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Electrifying the Building Sector: Recent research perspectives on available technologies, policies, and mitigation strategies

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Eliminating building sector greenhouse gas (GHG) emissions is widely acknowledged as critical to limiting global warming. Residential and commercial buildings consumed 40 percent of energy in the United States during 2018, according to the U.S. Energy Information Administration. To limit warming to 2°C by 2100, 32 gigatons (Gt) of carbon dioxide CO_2 emissions must be eliminated from the building sector in the next 40 years. Meeting the even more ambitious 1.5°C target would require an additional 28Gt CO_2 reduction. For this goal, emissions rates would need to start dropping in 2020 (Wang et al. 2018).

This quarterly research review introduces emerging peer-reviewed research on available technologies, policies, and mitigation strategies centered on electrification of the building sector. Rapid emissions reductions can be achieved in this sector through electrifying building processes (such as air heating/cooling, water heating, cooking, lighting, and ventilation), while concurrently transitioning to a power sector supplied by renewable energy sources (Leibowicz et al. 2018). High-income countries have an opportunity to lead this transition in the near term, with middle- and low-income regions following as constraints on emissions become stricter (Wang et al. 2018). It should be emphasized that electrification is only one approach to reducing emissions from buildings: building design and energy efficiency are absolutely paramount to decarbonizing this sector, but are not the primary focus of this piece.

Available Technology

The transition to an electrified building sector is already underway. Technologies are currently available that could feasibly decarbonize virtually all of the energy demands from buildings, though some practical and economic barriers exist.

Space heating is currently the largest source of non-electric demand in the U.S. building sector, accounting for approximately 70 percent of non-electric energy consumption in the residential sector, and 60 percent in the commercial sector (Deason et al. 2018). Water heating and cooking account for much of the remainder of emissions. Space heating needs can be electrified using air source heat pumps, which are technologically mature, easy to install in new construction or retrofit in existing systems, and

can both cool and heat buildings. They are more efficient than conventional systems and so are less expensive to operate. But, they are typically more expensive upfront than standard equipment (Deason et al. 2018). Analyses of future decarbonization scenarios show that electric heat pumps will be the predominant heating technology in future, as opposed to other direct electrification technologies (electric space heaters or electric resistance heaters), or indirect electrification technologies (e.g., synthetic gases in gas heaters or gas pumps) (Ruhnau et al. 2019, Jadun et al. 2017).

Deason et al. (2018) offers a comprehensive review of when and where heat pumps can be economical and practical for residential buildings, especially in areas with milder winter climates. Heat pumps already account for 20 percent of heating systems in the U.S. South, including more than half of new residential building heating systems over the last 15 years. In a California case study (the Sacramento Municipal Utility District, SMUD), heat pump space heating was economically advantageous in new residential single- and multi-family units as well as in existing multi-family units, and was only slightly more expensive in existing single-family houses. It was more expensive for small- and medium-sized office buildings. Various other studies on the cost effectiveness of retrofitting existing residential buildings with heat pumps have found they are most competitive when replacing both a heating system *and* an air conditioner, replacing technologies that rely on more expensive fuels (such as oil-fired systems common in the U.S. Northeast), or where electricity prices are low.

