ENERGY EFFICIENCY AND DEMAND RESPONSE: TOOLS TO ADDRESS TEXAS'S RELIABILITY CHALLENGES

Steven Nadel, Christine Gerbode, and Jennifer Amann

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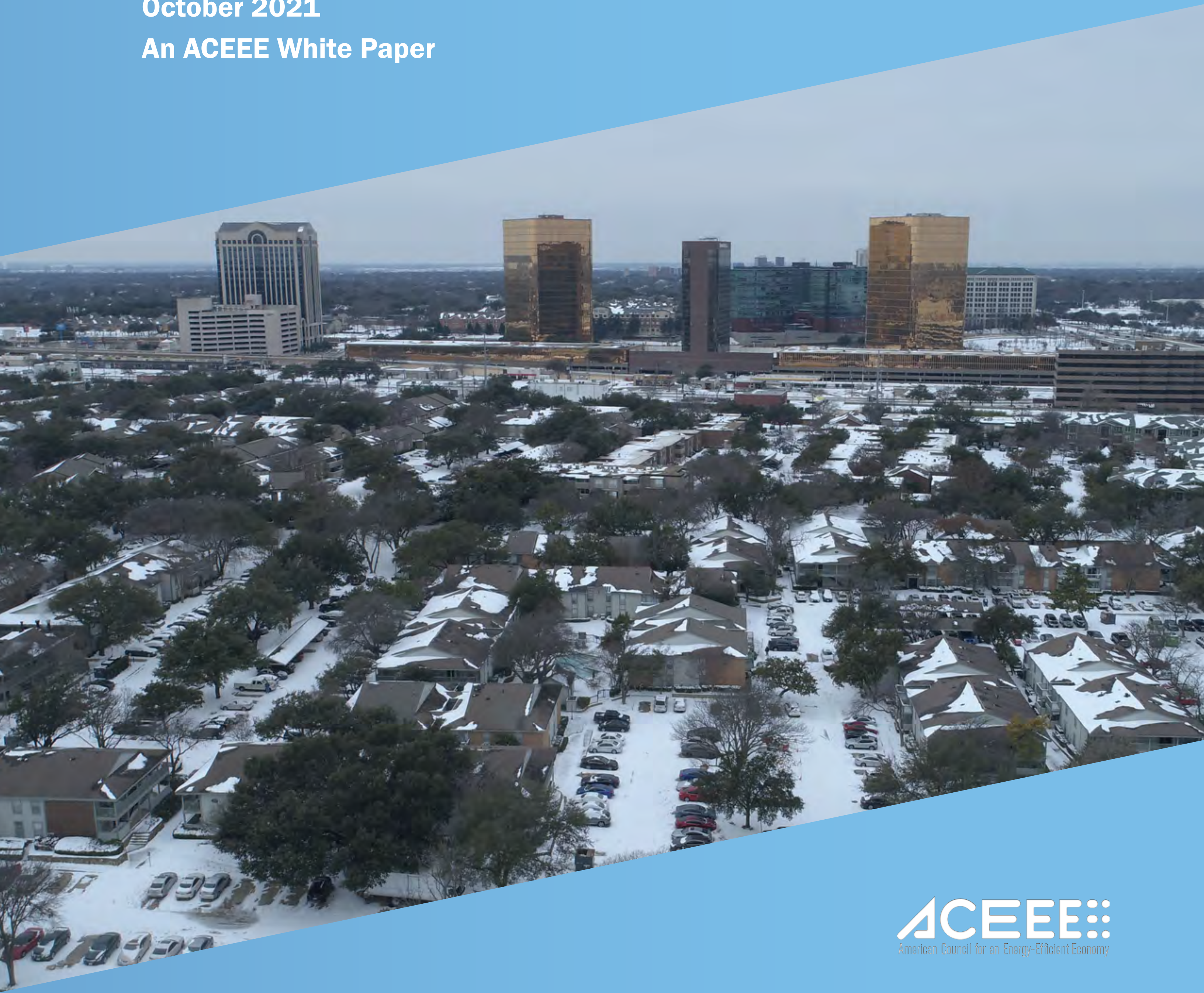

ACEEE
American Council for an Energy-Efficient Economy

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About ACEEE

The **American Council for an Energy-Efficient Economy** (ACEEE), a nonprofit research organization, develops policies to reduce energy waste and combat climate change. Its independent analysis advances investments, programs, and behaviors that use energy more effectively and help build an equitable clean energy future.

About the Authors

Steven Nadel is ACEEE's executive director, a position he has held since 2001. Prior to that he served as deputy director and led ACEEE's utility and buildings programs. He has worked in the energy efficiency field for 42 years, including with a utility, an environmental organization, and a community housing organization. He has more than 200 publications. Steve earned an MS in energy management from the New York Institute of Technology, an MA in environmental studies, and a BA in government from Wesleyan University.

Christine Gerbode is a senior research analyst in ACEEE's health and environment program. Christine conducts research and analysis related to the intersection of human health and energy use. She supports decisionmakers, policy advocates, and other ACEEE researchers in using energy efficiency policies and programs to protect health and promote equity for communities and vulnerable populations. Christine has experience across the boundaries of the natural science, social science, and communication fields. Prior to joining ACEEE in 2019, Christine completed a master's degree in environmental management at Duke University and a BS in earth science from Rice University.

Jennifer Amann is a senior fellow in ACEEE's buildings program. Jennifer's work promotes residential and commercial whole building performance improvements, explores behavioral approaches to improving energy efficiency, and analyzes the impacts of stronger appliance efficiency standards. She has authored dozens of publications and articles on appliances, lighting, consumer electronics, equipment installation practices, emerging residential and commercial building technologies, and the progress of market transformation initiatives, among others. Jennifer earned a master of environmental studies from the Yale School of Forestry and Environmental Studies and a bachelor of arts in environmental studies from Trinity University in Texas.

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Executive Summary

Texas has recently experienced major electric reliability problems, as illustrated by large load shedding during Winter Storm Uri in February 2021. This event reflected the extraordinarily high demand for electric home heating (from inefficient homes and equipment) combined with the loss of 50% of the state's generation fleet (due to freezing weather, fuel supply, and equipment failures). The Electric Reliability Council of Texas (ERCOT), the power system serving 90% of Texans, also faces summer supply challenges, as illustrated by calls for power conservation in June 2021. In that case, the shortage was driven by a large number of plants being out of service for unplanned repairs. ERCOT's energy-only wholesale market design and evolving generation resource mix are widely viewed as complicating the task of maintaining reliability as the power supply mix changes.

Numerous solutions have been proposed to address these problems, including subsidized winterization of existing power plants and critical grid infrastructure, and construction of many new power plants. For instance, two proposals would invest $8 billion in a fleet of new gas-fired power plants—to be used only in emergency conditions but charged to all ERCOT electric customers. An alternate way to address these problems is to expand Texas's currently limited energy efficiency (EE) and demand response (DR) programs, with a focus on programs that can substantially reduce summer and winter peak demand. This latter approach is the focus of this analysis, which explores the impact of a set of utility-administered energy efficiency and demand response programs targeting the residential sector.[1]

We find that a set of seven residential energy efficiency and demand response retrofit measures, deployed aggressively under statewide direction over five years (2022 start-up, 2023–2027 deployment) could serve about 9 million Texas households and offset about 7,650 MW of summer peak load and 11,400 MW of winter peak load—approximately equaling the capability of the proposed new gas combined-cycle generators—at a 5-year total programmatic cost of about $4.9 billion. This would be 39% less costly than the $8 billion of capital investment proposed for new, rarely used gas plants, and fully avoid additional costs for generator fuel, maintenance, and transmission infrastructure. Once installed, these efficiency measures would continue delivering around-the-clock comfort, energy and energy bill savings, and peak load reduction for 10- to 20-year measure lives.

[1] This paper focuses on EE and DR opportunities in the residential sector because the current Texas EE and DR programs direct the bulk of their efforts toward commercial and industrial customers. Since fully half of ERCOT's summer and winter peak loads come from residential customers' weather-sensitive loads, and Texas utilities deliver energy efficiency to fewer than 30,000 homes per year, it is appropriate to look now at residential customers for potential new efficiency and DR peak savings. Additional work can be done to estimate further peak reduction value opportunities from more aggressive commercial and industrial EE and DR programs.

Ongoing investment in EE and DR could continue growing these customer savings benefits over time, while giving ERCOT and the Commission time to stabilize the supply-side power market rules and infrastructure.

Specifically, this paper looks at seven residential retrofit measures selected for their proven capability to reduce summer or winter peak electricity demand. We also considered the impacts of a planned federal phaseout of incandescent lamps on energy demand in Texas. This paper estimates these measures' potential to improve ERCOT's system reliability by cutting summer or winter peak loads or delivering grid flexibility services:

- Program to replace electric furnaces with ENERGY STAR® heat pumps
- Attic insulation and sealing incentive program
- Smart thermostat incentive program
- Heat pump water heaters incentive program
- Central air conditioner demand response program with smart thermostat control
- Water heater demand response program
- Electric vehicle managed charging program
- Federal incandescent lamp phaseout (a federal measure that will have impacts in Texas)

Overall, we found that aggressive deployment of the first 7 of these EE and DR measures over 5 years, reaching about 9 million Texas households (single-family and multifamily), could reduce winter peaks in Texas by about 11,400 MW and summer peaks by about 7,650 MW (from what they would otherwise be; see figure ES-1). This nearly matches the total generation capacity of ten new gas-fired combined-cycle power plants of 800 MW each (similar to recent proposals), without incurring additional costs for gas fuel or additional transmission and distribution capital investments to serve increased load. The summer demand reductions are about 10% of Texas's all-time summer peak while the winter reductions are about 15% of what the peak would have been in February 2021 had power been provided to all customers without power shutoffs. The incandescent lamp phaseout adds 500 MW of summer peak reductions and 2,200 MW of winter peak reductions. Not including the incandescent lamp savings, the seven programs will reduce annual electricity consumption by about 6,600 million kWh of electricity, equivalent to the annual power draw of about 580,000 Texas homes (i.e., more homes than in Dallas).

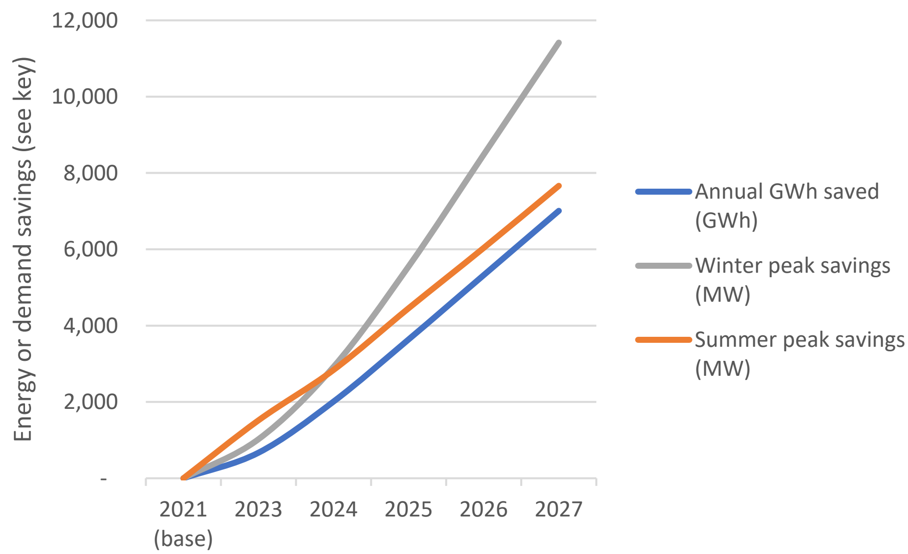

Figure ES-1. Cumulative annual energy and peak savings by year from the sum of the seven programs analyzed

Results by program are summarized in table ES-1. The largest winter peak reductions come from replacing electric furnaces with heat pumps. The largest summer peak reductions are from central air conditioner demand response. The attic insulation and sealing program has the largest energy (kWh) savings while the smart thermostat program has the best benefit-cost ratio. The attic insulation and sealing program will improve resident comfort and safety in extreme weather events in addition to energy and peak savings. This program accounts for about 60% of the total cost of the seven-program package but is foundational to make heating and cooling measures more effective.

The first seven proposed programs will cost about $700 million in the first full-scale year and about $1 billion per year for the next four years. We recommend that 2022 be used for program planning and launch, with 2023 being the first full year of expanded programs. For 2022 we recommend that present energy efficiency and demand response budgets be doubled from the $140 million budgeted in 2021 to about $280 million in 2022. This increased budget can be used to plan and begin implementing scaled-up programs and can also be used to assess and assist contractors who implement programs and install measures to scale up their operations, including in rural areas. New federal programs could make substantial contributions to these budgets as discussed in the body of the report.

While these costs are substantial, new power plants will cost even more in terms of capital costs but will deliver capacity and energy more slowly, with additional costs for fuel and maintenance that must be paid each year. For the energy efficiency and demand response programs we modeled, annual operating costs to the utilities are included in the $1 billion/year budget. Over the life of these measures, the average cost of these energy savings is about 5.6 cents/kWh, nearly half the 10 cents/kWh avoided cost estimated by the Public Utility Commission of Texas (PUCT) and less than half the 12 cents/kWh average residential electric rate in Texas. And when extreme Arctic storms or summer heat waves strike, these measures will already be installed in homes, protecting Texans and posing no deliverability challenges.

Our analysis is a preliminary one, intended to offer ballpark estimates for what energy efficiency and demand response could accomplish quickly in Texas. Additional analysis will be needed. ACEEE is prepared to conduct a more detailed analysis looking more fully at programs costs, load shape impacts, rate impacts, and employment impacts (e.g., these investments will create many jobs).

The bottom line is that the energy efficiency and load management programs examined will deliver large benefits to Texas consumers and utilities. Consumers will benefit from the following:

- **Reduced peak demand in summer and winter** will enhance grid reliability by better balancing power demand and supply and creating more grid flexibility tools with demand response. These measures will make Texas much less likely to reach the demand-supply imbalance that triggers power curtailments.
- **Lower energy bills** (due to reduced consumption and reduced need for utility capital expenditures) will be useful for all Texas households but particularly useful for low- and moderate-income Texas households who often face high energy bills as a percent of their income.
- **Improved comfort, safety, and health** because insulation and sealing will make homes more comfortable and better able to retain temperatures during power outages, among other non-energy benefits.

Utilities will see reduced capital needs because lower demand will decrease needed transmission and distribution investments. ERCOT and Texas residents will benefit from a more reliable grid that is less vulnerable to increasing extreme weather events.

