5. Decarbonization of Buildings

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Key Takeaways

- Reducing emissions from space heating and water heating should be a primary policy focus for buildings within the Regional Decarbonization Framework.
- Policies should support increasing adoption of efficient heat pump-based space and water heating systems in both new and existing buildings, with particular focus on assistance for low-income residents and rental buildings
- Some existing fossil fuel equipment systems will only turn over once by 2050. Near-term action is needed to guide building owners away from replacing end-of-life fossil fuel equipment with like
- Low-carbon gaseous fuels can be used for hard-to-electrify end uses, though research and piloting is required
- Stranded cost risk is mitigated by minimizing unnecessary extensions or replacements of the gas pipeline system and by accelerating depreciation of existing utility assets.
- Improved data gathering is a low-cost, foundational action for future policy development

San Diego County is the fifth most populous county in the United States[1] and boasts a large and diverse building stock.[2] The unique geography and varied climates within the San Diego region have helped create an architectural montage, with distinct attributes across the county's 18 municipalities and unincorporated areas.[3,4] The local infrastructure is also shaped in part by the county's 18 Native American tribal reservations[5,6]—the most in any US county—and 16 military bases.[7] While it is one of the county's great assets, the building stock is also a key contributor to emissions: on-site fossil fuel combustion was responsible for about 300,000 metric tons of carbon dioxide-equivalent emissions in 2014 or about 9 percent of the county's total emissions.[8] Decarbonizing existing and new buildings in the San Diego region will be a critical strategy within the Regional Decarbonization Framework. This chapter is focused on direct emissions from buildings, resulting from the combustion of fossil fuels, and what it would take to eliminate those emissions by 2045. Emissions from electricity generation are addressed in Chapter 2 of this report.

Options for decarbonizing San Diego's buildings include electrifying end uses that are responsible for direct emissions, primarily space and water heating, and using lower-carbon fuels such as biomethane and hydrogen. The relative costs of pathways taking different approaches are similar, within the range of uncertainty. However, electrification-based approaches are generally lower-risk because they do not depend on technological innovation or the deployment of novel technologies at previously unseen scales.

All building decarbonization pathways cause a substantial change in the gas utility business, due to changes in the amount and sources of the gas sold. Electrification pathways, in particular, would require fundamental changes in the gas utility business model because traditional pipeline gas sales would be virtually eliminated by mid-century. We conclude this chapter with an analysis of some simple near-term steps that San Diego Gas & Electric, its regulators, and regional policymakers could take to mitigate risks associated with this transition and thereby make it easier to develop a long-term business transition plan.

5.1 Buildings in San Diego County

Residential Buildings

There are an estimated 1.3 million residential units across 0.9 million properties in San Diego County. These residences comprise approximately 1.7 billion square feet and are growing at a rate of 0.9 percent per year. [xviii] The relative sizes of the residential building stock vary considerably by municipality, as depicted in Figure 5.1. The City of San Diego and the unincorporated areas of the county represent 57 percent of the total. The City and County therefore have a large opportunity to reduce emissions in this sector through targeted policies, such as building energy codes.

[xviii] Synapse analysis of data provided by San Diego County Assessor's Office.

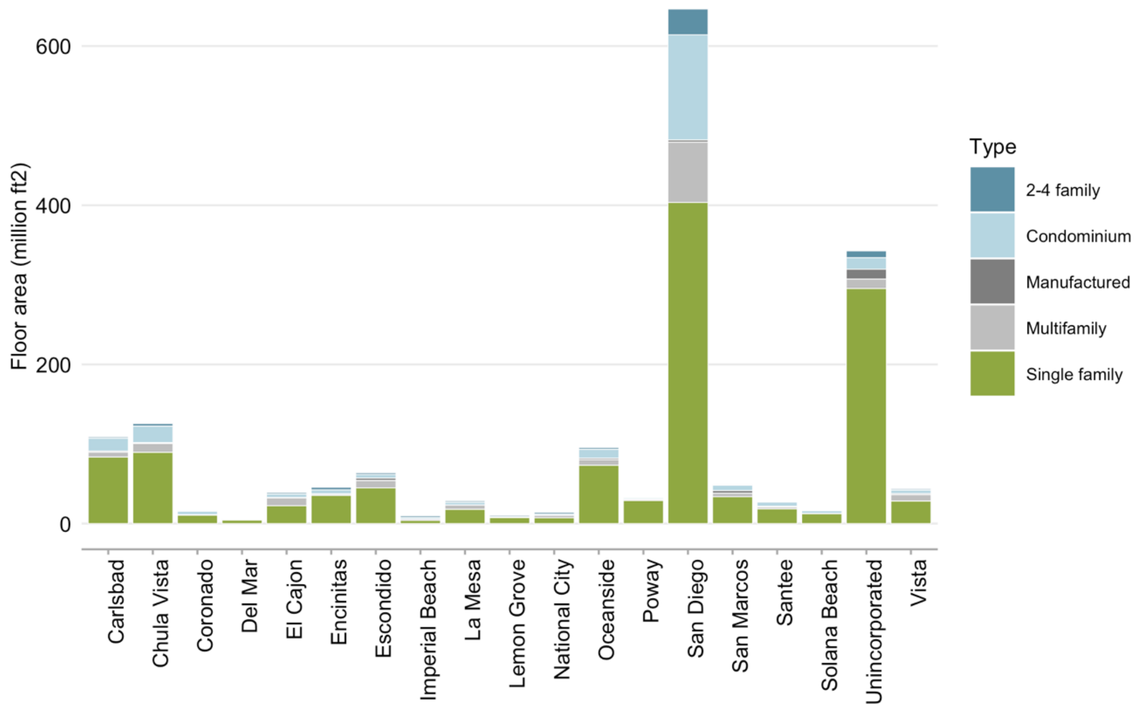

Figure 5.1. Residential building stock by municipality in San Diego County, 2021. Source: Synapse analysis of data provided by San Diego County Assessor's Office.

Figure 5.2 provides a breakdown of the building stock by type of residence and over time for each jurisdiction. These distinctions may affect how quickly and at what cost a community will be able to decarbonize its buildings. Strategies for addressing emissions for single family homes will differ from strategies for multifamily apartments due to differing ownership/occupancy paradigms and types of end-use energy equipment in the residences. Additionally, for communities with the fastest relative growth rates—which have recently been Imperial Beach, National City, Chula Vista, San Marcos, and Santee—more stringent building energy codes can play an important role locally.

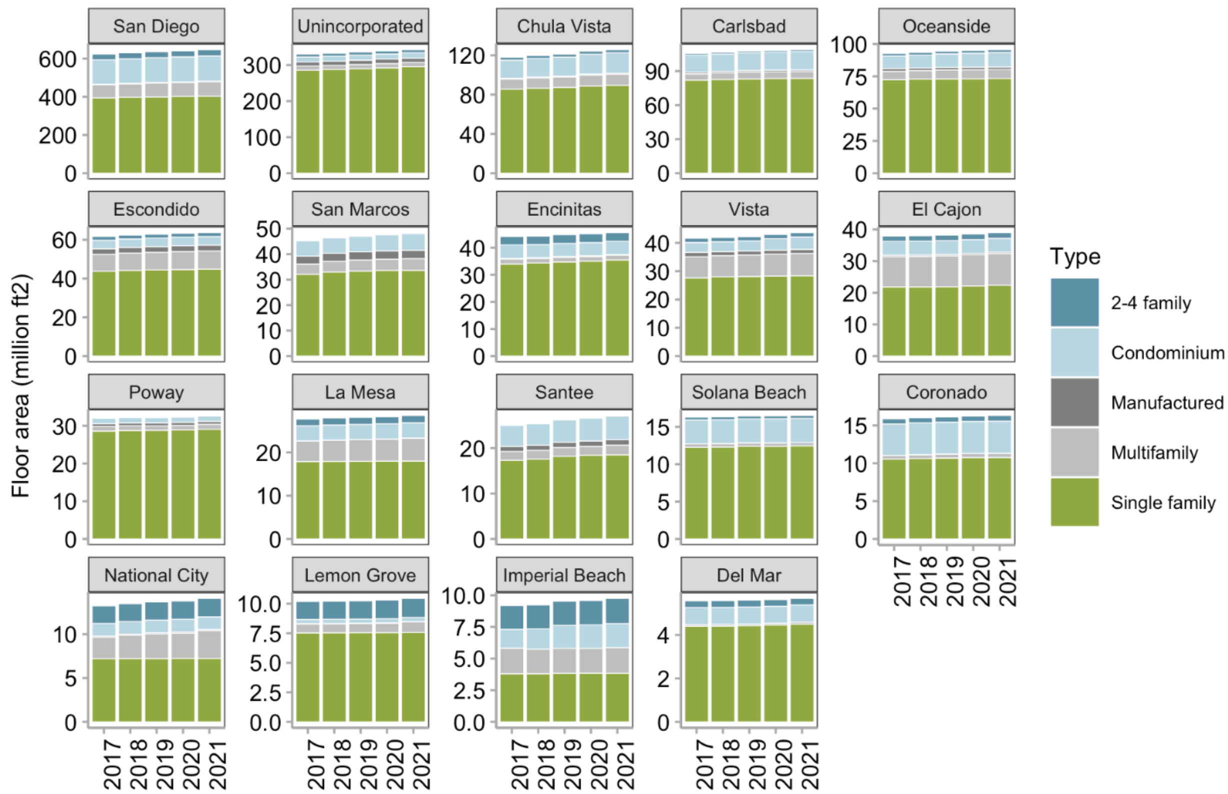

Figure 5.2. Residential building stock by municipality in San Diego County, 2017–2021. Source: Synapse analysis of data provided by San Diego County Assessor's Office.

Figure 5.3 provides a breakdown of the average pipeline gas usage for each major gas end use by residential customers under three investor-owned utilities, based on the latest *Residential Appliance Saturation Study*.[9xix] As shown in this figure, the average gas usage for water heating is 200 therms and accounts for the largest share (about 59 percent) of the total usage for the major end uses in San Diego Gas & Electric's (SDG&E's) jurisdiction. This share is much larger than the water heating usage share for PG&E, but very close to the usage share for SoCalGas. On the other hand, the average residential gas usage for space heating in the SDG&E area accounts for about 29 percent. These gas end use profiles show that SDG&E residential customers have the greatest opportunity for GHG savings in water heating. Lastly, a jurisdictional comparison of the total gas usage data in this figure shows that households in San Diego County are in more favorable positions to pursue building decarbonization because 1)

[xix] Note that while this figure excludes minor end uses with low customer saturations such as spa and pool heat, secondary heating, and gas backup for solar water heaters, the average natural gas consumption among all gas customers is lower than the estimates shown in this figure because some customers do not use gas for all major end uses.

their overall gas usage is lower and 2) it is easier for customers to reduce GHGs associated with water heating than space heating.

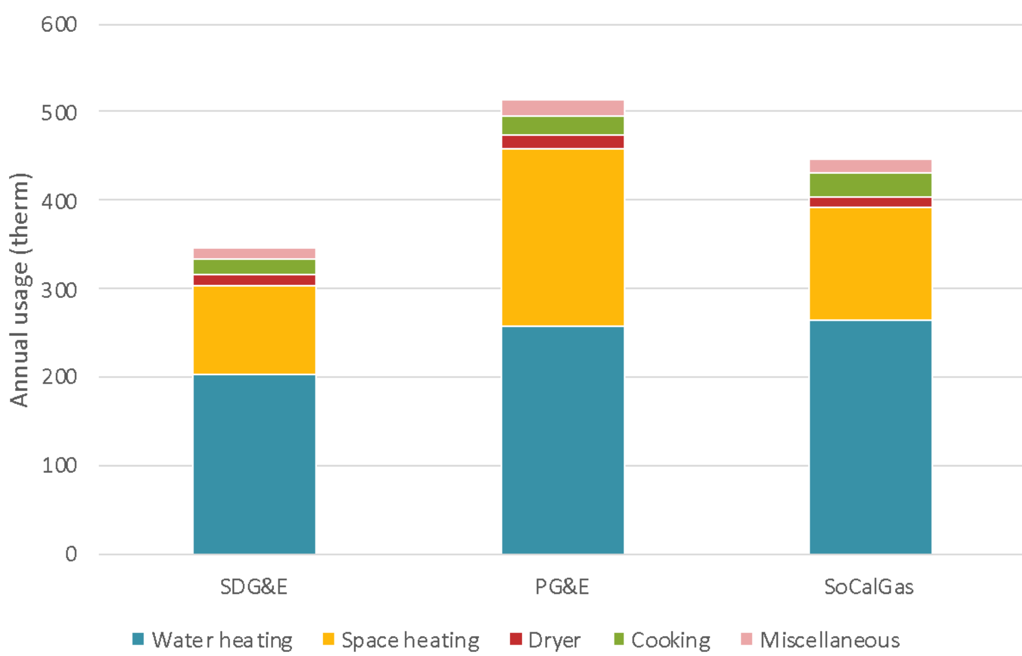

Figure 5.3. Average natural gas usage by end use and by utility for households who use gas as the primary fuel for major end uses. Source: DNV GL Energy Insights. 2021. 2019 California Residential Appliance Saturation Study (RASS).

Figure 5.4 presents residential fuel-use breakdowns for space and water heating end uses in terms of the number of utility accounts in San Diego County. Data for this analysis was based on the 2019 RASS study. As shown in Figure 5.4, natural gas is the dominant fuel for both space and water heating, while its share for water heating (about 83 percent) is more dominant than for space heating (about 69 percent). Approximately 28 percent of total households use electric space heating, while electric water heating is used less than half as much: about 12 percent.

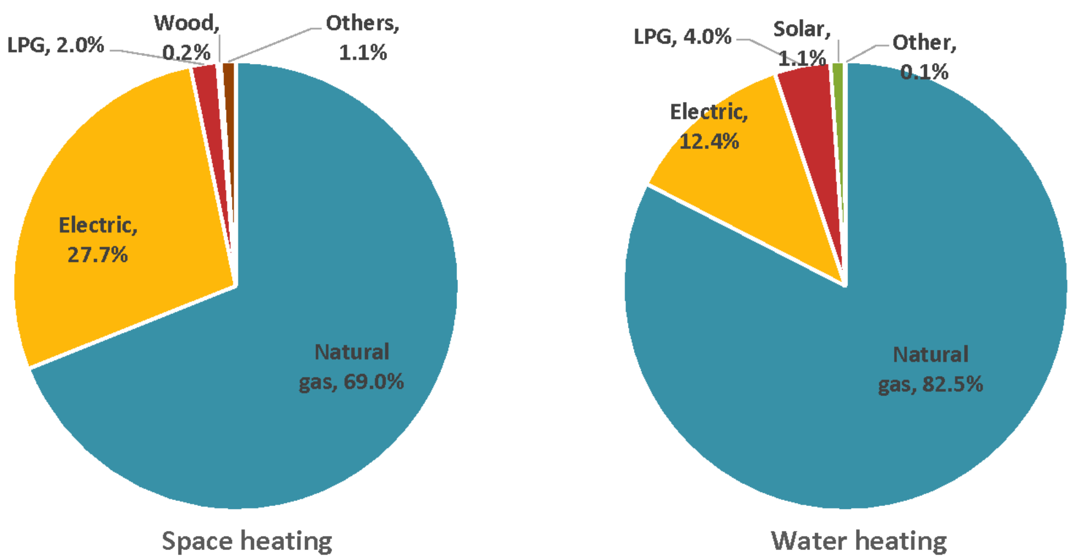

Figure 5.4. Residential space and water heating by fuel type (% of customer accounts).
Source: DNV GL Energy Insights. 2021. 2019 California Residential Appliance Saturation Study (RASS).

Figure 5.5 shows the breakdown of residential space heating equipment in terms of the number of utility accounts in SDG&E's service area (which has a nearly perfect overlap with San Diego County). Electric heat pumps account for about 6.3 percent of all residential systems. Central gas furnaces with ducts account for about 56 percent of the total systems. Three other heating systems that use ducts are central electric and LPG furnaces, and ducted air-source heat pumps (ASHPs). Together, the systems relying on ducts account for about 70 percent of the total residential space heaters. Excluding ducted ASHPs, such systems account for 66 percent of the total. These represent the prime candidates for fuel switching to ducted ASHP technologies. The rest of the space heaters, including electric unit heater (13 percent) and other fossil heaters (about 13.6 percent), can be converted to heat pumps through the use of ductless minisplit heat pumps.

