Improving the American Indoors

The Health, Economic, and Community Benefits of Zero-Carbon Buildings

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AMERICA IS ALL IN

Executive summary

- **BUILDINGS ARE A CORNERSTONE OF MODERN LIFE,** and are the basis for many of the social, physical, and economic patterns that form within communities.
- **ZERO-CARBON BUILDINGS OFFER BETTER AIR QUALITY, ENERGY-EFFICIENCY AND HOUSEHOLD SAVINGS GAINS**, high-quality local employment opportunities, a more equitable built environment, and climate-resilient grids and communities.
- **RECENT FEDERAL LEGISLATION PROVIDES SIGNIFICANT INVESTMENTS IN CLEAN ENERGY,** offering a historic opportunity to fundamentally transform U.S. buildings, reducing greenhouse gas emissions from buildings while driving innovation in key industries and delivering health and economic benefits to households across the country.
- **LOCAL COMMUNITIES STAND POISED TO BENEFIT** through building electrification and energy efficiency measures, land use planning that prioritizes housing stock, strategic use of procurement standards and a life-cycle approach to building design, construction, and demolition, and integrating building operations with the electricity grid.
- **BUILDING PERFORMANCE AND APPLIANCE STANDARDS,** as well as updates to building codes, can support the decarbonization of new and existing building stock and should be accompanied by measures to ensure housing affordability.
- **OUR CURRENT BUILT ENVIRONMENT IMPOSES DISPROPORTIONATE HEALTH AND ENERGY COSTS** on low-income and non-white communities, and thoughtful policy design can reduce inequality by targeting investments toward building decarbonization and energy efficiency initiatives for these communities.
- **AMBITIOUS NON-FEDERAL ACTION TO DECARBONIZE BUILDINGS** can accelerate the energy transition and help set the U.S. on a path to meet its Paris Agreement target of reducing emissions 50 percent below 2005 levels by 2030.

ACKNOWLEDGEMENTS

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Introduction

INTRODUCTION

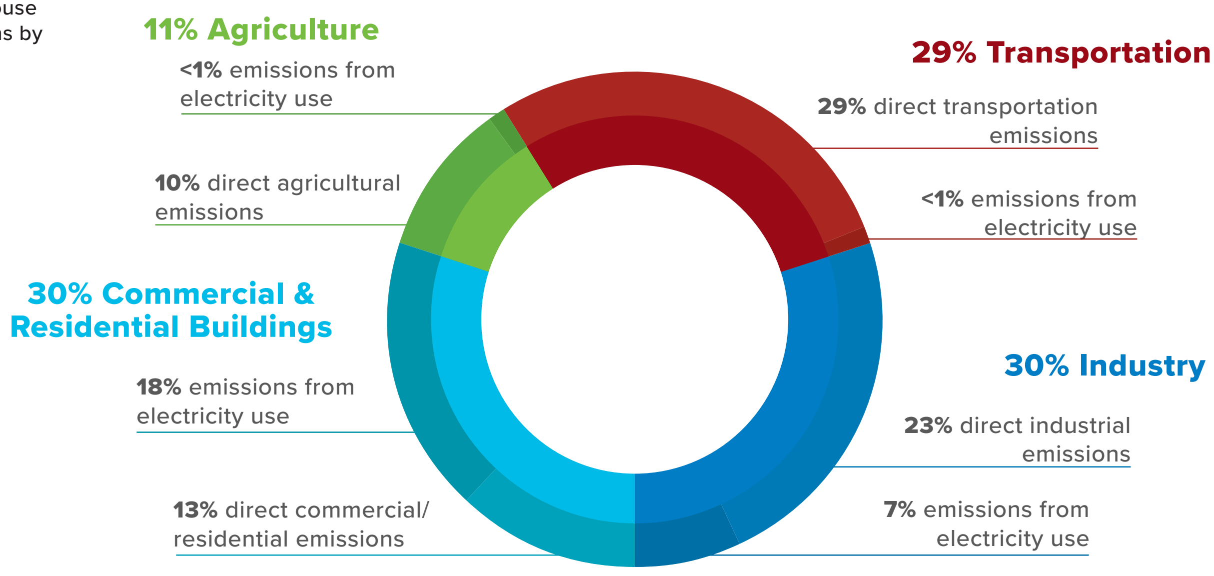
A

Why Buildings Matter

AMERICANS SPEND A MAJORITY OF THEIR TIME INDOORS, and building conditions impact the social, physical, and economic well-being of individuals and communities across the U.S. Poorly designed, constructed, and maintained buildings can cause irreversible health issues, unnecessary household expenses, and negative environmental impacts that threaten human safety and well-being. Buildings account for over 30 percent of total U.S. greenhouse gas emissions. Approximately a third of that–12.5 percent of U.S. emissions–comes from the direct use of fossil fuels for indoor heating, cooling, and cooking, while the remainder is indirectly attributable to the electricity used to power buildings (Cleary and Palmer 2021). Buildings are also a significant source of "embodied carbon" emissions, a category that includes everything from the resources used to make building materials, the energy used to transport them, and the emissions from both the construction and demolition of buildings (Adams, Burrows, and Richardson 2019). Reducing emissions from the buildings sector will be an important part of the U.S. meeting its targets to limit the worst effects of climate change.

By 2050, the U.S. is projected to add 11.24 billion m^2 of building floorspace, the equivalent of constructing New York City every year for the next 20 years (Abergel, Dean, and Dulac 2017). Existing residential buildings in the U.S. have an expected lifetime of between 30 and 60 years (Aktas and Bilec 2012). Given this longevity, decarbonization will require strategies to retrofit and address emissions from existing buildings as well as new construction. Furthermore, decisions on where to site buildings and accompanying zoning requirements dictate how land is used, which in turn impacts patterns and modes of transportation, as well as economic development.

