Bringing Clean Energy Home

Unlocking Innovation and Policy to Align US Household Energy Use with Ambitious Climate Targets

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Authors & Acknowledgments

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RMI was invited by Google to assess the impact of Google's Nest Renew service, announced in October 2021, and independently author this report putting the service into the context of opportunities to meet ambitious climate policy targets. Google provided funding to RMI to support this work. The findings presented in this work were independently derived by RMI, and RMI is solely responsible for the views expressed.

About RMI

RMI is an independent nonprofit founded in 1982 that transforms global energy systems through market-driven solutions to align with a 1.5°C future and secure a clean, prosperous, zero-carbon future for all. We work in the world's most critical geographies and engage businesses, policymakers, communities, and NGOs to identify and scale energy system interventions that will cut greenhouse gas emissions at least 50 percent by 2030. RMI has offices in Basalt and Boulder, Colorado; New York City; Oakland, California; Washington, D.C.; and Beijing.

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3: Barriers	**Making climate-aligned household energy decisions today isn't easy** Today, a household trying to take actions to reduce emissions will likely find existing options to be limited, complex, costly, and fragmented. Chapter 3 outlines the direct challenges households face when taking actions to reduce their emissions, and how utility and regulatory structures can exacerbate these challenges.
4: Customer Solutions 5: Utility and Regulatory Solutions	**Emerging solutions in technology and policy can help people decarbonize their homes** Households can't and shouldn't be expected to address today's barriers to decarbonizing homes by themselves. Chapter 4 describes how solutions providers, utilities, and regulators can support people in making climate-aligned home energy decisions. Chapter 5 lays out options for adjusting utility incentives and business practices to accelerate adoption of emerging solutions.
6: Assessing an Example 7: Conclusion	**Adopting customer-facing solutions at scale can help meet US climate policy targets** RMI was invited by Google to assess the potential climate impacts of its new Nest Renew service, as well as its ability to address the current barriers to household decarbonization. Chapter 6 lays out RMI's assessment of Nest Renew in this context, showing emissions benefits available today as well as the deeper savings from features that might be available in the future. Chapter 7 concludes this study by showing the ability of a service like Nest Renew, enabled by shifts in utility and regulatory structures, to support ambitious US climate policy targets.

Executive Summary

Aligning Residential Energy Use with Climate Targets

Over the next decade, we face an opportunity to radically change how energy is produced, delivered, and used across the entire economy, including within our homes. With more than 120 million households in the United States, the residential sector is one of the largest consumers of energy, and household-level energy decisions drive 40% of US energy-related carbon emissions. Positioning households to lead on decarbonizing our economy can both enable rapid emissions reductions and help improve critical human needs including health, resilience, and equity of access to energy services.

Yet, without fundamental shifts, household energy use is not on track to reduce emissions in line with ambitious climate targets nor to realize the benefits in our homes and communities of doing so. Residential emissions most likely need to **at least** fall in line with the US nationally determined contribution (NDC) of a 50%–52% emissions reduction by 2030 from 2005 levels. On a business-as-usual (BAU) path, the US residential sector's energy-related carbon emissions will fall only 20%–30% from 2005 levels by 2030.

To reduce emissions in line with the economy-wide emissions trajectory defined by the NDC, household energy decisions can help achieve two outcomes that complement ambitious climate policy. First, households can accelerate the transition to a carbon-free electricity system through both demand-side investment and deployment of carbon-free electricity resources. And second, they can reduce direct emissions associated with their energy use from both buildings and personal vehicles (Exhibit ES1).

A set of ambitious policies that affect residential emissions have the potential to realize these levels of deployment, if they are implemented. These include an 80% carbon-free electricity standard, a mandate requiring 100% of zero-emissions vehicle sales, and a mandate for all-electric sales of new appliances. Yet even if these or other ambitious policies are enacted, implementation must also move swiftly and equitably to achieve climate-aligned outcomes.

Exhibit ES1 What is needed to align residential energy-related CO_2 emissions with US climate targets

Accelerate system-wide electricity decarbonization:
Realize immediately available options to accelerate the system-wide transition to a carbon-free electricity system

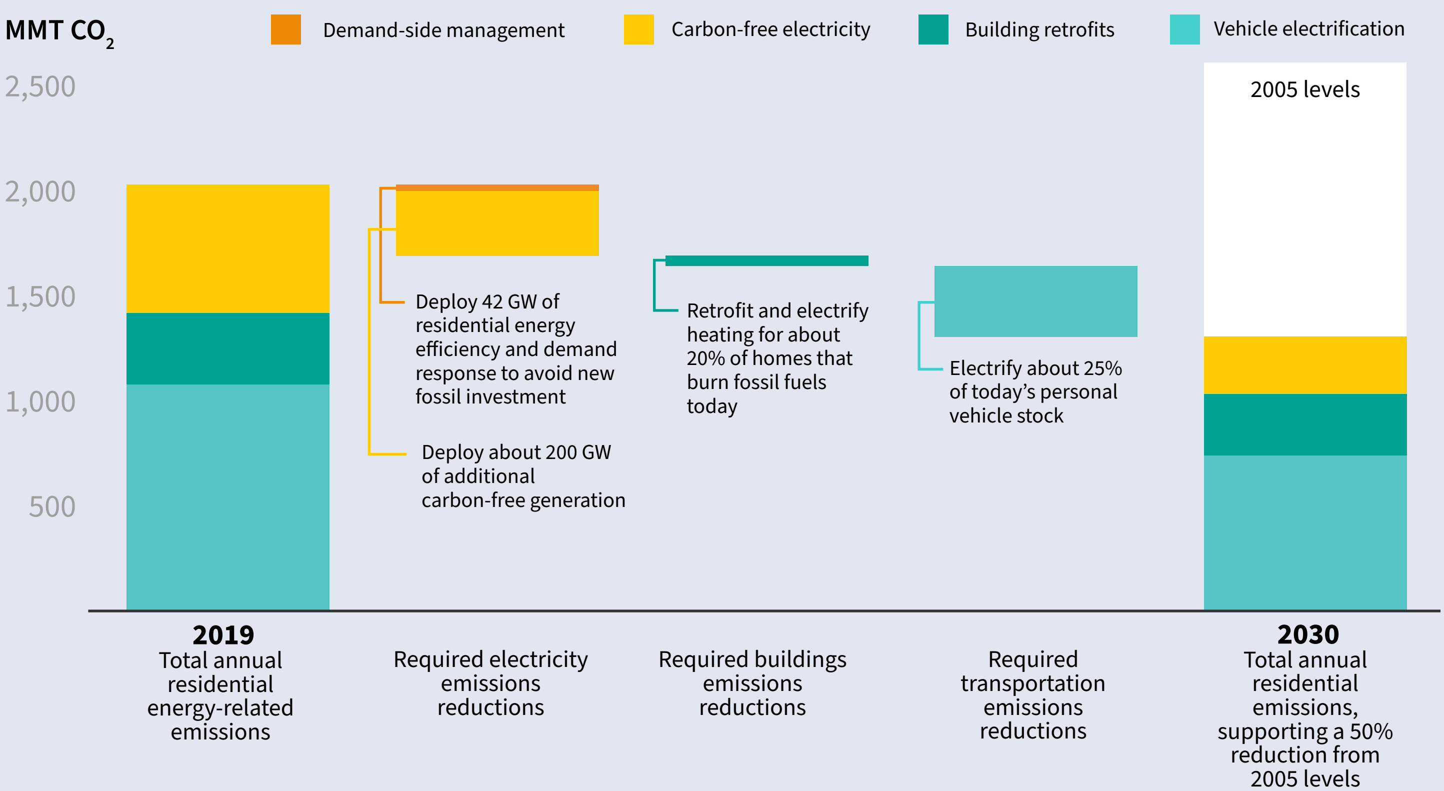
Demand-side management
Deploy the demand flexibility and efficiency needed to avoid new fossil investment and enable a carbon-free grid

Carbon-free electricity
Accelerate the deployment of carbon-free electricity

Reduce direct emissions:
Reduce direct household and vehicle emissions through electrification and deep efficiency improvements

Building retrofits
Retrofit and electrify residential buildings

Vehicle electrification
Electrify or eliminate internal combustion vehicle miles traveled



Addressing Direct Barriers to Household Adoption

Activating the transformation depicted in Exhibit ES1 will require overcoming significant barriers to adoption today. Although a set of presently available options can accelerate decarbonization, many have not been adopted widely by a diverse set of households because they are complex, costly, limited, or fragmented. These challenges are pervasive and have resulted in adoption of residential clean energy technologies and programs that are far short of a trajectory for meeting climate targets.

Four emerging opportunities made possible by innovation in technology and marketing can address these barriers: (1) customized insights and offers, (2) automation and optimization, (3) aggregation and collective action, and (4) deployment innovations, such as bundles of products and financing. These tools can allow solutions providers to address the barriers facing those making household energy decisions today, creating options that are simple, affordable, targeted, and integrated. This can unlock material emissions benefits along with opportunities for investments that make our homes and communities healthier and more resilient.

Addressing Utility and Regulatory Barriers

Addressing barriers to adoption through innovative products and services is not enough. Today, policy, regulatory rules, and utility structures and practices can exacerbate the challenges that households face in making climate-aligned energy decisions. Current structures can limit households' choices in prioritizing clean energy solutions, make it complex and costly to adopt such solutions, and result in fragmentation of value for customers and the grid.

To accelerate adoption, regulators, grid planners, and operators have an opportunity to consider how incentives, markets, and planning can be structured to ensure that all households benefit from decarbonization and that they can drive more impact through their choices. Three emerging strategies can help implement these changes:

1. **Adjust utility incentives and processes to maximize integration of demand-side resources:** Regulators can realign utility earnings toward meeting household objectives such as improving health, supporting emissions reductions, increasing resilience, and reducing energy burden (e.g., through performance-based regulation), and away from a primary focus on capital investment. Utilities can update planning practices to identify and operationalize opportunities for households to derive value from integrating distributed energy resources (DERs) such as energy efficiency and demand flexibility.

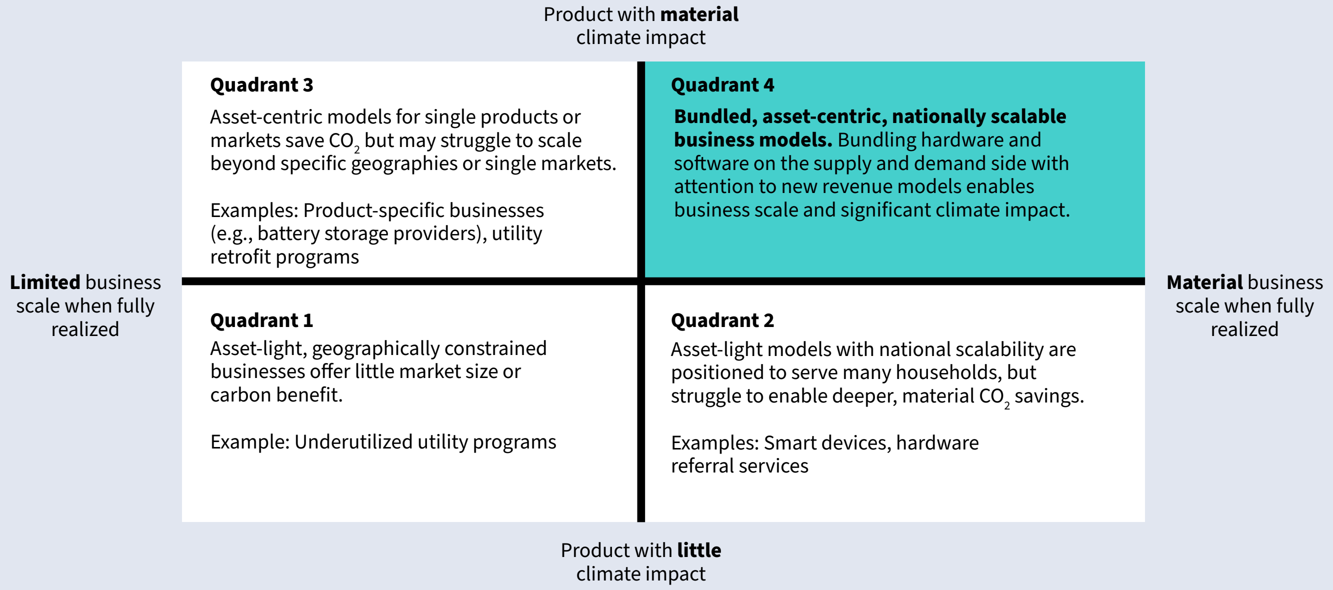
2. **Align residential incentives, programs, and rates with decarbonization objectives and household benefits:** Regulators can create and consolidate residential incentives and programs and make solutions more affordable, especially for low-income households. Utilities can make it easier for households or third parties to identify and access incentives, couple incentives with innovative financing, and ensure that all households have access to impactful options with limited up-front or ongoing costs.

3. **Enable data access and transparency:** Regulators can create rules that balance data sharing and customer protection and provide solutions providers with the information they need to innovate. Utilities can use and share data in ways that support developing residential clean energy solutions.

Business Opportunities for Scaling Residential Decarbonization

Currently, even without widespread adoption of favorable policy or utility practices, there are many businesses that support households in making climate-aligned energy decisions. But because of the limitations of policy and regulatory structures noted above, these businesses generally must balance climate impact (i.e., tons of CO_2 avoided per customer) against business scale (i.e., accessible market size), as illustrated in Exhibit ES2.

Exhibit ES2 **Classification of business models for residential decarbonization**



Few, if any, existing residential offerings sit within the upper-right quadrant of Exhibit ES2. In other words, very few have the potential to enable deep emissions reductions for each household while serving an accessible market of a sufficient size (i.e., tens of millions of households) and diversity to have a material impact in the context of economy-wide climate targets.

Assessing an Example: Google's Nest Renew

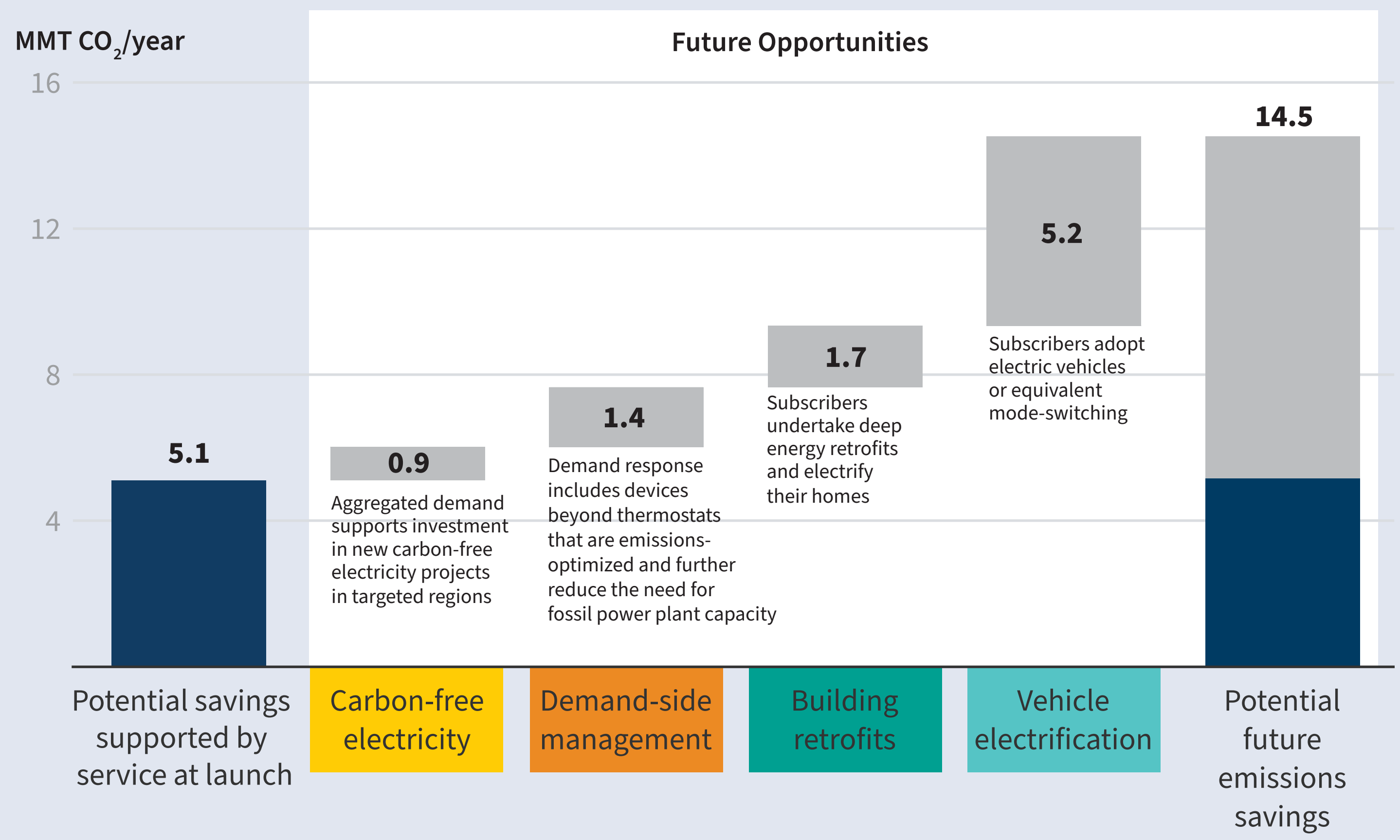
In October 2021, Google announced Nest Renew, a service that is free to join and provides customers with features that enable demand response and energy efficiency. For subscribers who choose to pay for access to the Premium tier, Google will also source renewable energy credits to match the subscribers' estimated fossil fuel-based electricity consumption. RMI was invited to review Nest Renew and independently assess its potential impact in the context of the opportunities and challenges associated with meeting economy-wide decarbonization as described above.

We find that with an illustrative subscriber count of 1 million customers, the Premium tier of the service as defined at launch could reduce customers' CO_2 emissions by approximately 5 million metric tons per year (Exhibit ES3). The majority of subscribers' near-term emissions reductions come from renewable energy generation, supported by purchasing renewable energy credits matched to their estimated fossil electricity consumption. A lesser though still significant amount of reductions come from the deployment and use of technology for demand response and energy efficiency enabled by the free service tier.

Beyond launch, a service like Nest Renew has the potential to build upon immediately available emissions savings and scale its carbon impact significantly. By leveraging the household-specific insights and economies of scale associated with subscriber growth to support more material household energy decisions, a service like Nest Renew can more than double potential emissions savings for its subscribers. Exhibit ES3 shows indicative potential associated with four categories of additional savings that can be supported by the evolution of the service through time, building on the savings immediately available to subscribers at launch:

- **Carbon-free electricity:** Aggregated subscriber demand enables support for new renewable energy projects within grid regions where wind and solar generation can offset the most-polluting fossil fuel power plants.
- **Demand-side management:** Enabling emissions-based energy management for more residential end-use loads (i.e., water heaters and EV chargers) can increase both direct and indirect emissions benefits of demand response.
- **Building retrofits:** Household-specific data and offers can unlock deep energy efficiency savings far in excess of that available from smart thermostats and other devices.
- **Vehicle electrification:** Understanding of driving needs and patterns can support households in transitioning to the use of an electric vehicle or equivalent mode-switching (e.g., public transit) to reduce emissions from internal combustion-based vehicles.

Exhibit ES3 **Emissions savings supported by a service like Nest Renew, per 1 million subscribers**



Unlocking the Opportunity

Nest Renew, both as defined by Google at launch and the potential it represents for deeper emissions savings as the service evolves, is an example of the opportunity at hand for household products to support ambitious climate targets. The service has an opportunity to set an example of a scalable, accessible, nationally relevant business that enables deep emissions savings for each participating household—breaking into the upper-right quadrant of Exhibit ES2 in a way that few, if any, residential offers have been able to do to date.

While a service or product like Nest Renew, either from Google or another solutions provider, has the potential to unlock material emissions savings, its potential can be expanded dramatically. This can be done by both broadening the scope of services offered to participating customers (e.g., enabling deep energy retrofits) and delivering these benefits to a larger customer base that represents all types of households.

