I²SL
International Institute
for Sustainable Laboratories®

Best Practices Guide
Decarbonizing Laboratories: A Primer

DECEMBER 2022

Across the United States, state and local governments are passing building performance standards that set specific energy and greenhouse gas (GHG) emissions targets for the operational energy use of existing buildings (DOE, n.d.). Many organizations with emissions reduction goals for their buildings are looking to go well beyond conventional energy efficiency toward whole-building decarbonization, striving to achieve very low and even zero carbon emissions. These market and policy drivers are increasing the imperative for laboratory operators and designers to implement decarbonization strategies in new construction and existing building retrofits.

This guide provides a primer on laboratory decarbonization, presenting key concepts and strategies. The guide is intended for laboratory owners, operators, and designers who may be relatively new to building decarbonization. It focuses on decarbonizing operational energy use and does not cover embodied carbon (i.e., the GHG emissions arising from the manufacturing, transportation, installation, maintenance, and disposal of building materials). The concepts and strategies are primarily relevant to life sciences laboratories, but most are also applicable to physical sciences laboratories. Note that this guide is not intended to be a manual and does not provide design requirements and specifications for decarbonization.

Section 1 introduces a framework with the three facets of decarbonizing laboratory buildings. Section 2 discusses the selection of metrics to assess decarbonization. Section 3 describes strategies for decarbonization, including energy efficiency and electrification.

1. Three Facets of Decarbonizing Operational Energy Use

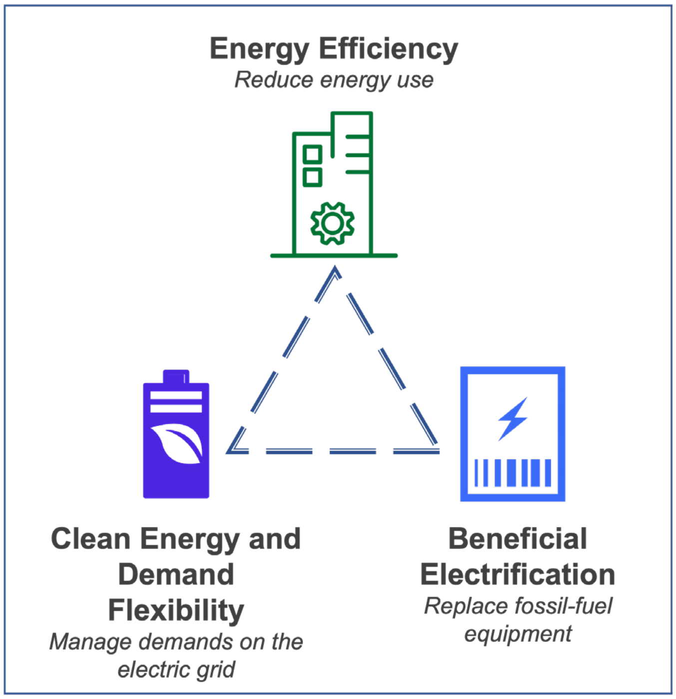


Figure 1. The three facets of decarbonizing laboratory operational energy use.

Figure 1 shows the three facets of decarbonizing laboratory operational energy use.

The first and foundational facet is **energy efficiency**. Simply put, reducing energy use remains the most important and effective aspect of building decarbonization. Lowering energy use inherently lowers carbon emissions. Even in areas where the grid is very low-carbon, such as the Pacific Northwest, energy efficiency is still critical, because it makes electrification more technically and economically feasible. In fact, electrifying buildings without reducing energy use can result in an increase in energy costs, depending on the relative difference in costs of electricity and natural gas in a given location. Additionally, energy efficiency helps mitigate capacity constraints on the grid when electrifying.

A key consideration for energy efficiency in the context of building decarbonization is not just how much energy is used or reduced, but when it is used or reduced. This is increasingly important with the introduction of more renewables on the grid. For decarbonization, electricity reductions are more valuable during periods when the grid has higher emissions per unit of electricity.

The second facet of decarbonization is **electrification**. This refers to replacing fossil fuel-using equipment with all-electric equipment. For example, gas boilers used for space heating or domestic hot water can be replaced by heat pumps. Electrification can be done in stages, as equipment reaches the end of its life.

The third facet of decarbonization is **clean energy and demand flexibility**. Clean energy in this context refers to renewable energy generation, such as solar photovoltaic (PV), solar thermal, and wind. The clean energy sources may be produced directly onsite or may be procured and delivered through the grid. Demand flexibility (DF), as used here, refers to a building's ability to manage its energy use dynamically so it can reduce usage when the grid has higher emissions and shift energy use to periods when the grid has lower emissions.

