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OVERALL BACKGROUND AND CHALLENGES

Buildings are a persistent and growing threat to global climate targets, collectively representing 40 percent of the world's greenhouse gas (GHG) emissions. In the United States, buildings consume three-quarters of electricity and burn one-third of the country's gas, while building construction is responsible for over 10 percent of emissions worldwide (EIA, 2019; Global Alliance for Buildings and Construction, 2021).

Despite progress in other sectors, the built environment continues to move in the wrong direction from a GHG emissions perspective. Rapid urbanization means global floor area will double by 2060; the equivalent of one new city the size of New York City will be constructed every single month between now and 2060 (Architecture 2030, n.d.) In the U.S., the gas system continues to expand to serve our buildings, with one new customer added every minute, totaling more than 600,000 new customers annually (EIA, 2022). The current state of our buildings is also a threat to the health and well-being of billions of people globally. 1.6 billion people live in substandard housing (United Nations, 2017). Burning fossil fuels in buildings for heating or cooking can also lead to hazardous levels of air pollution, which disproportionately burdens low-income communities and Black, Indigenous, and people of color (BIPOC). Eliminating climate and air pollution from the places people live and work is critical to improving human health.

In short, business as usual is not an option when it comes to tackling the climate and health impacts of the built environment. Moving forward, we need to ensure all buildings are zero-carbon. This includes both new construction and retrofitting existing buildings to a zero-carbon standard[1]: all-electric, efficient, built with low-embodied (or zero-embodied, when industry availability allows) carbon materials, including low-Global Warming Potential (GWP) refrigerants for electric heat pumps, and built either with on-site renewables or powered by a GHG-free electricity grid.

U.S. BACKGROUND AND CHALLENGES

Buildings consume three-quarters of U.S. electricity and burn one-third of the country's gas. Direct fossil fuel use in residential and commercial buildings accounts for over 10 percent of U.S. GHGs (EPA, 2022). Most of these emissions are the result of burning gas for space and water

[1] Note that ensuring completely zero-embodied carbon materials and low-GWP refrigerants depends upon the industrial sector meeting their decarbonization commitments. The goal here is that building developers can "push" for this to occur but should not bear the primary responsibility for industrial decarbonization.

heating, cooking, and drying clothes. Propane and heating oil appliances also cause GHG pollution, particularly in certain regions of the country. Another emissions source from gas usage in buildings comes from methane leaked throughout the gas distribution system (Lebel et al., 2022; Weller et al., 2020). Buildings also significantly contribute to industry emissions from the production of concrete and steel that goes into building construction.

Fossil fuel combustion in buildings also creates other types of pollution that directly harm human health, such as nitrogen oxides (NO_X) — a precursor to ozone smog — and particulate matter ($PM_{2.5}$). Building appliances emit more than twice as much NO_X pollution as gas power plants nationwide, with particularly high levels of pollution in communities of color (Dennison et al., 2021; Tessum et al., 2021).

While emissions-free technology for space and water heating is available in the market, policy has thus far failed to create a clear mandate for change, while consumers, builders, and manufacturers continue as usual.

Carbon reduction potential

Direct emissions-free heat pump technology for space and water heating has improved drastically in terms of cost and performance. As heat pumps are significantly more efficient than traditional gas furnaces (two to four times), electrifying appliances will save GHG emissions in 48 of the 50 states today, accounting for 99 percent of the U.S. population (McKenna et al., 2020). Meanwhile, the electricity grid is on track to reduce emissions by 80 percent by 2030, resulting in increased GHG savings from building electrification in the future. In short: any heat pump installed today becomes cleaner every year into the future because power emissions are declining.

