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Solar Water Heating Assessment Project: Understanding and Improving Effectiveness for California Households

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FINAL PROJECT REPORT

Solar Water Heating Assessment Project

Understanding and Improving Effectiveness for California Households

Gavin Newsom, Governor

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PREFACE

The California Energy Commission's Energy Research and Development Division manages the Natural Gas Research and Development program, which supports energy-related research, development, and demonstration not adequately provided by competitive and regulated markets. These natural gas research investments spur innovation in energy efficiency, renewable energy and advanced clean generation, energy-related environmental protection, energy transmission and distribution, and transportation.

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- Buildings End-Use Energy Efficiency
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- Renewable Energy and Advanced Generation
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For more information about the Energy Research and Development Division, please visit the Energy Commission's website (www.energy.ca.gov/research/) or contact the Energy Commission at 916-327-1551.

ABSTRACT

Solar thermal water heaters are an old technology used a century ago in California. They are now used extensively, in updated form, in many countries. According to government and industry estimates, well-functioning solar water heaters can theoretically displace 50 to 80 percent of the output of a natural gas-fueled household water heater, depending how hot water usage aligns with production and storage capacities. In so doing, they offer tremendous potential for reducing greenhouse gas emissions, fuel consumption, and energy bills. Such performance holds promise for California given its climate change and energy efficiency policy goals, since 40 percent of the natural gas used in California households is used to produce hot water. However, absent programs, only a specialty market for solar water heaters has developed. To encourage wider deployment, the California Solar Initiative—Thermal program offers financial incentives for systems qualifying under a carefully crafted set of specifications. The program has had some limited success since its inception in 2010.

Within that context, this research assessed the performance and potential future use of natural gas-displacing solar water heaters in single-family homes in California, attending to a wide range of sociotechnical considerations. This project documented high diversity in user satisfaction and perceived system performance, and a qualified decrease in project costs to below $5,000 per installation. Solar water heating is a technology in progress, not universally suitable but instead appealing to varied niches shaped by household sensibilities, abilities, and hot water use levels. Thus, recent evolution provides a counterpoint to the pessimism, even as serious difficulties remain. The suitability of solar water heating for California households is not purely a matter of cost-effectiveness within a typical energy efficiency framework, but also of evolving performance, perceptions, and values in light of ongoing and aspirational energy and social transitions ahead.

Keywords: Solar thermal water heating, renewable energy, domestic hot water, residential natural gas use, sociotechnical energy analysis, energy futures

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Introduction

California seeks ways to reduce greenhouse gas emissions (GHG), achieve carbon neutrality (having net zero carbon dioxide emissions by either balancing carbon emissions with carbon removal or by eliminating carbon emissions altogether), and decarbonize (reduce carbon dioxide emissions from) buildings in the state through several policy measures.

A key way to decarbonize buildings is to curb natural gas use. Forty percent of the natural gas purchased by California households is used for water heating, making solar thermal water heating a potentially important alternative to traditional natural gas water heaters. In theory, a solar thermal water heater could reduce natural gas use by as much as 50 to 80 percent relative to standard storage tank natural gas water heating, depending on how hot water usage aligns with production and storage capacity. This theoretical potential for savings is far greater than that of standard natural gas water heating efficiency measures. Furthermore, solar water heating uses a renewable energy source, has been tested and widely used in many countries, and is well-suited to many of California's climate regions. But even with generous incentives through the California Solar Initiative—Thermal (CSI-T) Program uptake of solar water heating systems has been slow. Some argue that the time of the program has passed, with alternatives available that are better and cheaper and do not require fossil fuel backups for solar production shortfalls.

The research team—composed of UC Davis, Ghoulem Research (now QQ Forward), and several small subcontractors—set out to understand the reasons behind this slow uptake, examine how residential solar water heating systems are working in terms of technical performance and user experience, assess what changes might increase solar water heater uptake, and provide guidance on how appropriate and feasible such changes would be relative to other options. In short, this project provided a sociotechnical assessment of solar thermal water heating in California. The project focuses on single-family homes with natural gas water heating in investor-owned utility territories.

Solar water heating is different than most technologies that have been promoted under the banner of energy efficiency. First, it is neither purely efficient nor purely a renewable energy technology in the California context. Solar water heating is nearly always used as a complement to electric or natural gas water heating rather than a substitute since fossil fuel backup systems are typically used to cover any shortfall in solar hot water production (which is common in winter and at night). Second, it is an old technology; solar thermal water heaters were popular in some areas in California more than a century ago. The aggressive promotion of natural gas water heating in the 1920s and 1930s helped end the popularity of these solar water heaters, and a second wave of popularity in the 1970s and 1980s in response to the energy crisis ended when incentives were removed. But by 2009, solar water heating was again more prominently on the table as attention turned to large-scale reduction of greenhouse gas emissions and hedging against natural gas price increases.

The basic challenge for solar water heating is clear: natural gas tank water heating dominates the water heating landscape in California. Functionally, natural gas tank water heating is reliable. It forms the basic social and cultural expectations for how water heating should work. The output—hot water when you call for it—is conceptually simple. In general, manufacturers have focused on the basics of water heaters (size, efficiency rating, expected longevity, cost, and safety) and have shown little inclination to add innovative features to water heating systems. However, a recent move toward on-demand natural gas water heating suggests traction for the idea of more abundant or "unlimited" hot water, which is one of the features that solar water heater users said they most appreciated. Solar water heating also offers environmental benefits that could be appreciated by users and communities, along with very low-cost water heating, at least at certain times of the year. However, the technology has a considerably higher installation price than standard natural gas-fired storage tank water heating alone and requires more space, and there are fewer skilled installers and repair people when problems arise.

Given the technical potential, solar water heating technologies warrant close examination to determine how they might contribute to large-scale efforts to decarbonize California's buildings. To do this, it is important first to understand adoption and performance issues and determine the potential real-world benefits of solar water heating based on recent experience through the state. There are many perspectives about the prospects for solar water heating, but few take account of the full picture. For example, there has been little examination of household attitudes and experience, assessment of the supply chain, or careful consideration of how things might change. This research is a contribution to addressing the existing knowledge gap.

Project Purpose

The project team designed this research to provide a coherent and integrated picture of the current performance of domestic solar water heating in California using the best data possible, together with an actionable assessment of the future prospects for adoption, diffusion, and contributions toward California's climate policy goals. The primary intention is to inform policy makers and program managers; the audience also includes industry, researchers, and marketers.

The major innovation in the formulation of this research is the effort to provide an integrated picture of solar water heating technology in a real-world context. It ties together how households use, purchase, and think about solar water heaters with those who sell and install them, as well as how the technology performs in the field, and how these factors relate to each other. This perspective intentionally distances itself from relying on any conceptual model—such as expected cost-effectiveness, average modeled or normative performance, greenhouse gas emissions savings, technical potential, or market assessment. Instead, it focuses on the broadest characterization of solar water heating—including the use of this technology in households, the performance with respect to providing hot water and contributing to climate policy goals, and the associated market prospects for the future—reasonably possible, and with these models and related questions located in context.

Project Approach

An interdisciplinary team of collaborators from the University of California, Davis (CEC award recipient/prime contractor) and Ghoulem Research (now QQ Forward) and several small subcontractors conducted the research. Staff included sociologists, an anthropologist, a policy analyst, a systems scientist, engineers, a water heating expert, an anthropological folklorist, and an ecological behaviorist. To provide industry insights, technical and market expertise, and contacts with other solar water heating stakeholders, two industry groups were contracted to the team: the California Solar + Storage Association (formerly the California Solar Energy Industries Association) and the International Association of Plumbing and Mechanical Officials. In addition, a technical advisory committee created for the project included representatives from the solar water heating industry, research institutions, and a natural gas utility.

The project took a layered approach, beginning with an in-depth depiction of the solar water heating market in California compiled from existing data sets; a wide range of academic, grey (unpublished or published in non-commercial form), and popular literature; and early interviews with a range of industry experts. Findings from the landscape analysis in turn informed data collection from households and industry. Household-centered data collection started with interviewing households that use solar water heating, followed by surveys of households that had installed solar water heating using a CSI-T program incentive. These social data were paired with technical data streams, including CSI-T program data collected for each installation with incentives, a small set of household natural gas use data, and metered data collected through a CSI-T evaluation. To understand the supply chain and industry arrangements, researchers interviewed industry specialists supplemented by available quantified supply chain and product data.

There were two major integrated analyses. One modeled the impacts, benefits, and possible evolution of solar water heating based on existing household-level data under a range of scenarios and assumptions constructed from the patterns identified earlier in the project. The other pulled together multiple types of evidence on patterns, niches, trends, and processes to characterize solar water heating in California in light of state policy, household experience, and industry and supply chain dynamics and potentials.

The research team achieved the primary goals set out for the project. The biggest practical difficulty faced was getting enough detailed energy use data from households using solar water heaters to provide solid results on actual performance and performance variation. The research team obtained and successfully analyzed some household energy use data. It also identified, scoped, and negotiated to use data in an hourly gas consumption dataset, gaining permissions from the relevant utility, the California Public Utilities Commission, and the University of California, Davis. Because of a legal impasse on the details of the nondisclosure agreement, however, the dataset could not be obtained. This data blockage reduced the certainty of the natural gas savings analysis and reduced the ability to map variation in performance to technical, environmental, and social details.

The current landscape of solar water heating in California is highly dominated by the CSI-T program. The program's 10-year tenure means that most of the data collected on solar water heating, the installers, and users are strongly influenced by the program. For example, many of the recent adopters of solar water heating actually had their solar water heater installed at virtually no cost to the household. Also, in all installations with incentives, systems were required to conform to CSI-T rules restricting certain configurations and other specifications. Without the program, the situation would be much different. Throughout, project results have been interpreted with this condition in mind when making projections about the future.

Project Results

From a research angle, the basic story of solar water heaters in California is not complicated. But for planning purposes, thinking about how solar water heating could or should change requires recognizing aspects and dynamics usually considered separately or not at all—for example, evaluating household experience in using solar water heaters, and distinguishing different pathways or kinds of adopting households versus some average or ideal adopter. Thus, the project analysis and results are structured by starting with some basic and common arguments about solar water heating and then adding nuances uncovered throughout the research. Rather than being extraneous details, these nuances are crucial to understand why things are the way they are and to evaluate possible changes.

The traditional explanation for limited interest in solar water heating in California households starts with pointing out that natural gas prices are modest and solar water heating system costs are high relative to conventional water heaters. For example, the 2009 California Residential Appliance Saturation Study estimates residential natural gas water heating unit energy consumption at 188 therms per year for the PG&E utility service area. This amounts to about $244 using the June 2019 California price of $13 per thousand cubic feet of natural gas. Viewed as an energy efficiency technology, solar water heating has limited appeal because the cost-effectiveness is low. There are some people who are skeptical of solar water heating because of the poor performance of systems from several decades ago. On the other hand, some households are very happy with their solar water heaters. As project results discussed below illustrate, the answers to "How well does solar water heating work?" and "What are its prospects?" are complex and nuanced.

Market Basics

- Solar water heating is competing against an established incumbent technology. Natural gas water heating, especially using a storage tank, is a long-established and highly dominant technology in California. It seems to satisfy most households' needs for hot water, given current usage patterns.
- Solar water heating struggles to show a clear competitive advantage against this incumbent. For households, the clearest advantages of solar water heating are reducing monthly bills; increasing availability of hot water; and reducing natural gas use for environmental, climate change, resource, or personal reasons. But these advantages do not seem to have widespread recognition, and the energy and financial benefits are relatively modest for most households.
- Solar water heating has other competitors. Rooftop photovoltaic (PV) systems may compete with solar water heating. Many households consulted in this project had rooftop PV in addition to solar water heating. The two solar technologies often attract each other, though PV has far higher penetration. It seems the more generic, transferable, and obviously "modern" solar provided by PV seems to trump the "quieter" solar provided through solar water heating.
- Solar water heating has a reputation for uneven performance, which seems to be deserved. Historically, the system failures in California have garnered public attention. While it is true there are inherent technical susceptibilities with solar water heating (for example, water and metal exposed to the elements, often paired with relatively complicated plumbing and component configurations), other factors play a role, too. Problems are also undoubtedly due in part to the wide and changing range of system configurations, general need for customization, and relatively small portion of installers that appear to have achieved sufficient experience and scale to work out the kinks and progress up learning curves. While technical innovations offer the potential for better performance, cheaper systems, or other advantages, they may require field-testing and experience to attain smooth performance.
- Pathways to adoption are elective and ad hoc. As an add-on to conventional water heaters, solar water heating does not naturally fit into existing water heater replacement or new installation pathways through which the great majority of water heaters are sold and installed. In contrast to conventional gas and electric water heaters, which are typically installed by plumbers, solar water heaters are installed by a range of firms and public entities. California households seem to have little awareness of solar water heating as a current viable technology, so "not adopting" is not necessarily a matter of rejecting solar water heating.

Economics

- From a traditional household cost-effectiveness standpoints, one of the biggest challenges in more widespread deployment of solar water heaters in California has been the cost, which 10 years ago ran about $9,000-$10,000 (sometimes much more) without incentives. This cost made them an expensive upgrade and difficult to justify on the basis of cost-effectiveness at prevailing natural gas prices. Since 2010, most California households that bought a solar water heater through the CSI-T program actually paid much less given the financial incentive, sometimes equal to the total cost of the system.
- Lowering the cost of installations is possible. According to CSI-T project database, one installer in Southern California was able to install hundreds of solar water heating systems for as little as the CSI-T incentive available to those households (about $4,800) reportedly by leveraging scale economics and an existing customer base. These were primarily systems with on-demand backup.
- Cost-effectiveness may not be the most relevant financial metric to the current set of solar water heater adopters. The high cost of systems combined with the low cost of natural gas in the state means that the advantages phrased as cost-effective investments pencil out only for households that use large amounts of hot water or have very low system out-of-pocket installation costs. Based on the households contacted in this research, households that paid something for their solar water heater typically care if they save money on monthly bills and that the system was a reasonable (in their estimation) investment in the long run given the various benefits and costs they perceive, even if they do not care about cost-effectiveness, per se.
- Households with low electricity bills may find solar water heating one of the most economically favorable ways to save energy costs. Households in mild climates such as coastal areas can have electricity bills that are too low for PV to be appealing in terms of the investment or other costs of installing PV; for example, they may not use air conditioning and have no large electric uses such as a swimming pool pump. Solar water heating can be one of the simplest ways for these households to use renewable energy and save on energy bills, especially when space heating energy use is low.
- Some households that installed solar water heating are willing to accept a long payback period and place more value on the ability to avoid natural gas and related costs, having more plentiful hot water, or other more intangible benefits such as using renewable energy, having a feeling of independence from the gas utility, technology leadership, or reducing the household's environmental footprint.
- Some households seemed relatively indifferent to costs as long as they felt their solar water heating system was legitimately generating benefits. These respondents were often wealthy.

User Experience

- Most households who installed a solar water heater were satisfied with various aspects of their systems. They cited monthly natural gas bill savings, having plentiful hot water, using solar energy, and the low cost of the systems they received as subsidized under CSI-T. Some noted that using solar water heating was pleasurable. However, with incentives, many of these systems were installed at below-market costs and often at no cost to the household at all.
- One-sixth of household survey respondents (17 percent) were mildly or highly dissatisfied with their systems. About 17 percent of survey respondents were dissatisfied with their solar water heating system. For some, the system took quite a while to install and commission properly, which involved multiple callbacks with the installer.
- Most households with solar water heaters did not think that it changed how or how much they used hot water relative to their previous (conventional) water heater; they did not consciously manage their hot water use to take advantage of the solar portion nor monitor savings or system performance closely. Some households, however, did say that they changed the timing of their hot water use, and 10 percent said they probably used more hot water, while 4 percent said they probably used less.

Technical Performance

- Most systems save energy and emissions relative to natural gas tank water heating. The data available to evaluate field performance were limited, but results of analysis are consistent with what has frequently been seen in field studies: solar water heating systems do save energy (especially in households using large volumes of high hot water), thereby also reducing greenhouse gas and oxides of nitrogen (NO_x) emissions. Most systems, however, save less than modeled, and performance is uneven.
- More detailed field data are necessary to fully characterize solar water heating system performance. One route would be to require or nudge households who receive CSI-T incentives for their solar water heater to share billing or interval natural gas data through a centralized mechanism, enabling ongoing review of benefits at an installer or program level.