Exhibit ES4 **How residential decarbonization products and services can help us reach US climate targets**

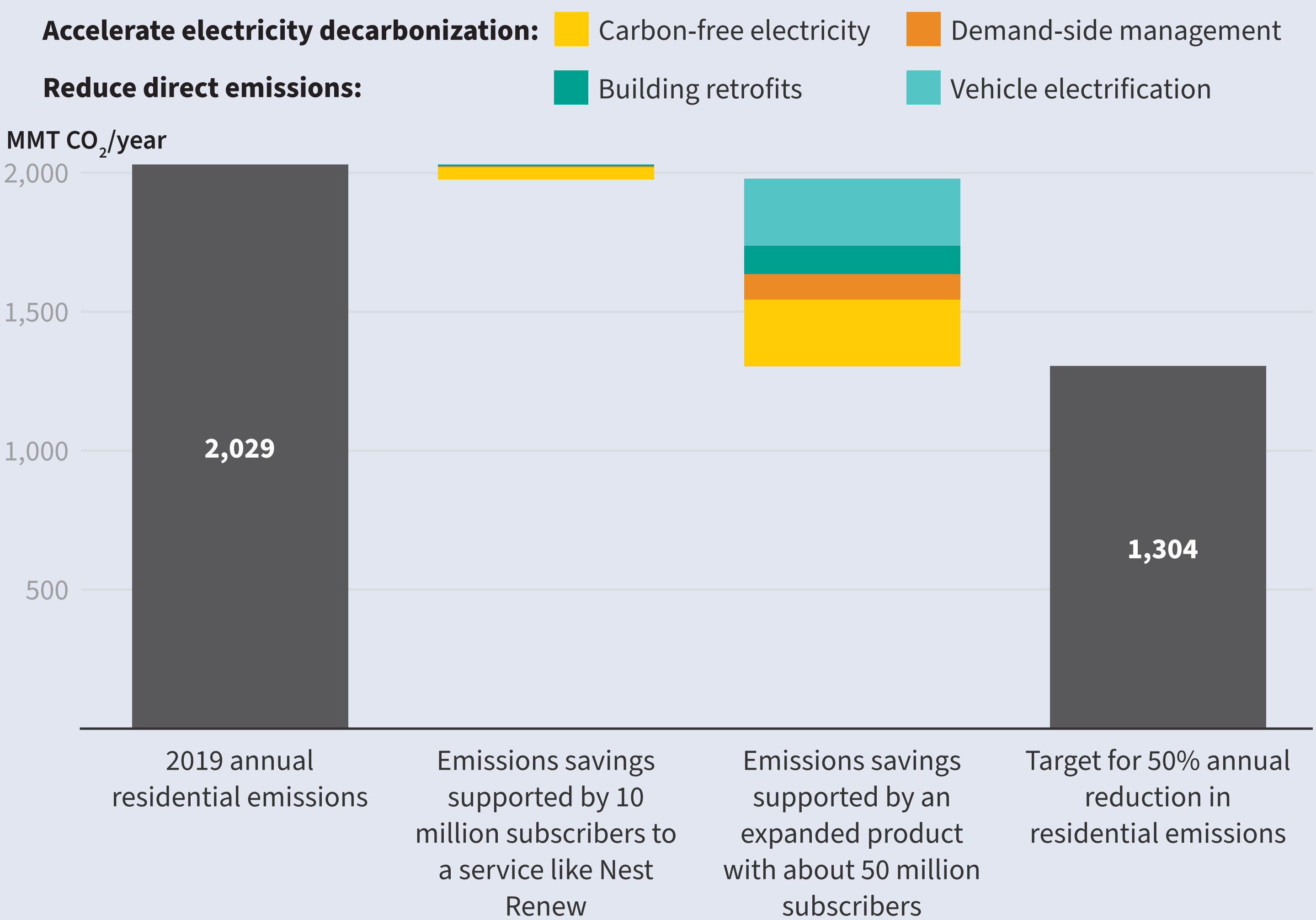


Exhibit ES4 summarizes the emissions impact of a service like Nest Renew in the context of a pathway to a 50% reduction in annual residential emissions for household energy use. At an indicative market size of 10 million subscribers—approximately equivalent to the total participation level in residential demand response programs in the United States in 2019—the renewable energy and demand-side management supported by a service like Nest Renew could reduce approximately 50 million metric tons of CO_2 per year. This is less than 10% of the gap between today's emissions and the at least 50% reduction that might be required to align with the NDC. A fully realized service or product, offering a broader scope of services to five times as many subscribers, could fully bridge the gap between today's household energy emissions levels and an annual level of residential emissions supportive of the NDC.

To unlock this level of emissions savings for 50 million households, both solutions providers and the policymakers, regulators, and utilities who shape the markets in which they operate must act, quickly and in coordination, to break down barriers to adoption for all households. Delaying action or impeding innovation to overcome today's barriers will result in a significant missed opportunity for households themselves to accelerate the energy transition and realize its benefits where they matter most—in our homes.

Introduction

Catalyzing the Clean Energy Transition from Our Homes

Over the next decade, we face an opportunity to radically change how energy is produced, delivered, and used across the entire economy, including within our homes. With more than 120 million households in the United States, the residential sector is one of the largest consumers of energy. We consume electricity when we turn on our lights and use appliances, we burn fossil gas directly when we heat and cook, and we burn gasoline when we drive our vehicles. All of these actions produce carbon emissions that need to be reduced significantly to avoid the most catastrophic impacts of climate change.

Positioning households to lead on decarbonizing our economy can both enable rapid emissions reductions and support improving critical human needs including health, resilience, and equity of access to energy services. Energy is essential for today's households: we require heating and cooling in the face of increasingly extreme weather; we require electricity for internet and communications for our jobs, education, and emergencies; many of us require electricity for life-sustaining medical devices; and increasingly we will need electricity to power our vehicles and enable mobility. These needs are especially vital for households that have experienced disproportionate harm from the legacy, fossil fuel-based energy system and have limited access to today's cleaner solutions.[1]

There is a set of presently available options for reducing emissions associated with household energy decisions, but innovations are needed to speed currently slow rates of adoption, align deployment with the urgency required by the climate crisis, and meet the needs of a diverse set of households. Today's options face significant barriers to rapidly scaling and providing benefits to all customers, including those most likely to experience harm from climate change. These barriers can result from broader utility and regulatory frameworks, where often incentives and operations do not always align with accelerating residential decarbonization solutions.

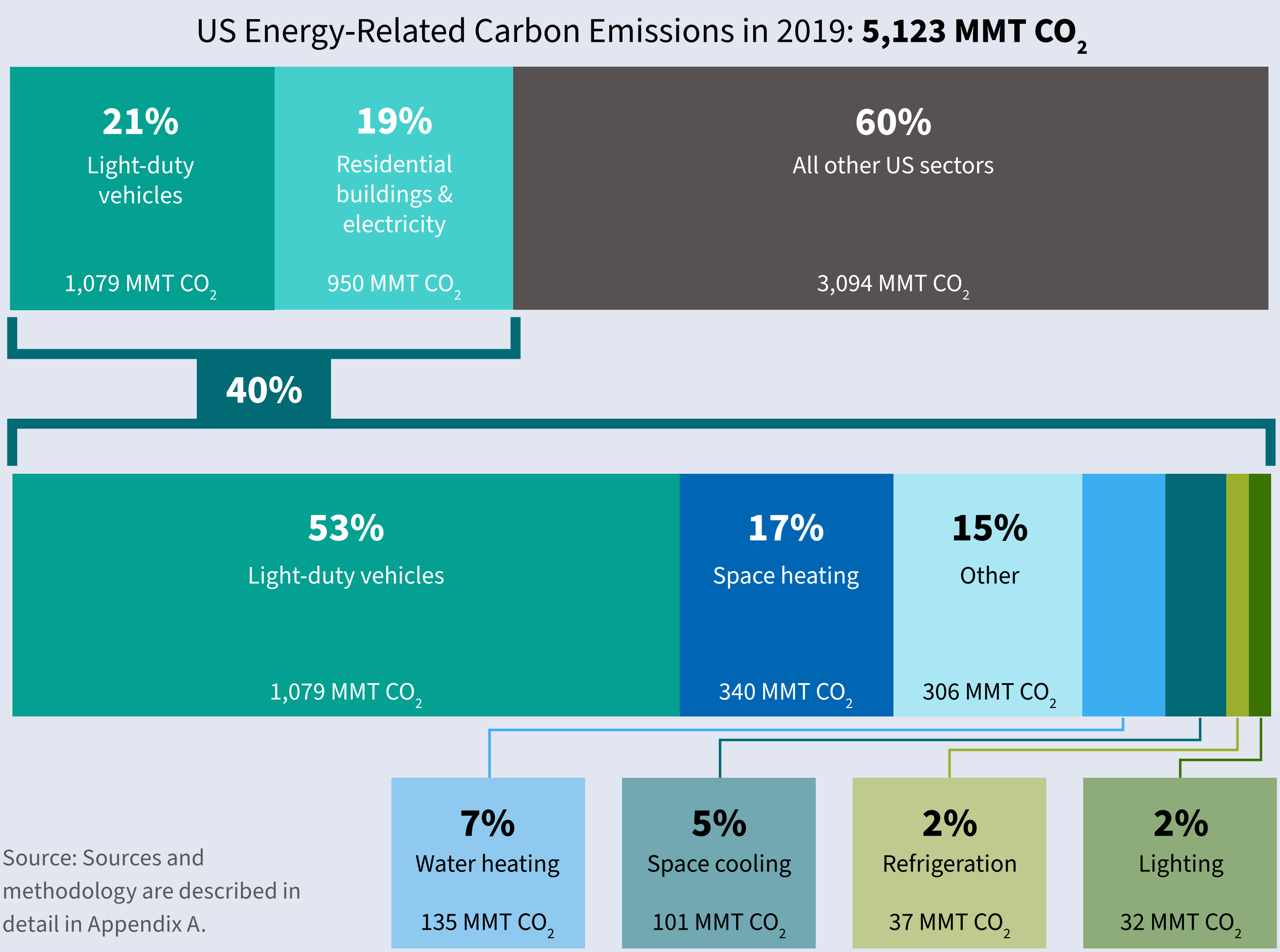
In this report, we describe the challenges, opportunities, barriers, and emerging solutions associated with aligning household energy decisions with ambitious climate policy targets. We conclude with recommendations for solutions providers, policymakers, regulators, and utilities, and an assessment of an example household energy service that could help unlock clean energy for American households.

1. The Challenge

Aligning Household Emissions with Climate Targets

Household-level energy decisions, including home and vehicle energy use, drive about 40% of US energy-related carbon emissions—21% from gas-powered vehicles and 19% from residential building and electricity usage. A wide variety of household energy decisions contribute to the residential sector's share of greenhouse gas emissions. These include where a household's electricity is sourced; the hourly patterns of electricity consumption; the choice of energy source used for space heating, water heating, and cooking; and whether personal vehicles are fueled by gasoline or charged with electricity. Exhibit 1 shows the share of emissions driven by household energy decisions, and the breakdown of those emissions across household energy uses.

Exhibit 1 **Residential sector emissions, 2019**

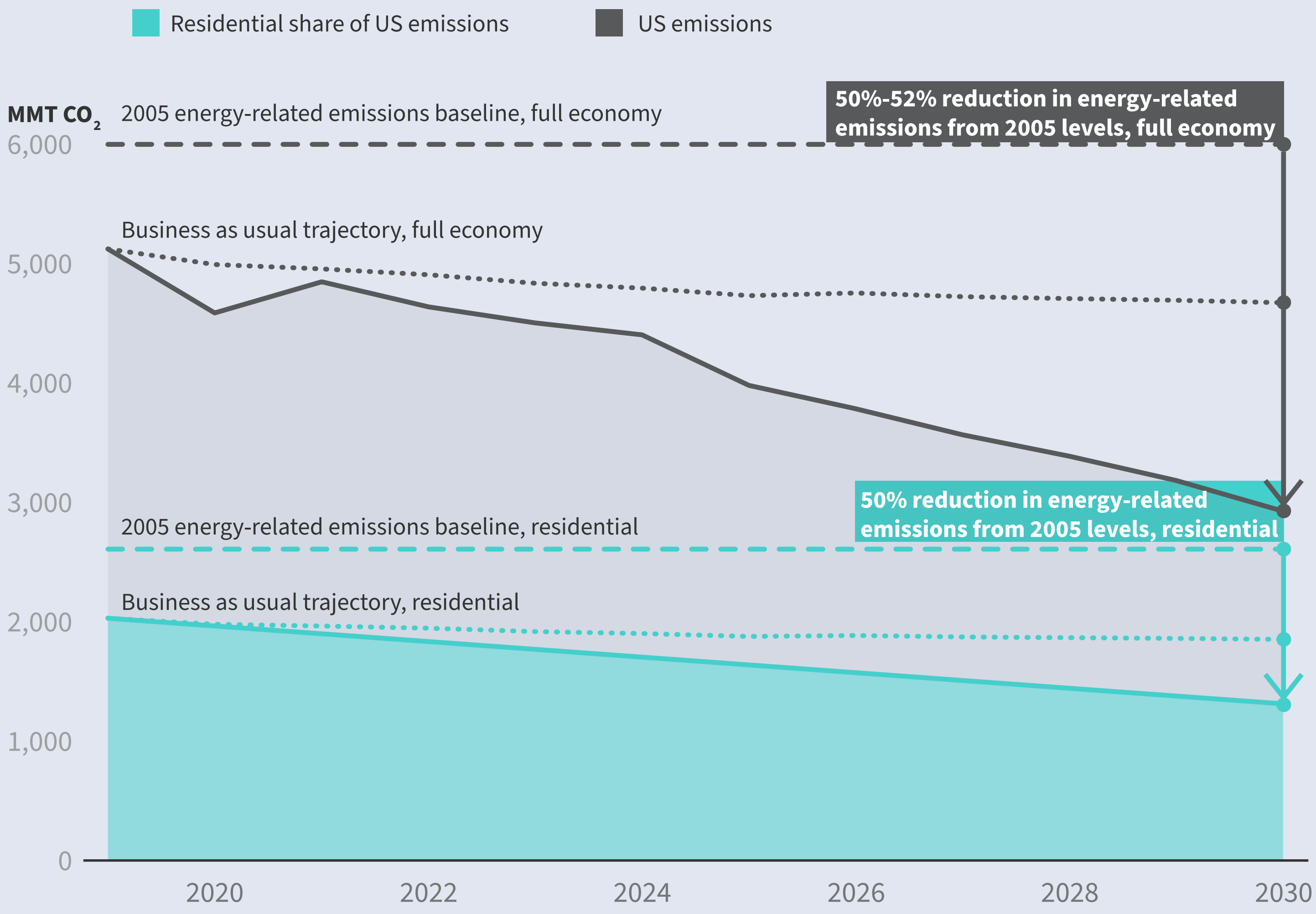


Source: Sources and methodology are described in detail in Appendix A.

Without fundamental shifts in how we produce and use energy across the economy, energy use will continue to produce emissions above scientifically recommended thresholds for climate safety. The Intergovernmental Panel on Climate Change calls for limiting global temperature rise to 1.5˚C (2.7˚F) to avoid the worst climate impacts.[2] This means that global anthropogenic greenhouse gas emissions need to be reduced by at least 50% from 2005 levels by 2030—within the next eight to nine years—and fall to near zero by 2050.

On a business-as-usual (BAU) path, the United States is set to reduce energy-related CO_2 emissions by 22% from 2005 levels by 2030, far less than implied by the US nationally determined contribution (NDC) of a 50%–52% reduction[3] (as seen in Exhibit 2). Given that household energy use drives 40% of energy-related CO_2 emissions, there is an opportunity for residential customers to lead in accelerating solutions that can bring emissions in line with climate targets. To impact this trajectory, residential emissions most likely need to at least fall in line with or exceed this economy-wide emissions reduction target—achieving a 50% or greater reduction in emissions.

Exhibit 2 **US energy emissions reductions required by 2030 to reach US climate targets**



Source: Sources and methodology are described in detail in Appendix A.

2. The Opportunity

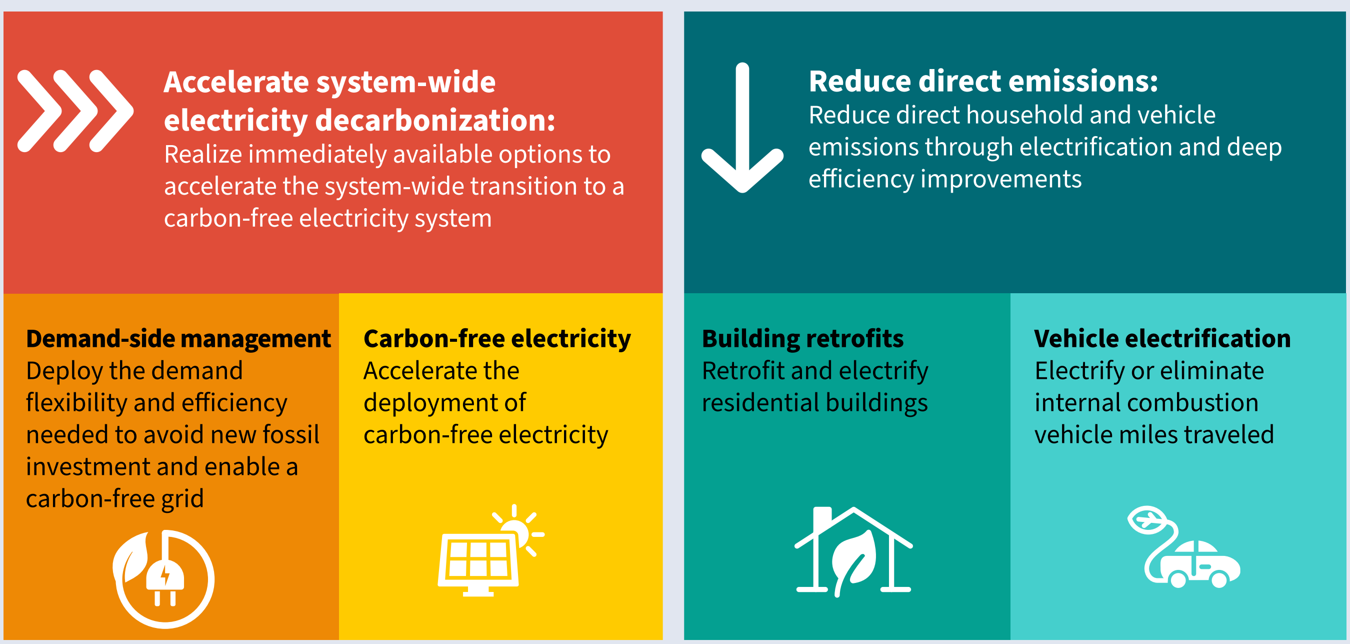
Options for Decarbonizing Household Energy Use

There are clear solutions today for households to lead on reducing emissions to align with ambitious climate targets and realize the benefits of the energy transition. In this chapter, we describe two main categories of household energy decisions that can contribute to climate-aligned emissions reductions.

First, households can accelerate the system-wide transition to carbon-free electricity by deploying the demand-side management and efficiency necessary to avoid new fossil investment, and by using collective buying power to deploy new carbon-free electricity generation. While households may feel removed from the utility and policy decisions driving their electricity-related emissions, there is a clear opportunity to improve access to and meet latent demand for carbon-free electricity.[4]

Second, households can reduce direct emissions from fossil fuels by dramatically increasing the energy efficiency of homes, electrifying appliances that burn fossil fuels, and reducing the miles traveled in gasoline vehicles through mode-switching (e.g., transit or alternate mobility solutions) and switching to electric vehicles.

Exhibit 3 **What is needed to align residential energy-related CO_2 emissions with US climate targets**



Achieving these outcomes will require deploying technologies in the home or otherwise making household decisions that prioritize energy efficiency and carbon-free electricity. Many of today's options, described in Exhibit 4, can enable the outcomes described above, but are not accessible to all households across housing types, geographies, and income brackets.

