG emissions option for larger equipment.
- Where applicable for heat pumps, the low global warming potential (GWP) refrigerant column depicts whether the equipment has readily available low-GWP refrigerant options. For the purposes of this report, low-GWP is defined as equipment with a GWP less than 150, which includes natural refrigerants such as carbon dioxide (R-744), propane (R-290), and ammonia (R-717).

5. School Electrification Scenario Spotlights

To help illustrate the tradeoffs and decisions required when considering electrification retrofits, the following examples put a "spotlight" on specific building types, existing gas systems, and scenarios where electrification solutions should be considered. Each spotlight includes cost ranges for replacing the existing gas system with a like-for-like solution as a baseline and cost ranges for a recommended electrification solution as well as one or two alternatives. One spotlight also highlights the potential cost of electrical service upgrades that may be required due to the electrification retrofit. These spotlights can be used when starting to make a plan for electrification to anticipate potential hurdles down the road. Spotlight school space conditioning capacities determined based on the climate for Riverside, California.

5.1 Large Secondary School HVAC System

Scenario: A large secondary school—two stories, 211,000 square feet, 24 classrooms, two gyms, and an auditorium—is planning for capital improvements to its mechanical system.

Existing equipment: A central boiler provides steam for heating. Cooling is provided by a chiller, which provides chilled water to variable air volume (VAV) boxes in each zone of the building, which are serviced with air via ducts from two air handlers. The boiler is reaching the end of its estimated useful life, so the school is considering options for replacements that achieve electrification. Replacing the gas boiler, chiller, and VAV boxes with like-for-like systems would likely cost between $0.45 million and $0.9 million for equipment and $0.4 million and $0.6 million for labor, overhead, and profit.

Simplest electrification solution: An electric resistance boiler would be the simplest electrification solution from an installation perspective, but is not a feasible replacement due to the untenable increase in energy costs associated with the system change. In most cases, this is not a permitted solution per local code requirements.

Additional solution for consideration: One option the school could investigate is replacing the boiler with a central high temperature air-to-water or ground source water-to-water heat pump. The downside to this option is that the technology is still relatively new, and these systems are often not able to produce temperatures high enough to replace boilers without redesigning the heat distribution system and the VAV boxes. Waste heat recovery from the chiller could be an option but would require a full system redesign, may require an electrical service upgrade, and will not necessarily allow the school to fully electrify their heating system. These systems are most common in new construction projects and are especially valuable in colder climates where outside air temperatures in winter are low.

In Southern California, it is estimated that a central heat pump system with new VAV boxes could cost between $0.9 million and $1.6 million for equipment and between $0.8 million and $1.5 million for labor, overhead, and profit for a school of this size. This does not include the costs of resizing the entire pipe system to handle water instead of steam or the cost of additional upgrades to make the design feasible such as waste heat recovery or maintaining a boiler. If the main service panel and distribution transformer need to be upsized this could add at least $0.2 million to the project cost. Also, energy and air quality performance will be no better than the original system and will likely be more difficult to maintain due to the relatively new technology.

Recommended solution: The most long-term beneficial solution for both efficiency and air quality considerations first decommissioning the boiler, chiller, and VAV boxes. Replace the air handler with a Direct Outdoor Air System (DOAS) including an Energy Recovery Ventilator (ERV) and MERV 13 filters or higher. Install a multi-split air source heat pump system with one or two outdoor units serving multiple indoor unit heads with variable refrigerant flow (VRF).

In Southern California, this system is estimated to cost between **$2.8 million and $4.3 million** for equipment and between **$0.54 million and $1.1 million for labor,** overhead, and profit for a school of this size. This does not include any costs for decommissioning, duct replacement, or electrical service upgrades, although this option minimized the risk of needing an electrical service upgrade, as it is the most efficient of any electrification option.

Additional measures to consider: To improve the performance of this system, protect indoor air quality, and lower the risk of an electrical service upgrade, the school may consider envelope upgrades that include:

- install caulking to seal gaps in building envelope;
- replace existing windows with double-pane tightly sealed windows;
- add exterior insulation finishing system on exterior walls;
- install rigid insulation sheathing on the roof.

The cost of these improvements could cost from $1.0 million and $2.0 million, but, if added in tandem with the mechanical system upgrades, could reduce the required capacity of the mechanical system, providing savings on upfront and energy costs.

5.2 Relocatable Classroom HVAC System

Scenario: A relocatable classroom building—1,680 square feet with two separate classrooms—has the HVAC system fail unexpectedly. The school is considering options for replacement.

