Global Innovation Needs Assessments

Buildings

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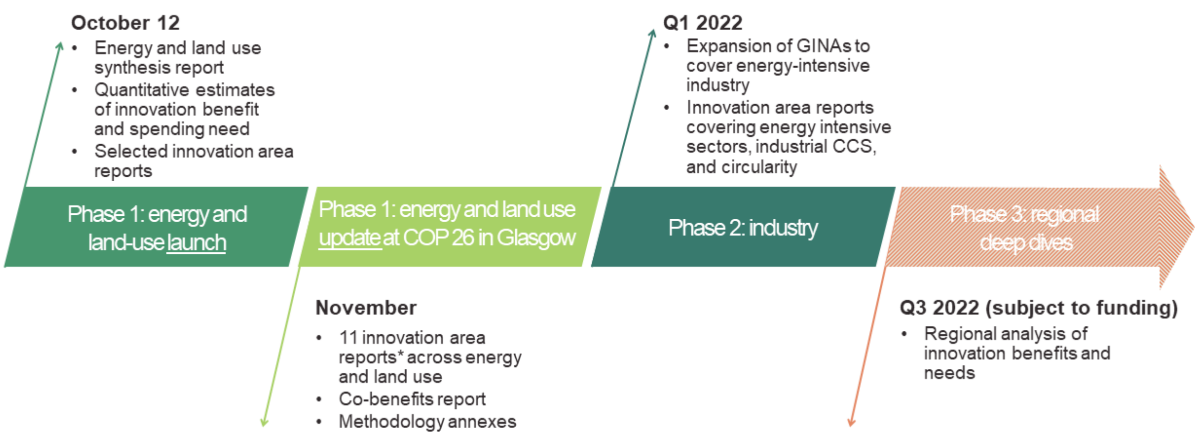
The Global Innovation Needs Assessments

The Global Innovation Needs Assessments (GINAs) is a first-of-its-kind platform for assessing the case for low-carbon innovation. The GINAs take a systemwide perspective, explicitly modeling the impact of innovations across the global economy. Uniquely, the analysis quantifies the economic benefits of low-carbon innovation and identifies the public investments—from research and development to commercialization—needed to unlock these benefits. The analysis is divided into three phases: Phase 1, global energy and land use; Phase 2, global industry; and Phase 3, regional deep dives.

The GINAs analyses neither assess all relevant technologies nor evaluates all relevant factors for policy judgments. Instead, they provide a novel evidence base to better inform policy decisions. The Phase 1 analysis examines climate mitigation technologies in energy and land use, ranging from demand response to protein diversification, to model the economic value of related innovation investment. Later phases expand this research. Like all technologies, adoption poses risks and potential downsides; some technologies in the analysis remain controversial. Which innovations to invest in is ultimately a policy judgment. This analysis provides no policy recommendations regarding investment in specific technologies.

Phases of the Global Innovation Needs Assessments



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The findings and views expressed here do not reflect the view of ClimateWorks, the Government of the United Kingdom or Mission Innovation.

Phase 1 GINA outputs

All GINAs reports and other GINAs outputs are available on the GINAs website at https://www.climateworks.org/report/ginas/.

The suite of outputs for Phase 1 of the Global Innovation Needs Assessments

1. Energy and land use synthesis report: slide-based summary for policymakers and executives

Synthesis of the findings across the innovations considered in energy and land use

2. Energy and land use and agriculture innovation reports: in-depth quantitative analysis for industry and policy analysts

- **Wind power** – Offshore and onshore wind turbines
- **Low carbon hydrogen** – Electrolyzers and gas reforming with CCS
- **Solar power** – Utility-scale and distributed PV
- **Low carbon fuels** – 2nd generation biofuels, synthetic fuels (H_2 + CO_2)
- **Nuclear power** – Small modular and large-scale advanced reactors
- **System flexibility** – Battery storage, power-to-X, demand response
- **Buildings** – Heat pumps, building fabric
- **Power CCS** – CCS in power generation (coal, gas, and biomass)
- **Zero-carbon road transport** – Battery electric vehicles, fuel cell electric vehicles
- **Protein diversity** – Novel protein-rich food and feed
- **Decarbonizing agrochemical inputs** – Innovative fertilisers and pesticides
- **Yield enhancing technologies** – Digital agriculture and vertical farming
- **Irrigation** – Improved irrigation methods and systems

The selected innovation areas were selected for their potential for further innovation and the potential magnitude of the associated system benefits. Their selection here is because they could play a key role in a net zero pathway but does not imply that an optimal net zero pathway necessarily includes them. Further notes on the rationale behind their selection is provided in the methodology annex on the GINA website

3. Co-benefits of innovation report: qualitative analysis of the environmental and other non-economic benefits of net-zero innovation

4. European case study: analysis of jobs and growth benefits in Europe specifically

5. Methodology annex: description of the modeling approach

Executive Summary

Buildings currently represent about 30% of global final energy use and 28% of energy-related CO_2 emissions. One-third of these emissions are direct emissions, mainly from the use of fossil fuels for space heating and water heating (80%) and cooking (16%). The remaining two-thirds are indirect emissions associated with the use of electricity for cooling, lighting, laundry, and other appliances as well as for district heating. Although power sector decarbonization will be a major driver of indirect emissions reductions, the buildings sector represents many mitigation opportunities. Abatement potential is particularly large in heating because of its large direct emissions as well as in cooling because of its increasing indirect emissions. This report focuses on two areas of innovations with the largest abatement potential: *heat pumps* and *building envelopes*.[1] Innovations in heat pumps can reduce emissions and energy associated with space heating, water heating, and cooling; innovations in building envelopes can significantly reduce the energy required for heating and cooling while increasing residents' thermal comfort. Emissions associated with the construction of buildings are not considered in this report, which focuses on abatement innovations in heavy industry.