Exhibit 4 **Examples of presently available household options**

Accelerate system-wide electricity decarbonization	**Demand-side management** Deploy the demand flexibility and efficiency needed to avoid new fossil investment and enable a carbon-free grid	• Install smart electric end-use devices like thermostats, air conditioners, and flexible water heaters and enroll in demand response programs • Opt for a time-of-use rate, and adjust behavior accordingly • Install residential energy storage
	Carbon-free electricity Accelerate the deployment of carbon-free electricity	• Enroll in a green pricing program or green retail product • Sign up for a community solar subscription • Install rooftop solar PV
Reduce direct emissions	**Building retrofits** Retrofit and electrify residential buildings	• Invest in deep, building envelope energy efficiency measures • Electrify gas end uses in the home by installing heat pumps, heat pump water heaters, and electric cooking
	Vehicle electrification Electrify or eliminate internal combustion vehicle miles traveled	• Reduce miles traveled in internal combustion engine (ICE) vehicles through mode-switching • Switch to an electric vehicle

This chapter characterizes a level of ambition of household decision-making and technology deployment consistent with reducing household emissions by 50% from 2005 levels by 2030, the same percentage reduction required for overall greenhouse gases (GHGs) as targeted by the NDC. Achieving at least a 50% reduction in residential emissions represents a scenario where households are playing a key role in the transition and investments have been prioritized to enable residential solutions to meet economy-wide climate targets.

Exhibit 5 lays out illustrative, sector-specific outcomes, roughly consistent with projected outcomes from policies or programs under discussion by policymakers and advocates at state and federal levels, which together enable a 50% reduction in residential energy-related emissions. Exhibit 6 summarizes illustrative emissions reductions by sector and the associated level of technology deployment implied by these sector-specific outcomes.

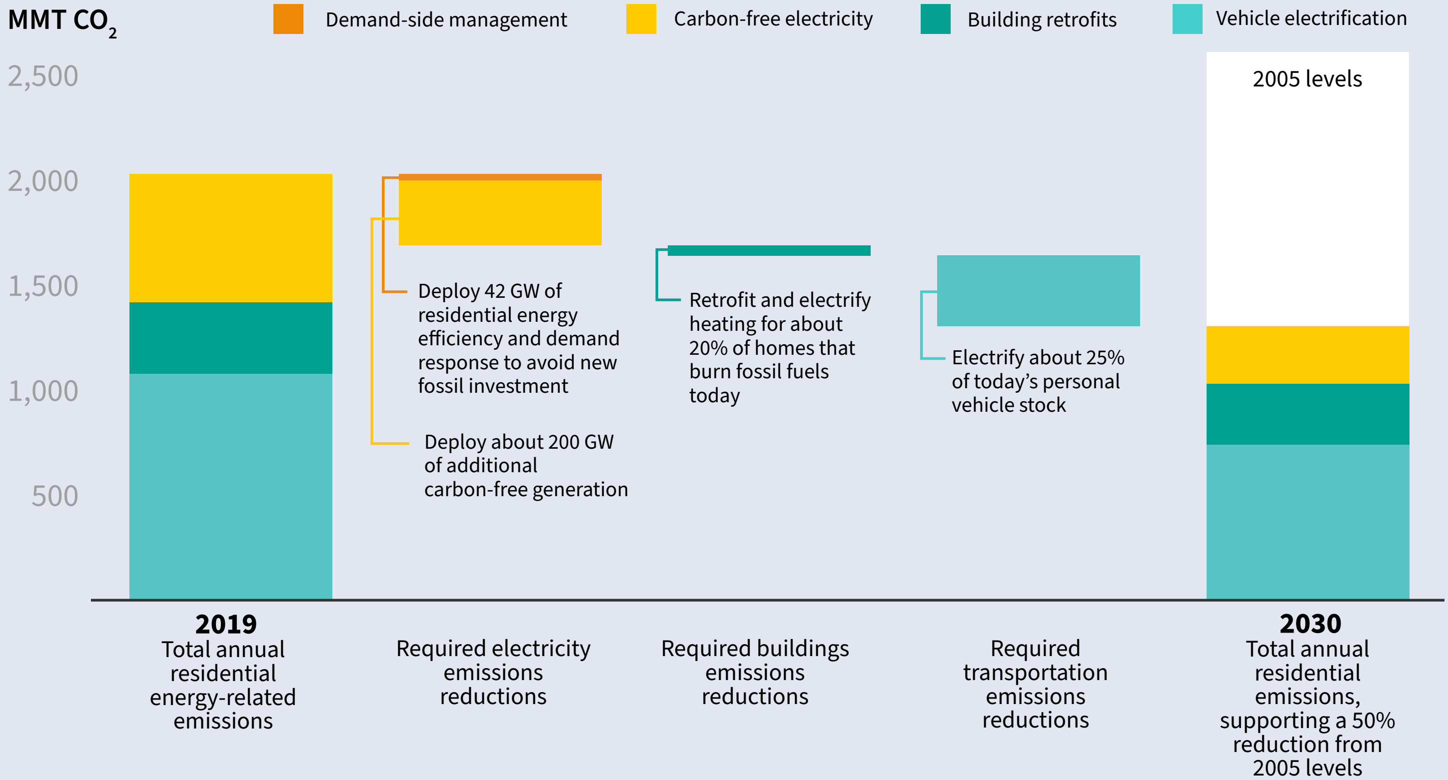
Exhibit 5

Components of a residential emissions pathway that together lead to a 50% reduction in energy-related CO_2 emissions from 2005 levels by 2030

Accelerate system-wide electricity decarbonization	**Demand-side management**	Reducing electricity sector emissions from residential energy use by **about 70% from 2005 levels by 2030 (56% from 2019 levels)**
	Carbon-free electricity	
Reduce direct emissions	**Building retrofits**	Reducing direct residential building emissions by about **20% from 2005 levels by 2030 (14% from 2019 levels)**
	Vehicle electrification	Reducing transportation emissions from personal vehicles by about **45% from 2005 levels by 2030 (31% from 2019 levels)**

Exhibit 6

Indicative actions to reach a 50% reduction in residential energy-related CO_2 emissions from 2005 levels by 2030



Source: Sources and methodology are described in detail in Appendix A.

Accelerating the System-Wide Transition to a Carbon-Free Electricity System

Reducing emissions associated with residential electricity use by about 70% from 2005 levels by 2030 can be accomplished by investing in both demand-side and supply-side solutions.

Demand-Side Solutions

At least 30 GW of peak-aligned residential energy efficiency and 12 GW of residential demand response could be deployed as part of "clean energy portfolios" to retire coal and avoid new gas-fired power plants.[5,i] These equate to 4% and 2% of the all-time US coincident peak, respectively.[6] Keeping aging fossil fuel plants online or building new ones at the levels currently reflected in utilities' planning documents are incompatible with emissions reductions targets in the electricity sector.[7] Investing in incremental energy efficiency and demand response resources can minimize the need for fossil fuel power plants, and complement other carbon-free electricity resources like wind and solar to accelerate overall grid decarbonization.

Supply-Side Solutions

After demand-side resources, approximately 208 GW of new carbon-free electricity generation could be deployed to support a 70% reduction in residential electricity sector emissions. This is equivalent to the

[i] A pathway to net zero by 2050 for the United States has ~90 GW less coal and gas capacity than a business-as-usual pathway by 2030, per Princeton University's *Net-Zero America* report (2020). We estimate that the residential DR and EE required to build a least-cost clean energy portfolio that displaces this fossil generation capacity are equivalent to 13% and 33%, respectively, of the avoided thermal capacity, based on RMI's 2019 report.

annual energy consumption of approximately 51 million homes today (out of about 128 million households in the United States). This can be met through the rapid deployment of wind, solar, and storage to replace existing fossil fuels on the grid and meet emerging needs from new electrified homes and vehicles.

Households can be a catalyst to accelerate carbon-free electricity deployment. As corporates have demonstrated through their investment in clean energy over the past decade, aggregation of demand has the potential to drive clean energy investment.[8]

Reducing Direct Emissions from Buildings and Vehicles

Reducing direct emissions from buildings by about 20% is equivalent to retrofitting 12 million homes and electrifying an additional 12 million homes that currently burn fossil fuels for heating today. Retrofitting our homes to be less leaky and to keep in more heat with improved insulation reduces the amount of heating needed, reducing gas consumption, and therefore reducing direct residential building emissions. Moreover, fuel switching and electrifying residential buildings decreases emissions from natural gas heaters by using electricity instead—and that electricity can be carbon-free.

Reducing emissions from personal vehicles by about 45% is equivalent to electrifying 65 million of today's light-duty vehicles (LDVs)—over a quarter of the current LDV stock in the United States.[9] As electric vehicles gain popularity and momentum, they will play a critical role in reducing direct emissions from personal vehicles and eliminating combustion vehicle miles traveled, while also providing demand flexibility and other grid services to maximize the value of new wind and solar energy projects.

The Role of Ambitious Policy

Exhibit 7 outlines a set of ambitious policies that have the potential to achieve the illustrative, residential sector-specific emissions reductions outcomes outlined above. Together, these policies can help meet the overall goal of at least a 50% reduction in annual residential emissions in support of economy-wide NDC targets.

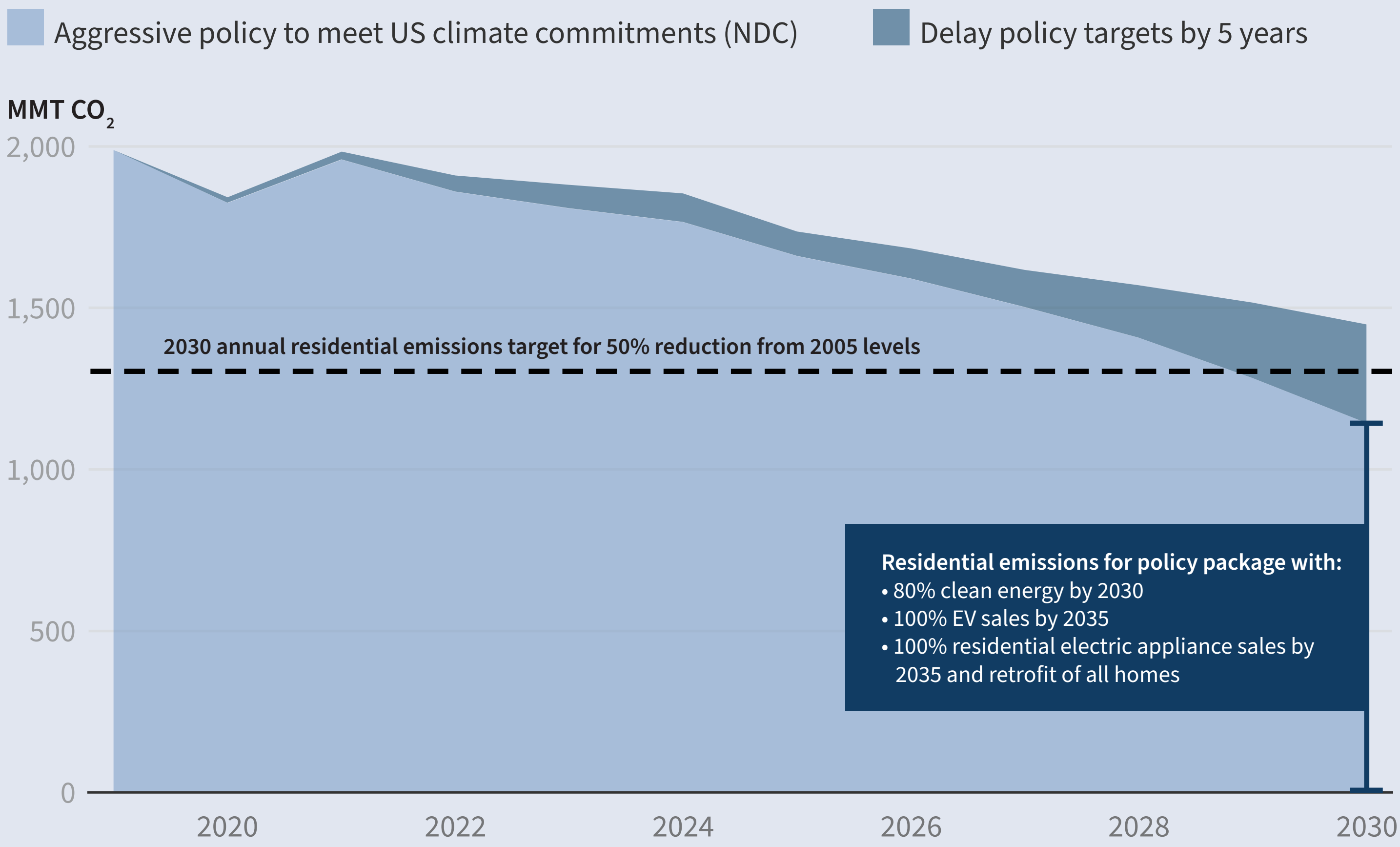
Exhibit 7 **Example policies to enable a 50% reduction pathway for residential emissions in support of US climate targets**

Illustrative component of emissions reductions	Example of policy consistent with achieving the reduction
Reducing electricity sector emissions from residential energy use by about 70% from 2005 levels by 2030 (56% from 2019 levels)	A clean energy standard specifying 80% carbon-free electricity by 2030
Reducing direct residential building emissions by about 20% from 2005 levels by 2030 (14% from 2019 levels)	A requirement for all-electric new appliance sales by 2035 and extensive support for existing home retrofits
Reducing transportation emissions from personal vehicles by about 45% from 2005 levels by 2030 (31% from 2019 levels)	A mandate requiring zero-emissions vehicles to be 100% of sales by 2035

However, even if these policy targets are aligned with NDC-consistent outcomes, policies will need to be implemented quickly to achieve emissions reductions at the pace required. Exhibit 8 illustrates the increased emissions associated with delaying achievement of targets by five years; in total, failing to meet targets on time would drive residential emissions well above the levels needed for a 50% reduction in 2030. To realize ambitious policy targets on time, we need catalytic solutions to transform the market and unlock technology adoption for all households.

Exhibit 8

Impact of delayed implementation of policies on meeting 50% reduction in residential emissions by 2030



Source: Sources and methodology are described in detail in Appendix A.

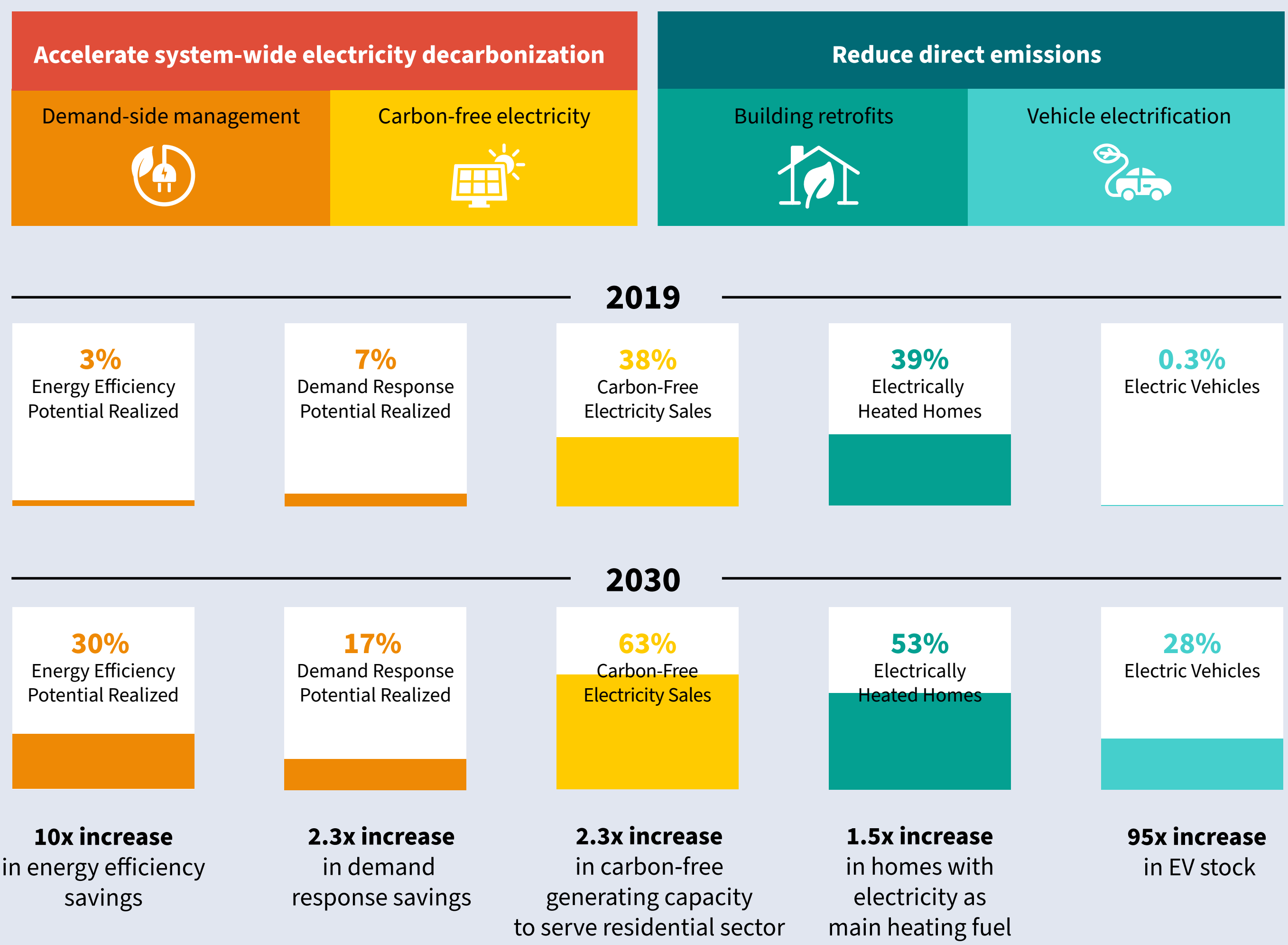
3. Barriers

The Need for Market Catalysts to Address Adoption Challenges

Activating the transformation described in the previous chapter will require overcoming significant barriers to household adoption that exist today. While a set of presently available options to households can accelerate decarbonization, most of these options have had limited adoption or slow growth. Exhibit 9 illustrates technology-specific adoption trajectories that build from the illustrative scenario in Exhibit 6 to achieve a 50% reduction in residential emissions. Each technology has a significant opportunity to grow by 2030.

Exhibit 9

Indicative adoption levels of key technologies consistent with achieving 50% emissions reductions targets



Source: Sources and methodology are described in detail in Appendix A.

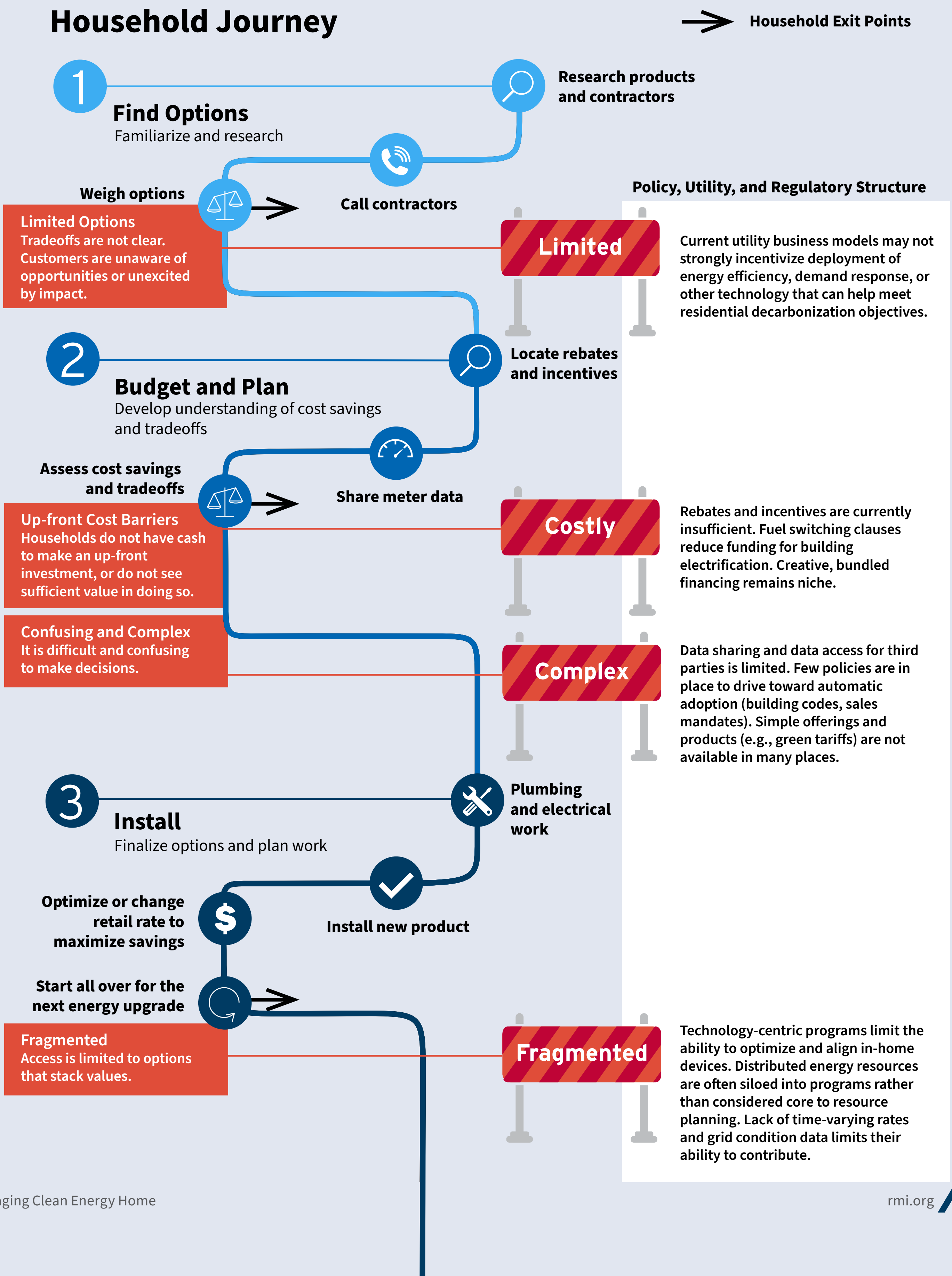
These adoption opportunities mirror household preferences to make progress on clean energy. Polls indicate that people would like to see the president (60%), corporations (70%), Congress (60%), state and local government (52%, 54%), and citizens themselves (64%) do more to address climate change.[10] But present adoption rates for key technologies indicate that there are few widely accessible options to apply this desire for more climate action into impact.