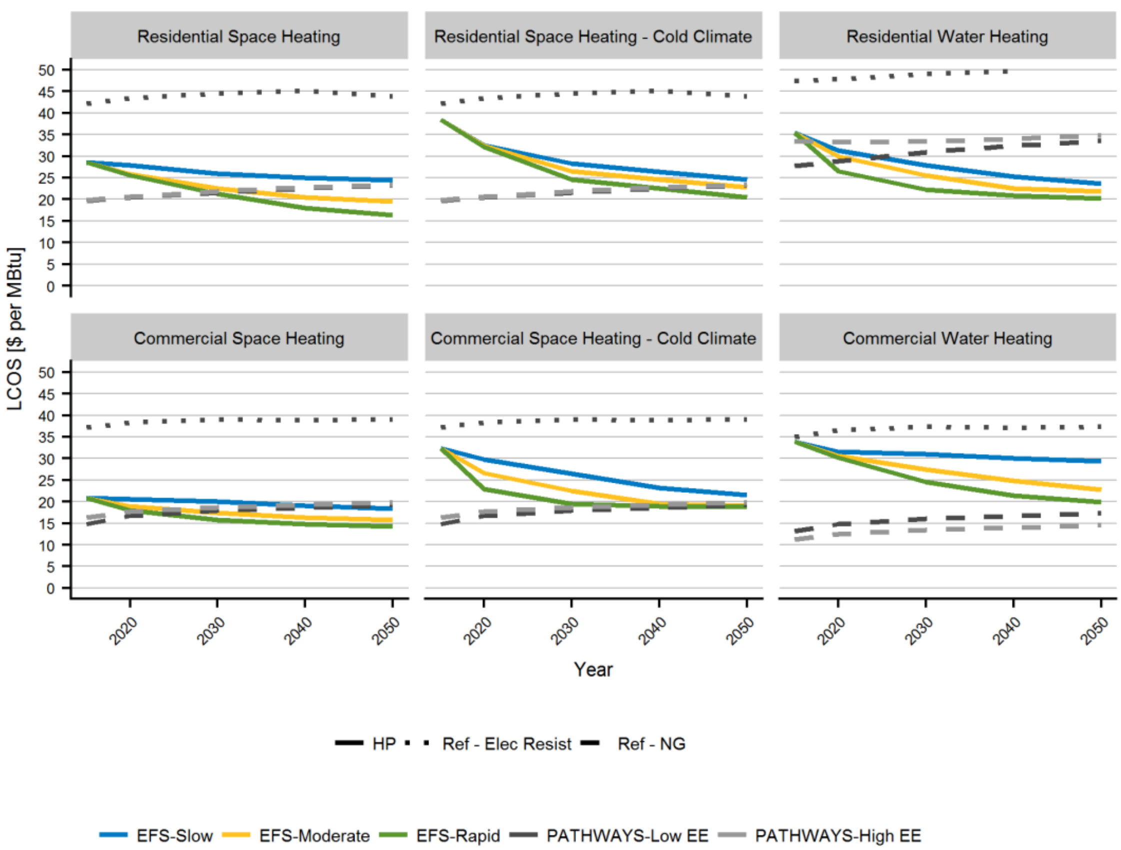

Figure 1. Cost competitiveness of heat pumps compared to natural gas-fired water heaters. Heat pumps are projected to outcompete water heaters in cost savings in residential uses, and even some commercial uses over the coming decades. Cost parity is met faster depending on slow, moderate, and rapid improvements to heat pump technology. Source: Jadun et al. 2017

Models by Jadun et al. (2017) show promise for heat pump water and space heating to become increasingly cost-competitive over natural gas heating systems over the next couple decades, in both residential and even some commercial buildings (Figure 1). New construction can be designed to be all-electric and is actually cheaper for homeowners due to savings in installation and maintenance costs. All-electric houses are technically slightly more expensive to builders ($127), but incentives can be offered to offset this (Deason et al. 2018).

Electrifying heating and cooling in buildings increases loads on the electric grid. A warming climate will simultaneously alter energy consumption trends. A recent study by Tarroja et al. (2018) provides a quantitative assessment of heating electrification and climate change impacts on grid capacity, demand, and emissions, using California in 2050 as a test case. This study finds that the higher peak demands placed on the electric grid due to *a changing climate* would temporally coincide with and be able to be met by available renewable energy. The peak demands required by *heating electrification*, on the other hand, may not coincide temporally with renewable energy availability and would therefore necessitate larger grid capacity and better thermal storage options (including building designs that capitalize on thermal mass). This is where effective and coordinated policy can be valuable.

Policy Options

Policy options recommended in recent scientific literature are aimed at multiple and concurrent objectives: 1) incentivize electric end uses in new and existing buildings, 2) ameliorate enhanced demand on the electric grid, 3) bolster technology and building efficiency, and 4) decarbonize the power sector.