These measures focus on residential energy efficiency retrofit measures, since Texas's large stock of old, inefficient homes is where much of the state's energy waste is occurring. But since Texas's population and economy are growing at robust rates, Texas can and should capture additional long-term energy savings and avoid locking in additional energy waste by adopting more rigorous energy efficiency standards for all new building construction.

Texas is now at a crossroads. The state can continue on the same path that led to massive power curtailments in February 2021 and more limited ones in June 2021. Or Texas can diversify its energy portfolio by tapping the huge potential of inefficient homes, buildings, and appliances to create energy efficiency and demand response resources that save money and improve reliability for all Texans.

Table ES-1. Estimated five-year costs, savings, and households served for seven residential energy efficiency and demand response programs targeting peak demand reductions

Program	Households served	Peak savings in year 5 (MW) Summer	Winter	Energy savings (GWh)	Costs (millions)
Efficiency					
Replace electric furnaces with ENERGY STAR HP	571,200	125	6,130	774	$571
Attic insulation/sealing and duct sealing	2,097,051	1,725	2,079	4146	$3,127
Smart thermostats	2,031,004	995	2,225	1831	$152
Heat pump water heaters	119,471	37	41	259	$117
Subtotal	4,818,726*	2,882	10,476	7008	$3,968
Demand response					
Central AC demand response	2,877,255	3,010	-		$587
Water heater demand response	1,553,120	876	876		$202
EV charging demand response	606,572	896	64		$120
Subtotal	5,036,947*	4,781	940		$909
TOTAL	9,855,673*	7,664	11,416		$4,877
Add 16% reserve margin		8,990	13,242		

***These totals include some households that participate in more than one program.**

Notes: These savings are for all of Texas and include investor-owned utilities, large municipal utilities (Austin Energy and CPS Energy, both of which are already implementing many of these programs), and smaller coops and municipal utilities.

The allowance at the bottom for reserve margin reflects the impact of reduced demand on needed generating capacity. ERCOT estimated a 16% reserve margin for summer 2021 and we use this figure for our calculation.

Introduction

Texas faces major electric reliability problems as illustrated by dramatic load shedding (power shutoffs) of about 20 GW of power, affecting 4.5 million customer accounts, during Winter Storm Uri in February 2021 (Magness 2021). It also faces a tight summer supply situation as illustrated by the calls for conservation in April and June 2021 driven by a large number of plants out of service for unplanned repairs (Sechler and Jankowski 2021). Compounding these problems, power demand has been growing, driven by population and economic growth. The 2020 Census showed that Texas's population grew 15.9% over the past decade, third among the states and trailing only the much smaller states of Idaho and Utah (Davis 2021). Over the same period, the state's economy has grown twice as fast, with real gross domestic product growing by 30.8% (St. Louis Federal Reserve Bank 2021). This population and economic growth increases the demand for power.

Power demand in Texas typically peaks on hot summer days, and as a result, the Electric Reliability Council of Texas (ERCOT) has emphasized summer peak loads in its planning. The all-time summer peak was 74,820 MW on August 12, 2019, trailed slightly by the 2021 peak of about 74,787 MW (estimated) on August 25 (ERCOT 2021a, Stempel 2021). Winter Storm Uri in February 2021 produced record cold temperatures (e.g., a low of 4°F at Dallas-Fort Worth airport; DFW Weather 2021), in turn causing drastic cuts in electricity services for the majority of Texas customers. Sharp, unexpected increases in power demand played an important role in the tragedy, in addition to the many supply-side and market design challenges commonly mentioned in many reports.[2] In terms of power supplied, this was not a winter peak for Texas, as many state power generators were not operating due to the cold weather and load was shed to match the available supply. The all-time Texas winter peak demand is 65,915 MW set in 2018 (ERCOT 2021b). In February 2021 the peak was just over 60,000 MW but would have been about 78,000 MW without load shedding (ERCOT 2021c), creating a new all-time peak.

[2] For example, see Wood et al. 2021.

Power Providers in Texas and the Electric Reliability Council of Texas (ERCOT)

The Electricity Reliability Council of Texas (ERCOT) manages wholesale power supply for about 90% of Texas load, covering 8 million customer meters and 26 million people. Small portions of the state along the borders are covered by other wholesale power pools (see brown shaded zones in map). Within ERCOT, 75% of customers are competitive choice customers who can select their own competitive retail electric provider (REP), with power transmitted to homes by transmission and distribution utilities. These utilities administer Texas's regulated energy efficiency programs. The other 25% of customers in ERCOT are served by cooperative or municipal utilities that do not participate in retail competition. Munis and coops are not required to implement Public Utility Commission regulations for energy efficiency and demand response but may implement the programs of their choice.

Map source: Shen et al. 2021

Two companies have proposed sole-sourced investments in emergency generation reserve fleets to meet future ERCOT power demands. Berkshire Hathaway proposed to build 10 natural gas–powered plants, at a cost of $8 billion with a guaranteed 9.3% rate of return, to be recovered through long-term charges to every ERCOT electricity customer; Starwood Energy Group proposed a similarly priced package for 11 such plants (Proctor 2021).

An alternate way to address these problems is to expand Texas's—currently very limited—set of energy efficiency (EE) and demand response (DR) programs, with a focus on programs that can substantially reduce summer and winter peak demand. Experience in other states demonstrates that using energy efficiency and demand response can be less expensive and more effective at bringing demand and supply into long-run, lower-risk balance (Lazar and Colburn 2013). And examinations of wholesale markets find that "energy efficiency diversifies the resource mix as a cost-effective distributed resource and reduces reliance on fuel sources that can be subject to limited availability and fluctuating prices" (Baatz, Barrett, and Stickles, 2018).

Demand response (DR) programs modify when electricity is consumed in response to price signals, grid conditions, or specific calls from the grid operator or other program coordinator. Most DR programs are dispatchable, in that they can be designed to be called to reduce load at times requested by the system operator or electricity provider. For example, such programs may cycle off air conditioners, water heaters or pool pumps for a short period of time across a large group of customers to minimize and stagger the aggregate load from these devices across a longer period—flattening the rate of increasing demand during peak hours and reducing the need to call new generation. In terms of minimizing the potential for imbalances between system-wide supply and demand, the role of DR programs is comparable to that of peaking power plants—but DR programs close this gap by reducing demand instead of by generating more power.

Energy efficiency (EE) programs reduce energy use, promoting measures that minimize energy waste while providing the same or equivalent services as less-efficient conventional technologies. While dispatchable demand response programs reduce demand at specified times by decreasing the amount of work done by participating devices at those times, energy efficiency programs reduce the amount of electric power needed to perform the same amount of work. In terms of balancing supply and demand over the course of a day, energy efficiency programs can replace generation needed from baseload or intermediate power plants, depending on the measures being promoted and when the associated demand reductions occur.

In our analysis we focus on energy efficiency measures that reduce energy use during the summer and winter peaks. The programs we analyzed tend toward the intermediate end of this spectrum—meaning they primarily save energy when residents are awake, similar to a gas power plant that may start up in the morning and ramp down as people go to sleep. The relationship between different types of loads referenced above—baseload, intermediate load, and peak load—are illustrated schematically in figure 1, which demonstrates how all three fluctuate over the course of 24 hours.

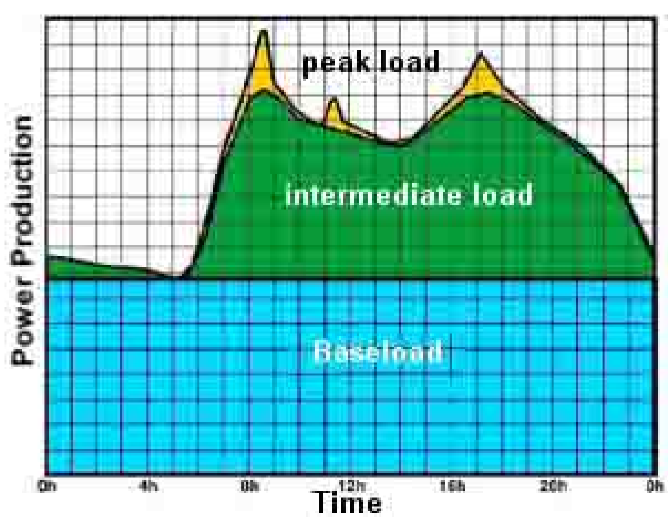

Figure 1. Schematic of base, intermediate and peak load. This shows a typical winter day. Source: Wind Watch 2021. Demand response programs help curtail the need for peak load generation, while energy efficiency programs lower the need for baseload or intermediate load generation.

With Texas's population and economy growing rapidly, additional generation will be needed in the future. Energy efficiency and demand response can slow the timing of this need and avert possible operational emergencies and load-shedding events in the future.

ENERGY EFFICIENCY AND DEMAND RESPONSE IN TEXAS

Despite a promising start in the early 2000s, Texas is now far behind other states in deploying energy efficiency and demand response to manage demand, support customer bill affordability, and reduce the likelihood of damage from future summer and winter extreme weather events. ACEEE's *2020 State Energy Efficiency Scorecard* found Texas ranked 38th among the 50 states in energy efficiency savings as a percent of electric consumption, and 36th in energy efficiency spending as a percent of electric utility revenues (Berg et al. 2020).

Texas has some foundational energy efficiency policies in place, but they require modernization and higher goals to deliver on the promise of energy efficiency and demand response as resources on Texas's grid. Texas established the first Energy Efficiency Resource Standard (EERS) in the country in 1999, which established a requirement for utilities to achieve a specified amount of energy efficiency savings annually. Such programs are required to be "cost-effective"—that is, the costs to the utility system of running energy efficiency programs (e.g., in terms of administration and incentive costs) must be less than their benefits, such as the avoided cost of supply.[3]

Since this policy was enacted, Texas has been leapfrogged by 26 other states and now has the weakest EERS in the country. Texas has the opportunity to ratchet up the ambition of this policy. Figure 2 below shows how Texas's EERS, a target of only 0.2% of MWh sales, compares to all other states with such a policy (most of which set goals of 1% or greater, more than five times Texas's savings requirement). Research from the National Renewable Energy Laboratory (NREL) and the Electric Power Research Institute (EPRI) demonstrate that Texas has the potential to catch up to other states, with savings potential beyond 1% per year (NREL 2017; EPRI 2017).

[3] This is the definition for the Utility Cost Test, which Texas relies on for cost-effectiveness testing (NESP 2021).

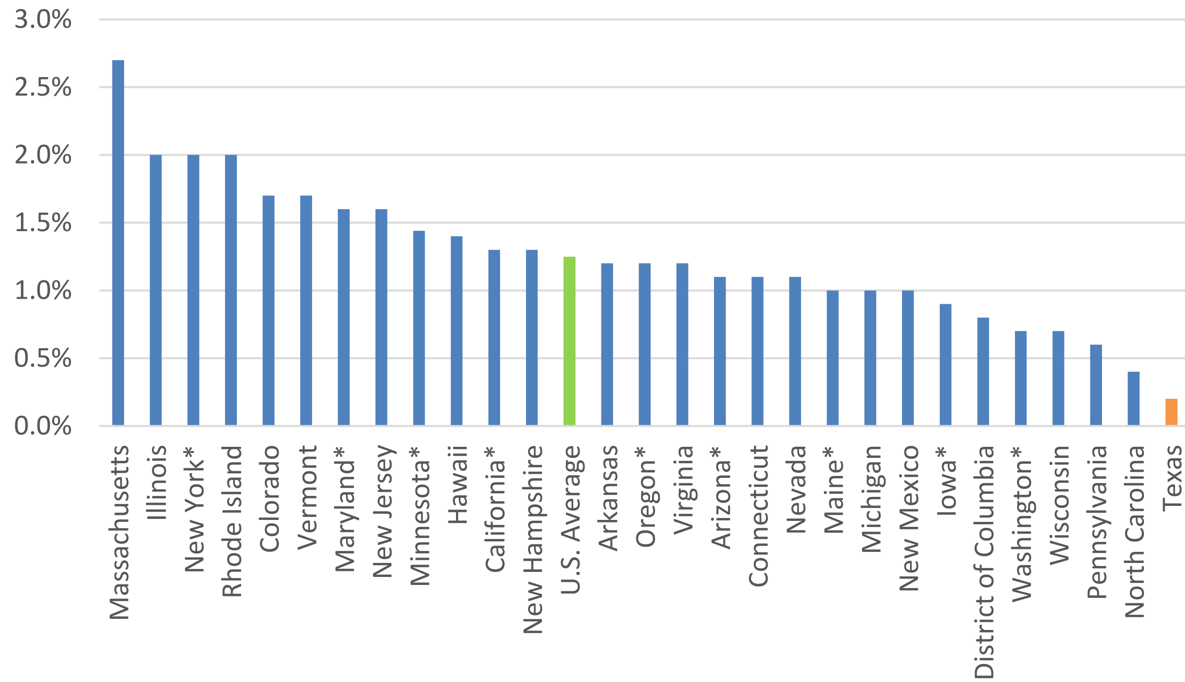

Figure 2. Annual electricity savings as a percent of state energy MWh sales per state EERS policies. For the purpose of comparison, ACEEE estimated an average annual savings target by calculating each state's EERS savings over the years specified in the EERS policy. *State savings are reported on a gross basis; a net adjustment was applied to compare with states' reporting net savings.

Utilities face several challenges in serving income-qualified customers, such as prohibitive up-front costs (relative to low-income customers' budgets) for efficiency investments and split incentives for renters. Texas requires that each utility spend a minimum of 10% of their annual energy efficiency budget on targeted low-income energy efficiency programs, and by setting relaxed cost-effectiveness rules for such programs to account for their additional benefits (e.g., indoor air quality, safety, bill affordability) to income-qualified customers (PUCT 2019).

THIS PAPER

This paper examines how much targeted energy efficiency and demand flexibility could be procured through a range of feasible EE and DR strategies within Texas over a five-year period. This analysis estimates both potential program costs and potential impacts on peak summer and winter electricity demand, as well as on overall electricity consumption and utility economics (through a simple program benefit-cost ratio from the utility perspective). We focus on the residential sector (single-family and multifamily), as during recent summer and winter peaks, the sector accounts for about 51% of the winter temperature-sensitive load and about 49% of summer temperature-sensitive load (Herbert 2018).[4] Therefore, reductions to Texas household electricity use during summer and winter peaks will translate directly into reductions of those peak loads, as well as reductions in the amount of electricity generation, storage, and transmission needed to serve all customers during peak and other grid-stressed periods.