Realizing the adoption growth depicted in Exhibit 9 and meeting latent demand for climate-aligned household energy solutions will require overcoming barriers both in the experience of technology adoption for households and in the regulatory and policy frameworks that underlie their feasibility and cost.

Direct Barriers to Household Adoption

Four key barriers to decarbonization limit the feasible pace of technology adoption. Namely, readily available solutions for decarbonizing household energy use are limited, costly, complex, and/or fragmented. These barriers result in an experience of making climate-aligned household energy decisions today that can be daunting. Exhibit 10 illustrates the steps in a household's journey toward making energy use decisions that will materially reduce household-related emissions, and the categories of barriers that present challenges along the way.

Exhibit 10 **Navigating direct household barriers to decarbonization**



Limited: Households have limited options for decarbonization today in many geographies and housing types. They may also have limited awareness or understanding of the options that are available and their impacts. The levels of adoption depicted in Exhibit 9 demonstrate that most of these solutions have not yet moved beyond niche into the mass market.

Renters may not have access to some of the more widely available products, such as smart thermostats or EV charging. Availability of options for clean energy and demand response varies widely across geographies—at least 28 states do not have green pricing programs for residential customers, 36 states do not have enrollment of residential customers in community choice aggregation programs (CCAs) or alternative retail providers, and some states do not allow power purchase agreements (PPAs) for rooftop solar.[11]

Costly: High costs, especially first costs (i.e., initial investment requirements), limit adoption of some clean energy solutions for many households. For example, depending on geography, the costs of fully retrofitting a home to electrify space heating, driving, and water heating end uses can come at a net cost to households, without policy intervention, on the order of $2,000 to $8,000 per year, according to research by Rewiring America.[12] The cost of measures such as deep energy retrofits may be difficult for households to predict given significant variation across housing vintage, housing type, and local climate—even total retrofit costs in a single state (Ohio) varied from $10,000 to $50,000 across households.[13] Mechanisms to reduce first-cost barriers, such as on-bill financing, are not ubiquitous—they are only offered by about 110 utilities across the country.[14]

Complex: There is no clear roadmap for most households trying to make climate-aligned energy decisions. Many impactful household decisions such as installing rooftop solar, storage, heat pumps, or EV charging equipment require interested individuals to locate available rebates, identify capable contractors, coordinate electrical and/or plumbing work, complete local inspections, and more, as depicted in Exhibit 10. Even single steps of the process, such as identifying knowledgeable contractors for electrification upgrades, can be nontrivial. Decisions that may be simpler—such as installing smart thermostats or enrolling in a utility program—may still require multiple approval steps and enabling third parties to access customer usage data. Further, households have few resources for understanding how to optimize the timing and benefits of options across electric vehicle purchases, appliance and household upgrades, devices, program options, and rate designs available to them.

Fragmented: In most instances today, people retrofit their homes, switch out devices, and enroll in utility programs independently. While this approach alleviates some up-front spending and lends itself to incremental education, it fails to capture the benefits of a bundled or coordinated approach. For example, pursuing deep energy retrofits before switching from gas to electric heating can reduce the size of needed appliances, and coordinating all electric work for upgraded, electric appliances (e.g., EV chargers, heat pumps, dryers, and induction stoves) can provide incremental soft cost savings.[15]

Barriers in Policy, Regulation, and Utility Operations

The regulatory and policy environment in many states can limit household access to decarbonization options, and exacerbates the direct barriers described above. The regulatory and policy landscape sets a critical foundation to either challenge or support customers in leveraging their autonomy and decision-making to reduce household-related carbon emissions.

Limited: Regulators, utilities, and market operators largely determine the options available to households for accelerating the transition to carbon-free electricity. If utilities in a state are not incentivized to deliver energy or cost savings outcomes, they may offer more limited options. For example, utilities that have an incentive for growing energy sales may not be motivated to offer their residential customers an array of energy efficiency programs. Options for residential access to carbon-free electricity such as community solar or green tariffs have been authorized on a state-by-state or utility-by-utility basis.

Costly: Regulators, utilities, and market operators can influence the economics of household options through rates, incentives, programs, and financing. Households in states or utility service territories that have not put incentives, programs, or financing in place for residential decarbonization may face stronger first-cost or cost barriers to adoption. This limits not only near-term adoption but also the potential for market transformation that can deliver self-sustaining and cost-effective technology adoption.[16] For example, households in 24 states do not have access to incentives or rebates for in-home electric vehicle charging equipment, and people in 39 states do not have access to rebates for electric vehicles.[17] Conversely, many states or utilities still have incentives in place for households to adopt new fossil fuel-powered appliances, such as new gas furnaces.

Complex: Regulators, utilities, and market operators can make it more complicated for households to adopt new solutions. For example, 27 states do not have a clear framework for residential utility customers to provide third parties with access to energy usage data to help them identify promising solutions.[18] Policies that focus on standardization or automatic adoption of solutions, such as building codes or fuel-switching policies requiring all-electric new homes, are rare. For example, only 10 states encourage fuel switching in buildings through policies, guidelines, or fuel-neutral goals.[19]

Fragmented: State regulators, utilities, and market operators today influence the extent to which household decarbonization solutions can provide meaningful value to the grid, their community, or their own energy bills. For example, only 46% of households across the United States have access to time-based pricing, so they can understand and choose to respond to the time value of energy. Several wholesale market operators have yet to align rules to allow aggregations of behind-the-meter resources to participate in energy markets.

4. Customer Solutions

The Opportunity for Innovation to Address Direct Barriers to Household Adoption

It is critical to address these structural barriers in the places where they persist today in policy, regulation, and utilities, as shown on the right side of Exhibit 10. However, solutions providers can work in parallel to dramatically reduce the barriers to the household experience of decarbonization shown on the left side of Exhibit 10 and support utilities and regulators to improve and expand access to offerings within existing constructs. This chapter summarizes principles and emerging tools for overcoming direct household adoption barriers, and the potential emissions savings and benefits of these solutions deployed at scale.

Principles and Tools for Overcoming Direct Barriers to Household Adoption

Emerging innovation in technology and marketing makes it possible for solutions providers to address many of the direct barriers households face when making energy decisions. Four design principles can enable residential energy solutions that directly address the barriers presently limiting adoption of clean energy technologies, as depicted in Exhibit 11.

Targeted

Choices for decarbonization are available and apparent to households, and the opportunities that will most benefit the individual's circumstances are clear.

Affordable

All households can afford decisions that enable household decarbonization, including those with low and fixed incomes.

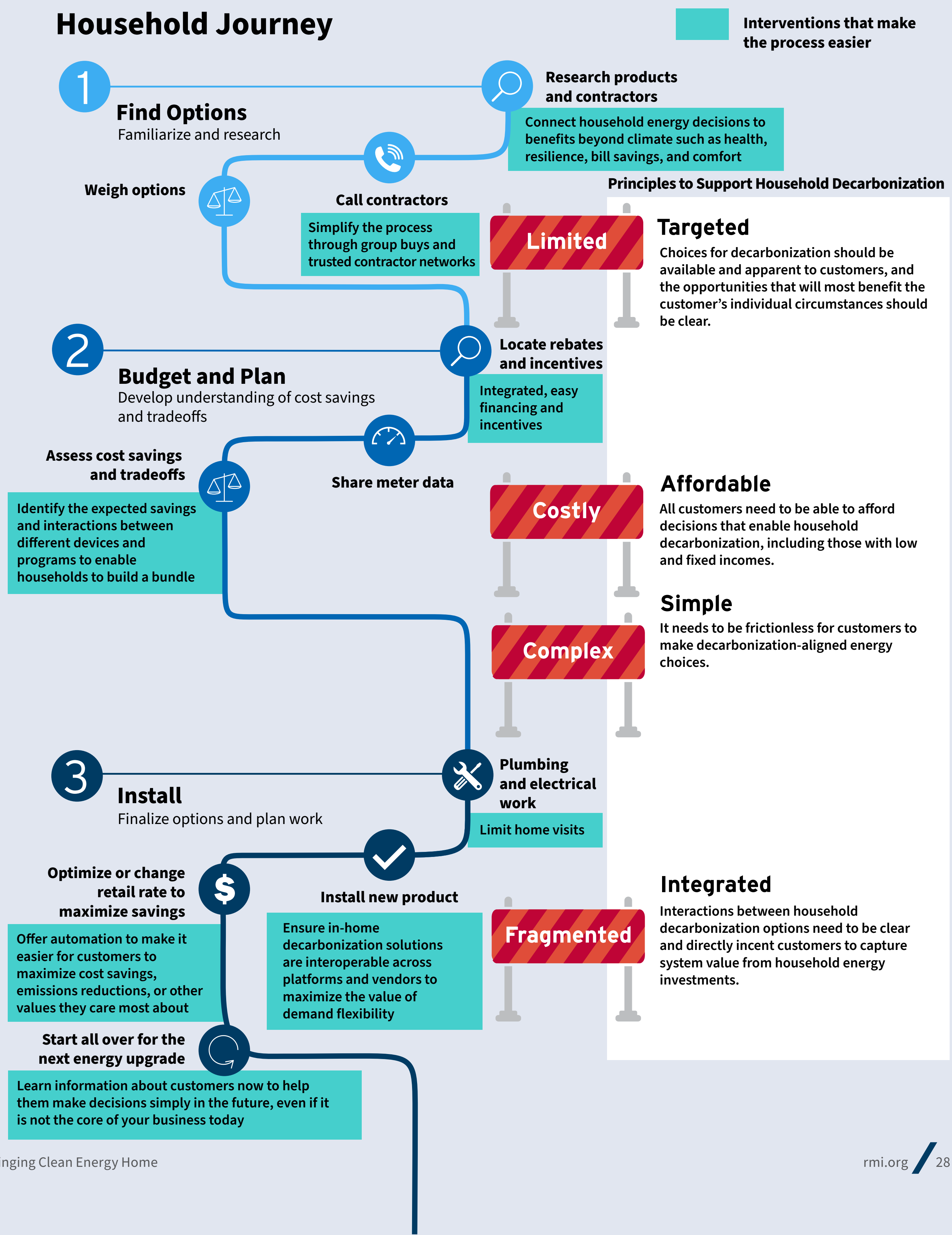
Simple

It is frictionless for households to make decarbonization-aligned energy choices, versus the status quo of having to choose between many disconnected programs through multi-step processes.

Integrated

Interactions between residential decarbonization options are clear to households, and price signals or programs directly incent people (or their aggregators) to capture grid value from their energy investments.

Exhibit 11 **New solutions to support household decarbonization**



Putting the Principles into Action

The remainder of this chapter describes how the opportunities described above can be applied to increase adoption of key residential technologies, enabling households to lead on achieving emissions reductions and realize the outcomes they care most about in their homes and communities.

Opportunity for Application #1: Minimizing Fossil Generation by Scaling and Integrating Demand Response and Energy Efficiency

Each of the principles and associated tools outlined above can help grow residential adoption of incremental energy efficiency and demand response technologies by 2–10 times (Exhibit 9) to support a 50% reduction in residential emissions:

- **Customized insights and offers:** Recommending demand response and energy efficiency programs based on housing type, projected savings, and existing devices.
- **Automation and optimization:** Automating control of flexible loads in response to grid emissions signals or price signals, co-optimized with a household's comfort, cost-savings, or emissions-savings objectives.
- **Aggregation and collective action:** Aggregating devices to enable participation in electricity markets, which can increase potential to avoid fossil generation at scale.
- **Deployment innovation:** Bundling demand flexibility with energy efficiency, carbon-free electricity products, or other major electrification investments (e.g., purchase of an EV or water heater).

Examples of Emerging Applications with High Impact Potential

Automated emissions reductions (AER): Automated emissions reduction, where demand response is implemented to reduce marginal grid emissions, holds the potential for demand response to have a greater impact on air pollution and health. Several pilots are underway using AER signals to reduce CO_2 and other harmful pollutants such as mercury.[20] There is ample opportunity to create AER signals that target local health outcomes and enable households to support those outcomes through automated load shifting. Analysis by RMI in 2017 found that AER deployed for common household and commercial end uses could reduce CO_2 emissions by the equivalent of 1 million cars.[21]

Integrated demand-side management programs: While traditionally energy efficiency and demand response have been separate programs, devices like smart thermostats and mobile applications are bridging the divide.[22] For example, new algorithms and understanding of household comfort make it possible to save energy through lowering or raising temperature setpoints on a seasonal basis (energy efficiency) and to reduce peak heating or cooling loads at times of grid strain (demand response). Integrated programs can ensure that savings for both energy efficiency and demand response are maximized, rather than conflicting across programs, and may be able to increase overall peak reduction compared with separate programs. Early examples of integrated programs have reported high levels of customer satisfaction and reduced program administrator costs compared with individual program delivery.[23]

Opportunity for Application #2: Accelerating Carbon-Free Electricity through Scaled Deployment Models

Aggregation of carbon-free electricity demand across large numbers of homes has the potential to enable construction of new capacity and lead to material CO_2 reductions. New financing and deployment models can also help meet the target of building two to three times more carbon-free capacity for residential end use that would be needed to achieve a 50% reduction in total residential emissions. New technology and marketing innovations could support this outcome through:

- **Customized insights and offers:** Providing households with actionable options for carbon-free electricity based on their priorities (cost, impact, resilience) and nudging them to enroll in presently available options.
- **Automation and optimization:** Leveraging remote ledgers and tracking to credit households for remote generation (e.g., community solar, virtual power purchase agreements).
- **Aggregation and collective action:** Aggregating residential demand for deployment of new, additional carbon-free electricity projects.
- **Deployment innovation:** Offering households options beyond undifferentiated renewable energy credits (RECs) from legacy projects that enable them to accelerate the pace of change in the electricity system by supporting new investments.

Examples of Emerging Applications with High Impact Potential

Prioritizing carbon-free electricity projects with the largest benefits: Aggregating residential demand to build new carbon-free electricity projects in regions with low existing levels of carbon-free electricity can have outsized benefits. These benefits include 1) providing immediate and lasting direct emissions reductions by offsetting emissions in the dirtiest grids, and 2) opening up these markets to renewable energy industry investment, creating networks, jobs, and infrastructure that can scale quickly beyond the first projects. Aggregating residential demand can help break open markets for these pathbreaking projects and lay the groundwork for further industry growth. Putting new renewables onto the dirtiest grids can displace up to 2.5 times as many tons of carbon as placing them on the cleanest grids over the course of a year.[ii]

Making renewable energy credits (RECs) more material: There are emerging opportunities to raise the bar for what a REC does with respect to bringing new renewables onto the grid, and to provide households with a higher-impact option. Procuring RECs on a forward basis could enable contracted revenues to contribute to financing new projects and cost-efficiently address the “missing money” problem that otherwise limits renewable project development.

[ii] Using EPA’s online AVERT tool, 100 MW of wind and 100 MW of solar in California displaces 186,840 metric tons of CO_2. And 100 MW of wind and 100 MW of solar in the Central region of the United States displaces 482,790 metric tons of CO_2. See **https://www.epa.gov/avert/avert-web-edition** for more.

Opportunities for Applications #3 and #4: Minimize Household and Vehicle Emissions through Streamlined, Tailored Support for Major Electrification and Efficiency Decisions

Technology and marketing can accelerate market transformation and enable mass adoption of major household energy upgrades, electric appliances, and electric vehicle purchases through:

- **Customized insights and offers:** Providing households with recommendations for electric appliances and vehicles that include anticipated savings based on past usage and behavior; reinforcing and "nudging" stock turnover decisions for appliances and cars to ensure that a greater share of new sales are electric.
- **Automation and optimization:** Optimizing electric appliances and vehicle charging within the home; automating finding and processing of rebates relevant to the household.
- **Aggregation and collective action:** Using scale from aggregated purchasing to build contractor networks, create jobs, and drive down product and installation costs for all households.
- **Deployment innovation:** Developing standard bundles of energy efficiency and electrification upgrades, coupled with integrated financing and program (e.g., EE, DR, time-of-use rate) enrollments.

Examples of Emerging Applications with High Impact Potential

Lighter-touch audits: There are emerging opportunities to identify customized portfolios of energy efficiency upgrades and electric appliances—and their expected costs and savings—prior to a full, in-home audit. Using data to identify housing type and vintage, and analyzing home videos and photos, can help reduce the time needed to design deep energy retrofit packages or recommend appropriate appliances.

Growing and fostering smart contractor networks: The network of contractors familiar with the benefits and installation of electric appliances and electric vehicle chargers will need to be vastly expanded to scale building electrification at the pace required. Contractor networks can be scaled more rapidly through direct access to aggregations of households that have made commitments to electrify their appliances. In addition to scaling, businesses can support their contractor networks by incentivizing education and awareness of zero-carbon options, and encouraging contractors to collect information that can lead to insights about future decisions that benefit households when they perform installations. Clean Energy Connection is an example of an emerging contractor network in California.[24]

5. Utility and Regulatory Solutions

The Opportunity for Utilities and Regulators to Accelerate Adoption

Innovative products and services for homes can support utilities and regulators to meet emissions and social impact goals more rapidly today. Yet, changes to the regulatory and utility environment have the potential to unlock even greater speed, scale, and equity of deployment. While much is possible today, scaling the solutions described in Chapter 4 to meet ambitious climate targets and scale benefits to all households will be best supported by change from regulators, utilities, and market planners and operators.

This chapter highlights opportunities for regulators, grid planners, and market operators to align incentives, market rules, and planning processes to accelerate deployment of emerging solutions for household decarbonization.

Regulatory and Utility Innovation to Unlock Change

Regulators and utilities have a set of emerging tools they can apply to support rapid scaling of household solutions for decarbonization:

Adjust utility incentives and processes to maximize integration of demand-side resources

- **Regulators** can realign utility earnings toward meeting household objectives such as improving health, supporting emissions reductions, increasing resilience, and reducing energy burden (e.g., through performance-based regulation).
- **Utilities** can update planning practices to identify and operationalize opportunities for customers to derive value from integrating DERs.