Deason et al. (2018) highlights the need for policies, regulations, and incentives that shift builders and homeowners towards electric end use options, and support load balancing. Education and outreach will be important in the early stages of a transition, especially to builders and contractors who may not be aware of electric alternatives and tend to default to fuel-powered systems. Some electric-only utilities already offer incentives such as rebates for heat pump upgrades to homeowners, as well as to builders, manufacturers, and retailers to incentivize heat pump installation in new buildings.

The penetration of electrified systems can also be supported by policy that encourages flexible loads, demand response programs, or the use of electricity during off-peak times. Electricity rate design (namely time-varying pricing) will be important in the immediate future since heat pump systems currently tend to peak in demand in the mornings when electricity is often lower in cost (Deason et al. 2018). As building sector electrification scales up, market design and demand response programs coupling flexible demand technologies (including smart sensors) with wholesale electricity markets will help to smooth peak loads and more broadly bolster the economics of electrification. Additional measures to offset peak loads such as thermal storage should also be implemented (Ruhnau et al. 2019).

Policies and building codes that improve building efficiency should be carried out in conjunction with electrification. More efficiently designed buildings can reduce costs associated with peak demands, heat pump (and other appliance) capacity, and energy storage. In a model case study in Austin, Texas, researchers found that simultaneously implementing electrified heating/cooling technologies and building thermal efficiency standards resulted in cost savings of 37 percent over a scenario in which only electrification was prioritized. This study underscores the value of multi-facet climate policy, as well as the role that local governments (which control building codes) can play in enacting meaningful climate policy (Leibowicz et al. 2018).

Policy aimed at reducing emissions must consider the energy system as a whole, because when designed poorly they can end up being applied only to electricity generation, omitting direct fuel use. This penalizes utilities that see increases in electricity demand, thus setting up a barrier to electrification (Deason et al. 2018). Long term mitigation objectives must also be considered when designing policy, since some policies aimed at reducing emissions in the short term may end up delaying long term success. For example, policies aimed at increasing the fuel efficiency of conventional heating systems in buildings may reduce immediate emissions but will extend path dependency on fossil fuel-based technology instead of shifting to electrified end-use technologies (Leibowicz et al. 2018).

Coordinating all these policy approaches can prove be complex, so state officials, utilities, and grid operators must all be involved in the process of aligning incentives, rate and market design, and infrastructure planning. Predicting how increasingly complex energy systems will respond to policy mechanisms will likely require more integrated energy system models able to capture residential building stock, diverse household behavior, specific demands on networks, supply options, distribution pathways, storage, energy conversion technologies, economics, and socio-technological dynamics. Decision makers will need to engage in careful and complex policy analysis; otherwise they run the risk of outages, higher costs, and/or more carbon intensive energy systems (McCallum et al. 2019).

Global Mitigation Strategies

Curbing building sector emissions through electrification and renewable energy is a high priority outside the U.S. as well. Many of the aforementioned policy options have some generalizability to other countries with developed economies.

In the context of countries with developing economies, alternate approaches may be more appropriate. For instance, Chen & Chen (2019) examine mitigation options to more rapidly curb greenhouse gas emissions from the building sector in Hubei, China, and in that context recommended a tiered mitigation strategy that considers economic development levels. The authors found that while the most expedient way to peak emissions will be to rapidly shift towards electrifying heating, cooling, and cooking; and supplying that electric demand with renewables, areas with less developed economies may want to focus on decarbonizing the broader grid or improving energy efficiency.

Wang et al. (2018) also underscores varying transition strategies based on region income. High-income countries may benefit from steadily shifting the building sector towards electrification plus renewable energy through renovating existing building stock, improving building envelopes, and deploying high-efficiency technologies. This approach may mean only small decreases in energy demand at first but by 2050 could result in steeper declines.

In middle-income countries where more new building is expected in the coming decades, Wang et al. (2018) recommend focusing more on shifting fuels used to power buildings (especially commercial buildings) from oil and coal to renewable sources. Another important mitigation strategy in middle-income regions will be more efficient building design (passive solar, thermal insulation, more efficient appliances, and energy-saving lighting options).