This analysis is intended to inform the Public Utility Commission of Texas, the ERCOT grid operator, Texas utilities, others involved in utility policy debates, and the Texas Legislature as they consider market and regulatory changes to assure power system reliability in Texas.

The Residential Sector in Texas

According to the U.S. Census Bureau, as of 2019 there were about 12.3 million housing units in Texas (Census 2021a). Of these, about 21% are multifamily, meaning 5 units or more per building (Census 2021b). One-story ranch-style homes with large attic areas are common in Texas. According to federal data, less than half of homes in the West South Central region (Texas, Oklahoma, Arkansas and Louisiana) have well insulated attics and nearly 20% are poorly insulated (EIA 2018). Sealing for heat leaks between the attic and living space is often poor. Heating and cooling ducts often are in the attic and many of these are not well sealed, leaking conditioned air into the attic (Miller et al 2014). The most common type of heating system in Texas is an electric furnace (EIA 2013)—a central heating system using inefficient electric resistance heat. The predominance of inadequately insulated homes and older, low-efficiency electric resistance heating measures (furnaces, wall, baseboard and plug-in heaters) provides opportunities to reduce energy use and peak demand while improving occupant comfort and safety.[5]

Methodology

We identified and analyzed seven potential programs that can have large peak demand impacts—four energy efficiency programs and three demand response programs. In addition, we looked at the impact of a proposed federal standard to phase out incandescent lamps. For each program we estimated the number of Texas homes that might participate, program costs, and energy and peak demand savings per home (summer and winter). To the extent possible, we used data specific to Texas, such as values from the latest *Technical*

[4] More recent (2019) values sourced from ERCOT presentation without clear citation are 51% and 48% residential demand load for winter and summer respectively.

[5] For example, after an ice storm in Maine, power outages and subzero temperatures forced hundreds of residents into heated shelters. Yet others in particularly well-sealed homes saw their indoor temperature stay as high as 58 degrees after more than four days, allowing them to safely shelter in place (Cox et al. 2017).

Reference Manual (PUCT 2020). Where Texas-specific data were not available, we used data from other states that approximate conditions in Texas as much as possible. In most cases the data were based on electric utility programs in operation.

In our program benefits calculations, we value demand reductions and energy savings at the PUCT official avoided costs of $80/kW-year (one kW of power available over one year) and $0.10/kWh saved (Harris 2020). A prior PUCT proceeding has determined that the electric system saves these costs when energy efficiency and demand response programs are used to reduce energy use and peak demand (Harris 2020). Energy savings estimates include savings on the customer side of the electric meter as well as avoided transmission and distribution losses between the power plant and customer meters, using loss factors from ERCOT (2021d). We modeled each program to run for five years, starting in 2023, with 2022 used to plan and launch the new programs.

Our analysis looks at all of Texas within and outside ERCOT and all types of utilities (investor-owned, municipal, and cooperative.) We recognize that the PUCT only regulates some utilities and that ERCOT does not cover the whole state, making statewide programs unlikely. In the Recommendations section, as well as in a few of the program sections, we discuss potential ways to navigate this landscape.

Detailed assumptions, sources, and calculations for each program are provided in the Appendix.

Programs Analyzed

We analyzed seven potential programs and one policy for Texas that could produce substantial reductions in summer and winter peak demand. The programs we analyzed are listed in table 1. We selected these programs based on our understanding of the Texas housing stock and ACEEE's 30 years of experience working with electric utilities and states across the nation to design, implement, and evaluate effective EE programs serving every customer sector. The effectiveness and cost-effectiveness of the programs below for saving energy and reducing peak demand have been documented in many years of ACEEE's *Utility Efficiency Scorecard* reports (e.g., Relf et al. 2020). Experience has shown that these programs can be cleanly designed and quickly implemented, given appropriate policy direction, programmatic funding, and utility compensation; the cost and impact estimates below are based on other utilities' success and presume that Texas would bring equal commitment to new EE and DR program efforts.

While we classify the analyzed programs as either energy efficiency or demand response, some technologies enable programs that might straddle these categories. For example, we examine smart thermostats as an energy efficiency program, but some utilities also use these thermostats as part of their demand response efforts. In this case, we analyze and discuss the efficiency benefits and the demand response benefits as separate programs, but do not double-count their potential benefits. Additionally, attic insulation and sealing (and home weatherization generally) should be viewed as foundational to the effectiveness of most other EE and DR measures, because a home that does not leak conditioned air will enable more economical use of heat pumps, air conditioners, and smart thermostat DR programs. Furthermore, we recommend that these measures be viewed as a portfolio of solutions that should be deployed and evaluated in a coordinated, consolidated fashion, rather than pursuing only a few individual measures from the eight discussed here.

Table 1. Programs analyzed in this report

Energy efficiency programs	Demand response programs
Replace electric furnaces with ENERGY STAR electric heat pumps	Central air conditioners with smart thermostat control
Attic insulation and sealing	Water heaters
Smart thermostats	Electric vehicle charging
Heat pump water heaters	
Federal incandescent lamp phaseout*	

*** This phaseout is happening at the federal level but Texas utilities and ERCOT should include the impacts in their load forecast. Since this is not a utility program, we do not include these savings in our estimates of savings from utility programs.**

The sections below describe each of these programs and the structure of our analyses. A subsequent section discusses the results for each program, as well as their potential cumulative impacts and costs. For reference, a summary table of results for each program is included with the methodology descriptions below; these results are discussed together in the later sections of this report.

1) REPLACE ELECTRIC FURNACES WITH ENERGY STAR HEAT PUMPS

Program	Customers served	Peak Savings in year 5 (MW)		Energy savings (GWh)	Costs ($million)
		Summer	Winter		
Replace electric furnaces with ENERGY STAR HP	571,200	125	6,130	774	571

The most common type of heating and cooling system in Texas is a central air-conditioning system combined with an electric resistance furnace that heats air to be distributed throughout the home via ducts and registers. In 2009 there were 3.4 million homes in Texas with such systems (EIA 2013) and the number is likely greater today. These homes can be upgraded to use a high-efficiency heat pump at the same time an existing central air-conditioning unit is replaced. (A heat pump is essentially an air conditioner that can be run in reverse—providing indoor cooling in the summer, but in the winter operating in reverse to draw heat from outside air and warm the home.) Both heating and cooling savings typically result from this upgrade, year-round and at peak times, particularly if the heat pump is a high-efficiency unit as certified under the ENERGY STAR program. Even at winter design temperatures for Texas (the very coldest hours of the year), an ENERGY STAR heat pump will generally be at least twice as efficient (use half as much electricity per unit heat output) as an electric resistance heater. Cooling savings are expected because high-efficiency heat pumps are also more efficient than the average new air conditioner.[6]

For this measure, we assess a program in which Texas utilities give an incentive of approximately $1,000 per home to Texas air-conditioning contractors to encourage them to sell a heat pump instead of an air conditioner when an existing air conditioner needs replacement. The incentive should cover the incremental cost to the contractor of installing a heat pump rather than an air conditioner.[7] Because the incentive covers the incremental cost, we expect high rates of participation, gradually ramping up to 80% heat pump purchases in lieu of central air conditioner purchases by the end of the five-year program. While some heat pumps are presently incentivized by utility standard offer programs, available budgets limit the number of projects and programs are only available to some customers. A widely available program working “upstream” with contractors and wholesalers can increase participation substantially.[8] Texas has recently begun using upstream programs for lighting and retail appliances (Tetra Tech 2020), but we could not find mention of upstream programs for heat pumps. A proposed federal program called the High Efficiency Electric Home Rebate Program may be passed by Congress in the coming weeks that could fund these incentives; a bill has been reported out of committee in the House of Representatives (House Energy and Commerce Committee 2021) and is waiting for agreement with the Senate on a path to enactment.[9] As discussed in the results section, our proposed electric furnace program would have substantial summer peak reductions and the largest winter peak reductions of all the programs we examined.

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[6] The 2023 ENERGY STAR specification for air conditioners and heat pumps will require either two-speed or variable speed operation, which can reduce fan energy use by 60% or more compared to conventional air conditioners and heat pumps (EPA 2021; DOE 2016).

[7] By providing the incentive to the contractor, costs are reduced before markups are applied, substantially increasing the impact of a $1,000 incentive.

[8] For example, a study on upstream incentives by the Southwest Energy Efficiency Project reports that rebates for commercial high-efficiency air conditioners were 5 to 10 times more effective during periods of upstream incentives relative to periods of consumer incentives (Quaid and Geller 2014).

[9] The House program has a budget of $9 billion. Based on population, the Texas share would be approximately $775 million. This bill includes higher incentives for low- and moderate-income households.

It should be noted that significant energy savings might also be obtained from replacement of electric baseboard heaters (which are inefficient and energy-wasteful) with heat pumps, but this upgrade is more complicated than replacing electric furnaces. We discuss this possibility in the Other Opportunities section of this paper.

Texas utilities could relieve some local reliability challenges caused by transmission congestion by concentrating the electric furnace, air conditioner and heat pump replacement strategy in combination with attic insulation and sealing in particular areas with high demand growth behind transmission bottlenecks. Geo-targeted deployment of EE and DR has been used in other states for high-impact *non-wires solutions*.

2) ATTIC INSULATION AND SEALING

Program	Customers served	Peak savings in year 5 (MW)		Energy savings (GWh)	Costs ($million)
		Summer	Winter		
Attic insulation/sealing and duct sealing	2,097,051	1,725	2,079	4,146	3,127

An estimated 50% of single-family homes in Texas have inadequate attic insulation (NREL 2021b), which allows cooled or heated air to return to outdoor temperatures faster than would otherwise occur. This contributes to occupant discomfort and excessive energy bills[10] while leaving residents vulnerable to extreme temperatures in summer and winter. Attic upgrades incorporating improved insulation, air sealing, and duct sealing yield heating and cooling energy savings and reduce winter and summer peak demand. Insulating to R-38 or higher is recommended for attics in Texas climate zones (EPA 2016; Less and Walker 2015). Increasing insulation to a thermal resistance of R-38 and air-sealing attics in homes currently insulated to R-19 or less would save 10–30% of the annual heating and cooling electricity use for an average Texas home, depending on existing insulation levels and type of heating (e.g., electric furnace or heat pump). Leaky air ducts also contribute to the loss of heated and cooled air; duct sealing could save an additional 4–16% of heating and cooling energy use.

[10] Excessive energy bills place a particularly high burden on low-income residents in cities and rural areas. ACEEE research characterizes energy burdens at the national and regional level as well as 25 metro areas including Houston, Dallas, and San Antonio (Drehobl, Ross, and Ayala 2020). Weatherization including attic insulation and duct sealing is a leading strategy for significantly reducing high household energy burdens.

Attic insulation and sealing, and duct sealing, directly reduce both summer and winter electricity use and make DR more effective. A well-insulated home keeps the occupant comfortable under a wider range of outdoor and in-home temperatures.

For our proposed EE retrofit program, we suggest utility incentives covering 50% of customer project costs in year one of the program to ramp up participation. For year two, the utility incentive falls to 40% of project costs, before dropping to 30% for the final three years of the program. We estimate that over five years, 30% of Texas homes could be served under this program. Typical attic insulation and associated air sealing costs about $2,250, and duct sealing costs $1,250, for a total project cost of $3,500 on average.[11]Presently, some attic insulation is done through utility standard offer programs, but we have heard reports that the number of homes that can be insulated is severely limited by available budgets.

Of the programs we included in our analysis, the attic insulation and duct sealing program yields the second largest summer peak impacts and the largest electricity savings.

The program design proposed above for attic insulation and sealing in single-family homes would not be effective for low-income and multifamily housing, where the residents may have neither the money nor capability to initiate and co-fund an EE upgrade. At least 40% of Texas households are low- and moderate-income (TEPRI 2021) and just over 20% live in multifamily housing (U.S. Census Bureau 2021b), offering ample opportunity for peak and energy savings from both EE and DR. Since it will be useful for both electricity peak reduction and social and economic equity reasons to deliver weatherization to low-income and multifamily homes, we recommend that the Texas PUC develop additional programs to deliver EE cost effectively to these communities. ACEEE may be able to help with this in a future analysis.

[11] Two federal incentive proposals under consideration in Congress could increase the incentives available for insulation projects: the High Efficiency Electric Home Rebate Program (which includes an insulation component) and Zero Emissions Home Act; or for larger projects incorporating insulation, air sealing, and duct sealing, the Home Energy Performance-Based Whole House Rebate and Training Grants program. Both are incorporated in budget reconciliation legislation recently reported out by the House Committee on Energy and Commerce (2021). In both programs the incentives are higher for low- and moderate-income families. In the House bill, each of these programs has a budget of $9 billion ($18 billion total). Between the two programs, based on population, the Texas share would be more than $1.5 billion.

3) SMART THERMOSTATS

Program	Customers served	Peak savings in year 5 (MW)		Energy savings (GWh)	Costs (millions)
		Summer	Winter		
Smart thermostats	2,031,004	995	2,225	1,831	$152

Smart thermostats provide energy savings and demand reduction by simplifying residents' control and management of air-conditioning and heating systems, and by adjusting to variations in home occupancy patterns. Like programmable thermostats, smart thermostats save energy by raising cooling temperature setpoints and lowering heating setpoints when the home is unoccupied or while occupants are sleeping. Smart thermostats have the potential to save more energy than programmable thermostats by automating setpoint changes, responding to actual home occupancy, and allowing for remote operation and control. The widespread use of central air-conditioning and heating in Texas households makes smart thermostat use an option for most residents. A number of municipal utilities and cooperatives in Texas offer rebates for smart thermostats; other utility customers may be eligible for discounts or incentives as well (e.g., CenterPoint customers can get a $50 coupon for the purchase of a smart thermostat).

We propose an incentive program offering $75 (or thermostat cost, whichever is lower) for installation of ENERGY STAR-certified smart thermostats. Most incentive programs start with incentives of $75 to $100 and reduce the incentive levels over time (EPA 2020). Prices for ENERGY STAR thermostats range from $65 to $300; prices for the most popular products are $125 to $200 (Enervee 2021). Higher incentives will likely be needed for low- and moderate-income households. Smart thermostats are popular products and can generally be installed by competent homeowners. We estimate participation will ramp up to reach 20% of eligible participants cumulatively over the five-year program. Annual energy savings per unit are based on a review of smart thermostat programs and savings included in state technical resource manuals (Snell and Valentine 2020). This yields a more conservative savings estimate than the estimate we derived using the deemed savings tables in the Texas Technical Resource Manual (PUCT 2020 with weighting to account for climate zone and heating equipment type). Even with this more conservative estimate, the savings are substantial. Programs can increase savings by facilitating participant enrollment in a central AC demand response program (discussed below). Presently, some smart thermostats are installed via utility standard offer programs, but the number of homes that can receive thermostats appears to be limited by available budgets.