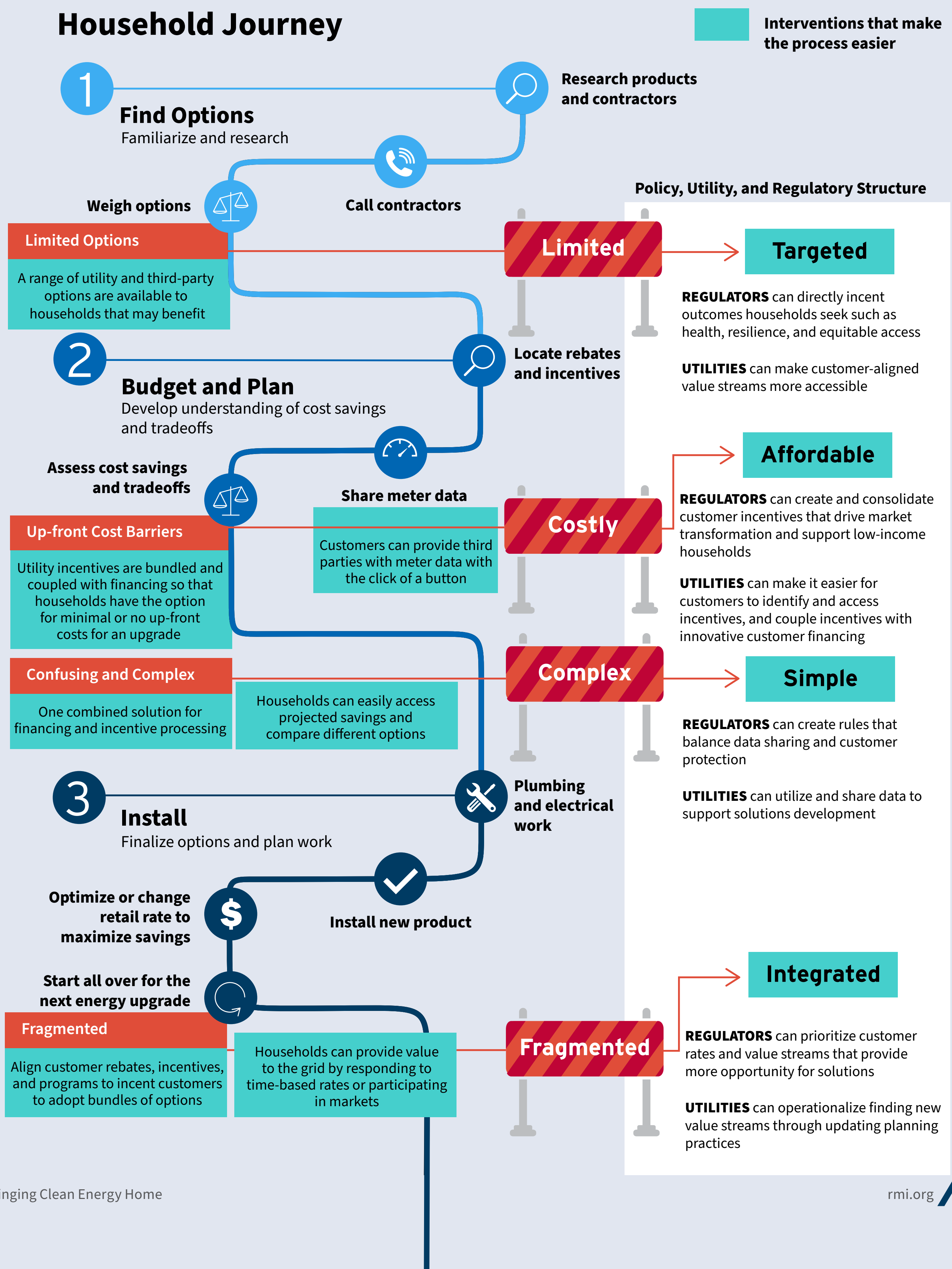
Align residential incentives, programs, and rates with decarbonization objectives and household benefits

- **Regulators** can create and consolidate residential incentives and programs and make solutions more affordable, especially for low-income households.
- **Utilities** can make it easier for people or third parties to identify and access incentives, couple incentives with innovative financing and rate structures, and ensure that households have access to impactful options with limited up-front or ongoing costs.

Enable data access and transparency

- **Regulators** can create rules that balance data sharing and customer protection and that provide solutions providers with the information they need to innovate.
- **Utilities** can use and share data in ways that support developing residential decarbonization solutions.

Exhibit 12 Applying regulatory and utility innovation to accelerate adoption



Utilities and regulators can apply these innovations to address barriers to adopting technologies that support households to decarbonize and enable solutions providers to deliver customers products and programs that are targeted, affordable, simple, and integrated.

Specific Opportunities and Examples of Application

Given the fragmented nature of the US electric utility industry, tools for implementing regulatory and utility changes to address structural barriers may only be applicable to certain types of utilities or market structures. In the next few sections, we indicate where the options are most applicable:

Exhibit 13 **Types of utilities and market operators**

Organization type	Applicability of identified opportunities
Vertically integrated utilities	Utilities that may own and operate generation, transmission, and distribution assets, or state regulators of vertically integrated utilities.
Poles and wires utilities	Utilities that do not own generation, but may own and operate transmission and distribution assets, or state regulators of primarily poles and wires utilities.
Restructured markets	Regional transmission operators or independent system operators that coordinate generation in an organized energy market, or the Federal Energy Regulatory Commission.

Adjust utility incentives and processes to maximize integration of demand-side resources

Regulators can realign utility earnings toward meeting household objectives such as improving health, supporting emissions reductions, increasing resilience, and reducing energy burden through performance-based regulation. Reducing bias toward capital investments is particularly important for unlocking greater adoption of demand-side resources in homes and participation by third parties like aggregators and virtual power plant operators. The most common way that regulators have realigned utility incentives is through implementation of comprehensive or incremental performance-based regulation, such as performance incentive mechanisms (PIMs) that tie utility compensation to specific outcomes and decoupling.[25]

In wholesale markets, aggregation of home devices for market participation holds great promise but faces many practical barriers today. Simplifying rules for market participation, compensation, and access can provide solutions providers with more certainty around revenues, and enable them to raise the capital needed to rapidly scale this business model.

Exhibit 14

How regulators can adjust utility incentives and processes to maximize integration of demand-side resources

How regulators might apply this tool	Applicability			Examples in practice
	Vertically integrated utilities	Poles and wires utilities	Restructured markets	
Implement PIMs that encourage utilities to pursue outcomes that homes can support (e.g., for strategic demand reduction, DER deployment, resilience, customer engagement).	x	x		Hawaii's Public Utility Commission identified several emergent societal outcomes that will be tied to utility compensation in its proceeding on performance-based regulation, including acquisition of grid services through DERs and deploying energy efficiency for low- and moderate-income households.[26] These performance incentive mechanisms will incent the utility to enable more customer participation and increase adoption of household decarbonization solutions.
Reduce capital bias through decoupling or equalization of earnings on operational expenditures to level the playing field for customer-sited solutions and third-party participation.	x	x		
Eliminate practical barriers to DER participation in restructured markets.			x	Testimony provided by the DR Coalition—a group of solutions providers—outlines the many practical challenges that DR providers have faced in California. Their recommendations include but are not limited to: implementing new baselining methodologies, lifting procurement caps for IOUs, and allowing providers to manage their own rebate processes.[27]

Utilities can update planning practices to identify and operationalize opportunities for households to derive value from integrating demand-side resources. Planning is critical to identifying where and how homes can provide the most value to the system-wide transition, and how the system-wide transition can most benefit households. Planning should prioritize both understanding grid needs and understanding home and community needs in order to find opportunities for projects that are mutually beneficial. Emerging best practices for considering DER values should be applied to integrated resource planning, integrated grid/systems operation planning, or integrated distribution planning.

Exhibit 15

How utilities can adjust processes to maximize integration of demand-side resources

<table>
<tr><th rowspan="2">How utilities might apply this tool</th><th colspan="3">Applicability</th><th rowspan="2">Examples in practice</th></tr>
<tr><th>Vertically integrated utilities</th><th>Poles and wires utilities</th><th>Restructured markets</th></tr>
<tr><td>Integrate DERs into integrated resource planning or transition to an integrated grid planning approach to identify where household solutions can provide the most system value.</td><td>x</td><td></td><td></td><td rowspan="2">In Oregon, resource planning rules require utilities to procure all cost-effective demand-side resources before proceeding with procurement of other supply-side resources.[28]

Hawaiian Electric in Hawaii is in the process of pursing comprehensive integrated grid planning coordinating generation, transmission, and distribution system planning into one process. The process expands the opportunity for non-wires alternatives to provide transmission and distribution services.[29]

The California Public Utilities Commission (CPUC) requires utilities to develop distribution resource plan proposals that identify optimal locations for distribution energy resources in all planning, operations, and investment decisions.[30]</td></tr>
<tr><td>Implement distribution system planning to identify where household solutions can provide the most system value.</td><td>x</td><td>x</td><td></td></tr>
<tr><td>Operationalize competitive procurement or tariff structures that enable DERs to meet grid needs and open up opportunities for third-party participation.</td><td>x</td><td>x</td><td></td><td>Glendale Water & Power in Glendale, CA, released a competitive solicitation for alternatives to repowering a gas plant. DERs, including residential solar + storage and energy efficiency, were chosen as part of the least-cost portfolio.

The California Partnership Pilot proposed by the CPUC outlines a tariff-based "pay as you go" procurement pilot that would replace the existing "all at once" RFO process. The new pilot would allow customer-sited DERs to be individually and incrementally rewarded for their grid value based on three- and five-year load forecasts, conducted annually.[31]</td></tr>
</table>

Where these opportunities are actionable:

- Only 13 states currently (CA, CT, HI, IN, MA, MI, MS, NY, OH, RI, TX, WI, VT) have PIMs for strategic demand reduction.[32]
- Only 17 states are decoupled for electric utilities.[33]
- Only CO and WA require all-source competitive procurement.[34] WA's rules specifically include demand-side resources and efficiency as resources that can participate in an all-source RFP.[35]
- At least 18 utility programs have implemented tariffs for DERs that open up a role for third-party aggregation.[36]
- At least nine states (CA, CT, HI, MA, NY, MD, MI, MN, OR) have established requirements and processes for distribution system planning or integrated system planning.
- Most states in MISO and SPP currently prohibit market participation by third-party aggregators.

Align residential incentives, programs, and rates with decarbonization objectives and household benefits

Regulators can create and consolidate residential incentives, programs, and rates and make solutions more affordable for low-income households. Currently, residential programs may be constrained by out-of-date cost-effectiveness tests that constrain the ability to fund electrification programs or programs that produce benefits beyond cost, or the ability to develop integrated value streams across resources.

Exhibit 16

How regulators can align residential incentives, programs, and rates with decarbonization objectives and household benefits

How regulators might apply this tool	Applicability			Examples in practice
	Vertically integrated utilities	Poles and wires utilities	Restructured markets	
Update cost-effectiveness tests and fuel-switching rules to ensure that DER and electrification benefits are adequately captured in design of utility residential customer programs, and that multiple or aggregated DERs can be considered.	x	x		Rhode Island updated its benefit-cost framework from 2016–2018 to include 34 different costs and benefits that reflect impacts to utility customers, the power system, and society. The list of benefits includes low-income participant benefits—defined to include improved comfort and property value durability—and societal low-income impacts—defined to include reduced disconnections and poverty alleviation.[37] National Grid has applied this BCA in their System Reliability Procurement Plans[38] and Energy Efficiency Plans.[39]
Expand access to low-income incentives for decarbonization, including home and vehicle electrification.	x	x		In early 2020, the Sacramento Municipal Utility District (SMUD) updated its energy efficiency program investment metrics to switch from energy savings to avoided carbon emissions to support expanded electrification programs.[40]

Utilities can make it easier for people or third parties to identify and access incentives, couple incentives with innovative financing, and ensure that households have access to impactful options with limited up-front or ongoing costs. New solutions, such as on-bill financing and bridge financing, can reduce up-front costs for households and developers who may not have capital to undertake projects without rebates or incentives in hand.

Exhibit 17

How utilities can align residential incentives, programs, and rates with decarbonization objectives and household benefits

How regulators might apply this tool	Applicability			Examples in practice
	Vertically integrated utilities	Poles and wires utilities	Restructured markets	
Couple programs with innovative financing such as on-bill financing for households or bridge financing for developers to reduce first-cost barriers.	X	X		California created unique bridge financing through the Golden State Finance Authority to expedite deployment of solar and storage to households that most need it. The fund provides up-front cash to developers (on behalf of homeowners) to cover the cost of equipment purchase and installation while they are waiting for reimbursement from the incentive program.[41]
Create cross-functional program and rate design teams within utilities and integrate program funding streams across DERs to reduce program administrator costs and maximize customer benefits.	X	X		Program administrators in California, Hawaii, New York, and Detroit identified integration of program budgets and teams as a key opportunity for delivering integrated DSM programs in a survey.[42]
Work with local partners to improve incentives and access to residential programs and rates, especially for underrepresented housing types such as multifamily homes and renters.	X	X		In Minneapolis, the City has two programs that work together to incentivize rental property owners to implement efficiency upgrades, keep rents low, and enhance the health of tenants. Costs for the programs are shared between the City and utilities.[43]

Where these opportunities are actionable:

- Eleven states (AR, AZ, KS, LA, MN, OK, PA, SC, TX, WA, WV) have rules prohibiting or discouraging funding for fuel-switching programs that can be addressed.[44]
- Sixteen states do not have state requirements or utility programs for low-income energy efficiency programs.[45]
- Fifteen states plus D.C. do not have state requirements or utility programs for on-bill financing.[46]
- A survey of 2017 filings identified only 22 programs that integrated energy efficiency and demand response across the 50 largest utilities, indicating that many do not have such programs today.[47]

Enable data transparency and access

Regulators can define frameworks for data access to activate the market. In order for solutions providers to innovate, they often need access to utility energy and billing data, system data, and aggregated community-level data. Regulators can play a leading role in standardizing the process, protections, and security requirements to ensure that this data can be accessed by third parties and households themselves.

Exhibit 18

How regulators can enable data transparency and access

How regulators might apply this tool	Applicability			Examples in practice
	Vertically integrated utilities	Poles and wires utilities	Restructured markets	
Develop frameworks for sharing utility energy and billing data, system data, and aggregated data.	x	x		The New York State Public Service Commission (PSC) adopted a data access framework in April 2021. The data access framework order requires the state's utilities to make system data available, creates a process for sharing aggregated data, and defines types of utility customer data that can be made accessible. [48]
Make time-based pricing and emissions data accessible to solutions providers and customers with adequate protections.	x	x		Since 2007, ComEd in Illinois has offered residential customers hourly pricing, which has saved participants $23 million, and 58,193 metric tons of CO_2.[49] The transparency of this pricing enables its residential customers and solutions providers to develop solutions that enable them to save money and carbon. In California, the Self-Generation Incentive Program now offers real-time and forecasted marginal emissions signals, which enable customer-sited batteries to charge and discharge without increasing overall grid emissions.[50]

Utilities and market operators can utilize and share data to support solutions development. There is an opportunity for utilities to use their advanced metering infrastructure (AMI) data to identify solutions that would most benefit households, and to make anonymized data available to third parties to accelerate and complement utility insights. Grid condition data—such as available hosting capacity and planned grid upgrades—can help providers generate creative solutions to arising grid problems or prioritize projects in locations with grid conditions that don't require additional upgrades. Real-time pricing and emissions data can help providers design products that maximize impact.

Exhibit 19

How utilities can enable data transparency and access

How regulators might apply this tool	Applicability			Examples in practice
	Vertically integrated utilities	Poles and wires utilities	Restructured markets	
Use AMI data (or enable solutions providers to use AMI data, with appropriate protection) to segment households and identify fit for decarbonization solutions.	X	X		Baltimore Gas & Electric (BGE) in Maryland has used its AMI to enroll all customers in its Smart Energy Rewards Program, which includes opt-out peak-time rebates.
Make grid condition data easily accessible to solutions providers, including hosting capacity.	X	X	X	Xcel Energy in Minnesota and Colorado is one of several utilities that has made distribution system data more accessible through a publicly available hosting capacity map. [51]

Where these opportunities are actionable:

- 56% of the country has AMI enabled for residential customers.[52]
- Only six states require utilities to provide energy usage data to customers, sixteen states have guidelines for third parties to access data if customers share access, and only ten of those states require utilities to provide the data upon request after customer authorization.[53]
- In 41 states, less than 5% of residential customers are enrolled in time-varying rates. Overall, 47.2% of customers in the United States have access to time-based pricing and 12.6% are enrolled.[54]
- As of 2020, there were no utilities with PIMs associated with leveraging AMI data. There were a few examples where leveraging AMI has been associated with shareholder compensation (e.g., BGE) or performance standards for AMI rollouts (e.g., SoCalGas).[55]
- Utilities in New York, California, Massachusetts, Maryland, Connecticut, Nevada, New Jersey, and Hawaii; Xcel Energy in Minnesota and Colorado; and Exelon for Pepco Holdings, PECO, and ComEd have made hosting capacity maps for grid conditions available.[56]
- California is the only known state that has adopted an emissions signal as part of a requirement for a state-wide incentive program and made it accessible through an API for devices to use.[57]

6. Assessing an Example

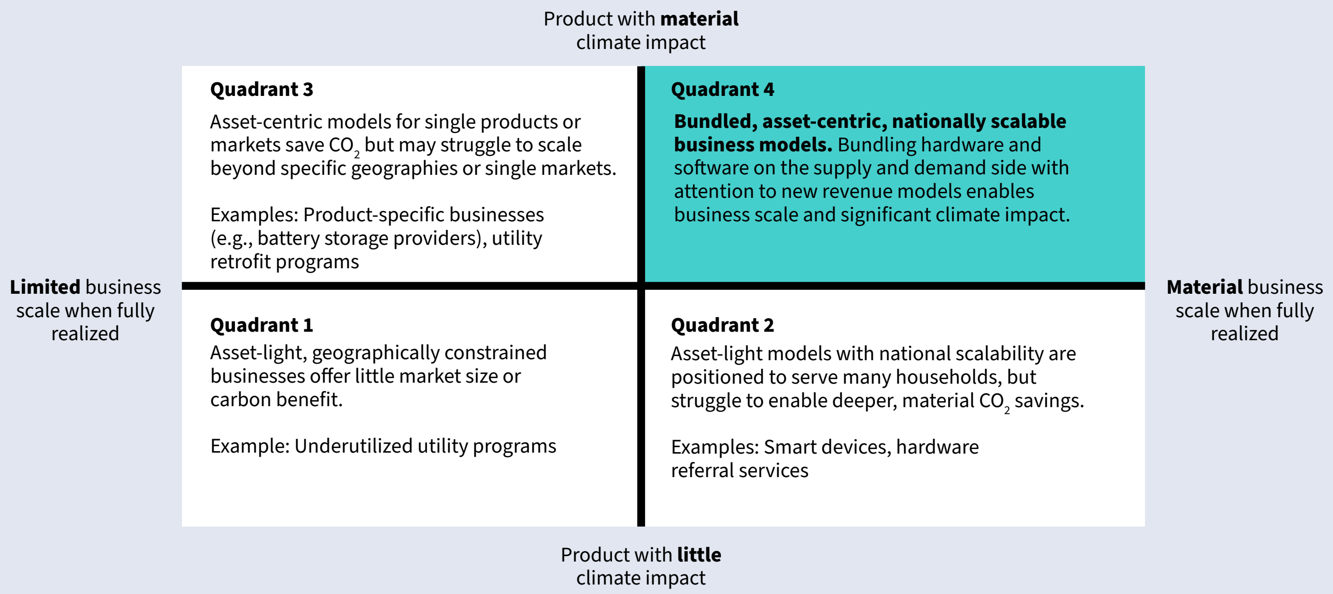
The Potential of a Service Like Google's Nest Renew to Unlock Market Opportunities for Household Energy Decarbonization

The Current Ecosystem of Residential Decarbonization Solutions

Currently, even without widespread adoption of the favorable policy and utility practices outlined above, there are many businesses that seek to support households in making climate-aligned energy decisions. But because of the limitations of policy and regulatory structures, these businesses generally have to balance climate impact (i.e., tons of CO_2 avoided per customer) with business scale. This tradeoff is depicted illustratively in Exhibit 20, where the x-axis represents the commercial scale of a business when fully realized (i.e., accessible market share), and the y-axis represents the materiality of climate impact delivered to each customer. Businesses can be categorized according to the quadrant they fall into:

- **Q1: Asset-light, geographically constrained businesses.** Businesses in this quadrant include REC-centric retail approaches for selling their customers carbon-free electricity offsets, and many utility hardware programs that are seldom used or do not produce deep savings (e.g., legacy demand response programs).
- **Q2: Asset-light models with national scalability.** Businesses in this quadrant are poised to serve many households but will struggle to enable material CO_2 savings. These include hardware referral services or sales of smart devices that have immaterial energy and emissions impacts.
- **Q3: Asset-centric models for single products or markets.** This quadrant includes businesses that are selling products with the potential for material climate impact, but that are constrained either by a single product focus or geography. Many hardware solutions offered by individual utilities within specific geographies (e.g., energy efficiency retrofits) or product-specific businesses with broad geographic scale (e.g., rooftop solar companies) fall into this category.
- **Q4: Bundled, asset-centric, nationally scalable business models.** There are few, if any, businesses that have emerged in this quadrant. Solutions providers in this quadrant will consolidate access to many different decarbonization products into a single touch point or service, use both hardware and software to engage customers, and scale across utility type, service territory, and housing type.