Industry

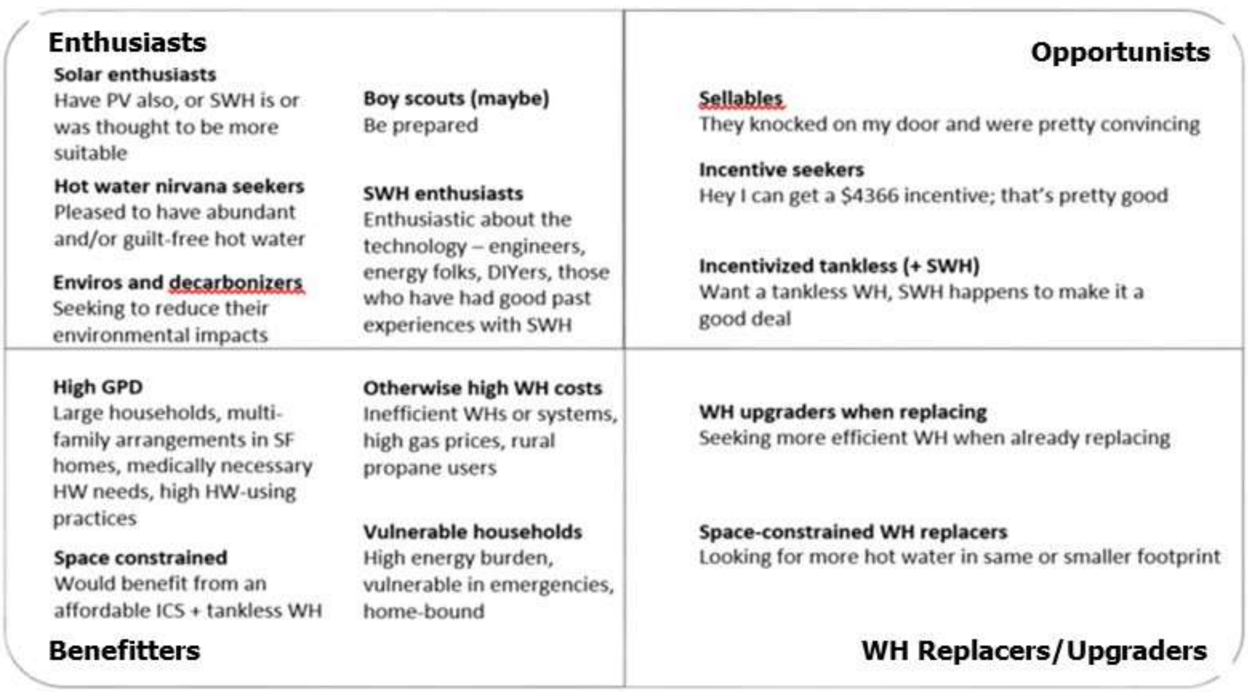
- The solar water heating market is concentrated. Of the 526 qualified installers listed in CSI-T, only eight have installed more than 100 residential systems through the program. Many installers have come and gone. This does not mean that the smaller installers are not important, but the handful of larger installers have driven the type of systems installed, the quality of the installation, the cost, and much of the innovation that has occurred.

- One relatively recent entrant, Titanium Power, has accounted for most of CSI-T incented solar water heater installations since 2016. Its scale-up appears to have succeeded through installing standardized systems and innovative customer acquisition methods, exploiting the opportunity created by the bumped-up incentives (particularly for low-income households and neighborhoods) offered by Southern California Gas Company in the wake of the Aliso Canyon natural gas well failure in 2015.

Niches for Benefits or Adoption

Several key subgroups were identified amongst current solar water heater owners, as depicted in Figure ES-1.

Figure ES-1: Potential Adopter Niches Among Single-Family California Households



Source: University of California, Davis

Key niches include:

- Solar enthusiasts: Around 40 percent of the CSI-T recipient survey respondents said they had PV along with solar water heating. Emphasizing the solar nature of solar water heating may be helpful in increasing the appeal of the technology.
- Low-income: Energy burdens tend to be higher for lower-income households, and the savings from solar water heating can be more consequential for these households. Some community action agencies in disadvantaged communities have very experienced and knowledgeable weatherization teams. These agencies maintain rosters of income-qualified clients and have earned the trust of the

community, both of which lower the costs associated with selling solar water heaters.
- High users: Hot water use varies dramatically from household to household. The higher hot-water-use households tend to see the greatest energy savings.

Policy

It is unlikely solar water heating installations will continue at the recent (2017-2018) pace if the CSI-T incentives are eliminated or greatly reduced. This research points to strategies that could increase the chances of solar water heating reducing GHG emissions in the state:

- Promote adoption at the household level, including raising awareness about solar water heating, exploring what people appreciate about solar water heaters, targeting high-potential niche markets, and finding ways to integrate solar water heating into normal water heater acquisition pathways.
- Improve performance, including reducing the rather high apparent prevalence of underperforming installations.
- Promote robust supply-side conditions, including ensuring the market is open to innovation, including low-tech options and customer acquisition pathways, while striking a balance between standardization and innovation; and establishing conditions that support increasing installer scale and help installers progress up learning curves.
- Promote efforts that inform policy decisions, including accelerating the ongoing assessment of the energy impacts resulting from future solar water heating installations and leveraging this to accelerate program, technology, and installer improvements; and revisiting model-based savings estimates and underlying assumptions to ensure these promote realistic expectations for programmatic and individual benefits.

Knowledge Transfer

The potential market for solar water heating in California is tremendous, since water heating is a substantial energy use in nearly every home. The current appeal of solar water heating is limited. The changes noted in the policy section above could help position solar water heating to contribute substantially to energy and greenhouse gas emissions reductions. Throughout this project, the researchers engaged with a wide variety of stakeholders (such as members of industry, policy makers, customers). Information about technical performance, market adoption, and the future potential for solar water heating in California was gathered and exchanged through interviews and a group discussion (that is, a technical advisory committee meeting). The researchers facilitated dialogues across diverse stakeholder groups that do not typically overlap. Niche markets were identified and explored, as were future market opportunities.

Benefits to California

Residential water heating is one of the highest natural gas uses in California. Given that, this project (and solar water heating itself) offers notable benefits to the state. In the current technical and institutional incarnation, single-family residential solar water heating is not positioned to play a large role in California's emission reduction policies for a variety of reasons. There is some evidence, however, that solar water heating could still contribute to decarbonization efforts and benefit some households in its current form. Technical and process improvements are possible toward improving performance reliability, lowering installed cost (for example, through simpler systems, workforce learning, and so forth), pinpointing good candidates for solar water heating, and increasing awareness of solar water heating amongst potential users. It has remained difficult to arrive at a solid picture of solar water heating performance, and, thus, how to improve this performance or estimate the real-world emissions reductions and household cost savings compared to theoretical models.

Slow levels of solar water heating adoption are a consequence of a combination of factors across the whole landscape, rather than a specific deficiency with either the technology, industry, suppliers, or customers. This research provides some foundation for making informed decisions regarding the possible futures for solar water heating in California.

Finally, this study demonstrates how a holistic technology assessment provides valuable insights into evaluating technologies and informing plans for energy transitions. Similar landscape assessments will be worthwhile for other technologies whose role in California's energy future needs to be thoughtfully considered.

CHAPTER 1:
A Holistic View of Solar Water Heating for California Single-Family Homes

Solar thermal water heating, like almost any household energy technology, has a long history. However, solar water heating is particularly interesting because it largely predates fossil fuel-based water heating in California. Policy efforts over the past decade have been aimed at helping this "old" technology make something of a comeback in an improved form. Solar water heating is also distinct from normal energy technologies in that it occupies an ambiguous position between an efficiency measure and an energy supply source; in California, it is rarely used without a non-solar backup system, and it produces hot water rather than electricity.

The history of solar thermal water heating is important for understanding the technology. It illustrates that use of the technology is neither just an individual choice or an industry one, but rather a combination that is also influenced by changing social circumstances, intricate actual and perceived technology characteristics, regulations, competition, and happenstance. In addition, real-world operating conditions can be very different from those in the laboratory under which these technologies are evaluated. Also, the current focus on evaluating and comparing energy technologies based on consumer financial costs and benefits does not take into account the complexities that affect technology diffusion and performance.

This project set out to develop a broader and well-grounded view of solar thermal water heating technologies. The research team's holistic approach used evidence and arguments based on technology, industry, household, environmental, and policy perspectives to understand the status and prospects for solar water heating with respect to California's single-family homes. The report is organized into two parts. Chapters 1-10 present overall findings in a narrative form and emphasize interpretation. The style is inspired by history and social studies of technology narratives blended with practical analysis of energy technology and policy. Several chapters include important side-stories and perspectives, and provide quantitative details where they seem most helpful. Appendices provide details on the research approach and data utilized.

Short History of Water Heating in California

Solar thermal water heating has never been widely used in the state. In the 19th century, water heating was done mostly via coal or wood-fired stove; or, for some households in cities toward the turn of the 20th century, using storage tanks fired by manufactured gas. Though the history of using the sun to heat water stretches for back thousands of years, the first commercial solar thermal water heater for homes, a model called Climax, was not patented until 1891. It was marketed as the "acme of simplicity" for providing hot water (Butti & Perlin 1980) and indeed would have seemed so compared to the labor and grit of manual coal- or wood-fire water heating. The patented solar water heating system was especially appropriate for Southern California, given the sunny weather and high fuel costs. There were reportedly 1,600 homes with solar water heaters in Southern California in 1900. The next twelve years brought many patents improving the design of Climax as well as competing designs; most notably, in 1909, the Day-and-Night helped keep water hot for longer, well after the sun went down. A hard freeze in Pasadena and the surrounding areas destroyed many of the solar water heaters in existence at the time.

In the meantime, the development of household gas water heating was underway. The (manufactured) gas-fired Ewart Geyser was patented in 1895, followed by various improvements. The transformative event, though, was the discovery and recovery of cheap natural gas in Southern California. By the 1930s, household water heating in California had shifted to natural gas, helped in part by natural gas utility efforts to make water heaters affordable thereby ensuring customers, and California became a state dominated by natural gas water heating.

In the 1970s and 1980s, there was a revival of interest in solar water heating due to energy crises and ecological interest in alternatives to fossil fuels and nuclear power (Scavo 2015). Research budgets for solar greatly increased (Scavo 2015). Purchase incentives were offered for solar water heaters, while installers increased prices in response to increased demand. When financial incentives were removed in 1986, the pace of installation slowed, companies dissolved, and the market largely fell apart. Although some customer experiences were good, the overall impression of solar water heating at that time, based on industry experts who lived through it, was negative. Industry experts speak of fly-by-night and inexperienced companies who made sales but were unable to deliver on quality and longevity. This led to widespread abandonment of systems that never worked well or those that worked for a short period but did not survive due to design vulnerabilities, lack of thorough testing, inconvenience, cost, or other concerns regarding maintenance, repair, and risks.

There was a resurgence of interest in solar thermal water heating during the first decade of the 21st century as an energy efficiency measure[1] and a way to reduce natural gas use and air pollution, including greenhouse gas emissions. The California Solar Initiative (CSI), launched in in 2006 to promote solar photovoltaic (PV) development, was expanded the following year to include solar thermal water heating systems through the Solar Water Heating and Efficiency Act of 2007 (Assembly Bill 1470, Huffman, Chapter 536, Statutes of 2007). Thus, the California Solar Initiative-Thermal program (CSI-T) was born. This program was piloted in 2009 and formally

1 Solar water heating was included as an energy efficiency measure in the 2006-2008 California investor-owned utility energy efficiency portfolios, for example.

launched in 2010. The vision and program details have evolved over the years, but the program has remained the dominant policy instrument for encouraging solar water heating in California.[2] CSI-T offers incentives for the installation of solar water heaters for investor-owned utility (IOU) customers and provides system and installation specifications and recommendations, training, and public data. While this report focuses only on domestic water heating systems installed for single-family homes using natural gas for water heating, the program also includes electric backup residential water heating, the commercial sector, and other solar thermal technologies such as pool heating.

The CSI-T program was designed specifically to address problems seen during the 1980s with solar water heating. For example, it requires that all solar water heating technologies eligible for an incentive be accompanied by a 10-year warranty. This helps to insure against performance issues experienced with earlier generations of the technology (and still experienced in other parts of the world) and instills confidence in a relatively unfamiliar technology among prospective customers. One manufacturer interviewed by the researchers observed that the long warranty is an unusual practice, but all manufacturers agreed that their systems should have a useful life of 20-30 years, well beyond the warranty period.

The CSI-T program has been the main impetus behind solar water heating installation over the past decade. The original funding allocation was $155 million to incent natural gas-displacing systems, along with an extra $50 million for low-income households. In December 2017, Assembly Bill 797 (Irwin, Chapter 473, Statutes of 2007 was modified to increase the proportion of remaining program budget allocated for low-income households, and set earmark over $80 million for projects in disadvantaged communities (CSI-T 2017).

Uptake of the incentives has been low relative to the goal of 200,000 solar water heating systems by 2017. As of June 2019, the program had 9,392 applications, 6,237 of which were for incentives paid for single-family domestic water heating displacing natural gas.[3] This total reflects a dramatic increase in the rate of installation activity starting in 2017, after incentives in Southern California Gas Company (SoCal Gas) territory were increased in response to the Aliso Canyon Gas Storage Facility well failure (CPUC 2018a). The increased incentives spurred a flurry of activity in Southern

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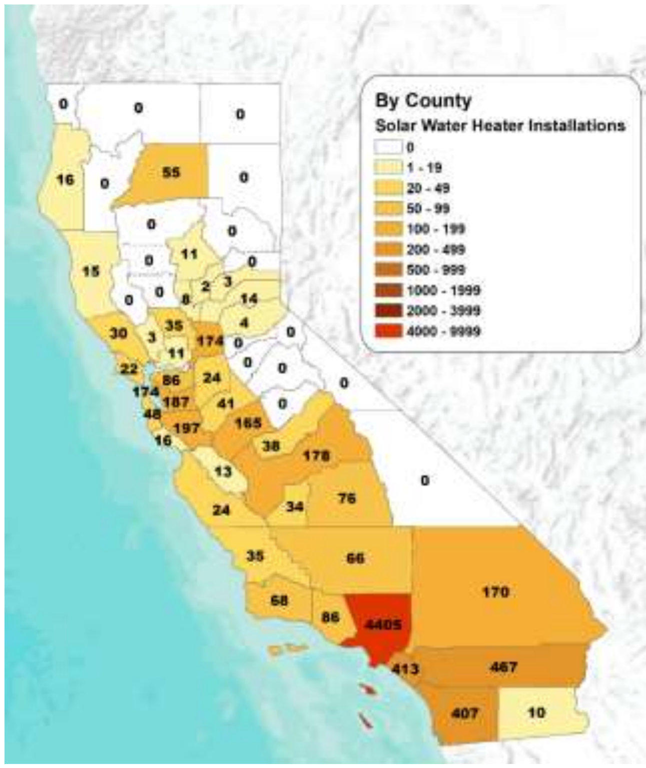
2 See History of Solar Energy in California for a useful background on solar in the state: (https://www.gosolarcalifornia.ca.gov/about/gosolar/california.php).

3 Program applications and the corresponding estimated annual natural gas savings and CO_2 offset values are provided at CSI Thermal Statistics (http://www.csithermalstats.org/) (as of December 3, 2018). The estimates for single-family domestic water heating installations are derived from the CSI-T "Current Public Export" file accessed 5 December 2018 (http://www.csithermalstats.org/download.html). The latter total excludes the 5 percent of applications for which incentive applications were filed but cancelled.

California. Figure 1 shows the geographic concentration of solar water heater installations in California. More than half are in Los Angeles County, with a few other notable pockets of activity in Southern California, the Bay Area and the Central Valley (notably Merced and Fresno counties where Community Action Agencies have been active in solar water heating installation).

Figure 1: Solar Water Heater Installations in California by County



Source: Non-public version of CSI-T-incentivized solar water heating systems for single-family households with natural gas backup systems, as of March 6, 2018.

Still, there is a 20-fold shortfall between the number of solar thermal systems of all types incented by the program relative to the goal. The solar thermal water heating market overall cannot be described as robust despite pockets of adoption highly concentrated among a few active installers. Most installations depend heavily on the existence of program incentives.

Clearly neither the 1980s nor the current CSI-T-led revivals have led to widespread installations of solar thermal water heating in California despite a largely favorable climate. Nor is there consensus around how much solar water heating might contribute to meeting the state’s goals for reduced greenhouse gas emissions and decarbonization of the energy system. At the same time, solar water heating for single-family homes is common in many other countries, as discussed in the next section. The fact that solar water heating is appealing in some countries but not in others is not surprising because countries have very different energy resources, circumstances, and technology histories. For example, in 1959 only 12 percent of households in the United Kingdom had electric refrigerators, while 96 percent of households in the United States did (Rees 2013); even today, households in the United States have considerably higher presence of clothes dryers than does the United Kingdom or France.

Solar Thermal Domestic Water Heating Internationally

The International Energy Agency (IEA) tracks the development of solar thermal energy systems through its Solar Heating & Cooling Programme (SHC) established in 1977.[4] SHC's Solar Heat Worldwide report includes statistics on solar thermal water heating. Table 1 gives IEA's estimates of the total number of solar water heating systems for single-family homes, by country, for countries with 250,000 or more systems.

Table 1: Solar Water Heating Internationally - Single-Family Systems by Country

Country	Number of Systems	Dominant Type of System
China	75.33 million	Thermosyphon
Turkey	4.91 million	Thermosyphon
India	4.17 million	Thermosyphon
Brazil	3.93 million	Thermosyphon
Germany	1.51 million	Pumped
Australia	0.97 million	Pumped
Japan	0.84 million	Thermosyphon
Italy	0.68 million	Pumped
Palestine	0.61 million	Thermosyphon
France	0.45 million	Pumped
South Korea	0.42 million	Pumped
South Africa	0.41 million	Thermosyphon
Spain	0.39 million	Pumped
Mexico	0.38 million	Pumped
Austria	0.36 million	Pumped
Taiwan	0.33 million	Pumped
Cyprus	0.30 million	Thermosyphon
Israel	0.29 million	Thermosyphon
United States	0.25 million	Pumped
All Others	10.01 million	

Source: IEA 2018, SHC Programme.

4 Further information is available at International Energy Agency (https://www.iea-shc.org/).

China has by far the greatest number of systems. The United States ranks nineteenth and has much fewer systems per capita than many developed countries. For more information on the international market, see Chapter 4.