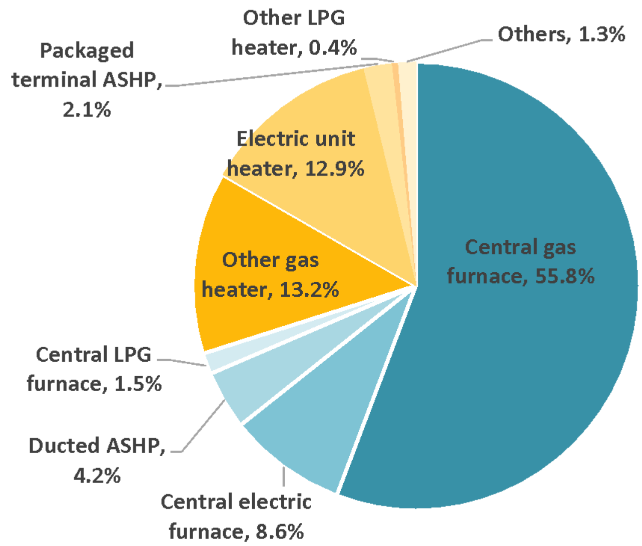

Figure 5.5. Residential space heating system share by equipment type. Source: DNV GL Energy Insights. 2021. 2019 California Residential Appliance Saturation Study (RASS).

Commercial Buildings

The commercial sector includes 158,000 building units across 36,000 properties in the county. Together, these properties represent an estimated 554 million square feet and are growing at a rate of 0.9 percent per year.[xx] Figure 5.6 highlights the relative sizes of the commercial building stock in each area within the county. The City of San Diego, the unincorporated areas of the county, Chula Vista, Carlsbad, Escondido, and Oceanside have the largest total floor areas. Given the sizable stock of commercial buildings in the City of San Diego, its policies can have an outsized effect on reducing emissions. The City's Building Energy Benchmarking Ordinance is an important step toward managing energy use and emissions in large buildings.[10] The ordinance lays the foundation for future innovative policies such as building performance standards, which establish mandatory energy or emissions targets that improve over time.[xxi]

[xx] Synapse analysis of data provided by San Diego County Assessor's Office.

[xxi] The following resources provide additional information on building performance standards:

American Cities Climate Challenge. 2021. *Building Performance Standards: A framework for Equitable Policies to Address Existing Buildings*. Available at: https://www.usdn.org/uploads/cms/documents/bps-framework_july-2021_final.pdf.

American Council for Energy-Efficient Economy. 2020. *Mandatory Building Performance Standards: A Key Policy for Achieving Climate Goals.* Available at: https://www.aceee.org/white-paper/2020/06/mandatory-building-performance-standards-key-policy-achieving-climate-goals.

Carbon Neutral Cities Alliance. 2020. Existing Building Performance Standards Targets and Metrics Final Report. Available at: http://carbonneutralcities.org/wp-content/uploads/2020/03/CNCA-Existing-Building-Perf-Standards-Targets-and-Metrics-Memo-Final-March2020.pdf

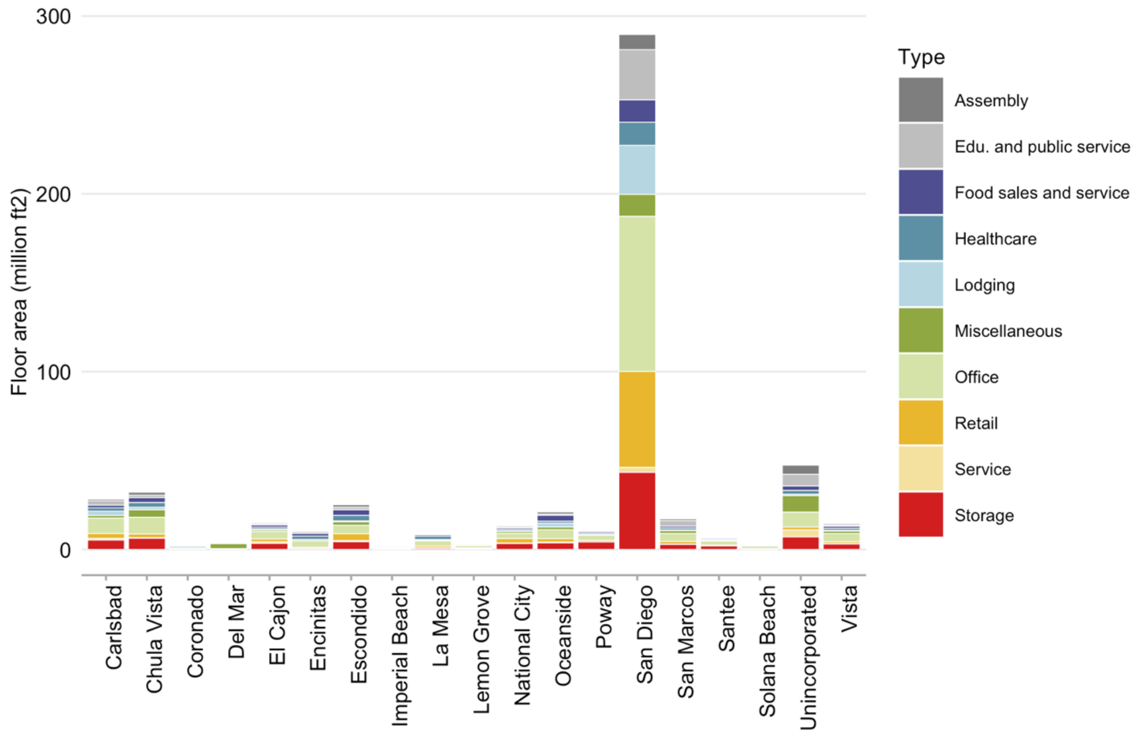

Figure 5.6. Commercial building stock by municipality in San Diego County, 2021. Source: Synapse analysis of data provided by San Diego County Assessor's Office.

The prominence of each commercial building type and the growth rate of the commercial building stock varies by location and over time, as shown in Figure 5.7. As with residential buildings, these distinctions will influence the jurisdictions' pathways to decarbonization. Some building types (*e.g.*, hospitals and restaurants) are more difficult to retrofit with equipment that reduces carbon emissions, particularly from onsite combustion of fossil fuels. Carlsbad, Imperial Beach, and San Marcos are experiencing higher rates of growth.

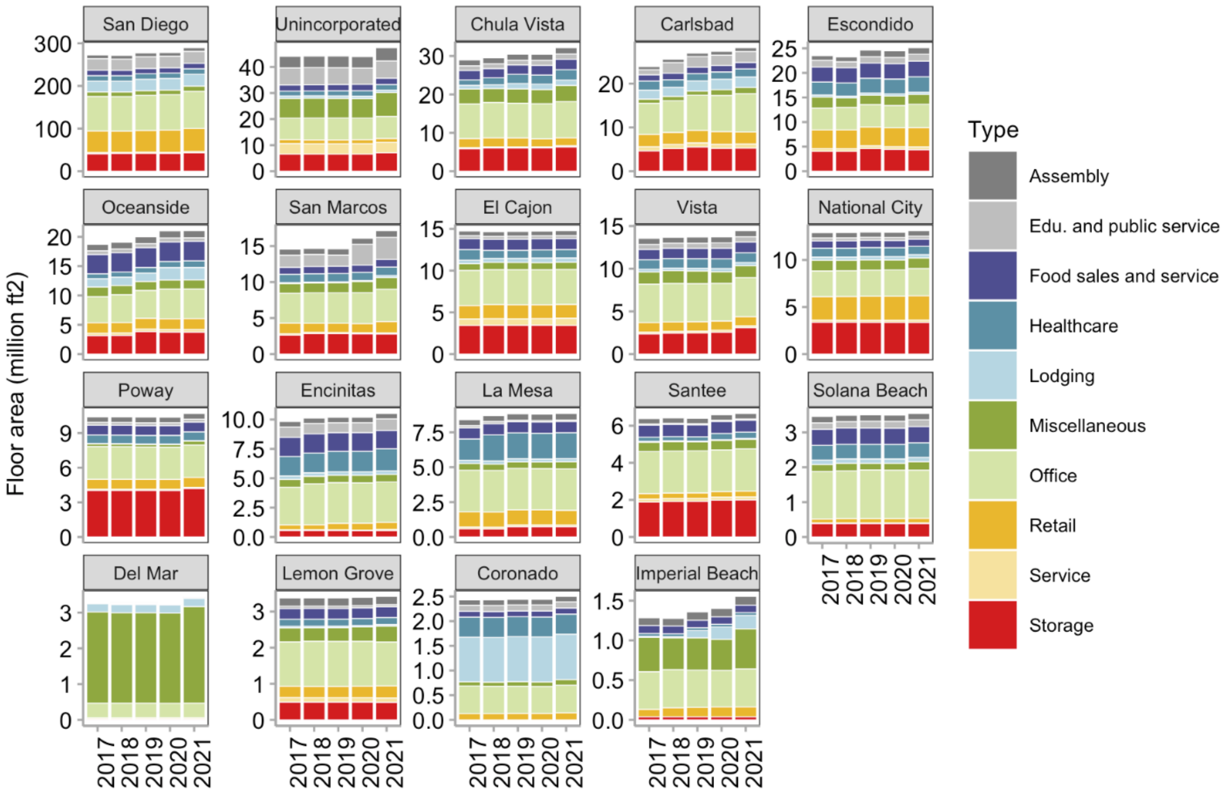

Figure 5.7. Commercial building stock by municipality in San Diego County, 2017–2021. Source: Synapse analysis of data provided by San Diego County Assessor's Office

Fossil fuel combustion is the main source of GHG emissions for buildings. Fuel is consumed onsite to provide services such as space heating, water heating, and cooking. Additionally, electricity, district heating, and district cooling are generated offsite using fossil-based fuels, and the associated emissions are attributable to buildings that use these utilities. To identify strategies for reducing these emissions in San Diego County, it is important to first understand the fuel use in local buildings—both how much of each fuel is used and what it is used for. Using data from SDG&E, the City of San Diego,[11] the San Diego County Assessor's Office, the U.S. Energy Information Administration,[12] and prior energy studies,[13,14] Synapse estimated the fuel, energy, and emission profiles for buildings in the San Diego region. Figure 5.8 presents the results for each building type and across the total commercial building stock.

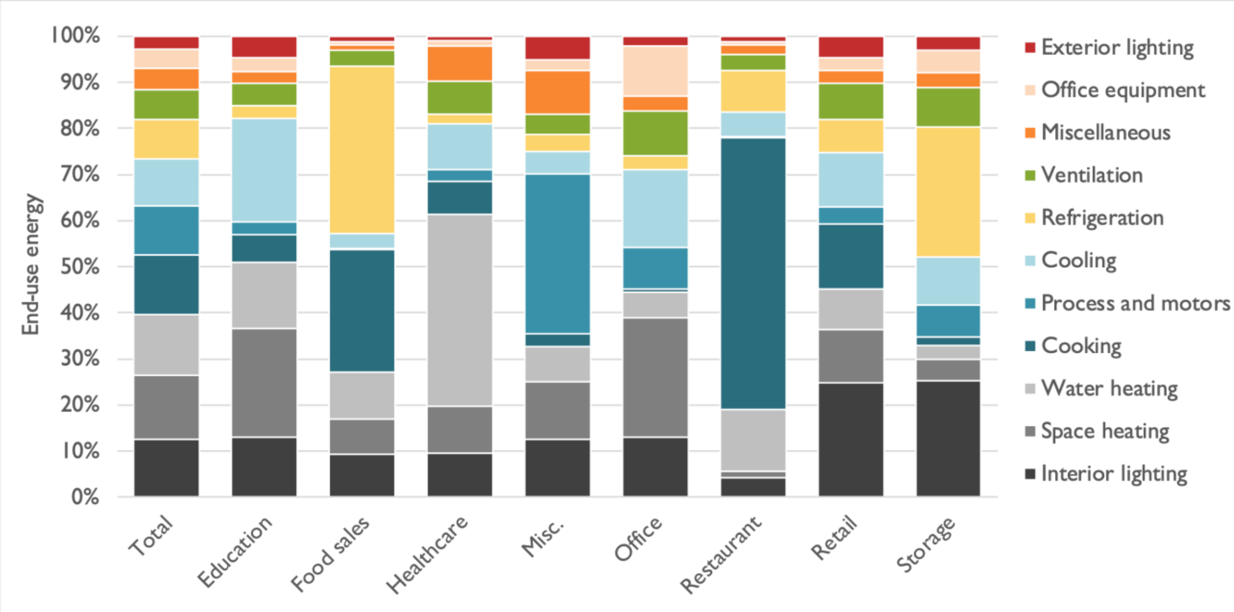

Figure 5.8. San Diego County energy end-use profiles by building type. Source: Synapse model

Space heating and water heating are the two end uses responsible for the most greenhouse gases in San Diego County. This is in part because they require large amounts of energy—together over a quarter of all energy used in commercial buildings in the county—and in part because they rely heavily on fossil fuels, specifically natural gas. Figure 5.9 provides a breakdown of the primary fuel used for space and water heating in commercial buildings. Additionally, end uses that rely on electricity will have fewer emissions over time as the electric grid incorporates more renewable generation. These facts together suggest that reducing emissions from space heating and water heating should be a primary policy focus within the Regional Decarbonization Framework. The existing types of equipment within a building plays an important role in determining what strategies will be most effective when decarbonizing a building. A breakdown of existing equipment types for space and water heating is provided in Figure 5.10 for commercial buildings in San Diego County.

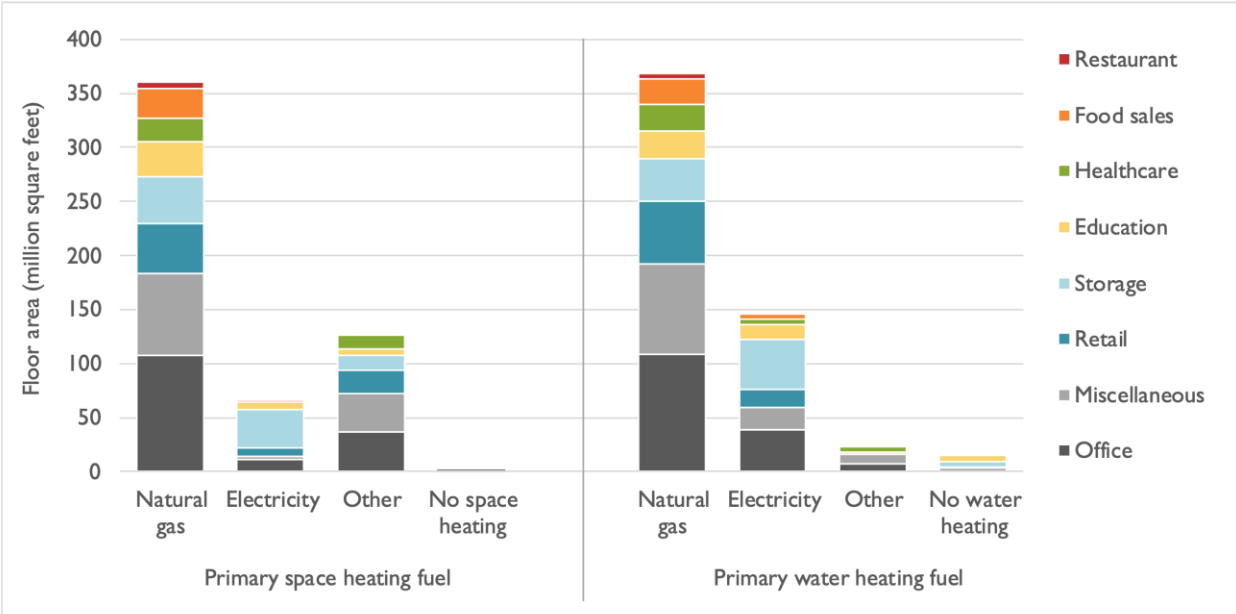

Figure 5.9. San Diego County primary fuel by building type: space heating and water heating. Source: Synapse model.