Exhibit 20 **Classification of business models for residential decarbonization**



Assessing Google's Nest Renew in the Context of Opportunities for US Climate Alignment

In October 2021, Google announced Nest Renew, a service that is free to join and provides customers with features that enable demand response and energy efficiency. For subscribers who choose to pay for access to the Premium tier, Google will also source renewable energy credits to match the subscribers' estimated fossil-fuel based electricity consumption. RMI was invited to review Nest Renew and independently assess its potential impact in the context of the opportunities and challenges associated with meeting economy-wide decarbonization as described above.

Exhibit 21 summarizes the key features of Nest Renew in the context of four principles for solving the direct adoption barriers currently limiting climate-aligned household energy decisions.

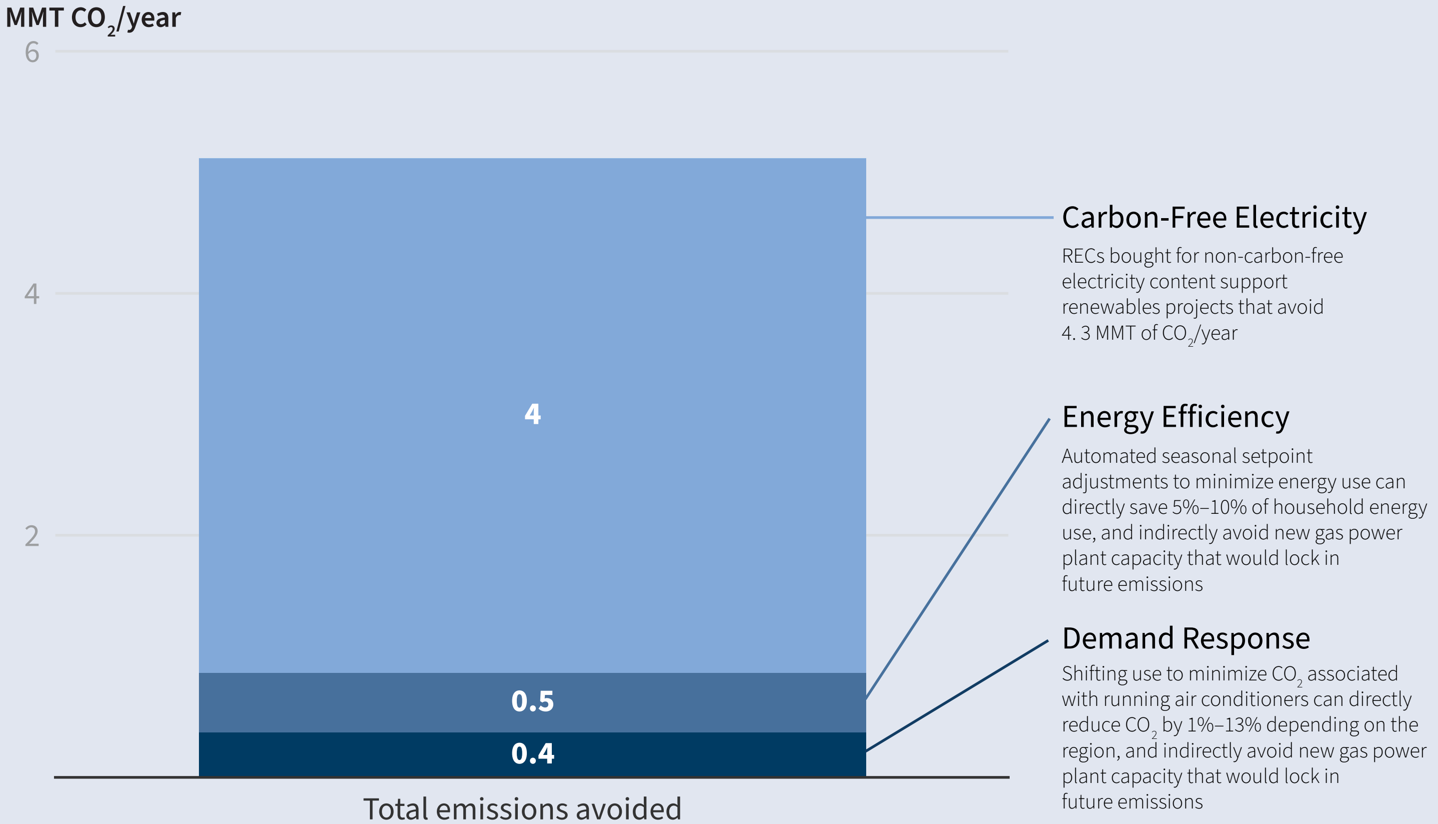
Exhibit 21 **How Nest Renew applies design principles for residential decarbonization**

Principles	How Nest Renew applies each principle
Simple	Emissions-based energy management will be automated per customer preference, with options for deeper customer control and engagement.
Affordable	Key features are available in the base tier, which is free to join. The Impact Program aims to provide financial support to a network of nonprofits working on expanding clean energy access, increasing energy affordability, and supporting clean energy careers.
Targeted	Customers will be able to access insights about their local grid mix. Energy management and energy efficiency through the service can be tailored to the individual's circumstances (e.g., time-of-use rates) or preferences (e.g., optimized for emissions).
Integrated	The service establishes a direct connection between household decisions and utility and grid value through demand response enrollment and emissions-aware energy management. Energy management, energy efficiency, and renewable energy credits are offered to customers in one service.

In addition to qualitatively assessing Nest Renew's features against design criteria for decarbonization, RMI also estimated the potential CO_2 savings associated with the services' adoption. We find that with an illustrative subscriber count of 1 million customers, the service as defined at launch could support renewable energy and energy management that reduce CO_2 emissions by approximately 5 million metric tons per year. The majority of subscribers' near-term emissions reductions come from renewable energy generation, supported by purchasing renewable energy credits matched to their estimated fossil electricity consumption. Lesser though still significant contributions come from demand response and energy efficiency. Exhibit 22 summarizes the scale of emissions savings available from each category of technology supported by the service.

Beyond launch, a service like Nest Renew has the potential to build upon immediately available emissions savings and scale its carbon impact significantly. By leveraging the household-specific insights to offer subscribers deeper savings opportunities and economies of scale associated with growth, a service like Nest Renew could more than double the potential savings it supports to approximately 14 million metric tons per year, for every 1 million customers enrolled.

Exhibit 22 **Emissions savings supported by a service like Nest Renew at launch, per 1 million subscribers**

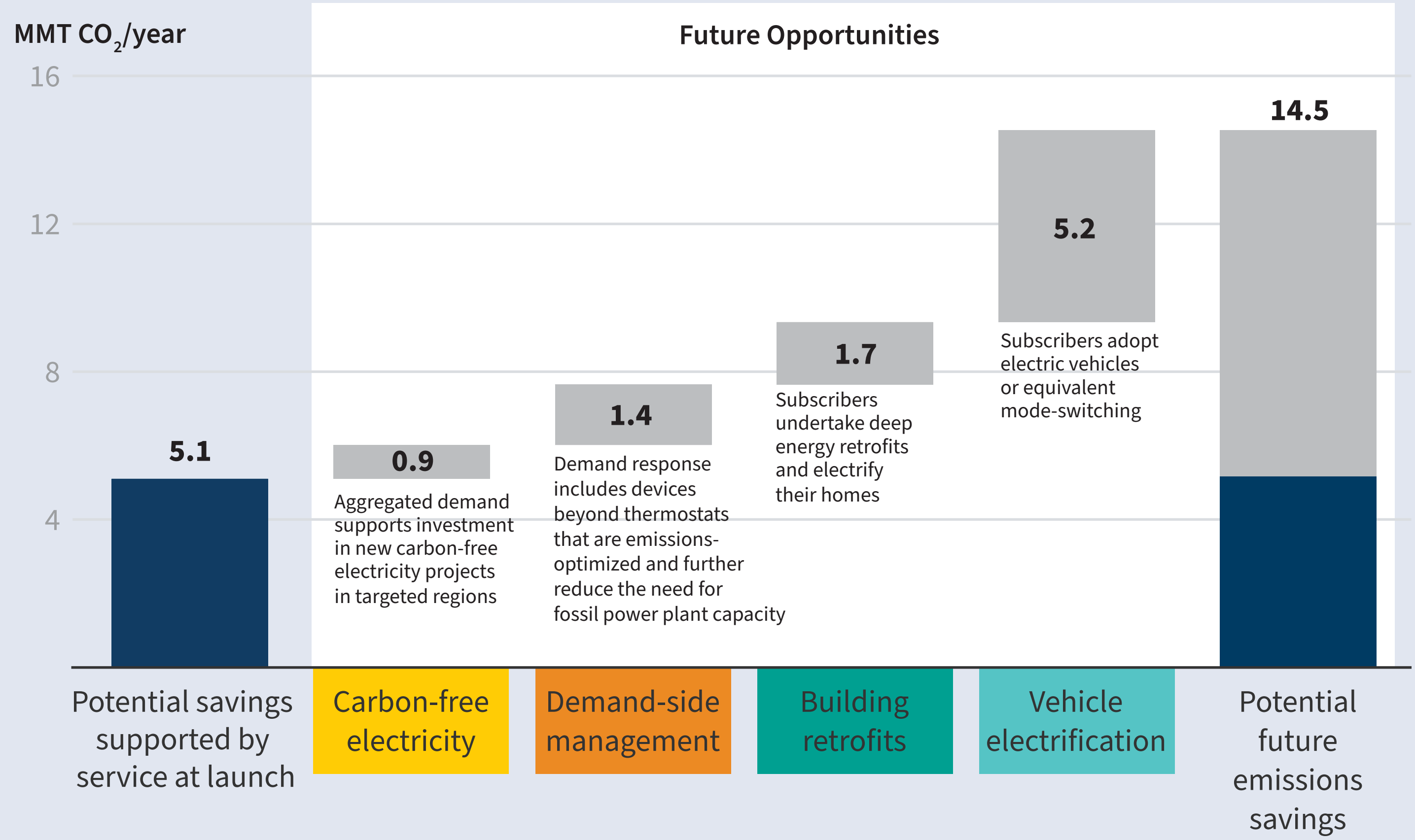


Source: Sources and methodology are described in detail in Appendix B.

Exhibit 23 shows indicative potential associated with four categories of additional savings that can be supported by the evolution of a service like Nest Renew over time. These additional savings reflect the opportunities available with emerging technology and marketing solutions described in Chapter 4, enabled by supportive regulatory and utility practice changes outlined in Chapter 5.

- **Carbon-free electricity:** Aggregated residential demand can enable siting new renewable energy projects within grid regions where wind and solar generation can offset the most-polluting fossil fuel power plants, amplifying both near- and long-term carbon emissions reductions.
- **Demand-side management:** Enabling emissions-aware flexibility for more residential end-use loads (i.e., water heaters and EV chargers) can increase both direct savings (i.e., by enabling more load to respond to Automated Emissions Reduction signals) and indirect emissions benefits (i.e., by providing more on-peak capacity that can help avoid or retire fossil power plant capacity and thus reduce future emissions).
- **Building retrofits:** Household-specific data and offers can unlock deep energy efficiency savings far in excess of that available from smart thermostats and other devices (e.g., tailored recommendations for deep energy retrofits and electrification upgrades that simplify and streamline household adoption).
- **Vehicle electrification:** Using data-driven insights can support households in transitioning to the use of an electric vehicle, or equivalent mode-switching (e.g., public transit), to reduce emissions from internal combustion-based vehicles.

Exhibit 23 **Emissions savings supported by a service like Nest Renew, per 1 million subscribers**



Source: Sources and methodology are described in detail in Appendix B.

Nest Renew, both as defined by Google at launch and the potential it represents for deeper emissions savings as the service evolves, is an example of the opportunity at hand for household products and services to unlock material climate benefits across the United States. The service has an opportunity to set an example of a scalable, nationally relevant business that unlocks material climate benefits for each participating customer—breaking into quadrant 4 of Exhibit 20 in a way that few, if any, household offers have been able to do to this date.

7. Conclusion

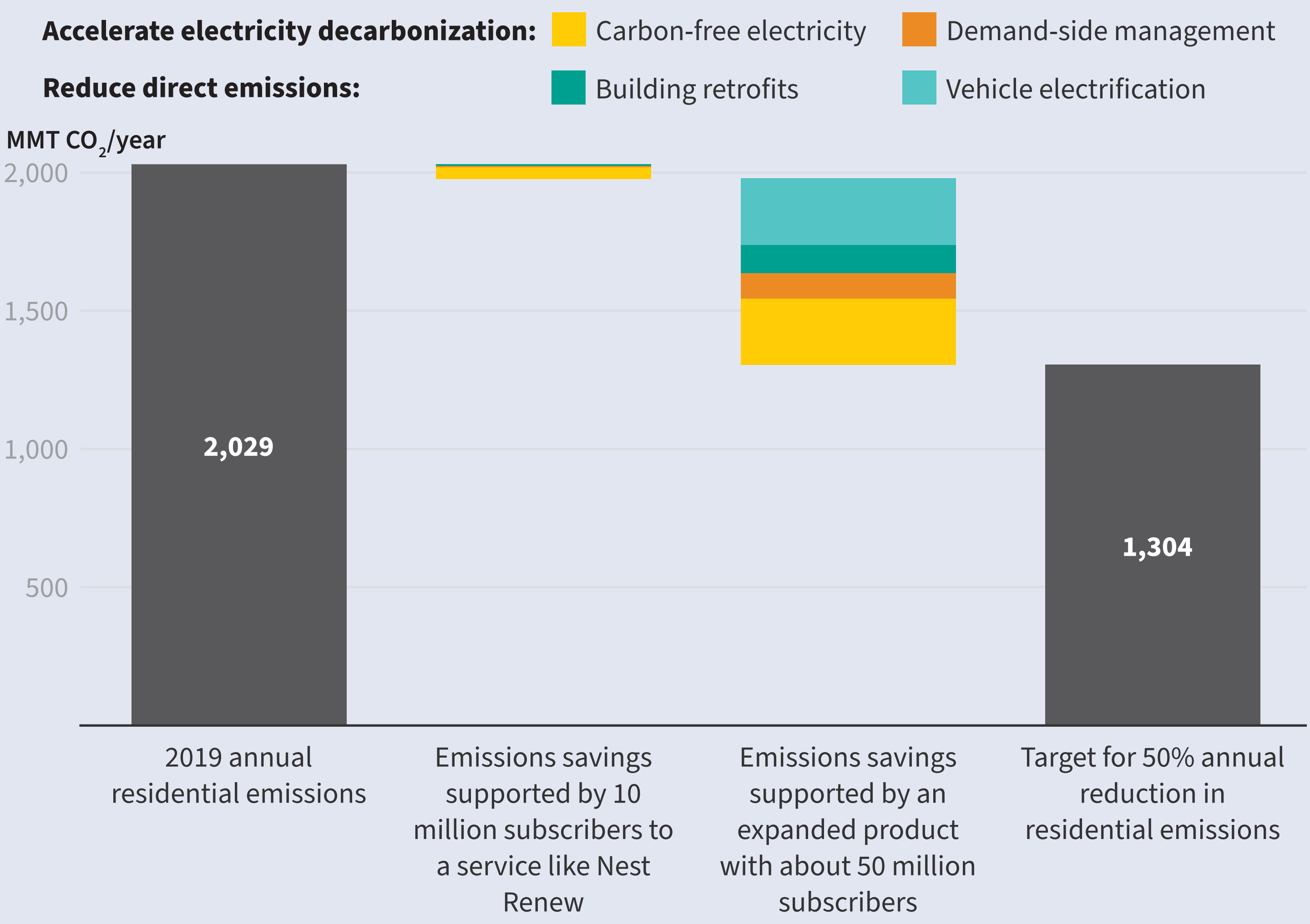
Helping Customers Accelerate the Energy Transition

A solution like Nest Renew, either from Google or a competitor, has the potential to unlock material emissions savings. However, its potential can be expanded dramatically by both broadening the scope of products and services offered to participating households (e.g., through deep energy retrofits) and delivering these benefits to a more diverse set of households. Exhibit 24 summarizes the emissions impact of a service like Nest Renew in the context of an NDC-consistent emissions pathway for household energy use.

At an indicative market size of 10 million subscribers—approximately equivalent to the total participation level in residential demand response programs in the United States in 2019—the renewable energy and demand-side management supported by a service like Nest Renew could reduce approximately 50 million metric tons of CO_2 per year. This is less than 10% of the gap between today's emissions and the at least 50% reduction in residential emissions that may be required to align with the NDC. A fully realized service or product, offering a broader scope of clean energy solutions to five times as many households, could fully bridge the gap between today's household energy emissions levels and a decrease in annual residential emissions supportive of the NDC.

To unlock this level of emissions savings for 50 million households, both solutions providers and the policymakers, regulators, and utilities that shape the market in which they operate must act, quickly and in coordination, to break down barriers to adoption for all. Delaying action or impeding innovation to overcome today's barriers will result in a significant missed opportunity for households themselves to accelerate the energy transition and realize the benefits where they matter most—in our homes.

Exhibit 24 **How a residential decarbonization product can help us reach US climate targets**



Appendix A

Methodology: The Challenge, the Opportunity, and Adoption

The tables in Appendix A describe the methodology behind Exhibits 1, 2, 6, 8, and 9.

The Challenge

Exhibit 1: Residential energy-related CO_2 emissions, 2019

Historical 2005 emissions are from the EIA *Monthly Energy Review* (April 2021).[58] EIA's *Annual Energy Outlook* (AEO) 2020 quantified residential and US-wide 2019 baseline energy-related emissions and 2030 projected business-as-usual (BAU) emissions. Since the EIA AEO does not include residential transportation in the residential end-use breakdown, passenger CO_2 emissions were represented by light-duty vehicles (passenger cars and light-duty trucks), pulled from the EPA's draft *Inventory of U.S. Greenhouse Gas Emissions and Sinks (1990–2019)*.

Assumption/Calculation		Value	Unit	Source
1A	Residential energy-related CO_2 emissions by end use	950	MMT CO_2	**EIA AEO 2020, Table 19**, 2019 data
1B	Light-duty vehicle emissions	1,079	MMT CO_2	**EPA Draft Inventory of GHG Emissions and Sinks (1990-2019)** Table 2-13, 2019 data, passenger cars + light-duty trucks
1C	Total US energy-related CO_2 emissions	5,123	MMT CO_2	**EIA AEO 2020, Table 18**, 2019 data
1D	Residential sector contribution to total US energy-related CO_2 emissions	40%	%	(1A+1B) / 1C

Exhibit 2: US-wide and residential energy-related CO_2 emissions reductions aligned with the US NDC in 2030

Historical 2005 and 2019 emissions and the BAU emissions trajectory were sourced from the EIA and EPA.

To determine a 2030 target for residential emissions representing a substantive contribution from the sector toward meeting economy-wide decarbonization, we assumed a 50% reduction in residential emissions from 2005 levels—a percentage equivalent to the economy-wide US nationally determined contribution (NDC).

Assumption/Calculation		Value	Unit	Source
2A	2005 residential building emissions—direct	364	MMT CO_2	**EIA Monthly Energy Review** (accessed May 2021)
2B	2005 residential transportation emissions	1,348	MMT CO_2	Extrapolated from **EPA LDV numbers** by comparing to those from **EIA AEO 2020 Table 19**
2C	2005 residential electricity emissions	897	MMT CO_2	**EIA Monthly Energy Review** (accessed May 2021)
2D	2005 residential energy-related emissions	2,609	MMT CO_2	2A + 2B + 2C
2E	2019 residential buildings emissions—direct	340	MMT CO_2	**EIA AEO 2020, Table 18**, 2019 data
2F	2019 residential transportation emissions	1,079	MMT CO_2	**EPA Draft Inventory of GHG Emissions and Sinks (1990-2019)** Table 2-13, 2019 data, passenger cars and light-duty trucks
2G	2019 residential electricity emissions	611	MMT CO_2	**EIA AEO 2020, Table 18**, 2019 data
2H	2019 total residential emissions	2,029	MMT CO_2	2E + 2F + 2G
2I	2030 target residential emissions	1,304	MMT CO_2	2E * 50% reduction

In Exhibit 2, the trajectory of total US energy-related CO_2 emissions to meet the NDC was pulled from the US Energy Policy Simulator (EPS)'s NDC emissions scenario.[59] The BAU emissions trajectory was drawn from **EIA AEO 2020, Table 18**, 2019 data. For both BAU and projected emissions reductions, we assumed that residential energy-related emissions would fall in consistent proportion to overall energy-related emissions, ending at the 50% reduction target.