IEA estimates that only a quarter-million single-family homes in the United States have solar thermal water heating (IEA 2016).[5] Many of these are in Florida or Hawaii (where solar water heating has been mandated for new construction since 2010) and supplement electric rather than natural gas water heating. Only about 28,000 households in California had solar water heating in 2009, the last year for which data is available (RECS 2009). By contrast, more than 600,000 households in California IOU territories had PV solar systems as of 2017.[6]

The common explanation for the low penetration of solar water heating in California is the availability of inexpensive natural gas in the state. This is definitely an important part of the picture, especially since solar water heating is, at least potentially, a mostly affordable and environmentally innocuous method of heating water. But the "cheap gas" explanation is not the whole story, especially when thinking about future possibilities, including changes in energy supply and political, social, and practical priorities.

There are many prior opinions about solar water heating and its prospects for California. Rather than contradicting these opinions, the research findings in this project put them into a different, less-constrained context with solar water heating as part of a larger system. Figure 2 provides a conceptual representation of the landscape of residential solar water heating in California showing the layers, components, and processes involved in designing, making, selling, regulating, and using these systems. Each box references a diverse set of features and factors potentially relevant to solar water heating. The purpose is to emphasize the mutual shaping of the various landscape components, rather than the evolution along single pathways. It also reflects the approach taken in this study, wherein detailed investigations are situated within the broader context.

Table 2 summarizes some of the key areas of debate and research findings presented in this report, along with a guide to where they are addressed. Rather than overturning current general explanations of why "solar water heating doesn't work (well enough)," the research found a number of corrections to these common opinions, as well as

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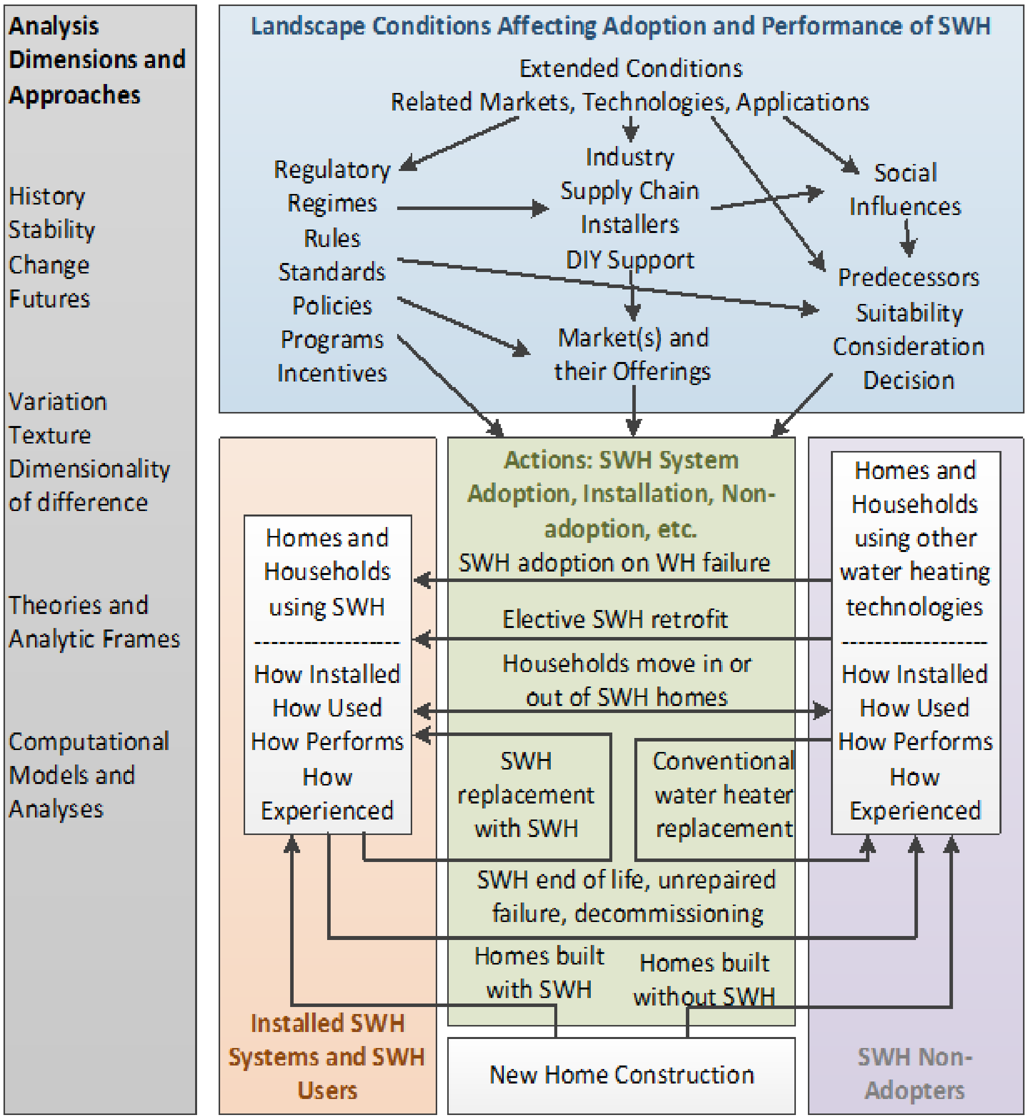
5 SEIA estimate 35,464 domestic solar water heating systems were installed in the United States in 2010, along with 29,540 pool heating systems. (Solar Energy Industry Association, https://www.seia.org/initiatives/solar-heating-cooling).

6 Photovoltaic project data are from California Distributed Generation Statistics (http://www.californiadgstats.ca.gov/charts/) (All IOUs, Projects, Residential, All Years) are reported 6 July 2017. Data on the number of customers in IOU territories are from the CPUC (Rockzsfforde & Zafar 2016) for 2015.

subtleties affecting their interpretation. This also moves from a more generic and average sense of what solar water heating is and should be to a more local and dynamic view. These counterpoints to the more commonly held opinions are not intended as a purely optimistic view of solar water heating but rather an opening to the possibilities that could reasonably arise in the long term as environmental, technical, social, and political conditions change.

Figure 2: General Sociotechnical Landscape of Solar Water Heating in California



Source: University of California, Davis

Table 2: Summary of Debates about Viability of Single-Family Solar Water Heating in California

Argument	Details	Research Findings and Counterarguments	Where Discussed in Report
Not cost-effective except for very high users	The high cost of systems combined with the low cost of natural gas in the state mean that the financial advantages only pencil out for households that use lots of hot water.	Cost-effectiveness is not necessarily perfectly applicable or the sole criteria. Some care more that the system eventually pays off or that they save fuel (and its costs). High users have high savings potential for a fairly small investment.	Chapters 6 & 7
Natural gas prices are low	California's residential natural gas prices are generally regarded as low, though they are actually higher than the national average (12.26USD/1000 ft^3 October 2018 nationally vs. 12.16USD/1000 ft^3 in California).* California ranks 24th across all states in terms of average monthly natural gas bill.	Natural gas prices are also volatile and subject to price spikes or long-term shifts especially over the long lifespan of a solar water heater. Natural gas prices have been increasing.	Chapter 9
System costs are high	Average reported total cost was $7,400	One company installed nearly 1,000 systems with a total project cost of $4,800 or less (before rebate). Simple (and DIY) systems can cost much less than average.	Chapter 4

Argument	Details	Research Findings and Counterarguments	Where Discussed in Report
Tend to deliver less savings than expected		Shortfalls can sometimes be interpreted as the result of overly optimistic expectations. Consider the distribution of effectiveness—minor deviations may be "okay" but poor performers may really hurt.	Chapter 6
Unreliability, high risk of failure, including roof and house damage	Reputation of being finicky to install may be fading. Notably uneven performance across households. Households may not know that they are working.	Improved systems and experience presumably minimize the risk of failure—but inexperience and incompletely tested innovations work against this improvement.	Chapter 4
PV is a better alternative for savings and for "going solar"	PV applies to more end uses. Electricity that the household does not use can be sold. Fits well with electrification. PV energy production is directly measurable, facilitating third-party ownership. While PV systems tend to be more expensive, the savings potential also tends to be much higher, while "soft costs" are probably similar.	PV is also subsidized. Depending on usage patterns natural gas savings through solar thermal may make more sense. PV can be expensive while solar water heating is a modest expense with respect to other home improvements. PV is not possible for all households.	Chapter 5
Bad reputation from the 1980s			Chapter 1

Argument	Details	Research Findings and Counterarguments	Where Discussed in Report
Negative aesthetics	Some consider solar water heating systems ugly on the roof.	Systems are often not visible from the street. Some installers offer less obtrusive options.	Chapter 6
Insufficient value	All things considered, it does not pencil out; it is "dead"	Total potential is high, but value is distributed and difficult to access at scale due to high soft/transaction costs relative to the savings/profits achieved in any particular home, savings potential in any particular installation is uncertain, problems happen and installation is not trivial, and systems do not always perform to expectations.	Chapter 2
Poor performance in the field, uncertain performance		Complexity combined with inexperienced installers can lead to problems; field experience is needed. Packages can help reduce problems.	Chapter 7
Maintenance		Maintenance required may not be too much but is necessary.	Chapter 6

*** https://www.eia.gov/dnav/ng/ng_pri_sum_dcu_nus_a.htm**

Source: University of California, Davis

Basic Data Collection Activities and Research Structure

In addition to consulting the academic and gray literature, the following main sources were compiled and analyzed as part of this research.

- Market characterization: To characterize the market (e.g., supply chain actors, customers, economics), the researchers used data from the following sources.
    - CSI-T database, for number of installations, rebate values, project costs, characteristics of installers, range of technologies installed. This data was provided by the California Public Utilities Commission (CPUC) under a non-

disclosure agreement (NDA). This data set also provided the sampling list for household surveys.

  - Interviews with industry stakeholders to seek explanations of findings observed in the data, and a richer explanation of various aspects of the market.
  - Analysis of the various policies that influence solar water heater adoption directly and indirectly to elucidate the policy context.

- Technical performance: To assess the technical performance of installed systems, data from the following sources was analyzed.
  - Data from the CPUC-sponsored measurement and evaluation (M&E) effort for the CSI-T domestic solar water heating program was obtained from Itron. The data included detailed technical monitoring of solar water heating systems at 19 sites for approximately one year: 4 incented under the Low-Income Single Family Residential program and 15 incented under the Single Family program.
  - Gas billing information for the prior two years, was provided by survey respondents who granted access to their records via a UtilityAPI app Despite extensive efforts, the research team was unable to obtain detailed billing data for a large sample of households with solar water heaters.
- User experience: When conducting household-level research involving solar water heater owners, the basic challenge is identifying and contacting households that use solar water heating. There is no single sampling list of users, so the research team identified a variety of sample lists, including building permit databases, friend-of-friend referrals, the customer list of a solar water heater installer, Google Earth rooftop inspections, addresses in known solar villages, local programs, and the CSI-T client list obtained under an NDA with the CPUC. The CSI-T database provided the sampling list for the surveys, with households from the other sources targeted for in-depth household interviews. To understand user experiences with buying and using solar water heating systems the following data sources were developed and analyzed:
  - In-depth interviews were conducted with a variety of California households that have solar water heating (see Appendix A).
  - An online survey was conducted of individuals whose households received a rebate from the CSI-T program (see Appendix B).
- Environmental impact: To estimate the potential environmental impact of installation of solar water heating systems throughout California, the technical performance data was analyzed using published emissions factors.

Report Structure

This report examines the sociotechnical aspects of solar water heating in California to provide a basis for assessing the achievable economic and environmental benefits. Chapter 2 focuses on how solar water heating fits into California's water heating landscape. Chapter 3 briefly covers the role and goals of technology dissemination policy for context. Chapter 4 reports on the state of the solar water heating industry explored in this research, including how industry practices shape households' interest in solar water heating. Chapter 5 reports on households' views, including which households install solar water heating and why. Chapter 6 covers household experiences with, concerns about, and assessment of solar water heaters in use. One of the fundamental questions this research sought to answer concerned actual greenhouse gas emissions reductions, taking into account which households have solar water heaters and how these solar water heaters are working. Because of the variability of hot water use across households, differences between laboratory or simulated conditions and actual ones, and differences in installed efficiency of solar water heaters, model-estimated savings are not enough. This is a difficult question given the measurement, sampling, and data acquisition issues, but the results made headway both in estimation and in framing the question, as reported in Chapter 7.

Chapter 8 summarizes the researchers' assessment of current technology and how various elements fit together. Here the emphasis is on solar water heating "niches" such as the single-family household types that have so far shown an affinity for, or otherwise seem most favorably positioned for, solar water heaters. Chapter 9 examines the mid- and long-term future in light of expected lifetimes of solar water heaters, the need to consider technology transitions, and climate change-related changes in environment and energy supply. The last chapter, Chapter 10, presents implications of research results for policy makers, researchers, and technology developers.

CHAPTER 2: Solar Water Heating in California's Residential Water Heating Landscape

This chapter gives an overview of water heating in California's single-family homes. Most California households (e.g., 95 percent of single-family homes in 2009) heat water using a natural gas-fired storage tank system. Only 0.4 percent-1.4 percent of California single-family homes have solar water heating (Moezzi et al. forthcoming),[7] though this is still a much higher presence than the 0.09 percent penetration of solar water heaters nationwide as per 2015 data.[8]

The basic challenge for solar water heating is clear: natural gas tank water heating dominates the landscape in California. Functionally, this technology is reliable and forms the basic expectations for domestic water heating. The output, hot water on demand, is conceptually simple. In general manufacturers have focused on the basics—size, efficiency rating, expected longevity, cost, and perhaps safety—and have shown little inclination to "feature-up" hot water. However, a recent move towards on-demand natural gas water heating suggests traction for the idea of more abundant or "unlimited" hot water which is one of the features that solar water heater users said they most appreciated (see Chapter 6). Solar water heating also offers environmental benefits that could be appreciated by users and communities, and very low-cost water heating at certain times of the year. However, solar water heating comes with a considerably higher installation price than standard natural-gas fired storage tank water heating alone, requires more space, and increases the risk of things going wrong.

Natural gas use in California households is mainly for water and space heating. Water heating, primarily from bathing and tap use but also including hot water for dishwashers and clothes washers, accounts for 39.7 percent of residential natural gas demand, approximately 2 billion therms per year.[9] This is nearly as much as for space heating (41.7 percent). Natural gas-fired water heating is therefore one of the most important residential end uses from an emissions and energy consumption standpoint.

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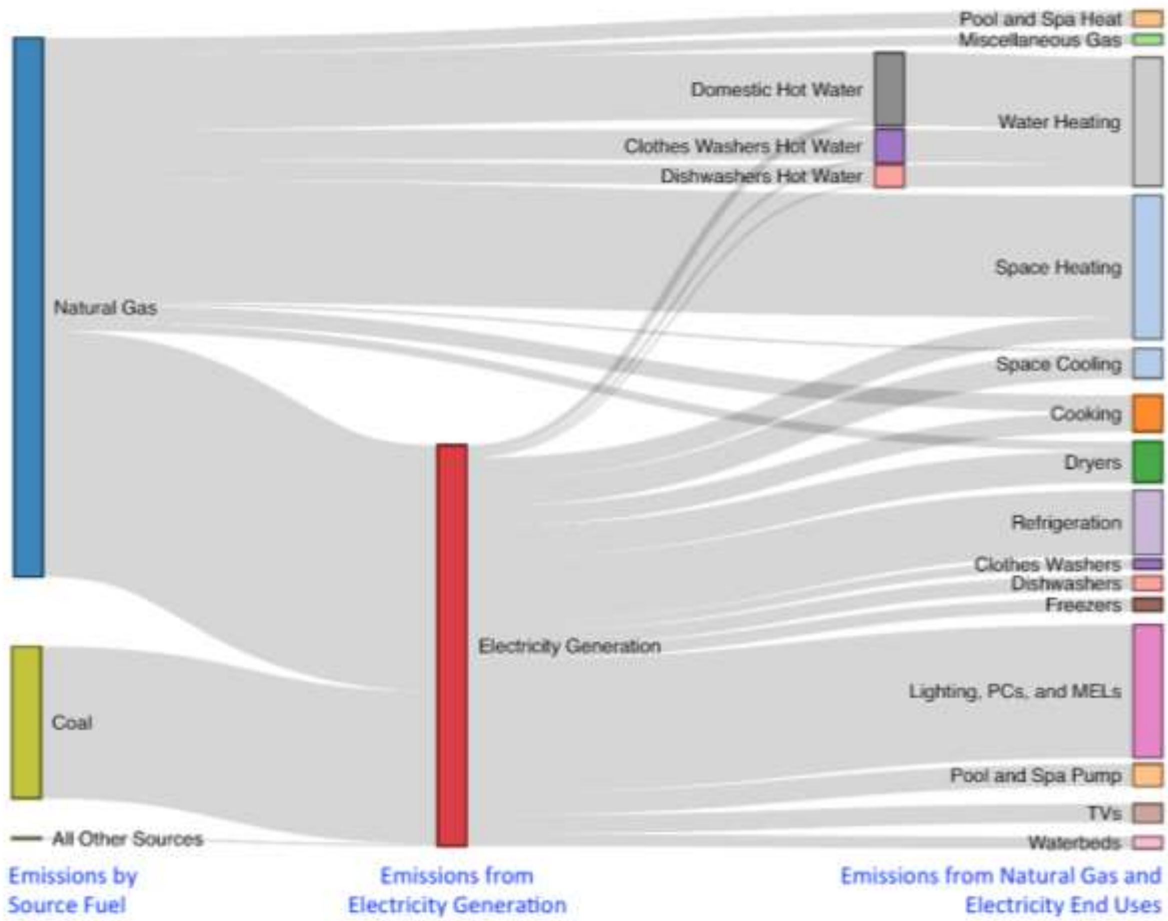
7 These data are based on RECS 2009, KEMA RASS Data Explorer, and the 2009 RASS data set, which is the latest California-specific data on appliance saturation available at the time of this report. The 2009 RASS distinguishes solar water heating as "backup" water heating and primary water heating, with most being reported as "backup" heaters. In this report, the backup and primary totals were summed to estimate total solar water heaters.