Innovation in buildings helps reduce costs and is critical to removing deployment barriers. In some markets, installation of heat pumps and refurbishment of improved building envelopes already provide long-term cost savings by reducing energy bills, particularly for new buildings in Europe, North America, and northeast Asia. However, the upfront costs and inconvenience of these efforts keeps their deployment low. Heat pumps currently have about 7% market share in the residential heating equipment market, and less than 5% of new buildings meet near-zero energy performance standards (IEA 2020b). Innovation in heat pumps and building envelopes could lower their deployment costs and improve their value to consumers. For example, conventional heat pumps cannot produce the high-temperature water that some water-heat distribution systems require, necessitating modifications to pipework and radiators. Developments in high-temperature heat pumps address this barrier, allowing the pumps to be installed in old buildings with much less hassle and at lower costs.

Greater innovation and commercialization could reduce global energy system costs by $100 billion per year on average between now and 2050. Next-generation heat pumps could help reduce emissions associated with heating and cooling by displacing fossil fuel use in heating and by achieving energy efficiency greater than that of other electrified equipment for heating and cooling. Energy-efficient building envelopes with improved insulation could reduce energy requirements for heating and cooling, moderating electricity demand in winter cold spikes and summer midday heat waves, respectively. Furthermore, heat pumps with smart controls are potentially a major source of demand-side flexibility because winter heating demand could represent up to a third of winter peak demand in some electricity systems.

[1] Heat pumps are functionally the same as air conditioners but operated in reverse to provide heating. This report uses "heat pumps" to describe all variants of heat pumps in residential and commercial buildings for space heating, water heating, and cooling. Building envelopes refers to all physical elements of the outer shell of a building, including roofs, walls, doors, windows, ceilings, and foundations. This report uses "energy-efficient building envelopes" to refer to any material or design that improves thermal efficiency and leads to energy savings for buildings.

By 2050, the (undiscounted) value of cost savings from increased innovation in heat pumps and building envelopes could reach $360 billion per year. The discounted cumulative benefits between now and 2050 could reach $500 billion.

To unlock these public benefits, public commercialization spending and RD&D spending need to reach $1.4 billion and $0.4 billion per year, respectively. Although some heat pumps and energy-efficient building envelopes are commercially mature, innovations can help speed deployment of less mature options that promise lower costs or better performance. Public spending on RD&D and commercialization can help realize the substantial benefits of rapid decarbonization of buildings. RD&D is estimated to require $400 million in public spending per year, which doubles current spending on heat pumps and building envelopes. Commercialization, such as subsidies for energy efficiency renovation, would require about $1.4 billion per year to increase production of energy-efficient building envelopes in markets where they are not yet widely deployed. However, innovation spending from governments should be accompanied by other "pull" policies that drive development, such as energy efficiency standards, stringent building codes, and time-of-use tariffs, to encourage adoption of demand-responsive appliances.

Innovation could bring business opportunities worth $100 billion in GVA per year and could support 900,000 jobs globally in 2050. Both heat pumps and energy-efficient building envelopes represent growing markets driven by stringent building codes and energy efficiency standards. Innovative companies operating in these supply chains stand to benefit from this trend. The global heat pump market could be worth $36 billion in annual GVA and could support 500,000 direct jobs in 2030. Meanwhile, the market for energy-efficient building envelopes could be worth about $72 billion in annual GVA and could support 900,000 direct jobs in 2030. About half of such economic value and jobs will be associated with installation and construction, which has limited exposure to trade. The other half will be associated with manufactured equipment and materials, which present export opportunities for innovative companies that come up with more efficient heat pumps or high-performance building envelopes.

Public benefits (i.e., energy system cost savings)	Cumulative 2021–2050, undiscounted: $3,200 billion Cumulative 2021–2050, discounted at 5% p.a.: $500 billion Annual average 2021–2050, undiscounted: $100 billion
Business opportunities	2035: $110 billion GVA, 1.3 million direct jobs 2050: $100 billion GVA, 0.9 million direct jobs
Public spending required	Commercialization, annual average 2021–2035: $1.4 billion RD&D, annual average 2021–2035: $0.4 billion

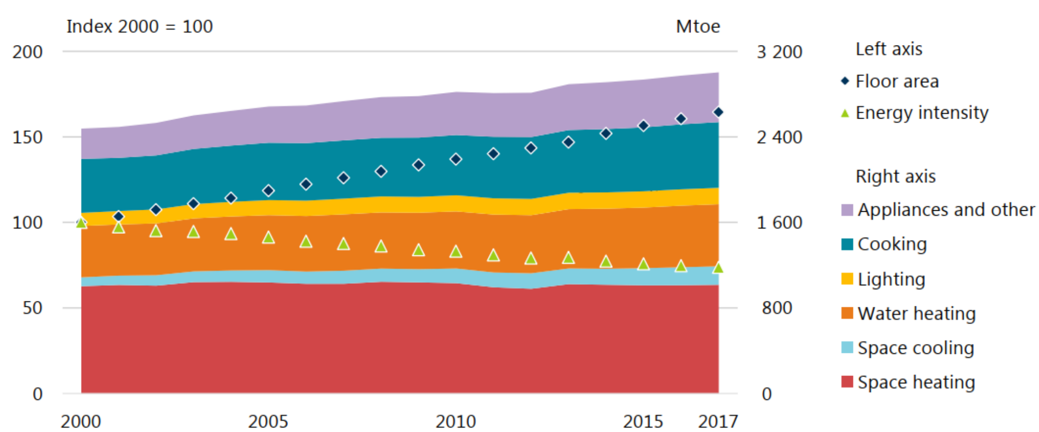
1. Buildings and the energy system

1.1. Current role in the energy system

The buildings sector consumes energy through space and water heating, cooling, lighting, and the use of appliances, accounting for 30% of global final energy use and 28% of energy-related CO_2 emissions.[2] The buildings sector comprises residential, public, and commercial properties.[3] The main energy end uses in buildings are heating and cooling. However, energy consumption patterns differ significantly by region: buildings in moderate and warm climates consume most energy through cooking (38%) and water heating (30%), whereas those in cold climates spend the most energy on space heating (45%) and appliances (32%) (BNEF 2021). Buildings in low-income countries spend much less energy on appliances and are more likely to use traditional biomass as their energy source. Overall, buildings represent 28% of global energy-related CO_2 emissions, two-thirds of which are indirect emissions attributed to power and heat consumed by buildings.