Nevertheless, the following challenges need to be addressed to realize the complete potential of building electrification and decarbonization:

- **Policies and, by extension, the market and intermediaries, defaulting to gas:** This includes building codes for new construction, rates, and incentives that block fuel-switching. By extension, builders, contractors, and building owners largely default to gas in new construction and retrofits. Policymakers need to provide a clear signal on building electrification and decarbonization to align the market (utilities, manufacturers, contractors, and builders, among others).
- **Lack of public awareness about disadvantages of gas and benefits of electrification:** Contractors, residents, and policymakers largely assume gas appliances are affordable, reliable, safe, and high-performing. While a number of organizations are swiftly flipping this narrative and exposing the damage caused by gas and benefits of electrification, it is indeed an uphill battle to win hearts and minds.
- **Concerns about reliability of electrification**: With some high-profile grid problems in recent years (Texas and California as recent examples), there is a public perception challenge to overcome around the reliability of electrification compared to gas. On the flip side, a more weatherized, energy efficient, well-insulated home can create significant resiliency benefits.
- **Lack of awareness and supportive policy on low-embodied carbon building materials:** Builders, building owners, and policymakers are not in agreement that embodied carbon is an issue that needs to be addressed, resulting in a lack of demand for low-embodied carbon products.
- **Economics**: Building electrification costs less than gas in several cases, such as new construction and a single heat pump replacing a furnace and an air conditioner. However, building electrification often entails several upfront costs (panel upgrades, wiring, etc.). Just as we subsidized infrastructure upgrades for electric vehicles and rooftop solar, we must work to lower the cost of heat pumps and building electrification.

- Need to upgrade and weatherize diverse building stock: The U.S. buildings stock is diverse and 45 million – 45 percent – of metropolitan homes in the U.S. have one or more health and safety hazards (National Center for Healthy Housing, 2020). Fortunately, states can avail significant federal funding (IIJA and IRA) for home upgrades. However, building upgrades increase the time invested and complexity compared to simple appliance swap outs. However, the longer term returns in health, safety, and energy affordability are well worth the investment. An energy efficient home that is well-insulated and air-tight will need a smaller heat pump, for example, than one that is less efficient. Overall, weatherization investments provide $2.78 in non-energy benefits for every $1.00 invested (Energy Efficiency & Renewable Energy, 2020; n.d. Global Alliance for Buildings and Construction, 2021).
- **Politics:** To date it has been difficult to implement federal mandates related to climate change. Progress at the local and state levels is fragmented and tough to scale. However, the recent infusion of funds for building decarbonization ($50 billion) in the Inflation Reduction Act is extremely promising and may spur further action. The next step is to ensure this money is spent effectively and equitably.

CHINA BACKGROUND AND CHALLENGES

China is and will continue to be the country with the largest buildings stock in the world. China's new building floor area is about 4 billion m2 per year, accounting for nearly half of the world's new building area. Carbon emissions in the entire lifecycle of buildings account for 51 percent of the country's total carbon emissions — 22 percent from the operational phase and 29 percent from materials and construction such as concrete and steel (China Association for Energy Efficiency, 2020; Global Alliance for Building Construction, 2021). Heating accounts for 20 percent of buildings' operational emissions and is the largest emitter in the sector due to on-site fossil fuel use and indirect emissions from fossil-fueled power plants.

China covers a vast geographic area and is officially divided into five major climate zones with different thermal design requirements. Northern China, which consists of the two coldest climate zones, needs space heating in winter. The urban areas mostly rely on district heating systems, whereas rural areas mostly use individual household heating systems such as heat pumps and gas boilers. While heat is considered a public service in Northern China, Southern China has historically gone without heat even though temperatures can fall below 5°Celsius (C) (41°Fahrenheit) in the winter in some regions. As incomes rise, residents in Southern China are demanding improved indoor comfort and are purchasing heating appliances. Absent intervention, we anticipate residents in this region will choose gas furnaces, not heat pumps. For example, the Yangtze River Delta (YRD) region in Southern China has 220 million residents – two-thirds of the entire U.S. population. According to RMI's analysis, carbon emissions from rising heating demand in the YRD region could triple in the next 10 years if YRD follows the gas appliance pathway, putting regional and national climate goals at risk (Wang, 2021).