Figure 1.
U.S. Greenhouse Gas Emissions by Sector, 2019

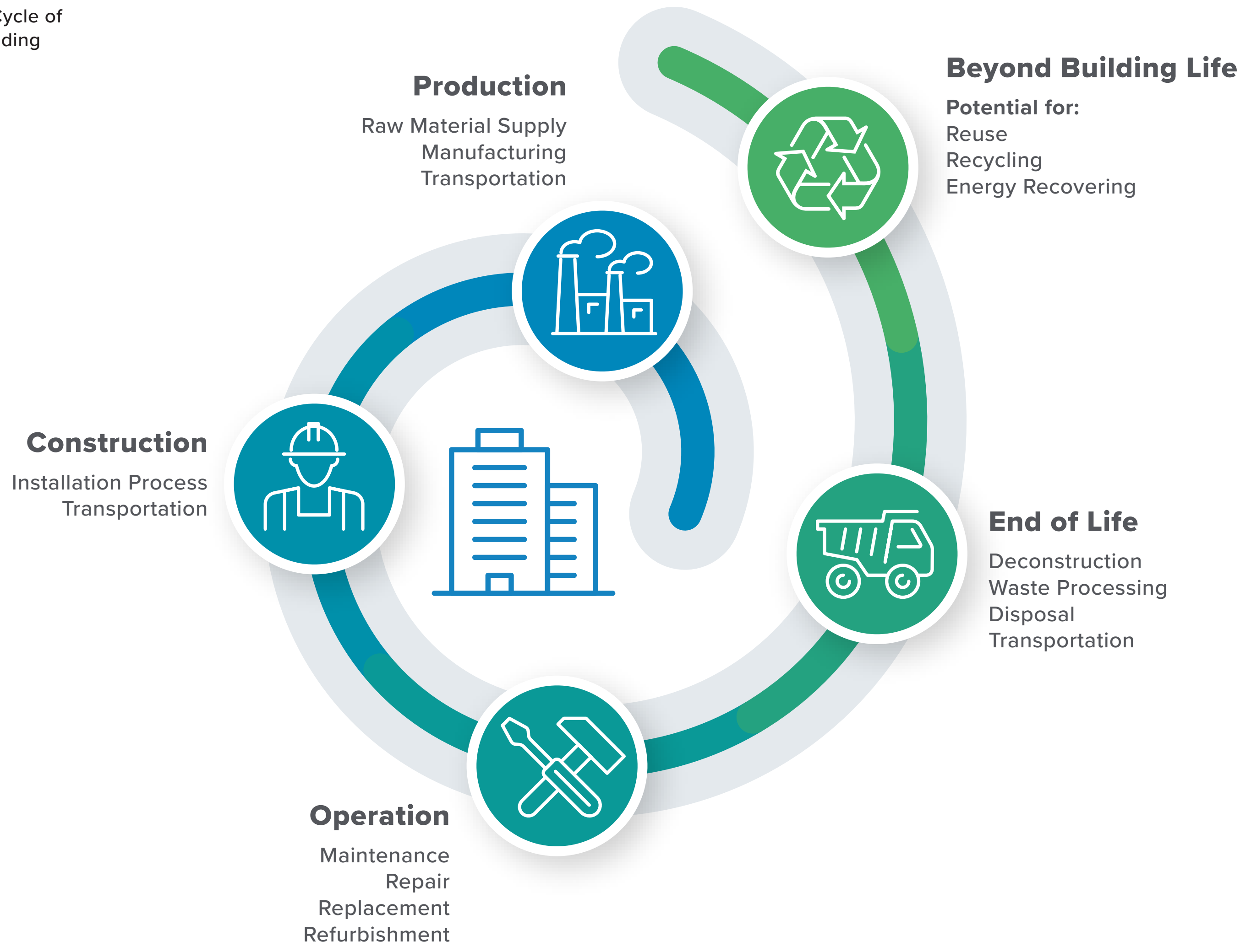


Source: EPA Greenhouse Gas Inventory 2019

Strategies for Improving Design and Operations

Improvement to the design and operation of buildings can create healthier, more comfortable spaces for inhabitants while using fewer resources and lowering costs for building occupants, owners, and operators. Life-cycle emissions assessments (LCAs) that evaluate the environmental impacts of construction and renovation proposals can be a critical tool in reducing a project's impact. Design decisions that maximize the useful life of a structure, factor emissions into choices about whether to build new or retrofit and what materials to use, optimize building shape and orientation for energy usage, and design for disassembly can reduce both emissions and waste from construction and demolition. Electric heating and cooling systems and energy-efficient appliances, along with improvements to building envelopes, can reduce electricity bills and remove health hazards from people's homes.

Figure 2.
Life Cycle of a Building



Beyond Buildings

Zero-carbon buildings offer the opportunity to expand the ways buildings contribute to community welfare and decarbonization efforts. Denser built environments facilitate better energy efficiency, low-carbon transportation options, housing development, and greater socioeconomic mobility. Grid-integrated buildings with on-site generation and storage capacity offer consumer savings, grid resilience, and improved energy security. Climate-friendly features like green roofs and increased tree cover clean the air, cool neighborhoods, increase energy efficiency, and offer greater access to greenspaces.

Incorporating sustainable materials and procedures into building design and construction can reduce hazardous waste, foster local job creation, and promote a circular economy. Utilizing low-carbon building materials can help spur demand for innovation in carbon-intensive sectors like cement and steel production, which will be key to supporting American industry and attaining decarbonization goals. Ensuring that buildings are efficiently designed, thoughtfully constructed, and well-operated is critical to creating a healthier, resilient, and more vibrant future.

Source: UBC Embodied Carbon Pilot

INTRODUCTION:

The Time to Act is Now

Designing a better built environment for the future requires taking action now. Recent federal legislation, including the 2021 Infrastructure Investment and Jobs Act and the 2022 Inflation Reduction Act, provide historic investments and incentives for building decarbonization. In addition, upcoming federal procurement standards, state and municipal policies, and private sector innovation and action all point toward a fundamental transformation of the U.S building sector—one which presents ample opportunity to improve public health, invest in communities, and address historical injustices.

Disadvantaged communities face disproportionately large energy and pollution burdens and stand to benefit more from lower energy bills and better air quality. Federal initiatives like Justice40 aim to deliver 40 percent of the overall benefits of certain federal investments to disadvantaged communities and are key to closing these gaps. Ensuring equitable access to energy efficiency and other decarbonization opportunities will require thoughtful policy design, innovative financing mechanisms to support early access, and adjustments to utility rate design to avoid late adopters bearing an undue share of transition costs. Federal policy will need to be supplemented by state and local efforts to ensure investments reach the communities most in need.

States, tribes, cities, towns, universities, businesses, and civil society actors can leverage buildings to create healthy, economically vibrant communities. Simultaneously, investing in better buildings can drive innovation in industries key to both American competitiveness and decarbonization, bolster climate and grid resiliency, and support vulnerable communities as we adapt to the effects of a warming climate. This paper undertakes a review of the existing evidence on building decarbonization strategies and their impacts on air quality, personal finances, and climate to highlight the importance of looking at buildings from a life-cycle perspective and the broader community benefits zero-carbon buildings can offer. A companion paper, "All In On Building Decarbonization in the Age of the Inflation Reduction Act," offers specific strategies for subnational actors seeking to secure these improvements for their communities.