The Opportunity

The total annual tons of CO_2 to avoid in the residential sector were divided up among four categories: (1) residential energy efficiency (EE) and demand response (DR), (2) residential carbon-free electricity, (3) residential buildings, and (4) residential transportation. Percentage targets for each sector were based on the annual emissions reductions plausible through aggressive policy measures impacting residential energy-related emissions—as modeled in Energy Innovation's Energy Policy Simulator according to the scenarios listed in Exhibit 8, scaled to the residential sector. Targets were chosen within the range of the sectoral reductions produced by the two scenarios described (8A, 8B) and rounded to sum to a total 50% reduction in residential energy-related emissions by 2030:

- 20% reduction in annual residential building emissions by 2030 from 2005 levels
- 45% reduction in annual residential transportation emissions by 2030 from 2005 levels
- 70% reduction in annual residential electricity emissions by 2030 from 2005 levels

Exhibit 6: Illustrative components of annual residential emissions reductions required to achieve 50% reduction in residential energy-related CO_2 emissions in support of the NDC

2030 target residential CO_2 emissions reductions were all calculated based on a 50% reduction from 2005 levels. The 2019 sectoral emissions are drawn from the sources listed in the prior table.

Assumption/Calculation		Value	Unit	Source
6A	2030 total annual residential building emissions (target)	291	MMT CO_2	2B * (1-20%)
6B	2030 total annual residential transportation emissions (target)	741	MMT CO_2	2C * (1-45%)
6C	2030 total annual electricity emissions (target)	272	MMT CO_2	2C * (1-70%)

Equivalencies to number of homes or devices were calculated for each of the four categories in order to put the reductions into perspective. All equivalency numbers in this Exhibit are presented as the number of homes or devices in 2019 that would need to change to result in the annual emissions reductions required to meet the 50% reduction in annual residential emissions.

Residential buildings emissions reductions were assumed to be achieved through reduction in direct fossil fuel consumption for space heating, which represents the majority of direct building emissions. To achieve the reduction target, a percentage of buildings that heat with gas were assumed to receive retrofits that reduced consumption and the remainder of emissions were assumed to be reduced by fuel switching to heat pumps. In this analysis we assume that additional electricity use in fuel-switched homes is matched by an incremental addition of carbon-free electricity to the grid, accounted for in the electricity sector analysis below.

Bar 3. Residential buildings emissions reductions				
Assumption/Calculation		**Value**	**Unit**	**Source**
6D	Annual emissions reductions required in residential buildings sector	48	MMT CO_2	2E – 6A
6E	Annual emissions from natural gas from residential space heating	201	MMT CO_2	**EIA AEO 2020 Table 4**, 2019 data
6F	Number of occupied homes	123 million	homes	Occupied housing units from 2019 **Census five-year estimate data profiles**
6G	Number of occupied homes that heat with natural gas	59 million	homes	6F * 48% of homes that heat with natural gas (from **Census source**)
6H	Original heating direct energy use of natural gas	3.8	quads	**EIA AEO 2020 Table 4**, 2019 data
6I	% reduction in heating energy usage from deep energy retrofits	20%	%	**NREL EE Potential in Single Family Housing Stock**, 2017
6J	% of homes that retrofits apply to	21%	%	Assumption
6K	Heating direct energy use after retrofits	3.6	quads	6H – (6H * 6I * 6J)
6L	Emissions reductions from retrofits	8.5	MMT CO_2	6E * 6I * 6J
6M	Additional emissions reductions needed from electrification	40	MMT CO_2	6D – 6L
6N	Heating emissions remaining	193	MMT CO_2	6E – 6L
6O	New heating emissions per home after retrofits	3.3	MMT CO_2 / million homes	6N / 6G * 10^6
6P	Number of homes needed to fuel switch heating	12 million	homes	6M / 6O
6Q	Percent of natural gas-heated homes needed to fuel switch	21%	%	6P / 6G

Transportation emissions reductions were assumed to be achieved through electrification of light-duty vehicles. In this analysis we assume that additional electricity use by fuel-switched vehicles is matched by incremental addition of carbon-free electricity to the grid, accounted for in the electricity sector analysis below.

Bar 4. Required transportation emissions reductions

Assumption/Calculation		Value	Unit	Source
6R	Number of registered light-duty vehicles (LDVs), 2019	254 million	LDVs	**BTS Number of Vehicles and Vessels**, LDV short wheelbase + LDV long wheelbase
6S	Number of electric vehicles (EVs) on the road, 2019	781,435	EV LDVs	Average between AFDC 2018 EV registrations and **2020 EV registrations**
6T	Number of internal combustion engine (ICE) LDVs, 2019	252.5 million	ICE LDVs	6R - 6S
6U	Avoided emissions by switching 1 million LDVs	5.2	MMT CO_2	**Alternative Fuels Data Center** tCO_2/vehicle * 10^6 vehicles
6V	Total annual residential transportation emissions reductions needed to hit target	337	MMT CO_2	2F – 6B
6W	Number of today's ICE LDVs that need to switch to EVs	65 million	cars	6V / 6U * 10^6
6Y	Percent of today's ICE LDVs that need to switch to EVs	26%	%	6W / 6T

We assume that electrified buildings and transportation would be served with carbon-free electricity. Therefore, we calculated their impact on overall residential electricity consumption in order to determine the total capacity of the portfolio that would be required to both serve these loads and reduce emissions in line with the electricity target.

Electricity sector impacts of building retrofits & electrification:				
Assumption/Calculation		**Value**	**Unit**	**Source**
i	Energy use that has been fuel switched	0.75	quads	6K * 6Q
ii	Average coefficient of performance (COP)	3	unitless	**EnergyStar rating** for air source heat pump
iii	*New load added to the grid from building electrification*	*73*	*TWh*	(i / 3412 BTU/kWh) * (10^{15} BTU/quad) / ii

Electricity sector impacts of vehicle electrification:				
Assumption/Calculation		**Value**	**Unit**	**Source**
iv	Annual miles driven by LDVs	11,824	mi/y	**Alternative Fuels Data Center**
v	EV kWh/mi	0.32	kWh/mi	**Alternative Fuels Data Center**
vi	Total VMT by additional electrified cars in 2030	769 billion	miles	iv * 6W
vii	Efficiency loss in EV charging	16%	%	**Vehicle Technologies Office**, 2018
viii	*New load added to the grid from vehicle electrification*	*293*	*TWh*	(v * vii) / (1 – vii)

Then, we calculated the total capacity of renewables that would be required today to reduce electricity emissions by 70% and serve the additional load from electrified vehicles and buildings.

First, we determined the total generation required to meet residential loads with newly electrified end uses and the amount of clean generation to serve residential loads in 2019.

Bar 1: Total electricity sector capacity calculations				
Assumption/Calculation		**Value**	**Unit**	**Source**
6Z	Annual residential electricity consumption per home, 2019	10,649	kWh/household/y	**EIA**, 2019 data
6AA	Annual residential electricity consumption, 2019	1,308	TWh/y	6Z * 6F
6AB	Total new residential electricity load from building and vehicle electrification	366	TWh/y	6AA + iii + viii
6AC	Line losses from transmission and distribution	6.87%	%	**EPA**, footnote 1, accessed with 2019 data
6AD	Total generation to meet 2019 residential electricity consumption	1,404	TWh/y	6AA / (1 – 6AB)
6AE	Total generation to meet new electrified loads	393	TWh/y	6AB / (1 – 6AB)
6AF	Percentage of current generation that is carbon free	38%	%	Calculated from **EIA**, Table 7.2B, 2019
6AG	Total clean generation serving the residential sector in 2019	533	TWh/y	6AD * 6AF

Next, we used the total allowable annual electricity emissions target of 272 MMT CO_2 (6C) for fossil fuel generation, assuming that the majority of remaining fossil emissions would be coming from gas-fired power plants.

Bar 1: Total electricity sector capacity calculations				
Assumption/Calculation		**Value**	**Unit**	**Source**
6AH	Gas emissions factor	0.0004	metric tons CO_2/kWh	**EIA** 2019
6AI	Total gas generation allowable	659	TWh/y	6C / 6AH

Then, we calculated the remaining generation that needed to be served by carbon-free electricity and determined a resource mix starting with energy efficiency and finished with a mix of wind and solar.

Bar 1: Total electricity sector capacity calculations				
Assumption/Calculation		**Value**	**Unit**	**Source**
6AJ	Total remaining new generation to be served by carbon-free electricity	605	TWh/y	6AD + 6AE – 6AG – 6AI
6AK	Total new efficiency contribution	30	GW	Analysis based on RMI *Clean Energy Portfolios* **reports** on efficiency needed to avoid 90 GW of fossil generation
6AL	Total efficiency load factor	25%	%	Analysis based on load factor of residential end-use profiles used in RMI's Clean Energy Portfolios Model
6AM	Total generation avoided through efficiency	65	TWh/y	6AK * 6AL * 8760 hours/y
6AN	Average capacity factor of carbon-free generation in 2030	29.6%	%	Averaged utility-scale solar, distributed solar, onshore wind, and offshore wind CFs from **2035 Report**
6AO	Total capacity of new renewables to meet remaining generation	208	GW	(6AJ – 6AM) / (6AN * 8760 hours/y)

Exhibit 8: Impact of delayed implementation of policies

Aggressive policy targets for buildings, transportation, and electricity were modeled with the US Energy Policy Simulator to quantify the imperative for quick, aggressive policy. The impact of waiting five years to implement these policies was assessed by modeling the same set of policies but moving targets out by five years—demonstrating that a 50% reduction in residential emissions could not be achieved by 2030 if we wait.

Assumption/Calculation		Source
8A	Baseline scenario to achieve 50%+ reduction in residential emissions by 2030	**Energy Policy Simulator—US**, energy-related CO_2 emissions: • 80% CES by 2030 with transmission expansion, demand response, and storage on same timeline • 100% new electric appliance sales for heating, appliances, and other components by 2035 for urban and rural residential households • 50% retrofit of existing rural and urban residential buildings by 2035 • 100% EV sales standard by 2035
8B	Scenario representing five-year delay	**Energy Policy Simulator—US**, energy-related CO_2 emissions: • 80% CES by 2035 with transmission expansion, demand response, and storage on same timeline • 100% new electric appliance sales for heating, appliances, and other components by 2040 for urban and rural residential households • 50% retrofit of existing rural and urban residential buildings by 2040 • 100% EV sales standard by 2040

The outputs of these scenarios were scaled to represent residential energy-related CO_2 emissions, using transportation emissions from cars and SUVs, total urban and residential building energy use, and an assumption that residential electricity use would decline in emissions proportional to the electricity system at large.

Adoption

Exhibit 9: Illustrative adoption of key technologies required to hit 50% residential emissions reductions

Adoption was modeled to connect the challenge and the opportunity of residential decarbonization. The numbers included in Exhibit 6 represent the change required in today's system to align annual emissions targets with what is required in 2030, whereas the adoption in these charts also captures growth over time. In order to maintain the sectoral annual reduction targets set in Exhibit 6, it is assumed that any additional homes or EVs due to growth are not allowed to increase emissions—resulting in additional stock turnover or adoption of new all-electric devices powered by carbon-free electricity. Total adoption numbers also reflect what has already been deployed through historic adoption—in contrast to the numbers in Exhibit 6.

Energy Efficiency and Demand Response

In order to hit the 50% reduction target for annual residential emissions, 30 GW of energy efficiency and 12 GW of demand response are needed in savings. This is based on RMI's Clean Energy Portfolios analysis of what is needed to avoid 90 GW of fossil generation as described in Princeton University's *Net Zero America* report (2020).[60]

Current peak demand savings for energy efficiency and demand response were pulled from EIA Form 861 in 2019. The economic potential for energy efficiency in 2030 is from NREL's Energy Efficiency Potential in the *US Single Family Housing Stock* report.[61]

The market potential for demand response in 2030 is calculated from the Brattle *National Potential for Load Flexibility* report,[62] summing the residential-relevant portions (smart thermostats, smart water heating, dynamic pricing) of the 198 GW 2030 stack. Each of the energy efficiency and demand response adoption percentages were calculated by dividing the megawatt savings by the potential in 2030.

Energy efficiency. Current adoption of residential EE

Assumption/Calculation		Value	Unit	Source
9A	Incremental life-cycle EE peak demand savings, 2019	3,322	MW	**EIA 861 Energy Efficiency**, 2019
9B	Economic potential of EE savings in single-family homes	245	TWh/y	NREL, **Energy Efficiency Potential in the US Single-Family Housing Stock**, 2017
9C	EE load factor, 2019	25%	%	Energy efficiency load factor (energy savings/non-coincident peak demand reduction potential), analysis of RMI CEP **reports**
9D	Economic potential of residential EE, 2030	111,688	MW	9B * 10^6 / 8760 hours/y / 9C
9E	**Percentage peak savings for residential EE out of the 2030 economic potential, 2019**	**3%**	%	9A / 9D
9F	Residential EE portion of CEP to replace fossil by 2030	29.7	GW	33% of CEP stack to avoid 90 GW of fossil generation by 2030 (based on **RMI Clean Energy Portfolios** report analysis of **Princeton paper**)
9G	Incremental life-cycle EE peak demand savings, 2030	33,022	MW	9F * 10^3 + 9A
9H	**Percentage peak savings for residential EE out of the 2030 economic potential, 2030**	**30%**	%	9G / 9D
9I	**Increase in EE potential MW savings, 2019-2030**	**10x**	unitless	9G / 9A

Demand response. Current adoption of residential DR				
Assumption/Calculation		**Value**	**Unit**	**Source**
9J	Potential peak demand savings for residential DR, 2019	8,867	MW	**EIA 861 Demand Response**, 2019
9K	Market potential of residential DR, 2030	118,800	MW	Brattle, ***National Potential for Load Flexibility***, 2019, slide 18, smart thermostats + smart water heating + dynamic pricing or approximately 60% of 198 GW total potential in 2030
9L	**Percentage peak demand savings for residential DR out of the 2030 market potential, 2019**	**7%**	%	9J / 9K

Demand response. Future adoption of residential DR				
Assumption/Calculation		**Value**	**Unit**	**Source**
9M	Residential DR portion of CEP to replace fossil by 2030	11.7	GW	13% of CEP stack to avoid 90 GW of fossil generation by 2030 (based on **RMI *Clean Energy Portfolios* report** analysis of **Princeton paper**)
9N	Potential peak demand savings for residential DR, 2030	20,567	MW	9M * 10^3 + 9J
9O	**Percentage peak demand savings for residential DR out of the 2030 market potential, 2030**	**17%**	%	9N / 9K
9P	**Increase in DR potential MW savings, 2019–2030**	**2.3x**	unitless	9N / 9J

Buildings

Adoption of electrified buildings was modeled using Census data of homes with electricity as their main heating fuel and total occupied housing units.[63] The target 2030 number was based on the following: (1) calculations of the number of homes needing retrofits and fuel switching to achieve the buildings proportion of the overall 50% reduction in residential emissions as calculated in Exhibit 6, (2) the current stock of electrically heated homes, and (3) assumption that any new growth in homes needs to be offset by additional homes that heat with electricity (i.e., there is not additional room for growth in emissions, even with growth of new homes).

Buildings. Current stock

Assumption/Calculation		Value	Unit	Source
9Q	Number of occupied homes, 2019	123 million	homes	Occupied housing units from 2019 **Census five-year estimate data profiles**
9R	Number of occupied homes that heat with electricity, 2019	48 million	homes	2019 **Census five-year estimate data profiles**
9S	**Percentage of homes that heat with electricity, 2019**	**39%**	%	9R / 9Q

Buildings. Future stock

Assumption/Calculation		Value	Unit	Source
9T	Number of occupied homes, 2030	134 million	homes	Extrapolated with CAGR for 2011–2019 of historical occupied housing unit data from 2019 **Census five-year estimate data profiles**
9U	Number of occupied homes that heat with electricity, 2030	71 million	homes	9R + (9T – 9Q) + 6W
9S	**Percentage of homes that heat with electricity, 2030**	**56%**	%	9U / 9T
9W	**Increase in electric home stock, 2019–2030**	**1.5x**	unitless	9U / 9R

Transportation

Adoption of electric vehicles was modeled using BTS data of light-duty vehicle (LDV) stock and battery electric vehicles (BEVs) as a percentage of LDVs.[64] The 2030 target value of electric vehicles was calculated as the sum of the number of today's vehicles that need to switch to meet our emissions target in Exhibit 5, electric vehicles on the road today, and any additional vehicles due to growth by 2030.

Transportation. Current stock

Assumption/Calculation		Value	Unit	Source
9X	Number of registered light-duty vehicles (LDVs), 2019	254 million	LDVs	**BTS Number of Vehicles and Vessels**, LDV short wheelbase + LDV long wheelbase; AA in last section
9Y	Number of electric vehicles (EVs) on the road, 2019	781,435	EV LDVs	Average between AFDC 2018 EV registrations and **2020 EV registrations**
9Z	**Percent of EVs of LDV stock, 2019**	**0.3%**	%	9Y / 9X

Transportation. Future stock

Assumption/Calculation		Value	Unit	Source
9AA	Number of today's ICE LDVs that need to switch to EVs by 2030	65 million	ICE LDVs	Calculation, 6W
9AB	Number of LDVs in 2030	262 million	LDVs	Extrapolated using a 0.29% CAGR from BTS data (9X)
9AC	Number of EVs in 2030	74 million	EV LDVs	9Y + 9AA + (9AB – 9X)
9AD	**Percent of EVs of LDV stock, 2030**	**28%**	%	9AC / 9AB
9AE	**Increase in EV stock, 2019-2030**	**94x**	unitless	9AC / 9Y

Carbon-Free Electricity

Carbon-free electricity adoption was modeled by calculating the percentage of carbon-free electricity MWh sales out of total sales to residential customers using the grid's historical and projected carbon-free percentages.[65] The 2030 target sales for carbon-free electricity were based on the opportunity calculations to reduce electricity emissions by 2030. Total residential MWh sales were projected using a CAGR based on 2013–2019 historical data, while carbon-free sales to customers were interpolated from 2020–2029 using an exponential regression.

Electricity. Residential carbon-free electricity generation and capacity today

Assumption/Calculation		Value	Unit	Source
9AF	Total renewable capacity serving residential customers, 2019	202	GW	6AG / 8760 hours/y / 30% average carbon-free capacity factor / 10^3
9AG	Carbon-free percentage of the US grid, 2019	38%	%	Calculated from **EIA**, Table 7.2B, 2019

Electricity. Residential carbon-free electricity generation and capacity in the future

Assumption/Calculation		Value	Unit	Source
9AH	Total electricity generation for residential customers, 2030	1,935	TWh/y	Total original (6AD) + Total new homes 6Z * (9T – 9Q) + total needed to serve additional electrified end uses with quantities in 9AC and 9U
9AI	Balance needed to be served by new carbon-free electricity, 2030	678	TWh/y	9AH - 6AI - 6AM
9AJ	New carbon-free capacity required by 2030 for residential load + building and transportation electrification impacts	258	GW	9AI / 8760 hours/y / 30% average carbon-free capacity factor / 10^3
9AK	**Increase in carbon-free capacity to serve residential sales, 2019–2030**	**2.3x**	unitless	(9AF + 9AJ) / 9AF

Appendix B

Methodology: Nest Renew Impact Assessment

Nest Renew Analysis Overview

For the analysis shared in Chapter 6, we developed a model to determine the avoided emissions supported by a service like Nest Renew for two different scenarios:

- **At launch:** given the announced features of Nest Renew at launch, an assessment of the avoided CO_2 emissions that could be supported if 1 million subscribers were to adopt a service with similar features.
- **Beyond launch:** given an expanded set of features imagined by RMI to maximize impact according to the design principles and regulatory enablers described in this report, an assessment of the avoided CO_2 emissions that could be supported if 1 million subscribers were to adopt a product or service including these features.