8 This figure is based on the United States Energy Information Administration's (USEIA) Residential Energy Consumption Survey 2015.

9 The Attachment 13 value of 2111 Mth (CEC 2014) was rounded due to likelihood of change since 2006.

Even small inroads in reducing single-family home water heating energy use can add up. Figure 3 summarizes estimated 2006 greenhouse gas emissions by end use for California residences.

Figure 3: Sankey Diagram of Carbon Dioxide Greenhouse Gas Emissions Associated with California Residential Natural Gas and Electricity End Uses, 2006 (CEC Forecast)



Update 2/29/16

Notes: Emissions calculated based on end-use share of total annual electricity and natural gas use. To estimate emission reduction potentials, marginal estimates would be more appropriate. For electricity end uses with quite variable loading (e.g., air conditioning), marginal time-of-use emissions reduction potentials, for example as developed by Energy+Environmental Economics (https://ethree.com/public_projects/ghg.php) may be more appropriate.

Sources: (1) Attachment 13: References for Energy End-Use, Electricity Demand, and GHG Emissions References and Calculations (May 2014; California Energy Commission); (2) Detailed California-Modified GREET Pathway for California Average and Marginal Electricity, February 27 2009 Version 2.1 Draft.(http://www.arb.ca.gov/fuels/lcfs/022709lcfs_elec.pdf)

Water heating's contribution, over 10 million metric tons of CO_2 equivalent emitted per year,[10] is close to that of space heating and of the diverse and diffuse electric "lighting+miscellaneous" category. Nitrogen oxides (NO_x) (an important contributor to smog) and nitrous oxide (N_2O), a greenhouse gas, are emitted in California homes by natural gas combustion for water heating at an estimated 11.87 tons/day (ARB 2016).

Past, Present, and Future Hot Water Use in California

Near-automatic delivery of domestic hot water is barely 100 years old for many regions in North America (Butti & Perlin 1980), and it is still possible to find immigrants to California who grew up without it. The current norms of hot water use and delivery are not fixed and will continue to change. The modern trajectory for basic energy services over time is toward increased demand (Shove 2003; Wilhite 2016). Solar water heating could accommodate this increase, at least technically. But with increasing resource and environmental pressures, maturation and scaling back of hot water use is also possible.

Solid data on hot water use levels in California are surprisingly scarce. Plausible estimates of household average daily hot water use range from about 45 to 64 gallons per day (DeOreo et al. 2016; Parker, Fairey, and Lutz 2015; Burch and Thornton 2012; Moezzi et al. forthcoming 2019). Actual water use in individual households can vary greatly, hence there is a wide range of water heating energy loads, energy use, emissions, and savings potential across individual households. Hot water use levels drive water heating energy use, though a significant proportion of California's water heating energy goes to standby, distribution, and firing losses.

In addition to this variability, water use levels are also dynamic over time. For example, the drought in California in recent years has led to substantial reductions in total household water use (see Figure 15 in Chapter 9) and presumably in hot water use as well.[11] Water prices in some cases have also increased. The CSI-T participants surveyed in this project often said that higher water prices or the drought had led them to reduce their water use. Hot water consumption of specific appliances has fallen as a result of improved technical efficiency, with particularly steep declines in water use in clothes washers (DeOreo et al. 2016) and water fixture flow rates. Nationwide, appliance efficiencies have helped push per-household water use down (Rockaway et al. 2011). Changes in household practices such as use of cold water clothes wash cycles and improved detergents have also reduced hot water demand. Declining household size may have played a role, but population growth continues even as household sizes

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10 This represents the author's calculation using 0.0053 mtCO2eq/Therm, from Attachment 13 (CEC 2014, CEC 2016).

11 Hot water use makes up one-quarter to one-third of total household water use (indoor and outdoor) on average (authors' estimates based on DeOreo et al. 2011).

decline and luxury-type fixtures (e.g., "rain" showerheads or large-volume and jetted tubs) are gaining popularity, factors which push total water consumption upwards. The uncertainties about future hot water use, and thus uncertainties in the contributions of solar water heating, are high.

Tank and Alternative Water Heating Technologies

Solar hot water is an old technology that is also new through a series of technical innovations. It may yet undergo a shift in its competitiveness thanks to changes in technological configuration or economic conditions (e.g., the viability of competing fuels). The different positioning of solar water heating across countries today illustrates the sensitivity to context. Solar water heating systems have several "natural" vulnerabilities, such as lack of replacement parts, weather-related failures, component interactions, high materials prices, and competition from natural gas. To date, the installation of solar systems has not scaled well. These vulnerabilities can often be managed, but may add effort and cost or reduce performance.

Understanding the relative merits of solar water heating requires a good understanding of its competitors. Solar water heating is situated in a market dominated by conventional gas-fueled tank water heaters that provide large volumes of stored hot water, and tankless or "on-demand" water heaters that burn gas at high rates for short periods of time to produce hot water only when needed. Electric and propane water heaters are much less common, typically used when natural gas is not a viable option.[12] Tankless water heaters are technically more efficient than storage water heaters because they eliminate most standby losses. They can be a cost-effective alternative in new construction, but are not usually cost-effective as a replacement (Bohac et al. 2010, Schoenbauer et al. 2012, Maguire et al. 2013). Higher-efficiency gas water heating options exist, but are more expensive and also not usually cost-effective as a replacement of an existing gas water heater (Maguire et al. 2013). The efficiency gains and greenhouse gas (GHG) emission reductions possible from available gas water heating technologies, though sizeable, are incremental—even at full adoption they will not bring GHG emissions dramatically closer to zero.

Heat pump water heaters use electricity to move heat from the surrounding air to heat water. The efficiencies of heat pump water heaters can be much higher than those relying on natural gas and electric resistance heat. The technology is relatively straightforward, using well-understood principles and the same readily mass-produced components used in air conditioners and heat pump heating systems. The technology is gaining strong support in the hot water heating policy and research communities as part of a pathway to decarbonization when adopted in concert with grid decarbonization

12 There is also some conversion to electricity for households that want to be all electric, in particular, to take advantage of solar PV or to avoid direct use of fossil fuels. This trend could continue with the current arguments for widespread electrification in California.

(e.g., Raghavan 2017; Colon and Parker 2018). Despite their apparent advantages, heat pump water heaters have yet to be fully embraced by the residential water heating industry but still could be an important alternative to solar water heating.

Other novel options that promise low-carbon water heating include PV-to-hydronic water heating or using PV to directly power a heat pump water heater. These options are rare or not yet commercialized and not well known even in water heating circles. These systems also face practical and grid integration problems (e.g., why run a local PV to a heat pump that works when the sun shines rather than simply feed PV-produced energy into the larger grid and draw power back from the grid when needed). However, given the popularity and decreased costs of PV panels, there is substantial optimism about this technology. A laboratory study (Parker et al. 2018) based on a single prototype solar PV-assisted heat pump water heater found that the technology could potentially save delivered electricity compared to solar thermal water heating combined with a heat pump water heater. The study did not directly compare PV-assisted heat pumps to solar thermal water heating with gas backup, but based on the data that were provided, rough calculations suggest that GHG emissions could be similar under certain conditions. However, the authors speculate that PV-based systems have the potential to be cheaper, have simpler installation and greater reliability, while avoiding susceptibility to problems from low temperatures. The extent to which solar PV-assisted heat pump water heaters can live up to these expectations, attract buyers, and avoid unforeseen problems remains an open question.

As discussed later in this report, technical efficiency is clearly important, but it is only one element of the field performance of water heating systems with respect to environmental and energy efficiency. It is entirely possible to have systems defined as more technically efficient component-by-component or even overall that still use more energy or are responsible for more GHG emissions than less-efficient alternatives.

Solar Water Heating Technologies

After years of technological development, there is quite a lot of variation among solar water heating systems. Many of these variations are absent or rare in California given the climate (e.g., a general risk of freezing) and policy conditions (CSI-T criteria). The vast majority of systems incentivized by CSI-T fall into one of several categories. Installers have chosen to offer certain systems for various reasons. Along with more mundane reasons (e.g., maximizing profitability, making happy customers, minimizing callbacks, ease of installation), their choices are shaped by CSI-T policies together with what is available and the installer’s particular competencies and proclivities. Table 4 presents popular solar water heating configurations within the CSI-T program and the attributes that might influence their popularity with installers.

Table 3: Popular Solar Water Heating System Configurations in CSI-T and Possible Explanations

Configuration	% of CSI-T	Possible Explanations for Popularity
Indirect forced circulation, glazed collectors	37%	Highest rated efficiency and savings, though typically involves adding a second tank in home/garage. More complicated and potentially more expensive system.
Integrated collector storage with tankless backup water heater	35%	Lower cost, simpler system, though also lower-performing and sensitive to hot water use patterns. Tankless efficiency increase taken into account in incentive calculation. Can free up space in home/garage, but can be visually obtrusive. Only partially freeze-resistant and not suitable for all locations in California. Weight on roof may require extra support. Installations almost exclusively conducted by Titanium, Inc.
Integrated collector storage with tank water heater	6-10%	Lower cost, simpler system, though also lower-performing and sensitive to hot water use patterns. Can be installed without taking much additional space in home/garage, but can be visually obtrusive. Only partially freeze-resistant and not suitable for all locations in California. Weight on roof may require extra support.
Indirect forced circulation, unglazed collectors	9%	Low cost. Popular for low-income program until removed from incentive program due to failures. Many have now been replaced.
Indirect Thermosyphon	4%	Tank is located on roof or in attic, so systems typically don't require much extra space in home/garage, but can be visually obtrusive. Allowed in all California climate zones. Weight on roof may require extra support.
Collectors directly heat water in backup tank water heater	2-4%	Simple system can be added to existing gas water heaters without taking much additional space in home. Installations almost exclusively conducted by Titanium, Inc. Likely lower rated savings.

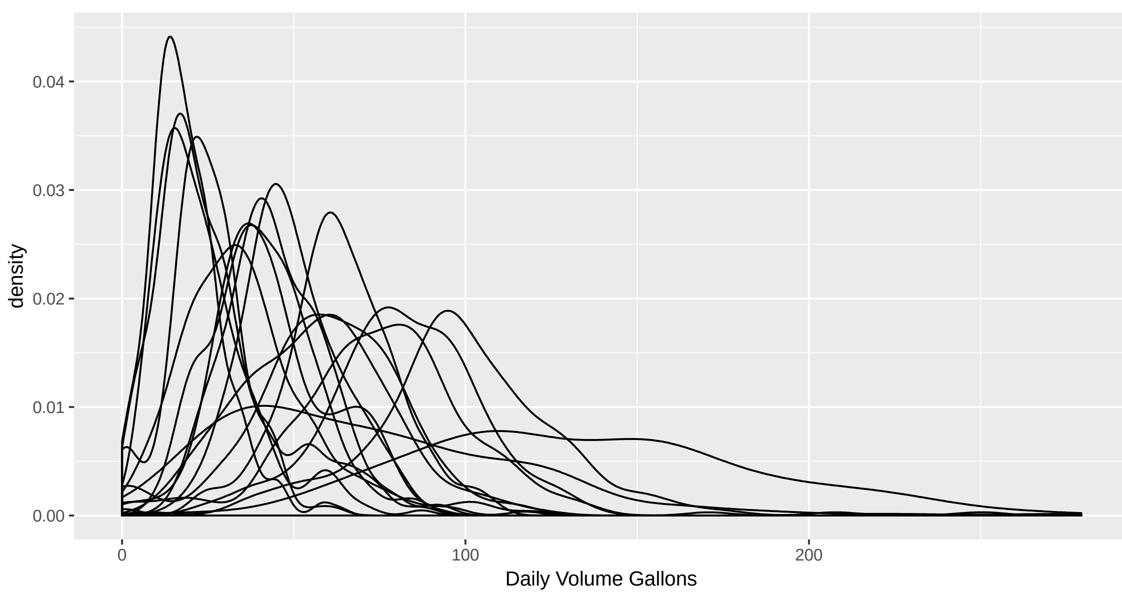
Source: University of California, Davis; analysis of CSI-T public database as of 9/18/2018.

Comparing Solar Water Heating to Gas and Electric Water Heating

Like most renewables, solar water heating has an intermittent nature while gas and (current) grid-connected electric systems do not. When there is sufficient solar energy, conversion of sunlight to hot water can be technically quite efficient. Thermal losses from storage can be large (especially for the integrated collector storage [ICS] systems relatively common in parts of California), the sun does not always shine, and solar irradiation drops in the winter even while inlet water temperatures are colder and heating energy loads higher. Large tanks help store the intermittently produced hot water so it can be used at other times of the day, which takes space, sometimes on the roof but for indirect forced circulation systems usually in the garage.

Compounding this supply intermittency problem is the variability of hot water demand. Levels of hot water use and the energy used to heat that water vary greatly between households and over time (Lutzenhiser et al. 2017). This heterogeneity stems from the many possible combinations of technical characteristics, environmental characteristics, occupants, and occupant behaviors in any one household. Figure 4 illustrates the variability within and between the daily hot water draw volumes of 18 California households from approximately June 2010 to June 2011.

Figure 4: Probability Density of Daily Hot Water Draw Volumes for 18 California Homes



Source: Reproduced from Moezzi et al. 2019 forthcoming; data collected as part of study detailed in Kosar et al. (2012). Gaussian smoothing kernel used.

To facilitate analysis, this diversity is often reduced to averages, or "typicals," for large groups of people. This makes analysis more tractable, but loses precision in trying to match "solutions" to circumstances, and can possibly even create norms that shift toward these typicals. The efficiency of electric resistance and conventional gas tank water heaters is not particularly sensitive to the specifics of hot water draw patterns, so typicals were adequate for determining efficiency standards and energy code implementation. However, electric heat pump water heaters, and to a lesser extent natural gas tankless water heaters, are sensitive to draw patterns. Energy modeling has accordingly moved towards more sophisticated representations of hot water use patterns that capture more of the variability of hot water draws (Kruis et al. 2017). Both data collection and problems have evolved in a way that allows us to better see variety, in the process opening up opportunities to better target technologies. But customization is also challenged by the fact that water heating draw patterns are not easy to predict and may not be very stable in a particular household over the long-term, and even less so if occupants move to another home.

Seeing and accommodating this diversity is also crucial in assessing the benefits of solar water heating. Variable hot water demands will sometimes exceed the available solar water heating production and storage capacities, while at other times the heated water will sit unused because the production of solar water heating systems is limited by the collectors and system configuration and by season, weather, and daily-varying solar irradiation. Solar-heated water will almost never be sufficient on its own, so the systems must be integrated with more conventional water heating fuels and technologies. The system is most often configured to preheat inlet water before it reaches the conventional water heater, now deemed "auxiliary" or "backup."

This is another version of the intermittency challenge often cited in renewable electricity planning. The more variable and out-of-sync hot water demands are with solar cycles, the more often the reservoir of solar heated water is depleted and backup water heating is needed, which in turn lowers the performance of the solar water heating system. Larger solar storage tanks can help increase system performance under variable loads to a point, but incur greater thermal losses. In addition, larger storage tanks take up valuable space. As with the electricity grid, aggregating loads from multiple households can smooth out the variability in water heating demand, as in some multi-family dwellings drawing from a centralized solar thermal water heating source (outside of the scope of this report), where low use by one household tends to be balanced by high use from another, resulting in the possibility of higher overall performance.

At the most basic level, in single-family homes solar water heating systems can only save energy that would otherwise have been used.[13] Savings potential varies across households, with frugal users having less to save. This cap on savings contrasts with the situation of rooftop PV, where excess production can be sold to replace higher-

13 This is actually a key factor in deciding how to count benefits from solar water heating, for example, if benefits are derived from increases in hot water use after adding solar water heating, energy savings from that increased use should be counted as "savings" or as "rebound."

carbon electricity and even generate negative utility bills for the household. For single-family solar thermal water heaters, there is no opportunity to export this excess production, and in fact under-use can contribute to the risk of overheating or stagnation of the solar water heating fluid, and is a key design constraint for sizing and configuring most systems.[14]

On the other hand, solar water heating does not need to be fueled in the way that the other water heating technologies do. Solar water heater industry actors frequently point out that fossil fuel demands and GHG emissions for solar water heaters are not simply lower (as is the case for heat pump water heaters absent a carbon-free electricity supply), but are essentially zero for the portion of water heated by solar. Taken as a complete system, however, the backup water heater fuel use must be considered, as must any grid electricity used for solar water heating fluid circulation. A key question for solar water heating in California is how well installations can and do perform under actual hot water use patterns, environmental conditions, and technical configurations. Also important is the degree to which solar water heating systems (combined with existing or replaced natural gas backup water heaters) can meet highly varied and variable hot water demands while also serving household environmental and economic objectives.

While solar water heating is clearly a very minor player in a scene dominated by fossil fuel-dependent (and often very inefficient) water heating technologies, its intermittency is a problem, and the need to integrate solar water heaters with existing (primarily natural gas-fueled) systems drives up costs and complexity. Solar water heating competes with more conventional water heating alternatives for the attention of plumbers and households, though in fact the technology is more complementary than directly competitive. Solar water heating also competes in the business of envisioning a decarbonized residential water heating future with electricity and heat pump water heating. The paradox is that solar water heating really can displace a substantial fraction of a home’s water heating energy in a zero-carbon way, compared to an array of more carbon-intensive conventional technologies.