The current Chinese government commitment is that carbon emissions in China's buildings sector will peak before 2030 and the country will achieve carbon neutrality before 2060. As part of the Chinese government's plan to implement its dual-peaking plan, the government will establish a policy system and institutional mechanism for green and low-carbon development of urban and rural construction. In addition, the government will set improved targets for the level of building energy conservation, and the utilization efficiency of energy resources will meet higher, international standards. Energy efficiency improvements, building electrification and decarbonization, and building distributed energy development could reduce carbon emissions in operations by 72 percent, while carbon capture and sequence technology could reduce embodied carbon emissions by 28 percent.

Challenges:

- **Underutilized and substandard buildings:** The average lifespan of buildings in China is 30 years, which is much shorter than that of buildings in European countries and the U.S. The vacancy rate of residential and commercial buildings is 12 percent, increasing the embodied carbon emissions of building material. At the same time, demand for thermal comfort in buildings is increasing with improvement in people's standard of living, especially in rural areas and Southern China. This may increase fossil fuel consumption when improving building quality and indoor thermal comfort without intervention.

- **Inadequate efficiency in construction and operational phases:** Although energy efficiency in the operations of new buildings is often incorporated into the planning and design phase, there are no low-carbon procurement or specification requirements for embodied carbon. This leads to carbon-intensive building materials being widely used in construction, even though low-embodied carbon products exist and can be further developed. For example, changing the specifications for concrete mix can significantly lower the carbon emissions, or, using biomaterials instead of steel can have a significantly improved impact on emissions, but these choices must be made at the design phase of a building. The energy efficiency of old and rural buildings is also significantly lower compared to new buildings, due to low energy efficiency requirements (or lack of requirements) in the past. Although new technologies such as digital controls and prefabrication improve building efficiency, they are not widely adopted.
- **On-site fossil fuel consumption:** On-site combustion of fossil fuels in buildings is very common for space and water heating and cooking. This portion of energy consumption could be replaced by electrification, such as heat pumps and electric cooktops. In Northern China, on-site coal for heating has been eliminated and replaced by electric-driven heat pumps and gas boilers since the "Clean Heating" subsidy program started in 2017. In Southern China, gas boilers are taking a dominant share of the market for growing heating demand. People's awareness and the economics of electrification are significant challenges, which need policies to improve. However, currently there's no guiding standards on all-electric appliances as opposed to gas. In addition, the distributed renewable energy penetration in buildings is low.
- **District heating in Northern China:** Heating is provided as a public service by district heating systems in China's northern urban areas. In terms of heating sources, coal fired CHP (combined heat and power) and coal boilers account for nearly 80% of building district heating systems in Northern China. Although the energy efficiency of coal fired CHP has improved during the past years, coal emissions for heating remain a big problem for achieving the carbon neutrality goal.

RECOMMENDATIONS FOR THE UNITED STATES

As discussed above, various challenges are holding back the complete decarbonization of the U.S. buildings stock. By implementing targeted policy and market transformation initiatives, the U.S. can catalyze a shift to healthy, affordable, and zero-carbon buildings for all. The following initiatives can help kick-start the building decarbonization revolution:

- **All-electric or electric-preferred new construction codes**

Electrification-focused building codes are a vital tool for decarbonizing buildings. New construction is the most cost-effective intervention point, as buildings can be optimally designed from scratch. In most regions studied, it is cheaper to build new all-electric homes rather than those with gas (McKenna et al., 2020).

While pro-electrification building codes have gained momentum in cities and states since Berkeley, CA passed the first all-electric code in 2019, it is essential to engage and convince more key stakeholders in new regions. Many building associations and trade unions are wary of building electrification requirements, especially where the technology is unfamiliar or uncommon in certain building types. Incentives, training, technical assistance, and other programs may help smoothen the transition and build the market for electrification.