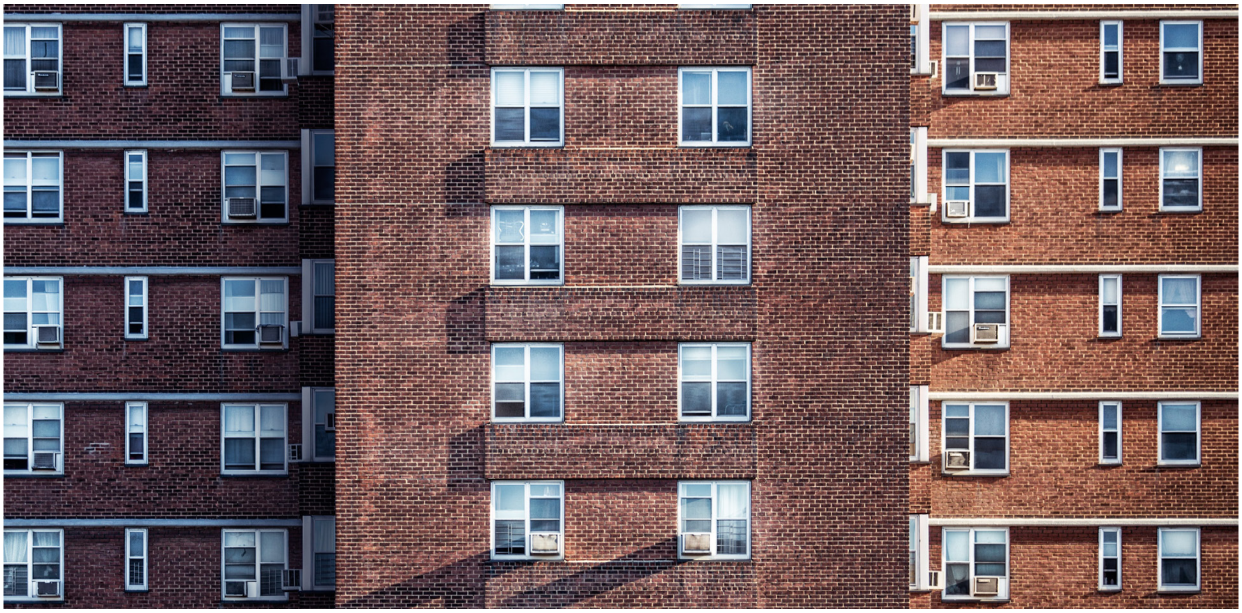
INFLATION REDUCTION ACT (IRA)

- **Rebates** to directly cover costs of home electrification projects and equipment, with more generous funding for low-and-moderate income households.
- **Tax Credits** for energy efficiency upgrades to homes as well as commercial buildings, energy-efficient new construction, residential clean energy installations, and investments in energy efficient technologies.
- **Grants and Loans** to improve indoor air quality, water and energy efficiency, and climate resilience in affordable housing, update building codes, train energy-efficiency contractors, establish environmental product declarations for construction materials, and label those with low-embodied carbon.
- **Other funding** to deploy climate-friendly technologies, reduce air pollution, and mitigate climate risks that targets low-income and disadvantaged communities and can be used to improve buildings.

INFRASTRUCTURE INVESTMENT AND JOBS ACT (IIJA)

- **Energy Efficiency Materials Pilot Program** to provide grants to supply nonprofit buildings with energy-efficiency materials.
- **Energy Efficiency Revolving Loan Fund Capitalization Grant Program** to enable states to fund energy efficiency audits, upgrades, and retrofits in residential and commercial buildings.
- **Cost-effective Codes Implementation for Efficiency and Resilience** to provide grants to update building energy codes.

Health Benefits



I

Air Quality

IMPROVING BUILDING DESIGN AND OPERATION CAN HAVE SIGNIFICANT BENEFITS from improved indoor air quality. Indoor air can contain between two to five times more pollutants than outdoor air and poor indoor air quality is implicated in thousands of cancer deaths, hundreds of thousands of cases of respiratory issues and elevated blood lead levels in children. This is in addition to more common complaints of headache, eye irritation, fatigue, dry throat, sinus congestion, dizziness, and nausea (Illinois Department of Public Health 2022). Americans, on average, spend 90 percent of their time indoors, meaning even slightly elevated levels of air pollutants can have dire consequences (U.S. Environmental Protection Agency 2014c). Improving building design and operation can have significant benefits from improved indoor air quality. Indoor air can contain between two to five times more pollutants than outdoor air and poor indoor air quality is implicated in thousands of cancer deaths, hundreds of thousands of cases of respiratory issues and elevated blood lead levels in children. This is in addition to more common complaints of headache, eye irritation, fatigue, dry throat, sinus congestion, dizziness, and nausea (Illinois Department of Public Health 2022). Americans, on average, spend 90 percent of their time indoors, meaning even slightly elevated levels of air pollutants can have dire consequences (U.S. Environmental Protection Agency 2014c).
The root causes of these health issues are combustion sources that release harmful substances–including carbon monoxide, nitrogen dioxide, formaldehyde, particulate matter, and bioaerosols–into homes, alongside poor ventilation (Illinois Department of Public Health 2022). Many of these pollutant sources, such as gas stoves and ovens, space heaters, dryers, and water heaters, coexist in homes. The compounding adverse health effects are often bundled into "sick building syndrome," a condition wherein "building occupants experience acute health and comfort effects that appear to be linked to time spent in a building, but no specific illness or cause can be identified" (U.S. Environmental Protection Agency 1991). In addition to poor indoor air quality, outdoor air pollution caused by residential buildings currently causes an estimated 15,500 premature deaths in the U.S. each year (Rewiring America 2021).

Children and historically marginalized groups are particularly vulnerable to the negative impacts of both indoor and outdoor air pollution.

HEALTH BENEFITS

Figure 3. Sources and Impacts of Indoor Air Pollution

In the home, appliances that burn fossil fuels, such as water heaters, furnaces, stoves/ovens, clothes dryers, and gas fireplaces emit several health harming pollutants. It is well documented that exposure to these pollutants over both the short and long-term can have serious health impacts.