Adding Solar Water Heaters to Existing Homes

Solar water heating does not fit neatly within the normal process for replacing a water heater. In existing homes, solar water heating is usually considered a retrofit to an existing water heater. In this way solar water heating is more of an elective decision along the lines of installing solar PV or doing an efficiency upgrade. Only 11 percent of the surveyed CSI-T-incentivized households said that they considered adding solar water heating because their existing water heater was failing or broken. The three most popular reasons by far were the desire for lower energy bills (62 percent agreed),

14 In some cases, the risk of overheating can be minimized by using less-efficient, rather than more efficient, collectors, as Larry Weingarten explains (Weingarten 2016).

attraction to the idea of solar energy (52 percent), and availability of the rebate (48 percent). Of these three, only the rebate provides a clearly actionable pathway.

Conventional storage tank water heaters are replaced on average every 13 years, depending on the type of unit, water hardness, and how they have been maintained (Lutz et al. 2011; Ryan et al. 2010). This means that about 500,000 natural gas tank water heaters are replaced in California single-family homes each year. If only 1 percent of tank water heater replacements added solar water heating, installations would far exceed CSI-T's peak installation rates. In a study for the northwest United States, suppliers reported that on average 61 percent of their sales were emergency replacements (NEEA 2012).[15] Emergency replacements are likely not a favorable situation for adding a solar water heater given the extra expense, more complicated planning, and scarcity of local solar water heater installers in many areas. Households calling a plumber or visiting a retailer in search of an immediate water heater replacement tend to do more limited research and rely strongly on their contractor or salesperson, favoring "like-for-like" replacement (Ciani 2018, KEMA 2006).[16] Water heating industry experts consulted for this study underscored that plumbers do not upsell—it is not part of their tradition, and doing so increases complications as well as their bid. Nor do most plumbers offer solar water heating. If they do, it is typically the higher-priced environmental option.

In this context, households considering water heater upgrades are rarely presented with a menu of options that includes solar water heating. This mechanism for solar water heating adoption implies substantially higher soft costs or transaction costs than would be expected if the decision was prompted in the context of a needed action (e.g., a failure). As noted in the next chapter, these soft costs are one of the biggest single cost centers for installers, even as new marketing innovations and CSI-T incentives have changed the scene.

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15 The northwest has a higher percentage of electric water heaters than does California, so the results do not necessarily directly transfer.

16 These studies were conducted in the northwest rather than in California.

CHAPTER 3: Policies and Expectations for Solar Water Heaters

Solar thermal water heating is encouraged in many countries throughout the world (IEA 2018) through regulations, incentives, standardization, government-supported research, and activities of private industry. Government support rests on assumptions about what solar water heaters can and should do and for whom. In some countries, solar water heaters are intended to supply hot water where little water heating is practically available or where water heating costs are very expensive. In California, however, solar water heaters are promoted as a matter of technical efficiency and GHG emissions reductions. Their regulation, evaluation, and support are thus based on quantified definitions of efficiency, expected fossil fuel savings and GHG emissions reductions, and consumer-protection elements like cost-effectiveness and reliability. Yet markedly higher levels of cost-effectiveness relative to standard tank water heating generally require lower system costs or higher hot water use than are the current norms. GHG emissions reductions are doubly invisible: their savings are relative to an abstract baseline and the reductions themselves literally cannot be seen . In the meantime, solar water heating faces competition from other efficiency and environmentally-oriented policy directions. These include rooftop PV, goals for high levels of electrification powered by a largely-renewable centered grid, and goals for high penetration of zero net energy homes, which do not preclude natural gas end uses but also do not invite them.

The political scientist Langdon Winner once asked in an essay “Do artifacts have politics?” (Winner 1980). His answer was an unequivocal “yes,” which has encouraged subsequent researchers to look at the political influences of the funding and production of scientific knowledge, technology design, regulation of technology-dependent markets, and the shaping of technologies that, in turn, significantly affect their users and social groups. Since then, evidence regarding the technology-policy relationship has accumulated. For example, widespread addiction to mobile devices, dependence of groups on social media platforms, nearly continuous connection to global information infrastructures, efforts to shape unconscious opinion and influence outcomes in governance and other technological outcomes with significant public and policy consequences were not imagined when Winner’s analysis was first published.

The public and private sectors cooperate and contend in the shaping of technologies of the future. Much private sector investment and risk-taking is necessarily conducted in secret. Yet the outcomes very often have public impacts that require new public investments and interventions. Also, more transparent public sector decisions (e.g., regulations of buildings, energy systems, transportation infrastructures, mortgage rates, and so on) affect technologies introduced into the marketplace or rejected in favor of publicly encouraged alternatives (e.g., electric vehicles, "green" buildings, and so on). In both cases, there are unintended consequences that require ongoing recognition, debate, and reaction.

While there has been considerable hesitation to pursue "technology policy" in the United States because of dramatic failures around the world in "picking (technology) winners and losers," federal technology investments in defense priorities have produced revolutionary advances in geo-spatial location (GPS and GIS), computer technology, data storage and manipulation, internet connections with global reach, and so on. These advances are unimaginable as the result of solely private sector investments or technology research and development. The private sector therefore reaps extraordinary benefits from public technology investments driven by political decisions about public priorities. At the same time, derivative private innovations (portable phones, cloud computing, sophisticated data storage and search capabilities growing from retail trade) have significant public and governmental benefits, as well as evolving costs. The balance between costs and benefits is assessed continuously, and there is no end in sight.

The larger lesson is that the public and private spheres are inextricably interconnected in the real world of technology and social life. But a primary problem is that both spheres often fail to recognize their interdependence, and the importance of the other—except through required interactions and self-interested filters.

Applying these insights to the case of solar water heating, one can see that to the degree that solar water heating can be "built into" important policy priorities such as "zero net energy" building goals or energy efficiency funding priorities, it would have greater legitimacy and validation in the supply chain. Another example may be strengthening and highlighting the links between solar water heating and statewide priorities for energy/environmental justice and low-income and disadvantaged communities in the context of climate change. Also, as community resilience and the need for systems to be able to operate off-grid become more important, solar water heating may have a role to play (although, to date, there are few systems in place that are not grid-tied). The larger point is that resources are more likely to flow through vetted and prioritized policy channels.

The elephant in the room is clearly CSI-T, which has delivered significant funding to promote solar water heating since 2010. Under normal circumstances, the solar water heating market would not have access to the large subsidies available under CSI-T. While the rebates may have had limited effect in most areas (with some larger effects in others), it is reasonable to conclude that solar water heating adoption in California was strongly boosted by CSI-T as a measure of public policy. However, when that program and its subsidies end, as is expected in 2020, business models and consumer choices built upon large rebates will be fundamentally disrupted. Innovation born of crisis can produce surprises (Gutenberg and the invention of moveable type or radar and war come to mind as historical examples). Solar water heating may yet "take off" as a solution to emergent problems. But the physics of sun-to-water energy transmission on rooftops and the market realities of solar water heating costs and consumer perceptions do not suggest an obvious high-growth trajectory for solar water heating as things are now, despite the influence of CSI-T.

While the industry actors consulted in this project were largely strong supporters of solar as a smart, carbon-neutral source of water-heating energy, they do not envision much growth in the California solar water heating market without subsidies. There are, as noted below, niches where solar water heating might work especially well (as in being marketable as reducing fossil fuel use without making households unhappy) even without rebates. These include single-family homes with natural gas storage heaters (as well houses with other fuels) and multi-family units (see above). In addition, technical innovations could change the nature of solar water heating (for example to be bundled typically with solar thermal heating or cooling), or it could become more popular for other reasons, such as improved economics—evidence of which is emerging through a huge uptick in the sales of low-priced (less than $4,800) systems in the last two years—or a new appreciation of solar technologies.

A holistic view of solar water heating shows that limitations encountered in the past are understandable and can be traced to multiple technological, environmental, social, and governmental sources. That landscape has not changed much. But the future is another story, and certainly a declaration that solar water heating is dead, now or for the imaginable future, is premature and not supported by facts or history.

The next two chapters address the industry (Chapter 4) and household (Chapter 5) sides of how households come to buy and use solar water heaters. They show a diversity of pathways and user motivations related both to efficiency and renewable energy.

CHAPTER 4: Industry View: Who Installs Solar Water Heaters, to Whom and Why?

The research team sought to understand the characteristics of households that have solar water heaters to help identify where they have been a good fit market-wise. Because the market is so small, the reasons depend on who is available to build, sell, and install these water heaters. That in turn depends on the CSI-T program through which most solar water heaters in California have been sold over the past decade and which continues to determine system features and overall costs. This chapter also describes the highly-concentrated solar water heating installation industry in California as pertinent to household sales. The following chapter discusses who purchases solar water heaters and why, based on what the research team learned from households who used them.

Several research methodologies were used to characterize the solar water heating industry in California. Primary and secondary data were collected and analyzed using both qualitative and quantitative methods. The two principle data sources utilized were the CSI-T database and interviews with members of the solar water heating industry. The CSI-T database was mined for information on solar water heater adoption, installations and industry members. Quantitative analysis of the data was conducted to identify salient patterns and trends in, for example, technology adoption by customers and installers, responses to changes in the rebate amount, and market participation among installers.

Interviews were conducted with a variety of stakeholders in the solar water heating industry (e.g., installers, manufacturers) and other experts to gather information about the industry, its challenges and opportunities. Nine interviews were conducted (3 with manufacturers, 4 with installers, 2 with other industry experts). Semi-structured interview protocols were used to enable systematic yet flexible data collection. Interviews were conducted over the telephone, and in most cases recorded and transcribed. Interviews were analyzed using a grounded theory approach, allowing themes and findings to emerge from the data.

The history of the solar water heating industry in the United States, and the current market conditions in selected foreign countries, draw on existing data sources, as cited.

Historical Background

The history of solar water heater manufacture and installation in California shows that it has not been an easy specialty business to sustain. Manufacturers and installers in the late 19th and early 20th centuries competed and came and went (Butti & Perlin 1980).

Companies innovated technically and competed for market share. Trends and events—such as a freeze in Pasadena that destroyed many systems, or copper shortages in the Florida market during World War II—could knock a company down. This is normal in technology history; for example, in the 1930s there was competition between natural gas-condensing refrigerators and electric compression refrigeration, with the former technology now almost completely unknown in the United States (Cowan 1985).

In the 1970s and 1980s, well-intended programs also brought in a multitude of inexperienced and even opportunistic[17] companies, according to some industry interviewees. This is a normal pattern when a market emerges in response to funding designed to launch a technology. In theory, players in the supported market compete to make money and ideally create a competitively-priced, well-functioning product that consumers are interested in, with the hope of creating a market that can thrive without incentives. This supported market, however, can also dilute the market for more experienced installers. Solar water heaters, at least in the past, have a reputation of being sensitive to fine details of installation (e.g., position relative to other equipment), to interactions and failures across various components of the water heating system (e.g., leaks, conductor corrosion), and to environmental conditions (e.g., freezing or overheating). Installer call-backs for solar water heating seem to be frequent relative to other domestic equipment, and some of the high degree of performance variability seen in solar water heating systems is due to these technical inefficiencies. A lack of technology experience can be especially consequential given these sensitivities, more so than for rooftop PV installation, for example. Many systems from the 1970s and 1980s were poorly built and did not last, according to industry interviewees, all adding to what has been called a decided lack of "sexiness" (Alter 2013)[18] for solar water heaters. However, as became clear in the household interviews described below (Chapters 5 and 6), some of these older systems have lasted for decades, especially if tended by engaged homeowners.

By 1986 the Reagan administration removed incentives for solar water heaters, and California-specific support for solar water heaters also faded away (Jones & Mowris 2020). Many systems installed during the 1980s boom proved difficult or too expensive to repair, and were orphaned when the original installer left the market, signaling continued hassles to come. This led to many systems being abandoned before their end of operating life, according to industry interviewees. By now, however, systems installed in the 1980s are at least three decades old and it is not clear how long ago they were abandoned. Some of these old water heaters still worked as of 2009 (see Chapter 2) and even work today, including systems serviced and maintained by companies active

17 Programs are intended to stimulate the market, including creating opportunities, so opportunism is not necessarily pejorative.

18 Treehugger.com (https://www.treehugger.com/renewable-energy/do-solar-thermal-hot-water-heaters-still-make-sense.html).

since the 1980s, as well as by homeowners who were fond of their systems and had the expertise and motivation to keep them running. Still, the dominant story from industry informants and from some households was that the 1980s' efforts shaped the public's view of the technology negatively, and as "something from the past" rather than a modern water heating option.

Renewed interest in limiting the state's reliance on fossil fuels ushered in a new era for solar water heating in California. The principle mechanism for supporting the present-day market, the CSI-T program, was approved in 2007 and established in 2010 (CPUC 2018).[19] While the program attracted new market entrants, some currently-active installation companies — for example, Aztec Solar with 126 installations under CSI-T — have installed solar water and pool heating since the 1980s, as well as maintaining existing solar water heating systems, and now install PV.

Not-for-Profit Installers

Several non-profit community action agencies (CAAs) deliver CSI-Thermal low-income installations exclusively. These include Merced and Fresno County organizations, among several others. They have a very different business model than for-profit installers in several ways. First, their technology choice was constrained by a dictate from the California Department of Community Services & Development, which mandated the system type. Second, CAAs can achieve some economies of scale from centralized purchase of a single technology configuration that is delivered across the state. Finally, the CAAs have long waiting lists of prequalified home owner households, so they do not have the customer acquisition problems and costs that for-profit installers have to deal with. Community action agencies also have deep knowledge of the community, its populations, and housing stock that less-established enterprises lack. Their local experience enables them anticipate and address the challenges that arise with retrofit projects making them a promising mechanism for spreading the benefits of sustainable technologies to disadvantaged communities and low-income households.

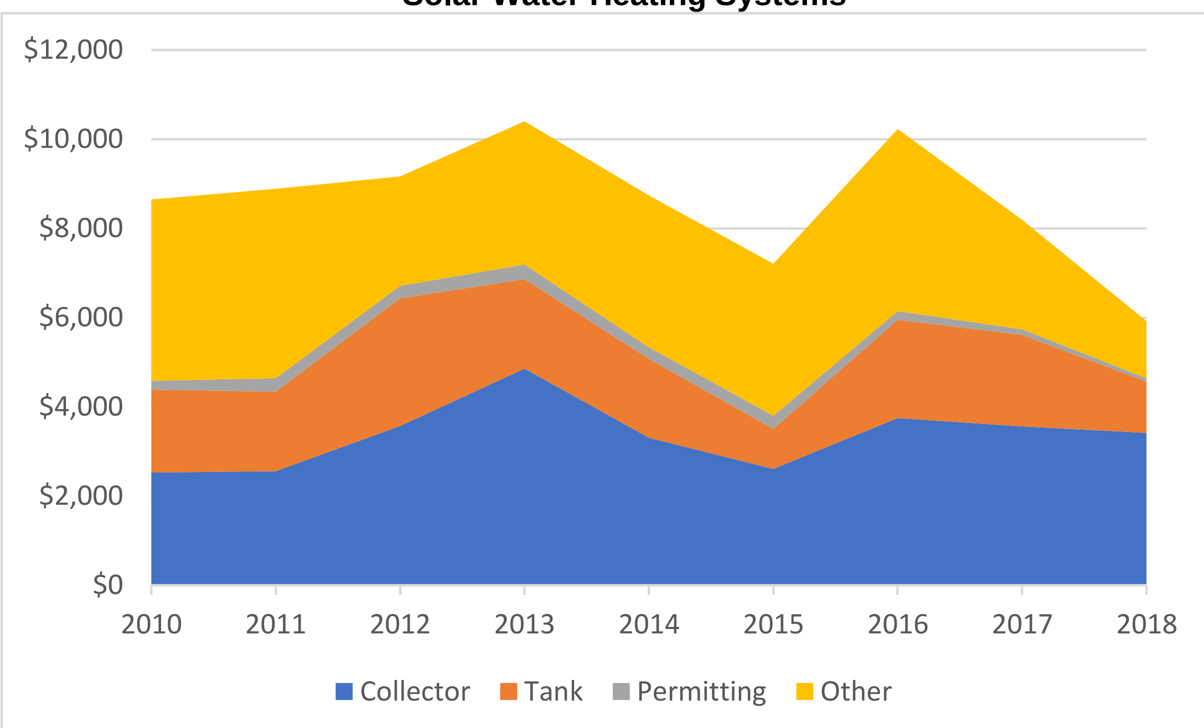
19 The CPUC is also required to evaluate data from the program to judge whether it is cost-effective for ratepayers and in the public interest (CPUC 2018). This has been accomplished through a series of studies led by Itron, and upon which the research team has built questions and findings.

System Costs

The total cost of installing a solar water heating system differs considerably by system type and has changed over time. According to interviews, active systems currently cost around $6,000-$7,000 for equipment and installation. Due to the complexity of the system, it usually takes a crew of two installers eight hours to complete an installation. By contrast, according to one industry member interviewed, the simpler systems in which storage is integrated into the collector panels may now cost about $4,000, including installation, which takes a two-person crew about half a day. Bigger or specialty systems may cost considerably more (see Chapter 5).

One industry expert estimated that a third of the cost of a solar water heating installation is hardware, a third is labor, and the remainder is "customer acquisition." Several experts cited the latter as the single most problematic cost component. Reducing the cost of acquiring customers could therefore reduce overall per-system cost (Figure 5).