Many technical guides and case studies on energy efficiency are available, including many developed by the International Institute for Sustainable Laboratories (I^2SL, n.d.). Therefore, this guide only provides a summary of the key energy efficiency strategies, in Section 3.1. Section 3.2 describes electrification strategies, and Section 3.3 briefly speaks to demand flexibility. (Clean energy for laboratories is not different from clean energy for other buildings, and there are numerous resources available in this area; therefore, this guide does not cover the topic.)

2. Metrics and Targets for Decarbonization

How is decarbonization measured? While there is no single metric for decarbonization, following are the three primary metrics:

Greenhouse gas intensity (GHGI), sometimes referred to as carbon emissions intensity (CEI), is calculated as the total emissions of the building normalized by floor area and expressed in kilograms of carbon dioxide equivalent per square foot per year (kg CO_2e/sf/yr) or per square meter per year (kg CO_2e/sq.m/yr). In its most common usage, it includes the emissions from all energy sources used by the building, or Scope 2 emissions, in the parlance of the World Resources Institute's GHG protocol (WRI, n.d.).

A key consideration is the emissions factors used for grid electricity and district systems such as a steam or chilled water loop. Some calculation protocols require the use of standard emissions factors for these sources (e.g., eGrid data from the U.S. Environmental Protection Agency [EPA]). Others may allow the use of custom emissions factors specific to the site.

Another consideration is how purchased, off-site renewable energy is handled (e.g., energy purchased through a power purchase agreement [PPA]). Some calculation protocols do not allow PPA green power to be included and require treating it as grid-supplied electricity.

When calculating and reporting these metrics, it is important to clearly state the assumptions used. The key advantage of GHGI is that it most fully characterizes the decarbonization of operational energy use. However, it incorporates grid electricity emission factors, which owners do not directly control.

Direct emissions intensity (DEI) is the direct onsite emissions (sometimes referred to as Scope 1 emissions in the parlance of the WRI GHG protocol) normalized by floor area. DEI counts only the direct emissions from fossil fuels burned onsite (e.g. natural gas, fuel oil, diesel). It is a key measure of the degree of electrification. A fully electric building

AIR CHANGE RATES BY LABORATORY TYPES

Laboratory use types can be broadly categorized as biology, chemistry, physical, and combinations thereof. These lab types have different energy use characteristics, which in turn impact the selection and prioritization of energy efficiency strategies.

The energy use in most laboratories is dominated by the need to heat, cool, and move large volumes of air to maintain the required laboratory air change rate as part of worker safety requirements specified by building codes and standards and enforced by the laboratory's environmental health and safety (EHS) personnel. Air change rates are commonly specified in air changes per hour (ACH), or the number of times per hour that the total volume of room air is exchanged for makeup air. Most research laboratories use six ACH as a standard for safe laboratory design. Six ACH is roughly equal to 1 cubic foot per minute (cfm) of outdoor air, per square foot of floor area, per 10 feet of ceiling height. This is approximately five times the air exchange requirement of an office space: a significant energy demand for heating, cooling, dehumidifying, and moving this very large volume of air through the building. The Smart Labs toolkit on the I^{2}SL website has a number of resources on laboratory ventilation (I^{2}SL, n.d.).

Biology labs have moderate chemical use and few fume hoods. These types of labs often have makeup and exhaust airflow in the range of 1 to 1.5 cfm per square foot and peak equipment electrical loads in the range of 6 to 12 watts per square foot or higher. They are driven by the minimum ventilation rates required for general exhaust and/or internal loads and not driven by fume hood exhaust. In general, they are less heavily driven by exhaust and makeup loads compared to chemistry labs.

Chemistry labs have heavy chemical use and many fume hoods. Their energy use is dominated by the need to heat, cool, and move huge amounts of air to supply fume hood makeup air demand, ventilated cabinets, and/or specialized processes. In chemistry laboratories with many fume hoods or vented cabinets, the fume hood air demands can far exceed the required air change rate, resulting in airflows three to six times those in a biology lab (3 to 6 cfm/sf or 18 to 30 ACH).