4) HEAT PUMP WATER HEATERS

Program	Customers served	Peak savings in year 5 (MW)		Energy savings (GWh)	Costs ($million)
		Summer	Winter		
Heat pump water heaters	119,471	37	41	259	59

Water heating represents the second largest source of residential energy demand after heating and cooling (EIA 2018). As of 2009, nearly 46% of Texas households used an electric water heater as their primary source of hot water (EIA 2013). Heat pump water heaters (HPWHs) are more energy efficient than electric resistance water heaters (ERWH); this represents an opportunity to reduce demand across more than five million households (assuming the proportion of electric water heaters has increased in line with new single-family housing construction rates since 2009 based on U.S. Census and RECS data; see details in appendix). Texas electricity providers including Austin Energy and United Cooperative Services currently offer rebates on heat pump water heaters, varying in size of incentive (Austin Energy 2021a; UCS 2021).

We propose an incentive program providing an $800 rebate to Texans to replace an electric resistance water heater with an ENERGY STAR-certified electric HPWH, generally at the end of life (13 year average life) for the current water heater. Austin Energy provides this level of incentive to customers installing an ENERGY STAR-certified HPWH. This amount covers nearly half the typical cost of replacing an ERWH with a HPWH instead of another ERWH, per values reported in NREL's National Residential Efficiency Measures Database (NREL 2021a). We estimate participation rates in line with those achievable by other energy-efficient appliance rebate programs nationally (as reported in Baatz, Gilleo, and Barigye 2016) and assume just under 8% of the state's water heater fleet will come due for replacement caused by failure annually (in line with a 13-year lifespan estimate based on DOE standards) (EERE 2010). Annual energy savings and seasonal demand savings are estimated based on deemed values for replacement of an ERWH with a HPWH in the Texas Technical Resource Manual (PUCT 2020), weighted across climate zones and indoor conditions (details in Appendix).

5) CENTRAL AIR CONDITIONER DEMAND RESPONSE

Program	Customers served	Peak savings in year 5 (MW)		Costs ($million)
		Summer	Winter	
Central AC demand response	2,877,255	3,010	-	587

Presently, Austin Energy and CPS Energy (serving San Antonio) have demand response programs to either cycle residential air conditioners during a limited number of peak demand periods or to use a smart thermostat to raise the setpoint during this period. Historically these programs have cycled air conditioners using radio paging technology, but most new installations are using smart thermostats with internet connectivity.[12] Consumers receive a discount on the thermostat and/or a monthly payment or credit during summer months. CenterPoint used to offer such a program but no longer does.

We propose a program that would offer demand response services to all Texas residents with central air conditioners, modeled on the Austin and San Antonio municipal programs.[13] We propose both cost sharing on the thermostat as well as regular payments during the summer months to help keep participants motivated to remain in the program. Austin does not provide such payments and has seen a significant number of consumers leaving the program (Austin Energy 2021). The cost-sharing of the thermostats may include some double-counting of costs with the smart thermostat program discussed above. The peak savings from this program are in addition to the peak savings from the smart thermostat program. San Antonio has experimented with various ways to control thermostats and achieved the largest savings with a specific schedule they developed to maximize impacts (CPS Energy 2019). Our peak demand impacts are based on the savings from a 33% cycling schedule which are about the same as the CPS schedule (details in the Appendix). As discussed in the Results section, this program has the largest summer peak impact of all the programs we examined.

DR programs have higher customer retention over an operating season and over multiple years if the utility or REP managing the curtailments conducts excellent communication with customers about when and why DR events are happening. The most effective DR programs also offer meaningful compensation to participating customers for their inconvenience and exercise some moderation in the number, magnitude, and duration of temperature shifts. Such efforts are important to ensure that these programs retain high numbers of participants, so that they can collectively deliver a predictable and substantial demand response while exposing participating households to tolerable temperature swings.

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[12] Programs are moving to smart thermostats because they regulate temperature directly, helping to maintain occupant comfort—and also because smart thermostats provide energy savings outside of the peak, as described in the smart thermostat program above. With radio control, air conditioners are cycled off and at times temperatures can move outside of occupant comfort ranges.

[13] While we recommend that all utilities implement such a program, we recognize that this may be hard to execute in practice. For example, municipal utilities and electric coops are not regulated by the PUCT. One option might be that ERCOT implement such a program, covering the 90% of the state that it serves, with some additional participants added from PUCT-regulated utilities outside of ERCOT.

Since a thermostat controls both heating and cooling, smart thermostat DR can also be used in winter emergencies (as San Antonio and Austin did during Winter Storm Uri). Although that application significantly increases the value of smart thermostat investments, this analysis does not evaluate winter peak reduction potential from smart thermostat investments. Out of all the programs reviewed in this paper, smart thermostats are the only measure that is routinely offered by REPs and Curtailment Providers (e.g., OhmConnect, Google Nest, and MP2) today. This means that utility investments in smart thermostats could help grow the pool of residential DR participants faster, to provide greater dispatchable load relief and operational flexibility to the ERCOT grid.

6) WATER HEATER DEMAND RESPONSE

Program	Customers served	Peak savings in year 5 (MW)		Costs ($million)
		Summer	Winter	
Water heater demand response	1,553,120	876	876	202

Water heater demand response programs enable a utility to shift or curtail energy use of water heaters through a control device, retrofitted or built into the heater. Curtailment of demand from these devices may provide an attractive option during severe peak events driven by high or low temperature extremes, as impacts to consumers from temporary reductions in hot water temperature are far less significant than the loss of heating, cooling, or other essential power uses.

We propose a program that would offer demand response services to all Texas residents with electric water heaters, a small (< 2%) number of which are assumed to be electric heat pump water heaters. The program would install and pay for the water heater control device, presumed to be available for a lower bulk or wholesale rate than the retail cost of devices sold directly to individual consumers. We further propose that annual payments be provided to motivate continued participation. Potential reductions of load per participating water heater are estimated based on an average of several reported or estimated values identified in literature (see details in Appendix). We also reduce anticipated demand savings for the estimated HPWH fleet to 50% of those from ERWHs (see details in Appendix.)

7) ELECTRIC VEHICLE MANAGED CHARGING

Program	Customers served	Peak savings in year 5 (MW)		Costs ($million)
		Summer	Winter	
EV charging demand response	606,572	896	52	120

Electric vehicles (EVs) currently constitute only a fraction of a percent of the vehicles titled in Texas. But as noted in ERCOT's 2020 Long-Term System Assessment documentation (ERCOT 2020), this fleet is anticipated to grow dramatically over the coming decades, fueled by advancing performance, reduced vehicle costs, increased model availability, increased availability of charging infrastructure, and emissions reductions goals worldwide. This coming growth represents a major potential challenge to grid operators in terms of new electric load to absorb; the collective EV infrastructure also presents an opportunity to smooth daily load curves through proactive managed charging. However, the retail structure of Texas's electricity market complicates the implementation of some forms of managed charging.

Demand response measures involving electric vehicles include both time-of-use and direct load control (often called managed charging) models. Time-of-use (TOU) programs vary retail electricity rates to encourage charging during off-peak hours, while managed charging models enable a managing entity to directly control the participant's EV charger and reduce its power draw when needed. San Antonio's CPS Energy offers both TOU and managed charging programs as of 2021 (CPS Energy 2021). Ev.energy has also developed a "virtual power plant" in Austin, enlisting a fleet of EVs to provide coordinated load curtailment (ev.energy 2021).

Although TOU programs have been highly effective at incenting EV off-peak charging, under current rules the PUCT cannot impose such programs upon competitive REPs. However, TDUS and demand aggregators could use managed EV charging programs to deliver dispatchable demand reduction. Pursuing this infrastructure would also help lay the foundation for future vehicle-to-grid power measures (Davar 2020), which could offer significant peak reduction and demand flexibility services in a future with high rates of EV adoption.

We propose a managed charging program to reward customers for providing demand response services as needed during peak hours. We estimate participation in such a program based on survey responses conducted by the Smart Electric Power Alliance (SEPA 2019a), which suggest that 72% of EV owners would be willing to charge their vehicles at off-peak hours. Summer peak demand impacts per vehicle are estimated based on ev.energy's estimate of average per-vehicle curtailment on the ERCOT grid among its EV DR fleet; winter peak demand curtailment potential is estimated based on a typical 8 a.m. EV charging profile (USDRIVE 2019), reflecting reduced demand load available to curtail during typical morning winter peak times in Texas. We model an upfront payment to enroll in this program, supplemented with declining annual payments to continue participation.

SAVINGS FROM FEDERAL INCANDESCENT LAMP PHASEOUT

In addition to the energy savings and demand reductions available from the program measures outlined above, pending federal standards phasing out incandescent lighting will yield significant savings over the analysis period at no cost to Texas utilities. Federal minimum efficiency standards for general service lighting (GSL) will dramatically reduce lighting energy use in homes and reduce summer and winter peak demand by accelerating the shift from older, inefficient incandescent and halogen lighting technologies to high-efficiency LEDs. DOE is currently reevaluating the 2019 determination that delayed implementation of the GSL standards originally scheduled to take effect in January 2020. The standards will cover the most common pear-shaped A-line bulbs as well as popular specialty bulbs such as candelabra, globe, and reflector bulbs. Despite growing sales of LEDs, research shows that incandescent and halogen bulbs still made up 38% of new bulb sales in 2019 (Apex Analytics 2020) and approximately one billion light sockets in the U.S. still use these inefficient bulb types (ASAP et al. 2021).

We are not proposing a program for lighting, but we include these products in our analysis to recognize the significant energy and demand reduction benefits the anticipated standard will deliver over the next five years without further utility investments. LEDs use up to 90% less electricity than incandescent lamps and 24% less than compact fluorescent lamps (CFLs) and last 25 times longer than old-fashioned incandescent bulbs. Many LED bulbs can be purchased for a small premium relative to incandescents; the added cost is recovered with energy savings in just a few months. With the relatively short life of incandescent bulbs (averaging 1,000 hours), many bulbs will be replaced in a short timeframe, providing energy and demand savings more rapidly than other measures in our analysis.

Residential lighting is an important contributor to peak demand—particularly in winter—and LEDs offer significant demand reduction. These lighting standards save more electricity than any other measure in our analysis (6,600 GWh), while providing significant winter peak reductions (2,200 MW). Utilities and ERCOT should include these savings in their load forecasts.

Serving Low- and Moderate-Income Households

Many of the programs discussed above can be specifically targeted to reach low- and moderate-income (LMI) Texas families, which are likely to benefit disproportionately from both reduced financial burdens associated with improved household efficiency and from measures that may improve indoor conditions and resident health. The attic insulation and sealing program and smart thermostats have particularly large potential to benefit these groups, as LMI families are less likely to already have smart thermostats and well-insulated attics (EIA 2013). Many LMI families can also benefit from the energy bill savings and any additional incentive payments involved in programs replacing electric furnaces and from air conditioner and water heater demand response programs. These households will additionally benefit from the incandescent lamp phaseout through reduced household energy costs and bulb replacement costs.

In order to reach LMI households, marketing should specifically target LMI communities, working with local partners in these communities that are trusted by residents. This may include community organizations, local governments, and churches. For LMI families, higher incentives may be needed. For example, instead of the utility paying 50% of the cost, perhaps they should pay 80% of the cost for families with an income less than 80% of the area median income (this is a common eligibility threshold for affordable housing programs). We have not incorporated these additional costs in this report, but we hope to further define these program ideas in a future phase of this work.

We can also extend these ideas to multifamily housing, where building owners often see little value to investing in energy efficiency for renters. But because ERCOT needs predictable, manageable ways to reduce peak and secure dispatchable flexibility services, the extensive electricity usage locked up in multifamily housing offers opportunity and value that could justify compensation incentives to building owners. This is another topic worth exploration in future work.

Other Opportunities

In addition to the proposed solutions discussed above, there are additional opportunities for peak demand reduction from residential programs. These include

- *Swimming pool pumps*. Texas has at least half a million swimming pools (Katz 2016). Pool pumps can be controlled through a demand response program, reducing peak summer demand by more than 1 kW per pool (Energy Solutions 2020).
- *Batteries*. A growing number of Texas homes are installing battery storage, either in conjunction with solar photovoltaic systems or as a backup when the power goes out. Some utilities are paying customers to use these batteries to run their homes during peak demand periods, reducing the load on the utility (SEPA 2019b). With proper wholesale market incentives and permissions, ancillary service aggregators could use distributed batteries to mitigate the rate of evening solar photovoltaic ramp-down on system net peak demand and frequency.
- *Room air conditioners*. Some Texas homes and rental multifamily housing use room air conditioners that could be managed for demand response, as Consolidated Edison has done in New York City and as Eversource is now doing in Connecticut (Tweed 2012; Eversource 2021).

- *Baseboard heaters*. While many Texas homes use electric furnaces, some have electric baseboard heaters. These can be replaced with "mini-split" heat pumps,[14] although costs will be higher than the electric furnace replacement program outlined above (Nadel and Kallakuri 2016).

There are also large opportunities in the commercial and industrial (C&I) sectors to reduce peak demand. Texas utilities and ERCOT already have some demand response programs that can be expanded. Texas utilities also have some C&I energy efficiency programs, but these have emphasized lighting upgrades. Now that LED lighting is becoming one of the most common types of lighting in commercial buildings,[15] Texas utilities should transition C&I programs to focus more on heating, ventilation, and air-conditioning (HVAC), weather-sensitive loads that are higher during peak periods. For example, there are efficiency opportunities through employing intelligent control strategies (Rogers 2013 et al.) as well as opportunities to manage and shift loads through grid-interactive efficient buildings (GEB) strategies (DOE 2021).

Results

We conclude that the seven programs analyzed, delivered as described to about nine million Texas households over five years, would in aggregate reduce winter peaks across the state by about 11,400 MW and reduce summer peaks by about 7,650 MW. This is nearly equivalent to the demand that could be served by the generation capacity of ten new 800 MW gas-fired combined-cycle power plants—but at a total program cost of about $4.9 billion over 5 years, about 39% less than the total cost of new gas-fired plants. These programs will also reduce annual electricity consumption by about 7 billion kWh of electricity, equivalent to the annual power use of about 580,000 Texas households (more than number of households in Dallas.)[16]

The demand reductions delivered by these programs prevent not only the need for power generation equal to the amount of avoided energy use by consumers but also the need to generate additional energy typically lost during the electricity delivery process. As noted earlier, our estimated savings include a 5.49% average estimated distribution loss factor

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[14] Mini-split air conditioners and heat pumps are typically mounted high on a wall and can cool and heat a room or set of rooms. They are common in Asia and Europe and becoming increasingly common in the U.S. Further information is provided in a *New York Times* article (Mahony and Sawyers 2021).