Driven by population growth and economic growth, energy use from buildings has increased 1.1% per year on average over the last two decades. Constructed floor space has increased by about 65% since 2000, reaching 245 billion square meters (m^2) in 2019 (IEA 2020a). A 25% decrease in average energy use per m^2 over the same period did not offset the rapid growth in floor areas, resulting in steady increases in energy use, as shown in Figure 1. Therefore, decarbonization of buildings requires decoupling energy consumption growth and emissions.

Figure 1. Buildings' energy consumption by type of energy service, 2000–2017.



Note: "Appliances and other" includes major household appliances such as refrigerators, clothes washers and dryers, dishwashers, and televisions as well as small plug-loads such as printers and computers.
Source: IEA 2019.

[2] The 28% reflects both direct and indirect emissions. When energy use in materials for building construction and renovation is included, the share of global final energy use is 36% and the share of energy-related emissions from buildings and construction is 37% (IEA 2020b).
[3] The residential sector is the largest component within the buildings sector by floor area (80%), final energy use (70%), and CO_2 emissions (60%).

Mitigation options to reduce direct and indirect emissions from buildings fall into four categories:

1. **Technology choice:** Reduce emissions by moving away from the use of fossil fuels for heating and cooking, for example, by switching to electric heat pumps, solar thermal, district heat, and induction cooking.
2. **Technology performance:** Improve the energy efficiency of appliances such as refrigerators, clothes dryers, and lighting.
3. **Building envelope performance:** Reduce the energy needed for heating and cooling through better insulation.
4. **Behavior:** Directly reduce the demand for heating, cooling, and other energy services.

This report focuses on innovations in two technology areas: heat pumps and building envelopes. Space and water heating are the main focus of mitigation in buildings because it is responsible for about 80% of direct emissions from buildings. Along with solar thermal units and district heat, heat pumps are expected to be the main lever to decarbonize heating. Because some heat pumps are reversible and behave as air conditioners, more efficient heat pumps imply more efficient cooling technologies, reducing indirect emissions. Meanwhile, energy required for space heating and cooling can both be reduced by energy-efficient building envelopes: better insulation can deliver a third of the reduction in energy used in the global building stock.[4] Other types of energy use in buildings, including cooking (which is increasingly electrified), lighting, drying, and other appliances, are not considered in this report because most abatement can be delivered through relatively mature technologies, including power sector decarbonization. Also not discussed in this report are hydrogen boilers for water heating, the main barrier to which is the cost of hydrogen (innovation in hydrogen is covered in another GINA report).

Heat pumps and energy-efficient building envelopes are commercially available but have low market shares. Residential heating is traditionally supplied by fossil fuel equipment (e.g., gas boilers) or electric resistance heating, with electric heat pumps serving 7% of the market in 2020 (IEA 2021). Similarly, less than 5% of new buildings meet a near-zero energy performance standard in building codes (IEA 2020b).[5]

1.2. Future role and deployment potential

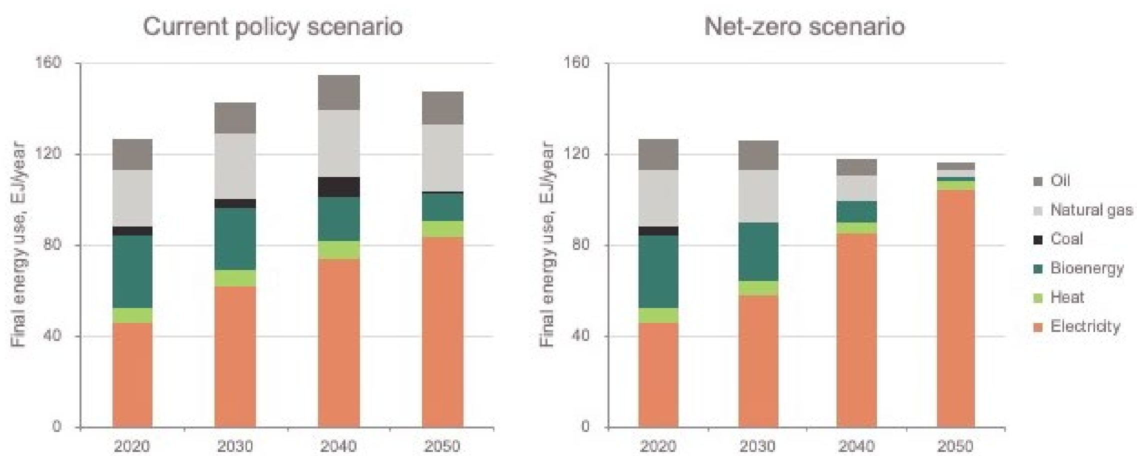
In the absence of significant reductions in buildings' energy intensity, energy use will continue to rise as floor area doubles by 2070. Growth in floor area is driven by population growth and economic growth, both of which are uncertain. The United Nations estimates global population will rise from 7.7 billion in 2019 to 9.7 billion in 2050 (United Nations 2019), and the OECD estimates global economic growth could increase from an average of 3.4% in 2010–2030 to 2.4% in 2031–2050 (OECD 2021).