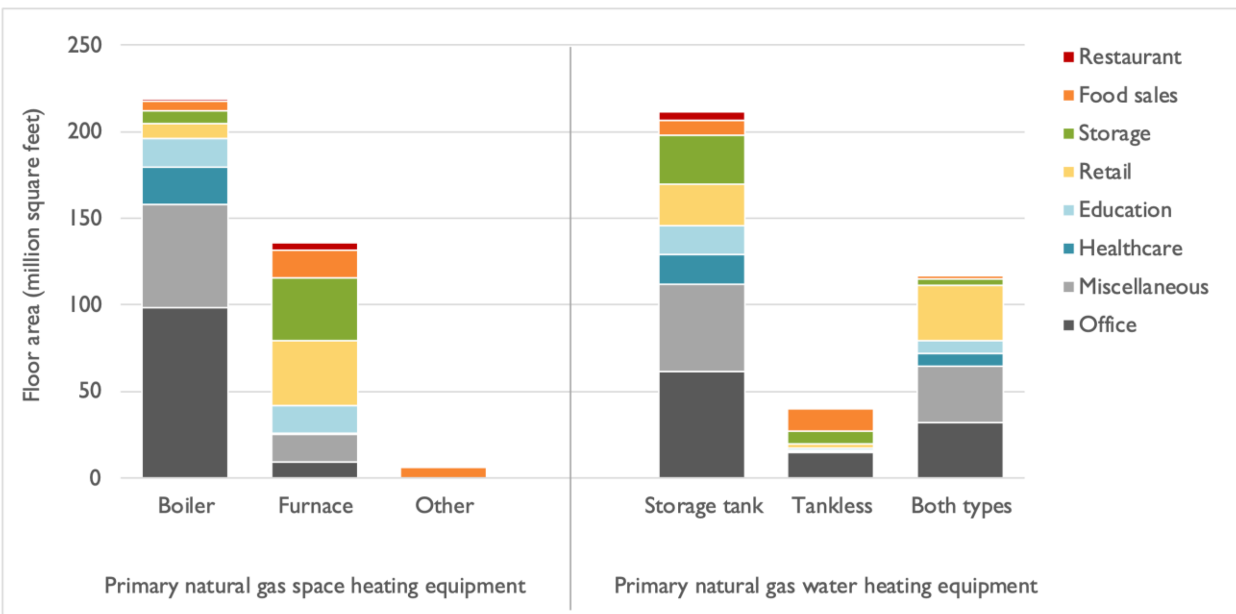

Figure 5.10. San Diego County natural gas equipment system by building type: space heating and water heating. Source: Synapse model.

5.2 Technologies and Fuels for Decarbonizing Buildings

Space heating technologies

Electric heat pumps are energy-efficient heating and cooling systems that work for all climates. Unlike fossil fuel-based heaters that generate heat by burning fuels, heat pumps provide space heating by extracting heat from outside and transferring it to the inside, using a vapor-compression refrigerant cycle connecting an outdoor compressor with an indoor heat exchanger. Heat pumps also work as an efficient air conditioner by reversing the heat transfer process to remove heat and moisture from the indoor air. Because of this heat transfer process, heat pump efficiency levels typically go over 250 percent (or a coefficient of performance (COP) of 2.5) for heating and 400 percent (or a COP of 4) for cooling. That means for one unit of energy input, a heat pump can provide 2.5 or more units of heating. By comparison, the most efficient gas heaters provide 0.98 units of heating for one unit of energy input.

Various types of heat pumps are available in the market. Heat pumps are primarily categorized by (a) the heat sources they draw from to heat buildings, (b) whether the systems heat air or water, and (c) how the extracted heat is distributed in the buildings. Primary heat pump technologies used for space heating include air-source heat pumps (ASHPs), ground-source heat pumps (GSHPs), water-source heat pumps (WSHPs), and air-to-water heat pump (AWHPs).

ASHPs are the most common heat pump system type used in the country. They move heat in the air between inside and outside. Because ASHPs use heat in the outdoor air, their performance (in terms of efficiency and capacity) degrades in cold temperatures. Thus, conventional ASHPs often have back-up electric resistance heating strips for cold temperature operation. However, cold climate ASHPs that are now widely available in the market can provide comfortable heat even under freezing temperatures without a backup heater.[xxii] Notably, the winter climate in the populated regions of San Diego County is very moderate, so there is little need for backup heat.

ASHPs include ducted ASHPs, mini-split ductless heat pumps, packaged terminal heat pumps, and variable refrigerant flow (VRF) ASHPs. A short summary of these technologies is provided below.

[xxii] A field study in Vermont observed that cold climate ASHPs operated at 5 F with a COP of 1.6 and even at -20F at above 1 COP. See Cadmus. 2017. *Evaluation of Cold Climate Heat Pumps in Vermont*. Prepared for the Vermont Public Service Department. Page 24. Available at: https://publicservice.vermont.gov/sites/dps/files/documents/Energy_Efficiency/Reports/Evaluation%20of%20Cold%20Climate%20Heat%20Pumps%20in%20Vermont.pdf.

- **Ducted ASHPs** are the most widely installed systems. Ducted ASHPs include split systems and packaged systems. Split heat pumps have an outdoor condenser and an air handling unit in the building to deliver heating or cooling through ducts similar to forced-air gas furnaces. Packaged heat pumps have all the components necessary for heating, cooling, and air circulation combined into a single system, usually mounted directly onto the building. They are typically installed on rooftops and thus are often called rooftop units (RTUs). Ducted ASHPs can be a suitable alternative to aging gas furnaces. Ducted ASHPs are installed in residential and small to medium commercial buildings.
- **Mini-split ductless heat pumps** are relatively new to the U.S. market but have been gaining popularity over the past several years as new residential and small commercial heating systems across the country. Mini-split systems also have outdoor condensers but use refrigerant pipes to deliver heating or cooling to each room where an indoor unit is installed. Because they use small refrigerant pipes and are relatively easy to install, they are suitable for heating system retrofits where ducts are not available. They also use variable speed compressors, which allow them to operate more efficiently and quietly than standard ducted ASHPs and to provide superior temperature controls.
- **Packaged terminal heat pumps (PTHP)** are all-in-one systems (including compressor, condenser and evaporator coils, fans, etc.), installed on an exterior wall. They are often installed in hotels and small apartment units. Compared to other heat pump systems, PTHPs do not perform well, and their operating temperatures are typically limited. However, a few cold climate PTHP models recently have become available in the market.[15]
- **Variable refrigerant flow (VRF) ASHPs** can distribute heating and cooling to numerous indoor evaporator units through a main refrigerant line from a single outdoor system.[16] Many VRFs can also provide heating and cooling simultaneously in different rooms by adding a heat recovery system, and thus are beneficial for buildings with diversely loaded zones.[17] VRFs are generally suitable for medium to large commercial buildings, but especially for medium/high-rise multifamily buildings, office, schools, and lodging.[18]

Compared with ASHP, GSHPs and WSHPs provide better performance in cold temperatures because they use heat reservoirs that have a higher temperature than ambient air during the winter.[xxiii] GSHPs use underground rock or groundwater as a heat reservoir. WSHPs use a well, lake, aquifer, or other source (*e.g.*, wastewater, cooling loop system, etc.) as a heat reservoir. GSHPs need to drill holes or dig trenches in the ground to install a heat exchanging group loop and thus are considerably more expensive than other heat pump technologies; however, total lifecycle costs for GSHPs can sometimes be lower, due to high-efficiency operation.

[xxiii] GSHPs and WSHPs also typically provide better cooling performance in hot temperatures because the heat reservoirs are generally lower temperature than ambient air during the summer.

AWHPs extract heat in the outdoor air and use water (or a mixture of water and glycol) as a heat transfer medium within the building instead of forced air. AWHPs are now widely available as heat pump water heaters for residential buildings. To date, their applications for space heating have been limited in the United States, although more systems are becoming commercially available in the early 2020s. For large commercial buildings with existing hot water heating systems (*e.g.*, with gas boilers), large-scale AWHPs can be a more energy-efficient alternative heating system or can provide supplemental heating.

GSHP, WSHPs, and even AWHPs can also produce temperatures high enough for a district heating energy system that circulates hot water. For example, Stanford University's new district heating energy system includes three large-scale heat recovery chillers (a type of WSHPs) that extract heat from waste heat from the University's cooling tower.[19]

Heat pump performance

For our building energy analysis, we developed average annual COP values for heat pumps separately for the residential and commercial buildings for a Reference case and for a Low Demand (high efficiency) case, as shown in Table 5.1 below. We developed these estimates based on our assessment of various data sources. The data sources include our own calculation of COP values based on real-world heat pump performance data on residential-scale heat pumps in other states, combined with hourly temperatures in San Diego County.[20, 21] We also reviewed COP values in California[22] and for the US market as a whole.[23] For commercial buildings, we assumed that heat pumps are 20 percent more efficient than residential systems under the Reference Case due to the availability of high-temperature heat sources, VRF's high COP values due to simultaneous heating and cooling functions, and advanced technologies such as multi-stage compressors. Finally, we developed projections of COP values through 2050 for the Reference case and for the Low Demand (high efficiency) case based on National Renewable Energy Laboratory's COP forecasts in its *Electrification Futures Study*.[24]

Table 5.1. Synapse projection of COP values for heat pump space heating in San Diego.

	2021	**2030**	**2040**	**2050**
Reference case				
Residential	3.3	3.6	3.8	3.8
Commercial	3.9	4.4	4.5	4.6
Low Demand case				
Residential	3.3	3.8	4.4	5.0
Commercial	3.9	4.5	5.0	5.5

We also developed our forecasts of total installed costs for heat pumps and gas space heaters for single-family and multifamily buildings, as shown in Table 5.2 below. We reviewed numerous data sources and developed the current cost estimates primarily based on a 2019 study by E3 which analyzed residential building electrification in California.[25] The main reasons why we decided to use this data source are that (a) some of the cost estimates in this study aligned well with our knowledge of system installed costs and the cost estimates in other data sources we trust; (b) the study conducted a detailed bottom up approach to estimate heat pump costs; and (c) the study provided cost estimates by climate zone, type of building, and building vintage. We selected cost estimates for coastal LA and downtown LA to develop cost estimates for San Diego County, as these areas have the most similar climate to San Diego. We then developed various factors using various data sources to develop weighted average cost estimates for single-family and multifamily buildings in San Diego County.[xxiv] We then forecasted future total installed costs of these systems using data from NREL's *Electrification Future Study*. Finally, we used the share of floor area between single-family and multifamily buildings (*i.e.*, 54 percent single-family and 46 percent multifamily) to develop per-unit costs for residential buildings on average, to align with how our decarbonization scenarios are defined. Equipment costs do not differ substantially between new construction and retrofits, provided that retrofits do not include changes in ductwork. (We assume that ducted systems are replaced with ducted, to avoid such costs.) Given San Diego's mild winters and prevalence of air conditioning, we do not expect electric panel upgrades to be required to adapt efficient electric space or water heating in typical homes.

[xxiv] We used the following sources to develop new construction and HVAC retrofit rates: Joint Center for Housing Studies of Harvard University. 2021. *Improving America's Housing*. Available at: https://www.jchs.harvard.edu/sites/default/files/reports/files/harvard_jchs_improving_americas_housing_2021.pdf; Statista. 2021. "Number of housing units in the United States from 1975 to 2020. Accessed September 27, 2021. Available at: https://www.statista.com/statistics/240267/number-of-housing-units-in-the-united-states/; San Diego County's tax assessor database. We also developed an estimate of HVAC retrofits by homes with ductless heaters (*e.g.*, wall furnace, electric resistance heater etc.) in San Diego Country based on the 2019 RASS.

Table 5.2. Synapse projection of average total installed costs of residential HP and gas space heaters in San Diego ($2021).

	2021	**2030**	**2040**	**2050**
Heat pump				
Single family	$14,200	$13,142	$11,967	$10,791
Multifamily	$10,900	$10,088	$9,186	$8,284
All residential	$12,673	$11,728	$10,680	$9,631
Gas heater				
Single family	$15,000	$15,000	$15,000	$15,000
Multifamily	$11,400	$11,400	$11,400	$11,400
All residential	$13,334	$13,334	$13,334	$13,334

Table 5.3 provides estimated building electrification costs for commercial buildings in San Diego County. These include costs to convert existing fossil-based systems to electric systems, as well as related building infrastructure changes. Energy efficiency retrofits, such as building envelope upgrades to reduce the peak-load impact of electrification, are not included. We draw on data from a 2021 building electrification study for Los Angeles,[26] heat pump cost trajectories from NREL's *Electrification Futures Study*,[24] and 2021 data on building characteristics from the San Diego County Tax Assessor's Office. We adjusted these data to align with the local building stock. Our economic analysis in Section 7.2 below is based on costs to electrify space and water heating (and does not yet include other end uses, the cost to disconnect gas, or potential costs to upgrade electrical service).

Table 5.3. Estimated commercial building electrification costs for San Diego County ($2021).

Item	**Units**	**2021**	**2030**	**2035**	**2040**	**2045**	**2050**
Space heat	*$/sqft*	$15.83	$13.79	$13.03	$12.28	$11.80	$11.33
Water heat	*$/sqft*	$0.65	$0.57	$0.53	$0.49	$0.46	$0.42
Cooking	*$/sqft kitchen*	$18.00	$18.00	$18.00	$18.00	$18.00	$18.00
Gas disconnection	*$/property*	$922	$922	$922	$922	$922	$922
Electrical upgrades	*$/property*	$32,975	$32,975	$32,975	$32,975	$32,975	$32,975
Other end uses, misc.	*$/sqft*	$1.75	$1.75	$1.75	$1.75	$1.75	$1.75

Source: Synapse model based on data from Jones (2021), Mai et al. (2018), and San Diego County Tax Assessor's Office (2021).

Water heating technologies

As mentioned in the previous section, residential water heating is the largest gas consuming end use and thus offers the largest GHG emissions savings opportunity through electrification of this end use.

Heat pump water heaters (HPWHs) have now become widely available in the market. The most popular HPWH technology is a hybrid HPWH which includes heat pumps, back up electric resistance coils, and hot water storage tanks. HPWHs are very efficient water heating systems. Their efficiency is measured using a Uniform Energy Factor (UEF) which presents an efficiency rating based on certain testing conditions.[xxv] The majority of the available products have UEFs above 3, and several products with a UEF of 4 are now available in the market.[27] Hybrid HPWHs can be installed in many places, including garages, basements, back porches, and outdoor-vented closets. Depending on where they are installed, their performance differs widely because of differences in air temperature and ventilation. In California, a garage is an optimal place for the best performance in warmer climates like San Diego, while basements may be a better place in northern parts of the state.[28]

Another HPWH technology is a split heat pump water heater with an outdoor compressor, sometimes called a "pure" HPWH because it does not need a backup resistance heater. Because it is a split system, it offers more flexibility for placing the indoor unit within the living space. Sanden produces a split HWPH that uses CO_2 as a refrigerant. This split heat pump water heater has several advantages over hybrid models: (a) it has a substantially higher capacity (approximately 3 times larger than hybrid models) and efficiency (with a rated COP of 5), (b) it only requires 13 Amp service, which could avoid upgrading an electrical panel (while a few new hybrid HPWH models also only require 15 Amps or so), and (c) it can raise water temperature up to 175 F and can operate in ambient temperatures down to -20 F.[29]

Both hybrid and pure HPWHs can offer load flexibility and work as demand response resources by storing additional thermal energy when electricity rates low to avoid energy usage during peak hours. A 2018 study by Ecotope, Inc. found that this HPWH load flexibility can result in customer bill savings of 15 to 20 percent, with about 35 percent utility marginal cost savings in California.[30]

Several large-scale HPWHs (which are either AWHPs or WSHPs) are available for commercial buildings in the market (including large multifamily buildings), though to-date, such applications have been limited in the country. HPWH configurations for commercial buildings can be quite

[xxv] UEF is comparable to coefficient of performance: it measures the ratio of the energy service output to the energy input. It is not exactly equal to the coefficient of performance for a water heater's heating element because it incorporates heat losses from the water storage tank.

different from single-family homes because commercial buildings have a lot of variations in water use and building structures, and also because some buildings have unique opportunities to utilize different heat reservoirs. For example, HPWHs can be placed in a below-grade garage, if available, and take advantage of the milder temperatures in the garage to produce hot water.[31] Mechanical rooms or laundry rooms can also be a suitable place for HPWHs installations if such those rooms are currently too hot or too humid, because HPWHs have the added benefit of cooling and dehumidifying the surrounding air. Further, HPWHs can be placed where they can utilize waste heat produced in certain commercial facilities such as spas, restaurant kitchens, or wastewater treatment facilities. Such HPWH applications provide space cooling benefits to the commercial facilities. Finally, large commercial and institutional buildings with a standard chiller system with a cooling tower could be a good candidate for installing HPWHs, more specifically heat recovery chillers. Heat recovery chillers can recover some of the waste heat from the electric chillers and produce hot water.[32]

Water heater performance

For our building energy analysis, we developed average annual COP values for HPWH separately for residential and commercial buildings for a Reference case and for a Low Demand (high efficiency) case, as shown in Table 7.4 below. We developed these values based on our assessment of a few different data sources. The primary source is NRDC and Ecotope's analysis of HPWH performance in California, where they estimated COP values in 16 climate zones in the state.[28] We selected climate zones suitable for San Diego County from this study and estimated the average COP values for garage and vented closet placement. We then adjusted the COP values upward to account for the technology improvement, since the study was conducted using the UEF ratings for the currently available HPWH products.[27] Finally, we developed our COP projections and COP estimates for commercial systems loosely based on NREL's COP forecasts for HWPH in its *Electrification Futures Study*.[24] NREL's COP estimates for commercial systems are generally lower than residential systems, with the difference ranging from 0 percent to about 14 percent, depending on the years. However, we assume commercial systems perform at least as well as residential systems and better than NREL's projections because some commercial buildings have access to unique heat reservoirs, unlike residential buildings.