Physics and engineering labs, though different in their research focus, share many design characteristics. Labs for these disciplines vary widely in their needs, from office-type spaces containing only light computing equipment, to highly intensive controlled-environment rooms with multiple mechanical, electrical, and plumbing services. Design requirements could include tight humidity and temperature control and/or filtration of airborne particulates. These labs generally have minimal or no chemical use, few or no fume hoods, and no biological hazards. Energy use is driven by the internal loads, tight temperature/humidity range and stability, and/or particulate filtration.

will have zero direct emissions. The measurement units are the same as GHGI (i.e., kg CO_2e/sf/yr).

Site energy use intensity (EUI) is a well-established metric that is calculated as the total energy use by the building normalized by floor area. Site EUI has been used widely as an energy efficiency metric and is therefore relevant for decarbonization as well. EPA recommends the use of site EUI and DEI in combination to measure decarbonization (EPA, 2022).

Once a metric is selected, the next step is to target a particular level of performance. In general, laboratory buildings vary so widely that it is difficult to specify broadly applicable absolute targets. Users may consider setting a percentage reduction from either benchmark data or an energy model baseline.

For existing buildings, benchmarks against other comparable buildings—for example, using the I^2SL Laboratory Benchmarking Tool—or a percentage reduction may be used as targets. For new construction, targets are typically set relative to the energy model baseline. In a few cases, the model baseline could be calibrated against benchmark data.

For existing buildings, targets may be set over a particular time frame. There may be interim targets, aligned with long-term goals of net zero. The state of Maryland has passed a building performance standard that requires 20% reduction of direct emissions by 2030 and zero by 2040. Interim targets may also be aligned with the capital plan for the building, including major renovations and equipment replacements (Jungclaus et al., 2018; Mathew et al., 2019).

3. Decarbonization strategies

3.1 Whole-building energy efficiency solutions for decarbonization

As noted in Section 1, efficiency is still the foundation of decarbonization because: a) it inherently reduces carbon emissions; and b) it is needed to make electrification cost-effective for owners and mitigate capacity constraints on the grid. Energy efficiency reduces capital expenditures needed for electrification. For example, one large research campus in the Boston area realized 25% capital expenditures reduction just from ventilation optimization (King, 2022).

There are a wide range of well-established and proven lab energy efficiency strategies, and numerous guides and resources are available, including other best practice guides published by I^2SL. Table 1 on the next page summarizes the key energy efficiency strategies for design and planning, HVAC, lighting, envelope, service hot water, and process and plug loads. Selection and prioritization of these strategies must be tailored to specific contextual factors such as climate, laboratory program, and more, but the list can be used as a starting point for envisioning solutions for any given laboratory.

How does energy efficiency for decarbonization vary from traditional efficiency? In general, the strategies used for traditional energy efficiency (i.e., strategies to reduce energy use and costs) are all beneficial for decarbonization. However, there may be some differences in priorities. Since a key aspect of decarbonization is fuel-switching from fossil fuel to electricity, energy efficiency for heating load reductions has a higher marginal value than

Table 1: Key Energy Efficiency Strategies for Decarbonization

Area	Key energy efficiency strategies
Programming and planning	• Design and lab planning that minimizes HVAC load (e.g., segregating office and lab spaces, cascading air, etc.). • Optimized ventilation requirements through laboratory ventilation risk assessment (LVRA), air change rate requirements assessment.
HVAC	• Biology and physical labs: Chilled beams, fan coil units, water-source heat pumps or variable refrigerant flow (VRF) at lab zones to decouple space conditioning from ventilation. Enthalpy wheel heat recovery for general exhaust, serving lab makeup air (for fume hoods and vivaria, see chemistry labs below). • Chemistry labs: All-air variable air volume (VAV) with reheat in spaces with high makeup air rates and low internal loads. High-performance run-around or heat pipe heat recovery. If the exhaust exceeds 50,000 cfm, consider adding the following enhancements to the run-around heat recovery system: free reheat coil, operate supply air at 65°F discharge, frosting exhaust coil, heat-pump boost (i.e., exhaust-source heat pump). • Non-lab areas: Fan coil units, water-source heat pumps, VRF or fan-powered boxes serving chilled beams to ensure that chilled beams are not coupled directly with air handling units using 100% outside air. • Teaching labs or labs with consistent chemical types: Filtered fume hoods, which may allow chemistry lab systems to be designed more like biology labs. • Air-quality monitoring with reduced ACH for normal occupancy and unoccupied periods or based on pollutants, and purge-mode capacity for a select number of zones simultaneously. • Low-pressure-drop design to reduce fan energy. • Variable volume exhaust discharge using fan staging and/or minimum turndown velocities based on wind tunnel analysis (active wind monitoring can be considered to optimize turndown). • Heat recovery from ultra-low-temperature (ULT) freezer farms, process chillers, and other lab equipment. • Continuous commissioning.
Lighting	• LED lighting with occupancy or vacancy sensors (motion and IR) and daylight-based dimming.
Process and plug loads	• Cooling through process water instead of heat rejection to room air. • High-efficiency ULT freezers. • Biological safety cabinets (BSCs) with low power mode. • Heat recovery from autoclaves. • Occupancy-based plug load controls for non-lab spaces.
Service hot water	• Water-efficient fixtures to reduce hot water consumption.
Envelope	• High-performance envelope (per IECC 2021/ASHRAE 90.1-2019; minimizing night heat loss minimizes perimeter heating needs and impacts on electrification). • Whole-building envelope airtightness 0.25 cfm/sf at 75pa or lower.