[4] This reduction is taken from the IEA (2020b), which compares the Sustainable Development Scenario relative to a baseline energy consumption in buildings for the period up to 2070.
[5] This standard is only a proxy because the definition of near-zero energy performance varies across countries. Moreover, there is also no single metric to define the market share for energy-efficient building envelopes because the market is heterogeneous (windows, walls, and so on), and there is no single cutoff representing "energy efficient."

The IEA estimates that global floor area could increase from 245 billion m^2 in 2019 to 460 billion m^2 in 2050; the majority of that growth will come from emerging economies (IEA 2019). Decarbonization of buildings would therefore require substantial improvements in energy efficiency and the transition to low-carbon energy sources.

Decarbonization of buildings is driven by efficiency improvements and widespread electrification. Figure 2 contrasts a current policy scenario against a net-zero scenario published by the Network of Central Banks and Supervisors for Greening the Financial System (NGFS) in 2021 to illustrate key changes required to decarbonize buildings.[6] Although assumptions about macroeconomic growth in both scenarios are the same, 2050 final energy demand in the net-zero scenario is about 21% lower, reflecting a wide range of energy efficiency improvements. Another key difference is the extent of electrification by 2050: 56% in the current policy scenario compared with 90% in the net-zero scenario. Most of this shift reflects heating technologies' movement from fossil fuels and traditional biomass to electric heat pumps.

Figure 2. Buildings final energy consumption by scenario, 2020–2050.



Note: Different modeling approaches and assumptions yield different modeling results on buildings. For consistency, the scenarios shown were both produced by REMIND-MAgPIE 2.1-4.2 and published in 2021.
Sources: NGFS (2020).

Deployment of heat pumps and energy-efficient building envelopes will grow significantly in this decade. The IEA study cited above suggests that heat pumps can theoretically supply 90% of heating needs, particularly in major heating markets such as Canada, China, Europe, and the United States. Meanwhile, energy-efficient building envelopes could be deployed extensively where they deliver clear savings. Innovation will be key to make them readily available to all types of customers and at lower installation costs.

[6] Different modeling approaches and assumptions yield different modeling results.

2. Innovation opportunities

This section identifies innovation opportunities for heat pumps and energy-efficient building envelopes, which represent two of the largest abatement options for which innovation plays a significant role. Deep decarbonization of buildings relies on deploying a wide range of energy efficiency improvements, many of which are commercially mature.

2.1. Heat pumps

Heat pumps are much more efficient than alternative heating technologies in buildings. Conventional heating technologies convert the energy in fossil fuels or electricity to heat with an efficiency of less than 100% due to energy losses. By contrast, heat pumps use electricity to extract the thermal energy from a low-temperature source and to channel it to a higher-temperature sink.[7] Consequently, the heat pumps' efficiency factor, or the ratio of useful thermal energy output to energy input, can be greater than 100%. The efficiency of heat pumps depends on ambient temperature; current technologies have an average efficiency factor of 4.5 in mild climates in Europe and of 3 to 3.5 in cold climates such as in northern Canada (IEA 2021). Heat pumps are far more efficient than conventional gas furnaces and boilers, which have an efficiency factor of about 0.85, and electric resistance heaters, which have an efficiency factor of 1.0.

Heat pumps are increasingly popular but have just a 7% share of the global market for residential heating because of deployment barriers. Globally, sales of air-to-air heat pumps have grown nearly 10% a year since 2010, while sales of heat pump water heaters have more than doubled (IEA 2020c). However, half of the residential heating market remains dominated by fossil fuel-based heating equipment such as oil or gas boilers, and another 20% of the market is supplied by conventional electric-resistance heaters. Heat pumps of various designs and sizes can readily serve all types of buildings, ranging from single-family homes to large commercial buildings. However, the extent of cost savings differs across applications. The key barriers to deployment of heat pumps are as follows:

- **Costs:** The upfront installation costs of heat pumps are often a few times higher than those for traditional gas boilers, and they are sometimes perceived as unaffordable to low-income households despite potential operating cost savings, which depend on the price difference between electricity and gas.
- **Cold-climate performance:** A majority of air-source heat pumps on the market perform less efficiently when the ambient environment approaches or goes below freezing temperatures. Even though technologies have improved, there remains a lack of confidence in the performance of cold-climate heat pumps. Furthermore, these cold-climate pumps remain more expensive than gas boilers.

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[7] There are gas-fired heat pumps as well. However, their efficiency factors are about 1.2–1.4. Heat pumps referred to in this report are exclusively electric heat pumps. Heat pumps could be used in some industrial applications for low-temperature heat but are beyond the scope of this report. Some heat pumps are designed to be reversible, behaving like air conditioners to provide space cooling.

- **Difficulty of retrofits:** Replacement of existing fossil-based heating equipment with electric heat pumps may represent significant disruption and inconvenience to both building owners and tenants. It might require modification of heat distribution systems, incurring piping or ductwork costs.
- **Incentive issues:** When tenants are responsible for their energy bills, landlords might have limited incentives to replace existing fossil-based heating equipment with heat pumps, which incur large upfront costs for the landlord to reduce energy bills for tenants.
- **User behavior and interface:** Heat pumps have some features to which some people find it difficult to adjust. The pumps take more time to warm up and are relatively noisy.