Table 5.4. Synapse' projection of COP values for heat pump water heating in San Diego.

	2021	2030	2040	2050
Reference case				
Residential	3.0	3.2	3.5	3.5
Commercial	3.0	3.2	3.5	3.5
Low Demand case				
Residential	3.0	3.3	3.6	4.0
Commercial	3.0	3.3	3.6	4.0

We also developed our forecasts of total installed costs for HPWHs and gas water heaters for single family and multifamily buildings, as shown in Table 7.5 below. We first developed the current cost estimates based on a literature review of a few different sources.[33] We then forecasted future total installed costs of these systems using data from NREL's *Electrification Future Study*. Finally, we used the share of floor area between single-family and multifamily buildings (*i.e.*, 54 percent single-family and 46 percent multifamily) to develop per-unit costs for residential buildings on average, to align with how our decarbonization scenarios are defined. As with space heating, we do not find that costs differ substantially between new construction and retrofit applications.

Table 5.5. Synapse projection of total installed costs of residential HPWHs and gas water heaters in San Diego ($2021).

	2021	2030	2040	2050
Heat pump water heater				
Single family	$3,000	$2,500	$2,037	$1,852
Multifamily	$2,125	$1,771	$1,443	$1,312
All residential	$2,595	$2,162	$1,762	$1,602
Gas water heater				
Single family	$1,650	$1,375	$1,120	$1,019
Multifamily	$1,600	$1,333	$1,086	$988
All residential	$1,627	$1,356	$1,105	$1,004

Cost data for water heating electrification for commercial buildings, including installing HPWHs, are provided in Table 5.3 above.

Cooking technologies

While cooking with fossil fuels is a relatively small contributor to GHG emissions in most homes, these end uses are also those which residents most directly see and engage with fuel combustion. Many people enjoy cooking with gas on the stovetop, especially when compared with older electric technologies. Consumers are generally less attached to a particular fuel for ovens, and almost every other cooking appliance (such as microwaves, slow cookers, and pressure cookers) is natively electric.

In the residential sector, cooking is therefore more important for the economics and pathways of decarbonization because it relates to whether residents retain a gas connection for their home, even after switching fuels for water and space heating, than it is as a source of GHG emissions. Aside from restaurants or other food preparation businesses, most commercial buildings have no or almost no cooking related GHG emissions. However, cooking is a larger component of GHG emissions in the commercial sector than it is in residential, due to high energy use in commercial kitchens and lower overall demand for hot water and space heating in commercial buildings.

New electric cooking technologies, particularly cooktops that heat using induction, have the potential to upend customer devotion to cooking with gas. Induction cooking works by using magnetic fields to excite electric currents to swirl inside the pots and pans used for cooking. This is more efficient than older cooking technologies because the pan is directly heated, with no waste heat lost into the room. Heat can be turned up and down very quickly, so heat levels can be changed as fast or faster than gas, and water commonly boils faster on an induction cooktop than a comparable gas one. The cooktop itself stays cool, which improves safety and makes cleanup easy. There are also no combustion emissions, so indoor and outdoor air quality is improved. Electric ovens are comparably priced competitors to gas ovens, and do not face technology-specific market or customer adoption barriers.

Barriers to the adoption of induction cooking include relatively higher upfront prices, the fact that some pots and pans are not compatible with induction, and customer unfamiliarity with the new technology. Both electric cooktops and ovens (and combined systems) can require new electric circuits to be run to carry enough power, and could even trigger the need for an electric panel upgrade (if the panel has not yet been upgraded to serve a fast electric vehicle charger and/or heat pump systems).

Laundry

Electric dryers have a large market share today; in the Pacific census region, the U.S. EIA found that two-thirds of homes that have dryers use an electric one.[34] Aside from potential building-specific barriers stemming from electric-panel capacity and new circuits, there are no substantial barriers to residential adoption of electric dryers. There are also new, more efficient, electric dryers that use heat pump technology. These pump heat into the drum, while the cool side of the heat pump is used to condense the water removed from the clothes. This eliminates the need for a vent, so heat pump dryers can be used very effectively in high-performance buildings with tight building envelopes. Heat pump dryers are gentler on clothes than traditional tumble dryers but can also take a longer time to dry a load of laundry and are currently substantially more expensive than traditional dryers.

Commercial laundry systems face higher barriers to the adoption of electric options than do residential. Running many large electric dryers, as in a laundromat, could require substantial upgrades to a building's electric system if the laundry is transitioning from gas equipment. The slower speed of heat pump dryers is also more of a challenge in throughput-limited commercial laundry systems than in residential applications.

Low-carbon fuels

One way to reduce the GHG emissions from buildings without changing building systems (or before changing those systems to non-emitting options) is to use a fuel that does not release net greenhouse gases into the atmosphere. The two primary ways to generate such a fuel are to process the waste from biological processes or to separate hydrogen from various feedstocks.

Biomethane

Biomethane is defined as methane recovered from or generated from a biological process. (Methane is the primary component of fossil natural gas.) Many microbes that digest organic matter in the absence of oxygen ("anaerobic" digestion) release a combination of carbon dioxide and methane, called syngas. Biological feedstock can also be gasified into syngas using high heat processes (called "pyrolysis"). The carbon dioxide can be removed (called "scrubbing" the gas), leaving pipeline-quality methane.

Biomethane supply is currently very limited, and supply is expected to remain limited to well below the level of current fossil gas consumption. This limitation comes from both the lack of infrastructure to produce biomethane from biological feedstocks and the more fundamental limitation of the amount of feedstock biomass material that can be sustainably produced. In the face of limited supply, use in the building sector may not be prudent or economical because other sectors (such as industrial use) that have fewer low-carbon alternatives may require all the available supply. Processing for pipeline use must also compete with the option to combust the unprocessed (or less processed) fuels at their site of production to generate electricity and transport the resulting low-carbon energy to customers that way. There are also concerns about leakage of biomethane and recovered methane. Fugitive emissions can be high in certain production processes, including digestate storage and biogas upgrading.[35]

Biomethane costs and emissions depend on the production pathway used. In general, though, biomethane has lower, but non-zero, greenhouse gas emissions (especially after leakage is considered), and costs range between $10 per MMBTU to over $50 per MMBTU.[36] (For reference, fossil natural gas currently costs less than $5 per MMBTU.)

Hydrogen-based fuels

There are two primary methods used to produce low-carbon hydrogen. The first of these is electrolysis, in which water is split into hydrogen and oxygen by running electricity through the water. If the electricity for this purpose is low-carbon, then the hydrogen is low-carbon. This is referred to as “green” hydrogen. The second method builds on today’s methods for making hydrogen, which rely on splitting methane into carbon dioxide and hydrogen using “steam reformation.” So-called “blue” hydrogen is low-carbon if the resulting carbon dioxide is captured and permanently sequestered. There are no fundamental physical limits to the amount of “green” hydrogen that can be produced, so this energy carrier holds promise to meet combustion energy needs not met by biomethane.

Hydrogen can be blended with natural gas up to the level of about 20 percent by volume, or 7 percent by energy, without requiring changes in pipeline or customer infrastructure. However, at higher hydrogen concentrations, some pipeline materials could be damaged and customer appliances might fail to work safely. Using pure hydrogen (or high-hydrogen blends) would therefore require a substantial infrastructure investment to replace pipes and ensure that all customer cooktops, furnaces, water heaters, etc., were upgraded before the gas were sent to their buildings. Because hydrogen-ready appliances are only just being tested today, and pipeline systems would also need to be upgraded, this change-over is arguably a larger shift for customers than electrification would be.

One way to limit the need for infrastructure change to accommodate hydrogen would be to combine the hydrogen with carbon captured from a biological source or from direct air capture, to produce synthetic methane. When using biological sources, this fuel would face the same feedstock limits as biomethane. This means that for wholesale replacement of fossil natural gas with synthetic gas, the carbon would likely need to be captured from the air. Net lifecycle GHGs from these processes would depend on powering the air capture with zero-carbon sources of energy and limiting the leakage of the produced methane to low-enough levels so as to not fully counteract the climate benefits of the fuel.

One planning implication of using green hydrogen, especially paired with direct air capture, is the immense requirements for electricity to power the electrolysis and air capture processes. The amount of electricity to produce these fuels and meet customer needs would dwarf the amount of electricity that would be required to directly meet customer needs with the generated electricity. As shown in Figure 5.11, meeting the same energy demand with green hydrogen as with heat pumps would require almost six times as much renewable energy generation.

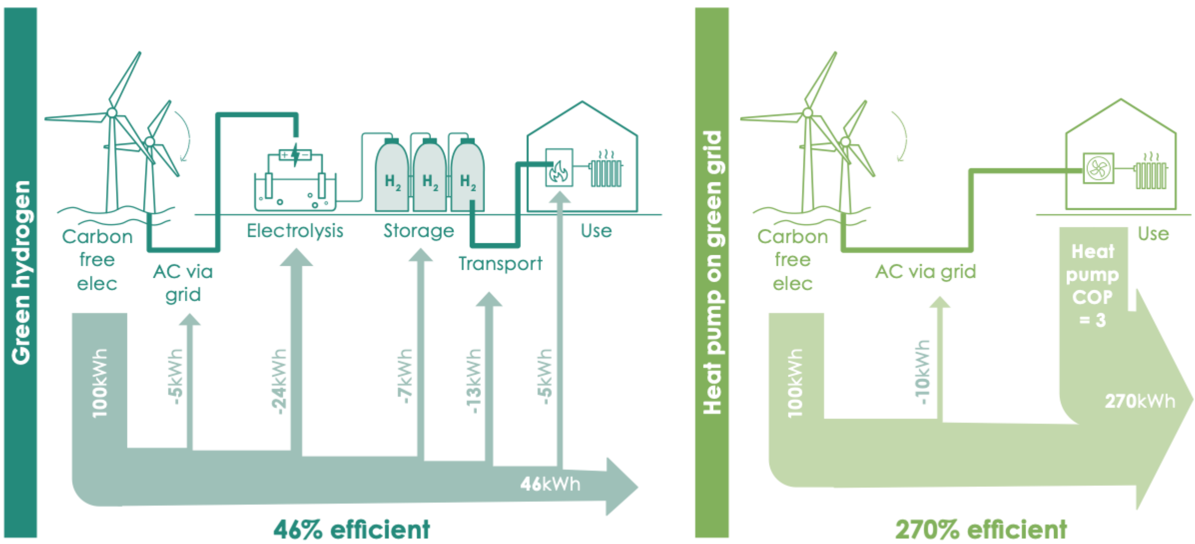

Figure 5.11. Comparison of efficiency of energy delivery between green hydrogen and heat pumps. Note that this figure does not include the added cost and efficiency loss from direct air capture and the manufacture of synthetic methane. Source: London Energy Transformation Initiative, 2021. "Hydrogen: A decarbonisation route for heat in buildings?," Available at: https://b80d7a04-1c28-45e2-b904-e0715cface93.filesusr.com/ugd/252d09_54035c0c27684afca52c7634709b86ec.pdf. Reproduced with permission.

While the ability to store and ship hydrogen and synthetic methane allows the generation to be located in distant places, and not be aligned with seasonal needs for heating, the added land use and cost associated with this electricity production should not be overlooked. Overall, synthetic natural gas is expected to be more expensive than biomethane when using direct air capture: E3 recently estimated a cost of about $70 per MMBTU.[37]

In the San Diego context, with the county's good year-round renewable electricity resource and lack of strong seasonal heating demand, these technologies face an even greater competitive challenge.

5.3. Pathways to Decarbonization of San Diego's Buildings

Synapse modeled three different trajectories to reach a carbon-free building sector in 2050. These scenarios were designed to align with multi-sector analysis performed by Evolved Energy Research, as detailed in Chapter 1 and Appendix A.[xxvi]

1. **Central (High Electrification).** This pathway assumes that over 95 percent of space heating and water heating equipment sales are fully electric by 2030 and 2032, respectively. In 2050, no residential water heating is served by gas and only 8 percent of residential space heating systems are unelectrified.
2. **Low Demand.** In this scenario, space and water heating system sales and stock numbers closely match the trajectories from the Central case. Heat pumps are assumed to perform at higher efficiencies, reducing electricity consumption.
3. **Partial Electrification.** This case models an alternative approach, where less than half of space and water systems sales in 2030 are electric. In this case, a low-carbon gas to use as a natural gas alternative is required to achieve decarbonization within the study period. The scenario assumes a linear increase in the use of a low-carbon gas,[xxvii] starting in 2030 and reaching 100 percent in 2045 and later years.

Table 5.6. Some of the important differences between the three modeled scenarios.

	Central	**Low Demand**	**Partial Electrification**
Electric space heat equipment sales share in 2030	96% (84% heat pump)	96% (84% heat pump)	41% (17% heat pump)
Electric share of installed residential HVAC systems in 2050	92% (75% heat pump)	92% (75% heat pump)	75% (54% heat pump)
New residential space heating heat pump COP in 2050	3.51	5	3.51
Residential and commercial electricity consumption from space and water heating in 2050	4.6 TWh	4.2 TWh	4.3 TWh

We have not examined a reference case which fails to achieve zero emissions by 2045 (in line with California's statewide net-zero goal). Because GHG reductions are required, the relevant

[xxvi] The Evolved Energy Research (EER) model assumptions are described in Appendix A Table 1.
[xxvii] Assumed to be a gas that reduces GHGs by 95 percent relative to fossil gas.

questions for policymakers and the public relate to which pathway to decarbonization to choose, not whether to decarbonize at all. Comparing the decarbonization cases to a "reference" or "business as usual" case that fails to reduce emissions would not provide useful insights.

Central Scenario (High Electrification) Results

This case illustrates a decarbonization pathway centered on switching space and water heating systems from natural gas (and delivered fuels) to electricity, predominantly heat pumps. Figure 5.12 shows the breakdown in sales for space and water heating in the residential and commercial markets.