POLLUTANT	
NOx	Nitrogen Oxides
CO	Carbon Monoxide
$PM_{2.5}$	Fine Particulate Matter
UFPs	Ultrafine Particles
HCHO	Formaldehyde

SHORT-TERM HEALTH HARMS	Pollutant
Decreased lung function	NOx
Respiratory infection	NOx
Stroke	NOx, $PM_{2.5}$
Asthma exacerbation	NOx, HCHO
Brain damage	CO
Memory loss	CO
Seizures	CO
Dementia	CO
Headaches	CO
Dizziness	CO
Nausea	CO
Death	CO, HCHO
Increase blood pressure	$PM_{2.5}$, UFPs
Respiratory/eye/skin irritation	HCHO
Sneezing, coughing	HCHO
Nasal congestion	HCHO
Drowsiness	HCHO
Chest tightness	HCHO
Shortness of breath	HCHO

LONG-TERM HEALTH HARMS	Pollutant
Shortness of breath	NOx
Cough	NOx
Wheezing	NOx
Lung and breast cancer	NOx
Respiratory illness in children	NOx
Asthma	NOx, $PM_{2.5}$, HCHO
Premature mortality	NOx, $PM_{2.5}$
Heart failure and cardiovascular disease	CO, $PM_{2.5}$, UFPs
Brain and heart toxicity	CO
Low birth weight	CO, HCHO
Bronchitis	$PM_{2.5}$, HCHO
Preterm birth	$PM_{2.5}$
Neurological disorders	UFPs
Memory loss	HCHO
Birth defects	HCHO
Spontaneous abortion	HCHO
Cancer	HCHO
Headaches	HCHO
Damage to respiratory system	HCHO
Sleep disorders	HCHO

Source: Detailed in Endnotes 15-40

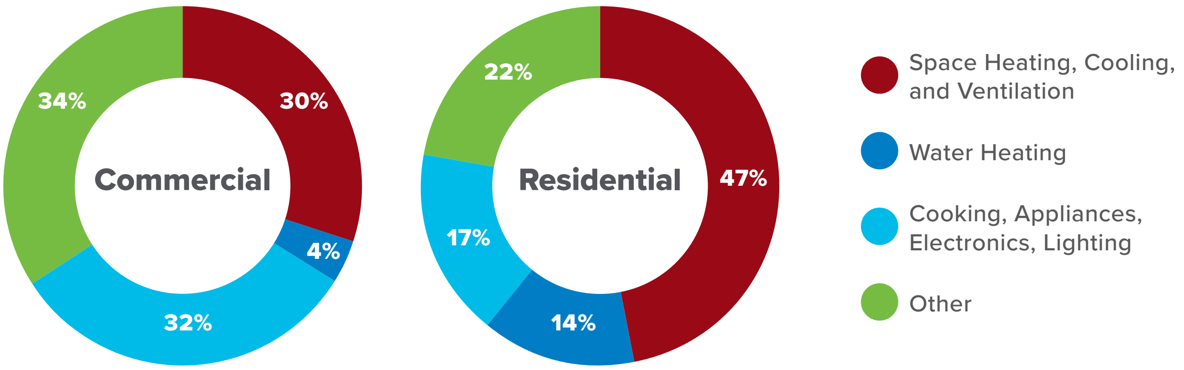
Children have higher breathing rates and levels of physical activity–increasing their exposure to polluted air–and because their lungs are still developing, exposure to air pollution has been shown to limit lung growth and function (American Lung Association 2020b). People of color at every income level in the U.S. are exposed to higher levels of air pollution than their white counterparts, and neighborhoods subjected to the racially discriminatory lending practices known as "redlining" in the 1930s continued to be associated with higher levels of air pollution in 2010 (Lane et al. 2022; Tessum et al. 2021). Low-income groups disproportionately exposed to air pollution are also less able to relocate or afford healthcare costs associated with living in unhealthy buildings.

Mott Haven, an area located in the South Bronx in New York City, has a population that is 97 percent Black and Latinx and is often referred to as "asthma alley." Residents are hospitalized at five times the national average rate for asthma, with nearby traffic and poorly maintained buildings contributing to one of the highest rates of asthma nationwide.

Building codes that reduce reliance on fossil fuels in new construction coupled with certain ventilation requirements can improve indoor air quality, decrease energy use, and reduce emissions (Mudarri 2010). For example, Washington state will require the use of heat pumps and tighter building envelopes in all new commercial and large multi-family buildings beginning in July 2023, which can prevent over 8 million tons of carbon emissions by 2050 (RMI 2022).

For existing buildings, building performance standards can set minimum thresholds for energy efficiency, safety, and alignment with climate targets. Replacing gas appliances with energy-efficient electric alternatives, as discussed in the following section, is an important improvement in existing buildings. Climate-friendly green roofs have been shown to double the lifespan of roofs while improving air quality by removing harmful pollutants directly from the air, lowering temperatures to slow the formation of secondary pollutants, and preventing additional air pollution by moderating building temperatures and reducing the need for heating and cooling (U.S. Environmental Protection Agency 2018).

Figure 4. Total CO_2 Emissions from the Commercial and Residential Sectors (2016)



"Other" in both the commercial and residential sector includes items such as data servers, medical imaging equipment, ceiling fans, and pool pumps which are categorized as "miscellaneous electric loads" by EIA

Source: *U.S. Energy Information Administration,* Annual Energy Outlook 2022 *(Washington, DC: U.S. Department of Energy, 2022),* *https://www.eia.gov/outlooks/aeo*

Clean and Efficient Appliances

Modern, climate-friendly appliances offer many important savings and health benefits for households. Gas-powered furnaces, water heaters, space heaters, and stoves can release hazardous pollutants into the air.

Gas stoves are harmful even when turned off, producing over 75 percent of their methane emissions when they are not in use (Lebel et al. 2022). Gas stoves also release nitrous oxide as a byproduct of burning methane—thereby increasing airway inflammation, worsening coughing and wheezing, reducing lung function, and increasing asthma attacks as well as the likelihood of emergency hospital admission (American Lung Association 2020a). Leaks from gas stoves in the U.S. have the equivalent effect of annual carbon emissions from half a million vehicles (Lebel et al. 2022).

Shifting from gas to induction stovetops improves indoor air quality, reducing the risk of children experiencing asthma symptoms by 42 percent (Lin, Brunekreef, and Gehring 2013). Furthermore, induction stovetops are cool to the touch even when in use and don't use electric elements, dramatically decreasing burn and fire hazards in homes. This is critical since more than half of residential fires are caused by cooking, causing an average of 550 deaths, 4,820 injuries, and $1.2 billion in direct property damage annually (Ahrens 2020).

Indoor air quality is managed by circulating air through heating, ventilation, and air conditioning (HVAC) systems, wherein the heating component is often a gas furnace, and the refrigerant in air conditioners can leak and be a source of air pollution. These systems can be replaced with more energy-efficient electric heat pumps which address both heating and cooling needs. Heat pump air purifiers are more effective than oil-, coal-, and gas-fired options. Ducted heat pumps use ducts to pump air from an outdoor and central indoor unit, while ductless heat pumps send refrigerant directly to individual air handlers throughout a home or building. While ducted heat pumps typically have better air circulation, both ducted and ductless heat pumps can purify air more effectively than HVAC systems while avoiding the additional pollutants that poorly maintained

HVAC systems can introduce to homes (Montilla 2021). In specific problem areas such as bathrooms and kitchens, installing exhaust fans can help with air circulation.