[15] The new Commercial Building Energy Consumption Survey found that 44% of U.S. commercial buildings used LED lighting in 2018 (EIA 2021b).

[16] This is based on 12,105 kWh/year per Texas household (EIA 2021a). Our GWh savings divided by 12,105 kWh per household means 1,385,000 households. According to Data Commons, Houston has 876,500 households and Dallas 519,000 households: datacommons.org/place/.

(ERCOT 2021d), representing power that would have been generated and lost through transmission and distribution.

Reducing power demand also reduces the size of ERCOT's needed reserve capacity. If we add a 16% reserve margin to the estimated power savings achievable through our analyzed programs[17]—representing reserve capacity no longer needed because of the system-wide demand reductions—the avoided generating capacity after five years totals about 8,900 MW in the summer and 13,200 MW in the winter (shown in table ES-1). This increase in estimated demand savings stemming from the reduced need for reserve margin is equivalent to the generation capacity of at least an additional gas-fired combined-cycle power plant. (Note that we do not include this reserve margin in our estimates that follow of cost-effectiveness of the total suite of analyzed programs, nor in our reporting of the energy and demand savings potentials of individual programs.)

Over the life of these measures, the average cost of these energy savings is about 5.6 cents/kWh, nearly half the 10 cents/kWh avoided cost estimated by the PUCT and less than half the 12 cents/kWh average residential electric rate in Texas. And at times of extreme weather, these measures will already be in place in Texas homes and will operate to keep the residents comfortable and safe despite external bad weather and its impact on generator and fuel availability.

Although $4.9 billion over 5 years is substantial, 8,000 MW worth of new gas plant capacity has been proposed at a cost of at least $8 billion, plus the costs of return on investment, fuel, and maintenance that must be paid each year after plant construction. EIA estimates that—on average—gas turbine combustion plant capital costs are only 42% of its total cost per kWh; for gas combined-cycle plants, capital costs on average 20% of total costs (EIA 2021c). In contrast, annual operating costs to the utilities are included in the $1 billion/year utility budget for the energy efficiency and demand response programs we modeled. Once installed, these efficiency measures would continue delivering around-the-clock comfort, energy and energy bill savings, and peak load reduction for 10- to 20-year measure lives. Ongoing investment in EE and DR could continue growing these customer savings benefits over time and give ERCOT and the Commission time to stabilize the supply-side power market rules and infrastructure.

We calculated an approximate benefit-cost ratio for the set of programs, finding that benefits are well over twice the costs for the energy efficiency programs in aggregate, and about 20% greater than the costs for the demand response programs. A subsequent section

[17] In the spring of 2021, ERCOT (2021c) estimated a summer 2021 reserve margin of 16%. The allowance for reserve margin reflects the impact of reduced demand on needed generating capacity. We use ERCOT's figure for our calculation.

describes these results and examines why the relative cost-effectiveness of energy efficiency and demand response differ.

PEAK DEMAND SAVINGS

Summer and winter peak demand savings by year for our seven programs are illustrated in figures 3 and 4. We estimate that after five years of development, the largest summer peak savings are from central air conditioner demand response (about 3,000 MW), followed by attic insulation and duct sealing (1,700 MW), smart thermostats (1,000 MW), electric vehicle demand response and electric water heater demand response (about 895 and 875 MW, respectively). The largest winter peak savings (about 6,000 MW) are from replacing electric furnaces with ENERGY STAR heat pumps when existing central air conditioners need to be replaced. Other large winter peak savings are from smart thermostats (2,200 MW) and attic insulation and sealing (2,100 MW). Due to the very large winter savings of replacing electric furnaces, and the fact that winter peak savings from attic insulation and smart thermostats are larger than summer peak savings, overall winter peak savings are about 73% greater than summer peak savings.

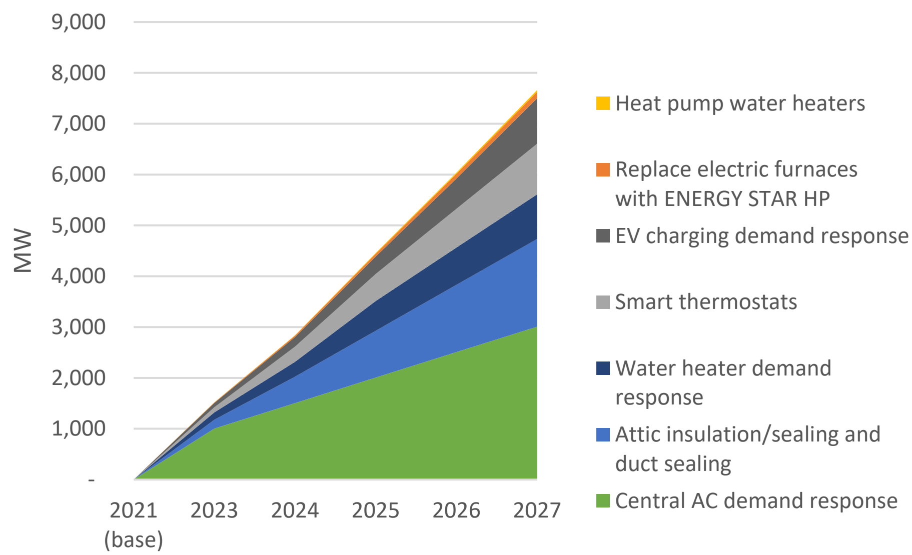

Figure 3. Summer peak savings by program and year

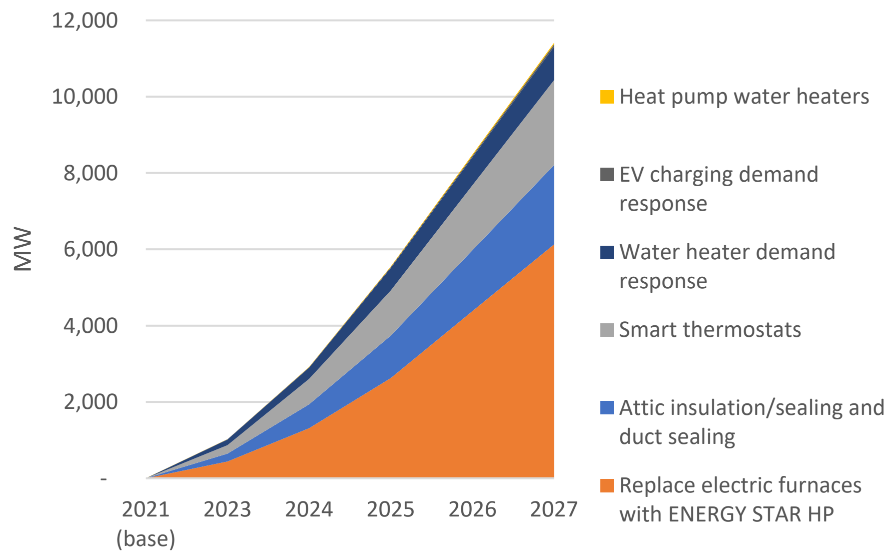

Figure 4. Winter peak savings by program and year

ENERGY SAVINGS AND LEVELIZED COSTS

Energy (kWh) savings by program and year are illustrated in Figure 5. The largest energy savings are from attic insulation and duct sealing (4,100 million kWh) and smart thermostats (1,800 million kWh). Heat pump water heaters will save about 250 million kWh. The demand response programs primarily shift energy use from one period to another and deliver very little energy savings.

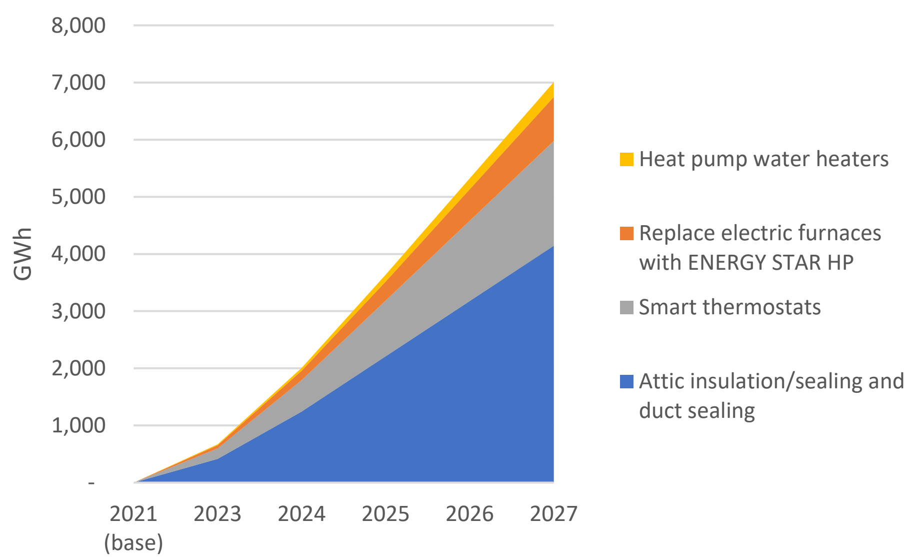

Figure 5. Energy savings (GWh) by program and year

We also estimated the average life of each of the energy efficiency measures and used this, the projected energy savings, and estimated program costs (discussed in the next section) to estimate the levelized (average lifecycle) cost per kWh saved. These levelized costs are summarized in table 2 and range from 1–7 cents per kWh saved—in all cases, less than the current PUCT estimate of avoided energy costs of 10 cents per kWh (PUCT 2020).

Table 2. Measure levelized costs per kWh saved

Program	Average life (years)	Levelized $/kWh
Replace electric furnaces with ENERGY STAR heat pumps	15	$0.071
Attic insulation/sealing and duct sealing	20	$0.061
Smart thermostats	10	$0.011
Heat pump water heaters	13	$0.048
Weighted average	14.5	$0.056

Levelized cost only calculated for energy efficiency measures and not demand response measures. Levelized cost calculated in 2021$ using a 5% real discount rate.

PROGRAM COSTS

Program costs by program and year are summarized in figure 6. Total costs are about $4.9 billion, an average of about $1 billion per year. Program costs will start low ($700 million) in the first full year as programs ramp up, but subsequently level out at around $1 billion annually as learning and economies of scale kick in, including some reductions of proposed incentives in later years. These costs do not include planning costs in 2022, in preparation for program ramp-up in 2022 (see discussion in Recommendations section).

The attic insulation and sealing program accounts for about $3 billion (more than 65%) of the total program costs of all seven included measures. Insulation costs are high because we estimate a cost per utility of nearly $2,000 per home and estimate just over 2 million participants out of Texas's nearly 9 million single-family residences. The next most expensive programs are the central air conditioner demand response program and electric furnace replacement program, costing about $585 million and $570 million respectively over five years. The latter costs a little over $1,000 per home (helping to pay the incremental cost between a heat pump and a central air conditioner) and involves not quite 600,000 homes over the five years. The former ramps up to nearly three million homes but costs much less per participant. As noted earlier, attic insulation and sealing make the demand response programs more effective in terms of delivered savings and occupant comfort.

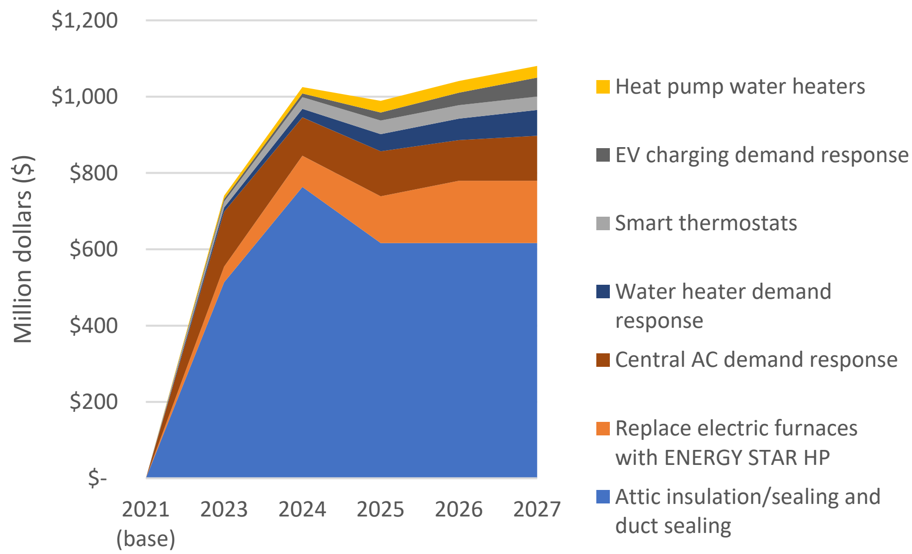

Figure 6. Utility costs by program and year. Our proposal includes reductions in the incentive for attic insulation in year three.

SIMPLE BENEFIT-COST ANALYSIS

Since programs save different amounts of energy and peak demand, we conducted a simplified benefit-cost analysis. We value benefits—limited to energy savings and demand savings—using the PUCT's official valuations for avoided costs ($80/kW-year (one kW of power provided, over one year) and $0.10/kWh saved (Harris 2020)). For peak demand reductions, since Texas peaks more in the summer than the winter, we valued summer savings at two-thirds and winter savings at one-third of the total capacity avoided cost. Costs included are limited to those borne by the utility, so this measure is essentially a benefit-cost test from the utility perspective. This is a simplified analysis and was conducted in terms of 2021 dollars without discounting.[18] Results of the analysis are summarized in figure 7.

[18] No discounting was applied for any future valuation of program costs, avoided utility costs, or other valuations in this preliminary analysis, but could be incorporated in more detailed future study.