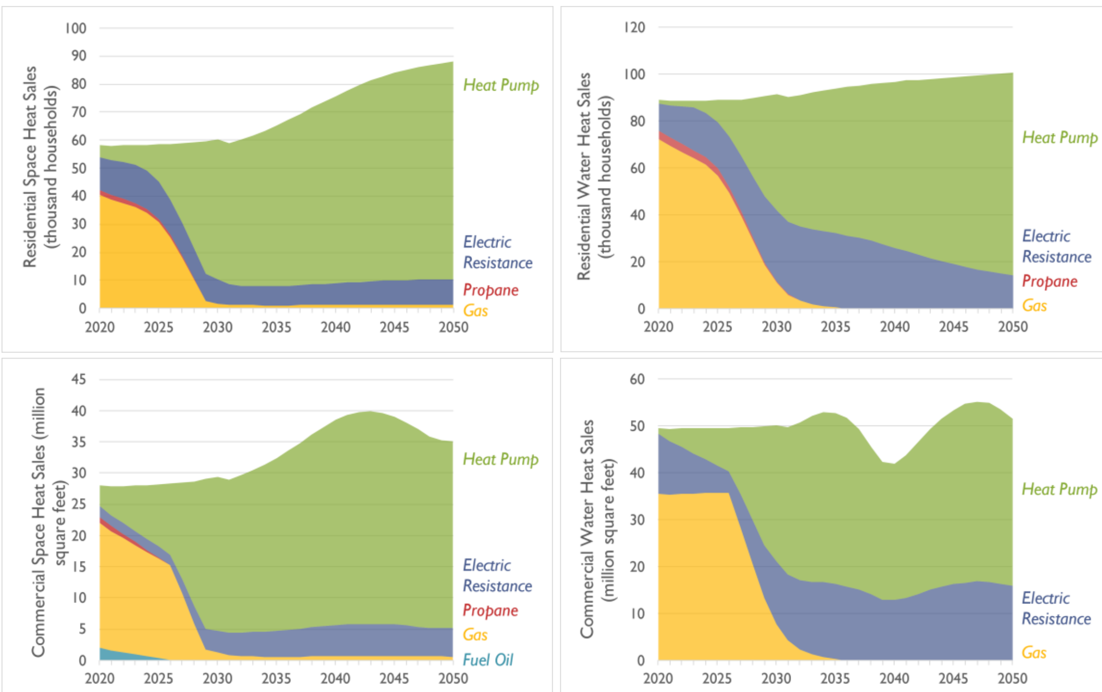

Figure 5.12. Sales of space and water heating equipment, by fuel and type, in the Central case.

Space heating systems are replaced at a slower rate than water heaters, so some gas space heating equipment remains in use in 2050, while gas water heating is effectively eliminated. Figure 5.13 shows the stock of space and water heating systems by fuel.[xxviii]

[xxviii] By "stock" we mean the total installed base of systems in buildings (not the equipment stocked for sale by distributors).

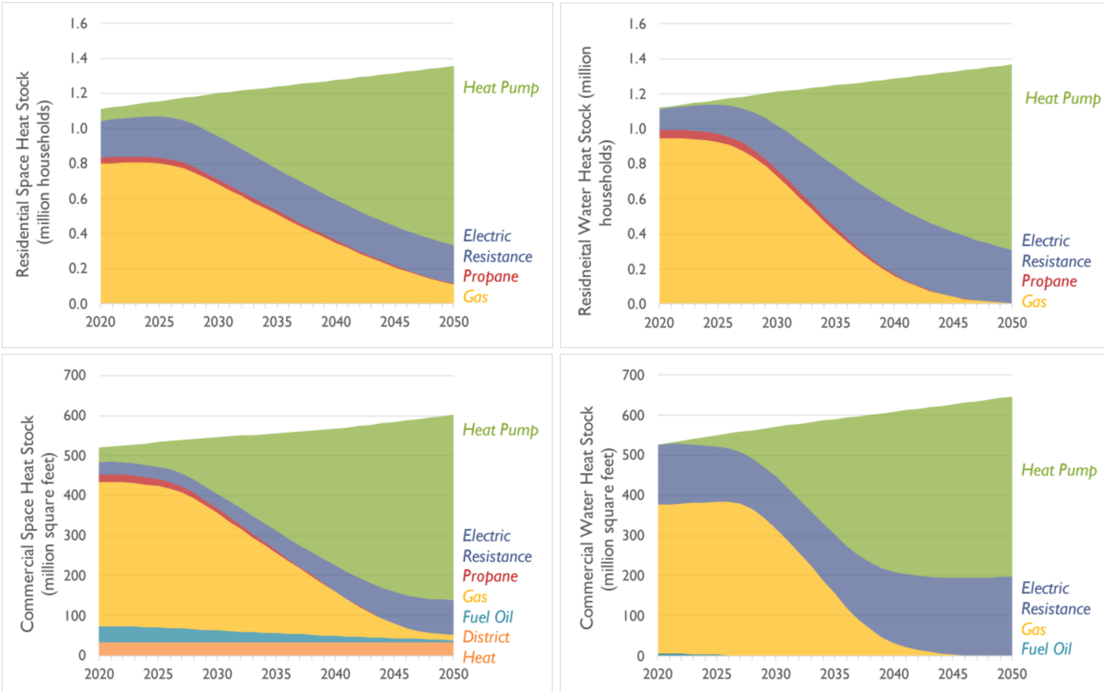

Figure 5.13. Stock of space and water heating systems, by fuel and type, in the Central case.

As building systems are electrified, the resulting on-site energy use and emissions change. Total site energy consumption falls, as shown in Figure 5.14, because electric heat pump technologies are much more efficient than combustion-based or resistive heating.

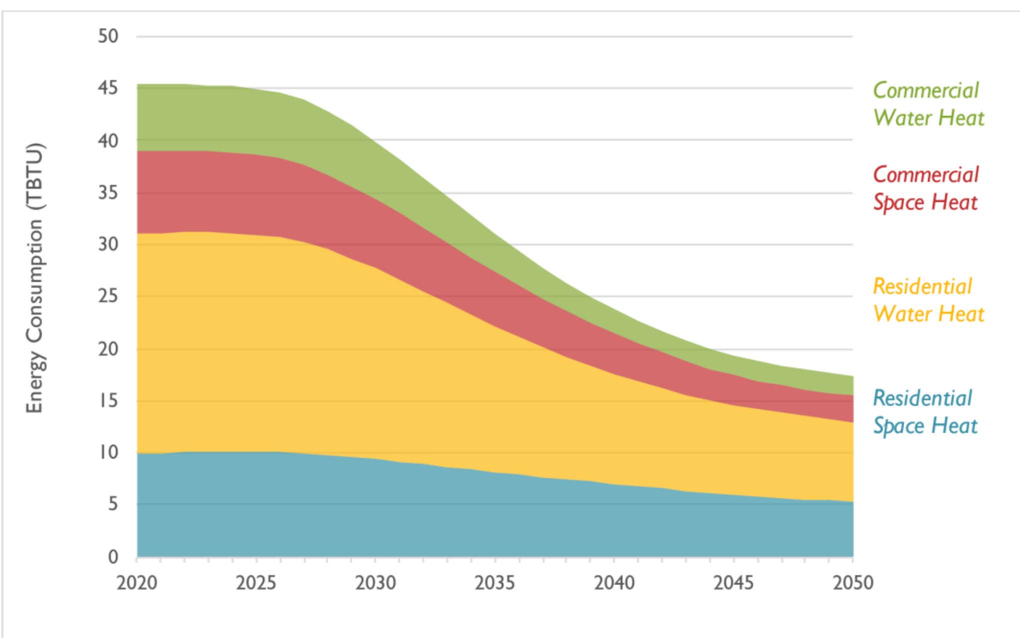

Figure 5.14. Total site energy consumption for space and water heating in the Central case.

Natural gas use would decline to about 3 percent of current levels, with remaining use primarily for residential space heating, as shown in Figure 5.15.

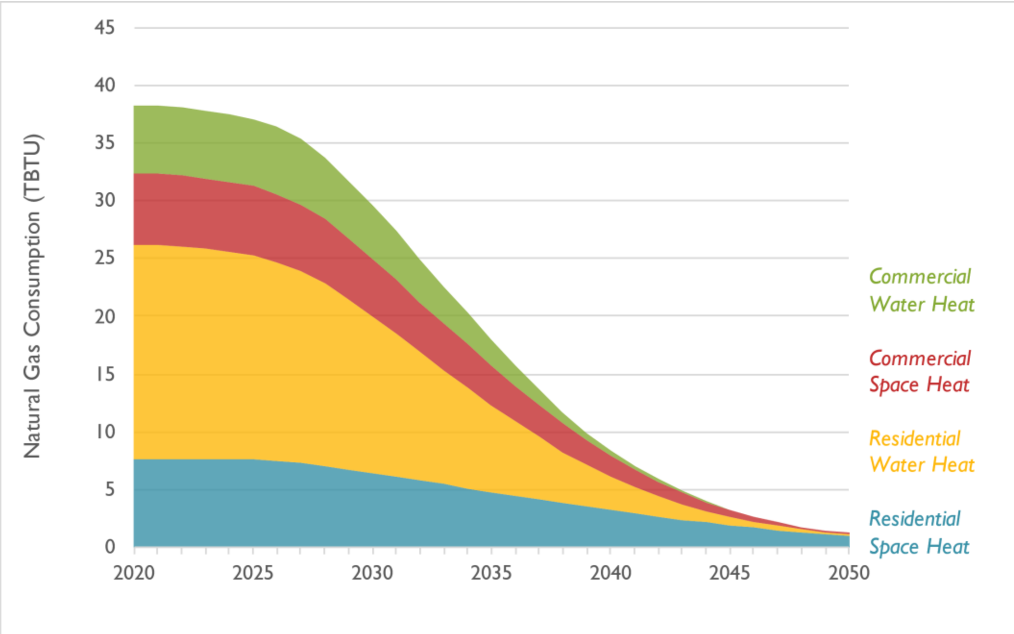

Figure 5.15. Use of natural gas for space and water heating in the Central case**.**

On-site GHG emissions, which are currently dominated by natural gas combustion, would follow a trajectory almost exactly aligned with the natural gas trajectory. Figure 5.16 shows the on-site emissions, by fuel. Remaining emissions in the natural gas sector could be reduced by using small amounts of low-carbon gas such as biomethane.

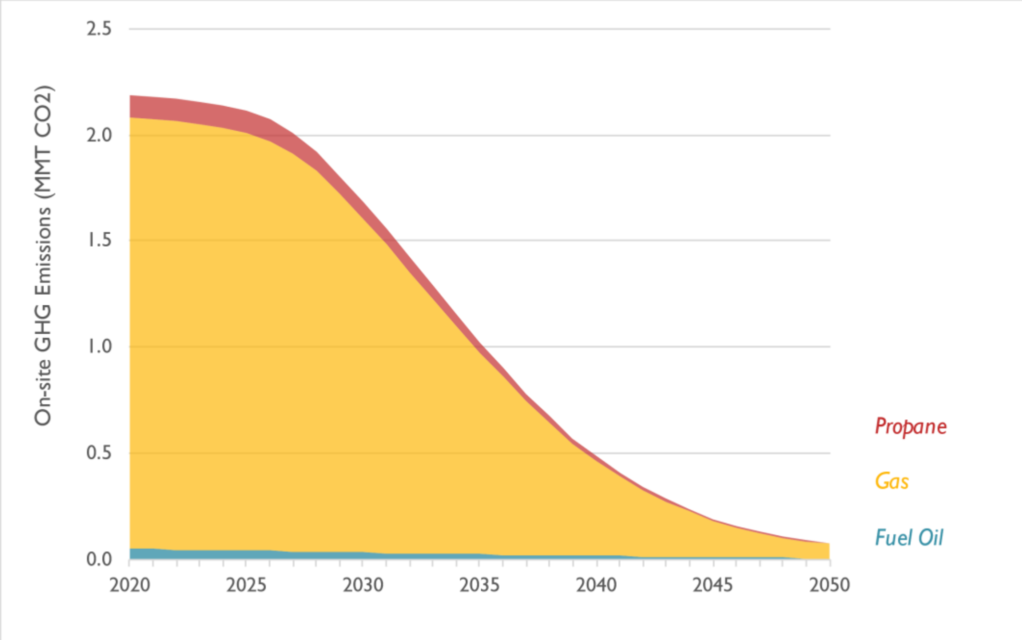

Figure 5.16. On-site GHG emissions from space and water heating, by fuel, in the Central scenario, without use of low-carbon gas.

Electricity use for space and water heating, however, would increase substantially, as shown in Figure 5.17. Electric sector GHG emissions are set to decline to zero by 2045 as a result of California state electricity policy.

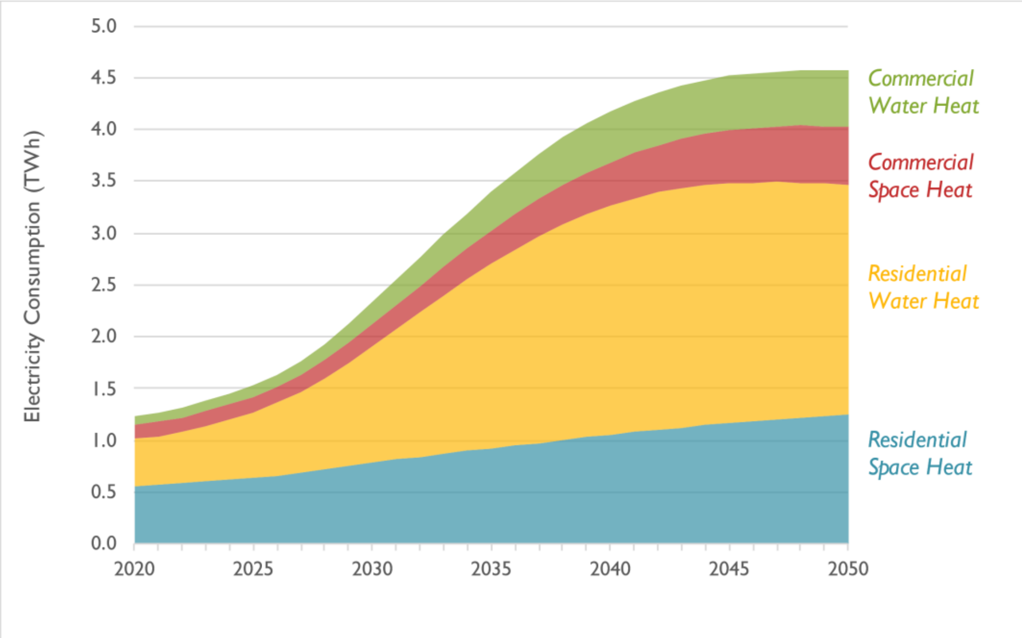

Figure 5.17. Consumption of electricity for space and water heating in the Central scenario.

While this analysis shows an increase of more than a factor of three in electricity use for space and water heating, the overall effect on SDG&E electric sales would be more muted. SDG&E's 2020 electric sales totaled a bit more than 14 TWh.[38] This is because electricity is used for many other purposes today, and those uses would continue. In addition, electric vehicles would drive an even greater increase in SDG&E's electric sales. Our analysis does not extend to an hourly look at load shapes from different end uses. However, the increase in electric consumption shown here does not appear likely to drive a substantial increase in SDG&E's peak electric demand. In 2020, SDG&E experienced a peak demand of about 4,600 MW, driven by summer air conditioning load, while its winter peak loads were less than 3,000 MW.[38] This indicates there is substantial headroom for winter heating load without driving new distribution system or transmission system peaks. To the extent that new water heating loads could add to the summer peak, rate design and control technologies can help to shift these loads to off-peak hours.

Low Demand Case Results

The primary difference between this case and the Central, or high-electrification, case is that the electric equipment that replaces combustion-based space and water heating equipment is more efficient. This case has minimal changes in the sales and stock of natural gas equipment. Figure 5.18 shows the electricity demand trajectory for space and water heating in this case, compared to the Central case.

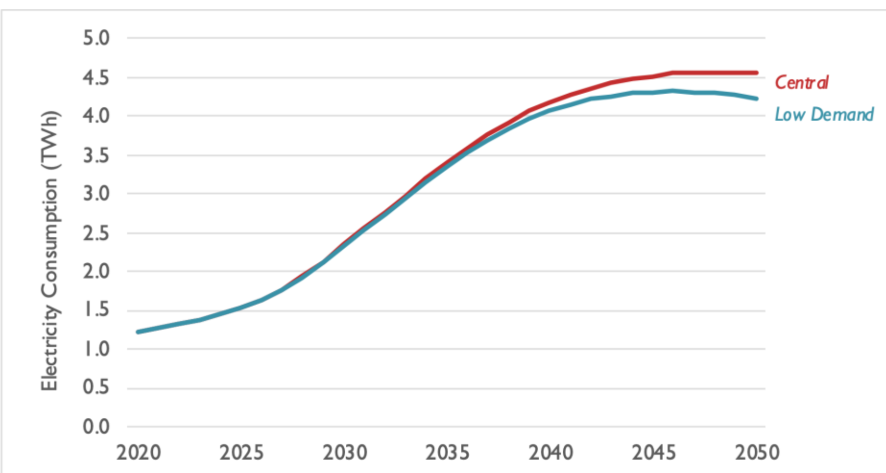

Figure 5.18. Electricity consumption for space and water heating in the Low Demand scenario and the Central scenario

The use of higher-efficiency equipment results in lower electric supply costs (see below) and a lower demand for the construction of zero-carbon electric generators. The electric consumption reduction in this case in 2050 relative to the Central case, about 330 GWh, is equivalent to avoiding the construction of about 124 MW of solar PV or 97 MW of onshore wind resources.