Innovation in heat pumps can further accelerate deployment in multiple ways:

- **New system designs to reduce costs and improve cold-climate performance.** Improved technologies such as gas sorption and new compressors will lower the installation costs of heat pumps and improve efficiency, reducing operating costs. Cold-climate performance of heat pumps can also be improved through advances in variable-speed inverter-driven compressor technology—technology commercially available but not at scale.
- **Development of high-temperature heat pumps (HTTPs).** Standard hot-water heat pumps operate at much lower temperatures than gas or oil boilers. Consequently, their installation in existing buildings requires significant modifications to heat distribution systems (pipework, radiators, and so on). High-temperature heat pumps can reduce the need for such modifications, lowering installation costs and inconvenience for consumers.
- **Smart control systems to increase integration and enable demand-side response.** Domestic users often have difficulty understanding instructions for using the complex controls of their heat pump. This difficulty impacts performance and efficiency. Smart and simple controls provide clear real-time feedback to users and enable them to adjust their consumption patterns, increasing value.
- **Modularization of HP systems and ease of retrofits.** Development of plug-n-play products would further reduce installation costs and facilitate deployment. Heat pump designs could be adapted to facilitate installation in old buildings, minimizing the costs of retrofits.

Increased innovation in heat pumps could lead to a 24% to 26% additional cost reduction by 2050. Table 1 below summarizes 2020 cost estimates, alongside 2050 estimates under high-innovation and low-innovation scenarios. The scenarios are constructed from an extensive review of cost-reduction studies for heat pumps. They do not explicitly identify the necessary technological advancements that drive these reductions. They represent an informed judgment about the scope of cost reductions with and without increased innovation. Costs decline between 2020 and 2050 even in the low-innovation scenario due to near-term technological improvements and learning by doing.

Table 1. Heat pump cost assumptions under high- and low-innovation scenarios

Technology	Cost assumption	2020	2050 low-innovation scenario	2050 high-innovation scenario	% further cost reduction under high-innovation scenario
Residential heat pumps	Capex, $/kW	514	385	285	26%
	Fixed Opex, $/kW/year	27	20	15	26%
Commercial heat pumps	Capex, $/kW	328	258	196	24%
	Fixed Opex, $/kW/year	16	13	9.5	24%

Note: Fixed opex = operations and maintenance.
Source: Vivid Economics based on Danish Energy Agency (2021), Kozarcanin et al. (2019), and Jadun et al. (2018).

2.2. Building envelopes

Building envelopes determine the thermal efficiency of buildings, affecting the energy requirements for heating and cooling. Building envelopes, sometimes referred to as building fabrics or building shells, include windows, walls, roofs, doors, floors, and so on. Energy efficiency improvements in building envelopes help reduce buildings' heat loss (in cold weather) and heat gains (in warm weather), thereby reducing the energy consumption needed for heating and cooling. Typical examples of improved insulation include double- or triple-pane glass windows and air sealing. More broadly, building envelope innovations are applicable across building design, construction, operation, and decommissioning, reducing energy consumption across the life cycle.

Energy efficiency improvements in building envelopes are one of the most important measures to reduce energy intensity in buildings. In a scenario with a fast transition in the buildings sector, IEA estimates that building-envelope renovation measures lead to improvements in energy intensity of more than 35% on average globally by 2050, while allowing for continued improvement in overall comfort (IEA 2019). Deep energy renovations can reduce existing buildings' energy consumption by 50% or more in developed economies and by 30% or more in developing economies (GlobalABC/IEA/UNEP 2020).

Innovations in building envelopes focus on reducing costs and overcoming deployment barriers to mass adoption. The choice of building materials and construction methods is highly cost sensitive. Energy-efficient materials and designs need to demonstrate cost advantages. The main innovations in energy-efficient building envelopes can be categorized as follows:

- **Advances in material design, modeling, and operations to improve energy performance:** Improved data collection and analysis will allow architects, engineers, and contractors to better understand how materials behave. Proving the performance of novel building envelopes will help dispel perceived utilization risks and uncertainties.

Continuous monitoring of buildings can encourage optimal energy use. Enabling technologies include remote heating technologies and occupancy sensors.

- **Offsite manufacturing and modular construction of energy-efficient building envelopes:** Building envelopes that are prefabricated in a controlled environment away from the construction site can be more accurately constructed than other envelopes. In factory settings, workers with specialized skills can manufacture components with high precision. Along with modular designs, offsite manufacturing allows cost reductions through economies of scale. This approach to construction is mature and can be scaled up to improve the energy efficiency of new building stock. Existing buildings can be retrofitted more cheaply with offsite assembly of modules before final fitting, as demonstrated by small-scale projects in the United Kingdom and the Netherlands (Vivid Economics 2019).

Greater innovation in building envelopes could accelerate improvements in buildings' thermal efficiency, saving an additional energy savings of 3,200 TWh per year by 2050. Building envelopes use a wide range of materials, designs, and technologies, which lead to different energy savings in different environments. The innovation scenarios in this report consider the total amount of energy savings from buildings' improved thermal efficiency. On the basis of the IEA's study of the role of building envelopes in reducing energy consumption, we define the low-innovation scenario as the absence of an active push to improve building envelopes and the high-innovation scenario as investments in building envelopes that result in annual energy savings of 3,200 TWh by 2050.

Box 1 Other opportunities for innovation in buildings

This report focuses on heat pumps and building envelopes because they represent two key technology areas to reduce direct and indirect emissions from space heating, water heating, and cooling. However, as shown in Figure 1, these technology areas represent only 60% of energy consumption in buildings. Other areas for innovation include

- **Cooking:** Although electrified cooking has been commercially available for decades in the form of electric resistance or induction cookstoves, some 65% of the population in developed countries still cook with gas (IEA 2020d). Induction cooking is the most energy efficient and should be more widely adopted.[a] However, consumer acceptance remains low because gas cooking is perceived to provide superior performance and because induction cooking requires relatively expensive equipment as well as ferrous pots and pans.

- **Clothes drying:** Replacement of gas dryers with electric dryers (especially heat pump dryers, which are more efficient) would significantly reduce emissions from clothes drying. Although heat pump dryers are relatively common in European residential buildings, they are not yet deployed widely in markets such as the United States because they are smaller than typical residential dryers and are far too small for commercial applications.