- **Policies and programs to encourage low-Global Warming Potential (low-GWP) refrigerants**

Due to the high global warming potential (GWP) of many refrigerants, policies must push requirements for low-GWP refrigerants in buildings. The use of high GWP refrigerants is currently a U.S.-specific problem. Elsewhere in the world, low GWP refrigerants are regularly utilized in mechanical equipment. The European, Asian, and Australian markets provide many options that use R32, R290 (propane) and R744 (CO_2) and provide similar (and sometimes better) performance; however, the North American market is devoid of these options, except for small firms importing Asian/European units in the U.S.

The American Innovation and Manufacturing Act of 2020 authorized the U.S. Environmental Protection Agency to implement the phase out of hydrofluorocarbons (HFCs), following the Kigali Amendment. In September 2022, the U.S. Senate formally ratified the Kigali Amendment, and now the government needs to ensure that its implementation is effective.

U.S. codes and standards should be updated immediately to allow for low GWP refrigerants and their rapid deployment in all-electric construction.

Incentive programs such as the Inflation Reduction Act, all-electric new construction codes, and other policies should provide the highest level of incentives for low-GWP refrigerant heat pumps and provide funding for research into the lowest GWP refrigerants.

- **“Buy Clean” and low-embodied carbon codes**

Federal, state, and local policymakers can have a significant influence in driving preferential procurement of low-embodied carbon building materials. First, governments should drive demand through procurement policies, such as the “Buy Clean” policies that were passed in California and Colorado (Rempher & Olgyay, 2021). “Buy Clean” is a green public procurement policy that requires disclosure of GHG emissions as well as maximum emissions intensity targets for large volume building materials, such as steel and concrete. Given the scale of public government procurement and its large portfolio of properties, these policies send a clear demand signal to manufacturers.

New construction codes provide a second policy opportunity to accelerate low-embodied carbon material specification in the private sector. In May 2022, for example, the Denver building code committee adopted low-embodied carbon code language for the Denver Green Code, which requires developers of buildings 25,000 sq ft and above to select from a menu of sustainable building and procurement strategies

Beyond “Buy Clean” policies and code, which will push manufacturers to invest in decarbonization over time as GHG emissions intensity targets become more stringent, governments can provide financial incentives to create a differentiated market for innovative low-carbon building materials. The Inflation Reduction Act (IRA) provides over $2 billion for low-embodied carbon building materials for the federal government, which can be used to incentivize further procurement of deeply decarbonized building materials.

- **Incentives to lower upfront costs for consumers (especially for low- and moderate-income (LMI) communities and motivate the supply chain**

Targeted financial incentives play a key role to lower upfront building electrification costs for consumers and encourage industry actors to shift the market toward electrification. Upfront, point-of-sale rebates ensure low-income households can afford clean and efficient appliances without having to wait for tax credits. Consumer incentives should also include building envelope improvements and electric panel upgrades to effectively operate new heat pumps and improve energy savings and comfort. In alignment with the Department of Energy’s Justice40 recommendations, at least 40 percent of the consumer-facing incentives should be reserved for frontline communities most affected by poverty and pollution (Young et al., 2021).

Incentives for market actors can help lower costs and encourage the adoption of electric appliances. Mid-stream incentives for contractors and the building trades to install heat pumps and other technologies may be especially important, as these installers typically guide homeowners on purchases. Upstream incentives for manufacturers and distributors may also be appropriate to boost technology innovation and market development. Funding for these incentives can come from various sources—the Inflation Reduction Act just unlocked over $50 billion of incentives for building sector investments, for example. Additional funding can come from ratepayers (via utilities), state budgets and healthcare dollars from Medicaid or private insurers that could benefit from the positive health impacts of building decarbonization (Norton, 2022).

- **Utility rate reform to lower operating costs**

In addition to reducing upfront costs, it is vital to reform utility rates to ensure building electrification lowers household energy bills, especially for low-income households with high energy burdens. As discussed above, heat pumps are significantly more efficient than gas appliances. However, due to problematic utility rate design, consumers in some regions may run the risk of high energy bills with electrification. In some regions, electricity rates are artificially high and not designed to support electrification, while gas rates are artificially low.