Figure 5: Breakdown of Total Project Costs for Natural Gas Backup Single-Family Solar Water Heating Systems



Source: Non-public version of CSI-T-incentivized solar water heating systems for single-family households with natural gas backup systems.

One of the important considerations in pursuing possibilities for lower installed system costs is understanding the cost breakdown of installed systems. Some data on these costs are available through the CSI-T program database. As shown in Figure 5, a reduction in "other costs" has contributed to the reduction in total costs in 2017-2018

(Q1) versus earlier years in the program. On the other hand, collector costs are about the same in 2017-2018 (Q1) as they were early in the program, though their contribution to total costs has increased. While permitting costs are very small on average (less than 1.5 percent over the past three years) according to this data, some households reported frustration with the permitting process, which requires a lot of effort as well as considerable financial outlay. Interestingly, industry interviewees refuted the notion that permitting was a significant hurdle for solar water heating installations.

Of the solar water heaters incentivized through the CSI-T program, half were sold with minimal out-of-pocket cost to the household and half paid less than $222. For several hundred customers, there were either no out-of-pocket costs or they were paid by the installers (in particular the community action groups that organized installation). For households that paid virtually nothing for their systems, cost-effectiveness at the household level is not a relevant metric. In these cases, annual cost savings are a better gauge of how well the system is working financially for households; that is, how much does the system reduce household energy costs.

At the other end of the spectrum, about a fourth of households paid $7,000 or more out of pocket for their systems. Many of the more expensive systems likely received the 30 percent federal solar tax credit, reducing the purchaser's realized cost of the solar water heating system.[20]

But typical costs have declined dramatically over the program's lifetime, from a median of $9,000-$10,000 in the first years of the program (2013) to less than $5,000 more recently (2017-first quarter 2018). Figure 6 illustrates the distribution of project costs in the early years (in orange) and later years (in blue) of the CSI-T program. Until 2014, the more expensive "active" systems dominated the market. These were largely purchased by relatively wealthy households for whom a long payback period, almost certainly exceeding the warranty period, was not a deterrent. By contrast, the most common installation in the last few years has been a low-cost integral collector system for a low-income household, combined with on-demand water heating, priced such that the CSI-T rebate covered nearly the entire cost.

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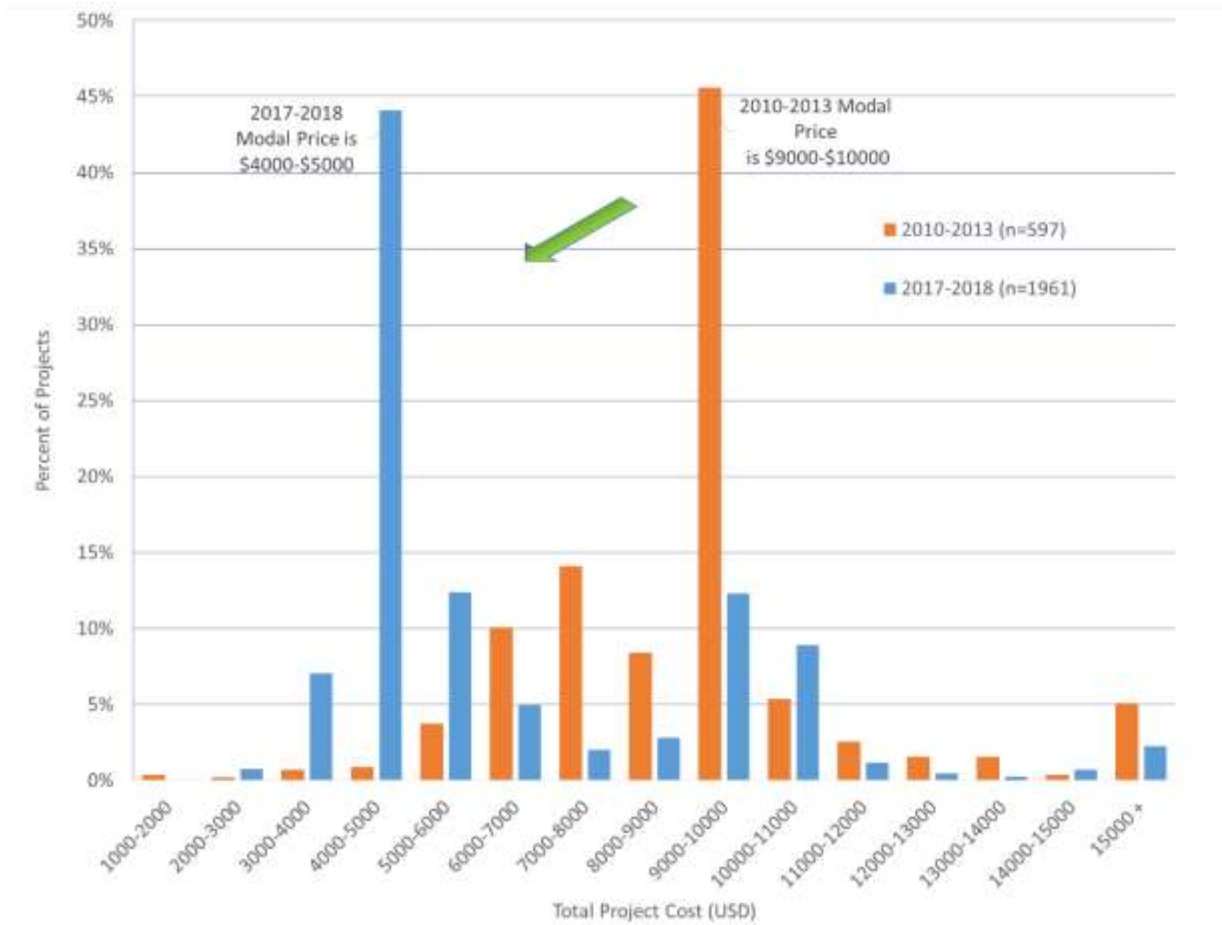
20 Information on the federal tax credit can be found here: https://www.energy.gov/savings/residential-renewable-energy-tax-credit. These credits are currently set to expire 12/31/2021.

Figure 6: Distribution of Total Project Cost for Systems Incented by CSI-T, Comparing 2017-2018 (Q1) to 2010-2013



Source: Non-public version of CSI-T incentivized systems database, obtained under NDA with CPUC, through March 2018

Entries, Exits, and Intensity among California Installers within CSI-T

Some companies have experience in solar water heating systems dating back 35 years or more (e.g., ACR Solar, Aztec Solar, and All Valley Solar). Others appear to have joined the market for only a few years before exiting (e.g., Siren Sales and The Solar Energy Company). However, some companies merged and rebranded). Of the 526 qualified installers listed in the CSI-T database maintained by the CPUC, many companies left the market after completing as few as 10 jobs, suggesting that they had trouble finding their footing. By contrast, 10 organizations have completed more than 70 installations since CSI-T's inception in 2010 (Table 3 presents a brief characterization of each, while Figure 7 illustrates their active period in the market).

The top 10 account for more than half of all CSI-T single-family installs, and two-thirds of those were done by two companies alone: Titanium Power and Zero Energy Contracting. Installers have focused on regional or local markets, with Aztec Solar a notable exception. Narrow geographic scope is particularly true of the community action agencies (e.g., Merced and Fresno counties) that have installed solar water heaters for low-income clients. CAAs have a very different "business model" than for-profit installers in several ways, including participation mandated by the California Department of Community Services & Development.

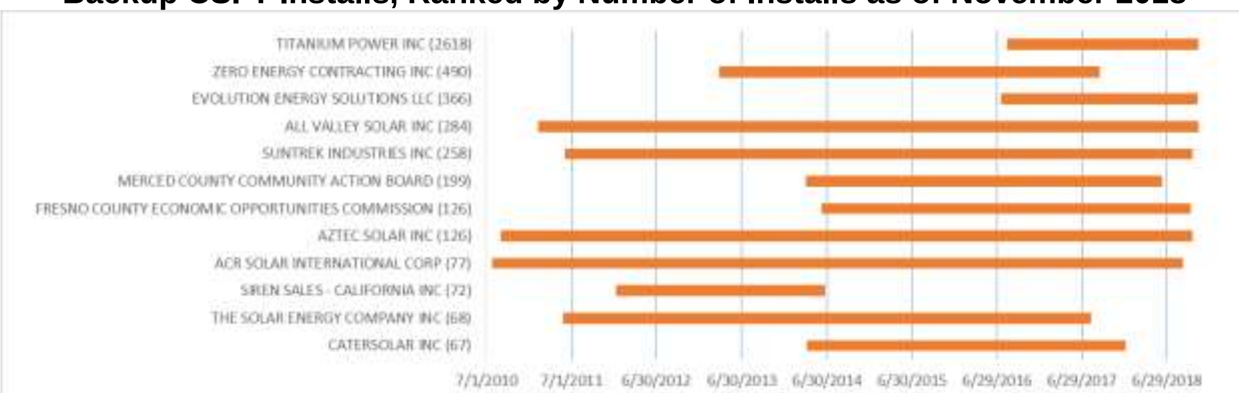
Table 4: Top Ten Installers for Single-Family Natural Gas Backup CSI-T Installs by Volume

Company	# CSI-T Installations	Primary Business	Type of installation for CSI-T Program
Titanium Power	2618	Electrical	Residential only
Zero Energy Contracting	490	Energy Efficiency	Residential only
Evolution Energy Solutions	366	Energy Efficiency	Residential, low-income, and commercial/multi-family
All Valley Solar	284	Solar	Residential, commercial/multi-family, pools
Suntrek Industries	258	Solar	Residential, commercial/multi-family, pools
Merced County Community Action Board	199	Community Service	Residential only (low-income)
Aztec Solar	126	Solar	Residential, commercial/multi-family, pools
Fresno County Economic Opportunities	126	Community Service	Residential only (low-income)
ACR Solar International	77	Solar	Residential only
Siren Sales - California	72		Residential only

Source: University of California, Davis

CSI-T attracted firms with a range of "primary business" activities, including plumbing, electrical, and light construction work. The "plug and play" integral collector systems require few specialized plumbing or electrical skills and personnel with a variety of licenses (e.g., plumbing, electrical, solar) meet installation requirements. However, many with appropriate licenses may lack the customer education skills required to sell the systems. In addition, there is a sense that the "on-the-roof" portion of the installation work is viewed as undesirable by many tradespeople (other than roofers). None of the top 10 installers works exclusively with solar water heating. Some do related work, like solar pool heating or PV, as well. Only half (Titanium, All Valley Solar, Aztec, Suntrek, and ACR Solar) directly mention solar thermal on their current websites, reflecting a weak emphasis on solar water heating installation among their other activities.

Figure 7: Timeline of 10 Most Prolific Installers for Single-Family Natural Gas Backup CSI-T Installs, Ranked by Number of Installs as of November 2018



Selling Solar Hot Water

Though a number of companies were selling solar water heaters well before CSI-T was instituted, the incentives available have clearly had a large effect on how companies recruit and sell, how households buy, and which households install solar water heaters. Companies that have been successful in installing many systems have leveraged some existing foothold in the market, though not necessarily in the solar water heating market.

For example, Community Action Agencies have existing lists of customers who likely qualify for nearly free systems. Titanium Power reportedly targets customers it served before through a Los Angeles Department of Water and Power (LADWP) program. The ability to build on existing mechanisms to recruit customers seems to have been critical to these installers' successes. This is because in general, finding potential customers ("leads") and converting them to buyers is time-consuming and difficult. Key informants told the research team that the costs associated with customer acquisition may account for 20-33 percent of the total cost of an installed system in the absence of a prior relationship with the customer. The industry members interviewed pointed to a fundamental problem: "lack of consumer awareness." To make a sale, installers have to change public knowledge, perceptions, and appreciation of solar water heating. Many with the technical skills to install the systems simply do not have the skills to educate potential customers and, without large scale operations, there is little scope to differentiate those roles the way solar PV companies do. Installers without much field experience may also be prone to rookie mistakes which can have serious consequences on system function, as one industry expert emphasized.

Presumably, as the out-of-pocket cost for solar water heaters drops closer to zero, sales get easier, at least for price sensitive consumers. This may partially explain why uptake has recently been highest in the low-income program. However, verifying customer eligibility for the low-income rebates introduces another challenge in the sales process. Some of the contractors interviewed explained that it is very difficult to pre-determine whether a customer qualifies as low-income according to the program definition. This deters some installers, and customers, from even starting the conversation as interest in and affordability of the systems hinges on a steep incentive for many potential customers. Installers that can determine eligibility ahead of time from previous interactions (such as Community Action Agencies) have a distinct advantage.[21] The launch in December 2017 of the disadvantaged community sub-program of CSI-T helped to reduce the income verification burden for installers serving those areas because eligibility is based primarily on a residence's zip code, rather than household income.

Installer Success and Mystery: The Case of Titanium Power

The single most prolific installer (based on total units installed under the CSI-T program) is Titanium Power of Los Angeles. The firm has sold more than 2,600 systems, almost all integrated collector storage (ICS) designs, and many with gas-fueled backup demand water heaters as replacements for older gas tank heater systems. Most of Titanium's completed systems (72 percent as of November 2018) were eligible for low-income homeowner subsidies. Titanium has been successful at minimizing their costs and delivering systems that come in at a price point that is lower than the CSI-T subsidy available, making the systems essentially free to purchasers. The extent to which this strategy is profitable or sustainable could not be ascertained. Titanium had prior experience with this business model, providing low or no cost low-flow toilet replacements to LADWP customers by taking advantage of rebates.

On one level, the Titanium success story was the hoped-for outcome of the CSI-T program when the program administrators decided to offer rebates to homeowners to help lower the costs of purchasing a solar water heater. Rebates have been a fixture of

21 An interviewee implied that Titanium was able to use customer information from a prior rebate program they participated in (installing low-flow toilets) to gain a head-start for generating solar water heating sales. The team was not able to verify this claim.

energy efficiency policy and regulations for decades to lower the costs of technologies that might otherwise be seen as risky (with risk often reflected in higher first costs to consumers). Rebates also are seen as incentives for contractors and other supply chain actors to invest time and resources in selling devices with improved efficiency. In the first years of the CSI-T program, rebate levels were so low that homeowners often paid much of system costs out-of-pocket. With increases in subsidy levels later in the program, particularly in the Southern California Gas territory, homeowners paid a lower share of system costs. But there was no general surge in solar water heating installations, except for the very high number of systems sold by Titanium Power in a few areas of the Los Angeles suburbs.

The mystery here is how one firm could make the program offerings work for homeowners and work for the company as a business model, when hundreds of other firms either did not see the opportunity or could not take advantage of it. The answer is important for understanding how subsidies are used in real-world contexts to better understand how they might best be deployed in the future.

While there are no definitive conclusions, there are some useful insights into Titanium's success based on observations by key informants and inference from the CSI-T data. First, Titanium was able to bring experience and organizational capacities to the problem, allowing very high volumes of sales and installations. This high volume reduced their costs for solar water heating systems. It also allowed multiple teams of installation workers to hone their skills working with identical, fairly easy-to-install ICS systems and demand heater change outs. As a result, perhaps double the number of installs could be done by a team in a day compared to installations using less practiced labor and more elaborate active solar water heating systems. This dramatically increased labor efficiency. Finally, an experienced marketing operation may have dramatically cut the costs of customer acquisition. This is likely some combination of telemarketing, social media, door-to-door sales and referrals from customers who had just received nearly free systems (although the research team has no direct knowledge of the strategies used). Solar water heating is not particularly highlighted on the Titanium website (titaniumpower.com), but electrical services and lighting retrofits are displayed prominently.

So it would seem to be the case that the Titanium success story is based in part on the fact that they had a fairly large-scale operation in place that could drive down costs of labor, materials/systems, and customer acquisition to the levels that CSI-T subsidies essentially covered the costs and profits for delivering solar water heating systems at large volumes. In the commercial heating, ventilation, and air conditioning (HVAC), plumbing, home improvement, and solar contracting spaces there are likely few similar companies. Industry observers have noted that the large volume of water heater replacement businesses may evidence some of the economies of scale necessary to deliver solar water heating at volumes needed for profitability, at least in the context of ample subsidies being available to cover costs and profits. The research team was not able to study this sector to determine the prospects and problems involved in shifting attention to solar water heating. But if this supply chain is like others, there are factors at play such as: lack of familiarity with solar water heating technology installations at scale, adequate profitability in current business lines and marketing capacities (in a business where aging water heaters continuously fail and deliver customers to the doorstep in need of immediate replacement), and likely perceptions of the riskiness of a subsidy-based business model.

There is much to celebrate in the Titanium case. But the details remain proprietary and there are likely few other market actors situated as well as Titanium has been with experience, expertise, simple technology, and willingness to take risks in a temporarily subsidy-rich CSI-T environment.

Supply Chain Characteristics

An earlier study of the solar water heater supply chains by researchers at the City University of New York pointed to "supply chain fragmentation" as a persistent problem that constrained the growth of the solar water heating marketplace in New York. Perhaps anticipating similar issues, the CSI-T legislative and regulatory goals point to possible solar water heater market problems that include high costs of systems, weaknesses in efficiency and innovation, and "market barriers" to solar water heating adoption that include high permitting costs, lack of access to information, lack of confidence in benefits, and lack of trained installers. This research found little evidence of such constraints.

No industry informants mentioned permitting as a notable challenge, though some households found it frustrating. Industry experts did, however, note that some installers had found it challenging to find workers who had the skills to both sell and install the systems. Being an unfamiliar technology, selling solar water heating systems reportedly requires a great deal of customer engagement, experience that many qualified installers do not have. By comparison, the solar PV industry owes its success in part to the separation of sales and installation into two distinct roles. The small scale of most solar water heating installers does not allow for such specialization.