[a] Induction cooking is 5% to 10% more efficient than conventional electric-resistance units and about three times more efficient than gas.

3. Benefits of innovation

3.1. Low-cost decarbonized energy

Box 2 System benefits and low-cost decarbonized energy

Lower energy costs are unlocked by the system benefits of innovation. System benefits of innovation refer to the net reduction in costs across the entire energy system as a result of technology RD&D *and* commercialization. In the context of this report, system benefits are calculated as the difference in the total system costs of a high-innovation scenario and those of a low-innovation scenario, whereby:

- System costs are all capital, operating, and fuel costs within the global energy system.
- Low-innovation scenario represents market-driven progress in the absence of government support.
- High-innovation scenario represents progress driven in part by government support of RD&D and deployment (i.e., commercialization).

This metric provides an aggregate estimate of how innovations in selected technologies can reduce system costs after least-cost optimization of all energy carriers and technologies from both the supply and the demand sides.

A high degree of innovation in heat pumps and building envelopes could provide $500 billion in discounted cumulative system benefits to the energy system by 2050. The annual system benefits from heat pumps and building envelopes become significant only after 2035 because deployment of heat pumps and energy-efficient building envelopes represent significant upfront investments. Benefits accrue as these investments are more widely reflected in the global building stock, reducing energy consumption. Energy efficiency renovations in the 2020s for old buildings represent significantly higher costs in the high-innovation scenario than in the low-innovation scenario. The cost gap between the two scenarios narrows as the benefits from reduced energy consumption become significantly higher toward the late 2030s. Table 2 reports the system benefits from 2021 through 2050 in the high-innovation scenario in heat pumps and building envelopes as measured by the cost savings of that scenario compared with those of the low-innovation scenario.

Table 2. System benefits of innovation in wind power

System benefits	2021–2050, cumulative, undiscounted	2021–2050, cumulative, discounted at 5%	2021–2050, annual average, undiscounted
High innovation in heat pumps and building envelopes	$3,200 billion	$500 billion	$110 billion

Note: Discounting reduces the present value of future benefits.
Source: Vivid Economics.

Innovations in heat pumps and building envelopes could lead to large benefits through energy savings, and with respect to heat pumps they further benefit the power system by providing a source of demand-side flexibility. As illustrated in Figure 3, system benefits from innovations in heat pumps and building envelopes are driven through two main channels:

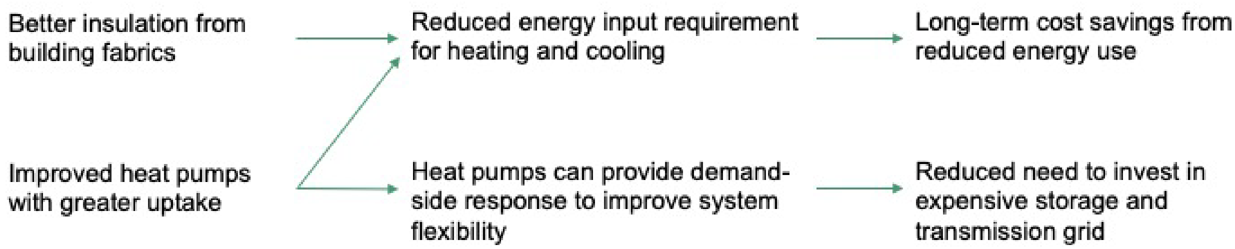
1. **Reduced energy requirements for heating and cooling**

   Innovation in heat pumps and energy-efficient building envelopes could increase uptake of both technologies in new *and* old building stock, reducing final energy consumption associated with building heating and cooling and in turn reducing electricity demand in buildings as well as fossil fuel demand (in buildings where heating is provided by oil or gas). Knock-on effects in the energy system are decreased capex and opex needed for upstream energy assets.

2. **Additional potential for demand-side flexibility**

   Heating for residential and commercial buildings provides an opportunity to increase power system flexibility by reducing demand during peak hours. Heat pumps are well-positioned to provide this kind of demand-side flexibility, which is increasingly valuable as countries grow to rely more on intermittent power from solar and wind. Innovation in heat pumps could provide smart controls to help users adjust their load efficiently in response to price signals. The potential contribution to system flexibility is large, particularly if coupled with thermal storage, because residential and commercial heating demand could represent up to a third of winter peak electricity demand in some countries (National Grid ESO 2021).

Figure 3. Impact of innovation on the energy system.



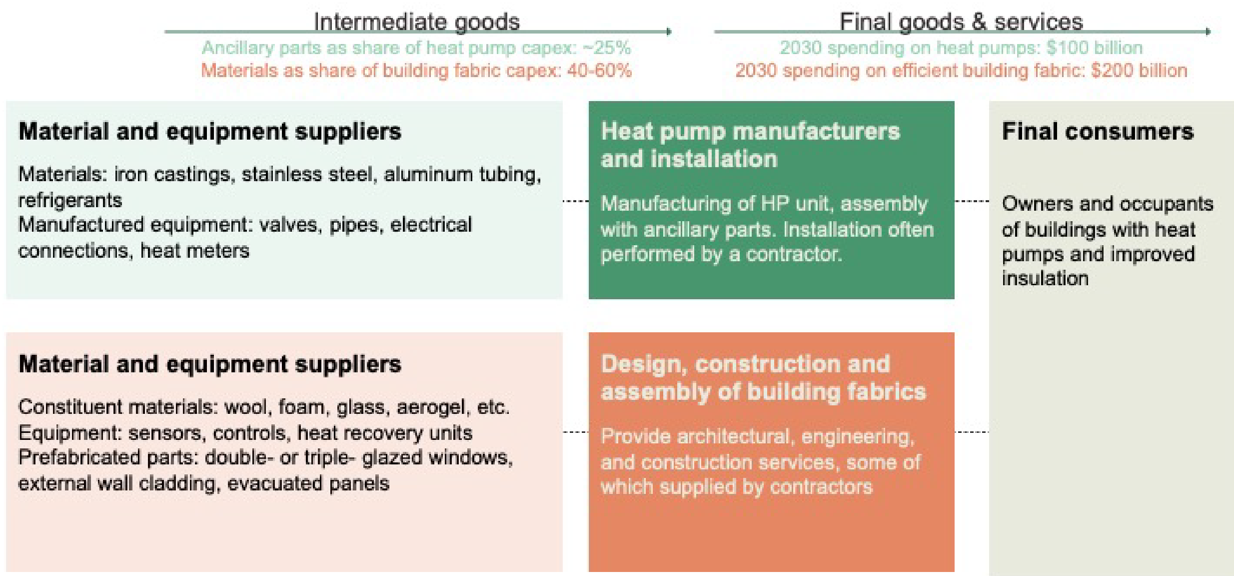
Note: Illustrative only
Source: Vivid Economics