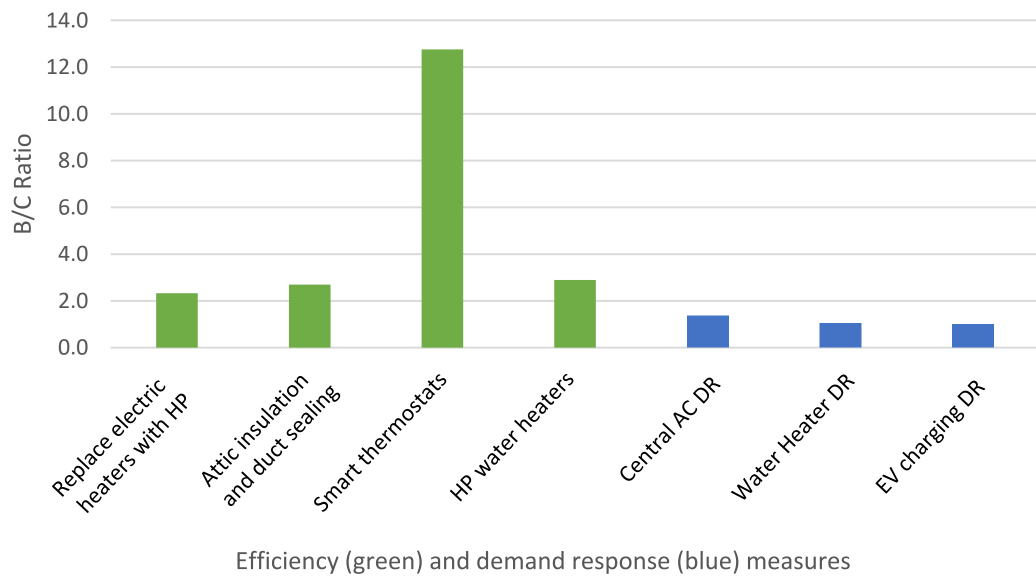

Figure 7. Benefit-cost ratio by program (simplified analysis)

The efficiency programs have a benefit-cost ratio ranging from 12.8 for the smart thermostat program to 2.3 for the electric furnace replacement program. The attic insulation and sealing and heat pump water heater programs have benefit-cost ratios of 2.7 and 2.9 respectively.

Benefit-cost ratios for the demand response programs are generally just over 1.0 because the PUCT values peak reductions based on the cost of generation at peaker power plants. If peak reductions were valued at the capital cost of combined-cycle power plants, such as those proposed for Texas by Berkshire Hathaway and Starwood (Proctor 2021), the benefit-cost ratio would be significantly higher (because the low-cost DR programs would be compared to higher-cost combined cycle gas plants). This comparison may be more appropriate, given that the implementation of these demand response measures would avoid or delay the need for this new generation construction.

Of the demand response programs, the central air conditioner program has the best benefit-cost ratio (1.4); the water heater demand response program and EV managed charging program, as modeled, each have a benefit-cost ratio near 1. Additionally, some of our assessed program types are likely to become more cost effective over time. For example, the water heater control program includes substantial costs for water heater controllers and has a benefit-cost ratio of 1.04 in our simple analysis. However, many new water heaters are equipped with WiFi capabilities; as these units become more common, the cost of water heater demand response is likely to decline. Similarly, the expectation of significant growth in EV adoption in the coming decade is likely to spur other creative solutions to unlock the huge potential of utilizing the EV fleet for demand response.

The aggregate benefit-cost ratio of the proposed suite of 7 programs is 2.7 for the efficiency programs and 1.2 for the demand response programs. While the benefit-cost ratio of any individual measure is subject to change through the details of program design, incentive size, and implementation success, the aggregate cost-effectiveness of this suite of measures taken together highlights the significant potential to utilize energy efficiency and demand response programs as tools to meet ERCOT's needs.

Historically, the PUCT and utilities may have designed these programs to deliver maximum energy savings, and so they selected measures that have high delivered energy value; but today Texas needs kW peak reductions far more than kWh reductions, so the fact that kWh levelized costs are lower is less problematic given the significant cost advantage per kW saved.

OTHER BENEFITS

Because our benefit-cost analysis is conducted from a utility perspective, our accounting omits the significant potential value of this suite of interventions to participating electricity end consumers. Decisionmakers should bear in mind the potential value of these measures in terms of improvements to the health, safety, and well-being of millions of Texans.

The potential non-energy benefits (NEBs) of several of these programs include improvements to participant health stemming from direct modifications to the home environment. While precise quantification of the individual health impacts of specific energy efficiency measures remains a challenge, evaluations of NEBs based on weatherization interventions by the federal Weatherization Assistance Program (WAP) suggest that each home weatherized yields several thousand dollars of non-energy benefits, spread between households and society (Tonn et al. 2014).

Basic weatherization measures, including attic insulation and duct sealing, in combination with measures to ensure adequate ventilation and moisture exclusion, correlate with improved resident comfort and fewer extreme indoor temperatures (Wilson et al. 2016). A review of the impacts of more comprehensive weatherization approaches strongly suggests that these measures can reduce in-home stresses and triggers linked to increased frequency or severity of respiratory illnesses like asthma (Wilson et al. 2016). We anticipate that a statewide program of attic insulation and duct sealing would make treated homes safer and more resilient during future extreme weather events in addition to improving comfort and health year-round.

Large-scale programs like those analyzed also offer a highly cost-effective opportunity to identify and address basic health and safety hazards as part of program implementation. For example, a range of such services may be included with in-home efficiency programs funded by WAP (EERE 2017). At grantee discretion, these measures may not only remedy unsafe conditions to allow implementation of energy efficiency measures, but also include simple but impactful benefits like installing smoke alarms and CO monitors.

Household energy expenditures are expected to decrease with the energy efficiency program measures, as well as with rebates or incentives connected to all programs. A home's "energy burden" is the proportion of household income spent on energy costs; households with high energy burdens (which are disproportionately low-income and minority households (Drehobl, Ross and Ayala 2020)) may face impossible decisions between essential expenditures such as adequate heating, sufficient food, and prescribed medication. These so-called "heat-or-eat dilemmas" can create a cascade of negative impacts to a household's health and well-being (Hernández 2016). Benefits to households from reduced total energy expenditures may also translate back into savings for utilities in the form of reduced transmission and distribution costs, reduced collections actions, and reduced disconnection and reconnection activities (Tonn et al. 2014).

Expanding energy efficiency and demand response programs will also grow the Texas economy. Energy efficiency and demand response measure installation creates many jobs.[19] And as consumer bills decline due to reduced energy use, consumers generally spend those savings on other goods and services such as home improvements and meals and entertainment. While we did not have time in this preliminary study to model the impacts of these programs on the Texas economy, a prior ACEEE study on a somewhat different set of programs estimated that employment gains would be about 5,500 jobs in the first year of expanded programs, growing to 38,000 jobs in the last year of the analysis (Laitner, Elliott and Eldridge 2007). And as consumers' bills decline due to their reduced energy use, they will generally spend those savings on other goods and services such as home improvements, meals, and entertainment.

Recommendations and Next Steps

We recommend that Texas utilities begin planning for the following seven programs, all of which have large peak demand savings and appear to be cost-effective to the utility:

- Program to replace electric furnaces with ENERGY STAR heat pumps
- Attic insulation and sealing incentive program
- Smart thermostat incentive program
- Heat pump water heaters incentive program
- Central air conditioner demand response program with smart thermostat control
- Water heater demand response program
- Electric vehicle managed charging program

[19] The *2020 U.S. Energy and Employment Report* notes that in 2019 Texas had over 169,000 jobs in the energy efficiency sector, even without the significant program expansions recommended here. (NASEO and EFI 2020). See https://www.usenergyjobs.org/2020-state-reports.

In addition, utilities should factor the federal incandescent lamp phaseout into their load forecasts; this transition is essentially a free program with significant demand reduction implications.

We recognize that the path forward to implement these programs must address several barriers and will require creative solutions. Some of these programs can be implemented via the current standard offer approach, but others can benefit from additional approaches. Specific barriers and potential solutions are summarized in table 2.

Table 2. Barriers to expanded EE and DR programs and potential solutions

Barrier	Possible solution
Program participation rates are limited by available budgets.	Increase program budgets by increasing Energy Efficiency Cost Recovery Factors through a change to PUCT rules. Allow smaller, often rural utilities to purchase savings credits from larger utilities.
Demand response programs emphasize commercial and industrial customers, and residential DR programs are limited except for Austin Energy and CPS Energy.	Have ERCOT operate residential DR programs or direct the distribution utilities to operate such programs.
Current heat pump and heat pump water heater programs are limited and often involve consumer incentives.	Implement a midstream or upstream program by which distribution utilities provide incentives to contractors or wholesalers. [20]

We recommend that 2022 be used for program planning and launch, with 2023 being the first full year of expanded programs. For 2022 we recommend that present energy efficiency and demand response budgets be doubled from the $140 million budgeted in 2021 to about $280 million in 2022. This increased budget can be used to plan and begin implementing scaled-up programs; it can also be used to assess and assist contractors who implement programs and install measures to scale up their operations, including in rural areas. Budgets should be raised to $700k in 2023 and to about $1b in 2024, and then held approximately level after that. New federal programs could make substantial contributions to these budgets (leveraging and expanding the total budget and impact on Texas reliability or allowing some strategic customer funding reductions), as discussed in the body of the

[20] Texas has recently begun using upstream programs for lighting and retail appliances (Tetra Tech 2020), but we could not find mention of upstream programs for heat pumps.

report. The Texas Commission should continue the practice of allowing the utilities that manage these energy efficiency and demand response programs to earn a share of energy savings, as a way to ensure that the utilities remain committed to excel in delivering these strategically critical programs.

We also recommend that the Commission substantially increase the 10% of program budgets currently allocated for low-income households. For example, Delaware, Montana, New Hampshire, New York, and the District of Columbia all set aside 15–20% of their energy efficiency budgets for low-income households (Berg and Drehobl 2018). We recommend that Texas double its percentage to 20% to make up for how little has been accomplished over the energy efficiency program history and begin realizing the significant energy-saving potential of low-income housing.

Taken together, these programs will cost far less than the $8 billion that has been proposed to build an emergency generation reserve of new power plants and eliminate the need for an equivalent magnitude of generation during summer and winter peaks. These investments are significantly more expensive than their upfront cost -- for new power plants, generation and transmission capital costs are just the down-payment, with additional fuel and maintenance costs to be paid every year. In contrast, the costs of the energy efficiency and demand response programs that would be charged to all Texas electricity customers are incorporated into our cost estimate through 2027.

The programs evaluated above focus on residential energy efficiency retrofits. But Texas is one of the fastest-growing states in the nation, with an extraordinarily high rate of new building construction. We strongly recommend that the state Legislature and cities adopt the most recent model energy efficiency building codes to upgrade the quality of new housing and building stock (including commercial and industrial buildings). This would deliver long-lasting benefits in terms of energy bill savings and grid reliability without any incremental cost to taxpayers or utility customers and would lessen the need for future efficiency retrofits.

Our analysis is a preliminary one, intended to offer ballpark estimates for what energy efficiency and demand response could accomplish quickly in Texas. Additional analysis will be needed to refine these estimates. ACEEE is prepared to conduct a more detailed analysis, looking more fully at programs costs, load shape impacts, and rate impacts. We can also conduct an input-output looking at the job impacts of our proposed programs. Utilities should also look at these program details. We look forward to engaging with them through this process.

The bottom line is that the energy efficiency and load management programs we have examined have large benefits to Texas consumers and utilities. Consumers will benefit from the following:

- **Reduced peak demand in summer and winter** will enhance grid reliability by better balancing power demand and supply and creating more grid flexibility tools with demand response. These measures will make Texas much less likely to reach the demand-supply imbalance that triggers power curtailments.

- **Lower energy bills** (due to reduced consumption and reduced need for utility capital expenditures) will be particularly useful for low- and moderate-income Texas households who often face high energy bills as a percent of their income.
- **Improved comfort, safety, and health,** because insulation and sealing will make homes more comfortable and better able to retain temperatures during power outages, among other non-energy benefits.

Utilities will see reduced capital needs because lower demand will reduce or modify needed transmission and distribution investments. ERCOT and Texas residents will benefit from a more reliable grid that is less vulnerable to increasing extreme weather events.

Texas is now at a crossroads. The state can continue on the same path that led to the massive power curtailments in February 2021 and more limited ones in June 2021. Or Texas can diversify its portfolio by tapping its huge resource of inefficient homes, buildings, and appliances to create energy efficiency and demand response resources that save money and improve reliability for all Texans.

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Appendix. Program Assumptions and Calculations

Texas Electricity Savings Analysis									
	Total	2021 (base)	2023	2024	2025	2026	2027	Notes	References
Cross-cutting data									
Housing units in Texas	11,283,353							This is for 2019, from https://www.census.gov/quickfacts/TX .	https://www.census.gov/quickfacts/TX
Percent multifamily	20.8%							From American Community Survey 2019 one-year estimates.	https://www.census.gov/programs-surveys/acs
Average T&D losses	5.49%							This is the default in the ERCOT 2021 TDSP Distribution Loss Factors Methodology. Varies by company and type of circuit.	http://www.ercot.com/mktinfo/metering/dlfmethodology
Electricity use/household		12,105						For Texas for the first half of 2021, multiplied by 2 to annualize.	https://www.eia.gov/electricity/monthly/

Replace electric furnaces with ENERGY STAR HP									
	Total	2021 (base)	2023	2024	2025	2026	2027	Notes	References
Number of electric furnaces		3,400,000	3,400,000	3,400,000	3,400,000	3,400,000	3,400,000	From RECS 2009 (state-specific data not reported in RECS 2015). Do not have data on rate of growth so left level to be conservative.	https://www.eia.gov/consumption/residential/data/2009/index.php?view=characteristics
Percent of homes also with AC		90%	90%	90%	90%	90%	90%	In 2009, 84.7% of Texas homes have central AC per EIA's Residential Energy Consumption Survey. This figure has likely increased since then. Also, homes with electric furnaces more likely to have AC; if they didn't have AC the builder could save money by putting in baseboard heaters instead of ducts.	https://www.eia.gov/consumption/residential/data/2009/index.php?view=characteristics
Number replacements/year		204,000	204,000	204,000	204,000	204,000	204,000	Number of homes with electric furnaces times % with central AC divided by average 15 year life (from DOE).	
Percent who choose HP w/ incentive			20%	40%	60%	80%	80%	Ramp up to 80% since program covers incremental cost and there are benefits to homeowner in reduced energy costs and feeling that they are helping to address winter peaks.	
Number of participants	571,200		40,800	81,600	122,400	163,200	163,200		
Average kWh/home for space htg		1847	1847	1847	1847	1847	1847	For Texas from 2009 EIA RECS. More recent RECS doesn't have state-specific data.	https://www.eia.gov/consumption/residential/data/2009/index.php?view=consumption
Heat pump COP		3.35	3.35	3.35	3.35	3.35	3.35	Based on new ENERGY STAR HSPF2 for split systems. ENERGY STAR should be a requirement for incentives. This is the minimum and most units will be a little higher so add 10%. This is the minimum and most units will be a little higher so add 10%. HSPF ratings are based on a Houston climate so we further adjust for performance in Texas relative to Houston, according to a study by FSEC. The FSEC study looked at performance in Fort Worth and Houston and we took the average.	ENERGY STAR spec: https://www.energystar.gov/sites/default/files/ENERGY%20STAR%20Version%206.0%20Central%20Air%20Conditioner%20and%20Heat%20Pump%20Final%20Specification%20and%20Partner%20Commitments.pdf . FSEC report: http://www.fsec.ucf.edu/en/publications/html/fsec-pf-413-04/
kWh saved/home space heating			551	551	551	551	551	Consumption divided by average annual COP. This underestimates fan energy savings as ENERGY STAR 6.0 requires 2-speed or multispeed fans.	
Average kWh/home for space clg		4256	4256	4256	4256	4256	4256	For Texas from 2009 EIA RECS. More recent RECS doesn't have state-specific data.	https://www.eia.gov/consumption/residential/data/2009/index.php?view=consumption
kWh saved/home space cooling		733	733	733	733	733	733	Based on new ENERGY STAR SEER2 for split systems plus DOE estimate of fan energy savings in a hot-humid climate. ENERGY STAR should be a requirement for incentives.	New DOE standard for HP is 14.3 SEER2, ENERGY STAR spec is 15.2. Fan energy savings from DOE TSD, Table 7G.3.1. https://www.regulations.gov/document/EERE-2014-BT-STD-0048-0098. Energy Star spec here: https://www.energystar.gov/sites/default/files/ENERGY%20STAR%20Version%206.0%20Central%20Air%20Conditioner%20and%20Heat%20Pump%20Final%20Specification%20and%20Partner%20Commitments.pdf .
Annual GWh saved	774		55	166	332	553	774	Number furnaces replaced per year * % participating * Savings per home / 1m (to convert to GWh) + savings from prior year (as heat pumps sold in earlier years are still saving energy). Add T&D losses.	