efficiency strategies for cooling load reductions. Exhaust heat recovery is an especially high-priority strategy. Using intermittent renewable energy sources such as solar and wind, and efficiency strategies where the load reductions are aligned with times when the grid has higher emissions, have more benefit. Peak demand management becomes much more important, to minimize the cost and space requirements of heating and electrical infrastructure, and peak demand on the grid. See Section 3.3 for more information on demand flexibility.

3.2 Electrification Strategies and Considerations

Space Heating

Heat pumps are the predominant technology for electrifying heating. There are three typical approaches to heat pumps in laboratory buildings, based on the source of the heat: ground-source, air-source, and exhaust-source. In all cases, it is assumed that large laboratory buildings start by incorporating heat recovery chillers into the design to take advantage of simultaneous heating and cooling loads, before adding heat pumps to achieve further electrification.

Selecting a heat pump system type requires evaluation of several factors, including type of lab, peak load, available site area, roof area, new vs. retrofit, heating hot water temperature, climate zone, budget, investment strategy, incentives, and more. Figure 2 shows the implications of site and climate on system selection.

When using air-source heat pumps for large laboratory buildings, air-to-water heat pumps are typically chosen (note that these are not the same

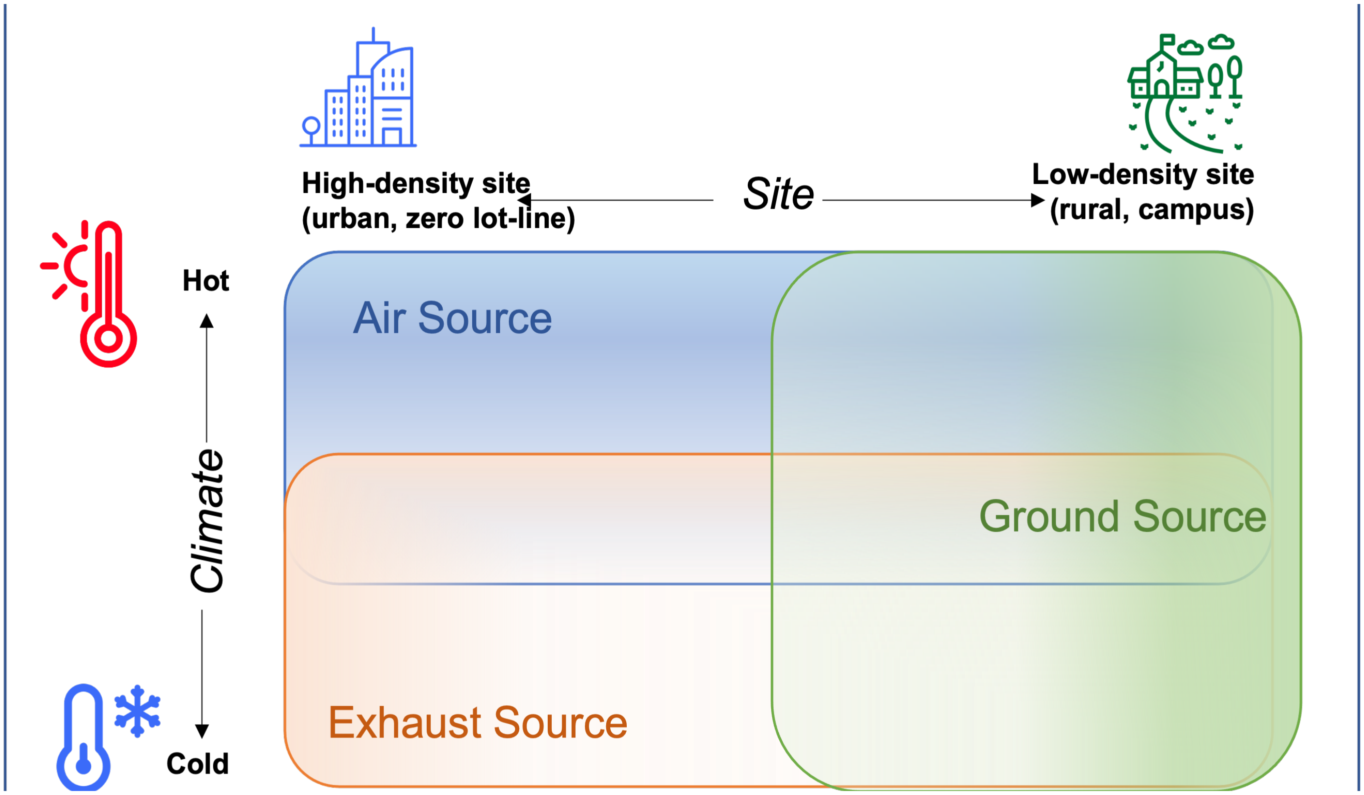


Figure 2. Implications of site and climate on system type selection.

as variable refrigerant flow or “VRF” systems). Air-source heat pumps are generally more viable in warm climates where temperatures rarely fall below freezing. Simultaneous water-to-water or air-to-water heat pumps can be used when there are simultaneous loads.

In cold climates, ground-source heat pumps have historically been the preferred solution. This is due to the fact that the ground is warmer than the winter air, allowing the ground-source system to operate efficiently and effectively when it is cold outdoors.

More recently, exhaust-source heat pumps have come to the forefront. This system type relies on the warm exhaust air to allow efficient and effective operation even when the outdoor air temperature is very cold. Exhaust-source technology is particularly useful in cold climates when there is limited space available for a ground-source bore field to be installed. Exhaust-source is typically integrated with a glycol run-around heat recovery system, relying on the exhaust heat-recovery coil as the source for the heat pump. Therefore, exhaust-source heat pumps are not viable for labs that use enthalpy wheels for exhaust heat recovery.

In some cases, multiple heat pump technologies are used in a single building—for example, ground-source and air-source; ground-source and exhaust-source; or exhaust-source and air-source. Historically, fossil fuels have been commonly included as a peak and/or back-up sources of heat, regardless of the heat pump system type.