3.2. Jobs and Growth

Only 3% of the $5.7 trillion annual investment in the global buildings sector in 2019 was related to spending to improve energy efficiency. According to recent IEA estimates, construction alone represented 60% of global investment in buildings; energy-related investments made up the remaining 40%. In the absence of clear definitions about what constitutes an investment in energy efficiency, a useful indicator would be total spending on energy-efficient products and building refurbishments that exceed the status quo. In 2019, this indicator, known as incremental spending on energy efficiency, amounted to $150 billion, or about 3% of global buildings sector investment (IEA 2020e).

Driven by government regulations to improve buildings' energy performance, the markets for both heat pumps and energy-efficient building envelopes are set to grow steadily in the 2020s. These expanding markets will create business and employment opportunities along the supply chain, primarily in construction and installation but also in the supply of related equipment and building materials. Figure 4 displays simplified value chains for heat pumps and building envelopes, alongside estimates of their market size in 2030. These supply chains are both well developed: heat pump manufacturers and building contractors purchase a range of material and equipment inputs from local or regional suppliers. Part of the installation or build process typically involve subcontractors.

Figure 4. Simplified value chains for heat pumps and building envelopes.



Note: The GVA and jobs quantified in this section cover the entire value chain at a high level.
Source: Vivid Economics.

In 2018, sales of electric heat pumps were about $55 billion, representing a small but growing share of the heating equipment market. There is significant potential for growth because the addressable market for heat pumps, that is, heating equipment for residential and commercial buildings, is large. Conventional options for heating, which include gas boilers, oil boilers, and electric-resistance heaters, together represented 75% of global sales of residential heating equipment in 2019. Heat pumps met just 5% of this demand. Heat pumps are popular in some market segments, such as new residential buildings in the United States and Europe, but not in others, such as old buildings. The market for heat pumps is typically segmented according to the pumps' use (commercial versus residential) and design (air-to-air, ground source). The following analysis does not distinguish among heat pump design types but does distinguish residential deployment from commercial deployment.

Under the high-innovation scenario, the market size for heat pumps could double, reaching $100 billion by 2030. In this scenario, global heat pump installations will accelerate, with annual net capacity additions across residential and commercial buildings reaching 160 GW by 2030. This increase is comparable to that in some net-zero scenarios in which annual heat pump sales reach about 70 million units per year by 2030.[8] Residential heat pumps could represent about 70% of the heat pump market by market value.

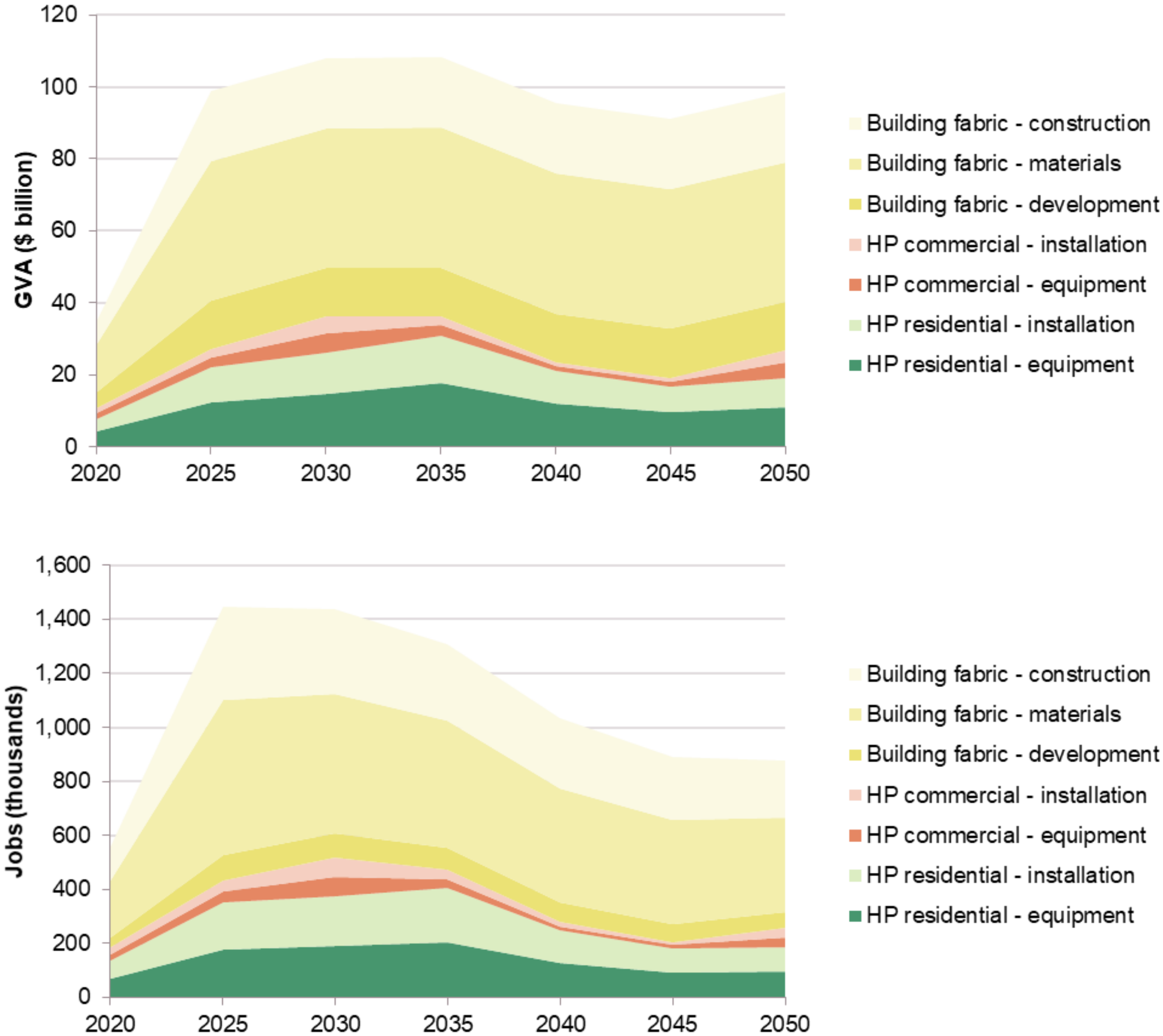
[8] These estimates are from NGFS net-zero scenarios downscaled by Vivid Economics.