Winter kW/home with elec. furnace		18	18	18	18	18	18	From Energy Use Calculator.com. This is about equivalent to a 60,000 Btu/hour heating load on the very coldest days.	https://energyusecalculator.com/electricity_furnace.htm
Heat pump COP at winter peak		2.3	2.3	2.3	2.3	2.3	2.3	For a Goodman 4 ton HP at 17 F. Design conditions in Texas are for temperatures in the 20s F but given cold during storm Uri, we use 17 F.	https://www.goodmanmfg.com/pdfviewer.aspx?pdfurl=docs/librariesprovider6/default-document-library/ss-gszc16.pdf?view=true
Winter kW saved per HP			10.2	10.2	10.2	10.2	10.2	Heat pump COP * (electric furnace COP/heat pump COP)	
Winter peak savings (MW)	6,130		438	1,314	2,627	4,379	6,130	Number furnaces replaced per year * % participating * kW savings per home / 1000 (to convert to MW) + savings from prior year (as heat pumps sold in earlier years are still saving energy). Add T&D losses.	
Summer peak savings per HP		0.21	0.21	0.21	0.21	0.21	0.21	Based on AC power draw times savings from improvement in SEER2 for Energy Star.	
Summer peak savings (MW)			9	27	54	89	125	Number furnaces replaced per year * % participating * kW savings per home / 1000 (to convert to MW) + savings from prior year (as heat pumps sold in earlier years are still saving energy). Add T&D losses.	
Average cost per home		$ 2,000	$ 2,000	$ 2,000	$ 2,000	$ 2,000	$ 2,000	$1,440 difference in cost between an ENERGY STAR heat pump and a minimum efficiency central AC, both based on 2023 DOE and EPA standards. Costs from DOE Techincal Support Document; in 2015$ and converted to 2021$ using Federal Resere GDP deflator. These are for widespread sales so we round up by $273 to $2,000 as heat pumps will often be a little more expensive than DOE estimates.	DOE TSD: https://www.regulations.gov/document/EERE-2014-BT-STD-0048-0098. Implcit price deflator from: https://fred.stlouisfed.org/series/GDPDEF.
Average utility share		50%	50%	50%	50%	50%	50%	A very common utility incentive level.	
Marketing and administrative costs as a percent of rebate costs			40%	30%	20%	20%	20%	LBL reports a range of 20-40%. We start at the high end and gradually decline to the low end as experience is gained and participation increases.	https://eta-publications.lbl.gov/sites/default/files/cose_final_report_20200429.pdf
Utility cost ($million)	$ 571		$ 41	$ 82	$ 122	$ 163	$ 163	Number furnaces replaced per year * % participating * Cost per home * Utility share / 1m (to convert to $millions).	

Attic insulation/sealing and duct sealing									
	Total	2021 (base)	2023	2024	2025	2026	2027	Notes	References
Number of single family hom	6,990,171								https://resstock.nrel.gov/dataviewer/efs_v2_base#building-characteristics
Percent retrofit thru program	30%							50% of single-family homes have insulation levels of R-19 or lower (ResStock); reach 60% of these through program	
Retrofits per year	2,097,051		209,705	419,410	489,312	489,312	489,312	1/10 in 1st year, 1/5 in 2nd year, make up first year shortfall in years 3-5	
Annual kWh saved per home			1874	1874	1874	1874	1874	Used RECS 2009 and ResStock for data on average house size/configuration, existing insulation levels, and equipment types. Assume avg home 1800sf, 63% of homes are one story and 37% two story. Insulate homes with existing attic/ceiling insulation less than R-19 to R-38. Calculated savings with TRM used TRM average duct sealing savings for all	RECS: https://www.eia.gov/consumption/residential/data/2009/#sqft ResStock: https://resstock.nrel.gov/dataviewer/efs_v2_base#building-characteristics
Summer kW saved per home			0.78	0.78	0.78	0.78	0.78	used TRM; 0.45 insulation + 0.34 duct sealing	
Winter kW saved per home			0.94	0.94	0.94	0.94	0.94	used TRM; 0.65 insulation + 0.28 duct sealing	
Annual GWh saved	4,146		415	1,244	2,211	3,178	4,146	Number of participants times savings per participant. Include savings from prior year participants and include T&D losses.	
Summer peak savings (MW)	1,725		173	518	920	1,323	1,725	Same method as for row above.	
Winter peak savings (MW)	2,079		208	624	1,109	1,594	2,079	Same method as for row above.	
Average cost per home			$ 3,500	$ 3,500	$ 3,500	$ 3,500	$ 3,500	Cost data from program evaluations, National Residential Efficiency Measures Database, and review of several online calculators. Assume contractor installed: $2,250 for insulation and $1,250 for duct sealing.	https://remdb.nrel.gov/
Average utility share			50%	40%	30%	30%	30%	50% is pretty common for contractor installed insulation and duct sealing; some utilities offer lower incentives for DIY. We start at 50%, but to reduce costs ramp down in years 2 and 3.	
Marketing and administrative costs as a percent of rebate costs			40%	30%	20%	20%	20%	LBL reports a range of 20-40%. We start at the high end and gradually decline to the low end as experience is gained and participation increases.	https://eta-publications.lbl.gov/sites/default/files/cose_final_report_20200429.pdf
Utility cost ($million)	3,127		$ 514	$ 763	$ 617	$ 617	$ 617		

Smart thermostats	Total	2021 (base)	2023	2024	2025	2026	2027	Notes	References
Number of homes and apartments	11,283,353		11,283,353	11,283,353	11,283,353	11,283,353	11,283,353	From above.	
Percent with individual control	90%		90%	90%	90%	90%	90%	In 2009, 84.7% of Texas homes had central AC per EIA's Residential Energy Consumption Survey. According to ResStock - 3% of TX homes have electric baseboard and 2% have no form of heating. There are also a few multifamily buildings without individual apartment thermostats. Per 2009 RECS, less than 2% of TX households did not have thermostats (and nationally, less than 1% of MF units don't have thermostats)	
Percent retrofit thru program	20%		2%	6%	10.67%	15.33%	20%	Estimated 40% of market adopted by 2021; Only included units with existing equipment.	
Retrofits per year	2,031,004		203,100	406,201	473,901	473,901	473,901	1/10 in 1st year, 1/5 in 2nd year, make up first year shortfall in years 3-5	
Average kWh/home for htg + AC	6103		6103	6103	6103	6103	6103	Used RECS from electric furnace analysis from above for consistency.	
Average kWh savings (%)	14%		14%	14%	14%	14%	14%	Used TRM to calculate deemed savings for installation with EXISTING equipment using TRM defaults of 3.7 tons; calculated 1433 kWh/yr savings or 23% -- seems too high. Adjusted to 14% savings to align with findings of program evaluations and range of savings in other TRMs	https://www.esource.com/system/files/esource-aceee-making-the-smart-home-work-for-you.pdf
Annual GWh saved	1,831		183	549	976	1,403	1,831	Number of participants times savings per participant. Include savings from prior year participants and include T&D losses.	
Summer peak savings/home (kW)	0.49		0.49	0.49	0.49	0.49	0.49		
Winter peak savings/home (kW)	1.10		1.10	1.10	1.10	1.10	1.10		
Summer peak savings (MW)	995		100	299	531	763	995		
Winter peak savings (MW)	2,225		223	668	1,187	1,706	2,225		
Average cost per home			175	175	175	175	175	Prices for 50 ENERGY STAR connected thermostats range from $65-$300 with all major manufacturers offering products in $175 range; used $175 + $100 for program costs	https://choose.enervee.com/thermostats/?sortBy=price&filters=energy-star-10-connected-thermostats%3D1
Average utility share			43%	43%	43%	43%	43%	As of 2019, average utility incentive $65 per EPA with most starting at $75 or $100 and dropping down over time; assumed $75 as common incentive for newer programs	https://www.energystar.gov/sites/default/files/asset/document/ES_ST_BP-Guide%20FINAL.pdf
Utility cost ($million)	$ 152		$ 15.2	$ 30.5	$ 35.5	$ 35.5	$ 35.5	Administrative costs included in per participant costs.	

Heat pump water heaters	Total	2021 (base)	2023	2024	2025	2026	2027	Notes	References
Number of electric water heaters		5,177,068	5,177,068	5,177,068	5,177,068	5,177,068	5,177,068	3.9M electric WH drawn from 2009 RECS; estimated additional units as [TX Housing Units in 2019 from Census (~11M) - TX Housing units in RECS survey (~8.5M)], multiplied by proportion of TX housing units with electric as their primary water heater fuel source (3.9/8.5 per RECS 2009)	Census data at top of doc; https://www.eia.gov/consumption/residential/data/2009/#water
Number of replacements per year	398,236		398,236	398,236	398,236	398,236	398,236	13 year life per last DOE standards rule	https://www.govinfo.gov/content/pkg/FR-2010-04-16/pdf/2010-7611.pdf
Percent who participate in program			2%	4%	8%	8%	8%	Ramp up to 8% in third year. ACEEE Big Savers report includes 9% participation in mixed residential appliance upgrades for Efficiency Vermont program. 454,616 Austin Energy residential customers in 2020; CES appliance rebate program (including more than HPWH rebates) had 3823 participants in 2020, = 0.8%. If we assume that only the % of customers trying to replace a water heater are potentially participating in a WH rebate program, we could divide the total customer # by the lifetime of 13 (=10%) and then multiply by .8%, but that ignores the other types of rebates this program participation # includes.	
HPWHs installed per year			7,965	15,929	31,859	31,859	31,859		
Total HPWHs installed	119,471		7,965	23,894	55,753	87,612	119,471		
Deemed annual kWh savings per HPWH			2052	2052	2052	2052	2052	Weighted and averaged the TRM values for kWh annual deemed savings and kW summer/winter demand savings: weighted across the 5 Climate Zones using the proportion of TX population in the included counties of each Zone, and across specified indoor conditioning types (heat or AC)	Data package available for download here: https://www.energystar.gov/products/spec/residential_water_heaters_specification_version_4_0_pd Weighted average calcs here:
New annual savings from HPWHs installed (GWh)			17	34	69	69	69	# heat pumps installed * deemed annual kWh energy savings / 1000000 (to convert to GWh). Add T&D losses.	
Total annual savings by end of year (GWh)	259		17	52	121	190	259	Add in participants from earlier years.	

Deemed summer demand savings (kW) per HPWH			0.293	0.29	0.29	0.29	0.29	Weighted avg. from TRM values -- deemed summer demand savings (kW). Weighting accounted for Climate Zone, conditioning type (y/n air conditioning); values were also adjusted to meet required UEF for Energy Star 4.0 standards in the same way the deemed annual savings was adjusted. All units assumed to be <55 gal.	Weighted average calcs here: https://aceeeorg.sharepoint.com/:x:/s/rp/EQ-ryR1cXFxMgO0XKV7ASZEBbflxNuOFS0PI2Ob-JSK1fQ?e=zKL08v CF values from TRM vol. 2 page 265
Deemed winter demand savings (kW) per HPWH, weighted avg. from TRM adjusted for Energy Star 4.0 performance req's			0.325	0.33	0.33	0.33	0.33	Weighted avg. from TRM values -- deemed winter demand savings (kW). Weighting accounted for Climate Zone, conditioning type (electric, gas, heat pump, or unconditioned) ; values were also adjusted to meet required UEF for Energy Star 4.0 standards in the same way the deemed annual savings was adjusted. All units assumed to be <55 gal.	Weighted average calcs here: https://aceeeorg.sharepoint.com/:x:/s/rp/EQ-ryR1cXFxMgO0XKV7ASZEBbflxNuOFS0PI2Ob-JSK1fQ?e=zKL08v CF values from TRM vol. 2 page 265
Total summer demand savings (MW) by year 5	37		2.5	7.4	17.2	27.1	36.9	kW deemed summer savings * number of units, /1000 to convert to MW	
Total winter demand savings (MW) by year 5	41		2.7	8.2	19.1	30.0	41.0	kW deemed winter savings * number of units, /1000 to convert to MW	
Average cost per home (cost of HPWH above avg. cost of ERWH)			$ 1,600	$ 1,600	$ 1,600	$ 1,600	$ 1,600	National res. efficiency measures database: avg. cost of 1700 to switch from an ERWH to a 50 gal HPWH. Online calculator from RenovationEstimate for Texas suggests ~$1500 as mid-range estimates for comparative purchase of HPWH vs ERWH equipment (see tab in WH calc spreadsheet). Installation costs are available too, but the incremental difference is minimal (1485 vs 1520).	https://remdb.nrel.gov/ calculator estimates: see values pulled into tab in WH calc spreadsheet: https://aceeeorg.sharepoint.com/:x:/s/rp/EQ-ryR1cXFxMgO0XKV7ASZEBbflxNuOFS0PI2Ob-JSK1fQ?e=zKL08v
Utility rebate cost ($million)		$800	$ 6.4	$ 12.7	$ 25.5	$ 25.5	$ 25.5	Austin Energy offers a HPWH rebate of $800. USC: $150 rebate for electric WH Also offers $100 for fuel switching to electric HPWH = $250 total rebate for new HPWH Guadalupe Valley EC: $300/unit (may no longer be active)	Austin Energy rebate: https://austinenergy.com/wcm/connect/psp/ri-demo/commercial/offerings/appliances-and-equipment/heat-pump-water-heaters USC rebates: $150 for HPEWH; $100 for fuel switching to a new HPEWH : https://ucs.net/rebate-programs Additional TX rebate program examples documented by Solar Secrets (http://www.solarsecrets.org/index.php?texas); searched out documentation directly from company where possible
Marketing and administrative costs as a percent of rebate costs			40%	30%	20%	20%	20%	LBL reports a range of 20-40%. We start at the high end and gradually decline to the low end as experience is gained and participation increases.	https://eta-publications.lbl.gov/sites/default/files/cose_final_report_20200429.pdf
Utility cost ($million)	$ 117		$ 9	$ 17	$ 31	$ 31	$ 31		