The temperature of heating and process loads is also a significant consideration. New buildings can typically be designed with heating hot water at 130°F supply or lower. Most heat pumps can supply this temperature. However, existing buildings often require higher temperatures. If it is not financially or logistically viable to reduce the existing hot water temperature, heat pumps may need to be selected for higher temperatures. In addition, there are some cases where existing process loads are a significant driver of total heating demand. These process loads often rely on steam. High-lift trans-critical CO_2 heat pumps can provide first-stage heating to reduce electric steam load. Additionally, steam heat pumps are an emerging technology, available from a few manufacturers.

Electric resistance boilers should typically be avoided, due to high peak demand on the grid and high energy costs. However, there are some instances where their use is warranted or necessary, preferably as a hybrid with heat pump technology.

It should be noted that the amount of heat pump equipment required to eliminate the last few percentage points of annual fossil fuel consumption at peak heating load results in a significant increase in embodied carbon and amount of refrigerant. Therefore, a hybrid system combining heat pumps for 25% to 50% of the peak load and fossil fuel boilers for the remainder of the peak load may result in the lowest lifecycle carbon footprint.

Service Hot Water

Options for electrifying service hot water (SHW) include heat pumps and electric resistance. There are specialized heat pump products for SHW; it is typically separate from the building heating system, but can be integrated. For SHW heat pumps, thermal storage is often advantageous to reduce the amount of heat pump equipment required.

Process Loads

Process equipment for labs varies widely, but often includes sterilizers, cage washers, tunnel washers, bunsen burners, humidification, water for injection (WFI), water for process use (WPU), and more. Options for electrifying these loads include the following:

- Specify laboratory equipment (sterilizers, cage washers, tunnel washers) with local electric steam generators so the equipment won't require building steam.
- Explore alternatives to natural gas use at laboratory benchtops. Traditionally, natural gas is used for sterilization, but there are electric options for that purpose. Use electric bunsen burner alternatives (Stanford, n.d.). A chief operating officer of a pharmaceutical company says, "[Natural gas] is not really very important. Some chemists still use it but not that much, and they can always use portable butane instead of plumbed-in natural gas" (Rumsey & Le Garrec, 2022).
- Use steam heat pumps and electric resistance for local steam generation. High-lift heat pumps can provide the first stage of makeup water heating to reduce overall demand to produce the steam.
- Humidification can rely on adiabatic systems that spray a fine mist of water into the supply airstream. Note that these systems do increase the load on the heat pumps to increase the entering air temperature.