Partial Electrification Case Results

In the Partial Electrification case, market share for electric technologies is smaller, and increases later, than in the Central case. Figure 5.19 shows the heat pump market shares for residential and commercial space and water heating used for this case.

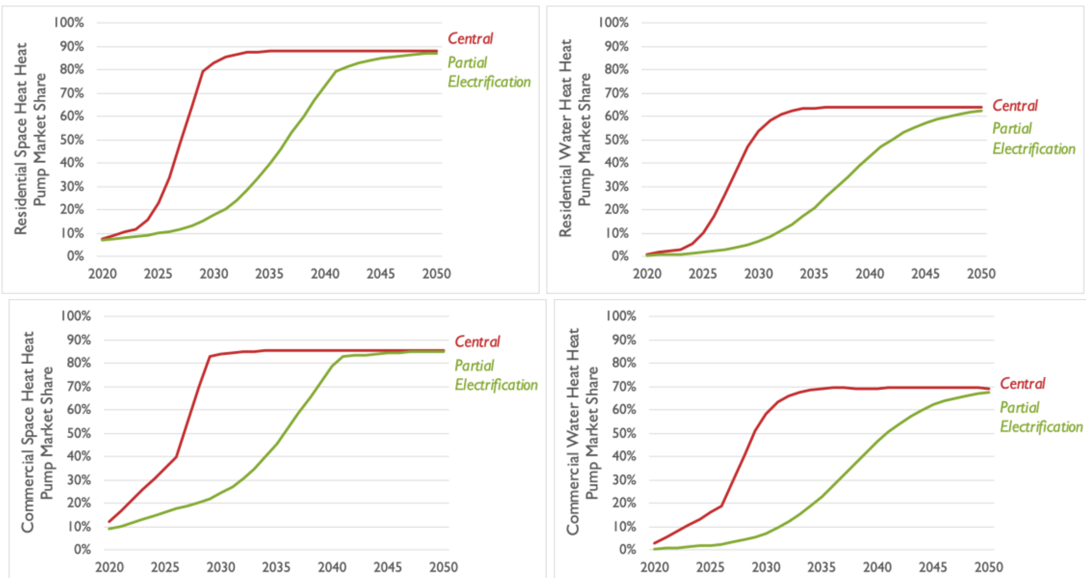

Figure 5.19. Heat pump market shares of new system sales in the Partial Electrification and Central scenarios.

As a result of this slower uptake of electric options, the stock of natural gas systems remains higher throughout the study period, as shown in Figure 5.20. (Compare with Figure 5.13 above.)

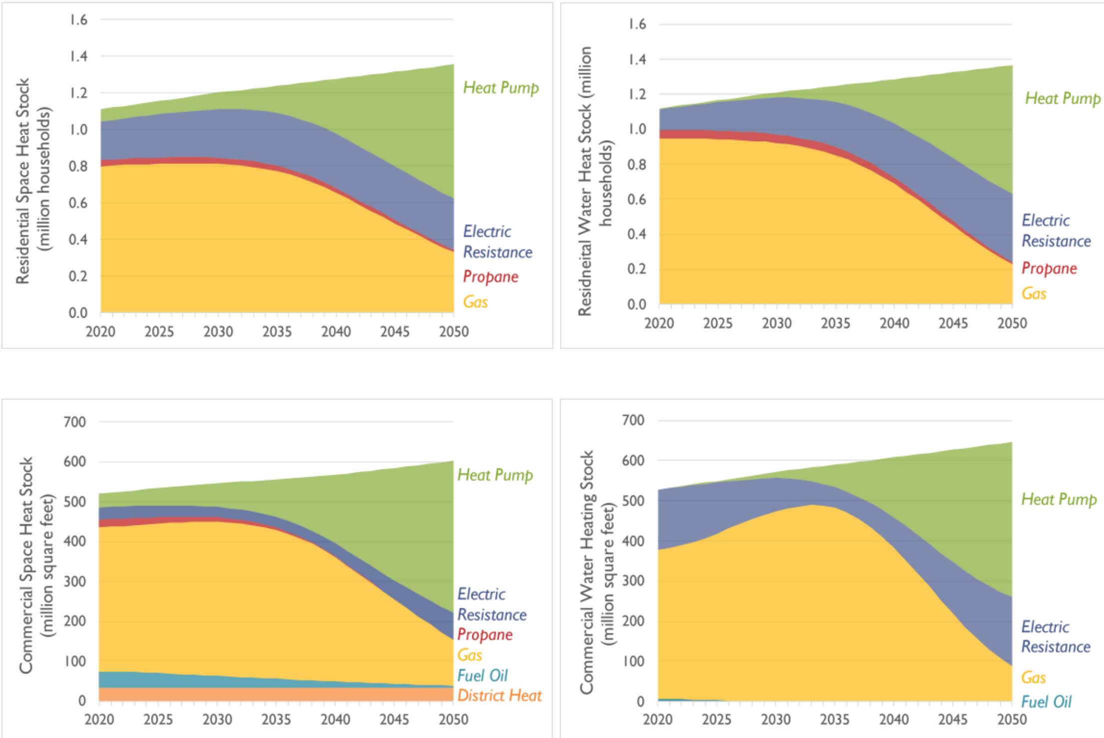

Figure 5.20. Space and water heating stock in the Partial Electrification scenario.

On-site pipeline gas use also remains higher through 2050, as shown in Figure 5.21.

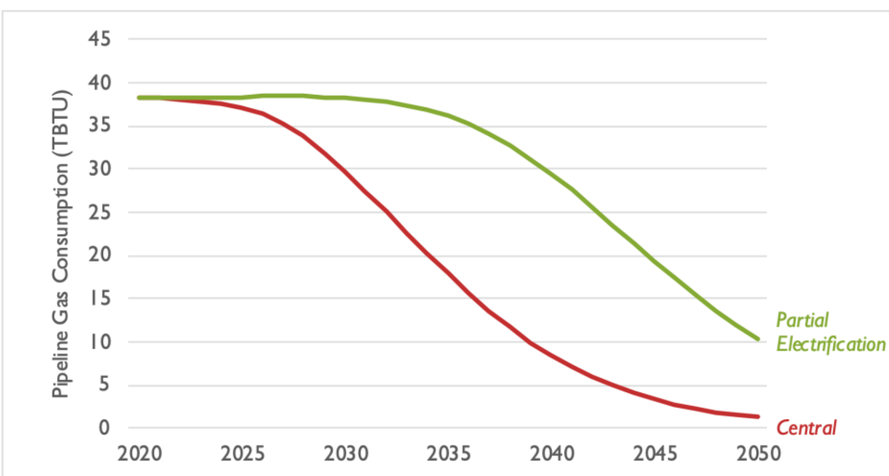

Figure 5.21. Pipeline gas consumption in the Partial Electrification and Central scenarios.

To represent potential scaling of low-carbon gaseous fuels in this case, we have increased the amount of biomethane and synthetic natural gas distributed using the pipeline gas system from zero in 2030 to 19.4 TBTU in 2045. This is enough to fully replace fossil gas in 2045 and later years. If we optimistically assume that this gas has emissions equal to 5 percent of fossil natural gas emissions, then the emissions trajectory for this case is as shown in Figure 5.22. For the purposes of cost estimation in the following section, we assumed that this low-carbon gas has an average cost of $30 per MMBTU.[xxix] This cost reflects the limited quantity of fuel required and thus the ability of biomethane to meet some or all of the demand.

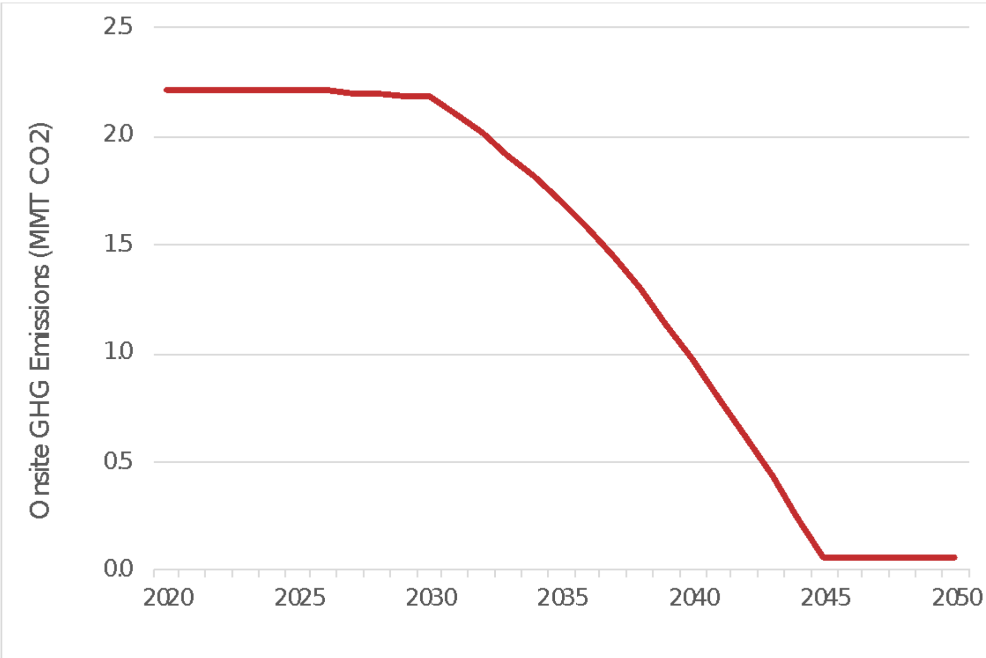

Figure 5.22. Onsite GHG emissions in the Partial Electrification scenario, reflecting increasing use of low-carbon fuels in place of pipeline gas starting in 2030.

Capital and Operating Costs

All the decarbonization scenarios considered here result in substantial changes in household and business spending on heating systems, water heaters, and the fuel and electricity to operate those systems. Heat pumps displace the need to pay for separate air conditioning and furnace systems. Heat pump water heaters are more expensive upfront than traditional electric resistance or gas storage water heaters.

Fuel and electricity costs are driven by the need to maintain the delivery infrastructure for each fuel, as well as the cost of low- to zero-carbon energy sources to reliably meet energy demands.

Table 5.7 shows the present value of estimated capital and operating costs between 2021 and 2050 for each case, using a 3 percent real discount rate. Interestingly, the three scenarios have

[xxix] We also assumed that fossil gas would have the cost for Henry Hub projected by the *Annual Energy Outlook 2021* published by the U.S. Energy Information Administration.

almost indistinguishable present value costs—well within the margin of error of the numerous cost assumptions that went into developing them. As expected, the Partial Electrification case has lower building system capital costs (because it depends on mature technologies), but fuel costs are higher as a result of the need for low-carbon gas fuel. If low carbon gas were to become available at scale and at costs well below $30 per MMBTU, this case would be distinctly less expensive than shown here. Similarly, if low carbon gases are not available or only available at scale at costs above $30/MMBTU, the high electrification cases would be less expensive. While the uncertainty is smaller, electricity costs could have a similar effect. This analysis uses long-term marginal electric supply costs from SDG&E's integrated resource plan (approximately 11 cents per additional kWh).[39]

The costs presented here are only the marginal costs associated with the electric and pipeline gas systems under a case in which those systems continue to be operated at the scale and with the same regulatory treatment as they are today. Therefore, these costs also do not reflect the potential to reduce gas system costs in the electrification cases, which are discussed in the following section. These costs are societal costs. How they are spread among customers is a matter of public policy, including incentives, weatherization and utility demand-side management programs, rate design, and tax policy.

Table 5.7. Present value capital and operating costs under three decarbonization scenarios (in billions of $2021).

	Central	**Low Demand**	**Partial Electrification**
Capital costs			
Res. space heating	$12.8	$12.8	$11.7
Res. water heating	$2.8	$2.8	$2.5
Comm. space heating	$7.3	$7.3	$7.0
Comm. water heating	$0.4	$0.4	$0.4
Electric upgrades	$0.6	$0.6	$0.4
Operating costs			
Electricity	$6.3	$6.1	$4.8
Pipeline gas	$2.0	$2.0	$5.2
Total	$32.2	$32.1	$32.0

5.4 Gas Utility and Rate Impacts

Introduction to Utility Finance and Economics

No matter what pathway is pursued, decarbonizing San Diego's buildings will transform the business of the county's gas utility, San Diego Gas and Electric (SDG&E). In any case, SDG&E will transport much less gas to homes and businesses than it does today. This section focuses on the economics and business model of the gas utility portion of SDG&E. SDG&E as an enterprise also has the ability to coordinate its electric utility planning with changes on the gas side.

SDG&E, like all investor-owned regulated utilities in the United States, is allowed to earn a rate of return based on the amount of capital that it has invested in the transmission and distribution assets that serve its customers. The utility's rates are designed to recover the company's "revenue requirement"–the amount of money it must collect from customers each year to pay for that year's depreciation of its assets, cover operating costs, and leave a just and reasonable return on invested capital for its bondholders and shareholders. Gas rates are composed of the delivery rate, which covers the cost of the local transmission and distribution systems, and the supply rate, which covers the cost of the commodity fuel that flows through the pipes. SDG&E does not make any profit on the supply rate – it simply passes fuel costs through as an operating expense.

Changes in how pipeline gas is used in San Diego County will cause a substantial change in how this business model functions. If the utility maintains its full gas system and invests in that system as it has historically done, while gas sales fall, it will need to raise the rates it charges per unit of gas in order to recover its full revenue requirement. If it doesn't raise rates sufficiently, its returns to investors will fall. However, as the gas utility raises rates, more customers may choose to use electricity instead of gas, to lower their energy bills. At the same time, greater utilization of the electric system, without creating new peak-related costs, would allow electric rates to decline. Combined, these rate effects would create an accelerating departure from the gas system, as continued electrification would accelerate the rate differential.

Delivery rate increases could be mitigated by retaining a larger amount of pipeline gas sales. However, for the County's GHG goals to be met in this case, the remaining fuel sales must be low-carbon fuel. This fuel is much more expensive than fossil natural gas. As a result, the supply portion of gas rates would increase substantially.

Low-income customers and tenants are particularly vulnerable to accelerating gas rate increases because these households have the least ability to invest in changes in their home's water and space heating systems to mitigate rate changes. The gas utility's transition path is also particularly important to the utility employees and contractors who install and maintain the gas pipeline infrastructure. Understanding the dynamics and timing of rate increases and gas customer economics is important to managing the equitable and just transition of the gas system into a decarbonized future.

Scenario Results without Mitigation

In order to investigate the impact of changes in gas sales and the number of gas customers as county residents and businesses decarbonize their buildings, we modeled SDG&E's gas utility revenue requirements (in total and per customer), rate base, and rates in both the Central and Partial Electrification cases. In both cases, we did not apply any of the mitigating actions that we detail below. In that way, these results present a bookend case, with higher rates and more assets at risk than would be experienced in reality. We have also not modeled the impact of electrification on electric rates and bills (which will also be strongly impacted by transportation electrification).

Because we assumed no mitigating actions, SDG&E's total revenue requirements (other than the cost of fuel) and rate base are not affected by the scenario. In both cases, we assume that SDG&E continues to add new customers through 2036 (albeit at a declining rate) and continues to replace aging assets at the same pace it does today. It maintains the full extent of its gas pipeline system. Figure 5.23 shows the resulting revenue requirement for the regulated gas delivery business (that is, not including the cost of fuel), while Figure 5.24 shows the utility's rate base. [xxx] In both cases, we have adjusted to real 2020 dollars, to subtract out the effect of underlying inflation.

[xxx] Rate base is the amount of unrecovered assets on which the utility earns its return for shareholders. It is generally equal to the undepreciated (remaining) value of the utility plant in service, adjusted by the tax treatment of depreciation.