Product standards like those from the Department of Energy's Appliance and Equipment Standards Program reduce emissions, improve air quality in buildings, and reduce energy and operating costs for building owners and occupants, and states like California have enhanced those efforts by setting minimum energy and water efficiency requirements for additional appliances. According to ENERGY STAR, a federal initiative that offers information about the energy consumption of appliances, modern induction stoves not only offer health benefits but also have an efficiency of about 85 percent compared to the 32 percent efficiency of traditional gas stoves (ENERGY STAR 2022). Modern electric appliances are often affordable, more durable, and easier to care for than older, carbon-intensive ones (Entek Corporation 2017).

Building Envelopes

Indoor air quality can be affected by building materials including insulation, paneling, paint, glues used in veneers, and various types of finishes. Formaldehyde is common in building materials, especially in pressed wood products such as particleboard, hardwood plywood paneling, and medium density fiberboard, that contain high levels of urea-formaldehyde resins (The National Center for Healthy Housing 2022). Many of these materials also require spaces to be ventilated for certain amounts of time before being inhabited because of the toxic chemicals they release. In some cases, reusing and refurbishing older and existing materials through a life-cycle approach to buildings that designs for demolition and recycling, instead of using harmful newer products, can save on construction time and costs while contributing to better air quality overall.

Some materials–such as insulation–are critical to making buildings more energy-efficient and reducing overall costs for residents but can have adverse health effects on workers installing the material as well as building residents. As with building codes, improvements to building insulation should be made in tandem with improvements in ventilation to ensure that energy savings don't come at the cost of worsened indoor air quality.

Indoor air quality can be maintained with electric heat pumps but retrofitting windows in older buildings with ones that insulate better can be key to preventing harmful outdoor pollutants from entering. Windows are often the points of buildings with the most leakage, and especially as wildfires worsen the air quality across the country, they can be a critical point of protection (U.S. Department of Energy 2022c). Improved window or glazing performance can also help lower the costs of heating and cooling. Some types of dynamic glass can reduce lighting, heating, and cooling by 20 percent by allowing in visible light while reducing solar radiation as seasonal needs change (View 2022) and the Inflation Reduction Act includes an investment tax credit to help dynamic or electrochromic glass, which can be tinted on demand, achieve price parity with standard glass.

The ENERGY STAR program, run by the Environmental Protection Agency and the Department of Energy, provides consumers with information about the energy-efficiency of products and devices. The program and its partners helped Americans save 520 billion kilowatt-hours of electricity and avoid $42 billion in energy costs in 2020 alone, resulting in emissions reductions of more than 400 million metric tons of greenhouse gases. These energy savings led to reductions of 210,000 short tons of sulfur dioxide, 210,000 short tons of nitrogen oxides, and 20,000 short tons of fine particulate matter which saved an estimated $7-17 billion in public health spending (ENERGY STAR 2021).

Economic Benefits

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Savings from Energy Efficiency and Electrification

The Department of Energy estimates U.S. households could save 25 percent on home utility bills through energy efficiency measures (U.S. Department of Energy 2022a). These savings are achieved primarily through the replacement of fossil fuel appliances like stoves, dryers, water and space heaters and coolers with electric alternatives that are 3 to 5 times more energy-efficient, along with updates to building insulation and envelopes. Upfront construction costs of new all-electric single-family homes are already $7,500 to $8,200 cheaper than average homes, and for some appliances the upfront costs of the electric options are already cheaper than the cost of new fossil fuel alternatives (Denniston et al. 2022). The initial cost of replacing appliances can be significant, but the IRA provides rebates covering 100% of the costs of a suite of home energy efficiency upgrades for households earning below 80% of their area's median income, 50% of the costs or up to $14,000 for households making between 80-150% of their area's median income, and a 30% tax credit on energy efficiency upgrades available to all households ("The Electric Explainer: Key Programs in the Inflation Reduction Act and What They Mean for Americans" 2022).

Beyond upfront costs, the lifetime cost savings on modern climate-friendly appliances more than account for the cost of switching to more efficient appliances. Every $1 invested in retrofits like improved insulation, heat pumps, smart thermostats, LED lighting, and other energy-efficient appliances, saves $2 in avoided electricity generation and distribution costs ("Zero Carbon Building Accelerator" 2022). The electrification of home appliances also creates opportunities to unlock flexible demand with the help of a smart meter and time-of-use pricing.

Two-thirds of low-income households in the U.S experience a high energy burden, defined as the percentage of household income spent on energy bills. Given that Black, Hispanic, Native American, and older adult households also have disproportionally high energy burdens compared to the average household, energy efficiency measures are poised to deliver savings to those most in need (Drehobl, Ross, and Ayala 2020; Carlock et al. 2021). With 50% of household energy consumption attributable to households earning $60,000 or less, the IRA rebates targeting low- and moderate-income households, as well as the provisions for states to offer those households enhanced rebates for home energy retrofits, are critical to lowering emissions and improving health outcomes for all (Kerry 2021).

Employment

Investments in energy efficiency stimulate local job creation. Over 2.1 million Americans are employed in energy efficiency—the largest part of the energy sector—with 54 percent in construction, 22 percent in manufacturing, and 24 percent in professional services. Energy efficiency jobs have higher average entry-level wages than other occupations in these categories, a higher median wage than the national average as a field, and high rates of employer contribution to healthcare and pension plans (E4TheFuture 2021). Households installing just four key appliances—electric space and water heaters, upgraded breaker boxes, and induction stoves—could create over 450,000 installation jobs in the U.S. over a ten-year period. This would further generate 80,000 manufacturing jobs and 800,000 indirect and induced jobs (Rewiring America 2021). Energy efficiency jobs also include building design and contracting services that provide insulation, improve natural lighting, and otherwise reduce energy consumption in residential and commercial areas.

Importantly, jobs in this sector are high-quality, with a median hourly wage of $24.44, 28 percent above the national median hourly wage of $19.14, as of 2020 (BW Research, The National Association of State Energy Officials (NASEO), and The Energy Futures Initiative (EFI) 2020). Entry-level wages across occupational groups in the sector also compare favorably to national averages, with pathways to career advancement even for those without college degrees. Additionally, 80 percent of employers contribute to health insurance and 78 percent contribute to retirement, while 11 percent of workers are covered by a union or project labor agreement—almost double the national average of 6 percent (U.S. Department of Energy 2022b).