Existing equipment: Two vertical, wall-mounted packaged furnace and air conditioning units that are ducted throughout the building. Replacing the equipment with like-for-like systems would likely cost between $2,650 and $6,300 for equipment and between $1,775 and $4,700 for labor.

Simplest electrification solution: The simplest option is two vertical, wall-mounted packaged heat pumps. The circuitry and panel size required for the heat pumps should be available, as the existing air conditioners likely have similar sizing requirements, and the existing duct system can be re-used.

The two heat pumps may cost from $6,900 to $9,650 for equipment and from $1,775 and $4,700 for labor. However, this system will likely lead to slightly higher operational costs and no improvement to the indoor air quality, which is a serious concern in most existing relocatable classrooms.

Recommended solution: Another option is a mini-split heat pump with two indoor heads and one outdoor unit, with two dedicated outdoor air systems (DOAS) that utilize an Energy Recovery Ventilator (ERV) and MERV 13 filters or higher.

This system could cost between **$14,500 and $21,175 for equipment** and between **$4,300 and $6,200 for labor.** This may not be feasible for an emergency replacement but would produce the best outcome for energy costs and air quality. If it is not feasible, a capital improvements plan should be made for the building for the next funding opportunity for building improvements.

Additional measures to consider: Additional improvements to add to the plan could include caulking for air leakage, duct sealing, and additional insulation.

5.3 Small Primary School Service Hot Water System

Scenario: The gas water heater in a small primary school—one story, 24,000 square feet, 16 classrooms, one bathroom, and a cafeteria—fails unexpectedly. The school is considering its options for replacement.

Existing equipment: One 56 MBH, 50-gallon gas water heater. To replace this equipment with a like-for-like system would cost between $1,000 and $2,450 for equipment and between $350 and $575 for labor.

In most cases, Title 24 does not permit electric resistance storage or instantaneous service water heating systems, and these would likely require a circuit or electrical service upsizing, which is not feasible given the immediate need for replacement. A 240V heat pump water heater (HPWH) of a similar size, possibly with more storage to provide load shifting and performance benefits (65 to 80 gallons), would be an efficient replacement, with **equipment costing from $1,850 to $4,000 and labor costing around $475 to $1,025.**

However, if the mechanical room where the water heater is stored does not have a 240V outlet, another potential option is to install a 120V HPWH. The rated output (recovery capability) of these units is lower than the 240V option. However, costs are similar, with an **equipment cost range from $2,075 to $3,425 and somewhat lower labor costs, between $350 to $675.** These units are a good option in an emergency replacement situation or to incorporate into planned replacements if significant wiring upgrades would be needed to install a 240V HPWH.

In either case, HPWHs tend to be larger and require more space than gas storage water heaters, as they have the compressor heat exchangers on top of the storage tank and exchange heat with the space they are in. If the mechanical room does not have sufficient space for a standard tank-style (integrated) HPWH, there are some split HPWH options that exist, which have an outdoor unit for the compressor and the tank indoors. However, this requires running a refrigerant line outdoors, and these systems are not readily available in most stores.

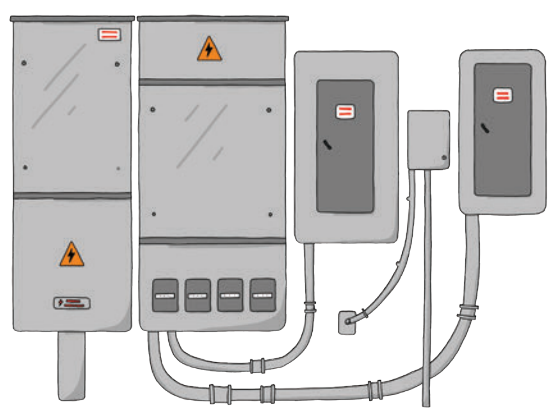
Additional measures to consider: In all cases of an alteration to the water heating system, Title 24 requires the hot water tank and piping to be insulated, which will add some cost to the project. However, this will be very beneficial to performance and will reduce operating costs.