Utility commissions should update rates to reflect the health, climate, and resiliency benefits of building electrification. These rates should be designed as time-of-use rates that encourage the use of electric appliances when clean energy is most available on the grid. Many utilities have begun to make positive changes in rate design for electric vehicle rates to encourage transportation electrification, and we recommend additional rate programs be designed for encouraging building electrification.

- **Health-protective performance standards for appliances**

70 million buildings in the U.S. currently burn fossil fuels in their direct operations. While the extensive renovation or reconstruction of a complete building takes place roughly every 20–30-plus years, appliances such as water heaters and furnaces are replaced much more often — every 10 –15 years on average. Thus, appliance replacement upon burnout is a key intervention point to electrify the existing buildings.

Air regulators in California, Texas, and Utah are limiting health-harming pollutants such as Nitrogen Dioxide (NO_X) pollution from gas appliances by mandating the sale of clean versions of these devices. Drawing inspiration from the California Zero-Emission Vehicle standards, which started a movement toward electric vehicles in California and other states, air regulators can also institute zero-emissions appliance pollution standards for building appliances. Thus far, air regulators in two regional California air districts and statewide at the California Air Resources Board have proposed zero-emissions standards for building appliances. When finalized, these standards will end the sale of gas appliances throughout California by 2030.

In addition to state and federal air agencies developing emissions-based standards on appliances, the Department of Energy (DOE) can also issue more stringent efficiency standards for appliances. For example, the DOE recently proposed increasing the annual fuel utilization efficiency (AFUE) for home furnaces, which will incentivize a transition toward cleaner appliances (DOE, 2022). Under appliance efficiency laws, states are preempted from issuing their own efficiency standards when DOE has set a federal efficiency standard, and DOE is limited in its ability to require fuel switching (Klass, 2010; Sallee, 2022). So, while DOE efficiency standards can be a helpful complement to appliance emissions standards, efficiency standards alone will not be sufficient to fully address GHG pollution from buildings.

- **Gas planning and alignment**

In addition to utility rate reform, state Public Utilities Commissions play an important role in winding down subsidies for gas and gradually scaling back the costly and leaky gas distribution system. Ending subsidies for expanding the gas system can help reduce overall energy costs and level the playing field between gas and electric services. Currently, many states allow gas companies to use ratepayer money to pay builders to put new gas lines in homes — so-called line-extension allowances (Alter et al., 2021). These costly and inefficient subsidies to extend the gas system must be eliminated.

Other public utilities commission policies that help reduce reliance on gas in buildings include (Billimoria & Henchen, 2020) requiring gas utilities to conduct a "non-pipe alternative analysis" rather than automatically gaining approval to invest in gas line repairs, replacements, or extensions; exploring what "pruning the gas system" is; and determining a strategic way to begin decommissioning large sections of the gas distribution system.

RECOMMENDATIONS FOR CHINA

- **Reasonable construction volume with up-to-standard building performance**

Government policies should encourage developers to avoid frequent demolition and construction, shifting the focus from new construction to maintenance and function improvement. Policies should also offer incentives to reduce the vacancy rate and increase the building utilization rate by revitalizing the building stock. For buildings lacking energy services, standards should promote electrification approaches and gradually limit fossil fuel use to meet the demand for thermal comfort.

- **Improve efficiency of building operations**

The government should improve the building efficiency standard system to promote zero-carbon building retrofits and low-carbon urban renewal. Carbon neutrality should be included in the legal procedure of urban planning and building design. To accelerate new technology deployment, incentive policies must enhance technology adoption such as digital controls and prefabrication.

- **Adopt low- or zero-carbon heat sources for district heating systems and develop new technologies**

To phase out coal fired CHP and coal boilers, policies should encourage the utilization of low-carbon heat sources such as geothermal, industrial waste heat, and ground/water source heat pumps to replace coal. As district heating systems are a traditional heating method, governments should increase research funding support for new technologies to replace district heating systems.