In low-income regions, building sector energy demand will grow rapidly in the coming years to meet even the basic needs of growing populations: cooking, lighting, and cooling (especially in the tropics). This could mean a quadrupling of electricity demand by low-income countries in the next few decades. Cooling demands are projected to increase rapidly in the coming years, and relief (whether from air

source or ground source heat pumps, air conditioners, or fans) will rely on grids that are currently powered by fossil fuels. Mitigation strategies should therefore be aimed at meeting growing electricity demand with renewables rather than with fossil fuels. This would enable low-income countries to "leapfrog" conventional emissions-intensive fuels, entering directly into cleaner energy systems. Biogas digesters could be an appealing substitute for traditional biomass burning, keeping energy net-zero, while reducing air pollution, and stimulating local biogas economies (Wang et al. 2018).

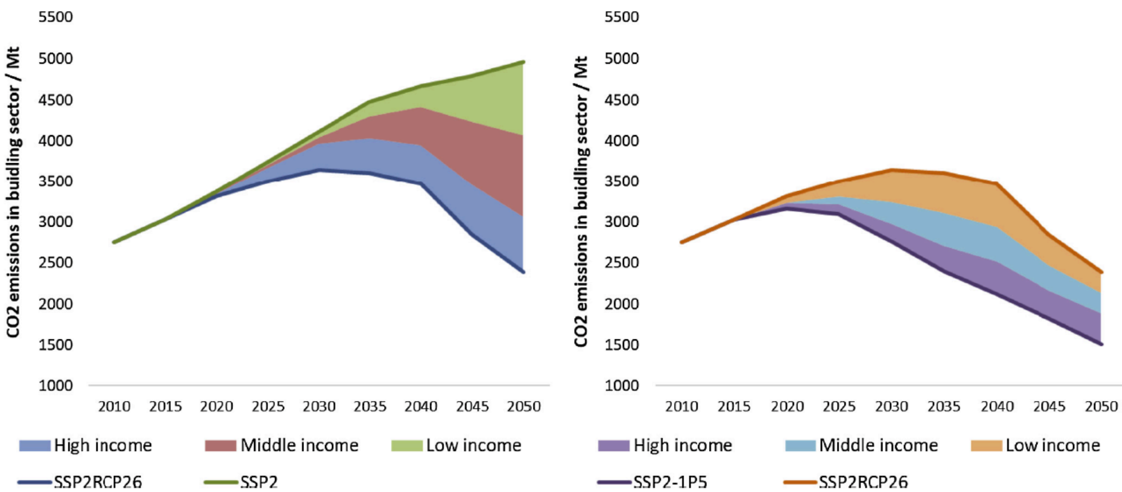

Figure 2. Building sector mitigation contributions from low-, middle-, and high-income regions to meet 2°C and 1.5°C emissions pathways. Credit: Wang et al. 2018.

Research Priorities

The scientific literature also highlights R&D priorities and opportunities for future academic investigation. One high priority is technological improvement of heat pump systems in areas with colder winters., Advances have already been made so that heat pumps can work in all U.S. climates, but continually improving their efficiency and performance in cold climates will help drive down costs further and incentivize a transition at scale. Beyond heat pumps, research should extend to other electric as well as non-electric (e.g., solar thermal) technologies that decarbonize the building sector (Deason et al. 2018).

U.S. decision-makers could benefit from peer-reviewed regional- or utility-scale case studies that can illustrate impacts of mass electrification of heating/cooling on load growth, peak load times, as well as benefits to the environment, consumers, and grid management (Deason et al. 2018). Also, comprehensive simulations of zero-net building prototypes that represent building stock, distribution changes, and building energy use as a function of climate and weather data (Tarroja et al. 2018). From a global perspective, the literature would benefit from global analyses of building electrification scenarios, and in particular pathways in developing countries (Wang et al. 2018).

The transition to an electrified and decarbonized building sector is ripe for deployment at scale. Technologies are available, mature, and continually advancing; policy mechanisms have been identified; and future mitigation directions have been outlined. Coordination and education of key decision makers in governance, within utilities, and among builders will now be critical to ensure a smooth and fast transition.

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