Central AC demand response									
	Total	2021 (base)	2023	2024	2025	2026	2027	Notes	References
Percent of homes with central AC		85.0%	85.0%	85.0%	85.0%	85.0%	85.0%	Was 84.7% in 2009 per EIA's Residential Energy Consumption Survey.	https://www.eia.gov/consumption/residential/data/2009/index.php?view=characteristics
AC kW/home		3.5	3.5	3.5	3.5	3.5	3.5	3.5 kW/home. This is consistent with other sources we found.	https://blog.firstchoicepower.com/energy-savings/how-can-high-temperatures-affect-my-texas-electric-bill/
Percent cycled off at a time		33%	33%	33%	33%	33%	33%	Can range up to 50% but a substantial number of households will prefer less frequent cycling. Using 33% and the load in the row above provides the same demand savings per home as recommended by Faruqui to PUCT in 2012. San Antonio has 33% and 50% cycling options and with a Whisker Labs cycling pattern are getting 1.12 kW/home.	https://brattlefiles.blob.core.windows.net/files/6566_direct_load_control_of_residential_air_conditioners_in_texas_faruqui_puct_oct_25_2012.pdf; https://www.sanantonio.gov/Portals/0/Files/Sustainability/STEP/CPS-FY2019.pdf
Ratio home peak to coincident peak		86%	86%	86%	86%	86%	86%	From evaluation of San Antonio 2018 Smart Thermostat AC cycling program	https://www.sanantonio.gov/Portals/0/Files/Sustainability/STEP/CPS-FY2019.pdf
Participation in cycling program			10%	15%	20%	25%	30%	10-30% from Faruqui recommendations to PUCT in 2012 based on best programs around the US.	https://brattlefiles.blob.core.windows.net/files/6566_direct_load_control_of_residential_air_conditioners_in_texas_faruqui_puct_oct_25_2012.pdf
Number of participants			959,085	1,438,628	1,918,170	2,397,713	2,877,255		
Summer peak savings (MW)	3,010	-	1,003	1,505	2,006	2,508	3,010	Multiply above rows, add T&D losses. Note: This includes Austin and San Antonio who already have programs.	
Incentive per year per home		$125	$125	$58	$51	$37	$34	Austin provides $85 incentive to enroll. To this we add $10/month for the four summer months, declining to $5/month in the fifth year.	https://savings.austinenergy.com/rebates/residential/offerings/cooling-and-heating/pp-thermostat/
Utility cost ($million)	$ 587	$ -	$ 144	$ 101	$ 118	$ 106	$ 118	Add 20% for administrative and marketing costs.	E-Source DSM Insights database.

Water heater demand response									
	Total	2021 (base)	2023	2024	2025	2026	2027	Notes	References
Number of electric water heaters		5,177,068	5,177,068	5,177,068	5,177,068	5,177,068	5,177,068	From HPWH analysis	
Percent participating in DR			5%	10%	20%	25%	30%	Brattle 2016 modeling assumes 20% participation, but notes examples up to 40-50% for other direct load control programs. We gradually ramp up to 30%.	2016 Brattle Group report for NRDC, NRECA and PLMA https://rpsc.energy.gov/tech-solutions/technologies/heat-pump-water-heater/resources/hidden-battery-opportunities-electric-water-heating
Participants			258,853	517,707	1,035,414	1,294,267	1,553,120		
Avg. summer kw peak reduction / participant (ERWH)			0.54	0.54	0.54	0.54	0.54	Average of Austin Energy, MISO, and PJM values = .54 kW Austin Energy 'Cycle Saver' Program (multifamily-targeting WH DR program) reports .47 MW demand reduction/723 devices =~.65kW curtailed/device. Is this higher than would be reasonable with single-family residential? Other possible values below, but not TX- specific. PJM case study finds 0.36 kW. Brattle 2016 model for MISO market scenario in 2014 uses .46 for ERWH (.22 for HPWH).	Data tables for Austin Energy program evaluation in this report: https://austinenergy.com/wcm/connect/97af76f9-b1fc-41ed-8781-cdbf3fd90099/CES_Program_Progress_Report_2020.pdf?MOD=AJPERES&CVID=nyao-5C PJM case study: https://plma.memberclicks.net/assets/resources/Guidehouse%20Insights_ArmadaPowerWhitePaper.pdf 2016 Brattle Group report for NRDC, NRECA and PLMA https://rpsc.energy.gov/tech-solutions/technologies/heat-pump-water-heater/resources/hidden-battery-opportunities-electric-water-heating
Avg. summer kw peak reduction /participant (HPWH)			0.27	0.27	0.27	0.27	0.27	Currently using above kW demand reduction/2 for HPWH	

Avg. winter kw peak reduction /participant (ERWH)			0.54	0.54	0.54	0.54	0.54	Have not located separate summer and winter factors. In winter the entering water is a little colder but people tend to shower less.	
Avg. winter kw peak reduction /participant (HPWH)			0.27	0.27	0.27	0.27	0.27		
Summer peak savings (MW)	876		147	293	586	731	876	Adjusted for ~1% of installed market HPWH (<1% as of 2017 per PNNL report). Assume this grows to 2% by fifth year. 2% 2020 market penetration estimated by Energy Star Unit Shipment & Market Penetration analysis. Added T&D losses.	PNNL Report: : https://rpsc.energy.gov/tech-solutions/sites/default/files/resources/attachments/ECEEE_EEDAL_Paper-159_US-HPWH-Mkt-Transformation_7-21-2017%5B1%5D.pdf ENERGY STAR® Unit Shipment and Market Penetration Report Calendar Year 2020 Summary: https://www.energystar.gov/sites/default/files/asset/document/2020%20USD%20Summary%20Report_Lighting%20%20EVSE%20Update.pdf
Winter peak savings (MW)	876		147	293	586	731	876		
Incentive per home - startup cost ($25 incentive to sign up, plus cost and installation of device), plus $25 annually to allow device management	$ 95	Cost of control device/ installation + signup incentive						Quick scan of online prices suggests control devices run $70-$200, with ~$150 being common at retail. We estimate utilities can buy in bulk at half this cost.	
	$25	Continuation payment (annual)						Duke EnergyWise (SC) water heater DLC and HP DLC program: Incentive is $25 to sign up, $25 annually to remain	
Capitalized costs of control device			$ 2.9	$ 5.7	$ 11.5	$ 14.4	$ 17.2	Capitalized for 15 years at 8% rate of return	
Annual customer payments			$ 6.5	$ 12.9	$ 25.9	$ 32.4	$ 38.8		
Administration costs			$ 1.9	$ 3.7	$ 7.5	$ 9.3	$ 11.2	Add 20% for administrative and marketing costs.	E-Source DSM Insights database.
Utility cost ($million)	$ 202		$ 11	$ 22	$ 45	$ 56	$ 67	Cost of control device plus one-time incentive ($25) plus $25/year to remain, /1M	

EV managed charging									
	Total	2021 (base)	2023	2024	2025	2026	2027	Notes	References
Projected US EV sales		526,004	1,154,210	1,570,315	2,056,320	2,707,805	3,077,825	Base year is for 2019 by state from evadoption.com.	https://evadoption.com/ev-sales/ev-sales-forecasts/
Texas proportion	1.80%	2.97%	4.13%	5.30%	6.46%	7.63%	8.79%	Base year is for 2019 by state from evadoption.com. Final year based on Texas share of US population per the 2020 Census. Interpolate intermediate years.	https://evadoption.com/ev-t-share/ev-market-share-state/
Number of EVs in Texas	52,190	67,795	115,487	198,673	331,566	538,118	808,762	From multiplying the above rows.	
For reference: Approximate ERCOT assumptions on EV adoption used in LTSA		*70,000*	*110,000*	*400,000*	*500,000*	*700,000*	*820,000*	These are approximate numbers from their graph but raw numbers were not published that we have found.	LTSA (Long-Term System Assessment, pub. 2020 forecasting to 2035) pg. 47 downloaded from: http://www.ercot.com/gridinfo/planning
Avg. [summer] kW curtailed/participant [current value isn't season-specific]	1.4	1.4	1.4	1.4	1.4	1.4	1.4	EV.Energy Virtual Power Plant curtails charging for a fleet of EVs on the ERCOT grid-- reports avg. 1.4kW curtailed demand per participating vehicle GITT study estimates 1.5 kW/vehicle demand load estimate from GITT study for midafternoon. We use the estimate for ERCOT.	https://ev.energy/ev-energy-ercot/ https://www.energy.gov/sites/prod/files/2019/12/f69/GITT%20ISATT%20EVs%20at%20Scale%20Grid%20Summary%20Report%20FINAL%20Nov2019.pdf
Avg. [winter] kW/participant	0.1	0.1	0.1	0.1	0.1	0.1	0.1	From GITT study for an 8am peak.	https://www.energy.gov/sites/prod/files/2019/12/f69/GITT%20ISATT%20EVs%20at%20Scale%20Grid%20Summary%20Report%20FINAL%20Nov2019.pdf
Percent participating in DR program			50%	65%	70%	75%	75%	SEPA survey of EV drivers: 65% of those with access to Time-of-Use rate programs use them (75% in CA, 48% elsewhere in the nation), with ~95-100% off-peak charging 87% of the time. Same survey suggests 72% of non-enrolled EV drivers are willing to charge off-peak given incentives and convenient program structure. Assuming that an appropriately designed direct load control program could capture similar rates of participation.	SEPA 2019: https://sepapower.org/resource/residential-electric-vehicle-time-varying-rates-that-work-attributes-that-increase-enrollment/
Cumulative participants by year		-	57,744	129,137	232,096	403,589	606,572		
New participants each year		-	57,744	71,394	160,703	242,886	363,686		
Summer peak demand savings (MW)		-	85	191	343	596	896	Participants * impact/participant. Add T&D losses.	
Winter peak demand savings (MW)		-	6	14	24	43	64	Same as above.	

Enrollment and annual incentives per year	Annual incentive structured to fall off over time by participation year	incentive per participant year:	30	20	15	10	10	DLC program examples: San Antonio's CPS Energy FlexEV Smart Rewards program offers $250 bill credit for agreeing to allow adjustments to wifi chargers, + $5 monthly to remain enrolled. Note this is a pilot that started in April 2021-- no program evaluation report yet available. MA: Eversource -- $300 for a 3-year commitment (if you're buying an eligible charger); same cost structured differently for people who already have the charger (150 upfront + 3x$50). SEPA 2019 survey suggests half of drivers would enroll in managed charging with a benefit of $50/year, and half would be motivated by $100 per year. This incentive structure provides $100 in the first year before dropping in subsequent years. Details of effective EV managed charging program design possible within the ERCOT retail market should be the subject of further analysis.	CPS programs: https://cpsenergy.com/en/about-us/programs-services/electric-vehicles/ev-charging-solutions.html Eversource incentive: https://www.eversource.com/content/ct-c/residential/save-money-energy/explore-alternatives/electric-vehicles/ev-charger-demand-response SEPA report: https://sepapower.org/resource/residential-electric-vehicle-time-varying-rates-that-work-attributes-that-increase-enrollment/
		participant year	Y1	Y2	Y3	Y4	Y5		
		Annual incentives paid per year	$ 1,732,310	$ 3,296,680	$ 7,115,112	$ 12,148,973	$ 19,470,209		
	$70	Up-front enrollment incentives paid per year	$ 4,042,057	$ 4,997,548	$ 11,249,200	$ 17,002,010	$ 25,458,011		
Utility cost ($million)	$ 120		7	10	21	33	49	Add 20% for administration and marketing in early years, declining to 10% by fifth year	E-Source DSM Insights database for the 20%; ACEEE estimate for the gradual decline.

Federal incandescent lamp phaseout									
	Total	2021 (base)	2023	2024	2025	2026	2027		
Annual kWh per household	1310	1,310	1,310	1,310	1,310	1,310	1,310	Midpoint of range shown for Texas in a DOE report.	https://www1.eere.energy.gov/buildings/publications/pdfs/ssl/2012_residential-lighting-study.pdf.
Connected Watts per househ	1961	1961						Avg. Watts/lamp * number of lamps per household from same source as cell above.	
Savings with LED	70%							LEDs save "up to 90%" per DOE; we use 70% for the average assuming 85% savings for replacing incandescent lamps, 24% for replacing CFLs and weighting incandescent lamps 75% and CFLs 25%.	https://www.energy.gov/energysaver/lighting-choices-save-you-money. Typical percent savings from: https://dengarden.com/home-improvement/How-Much-Actual-Money-Do-LED-Lights-Save .
Percent already LED	34%							2019 DOE SSL energy savings forecast: 36% penetration in residential general service; 16% decorative; 37% directional	https://www.energy.gov/sites/prod/files/2019/12/f69/2019_ssl-energy-savings-forecast.pdf
Percent ultimately LED	95%							Close to 100% but we use 95% to be conservative.	
Summer coincidence factor	0.053							From Nov. 2020 Texas TRM.	
Winter coincidence factor	0.232							From Nov. 2020 Texas TRM.	
Annual GWh saved after turn	6,634			3,317	6,634	6,634	6,634	Households times savings per household; add T&D losses.	
Summer peak savings (MW)	499			249	499	499	499	Households times savings per household; add T&D losses.	
Winter peak savings (MW)	2,184			1,092	2,184	2,184	2,184	Households times savings per household; add T&D losses.	
Utility cost ($million)	$ -							This will happen due to new federal lamp standards.	