Moreover, by the nature of the work, these jobs are geographically dispersed and not subject to automation or offshoring, and the above estimates would grow by 100,000 manufacturing jobs through the implementation of domestic content requirements (Rewiring America 2021). Those job figures do not include efforts to electrify commercial buildings, which make up about 25 percent of the square footage of U.S. building stock (Potter 2020), and would drive even more job growth. Beyond work directly in energy efficiency, the majority of jobs created through household electrification are induced jobs that result from households spending their savings from lower energy bills in the broader economy. Different spending patterns result in different estimates of job growth, but investments in education, in particular, further promote economic mobility and innovation.

Currently, the workforce skews heavily male and has slightly lower proportions of Black and Hispanic workers than the nation as a whole (U.S. Department of Energy 2022b). The current demographic makeup, dispersed nature, and projected growth of the sector means hiring higher proportions of females, Black, and Hispanic workers is critical to ensuring equity and bringing associated benefits of decarbonization to communities across the U.S.

Replacing gas-powered space and water heating systems with electric heat pumps that serve as both heaters and air conditioners reduces overall energy use, avoids construction costs of gas lines, and would lower utility bills for 87 percent of U.S. households by a total of $37.3 billion a year. Over half of U.S. households use outdated electric resistance, fuel oil, or propane heating systems and the average American household would save $496 per year (Rewiring America 2021).

Ensuring Access

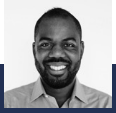
Ensuring those with the highest energy burdens and greatest exposure to hazardous air pollution have access to the cost-savings of energy efficiency measures and appliance upgrades will require proactive policy design. Higher-income groups tend to be the first to adopt new technologies, and energy efficiency measures often require upfront investments that pay off over years but remain inaccessible to those without the initial capital. In addition, building code updates can decarbonize new construction, but older buildings will need to undertake retrofits without increasing rent during a time when housing costs are rapidly increasing (National Association of Realtors 2021). Lastly, those who rent may not have access to energy efficiency measures due to building owners who do not face the same incentives to save on utility bills.

California has implemented a Low-Income Weatherization Program (LIWP) that provides low-income households with solar photovoltaic systems and energy efficiency upgrades at no cost to residents. Programs like this not only reduce emissions but also reduce household energy demand by an average of 40 percent, and bills by an average of 30 percent and as much as 75 percent, freeing up disposable income for energy-burdened families and reducing strain on the electricity grid (California Department of Community Services & Development 2022; 2020).

Other initiatives have focused on low and middle-income communities. For example, BlocPower offers residents and community organizations equipment leases or low-interest loans designed, with support from government incentives, to make installing and leasing climate-friendly home technologies affordable. It has also created a workforce development program to train prospective heat pump and solar panel installers, graduating over 800 people recruited from the communities the company serves, and helping diversify the energy efficiency workforce.

Community solar installations offer renters or those without control of their roofs the chance to "subscribe" to a project–like a nearby solar array that provides power to a local utility–and receive credits to their electricity bill in return. These kinds of projects can be led by businesses, utilities, or communities themselves, and are most accessible to the low and middle-income households that comprise 43% of the U.S. when subscriptions avoid high upfront costs and penalties or fees associated with contract termination (Hausman 2022).

BLOC POWER



Donnel Baird founded BlocPower in 2014 with the goal of providing clean, energy efficient retrofits in low-income neighborhoods. The company leverages private and public capital to install electric HVAC systems, solar panels, induction stoves, batteries, and smart energy management systems in low-income buildings, saving consumers 20-40% on energy bills and paying investors back from a portion of the additional savings. In New York City it has pioneered community ownership models for wi-fi networks and clean energy assets as well as a Civilian Climate Corps that offers residents of communities impacted by gun violence technical training programs in energy efficiency and building modernization, paid training opportunities, and connections to local employers looking to staff energy efficiency projects. To date the company has serviced over 1,200 buildings, raising property values and generating wealth for disadvantaged communities. BlocPower has recently partnered with the city of Ithaca to help it achieve its goal of carbon-neutrality by 2030, project managing over 1,600 energy-efficiency retrofits in the first phase alone. It works in 24 cities and is expanding operations in Georgia, Wisconsin, and California.

Managing An Equitable Transition

Managing the transition away from fossil fuel heating also presents challenges of timing and distributional impacts. Gas infrastructure maintenance costs are spread across the entire consumer base, and as consumers shift to electric appliances, those left using gas will bear a higher share of the cost of maintaining that infrastructure. Research shows that a 10 percent increase in residential gas customers leads to a 10 percent increase in revenues, while a 10 percent decrease in customers leads to only a 5 percent decrease in revenues, implying that remaining customers make up half the lost revenue through increased rates (Davis and Hausman 2022). Based on studies that assume roughly a 15 percent reduction in natural gas residential customers by 2030; 40 percent by 2040; and 90 percent reduction by 2050, annual bills will increase by $30, $120, and $1,600 per remaining residential customer, respectively.

From 1997 to 2019, the utilities experiencing customer losses tended to be in cities with higher poverty rates and a higher percentage of African-American residents, highlighting the potential to exacerbate existing societal inequalities (Davis and Hausman 2022). To avoid a regressive transition, adjustments to utility rate design are needed and could include strategies like shifting fixed cost recovery from gas customers to the general tax base.

Gas utilities will also need to transition their workforces to other fields of employment, though as the entire U.S. gas distribution workforce numbers just over 100,000, this figure is dwarfed by the expected employment gains from electrification. Nevertheless, planning for re-training programs and resources to smooth the transition for workers should be factored into decarbonization strategies (IBISWorld 2022).

Beyond Buildings: Strategies for Maximizing Impact

D

Densification for Decarbonization

Denser communities produce fewer per capita carbon emissions than spread-out ones, in part due to lowered personal vehicle use, better insulation due to shared walls, and shifts in land use patterns (Wu et al. 2020). Updating zoning laws to enable densification, sometimes referred to as "green zoning," is a key step in creating more efficient buildings and achieving local sustainability goals (Palmer-Dunning 2019). Updates can include a "density bonus" which allows developers to exceed standard floor-to-area ratios, meaning they can build taller and denser projects, in exchange for complying with more stringent efficiency standards (Schaffner and Waxman 2009). In addition to the climate benefits, such strategies allow developers to build projects with higher potential rates of return and boost housing supply amid the current affordable housing shortage.

Removal of mandatory parking requirements and incorporation of mixed-use zoning can create walkable neighborhoods that improve health outcomes while promoting transportation mode shifts and freeing up land for housing, public transit, and green space. This densification also benefits local economies–improving access to jobs, reducing commutes for residents, and decreasing logistical costs and geographic market constraints for businesses while offering access to a wider talent pool. As with efforts to retrofit buildings for energy efficiency, it is critical to include a focus on affordable housing development in any updates to zoning to ensure current residents are not displaced.