Emergency Generators

Emergency generators are typically exempted from code- and policy-driven electrification. Some green building rating systems (e.g., International Living Future Institute's Zero Energy Certification, Living Building Challenge) do require non-life-safety loads to be met with fossil fuel-free backup power. How this applies to, and gets interpreted for, labs is a gray area. Regardless, clients may also invite the conversation about moving in this direction as part of their project decarbonization goals.

Potential strategies commonly considered include:

- **Biofuels.** However, the availability can be very limited in many markets.
- **Hydrogen fuel cells plus storage.** Currently, green/renewable hydrogen has limited market availability; production could occur on site but would not likely be available during an extended outage.
- **Battery storage.** Extended-outage operational requirements may lead to prohibitive space and capital cost requirements for batteries. Capacity dedicated to critical standby requirements will not be available for utility rate or hourly grid emission arbitrage.

The applicability and manageability of these strategies are influenced by a number of factors. With the increased focus on embodied carbon, consideration of the need for sporadic usage of fossil fuel over the life of the equipment vs. the embodied carbon inherent in some non-fossil fuel-using equipment types may be helpful in decision making.

Additional Considerations

Space. Air-source heat pumps for laboratory buildings require significant rooftop or site area to meet heating and cooling demands. Many labs are developed on constrained sites with little room for pad-mounted mechanical equipment. Labs tend to have a lot of equipment on the roof, and roof space is often at a premium. If there is limited space, some lab buildings may expand their penthouse footprint to enclose exhaust air-handlers and generators, creating additional roof area above the penthouse for heat pumps. Water-source heat pumps used as part of geothermal and/or exhaust-source strategies can reduce needed roof area.

Capacity of electrical infrastructure. Electrification can increase the peak electrical load, unless it is coupled with deep energy efficiency and demand flexibility. This may require upgrades to the electrical service at the panel and building. In some cases, it may even require upgrades beyond the building at the distribution feeder and so on.

District systems. Most district heating systems use fossil fuels. Laboratories that use district systems would need to decouple from such district heating systems to fully decarbonize. However, some district system utility providers are working on decarbonizing their systems. This gives an option for laboratories to remain on these district systems. For campuses with district systems, decarbonizing the central system may be more cost-effective than decoupling many individual buildings from district supply and retrofitting each with onsite heat pumps.

3.3. Demand Flexibility

Demand flexibility (DF) refers to the ability of buildings to reduce or shift their energy loads to mitigate demands on the grid. There have been limited efforts to date on understanding the role of DF in laboratory buildings, which are highly specialized and have complex functional and safety requirements. The Lawrence Berkeley National Laboratory (LBNL) conducted an analysis of DF opportunities in laboratories (Mathew and Sanchez, 2022). There is an array of commercially available demand flexibility technologies that may be applicable to laboratories, as shown in Table 2.

Lawrence Berkeley National Laboratory interviewed several federal organizations to get an overall sense of the feasibility of implementing these technologies. While for the most part these strategies are technically feasible, significant

Table 2: Potential DF Technologies and Strategies for Laboratories

Category	DF Technology/Strategy for Load Shed or Shift
HVAC	• Smart thermostats to change temperature setpoints • HVAC equipment controls (e.g., raise chilled water supply temp) • Smart ventilation for demand-based ventilation • Thermal storage • Dual-fuel HVAC (i.e., switch to non-electric fuel during peak event) • Increase hybrid evaporative pre-cooling
Lighting	• Dimming controls to lower lighting power
Service hot water	• Water heaters with smart connected controls • Dual-fuel water heater (i.e., switch to non-electric fuel during peak event)
Process and plug loads	• Apply lower power mode • Switch to battery power • Schedule equipment use • Reduce temperature of ULT freezers
Envelope	• Dynamic glazing to lower thermal loads from envelope

implementation challenges remain. The primary concerns are potential risks and disruption to the lab's scientific mission and operations. In addition, lab stakeholders are uncertain about how changes in laboratory environmental conditions (e.g., temperature and light level) may affect experiments. Scientists may be open to DF measures that do not directly impact their work, such as use of battery or thermal storage systems. They may also be open to modest administrative measures like operating some equipment at off-peak hours, provided this does not affect their work and is not overly burdensome to administer (e.g., running glasswashers during off-peak hours).