5.4 Large Secondary School Electrical Service and EV Charging

Scenario: The same large secondary school has undergone a deep retrofit that requires an upgrade of the electrical service size from 1,600 amps to 2,000 amps, requiring the replacement of the switchboards and wiring to the transformer. Depending on the layout and components needing replacement, this could cost from **$31,125 to $60,050 for equipment** and between **$14,975 to $18,475 for labor.**

If the transformer needs to be upgraded, it will likely be from a 1,500 kVA transformer to a 2,000 kVA transformer assuming 277/480V service and a 2,000 amp main service panel. Depending on what transformer type is needed,[7] and whether additional labor is needed for handling in restricted spaces, the new transformer could cost between **$53,100 and $113,975 for materials** and between **$6,300 and $11,650 for labor.** Due to potential transformer material shortages, it could take up to a few years to procure and install the new transformer.

Additional measures to consider: While this upgrade is being planned and undertaken, the school could take advantage of the newly available capacity for additional load and install electric vehicle chargers. Assuming the school has 50 parking spaces and wants to install chargers in 10% of spaces, five electric vehicle chargers could cost between **$16,500 and $50,000.**



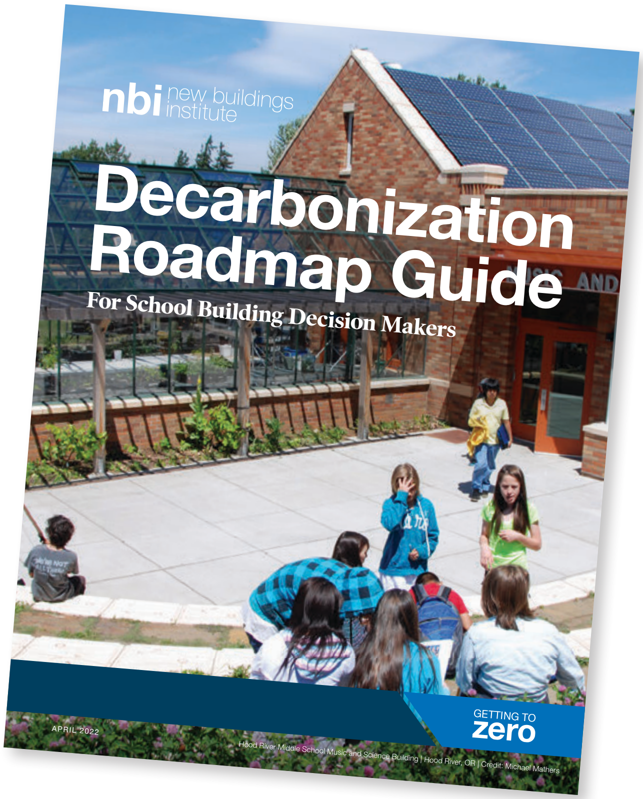
Electrical panel. Artwork by Nicole Kelner

7 Common transformer types include: dry type, oil filled padmount, or liquid filled padmount

Willie L. Brown Jr. Middle School | San Francisco, CA
Photo Credit: K2A Architecture

6. Electrification Decision Planning Guide for Schools

If you work with a school district, the [*Decarbonization Roadmap Guide for School Building Decision Makers*] can help you to work through the process of achieving a healthy and efficient school. In the guide's accompanying templates, you will find an Energy, Ventilation, and Emissions Checklist to help your energy teams and decision makers ask the right questions and ensure energy, emissions and health are considered in every aspect of the project. This checklist provides a list of things you may want to consider and incorporate into operations, management, and upgrades of school facilities.