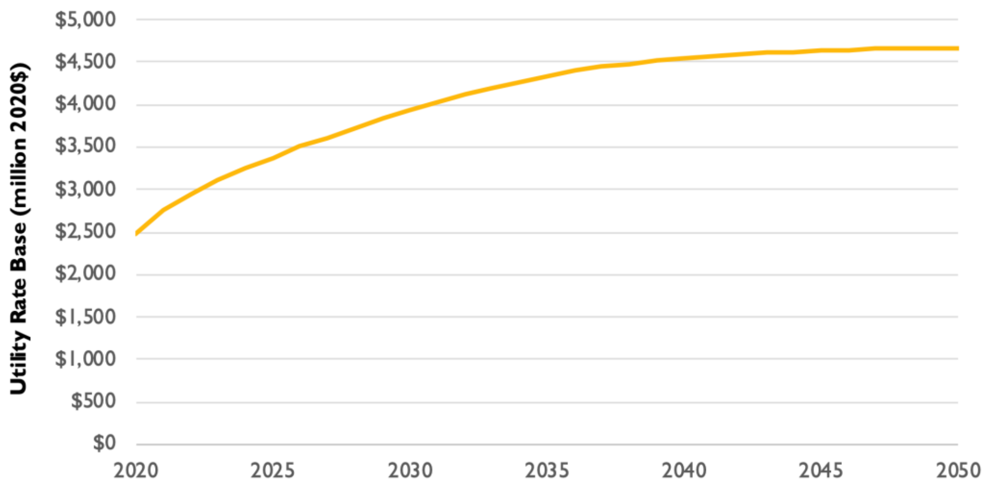

Figure 5.23. Gas utility revenue requirement for delivery services.

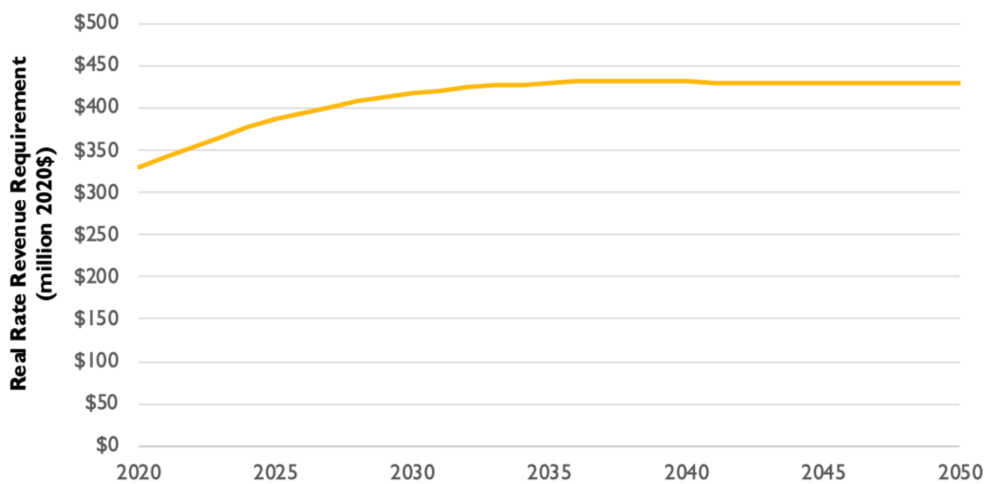

Figure 5.24. Gas utility rate base

Where the scenarios differ are in three further aspects: the cost of fuel, the number of customers, and the amount of fuel delivered. As shown in Figure 5.25, adding the cost of fuel to the delivery revenue requirement (dashed yellow line) results in the Partial Electrification (green) and High Electrification (red) trajectories.

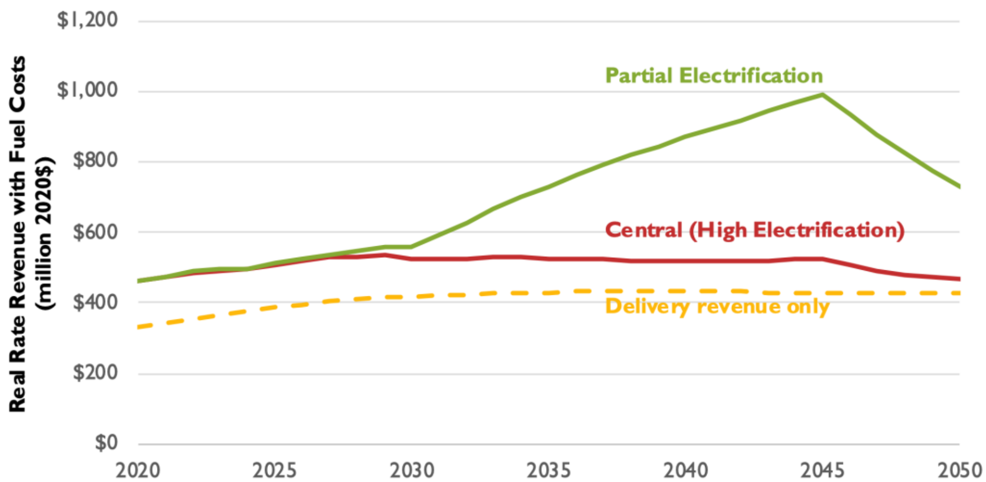

Figure 5.25. Gas utility revenue, including fuel costs.

To estimate the trajectory for delivered gas rates in each case, we divided the total revenue requirement by the total sales of pipeline gas in each case. This results in the forward rate curves shown in Figure 5.26. While the Partial Electrification case has lower rates than the Central case, even this case shows rates that far exceed today's average gas rates of just over $1 per therm. Both cases have rates that exceed $2 per therm by the 2030s (2033 in the Central case and 2038 in the Partial Electrification case). These higher per-unit rates could encourage customers to choose to heat with electricity, absent policy intervention to change the relative costs of fuels.[xxxi]

[xxxi] This analysis uses the total revenue requirement divided by total sales as a proxy for rate impacts. We do not distinguish between rate classes, and we do not distinguish between the monthly customer charge and the marginal rate for consumption, which each send different signals that shape customer behavior. Rate designs that shift more costs into the monthly customer charge would strengthen gas in marginal competition with electricity for each end use, while also giving customers a stronger incentive to fully disconnect from the gas network.

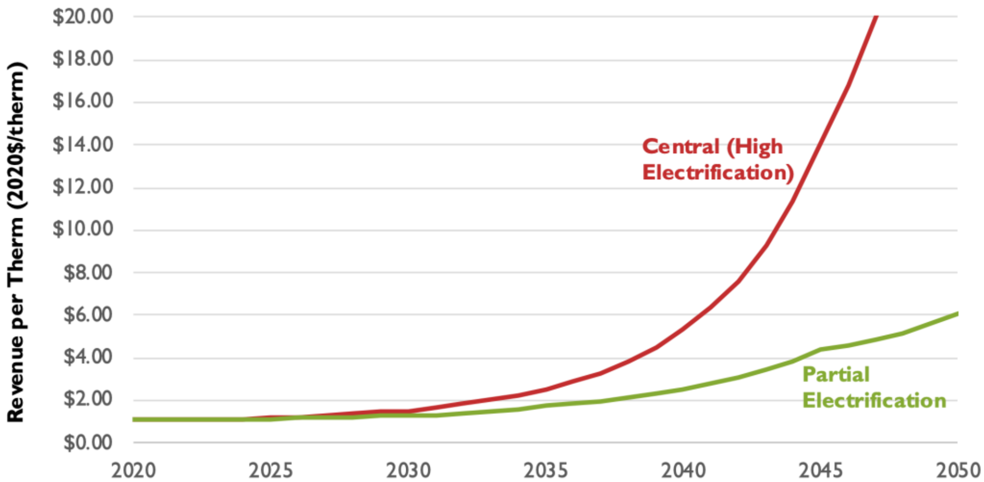

Figure 5.26. Forward gas rate curves for the Central (red) and Partial Electrification (green) scenarios.

Customers do not pay rates–they pay bills. Therefore, it is necessary to multiply the rates by the average consumption per customer to evaluate the impact of each scenario on the total annual energy costs of the customers who remain connected to the gas system. Figure 5.27 shows the resulting energy bills.

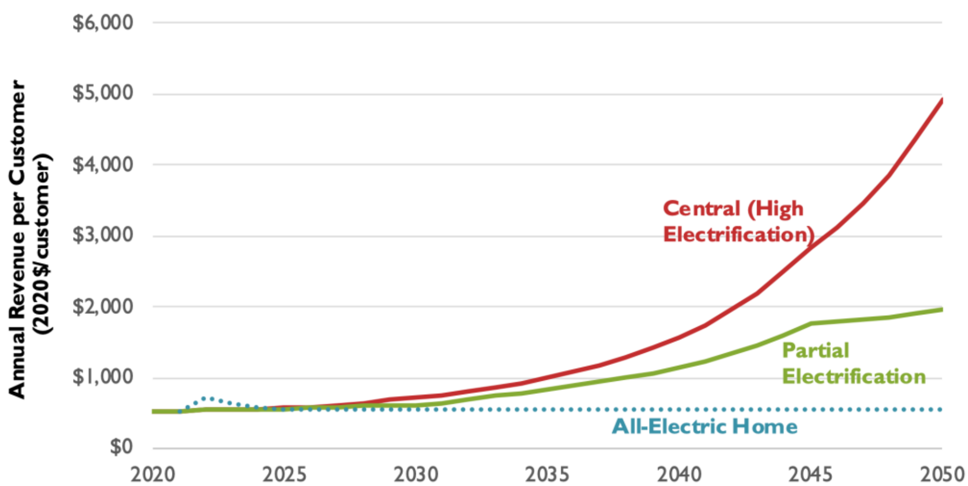

Figure 5.27. Average customer bills for gas customers in the Central (red) and Partial Electrification (green) scenarios, along with the per-customer increase in electric utility revenues from an all-electric home switching from gas (blue dashed).

These bills illustrate the challenge facing SDG&E and its stakeholders as it plans a path forward: in both cases the cost of gas service per customer increases substantially. While gas customer bills in the Partial Electrification scenario are lower than in the Central case, in both cases they rise to far exceed the bills for equivalent service provided with all electric appliances.[xxxii] Our analysis indicates that, absent policy intervention or mitigating actions, the Partial Electrification case is not a stable equilibrium.

Mitigation Approaches

SDG&E, its owners, and its regulators have numerous options to evolve the utility's practices and business model to mitigate the rate trajectories that would result from decarbonization. The objectives of these approaches would be to more equitably share the cost of the existing gas system between today's customers and future customers, as well as to limit the risk to residents and investors that the utility will leave substantial stranded assets. Stranded assets are investments that the utility made but which are retired before their full asset value has been recovered.

The cost of stranded assets could be passed to utility investors, which would risk the financial viability of the company. This is not optimal because San Diego residents require SDG&E to be a viable enterprise to continue to provide electric service, at least, and if financial viability were threatened while there were still gas customers their service would also be at risk. Safety of the electric and gas systems could be at risk in such a case. The value of some stranded assets could instead be recovered from electric ratepayers or from taxpayers. Both approaches would require changes in fundamental approaches to utility ratemaking. One option would be securitization, wherein stranded assets are bought out by a public bond-backed entity with a lower cost of capital (thus lowering the total funds to be recovered), and then the bond is paid back over an appropriate timeframe using electric ratepayer funds or tax revenues. California is using securitization to address electric utility costs associated with wildfire risk reduction.[xxxiii]

In order to limit the amount of stranded assets whose fate must be resolved in groundbreaking or painful ways, utility financial and infrastructure practices could be changed in the near term.[xxxiv] These approaches would have different effects on the utility's annual revenue requirements. In some cases, stranded cost risks are mitigated by recovering funds sooner,

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[xxxii] The exact customer economics depend on rate design for both gas and electric utilities. Figure 28 reflects the relevant per-customer costs of service (accounting for the fact that building electrification will not drive changes in electric transmission and distribution costs), as a proxy for the costs that would be assigned to each customer under a reasonable rate design.

[xxxiii] See, for detail, California Assembly Bill 1054 (passed 2019) and California Public Utilities Code, Sec. 8386.3.

[xxxiv] One resource to learn more about the options discussed here, and others, is *Managing the Transition: Proactive Solutions for Stranded Gas Asset Risk in California* by Bilich, Colvin, and O'Connor (2019) for the Environmental Defense Fund (available at https://www.edf.org/sites/default/files/documents/Managing_the_Transition_new.pdf.) While the analysis in this report differs somewhat from that study, the general conclusions and analysis are compatible.

while there is still extensive use of the gas system. In other cases, actions mitigate risks by reducing the size of the total investment at risk. Some actions do not change the total size of the investment or stranded cost risk, but can mitigate rate impacts and thereby buy breathing room to use rates to recover invested capital. In each case below, we change one aspect of the utility's action or accounting, in order to illustrate the impact of each change. In reality, the utility's management, along with its investors, regulators, and other stakeholders, would develop a portfolio of actions to best achieve their objectives.

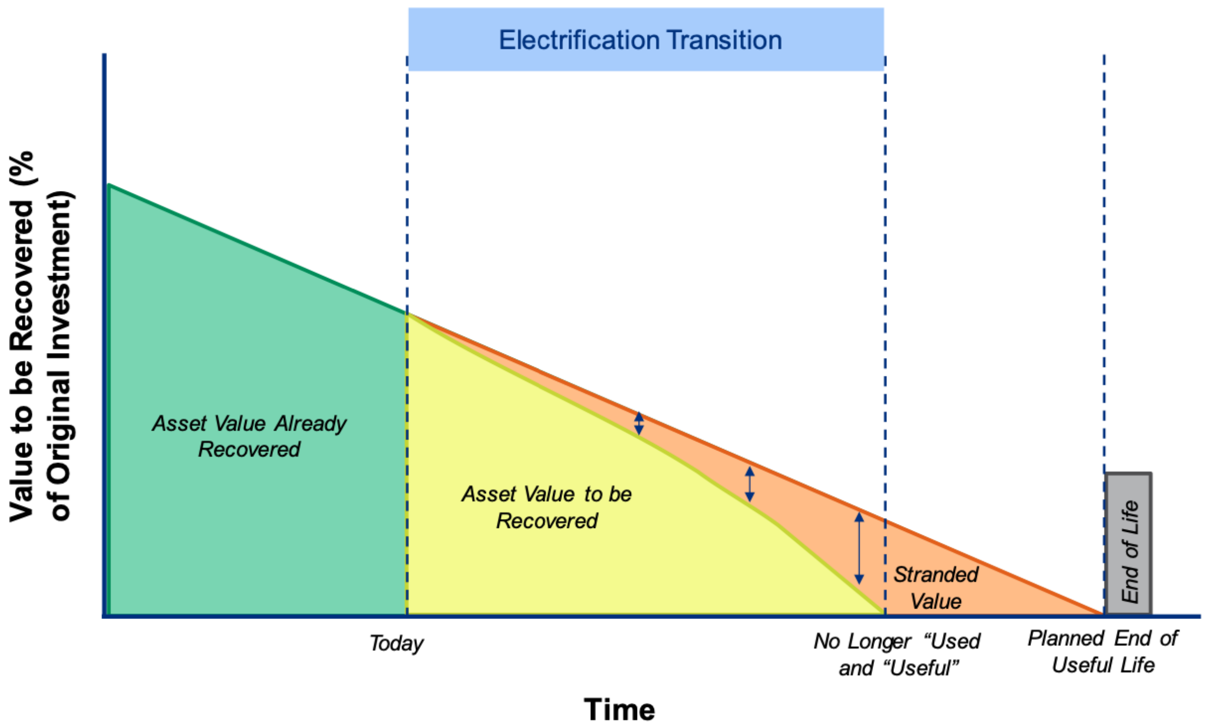

Figure 5.28. Illustration of the amount of stranded asset risk when an asset is no longer used and useful, before the end of its planned lifetime. Source: Bilich, Colvin, and O'Connor, 2019. "Managing the Transition: Proactive Solutions for Stranded Gas Asset Risk in California." Environmental Defense Fund. Reproduced with permission.

Accelerated depreciation

Gas utility assets are generally depreciated over their expected engineering lifetime—as many as 70 years for new plastic pipes, for example. However, for intergenerational fairness, this approach assumes that the pipes will carry roughly the same amount of gas each year throughout their lifetimes. As the gas sales trajectories shown in this chapter illustrate, this assumption no longer holds. Accelerating the recovery of the invested capital in the gas system (e.g., so that it would fully recover by 2045) would reduce stranded cost risk, at the cost of higher gas rates in the near term. Regardless of the treatment of depreciation, long-term gas rates would still rise with falling sales, as long as operations and maintenance (O&M) costs of the system remain roughly constant (in inflation-adjusted terms).