DF measures such as reducing light levels or increasing thermostat setpoints may be more feasible in non-lab spaces such as offices and conference rooms. However, impacts of such strategies may be relatively small. since most of the load in laboratory buildings is from the laboratory spaces themselves.

ALEXANDRA REAL ESTATE EQUITIES, CAMBRIDGE, MASSACHUSETTS

This new, 500,000-gross-square-foot laboratory building supports biology and chemistry research space and is designed to essentially eliminate fossil fuel consumption for all end uses except humidification. Features include:

Photo courtesy of NBBJ

- Site EUI below 130 kBtu/sf/year, which is 60% lower than regional average for this type of lab.
- Ground-source system using 600-foot-deep quad-loop boreholes, heat pump chillers for heating and cooling, and premium-efficiency water-cooled chillers and cooling towers for peak cooling.
- Triple-glazed windows to minimize loads and eliminate the need for perimeter heat.
- Enhanced heat recovery system with wrap-around reheat coil in the supply, which can significantly reduce cooling and heating loads.
- Heat pump chillers that boost exhaust heat recovery, resulting in no net heating load when the outdoor air temperature is above 15°F.
- A 0.5 MW roof-mounted solar PV array, supplemented by renewable energy from off-site sources, which will achieve Class D Net Zero Energy.

The project team included Alexandria Real Estate, NBBJ, and BR+A. For more information, visit https://www.brplusa.com/projects/alexandria-real-estate-equities-inc-325-binney.

UNIVERSITY OF WASHINGTON LIFE SCIENCES BUILDING, SEATTLE, WASHINGTON

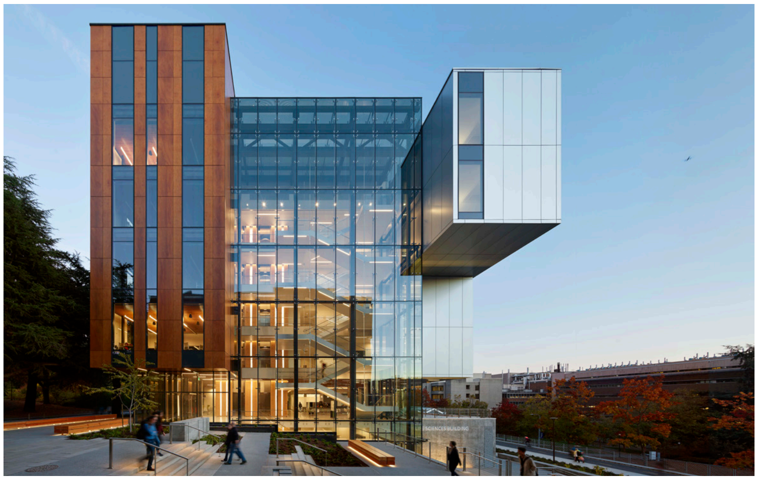


Photo courtesy of Kevin Scott (@k7scott)

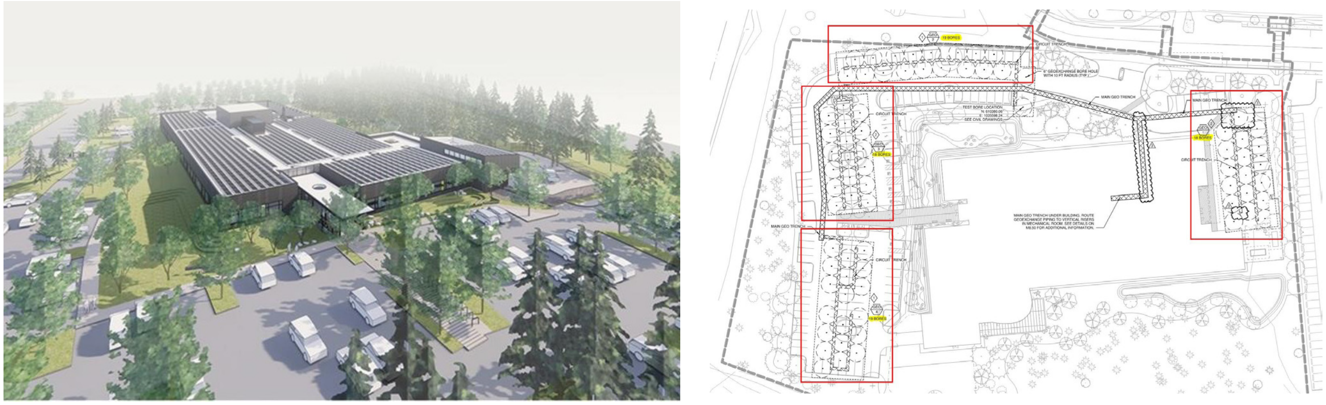
This 207,000-square-foot facility, completed in 2018, supports the largest STEM program in the state of Washington. It is 2030 Challenge compliant and received an AIA COTE Top Ten Award from the American Institute of Architects. Highlights include:

- The latest technologies for energy conservation, including radiant systems such as chilled beams and chilled waves for heating and cooling of labs, offices, and public spaces. These systems prove more effective than traditional variable air volume systems, and when paired with radiant floor heating systems, natural ventilation cooling, and a high-performance building envelope, they create a streamlined heating, cooling, and heat recovery hydronic loop.
- The design team used solar glass in previously unseen ways to both cool the building and generate electricity without emitting carbon. First-of-their-kind building-integrated PVs are installed on the southwest façade, reducing unwanted solar heat gain in the offices, providing expansive views, reflecting daylight, and producing enough electricity to light the offices on all four floors of the building throughout the year. In addition, the roof of the building is maximized with high-efficiency solar panels which, along with renewable energy credits, increase the energy reduction to over 80%—exceeding the 2030 Challenge, an aspirational energy target set by Architecture 2030. By meeting the upcoming 2030 Challenge threshold for the next five years, this project sets an example for future projects on campus.

The site predicted energy use intensity was 152 kbtu/sf/year, and the site measured EUI is 137 kbtu/sf/year.

The project team included Perkins&Will, Skanska, and Affiliated Engineers Inc. For more information, visit https://www.aia.org/showcases/6389788-university-of-washington-life-sciences-bui.

WASHINGTON STATE LABORATORY COMPLEX, TUMWATER, WASHINGTON



Source: AEI Inc. and ZGF

This all-electric laboratory, which supports the Washington State Departments of Agriculture and Labor & Industries, achieved an all-electric design with the following features:

- A high-performance envelope with 30% window-to-wall ratio, glazing U-value of 0.34, 0.25 cfm/sf infiltration, and exterior shading.
- Active demand-controlled ventilation and low-flow (70 fpm) fume hoods.
- Low-energy systems including natural ventilation, radiant heating and cooling slab, ceiling fans, and air-to-air heat recovery.
- Six-pipe water-to-water heat pump for simultaneous heating and cooling, and geothermal heating and cooling in the parking lot.
- Four-pipe air-source heat pump.
- Service hot water via water-to-water heat pump.
- Planned 1 MW solar PV rooftop array and parking lot canopies.

The guaranteed maximum estimate was only $1.4 million higher than the initial budget of $33 million. The project team included ZGF Architects, Affiliated Engineers Inc. (AEI), and Korsmo Construction.

4. Getting Started With Lab Decarbonization

This primer presents a framework and summary of key strategies for decarbonizing laboratory buildings. The optimal approach and specifics of decarbonization of a new or existing laboratory will depend on a host of factors, including organizational goals, location, timeframe, site context, and more. Following are some suggested steps for getting started on the laboratory decarbonization journey.

Set goals. The goals should include specific metrics, targets, and the timeframe for achieving them. Consider future organizational goals and regulations such as building performance standards when setting goals. Setting goals is often an iterative process, with the goals being refined with more in-depth analysis. The metrics and targets should provide clear guidance on how to account for aspects such as power purchase agreements, district systems, and more. Use the metrics indicated in this document as a starting point.

Prioritize and analyze strategies. First maximize efficiency, and only then consider electrification. Analyze energy and emissions reductions, costs, and other factors such as space requirements, electrical service upgrades, ease of operations and maintenance, etc. Use the list of strategies in this document as a starting point.

Develop an implementation plan. It may not be feasible to implement all strategies at once, especially in the case of retrofits in existing buildings. Consider the long-term capital plan, and align the decarbonization strategies with planned upgrades and equipment replacements.

Measure and track progress. Establish an emissions inventory and track progress over time with measured energy use data.

While laboratories—with their high heating and process loads—present unique challenges for decarbonization, many existing and proven strategies can be applied. Indeed, there are already examples of laboratories that are implementing decarbonization.

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