With new technologies, availability of equipment and parts can often be a concern, as can price-setting and other inefficiencies that can result when there are few suppliers in the market. It appears that California largely avoided these challenges by having short supply chains: manufacturers supply the solar water heater technology directly to the contractors, in some cases along with training. Three of the larger international solar water heater manufacturers are located in California. They report no problem supplying the local demand. Even at its largest, the CSI-T demand for systems represents a very small fraction of the global market. This also means that California is not a priority for major manufacturers, who are instead focusing their efforts on satisfying the needs of rapidly growing markets like China and various countries in Africa. To the extent that the needs of California customers resemble those in emerging markets, developments there could benefit California, but the converse is also true.

There were some surprising findings with respect to the entrants in the installer market as well. The researchers expected to find that solar PV installers and home performance contractors—both with strong technical skills, established businesses, and experience with government programs and subsidies—would be key players in the market. A few full-service PV contractors did enter the market, but home performance contractors did not because, as one reported, the addition of solar water heating overwhelmed their capacity. Instead, a range of companies with differing core businesses tried their hand at solar water heater installation, with varying degrees of success.

One notable misstep in the recent push to install solar water heating was the early failure of large numbers of systems from a single manufacturer (FAFCO®). As noted in the CPUC evaluation of the CSI-T program, these systems were identified as poor performers for domestic water heating, having actually been designed for commercial pool heating. The failure rate could not be determined and may depend on location, but an interviewee reported that there were many failures in California's Central Valley. The Community Action Agency worked with the California Department of Community Services & Development to identify an appropriate alternative, and eventually was able to replace all the failed systems for its customers. In 2017 FAFCO® systems were delisted from the Single Family and Low-income Single Family programs (Itron 2018).

Cross-National Comparisons

The strategies used to support and stimulate growth in solar water heating may be quite different across countries (Li et al. 2013). In some cases, such as Cyprus and Israel, solar water heating has been practiced for decades and appears to continue strong, due in part to favorable conditions such as a sunny climate and a lack of fossil fuel resources (see Kalogirou n.d.). According to one interviewee, these countries also have lower system and installation costs, although the systems are not designed to endure as long as those typically sold in California and do not have freeze protection. In other countries, including Japan, solar water heater sales peaked in the early 1980s.[22] The latest Solar Heating and Cooling statistical report shows that globally, the solar thermal market for small domestic systems is challenged by competition from heat pumps and PV systems, with solar water heater markets declining in China and Europe (IEA 2017).

Statistics quoted by one global manufacturer were that "There were more than 57 million square meters of newly installed collectors worldwide in 2015; 49 million square meters for thermosyphon systems. China is the main market: 87 percent of thermosyphon." The research team was also told that the Chinese market was moving

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22 Asia Biomass Office (https://www.asiabiomass.jp/english/topics/1302_04.html).

toward more large scale manufacture of flat plate and evacuated tube collectors, with some of the latter now exported to the United States.

Quality and longevity appear to have been important motives in the determination of product eligibility for the CSI-T program. For example, recirculation systems, which are common outside the United States, were excluded from the rebate program due to concerns they would not withstand freezing temperatures. Coastal and moderately inland California, together with Florida and southern Texas, have low probabilities of a freeze in 20 years (Hudon et al. 2012). However, as one industry interviewee pointed out, "there is no place in California that does not have a possibility of freezing." The policymakers at the time felt that the risk—however small—of system damage was not worth the benefit of including such systems in the program. The result is that some of the less expensive system configurations that are used elsewhere, but do not have freeze protection, are effectively not available in California. The federal research agenda backs up this approach, focusing on systems suitable for cold climates (Hudon et al. 2012).

Discussion

If installation of solar water heating systems can be scaled up, and if these systems work well for households that have at least moderate hot water use levels, the financial attractiveness of solar water heating systems becomes more appealing—both in terms of cost-effectiveness and in terms of a more manageable price point without incentives. Designing a reliable low-cost system that lasts and that pencils out in terms of competition (for example higher-priced solar water heating systems, heat pump water heaters, or high-efficiency gas water heaters), and operationalizing this kind of system in the market, has been a central question in recent federal research on solar water heating (Hudon et al. 2012).

The research team further evaluated the details of performance expectations, modeled and actual performance metrics, and comparative economics in the chapter on technical performance (Chapter 7). Cost-effectiveness relative to certain time frames or interest rates (the classic metric for judging the efficacy of energy efficiency improvements) is only one way of seeing solar water heating. For example, solar water heaters may be a financially effective way of saving natural gas relative to other efficiency measures, even if the amounts saved are modest. The other crucial financial element is unevenness of economic outcomes across households, and the difficulty of predicting this for any candidate household, a challenge that perhaps could be addressed in part with careful analysis of hourly gas consumption data.

CHAPTER 5:
Household View: Who Has Solar Water Heaters and Why?

One research goal was to understand which households found solar water heating appealing enough to install and why. The previous chapter describes how household acquisition of solar water heaters depends on industry structure and players, especially with the CSI-T program as a dominant force over the last decade. This chapter is a complementary look from the household point of view and processes, as deduced from interviews (n=14) and surveys (n=233) of single-family households with solar water heaters.[23]

User Segments

Solar water heating is an unusual case of diffusion of energy-related technologies over time throughout a population. It is a markedly old, albeit updated, technology that is being sold to complement a highly-dominant method of heating water that already works well, is inexpensive to install, and that provides hot water at a modest cost. Solar water heating does not have a solid place in acquisition pathways for water heating, nor is there high familiarity with solar water heating as a solar technology. Those who are aware of solar water heaters often know about it from the 1980s, which left a legacy that the industry experts consulted sometimes said they were still trying to overcome.

These are tough conditions, so households that did install solar water heating can be traced to specific characteristics or acquisition pathways. The rest of this section describes the main household user/purchaser segments identified in the research, and considers how they might play out in the future.

Old-Timers and Aficionados

Thousands of solar water heaters in California homes were functioning when the CSI-T program began in 2009. Some systems had lasted more than 30 years with adjustments, repairs, and updating of backup systems. There is little doubt that this longevity required personal dedication and skills, and might even be seen as a labor of love. Half of the applicants for the pilot run of CSI-T program had used solar water heating before (Itron 2008). One of the most important groups of "old timers" are households in solar communities (see Chapter 1).

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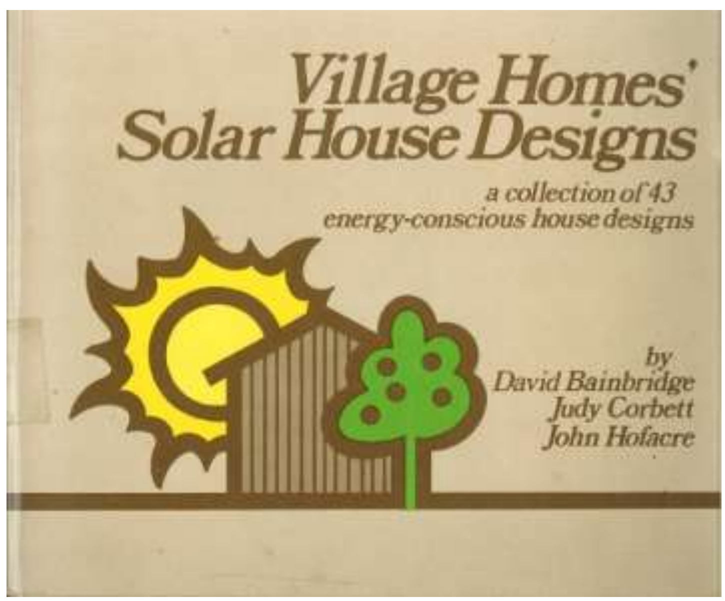
23 "n=" refers to the sample size. See Chapter 1 and the appendices for more details and discussion on how the sampling processes relate to overall interpretation.

In these cases of long-running systems, there is an aesthetic of keeping things functional, often with the tinkering and increased comfort with the technology that goes along with this. This contrasts with the break-and-replace, little-to-no maintenance mode of energy appliance ownership. One Village Homes resident, who had a simple box-style solar water heating system that she and colleagues had helped commission when her home was built, said that many of the more complicated systems (in particular those installed to replace the original simpler system) had failed in the interim. The mending, adjustment, and social aspects in this case echo those seen in an Austrian rural development of solar water heaters that helped lead to much broader dissemination (Ornetzeder 2010).

Other individuals encountered in the research had not purchased or used solar water heaters, but still considered themselves comfortable and familiar with it. Their knowledge was typically acquired through friends, their business, experience in other countries, or even school projects (usually from decades ago). These at first seem to be minor pathways. With effort, though, such as high school and college projects and demonstrations, they could effectively help people get comfortable with solar water heating, should the state decide to continue to promote the technology.

Twentieth Century Solar Villages

The energy crises of the 1970s led to a quest for "appropriate technology" (Schumacher 1973) in the United States and widespread solar experimentation as well as the development of pro-solar policies in California and other states. A few developers included solar hot water in their designs, either as options or standard features of residences. The process was helped along by public subsidies and a receptive group of homebuyers interested in more environmental and self-reliant lifestyles.



Source: http://www.indigoarch.com/solar-p 1

Examples of these communities in California include the Benicia Solar Village, where real estate agents reported that a number of units still used their original solar water heating system systems in 2001, approximately 20 years after installation (Richter 2001) and Village Homes in Davis, where solar water heating systems were often decommissioned over the years with remodeling "upgrades" according to one resident, although they were often quite functional.

Warranties might cover one failure (e.g., due to a freeze), but not a second. Another example is the Sun Ridge development in Rio Linda. These communities are interesting because they create neighborhoods where solar water heating is normal and where households might exchange information on managing problems, maintenance, and performance.

What seemed clear from the occupants and industry observers interviewed who had lived in or were familiar with these "solar villages" was that residents did have positive experiences with their solar water heating systems. In addition, some emphasized the pleasure derived from living in these energy efficient homes that went beyond lower energy costs stemming from carefully thought out design, build quality, and perhaps an elevated sense of self-sufficiency. Of course these residents are self-selected to value the homes that they decided to live in. As cities and neighborhoods increasingly explore disaster resilience and the potentials of "islanding" micro-grids in the context of energy supply threats from extreme weather and seismic events, earlier communities with built-in solar water heating serve as models, test-beds, and repositories of often-positive long-term experience with solar water heating. California, of all places, has a deep well of environmental concern and policy innovation that reflect sentiments born in the 1970s. As local concerns about sustainability and environmental equity grow, solar water heating may come to be seen as a practical and affordable zero-fossil-fuel alternative to both natural gas and electric water heating—if economies of scale and supply chain expansion can be achieved.

Low-Income Households Qualified for No-Cost Systems

The largest user segment among the CSI-T incentivized households was households that qualified for free or virtually free systems under the CSI-T program's Low-income Single Family budget. Most of these households came to CSI-T program indirectly by connecting with a community program or through an installer direct contact (see discussion of Titanium Power in Chapter 4). The household was probably not specifically seeking solar hot water. For example, one client of the Merced County Community Action Agency explained how his earlier actions on efficiency had not brought the expected results and that once he asked the agency what to do, they proposed and arranged the installation of both solar PV and solar water heating.

> *Well what I did, I bought this house on a short sale. It had been a drug house so it had a lot of damage. And my son, my youngest son, is a carpenter. So we were working on the house and I went into the Merced County Community Action Agency because I had already replaced all the windows in the house and the sliding doors and I still didn't seem to be saving much on electricity because it's hot here in the valley. And so unbeknownst to me the agency could have helped me*

> *with the windows but I didn't know that. My windows were already paid for, but they pulled up my house on Google and said that it was positioned perfect for solar and would I be interested in solar. Well of course I would. So they did all the solar panels on the roof and then they got that all done and then oh, within a couple of weeks, they did the solar water heater and added two more panels for the solar water heater.*

Households Wanting Solar

The main solar for California households is rooftop PV, versus solar water heating in the 1980s. The rooftop PV industry in California is competitive. There are many installers and a high focus on active sales. Most households judged to have a PV-favorable profile have been contacted very often by salespeople, annoyingly so according to some interviewed households. The trust level in PV installers may be quite low (Moezzi et al. 2017). Solar water heating is more complex to install than PV, and there are far fewer active installers.

Some households described making an active choice between PV and solar water heating, choosing the latter because, for example, with incentives it had a much lower price point than PV, it was more interesting than PV, the household was more concerned with natural gas costs or environmental impacts, their electricity use was low, or they could buy renewable electricity from their supplier.

Almost half of the CSI-T participants surveyed had rooftop PV in addition to solar water heating. Some of the households that received incentives under the low-income sub-program also got rooftop PV at no cost, for example as described in the quote above. Others said that they wanted to be completely solar; these households sometimes had to negotiate roof space decisions for PV versus solar water heating.

Not everybody who wants to use solar falls in line with the standard environmental reasoning, and some were even turned off by the environmental politics of solar, as Schelly (2014) also describes among early adopters of PV in Wisconsin. Some of the households consulted in the current study thought instead of resource efficiency or of independence from utilities; one interviewee, for example, was very dismissive of what they saw as environmental righteousness. So there is a risk in "over-environmentalizing" solar.

Efficiency or Economic Motives

Households surveyed had varying reasons for installing solar water heating and many factors that influenced their decision. The most common reason for installing solar water heaters, and the aggregate favorite aspect of using a solar water heater, was lower natural gas bills (62 percent). But more than half of respondents also said that they were attracted to using solar energy. One-fifth were influenced by an installer—many of these may be Titanium Power customers who used door-to-door sales techniques. Very few (6 percent) said that they were looking for better water heating performance, speaking again to the normalcy of standard natural gas storage tank water heaters.

Table 5: Factors that Influenced Decision to Install Solar Water Heater

Factors than influenced decision	Percentage Agreeing
Wanted to save on energy bills	62%
Attracted to idea of solar energy source	52%
Rebate available	48%
Approached by installer/salesperson	22%
Someone we know talked to us about it	19%
Planning/considering PV	15%
Doing other work on home	13%
Contractor recommended	12%
Previous water heater was failing/broken	11%
Saw it on a home or being installed	7%
Building/buying new home	6%
Wanted better water heater performance	6%
Heard about low-money-down options	6%
Saw ad or news article	3%
Offered at retail store, home show or community event	2%

Note: sample size n=193

Source: University of California, Davis survey analysis

Many households appear to have taken their particular circumstances and priorities into account when making the decision to install a solar water heater.

- High hot water use: The best economic case for solar water heating is when hot water use levels are high. Some households, of course, recognized this. One homeowner initially installed solar water heating several decades ago because her family fostered children. The system reduced the natural gas bill for her growing household and gave her less to worry about. There are other demographic or special circumstances where hot water use might be high—for example, where lots of sanitation is used for allergies or health needs, for home businesses, and so on.

- Low electricity use: Others explained that solar water heating was by far the best way to reduce overall fossil fuel use—for example, because they used little space heating and had low electricity bills so PV was not a very good choice.
- Energy efficiency: Some households came to solar water heating by seeking energy efficiency through established routes, including recommendations from home energy audits. It is unclear how common it is for energy audits to include solar water heaters on the upgrade menu—probably not very, but this could be a promising route.

Independence, Resilience, and DIY Motives

Several interviewees mentioned that their system allowed the ability to use hot water during energy supply shortages, citing this as a benefit when centralized supply is disrupted or when there are disturbances to the water distribution system. These disruptions seem to be of highest concern outside of urban areas, where restoration of services often takes longer and emergency support crews are smaller or farther away. With households and communities in California paying more attention to adaptation and resilience, these aspects of solar hot water might become more highly valued.

Few households likely now decide to use a do-it-yourself (DIY) approach for their solar water heating installation, but this contingent could increase, especially when the CSI-T incentives are no longer offered or as DIY installation gets easier.

Householders in rural areas without access to conventionally delivered natural gas were pleased to be able to reduce dependence on their propane backup systems.[24] This fits with other information indicating a higher sense of self-sufficiency in rural communities, likely due to experience, necessity, and ability. A general point made by many solar water heater owners was the advantages of decreased dependency on centralized supply of both water and energy. With households and communities in California paying more attention to adaptation and resilience, these "independence" aspects of solar hot water might become more highly valued.

24 Households with propane backup were not included in the survey analysis, which selected only homes using natural gas for water heating, as per the research plan.

Do-It-Yourself Solar Water Heater Installation

A small contingent of households who added solar water heaters have done it themselves. These are evident on dedicated websites, social media discussions, and blog and journalistic sources, especially in self-sufficiency sources, such as *Mother Earth News* (Reysa 2012) or the "Self Sufficient Living" website, which published an article linking to 12 different solar water heating system plans (Ahsan 2015). Pinterest has active solar water heater pin collections, while Amazon.com sells collectors and other products and includes product comment forums where many posters ask specific questions about system build. DIY is, in theory, cheaper than hiring an installer, though lower costs are not necessarily the primary motivation. DIY systems may provide a way to creatively adapt solar water heaters to local and individual needs and visions, and innovate on design, components, and construction.

A few DIY installations are reported in the CSI-T program, but most probably take place outside the program. In these cases, package systems or homeowner-integrated systems (or something in between) are installed in what one can imagine must be a sometimes challenging experience. DIY installers, unless they are contractors or skilled mechanical workers in their professional lives, must learn the basics of the system beforehand and then learn through doing in one unique installation. Industry informants have told us that the challenges DIYers encounter, along with lack of skill and required permits, etc. mean that this segment is likely to remain small.