By 2050, the direct GVA from deploying heat pumps could reach $30 billion per year and could support 300,000 jobs globally. About half of these jobs will be associated with the installation of heat pumps in buildings. The remaining half will be split between manufacturing of heat pump units and manufacturing of ancillary parts. Most of these manufacturing jobs are exposed to international trade, presenting an opportunity for export-oriented businesses.

Market opportunities for energy-efficient building envelopes could grow rapidly, with annual investments tripling by 2030 to reach $200 billion per year. Currently, energy efficiency spending on building envelopes is estimated at $67 billion (IEA 2019). Less than 5% of new buildings meet a near-zero energy performance standard according to building codes (IEA 2020b). In a scenario developed by the IEA consistent with the Paris Agreement, high-performance and near-zero energy buildings would make up more than half of new construction in 2030, with higher shares in advanced economies. Three markets could directly benefit from this trend: development of building projects, installation of building envelopes (walls, roofs, floors), and supply of thermal insulation materials (hemp, wool, glass).

By 2050, the direct GVA from investing in energy-efficient building envelopes could reach $70 billion per year and could support 600,000 jobs. About half of this GVA and employment opportunity is represented by upstream suppliers that provide building envelope materials, which include products that are traded globally (e.g., glass). The remaining economic value and employment opportunity is concentrated in the construction sector, which is much more localized and which could support domestic employment. In particular, energy efficiency retrofits present a fast-growing opportunity in many countries as governments subsidize refurbishments of old buildings.

Figure 7. GVA and jobs directly supported by global deployment of heat pumps and building envelopes



Source: Vivid Economics.

4. The case for supporting innovation

To realize the full benefits of heat pumps and energy-efficient building envelopes, public spending on RD&D of some $400 million per year is needed. This spending represents a doubling of the current global public RD&D budget for heat pumps and building envelopes. But compared with RD&D spending needs in other technology areas covered by the GINAs, this amount remains modest for two reasons. First, the market for heat pumps (and air conditioners, which represent the same underlying technology) is already large, with global sales of nearly $3 million in 2019. Consequently, heat pump manufacturers operate in a mature environment with strong incentives to innovate. Second, the market for building insulation largely consists of basic and cost-effective technologies, such as double- and triple-glazed windows. Faster deployment of energy-efficient building envelopes is a matter of regulation, rather than innovation. However, RD&D remains crucial to address current deployment barriers in some heat pump and building envelope market segments.

In addition, public commercialization spending of about $1.4 billion per year is needed to develop specialized markets and supply chains that are key to unlocking benefits. Again, the amount of public spending is relatively modest. As noted in Section 3.2, the market size of heat pumps and energy-efficient building envelopes could rise to $100 billion and $200 billion, respectively, in 2030. Nonetheless, public support for commercialization plays a valuable role, especially for growing supply chains that are not yet developed. For instance, construction and building retrofits require specialized workers and material suppliers. With the growth in demand for energy-efficient building envelopes, governments need to ensure that different market segments (e.g., residential houses, high-rises, historic properties, commercial buildings) all develop effectively. Commercialization spending such as targeted subsidies or procurement can help establish domestic supply chains for market segments like energy efficiency renovation that are underdeveloped. For instance, Paris has prioritized public schools for deep energy retrofits, which could help develop the supply chain for the refurbishment of old buildings.

Finally, government support for RD&D and commercialization will need to be accompanied by broad "pull" policies that ultimately drive deployment. Pull policies drive deployment and, hence, advance innovations. These policies effectively phase out inefficient appliances and equipment and require better insulation. For example, many countries include minimum energy performance standards for buildings (e.g., those in the European Union) and appliances (e.g., those set by the DOE in the United States). Another useful policy could be to lay out a timetable to phase out fossil fuel heating equipment, thereby sending a clear signal to producers in the market to scale up production to meet future demand. In general, building codes are a powerful regulatory tool for policymakers to advance innovations and to accelerate efficiency improvements and electrification of buildings. In old buildings, for which the costs of heating equipment replacements or refurbishments are high, subsidies or low-interest loans might be effective to support deployment, particularly for low-income households.

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