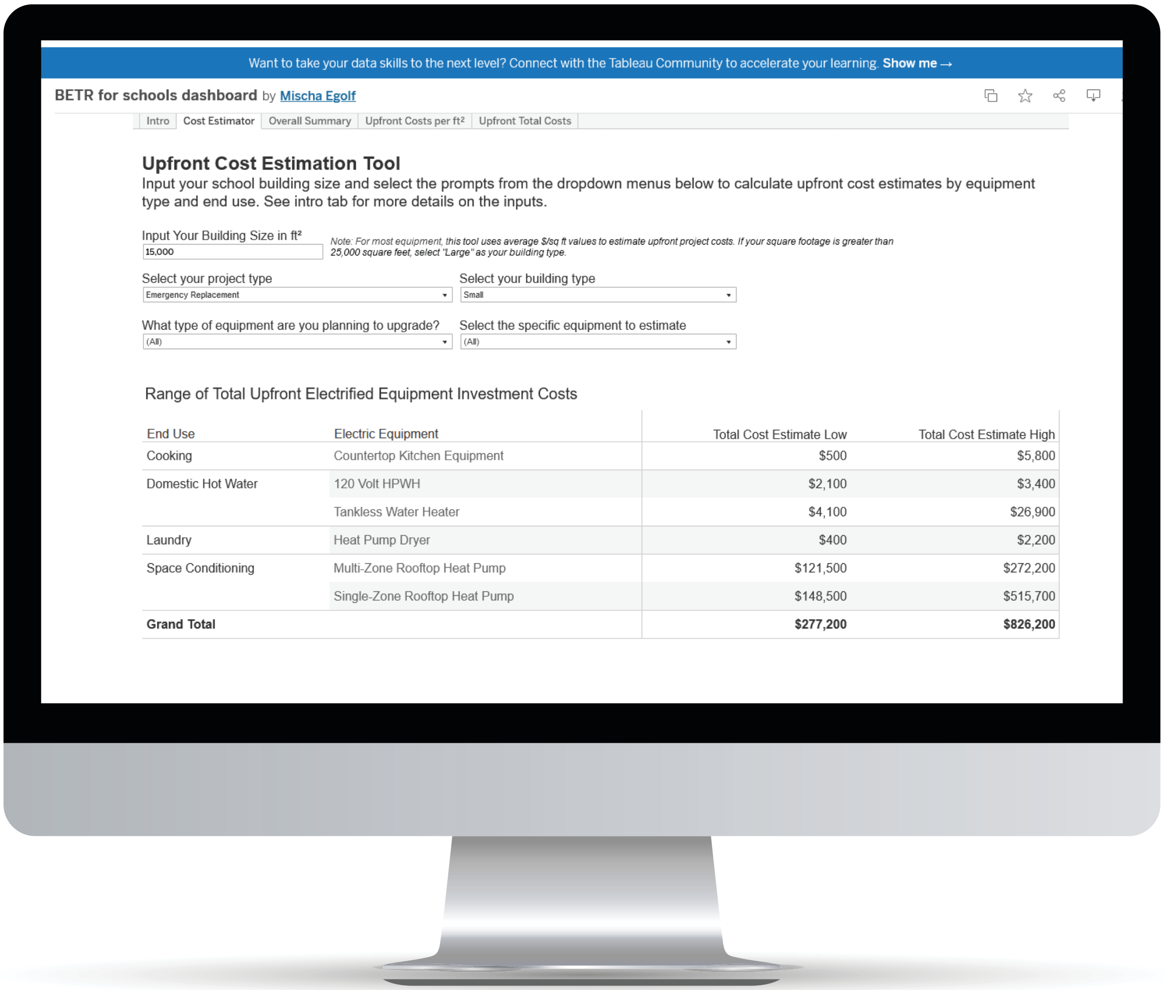


7. Conclusion and Summary

The high-level guidance found in this *Building Electrification Technology Roadmap (BETR) for Schools* can be used by school districts to consider electrification in their facilities. Every project is unique, but this guide offers a framework for considering the most common electrification technologies.

This team developed an interactive [dashboard] so school district decision makers and planners can see customized cost ranges for electrification projects.

If you need support in understanding decarbonization for your district, please feel free to reach out to schools@newbuildings.org.



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9. Appendices

Appendix A: Electrification Considerations

Section 3: "Technology: What Equipment in Schools Can Be Electrified?" includes the corresponding sections of the table below broken out by technology. We have included the full table below to see all equipment together. This may help serve district and other decision makers as a resource for prioritization or projects funds over the life of a building.

TECHNOLOGY	UPFRONT COST RANGE ($/SF)		SCENARIO				BUILDING TYPES			UTILITY COST IMPACT		BENEFITS				
	Low	High	Emergency Replacement	Planned Capital Improvement	Deep Efficiency Retrofit	Addition to Existing Building	Small	Large	Relocatable	Lower or similar utility costs	Likely to increase utility costs	Ease of Maintenance	Ease of Install	IAQ improvement potential	GHG emission reduction	Low GWP Refrigerant Option
Packaged Terminal Heat Pump	$1.03	$1.48	✔						✔	✔		High	High	-	Low	✔
Single-Zone Ducted Package ASHP + MERV 13	$9.90	$34.38	✔	✔		✔	✔		✔	✔		Low	High	Low	Medium	
Single-Zone Non-Ducted Minisplit ASHP w/ DOAS	$11.90	$17.47		✔	✔	✔	✔		✔	✔		Medium	Medium	High	High	✔
Multi-Zone Ducted ASHP + MERV 13	$8.10	$18.15	✔	✔		✔	✔	✔		✔		Low	High	Low	Medium	
Multi-Zone Multi-split ASHP w/ DOAS	$10.82	$25.27			✔		✔	✔		✔		Medium	Medium	High	High	✔
Air-to-Water Hydronic Heat Pump	$4.09	$8.40		✔	✔	✔		✔			✔	Low	Low	-	Medium	
Electric resistance tankless WH	$0.28	$1.80	✔				✔		✔		✔	High	High		Low	
120V HPWH (<80 gallons)	$1.23	$2.04	✔	✔			✔		✔	✔		High	High		High	
240V HPWH (<80 gallons)	$1.27	$2.54		✔	✔	✔	✔		✔	✔		High	Medium		Medium	✔
Central HPWH (>80 gallons)	$0.36	$1.43		✔	✔	✔	✔	✔		✔		Medium	Low		Medium	✔