Integrating Grid and Climate Resiliency

Renewable energy procurement and incorporation of distributed generation technologies like solar panels and batteries into building design can contribute to lower carbon footprints, savings on building operation costs, and more resilient electricity grids. The adoption of grid-linked technologies and time-of-use electricity pricing enable buildings to optimize energy demand and save money for consumers and utilities alike, as reducing peak demand avoids utilities having to build more generation and distribution capacity to meet it. One estimate of the technical potential of the U.S. building-grid resource found that between 2030 and 2050, the energy savings enabled through efficiency and flexibility measures could erase the need for one-third of coal- and gas-fired power generation (Langevin et al. 2021).

Buildings can also contribute to climate resiliency through features like green roofs that provide insulation and cooling, along with designs that incorporate tree cover and access to green spaces for residents. Urban areas with limited greenery and high concentrations of heatabsorbent pavement and infrastructure become "islands" of heat with daytime temperatures 1 to 7°F higher and nighttime temperatures about 2 to 5°F higher than outlying areas (U.S. Environmental Protection Agency 2014b; 2014a). Disparities in tree cover track disparities in income and race, with low-income blocks evincing an average of 15 percent less tree cover and 2.7°F higher temperatures than high-income blocks. Neighborhoods with predominantly non-white residents exhibit less tree cover than white neighborhoods in 67 percent of U.S. communities even after accounting for trends in income (McDonald et al. 2021) than outlying areas (U.S. Environmental Protection Agency 2014b; 2014a). Disparities in tree cover track disparities in income and race, with low-income blocks evincing an average of 15 percent less tree cover and 2.7°F higher temperatures than high-income blocks. Neighborhoods with predominantly non-white residents exhibit less tree cover than white neighborhoods in 67 percent of U.S. communities even after accounting for trends in income (McDonald et al. 2021). Nationally, land surface temperatures in areas that were redlined are approximately 4.7°F warmer than in non-redlined areas (Hoffman, Shandas, and Pendleton 2020).

Shade from trees can keep surfaces up to 45 degrees cooler than peak temperatures of materials exposed to direct sunlight (U.S. Environmental Protection Agency 2014a). Neighborhoods located near a park may be up to six degrees cooler than neighborhoods located over a half mile away from one (Trust for Public Land 2020). Moreover, in U.S. urbanized areas heat wave mortality risk increases by 2.5 percent for each 1°F increase in air temperature. Higher land surface temperatures correlate with higher summertime energy use, indicating that low-income and non-white residents may face increased mortality risk and higher financial burdens due to increased energy use (Anderson and Bell 2011).

As the climate warms, investing in green buildings and development in historically disadvantaged communities presents an opportunity to rectify historic injustices and ensure a more equitable, climate-resilient future. During increasingly frequent and extreme weather events, buildings can also act as vital heating or cooling centers, emergency shelters, and points of distribution. Having well-designed buildings that can act as such centers equitably distributed throughout the U.S. is critical to ensuring that communities are equipped to deal with extreme weather events and emergencies.

Fostering a Circular Economy

Materials like steel, cement, and aluminum—all commonly used in buildings—account for 21 percent of global greenhouse gas emissions and 3 percent of U.S. emissions due to their carbon-intensive production processes("Global Steel Industry's GHG Emissions" 2022; Nature 2021; "Why Addressing the Aluminum Industry's Carbon Footprint Is Key to Climate Action | Greenbiz" 2020). In addition to innovations in production, new systems for reducing, diverting, and recycling waste created on construction sites are critical to reducing emissions from the building sector. Construction waste is projected to nearly double in the coming years, presenting major health and environmental risks including damage to local ecosystems, water and soil pollution, the proliferation of pests, and safety

Buildings equipped with EV charging equipment could also leverage EV batteries as an energy resource as part of a vehicle-to-grid (V2G) arrangement—charging with rooftop solar panels during the day and selling back to the grid at peak times to support resiliency. While such arrangements have not been realized at scale yet, they can offer cost savings for building owners, vehicle owners, utilities, and electricity consumers. As electric vehicles reach upfront cost parity with combustion engine vehicles, households will see an increased need to install charging equipment at home, increasing the value in distributed energy resources like solar PV installations and battery storage. Federal funding has been allocated to build out EV infrastructure and making buildings EV-ready can help prepare for the projected increased demand already underway in some regions (Fitzgerald, Nelder, and Newcomb 2016).

risks due to landslides (Slowey 2018). Fostering design approaches and industrial systems that help repurpose rather than discard building materials is part of a life-cycle approach to building decarbonization.

Designing buildings to be deconstructed in the future, and modular design that makes use of common material sizes to simplify retrofitting can help reduce waste produced on site. Deconstruction can take more time than demolition, but designs that incorporate it can also speed up construction, benefitting residents and developers alike (U.S. Environmental Protection Agency 2015). Modular systems where building components are prefabricated offsite can reduce the time to construct a project and reduce carbon emissions by up to 45 percent compared to traditional building methods (Morby 2022). Building design that prioritizes flexibility of use in spaces and makes shared use possible can help extend the life of the structure, avoiding the emissions of demolition and new construction. Using innovative materials that are biodegradable or recycled–whether salvaged wood or permeable pavements–can popularize their use and promote emerging industries.

For both existing and new buildings, recycling or “down-cycling” materials for lower-grade use can also help the recycling industry grow and develop to meet the demands of a circular economy. While such processes may require energy, transportation, or additional materials to make building materials useful again, they can also offer supply chain security, significant cost savings, and employment gains (U.S. Environmental Protection Agency 2015). While such processes may require energy, transportation, or additional materials to make building materials useful again, they can also offer supply chain security, significant cost savings, and employment gains (U.S. Environmental Protection Agency 2015).

One study of applying ambitious circular economy measures in Europe found they could generate around 700,000 new jobs (European Commission 2020). Prioritizing the use of local suppliers and reclaimed materials can create jobs, reduce embodied carbon, and minimize construction delays due to global supply chain issues and shipping delays. Stricter monitoring of the amounts of materials purchased for a project and a commitment to finding certified waste haulers to take materials to certified recycling facilities were able to reduce construction waste by over 93 percent on two New York City housing development projects, indicating there can be significant gains from reducing material use in addition to recycling (Berg 2022).