- **Policies should incentivize and promote construction with low-embodied carbon materials**

Policymakers should implement incentive programs to discourage the use of carbon-intensive building material and promote low-carbon and natural building material such as low-carbon concrete and cement, bio-based materials, and green steel. "Buy Clean" procurement policies in the United States set a useful precedent for this. Emerging policies such as low-embodied carbon building codes, incentive funding for procurement of deeply decarbonized materials, and whole-building life-cycle assessment (WBLCA) performance benchmarks will accelerate building material decarbonization.

- **Regulations should incentivize and eventually require the elimination of on-site fossil fuel combustion from coal and gas and encourage on-site renewables**

Regulations should define a timeline to phase out on-site coal use in buildings. At the same time, policies should offer incentives to promote electrification approaches to replace fossil fuels. For example, in regions such as the Yangtze River Delta, where residents are beginning to adopt appliances, the local government should launch educational campaigns to demonstrate the health and efficiency benefits of heat pumps. In addition, the government should offer incentive programs to encourage residents to adopt heat pumps instead of gas furnaces. Finally, standards should add requirements to increase distributed renewable energy application on buildings.

OPPORTUNITIES FOR U.S.-CHINA COLLABORATION

There are a number of areas where there can be further U.S.-China Collaboration, including:

- **Track II conversation:** Establish a Track II conversation channel to create shared learning opportunities between the U.S. and China, both for federal/national level best practice sharing and leadership states/province communication, with a wide range of topics from policy, market mechanism, to technology, etc. One example is to create communication opportunities to compare best practices of all-electric new construction building codes of California, New York, and Washington to China's national program to pilot all-electric new construction public buildings.

- **Global Prize:** The U.S. and China should jointly run a bi-annual prize to encourage market leaders to design and invest in net-zero landmark buildings, with a goal of 300 landmark net-zero buildings by 2030.
- **Finance for All:** Establish a green finance mechanism to promote building decarbonization, such as the U.S.-China fund for zero-carbon-ready affordable housing and U.S.-China green fund for zero-carbon-ready rural housing.
- **Joint Research:** Establish official mechanism to conduct joint research supported by public funding from both countries to encourage corporate and academic leaders to collaborate on the most urgent topics to advance zero-carbon buildings at scale, such as finding district-level solutions to promote zero-carbon buildings and prefabricated zero-carbon retrofit for urban renewal.
- **Policy Benchmarking:** Conduct U.S.-China policy benchmarking on zero-carbon planning and design, green procurement, and heat pump promotion.
- **Technology development:** Share the progress of technical development in terms of building alternative material technologies, efficiency key technologies, and integrated renewable technologies.

CLOSING

It is impossible to achieve our global climate goals without decarbonizing the built environment. The buildings sector has not been making progress at the same pace as the electricity and transportation sectors, and change is urgently needed to ensure that all new buildings are built right from the start, all-electric, highly efficient, and low-embodied carbon materials zero-carbon buildings, so that we avoid unnecessary and costly build out of gas infrastructure and lock-in of emissions for buildings that often last 30 to –60-plus years.

The world needs a zero-emissions global buildings sector that lowers housing cost burdens and improves housing quality, creating a safe and healthy built environment for all. In order to be climate-aligned, we must ensure that:

- All new construction is climate-aligned (all-electric, efficient, grid-interactive), with embodied carbon reduced by 65 percent.
- Five percent of existing buildings are retrofitted to be climate-aligned annually (four times the current rate), with 25 million buildings deeply retrofitted by 2030.
- Gas appliances are no longer sold.
- Climate-aligned retrofits are at cost parity with fossil fuel retrofits.

In the U.S., we must create policies that prioritize low- and moderate-income households and protect them from serious cost increases, including significant new federal and state funding that has accelerated retrofit programs for low-income homes.

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