Figure 5.29 shows the approximate rate trajectory for SDG&E under an accelerated depreciation scenario, compared with the traditional depreciation approach. This scenario was developed by setting the minimum depreciation rate for any asset type to 4 percent (equivalent to a 25-year depreciation period if there were no removal cost). Revenue requirements, and therefore rates, are higher in the near term with accelerated depreciation, as expected.

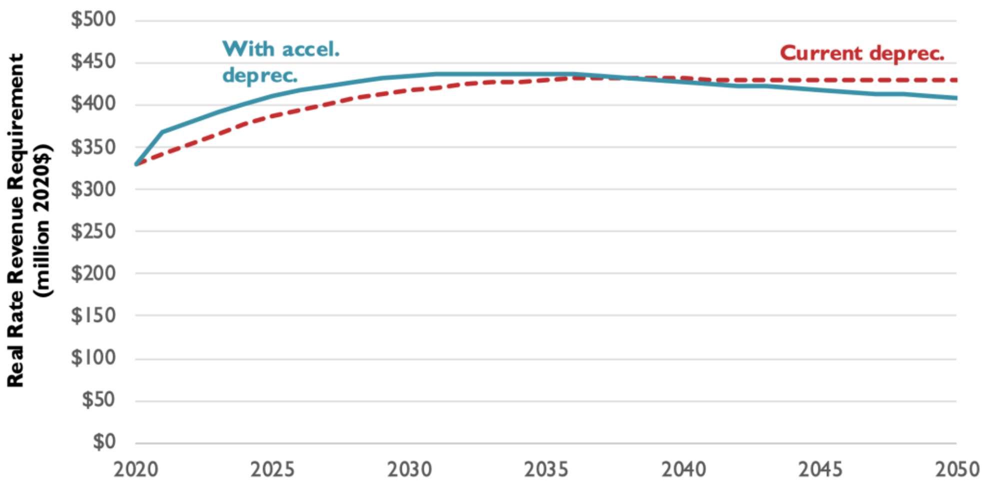

Figure 5.29. Gas utility revenue requirement with and without accelerated depreciation.

Figure 5.30 shows SDG&E's projected rate base in the Central case with and without accelerated depreciation. Rate base rises and then falls in the accelerated depreciation case, as the utility continues to make its historical pattern of capital investments. (Recall that this analysis changes only one aspect of utility behavior at a time.) However, the value of rate base at risk in the gas utility transition is reduced substantially—by more than $1.4 billion in 2050.

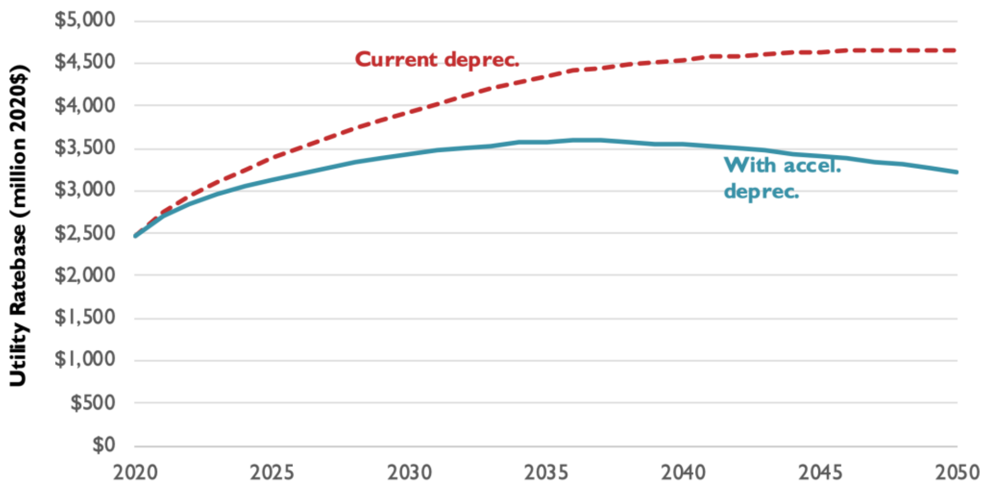

Figure 5.30. Gas utility rate base with and without accelerated depreciation

One minor, but impactful, change to depreciation practice could be the elimination of recovery of funds to remove gas assets upon their retirement. Standard depreciation practice recovers not just the amount invested in the pipe, but also the net cost of removal of the pipe at end of life. Because this action is expected to occur far in the future (when inflation will have raised the cost of removal), the removal cost can approach, or even exceed, the value of the asset itself. As a result, depreciation costs can be almost twice as large as they would otherwise be. If policymakers were to decide that gas pipes could be retired and abandoned in place, without removal, regulatory financial calculations could adjust, lowering gas rate pressures and creating room for accelerated depreciation or other approaches.

Limiting capital investment

Another approach to limiting stranded cost risk is to limit the amount of assets the utility has invested. Because past investments have already been made, the point of impact here has to do with the rate of new asset investment. SDG&E has been investing in assets for two primary purposes: (1) to extend pipes to serve new customers and (2) to replace old or damaged assets. Addressing these two drivers would require policy changes tailored to each.

Investment in pipes to reach new customers would be shaped by whether new customers demand gas service. If new construction is all electric, there would be no such investment. Other approaches, such as requiring customers that require a line extension to cover the full cost themselves, could also limit shareholder and other shared risk from these assets. Figure 5.31 shows the impact of eliminating gas line investments to reach new customers on the baseline trajectory of SDG&E's rate base. The utility's rate base is about $400 million smaller in 2050 without these additions.

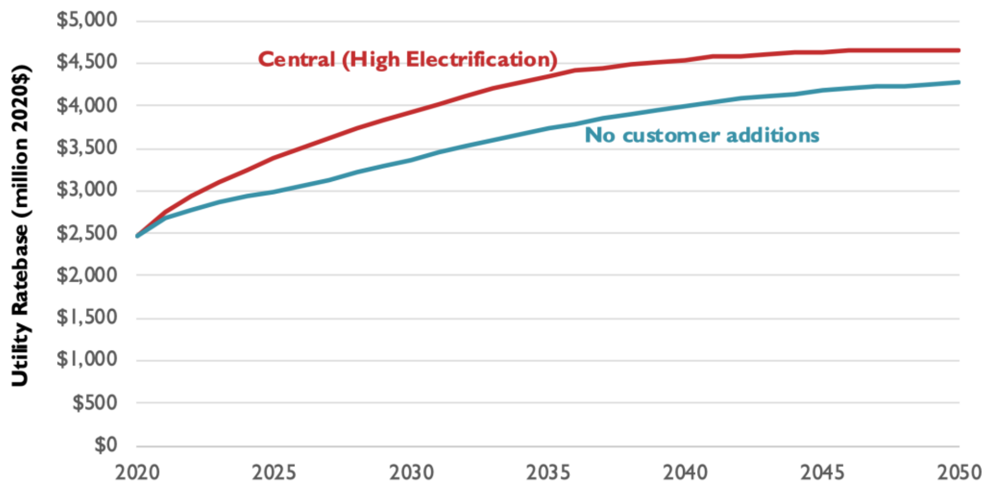

Figure 5.31. Gas utility rate base with and without new customer additions.

Most of SDG&E's capital investments relate to replacing old assets with equivalent new ones. These replacements occur because of actual leaks or damage to pipes, as well as on a proactive basis, and are justified on the basis of pipeline safety and leak reduction. We have not assessed the necessity of SDG&E's pipeline replacements. However, in order to indicate the potential ratepayer impact of slowing the pace of these replacements (which could correspond to targeting replacement only to the most urgent locations), we modeled a reduction in the pace of these replacements by a factor of three. The results are shown in Figure 5.32. This figure also shows the combined effect of eliminating new gas lines and reducing investment in existing asset replacement by a factor of three. Together, these changes would reduce the utility's rate base at risk in 2050 by $1.15 billion.

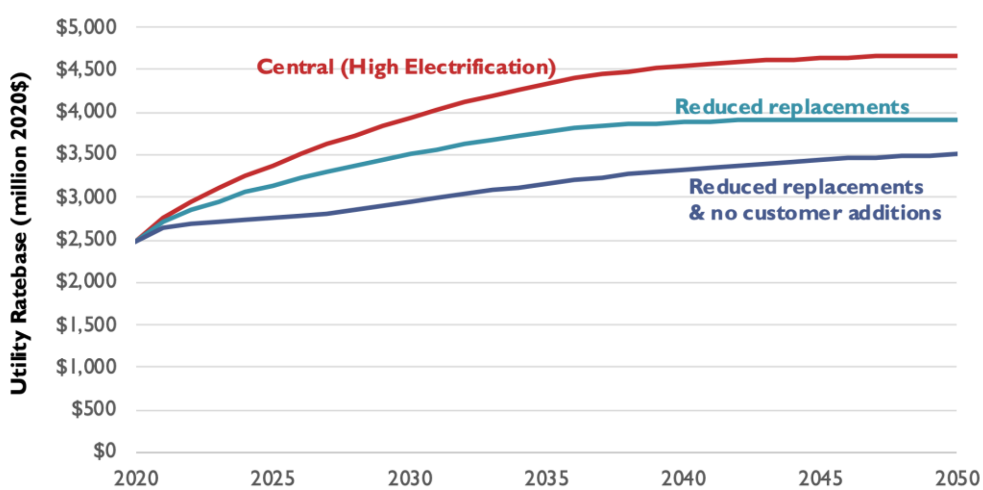

Figure 5.32. Gas utility rate base with reduced pipeline and service replacement rate, and combined with no new customer additions.

Targeted system retirements

One way to reduce the need for new capital investment, while also reducing O&M costs, would be to retire gas system assets instead of replacing them. Figure 5.33 shows an illustration of this. By targeting electrification to buildings served by a particular gas system asset, that asset can then be retired. Targeted retirement is likely to be a more cost-effective way to manage the gas transition than replacing assets, in the face of declining sales.

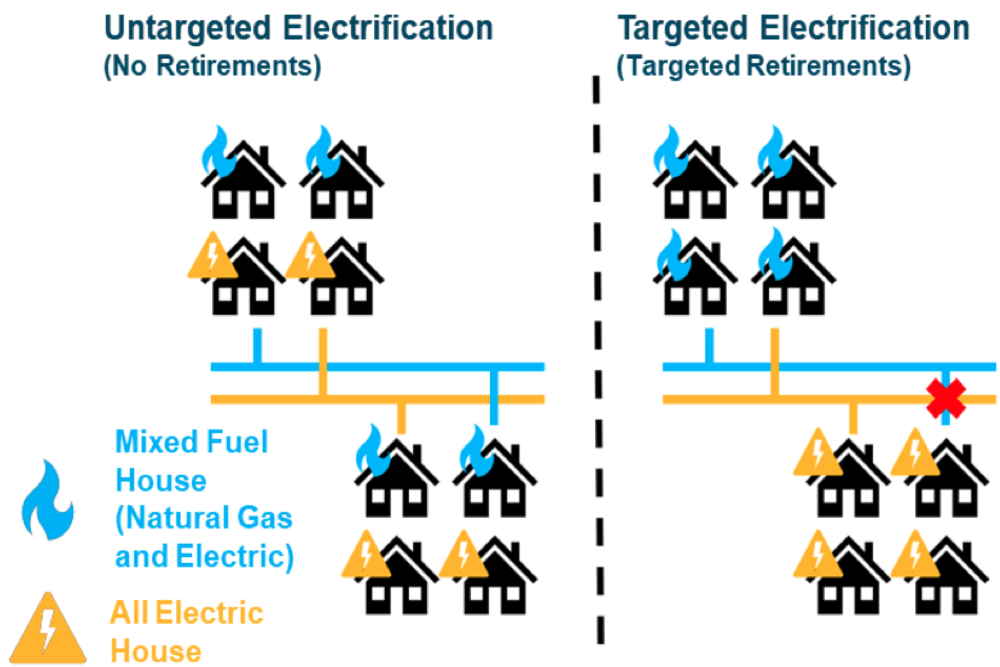

Figure 5.33. Illustration of the gas infrastructure implications of targeted vs. untargeted electrification. Source: Asa et al., 2020. "The Challenge of Retail Gas in California's Low-Carbon Future: Technology Options, Customer Costs, and Public Health Benefits of Reducing Natural Gas Use." E3 for the California Energy Commission.

One challenge with this approach is that the pace of natural system replacements in San Diego is much slower than the pace at which the system might be abandoned, particularly under a high electrification decarbonization pathway. SDG&E is currently replacing an average of about 33 miles of distribution main pipe per year. We estimate that SDG&E is also replacing about 1,400 service lines each year.[xxxv] If the customers served by these mains and services were electrified, rather than the pipes replaced, it would lower the utility's stranded cost risk by reducing its new investments.

While targeting electrification to the areas of pipe replacement would reduce stranded cost risk by limiting new capital investment, it does not eliminate the issue. Targeted electrification and

[xxxv] Services are the small pipes that connect customers to the mains.

pipeline retirement should also allow O&M costs to be reduced (since there are fewer miles of pipe to maintain), which could allow for either a stronger competitive position vs. electricity (thus allowing departures and sales reductions to be more measured and planned) or for more room in gas rates to recover asset value that would otherwise be stranded.

Figure 5.34 illustrates the impact on the utility's revenue requirements for gas distribution service (not fuel supply) in the Central case if mains replacement were replaced with targeted electrification, and customers due for new service lines were electrified instead. (As modeled, both transitions in utility practice would ramp in over the next decade.) In this example, we have also modeled no new customer additions. In this case the utility's rate base in 2050 would be about $1.4 billion less than in the unmitigated case. Further, targeting of electrification, which would involve retiring distribution mains not due for replacement, would create stranded costs that would need to be addressed in some fashion.

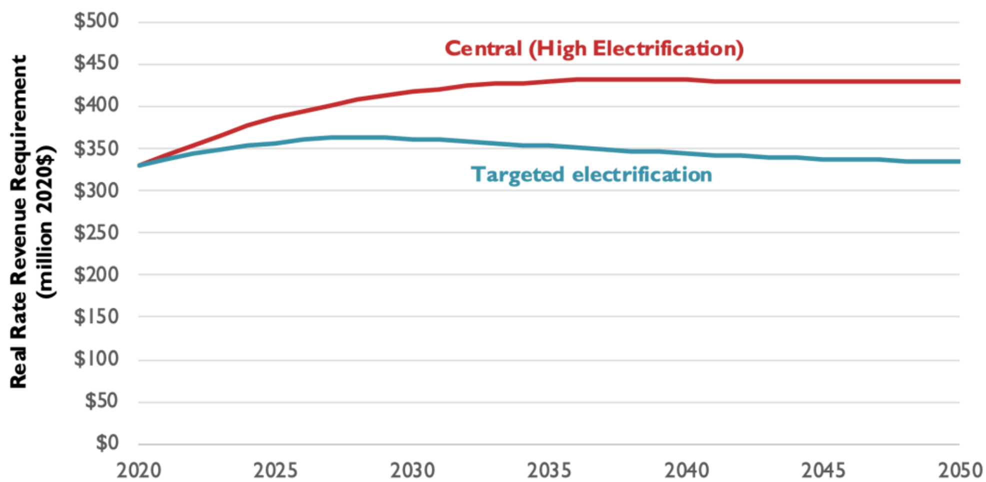

Figure 5.34. Gas utility delivery revenue requirement (without fuel costs) in the Central case, compared with a case where electrification is targeted to allow the utility to avoid rebuilding aging distribution mains.

Key Actions

- To put San Diego's buildings on a course for decarbonization by mid-century, it is important to take action beginning immediately. This timeframe is driven by the long lifetime of building components such as HVAC systems and water heaters, along with the relatively nascent state of the market for efficient low-carbon technologies that can reduce direct emissions from the region's buildings. While the end state for the region's buildings is not known, the initial steps are common across all pathways. These include:
- Increasing adoption of efficient heat pump-based space and water heating systems in both new and existing buildings, with particular focus on assistance for low-income residents and rental buildings;

- Researching and piloting production and use of low-carbon gaseous fuels that can be used for hard-to-electrify end uses; and
- Mitigating stranded cost risk by minimizing unnecessary extensions or replacements of the gas pipeline system and by accelerating depreciation of existing utility assets.

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