Leveraging Procurement to Support Innovation

Industrial innovation in low-carbon products is underway, with companies developing and scaling climate-friendly production processes for key construction materials like steel and cement. Low-carbon product standards and “Buy Clean” initiatives can reduce embodied emissions while accelerating this process and putting American industry at the forefront of the clean energy economy. By ensuring demand for clean products, standards can promote the uptake of existing low-carbon products, attract long-term investment in emerging technologies, and promote transparency in emissions accounting along the global supply chain (Fransen et al. 2021).

Over 100 businesses and organizations are party to the World Green Building Council’s Net Zero Buildings Commitment to decarbonize the sector halfway by 2030 and fully by 2050 (“The Net Zero Carbon Buildings Commitment” 2022). Reducing embodied carbon through low-carbon procurement is key to this effort, and the IRA helps pave the way for others by allocating billions for federal procurement of low-embodied carbon buildings products, the development of environmental product declarations, and labeling of low carbon construction materials. Both California and New York have implemented low-carbon procurement standards for specified construction materials, and cities like Pittsburgh have led the way in leveraging procurement to meet climate goals through building efficiency and renewable energy commitments (Sierra Club 2020). Universities, businesses, and civil society groups can build life-cycle emissions impacts and climate-aligned targets into their procurement policies, ensuring that buildings are constructed to minimize embodied carbon and operational emissions while supporting clean resilient grids.

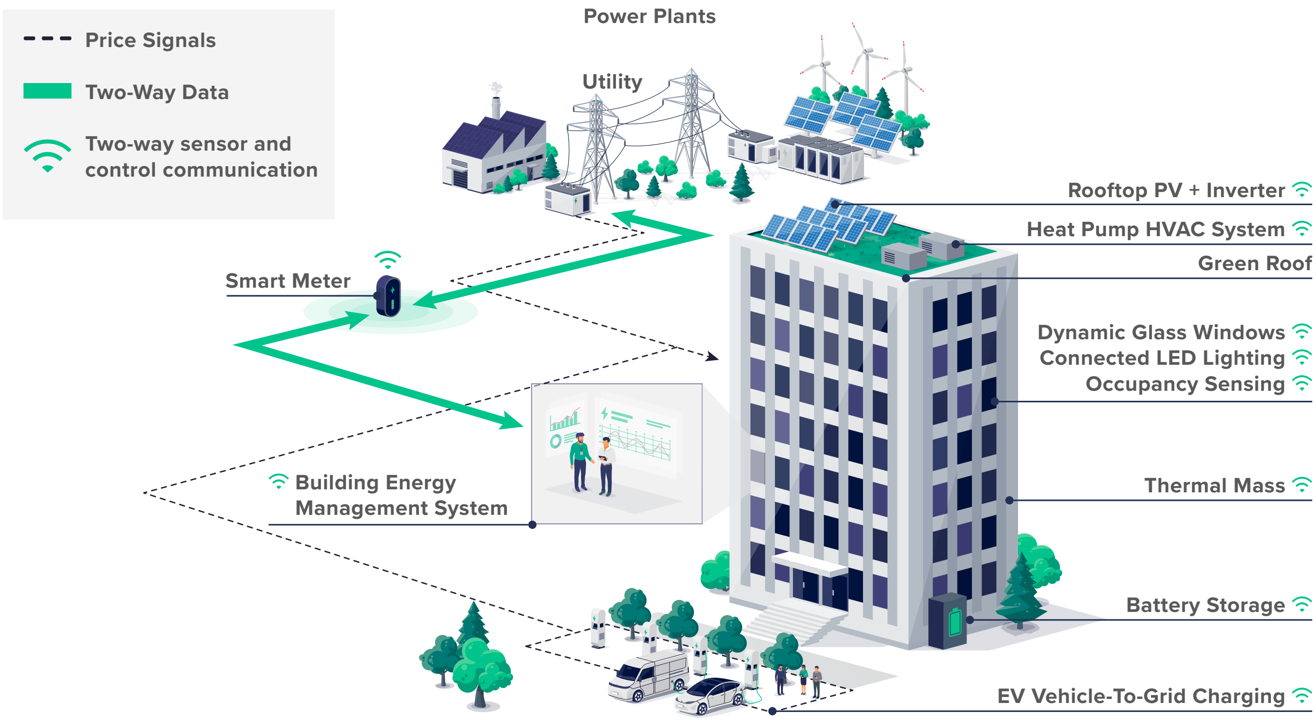
Figure 5.
Anatomy of a Low-Carbon Building

Efficient
Persistent low energy use minimizes demand on grid resources and infrastructure

Connected
Two-way communication with flexible technologies, the grid, and occupants

Smart
Analytics supported by sensors and controls co-optimize efficiency, flexibility, and occupant preferences

Flexible
Flexible loads and distributed generation/storage can be used to reduce, shift, or modulate energy use



Reducing waste from the construction and demolition of buildings can offer major environmental and health benefits. Construction and demolition waste accounts for 25 to 45 percent of the solid waste stream by weight (Zero Waste Design 2022) with 90 percent of all waste in the buildings sector resulting from demolition (Berg 2022). In 2018, the U.S. produced 600 million tons of waste as a result of construction and demolition. While about 75 percent of it was designated for "next use" like being turned into aggregate, over 140 million tons ended up in landfills (U.S. Environmental Protection Agency 2020). Since the waste produced on building sites is often contaminated with paint, adhesives, and other materials, such large amounts of waste are a public health hazard (Zero Waste Design 2022).

Conclusion

CONCLUSION

A COMMITMENT TO ZERO-CARBON BUILDINGS can improve public health, save households money, and ameliorate entrenched inequalities in our built environment. Better buildings and land use can foster walkable neighborhoods with green space for all, vibrant local economies, cleaner, more resilient grids, and cutting-edge low-carbon technologies. Unprecedented investments from the Infrastructure Investment and Jobs Act and the Inflation Reduction Act position non-federal actors to accelerate their ambitions for a climate-aligned future and pave the path to meeting national climate goals.

A shift to clean, energy-efficient appliances, and strategic retrofits to improve building envelopes and ventilation can substantially improve air quality and save on utility bills. Improved land use policies and building design can create equitable access to green space, mitigate the harms of a warming climate, and increase available housing. Life-cycle design frameworks can maximize the lifespan of buildings and reduce waste and embodied carbon while promoting local employment. Zero-carbon buildings can support resilient grids through flexible demand management and on-site generation of renewable energy, while procurement standards can help industry advance the clean energy economy. Developers, building owners, building operators, and occupants all stand to benefit from these shifts, and careful planning paired with deliberate policy design can help ensure groups currently bearing the highest burdens are the first to benefit from these improvements.

States, tribes, cities, towns, businesses, universities, and civil society actors can seize the present moment to make zero-carbon buildings the foundation of the climate-aligned communities of our future.

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