Key: ○ Low ◓ Medium ● High Full circles are most desirable.

Cost ranges are determined from RS Means 2023 where possible, with other sources including government cost reporting, cost studies, and manufacturer data also utilized. See Appendix A for full table with all end-uses and Appendix B for sources. Costs include both labor and equipment that will be needed to install the electrification solutions but not additional components used by both the gas baseline and electrification systems such as ducting and piping. Costs are adjusted to match 2023 Southern California costs, and, where necessary, the systems are normalized using typical capacity per area factors for similar building types and climate zones.

TECHNOLOGY	UPFRONT COST RANGE		SCENARIO				BUILDING TYPES			UTILITY COST IMPACT*		BENEFITS			
	Low	High	Emergency Replacement	Planned Capital Improvement	Deep Efficiency Retrofit	Addition to Existing Building	Small	Large	Relocatable	Lower or similar utility costs	Likely to increase utility costs	Ease of Maintenance	Ease of Install	IAQ improvement potential	GHG emission reduction
Full Electric Commercial Kitchen Equipment (total kitchen cost)	$14,265	$63,873		✔	✔	✔	✔	✔			✔	◒	◒	●	○
Electric Small Countertop Kitchen Equipment (total kitchen cost)	$489	$5,787	✔	✔	✔	✔	✔		✔	✔		●	●	○	○
Heat Pump Dryer (residential)	$435	$2,174	✔	✔	✔	✔	✔	✔	✔	✔		●	●	○	○
EV Chargers for Passenger Vehicles	$3,335	$15,000		✔	✔	✔	✔	✔	✔	✔		●	◒	◒	●
Level 2 EV Charger for School Buses	$3,335	$15,000		✔	✔	✔	✔	✔	✔	✔		●	◒	●	●
Level 3 EV Charger for School Buses	$60,000	$100,000		✔	✔	✔	✔	✔	✔	✔		●	◒	●	●
Electrical Service Panel	$0.14/ ft^2	$1.18/ ft^2	✔	✔	✔	✔	✔	✔				●	○		
Distribution Transformer	$0.17/ ft^2	$1.27/ ft^2	✔	✔	✔	✔	✔	✔				●	○		

Key: ○ Low ◒ Medium ● High Full circles are most desirable.

Cost ranges are determined from RS Means 2023 where possible, with other sources including government cost reporting, cost studies, and manufacturer data also utilized. See Appendix A for full table with all end-uses and Appendix B for sources. Costs include both labor and equipment that will be needed to install the electrification solutions but not additional components used by both the gas baseline and electrification systems such as ducting and piping. Costs are adjusted to match 2023 Southern California costs, and, where necessary, the systems are normalized using typical capacity per area factors for similar building types and climate zones.

* *EV chargers will increase electrical utility cost, but because the cost of gasoline or diesel fuel is avoided, overall operating cost is generally much lower for EVs compared to internal combustion vehicles.*

Appendix B: Analysis Sources

The following list includes all the resources used by Resource Refocus as part of the electrification cost analysis. The resources are broken out by equipment type.

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5. "NYS Scoping Plan Appendix G Annex 1: Inputs and Assumptions", 2023. https://climate.ny.gov/Resources/Draft-Scoping-Plan
6. Red Car Analytics, "Economic Analysis of Heat Recovery Equipment in Commercial Dedicated Outside Air Systems," 2019. (p.28-29). https://betterbricks.com/uploads/resources/NEEA-DOAS-Analysis-Report_Red-Car_Final.pdf
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COMMERCIAL APPLIANCES

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3. Miele, "TXD160WP," 2023. https://www.miele.ca/en/Shop/products/detail/tumble-dryers-txd160wp-11667290-p
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