Both estimates are based on present-day grid data and customer characteristics (i.e., not extrapolated into the future as the grid mix evolves).

Exhibit B1 **Features that were assessed for avoided emissions impact at launch and beyond launch**

Feature	Definition at launch	Definition beyond launch
Carbon-free electricity	Carbon-free electricity generation that could be supported by Premium subscribers' purchase of RECs, in proportion to their estimated consumption of fossil-generated electricity.	Carbon-free electricity generation that could be supported by Nest Renew subscribers' purchase of RECs, if projects are located in the top 25% most fossil-intensive grids in the United States.
Direct demand response	Reductions produced by shifting air conditioning loads to lower-emissions hours using smart thermostats.	Reductions produced by shifting air conditioning loads, heat pump hot water heater loads, and controllable EV charging loads to lower-emissions hours.
Indirect demand response	Emissions reductions enabled by using AC demand response to complement wind, solar, and storage resources as part of a clean energy portfolio, and thus avoid the need for investment in or retention of fossil fuel-fired power plant capacity.	Reductions enabled by using demand response from ACs, heat pumps, and EV chargers as part of a clean energy portfolio, and thus avoid the need for investment in or retention of fossil fuel-fired power plant capacity.
Energy efficiency	Energy use reduction from seasonal setpoint adjustment programs for air conditioners and heating from gas and electricity.	Emissions reduced by nudging customers to adopt a deep energy retrofit, including electrification of space heating, thus reducing building emissions from direct fossil fuel use. Emissions from resulting additional electricity demand is offset by generation sourced from new renewable energy projects.
Eliminating ICE vehicle miles traveled	N/A	Emissions reduced by nudging a household to electrify one vehicle, or otherwise eliminate fossil-fuel VMT for the equivalent of one vehicle (e.g., through mode-switching). Emissions from resulting additional electricity demand are offset by generation sourced from new renewables projects.

Carbon-Free Electricity

At launch, we assume subscriptions support new, carbon-free electricity generation for the proportion of an average subscriber's load that is currently met by fossil fuel-generated electricity. To calculate avoided emissions, we used the average annual residential customer load for 1 million households, the average non-carbon-free electricity grid mix percentage for the United States, and the average grid emissions factor from eGRID.

Beyond launch, we used the 75th percentile non-baseload output emissions rate from eGRID to model new, carbon-free electricity generation sourced from projects in the most carbon-intensive US grid regions for 1 million residential homes.

Exhibit B2 **Emissions calculations for carbon-free electricity**

Assumption/Calculation		Value	Unit	Source
A	Average home consumption, electricity, 2019	10,649	kWh/y	**EIA 2019**
B	Average non-carbon-free electricity grid mix for the United States	62	%	Calculated from **EIA Total Energy, Table 7.2b**
C	Average grid emissions factor	1,420	lbs. CO_2/MWh	**eGRID**, 2019 non-baseload output emissions rate
D	Total emissions savings supported by 1 million subscribers at launch	4.3	MMT CO_2/y	A * B * C * 1 million / (2204 lbs/mt)
E	Beyond launch, generation from carbon-intensive grids	75th	Percentile non-baseload output emissions rate (eGRID)	Assumption, representing the geo-targeting of projects to the country's highest emissions grids to maximize impact
F	Beyond launch, 75th percentile grid emissions factor	1,726	lbs CO_2/MWh	Calculated the 75th percentile of the eGRID non-baseload output emissions rate
G	Total additional emissions savings supported by 1 million subscribers for a service with targeted procurement	0.9	MMT CO_2/y	A * B * F * 1 million / (2204 lbs/mt)

Energy Efficiency: Seasonal Thermostat Adjustments

At launch, we use published estimates of the savings available from smart thermostats for air conditioning (AC) electricity use in the summer and heating energy use in the winter. We apply savings estimates for heating to reduce both gas and electricity for the proportion of US households heating with gas or electricity, respectively. The average proportion of household heating types is representative of the whole US population, and is not intended to be representative of the current population of smart thermostat owners.

Beyond launch, we do not assume additional incremental savings from thermostat setpoint adjustments. Instead, we estimate savings associated with electrification of heating, described in the next section.

To estimate near-term CO_2 savings from smart thermostats controlling these end uses, we use three different approaches:

- **Air conditioning**: We use average month-by-hour AC profiles estimated based on survey data of residential customers and normalize for average US residential electricity demand for AC. We then apply the published savings estimate for smart thermostats noted in Exhibit B3 and multiply the resulting profile by average month-by-hour CO_2 emissions intensities using WattTime data from 2019. We assume all subscribers of a service like Nest Renew have and use AC and thus realize these savings.

- **Electric heat:** We use average month-by-hour electric heating profiles estimated based on survey data of residential customers and normalize for average US residential electricity demand for electric heating. We then apply the published savings estimate for smart thermostats noted in Exhibit B3 and multiply the resulting profile by average month-by-hour CO_2 emissions intensities using WattTime data from 2019. We apply this savings estimate to the proportion of subscribers assumed to have and use electric heating, based on the US average of 39% in 2019.

- **Gas heat:** We use EIA data on average US residential natural gas demand for electric heating, apply the published savings estimate for smart thermostats noted in Exhibit B3, and use EPA data for the CO_2 emissions intensity of combusted natural gas. We apply this savings estimate to the proportion of subscribers assumed to have and use gas heating equipment, based on the US average of 48%.[66] We do not assume any greenhouse gas savings from avoided upstream methane leakage.

Exhibit B3 **Emissions calculations for energy efficiency from seasonal thermostat adjustments**

	Assumption/Calculation	Value	Unit	Source
A	Percent savings from smart thermostats for AC	15%	%	**Nest, 2015**
B	Percent savings from heating energy use in the winter	11%	%	**Nest, 2015**
C	Average household site energy use for AC	7.1	MBtu/ household	**EIA 2015 RECS**
D	Average household site energy use for electric heating	13.6	MBtu/ household	**EIA 2015 RECS**
E	Emissions from average residential AC	1.13	tCO_2/ household/ year	National average calculated from **WattTime API**, 2017–2019
F	Emissions from average electric heating	2.12	tCO_2/ household/ year	National average calculated from **WattTime API**, 2017–2019
G	Total annual consumption of residential gas for heating	3.79	quads/year	**EIA AEO 2020 key residential indicators**
H	Total annual emissions for gas for heating	201.45	MMT CO_2/year	I * 53.07 kgCO_2/million BTU (**EIA emissions factor**)
I	Emissions from average gas heating per household	3.43	tCO_2/ household/ year	J / total US homes * L
J	Share of electric heating across households	39%	%	**2019 US Census Data**
K	Share of gas heating across households	48%	%	**2019 US Census Data**
L	Normalized electric heating share	45%	%	J/(J+K)
M	Normalized gas heating share	55%	%	K/(J+K)
N	Potential emissions savings from AC control	169,006	tCO_2/year	A*E*1 million households
O	Potential emissions savings from electric heating control	104,489	tCO_2/year	B*F*L*1 million households
P	Potential emissions savings from gas heating control	208,166	tCO_2/year	B*H*M* 1 million households
Q	Total potential emissions savings from energy efficiency associated with setpoint adjustments	481,661	tCO_2/year	N+O+P

Energy Efficiency: Deep Energy Retrofits and Heating Electrification

At launch, we do not assume a service like Nest Renew has any impact on energy efficiency beyond automated setpoint adjustments achieved via a smart thermostat, described above.

Beyond launch, we assess the potential of a service or product that could avoid further emissions by nudging consumers to implement deep energy retrofits and electrification upgrades focused on reducing direct fossil fuel emissions from buildings. We assume a deep energy retrofit and electrification upgrade reduces fossil fuel consumption remaining for heating (the dominant source of fossil fuel use in buildings) by electrifying heating with an electric air source heat pump and sourcing carbon-free electricity for the customer to meet the resulting increase in electricity demand.

Exhibit B4 **Emissions calculations for direct energy efficiency from deep energy retrofits and heating electrification**

Assumption/Calculation		Value	Unit	Source
A	Additional emissions that can be eliminated per household from gas heating, after savings from seasonal setpoint adjustments	3.05	tCO_2/gas-heated household	3.43 tCO_2 (Row I, Exhibit B3) – 11% savings already achieved through savings from seasonal setpoint adjustments
B	Normalized % of households heating with gas	55	%	Row M, Exhibit B3
C	Total additional CO_2 savings potential	1,684,248	tCO_2/year	A*B*1 million households

Direct Demand Response

At launch, we assess the emissions reduction potential of shifting AC loads using a smart thermostat to lower-emissions time intervals while maintaining comfortable indoor temperatures.

Beyond launch, we assess the incremental emissions reductions available from shifting flexible heat pump water heaters (HPWHs) and electric vehicle charging to lower-emissions time intervals.

1. **Build a load profile for each device**

- **AC load profiles:** Hourly outdoor temperature profiles were used for representative cities within major US balancing areas (BAs) for calendar year 2019.[67] The AC load profile was derived from this temperature profile based on average load versus temperature response functions.[68] It was normalized to annual use for average customers for each BA according to EIA's Residential Energy Consumption Survey (RECS) database for the corresponding region.[69]

- **Heat pump water heater profiles:** Typical electric resistance water heater load profiles were adjusted to account for efficiency improvements using an HPWH. We used average electric resistance water heater load profiles measured in homes across the Pacific Northwest, [70] and applied a 52% scalar to account for the efficiency improvements associated with a heat pump water heater.[71]

- **EV charging load profiles:** We used weekday and weekend electric vehicle time-of-use load profiles from Southern California Edison's Separate Meter TOU-EV1 profile to build an annual EV profile.[72]

2. **Determine potential emissions reductions from shifting loads**

Marginal emissions rates from WattTime's API from 2019 were pulled for subregions within several balancing authorities (CAISO, Carolinas, ERCOT, Florida, ISO-NE, MISO, PJM, PNW, SPP) as a baseline for device loads.[73] We defined shiftable hours for each device: we assumed an air conditioner was capable of shifting load for 1.5 hours, a heat pump water heater for 4 hours, and an electric vehicle for 4 hours. We assumed an air conditioner's rated power was 4,000 W, a heat pump water heater's rated power was 2,250W,[74] and an electric vehicle's rated power was 6,200 W.[75] For each piece of hardware, emissions savings were calculated as the difference between the baseline load profile and the load profile assuming loads could be shifted into the lowest marginal emissions hours for the shiftable hours of each device, within each balancing authority.

3. **Calculate total savings for a service like Nest Renew**

We determined an average percentage of emissions savings for each balancing authority for each device and calculated a weighted average of total savings using representative stock numbers from NREL's Electrification Futures Study residential reference scenario for air conditioner and heat pump hot water heaters apportioned from states to balancing areas,[76] and data from the Bureau of Transportation Statistics for EV stock numbers.[77] Emissions savings attributable to each Nest Renew customer were assumed to be the national weighted average savings for each device. We calculated total savings assuming 1 million subscribers of a service like Nest Renew at launch adopt AC load shifting, and 1 million subscribers beyond launch adopt AC load shifting, heat pump water heater load shifting, and EV charging load shifting.

The methodologies for each device can be found in the tables below.

AC Direct Demand Response

Exhibit B5 **Emissions calculations for AC direct demand response**

Step 1: Build a load profile

	Assumption/Calculation	Value	Unit	Source
A	Outdoor temperature profile (˚F)	Hourly temperature profile for one major city within each balancing authority (BA) analyzed (CAISO, Carolinas, ERCOT, Florida, ISO-NE, MISO, PJM, PNW, SPP)	°F	**NOAA 2019 Global Hourly Access Data**
B	Change point (i.e., outdoor air temperature at which median customer begins to use AC)	65	°F	M. Dyson et al, ***Using Smart Meter Data to Estimate DR Potential***, 2014
C	Load increase factor (per ˚F above 65)	50	W/°F	M. Dyson et al, ***Using Smart Meter Data to Estimate DR Potential***, 2014
D	Typical load profile, unscaled	15-min unscaled load profile, for each BA	W	max((A-B)*C, 0), for each 15-minute window
E	AC load profile scaling factor, applied to interval profile	0.74–1.82, depending on the BA	Scaling factor	EIA residential end use consumption **database**
F	Typical AC load profile, scaled	15-min scaled load profile, for each BA analyzed	W	D*E

Step 2: Determine potential emissions reductions from shifting loads

Assumption/Calculation		Value	Unit	Source
G	Marginal emissions rate	15-min profile for each subregion, within each BA analyzed (CAISO, Carolinas, ERCOT, Florida, ISO-NE, MISO, PJM, PNW, SPP)	lbs CO_2/ MWh	**WattTime API, 2019**
H	Emissions associated with baseline consumption	Varies by subregion within each BA	lbs CO_2/ year	F*G
I	Shiftable hours	1.5	hours	Expert judgment
J	Rated power of typical AC unit	4,000	W	Estimate based on assessment of representative AC unit power consumption profiles
K	Emissions associated with optimized consumption profile	Varies by subregion within each BA	lbs CO_2/ year	Same methodology as H, applied to the shifted/optimized consumption profile
L	Emissions savings for each subregion within each BA	Varies by subregion within each BA	%	(H-K)/K
M	Average BA total savings per unit	Varies by BA	lbs CO_2/ unit	Average (H-K) for all subregions within each BA

Step 3: Calculate total savings for a service like Nest Renew

Assumption/Calculation		Value	Unit	Source
N	2019, central AC count across BAs assessed for marginal emissions savings	48,018,926	# of units	**NREL Electrification Futures Study**, residential reference scenario 2019 numbers apportioned to BAs
O	Total emissions savings, per BA	Varies by BA	lbs CO_2	M*N, for each BA
P	Total savings, across all BAs	3,937,402,944	lbs CO_2	Sum O (across all BAs)
R	Total savings potential for a service with 1 million subscribers	37,204	tCO_2/year	(P/N)* 1 million

Exhibit B6 **Emissions calculations for HPWH direct demand response**

Step 1: Build a load profile

Assumption/Calculation		Value	Unit	Source
A	Electric resistance water heater load profile	15-min load profile, applied to each BA analyzed (CAISO, Carolinas, ERCOT, Florida, ISO-NE, MISO, PJM, PNW, SPP)	W	Northwest Energy Efficiency Alliance **sub-metered energy data** — average across all sites, normalized to month/hour averages
B	Electric resistance to heat pump water heater profile efficiency factor	52	% efficiency improvement	**Florida Solar Energy Center**

Step 2: Determine potential emissions reductions from shifting loads

Assumption/Calculation		Value	Unit	Source
C	Marginal operational emissions rate	15-min profile for each subregion, within each BA	lbs CO_2/ MWh	**WattTime API, 2019**
D	Baseline emissions	Varies by subregion within each BA	lbs CO_2/ year	B*C
E	Shiftable hours	4	hours	Expert judgment
F	Rated power of HPWH	2,250	W	***Building Demand for Unitary Heat Pump Water Heaters***, Advanced Water Heating Initiative, 2020
G	Shifted emissions	Varies by subregion within each BA	lbs CO_2/ year	Same methodology as H in AC Direct DR, applied to the shifted/ optimized consumption profile
H	Emissions savings for each subregion within each BA	Varies by subregion within each BA	%	(D-G)/G
I	Average BA total savings per unit	Varies by BA	lbs CO_2/ unit	Average (D-G), for all subregions within each BA

Step 3: Calculate total savings for a service like Nest Renew

Assumption/Calculation		Value	Unit	Source
J	2019, HPWH stock count across BAs analyzed	2,845	#	**NREL Electrification Futures Study,** residential reference scenario, distributed from states to BAs
K	Total emissions savings, per BA	Varies by BA	lbs CO_2	I*J, for each BA
L	Total savings across all BAs analyzed	358,331	lbs CO_2	Sum K (across all BAs)
M	Total emissions savings for 1 million subscribers	57,141	tCO_2/year	(J/L)*1 million subscribers

EV Direct Demand Response

Exhibit B7 **Emissions calculations for EV direct demand response**

Step 1: Build a load profile

Assumption/Calculation		Value	Unit	Source
A	EV TOU load profile, representing EV charging behavior under a typical time-of-use rate structure	Daily weekday and weekend TOU profile, applied as full year to each BA	kW	Southern California Edison's **Separate Meter TOU-EV1 profile**

Step 2: Determine potential emissions reductions from shifting loads

Assumption/Calculation		Value	Unit	Source
B	Marginal operational emissions rate	15-min profile for each subregion, within each BA analyzed (CAISO, Carolinas, ERCOT, Florida, ISO-NE, MISO, PJM, PNW, SPP)	lbs CO_2/ MWh	**WattTime API, 2019**
C	Baseline emissions	Varies by subregion within each BA	lbs CO_2/ year	A*B
D	Shiftable hours	4	hours	Assumption
E	Rated power, Level 2 charger	6,200	W	ChargePoint, "**Level Up Your EV Charging Knowledge**," 2017
F	Shifted emissions	Varies by subregion within each BA	lbs CO_2/ year	Same methodology as H in AC Direct DR, applied to the shifted/ optimized consumption profile
G	Emissions savings for each subregion within each BA	Varies by subregion within each BA	%	(C-F)/F
H	Average savings per unit	Varies by BA	lbs CO_2	Average (C-F) for all subregions within each BA
I	Average savings across all BAs analyzed, per unit	404.17	lbs CO_2/ unit	Average H, across all BAs

Step 3: Calculate total savings for a service like Nest Renew

Assumption/Calculation		Value	Unit	Source
J	Total emissions savings for a service with 1 million subscribers	183,381	tCO_2/year	I* 1 million

Indirect Demand Response

At launch, we calculate the quantity of emissions from fossil fuel plants that can be avoided when flexible AC loads act as part of a clean energy portfolio that can obviate the need for building new or retaining existing fossil fuel-fired power plant capacity.

Beyond launch, we calculate the additional emissions from new or existing fossil fuel plants that can be avoided with the addition of heat pump water heater loads and controllable EV charging loads incorporated into a clean energy portfolio.

Exhibit B8 **Emissions calculations for indirect demand response**

Assumption/Calculation		Value	Unit	Source
A	Average proportion of demand response in a clean energy portfolio needed to avoid proposed gas plants	19%	% by portfolio capacity	RMI, ***The Growing Market for Clean Energy Portfolios*** —32.7 GW of DR / 173.3 GW total CEP to avoid all CCGTs
B	Proposed CCGT capacity as of 2019	56	GW	RMI, ***The Growing Market for Clean Energy Portfolios***
C	Emissions from those CCGTs if built and operated at typical capacity factors	100	MMT CO_2/y	RMI, ***The Growing Market for Clean Energy Portfolios***
D	GW of CCGT capacity that 1 GW of DR can help avoid	1.7	GW	RMI, ***The Growing Market for Clean Energy Portfolios***, B ÷ 32.7 GW of DR
E	Avoided CO_2 emissions from 1 GW of demand response	0.6	MMT CO_2/y	C / B * A * D
F	At launch, peak demand response savings potential (AC only)	0.58	kW	**Opening Prepared Testimony of the DR Coalition**, 2020
G	At launch, total emissions avoided through indirect DR	0.33	MMT CO_2/y	Opening Prepared Testimony of the DR Coalition, 2020; E * F * 1 million households * 100% of subscribers enrolled
H	Beyond launch, peak demand response savings potential (AC, EV charging and heat pump water heater)	3	kW	RMI 2015 ***Economics of Demand Flexibility***, mid-range from SRP case study
I	Beyond launch, total emissions avoided through indirect DR	1.4	MMT CO_2/y	(H-I)* E * 1 million households * 100% of subscribers enrolled

Eliminating Vehicle Miles Traveled with Fossil Fuels

At launch, we do not assume a service like Nest Renew has any emissions impact on fossil-powered vehicle miles.

Beyond launch, we estimate the emissions savings of a service or product that is able to avoid emissions from fossil-powered vehicle miles traveled. It does this by nudging subscribers to change behavior toward mode-switching or by electrifying one household vehicle and sourcing carbon-free electricity for the customer to meet the resulting increase in electricity demand.

Exhibit B9 **Emissions calculations for eliminating vehicle miles traveled with fossil fuels**

Assumption/Calculation		Value	Unit	Source
A	Average annual emissions per ICE vehicle	5.2	tCO_2/y	**Alternative Fuels Data Center**
B	Avoided fossil fuel emissions from vehicle interventions per subscribing household	5.2	MMT CO_2/y	A * 1 million subscribers

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