The Austrian example of widespread cooperative DIY solar water heating among farmers (Ornetzeder 2001) suggests that in a world after CSI-T subsidies are gone, DIY may become a non-trivial part of the solar water heating landscape in the future. Local self-help and non-profit models could strengthen DIY capacities, and local bulk purchase of systems/components might create economies of scale like those enjoyed by the Community Action Agencies and Titanium Inc. A successful model of "community solar" that also used local contractors in Portland, Oregon developed a critical mass of demand for PV systems that drove costs down fairly dramatically (BPS 2018). The policies, resources, information, training, and technical assistance in those cases would most likely look quite different from those of the CSI-T subsidized, utility managed solar water heater policy set.

Encountering Solar Water Heating

One fundamental set of questions about the prospects for future solar water heating are: who already knows about solar water heating, what do they know about it, and whether and how the technology is encountered when thinking about designing or upgrading water heating or the home in general. From a research perspective, this is a difficult question to answer, and cannot be directly answered based on the sampling used in this research. A 2012 report on household water heating in the Southern California Gas territory found that 59 percent of surveyed customers said that they were aware of solar water heating (Kosar, Glanville, and Vadnal 2012); the percentage of households that would consider solar water heating as a current option is probably lower. Some of the interviewed households said, for example, that "nobody" they talked to knew about the technology. This apparent lack of familiarity obviously prevents many households from even considering solar water heating. A United Kingdom study on residential solar water heating adoption found that "the support of a local energy agency was the single most important factor in their decisions" (Watson et al., 2006, quoting a 2006 master's thesis by K. Schulz). In California, the CSI-T program may play this role.

The solar water heater users surveyed cited a wide variety of sources for how they first heard about solar water heating (Table 6). The most common answer was from a plumber or contractor—but this was named by only 20 percent of the sample. Neighbors and media were the next most common answers.

Table 6: Source of Solar Water Heating Information for Surveyed Households

Source	Percentage
Plumber/Contractor	20%
Friends, Family, or Neighbors Had One	17%
Advertisement or Publication	
Media (magazine, TV, radio, Internet)	15%
Manufacturer's advertisement	5%
Program	
Utility company contact, ad, or program	5%
City or county contact or program	3%
Past Experience	
Used to live in a house with solar water heating	5%
Saw or used while traveling/living in another country	5%
Long-term knowledge	5%
Other	
When I moved into my current home	7%
Retailer	3%
Work in industry	2%
Miscellaneous other answers	8%

Source: University of California, Davis

Likes and Dislikes

The survey asked respondents for their three favorite and least-favorite things about their solar water heater from a list of possibilities (Table 7). Among the favorites that stood out were lower energy bills, using renewable energy, and better for the environment, each named by about half or more respondents. But there were also many less common reasons, likely highlighting special appeals, such as independence (31 percent) and having hot water when the power is out (13 percent), and pleasures such as a good feeling in using solar-heated water (18 percent) or simply liking the technology (15 percent). The least favorite aspects were higher installation costs and lower savings than expected, along with more problematic issues like leaks, failures, and installation difficulties.

Solar water heater owners reported a range of experiences with installers. The interviewed households were very positive about their installation experience and their experience with their installer, though the surveyed households were decidedly less so. The installers were characterized as competent and helpful. The survey data did not indicate a stand-out installer. At least the more active installers seem to complete installations in one day or less. These active installers apparently develop standard configurations and processes that help streamline the installation process.

Table 7: Desirable/Undesirable Characteristics of Household Solar Water Heaters

Favorite Things	Percentage (n=227)	Least Favorite Things	Percentage (n=164)*
Lower energy bills	57%	Installation cost	44%
Using renewable energy	51%	Doesn't save as much as expected	43%
Better for the environment	48%	Takes up too much space	29%
Plentiful hot water	31%	Don't like way it looks	26%
Independence	29%	Leaks, failures	21%
Feels good to use naturally-heated water	18%	Installation difficulties	18%
Like the technology	15%	High maintenance	13%
Positive example for others	14%	Poor performance	9%
Hot water when power is out	13%	Damaged house	5%
Inexpensive to install	8%	Cause conflict to manage	5%

***Note that these percentages are among only 164 respondents versus the 227 for "favorite things," so the overall proportion of dislikes in the population is less than shown in the table.**

Source: University of California, Davis

The above picture of who buys solar water heaters and why helps inform questions about future adoption pathways, households that are good prospects for solar water heating, and how solar water heating and its marketing might change for wider or more specific appeal. The next chapter describes household experiences, focusing on how households use, manage, repair, and maintain their solar water heaters, what they like, and what they wish was different.

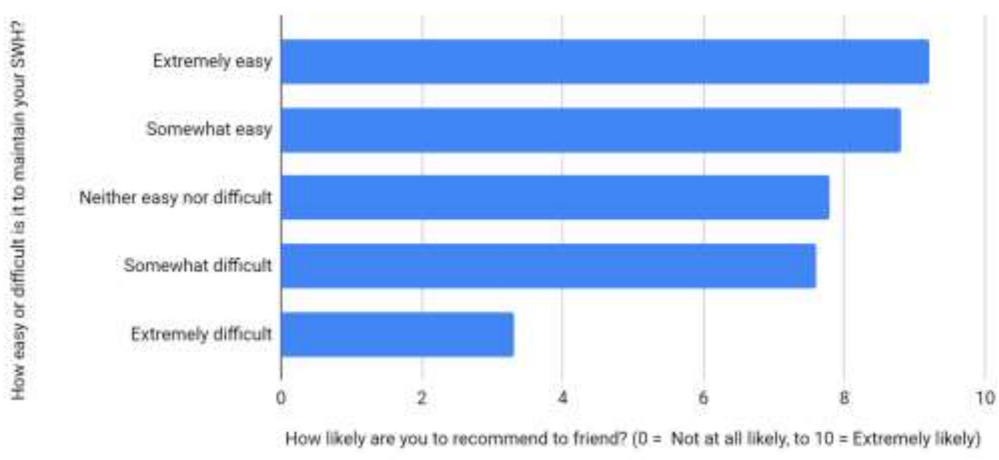
CHAPTER 6:
Household View: Learning, Using, Maintaining, Assessing

The previous chapter describes how households came to have solar water heaters. This chapter describes households' experiences using solar water heaters, including what they like and dislike about them. Energy technology evaluations often overlook this kind of information, but understanding user experience is critical to improve products, form realistic expectations for the technology going forward, and inform marketing. Two main data sources provided insights into user experience with solar water heaters: in-depth interviews with a small set of solar water heater-owning households, and an online survey of a larger set of households using solar water heaters incented under the CSI-T program.

Mastering and Maintaining the System

One of the important findings from this study is that most owners of solar water heaters prefer systems that need minimal monitoring or interaction on their part to keep them functioning as intended. This "set and forget" aesthetic seems to be the modern expectation for household equipment, in line with trends toward increased automation. A few technology aficionados enjoyed understanding, learning about, and monitoring their systems, and keeping track of performance and energy/water savings, but these were the exceptions. The easier that survey respondents perceived maintenance of their solar water heater to be, the more likely they were to recommend solar water heaters to others, an indicator of satisfaction (Figure 8)

Figure 8: Average Likelihood of Recommending Solar Water Heating to a Friend by Perceived Ease of Maintenance



Source: University of California, Davis, analysis of survey responses.

The installer is highly important in educating households on the functioning of their system and in setting overall expectations. For survey respondents, the installer was the main source of information on system use and management for most households (60 percent). Twenty-five percent said they learned using the manual, and only 13 percent said they experimented on their own. Twenty percent said there was nothing to learn, which implies a perception that solar water heating is no different to use than conventional water heating. Nor did maintenance requirements concern many before buying the systems (mentioned by 24 percent)—more households were worried about high initial costs, reliability over time, risk of damage to the home, and performance.

To the extent that there is something to learn—whether it be periodic inspections of the system, or timing hot water use to favor using the solar-heated portion—the communication skills of the installer are extremely important to successful knowledge transfer regarding the system. This can entail anything from recommending inspections, how to switch off the booster/backup system, monitoring temperature, or suggesting shifts in the timing of water use to best take advantage of solar heating. The extent to which this sort of information is provided presumably depends on expectations about the household's receptivity. Households who inherit solar water heaters when buying a home will not benefit from direct discussions with the installer unless they are interested enough to contact them later. As a result, a change of occupancy could lead to shortened longevity or diminished utility of the solar water heater.

Many households expressed frustration over their attempts to find competent technicians. "Finding a trustworthy and competent installer" was the most oft-cited difficulty survey respondents had when acquiring their solar water heater.[25] Along the same lines, interviewees expressed frustration with a lack of local contractors willing or able to maintain or repair their solar water heating systems. One in four survey respondents said they had problems during installation, ranging from minor to serious issues. Fifteen percent reported having had leaks or failures at some point.

Survey respondents also expressed a more general problem with lack of information about various aspects of solar water heating. As Figure 9 shows, roughly a third of households surveyed reported that it was "difficult" to get information on the suitability of solar water heaters for their household, how to get a system, and installation and maintenance issues.

Among solar water heater owners in solar communities such as Benicia, neighbors are an important source of information about system functioning and repair. The community network and proximity of other households with solar water heating makes this possible. Households in communities where there is high penetration of solar water

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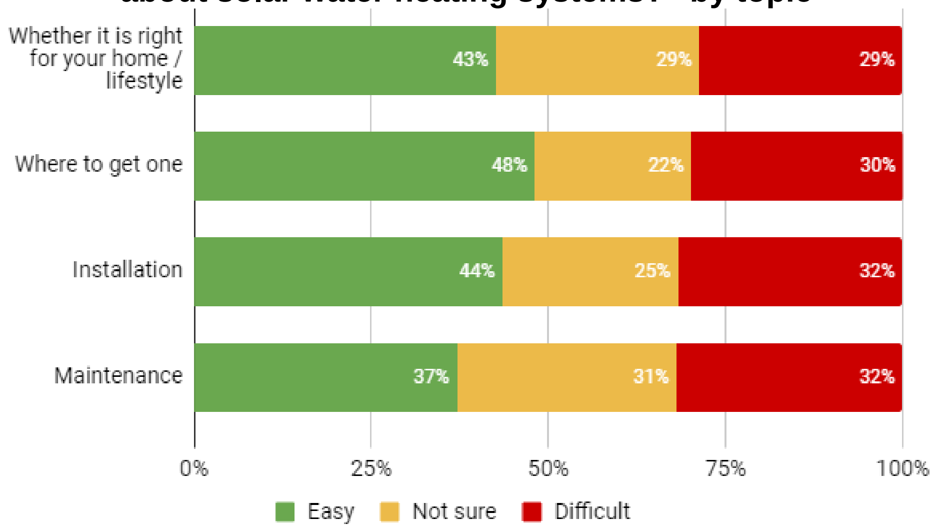
25 Eighteen percent of surveyed households answered that this was a difficulty they faced (20 percent among those with older water heaters installed before 2014); since this is only for those who actually did eventually install a solar water heater, there may be many more who were considering installing a solar water heater but gave up.

heaters, such as Benicia Solar Village, Village Homes, Davis, Berkeley, areas served by the Merced or Fresno community action agencies, or the Porter Ranch area where many Titanium Power systems are installed, may also utilize this type of resource. However, most households do not have easy access to other solar owners due to the low density of installations. Only 2 percent of surveyed households said that they had talked with other users. There seems to be little in the way of online exchanges such as owner forums or Facebook groups.

Figure 9: Survey Responses to "How easy or difficult is it to get information about solar water heating systems?" by topic



Source: University of California, Davis

Some interviewees liked the "maintenance specials" that their installer sent out every year, and followed through by scheduling maintenance every other year or so. Studies on HVAC maintenance (Heinemeier 2013) underscore how difficult it is to get households to adhere to recommended maintenance regimes, even with utility programs to encourage it. Maintenance that is convenient, regular, and reasonably priced could be a reassuring offer, though it also adds to planned costs and signals more effort required.

Domestication and Habituation

Researchers in an Australian study on residential solar water heating distinguished active and passive users of solar water heating systems, arguing that judicious use of the booster switch (e.g., boosting before evening showers, or turning off the booster/backup switch in the summer) leads to better savings (Gill et al. 2015). How to accomplish this type of system management is not obvious, and there is the risk of inconvenience since the decision to turn off the booster heat can lead to cold water. The 20 households in the study tried to learn by trial and error how to best manage the switch, but half of them gave up early on and became passive users of the system. The other half who continued to try to actively manage were dissatisfied with their system.

In contrast, most California households consulted in the current research said they had not changed much about their hot water practices to accommodate a solar water heating system. Shifting the time of hot water use was the most common adaptation according to the survey, but only 16 percent said they did this. For example, some of the more engaged households reported adjusting the timing of their showers or other hot water use (e.g., to mid-afternoon) to take advantage of the solar heated water when it was available, or even used hot water instead of cold to dissipate heat when they suspected there might be a problem with the system overheating. When hot water is made available by environmentally friendly, energy-efficient solar, a few respondents offered, it makes no sense to let it go to waste.

Hot water usage patterns are generally not communicated as a factor in estimating expected savings from a solar water heater, and there was little hint that installers discussed the issue. To change the timing of hot water use requires a change in the timing of social practices linked to existing schedules and practices; it is not a simple change for most people. For most solar water heater users in this study, the difference between solar and natural gas heated water may not have been transparent. Most solar water heater users in this research did not seem to seriously consider managing the timing of hot water use or the booster switch or perhaps even know that it mattered. This contrasts with the initial expectations conveyed to households in the Australian study, where many households did try to adjust timing but largely failed to satisfactorily do so.

A few survey respondents (10 percent) said they had increased hot water use since their solar water heater installation, most commonly because there was more of it, it cost less, and it felt less wasteful when heated with renewable energy.[26] From an environmental standpoint, one of the risks of cheap hot water is that it could encourage more water use overall, which has energy implications in terms of additional water treatment and conveyance[27] and creates additional pressure during recurring droughts in the state. An increase in hot water use could be unconscious. Also, an increase in hot water is not necessarily an increase in total water use. For example, some households mentioned more often using hot water instead of cold for laundry. This extra hot water may be an important sales point, especially for those who usually hold back, whether in the name of saving energy or controlling utility costs.

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26 As to the degree of actual changes in the amount of water or hot water use associated with acquiring a solar water heater, this is very difficult to measure or to claim causation, since water use may change for many reasons, for example, changing ages of people in the household, changing landscape, social pressures, etc.

27 For the energy implications of water use, see publications on the "water/energy nexus" in California; for example, the CPUC page compiling research and a calculator on this issue (http://www.cpuc.ca.gov/nexus_calculator/).

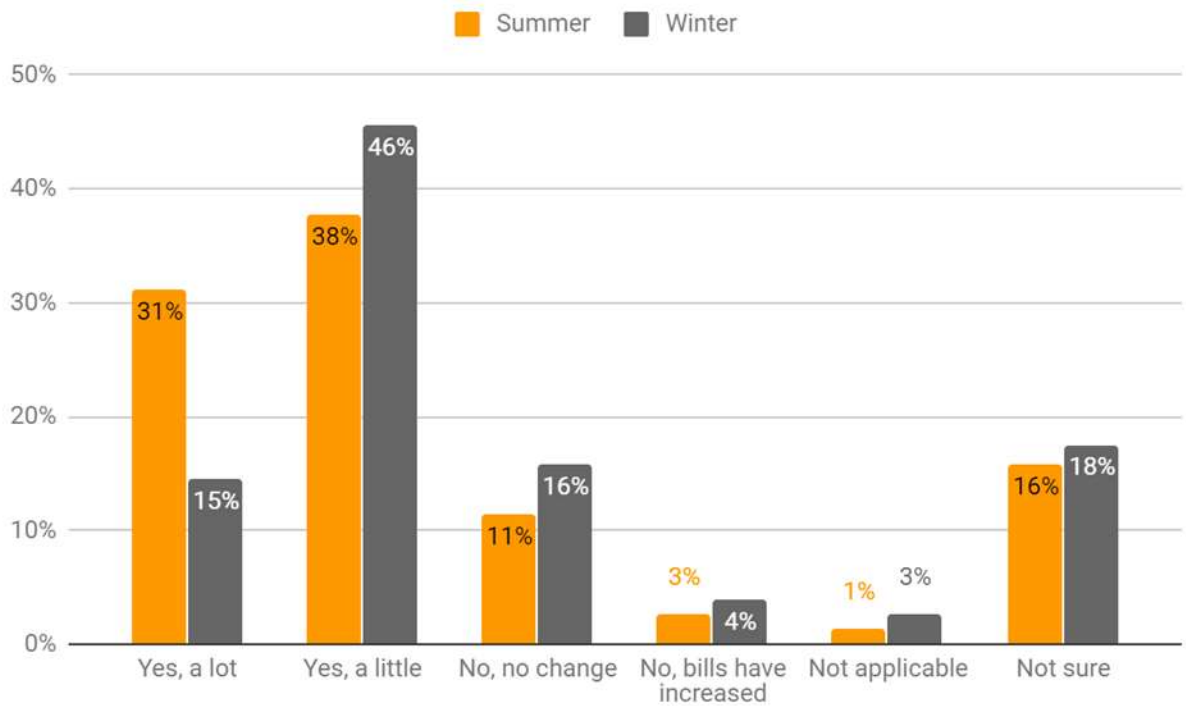
Household Assessment of Savings

The contribution of solar-fueled hot water to overall hot water consumption was probably difficult for many to discern, especially on a day-to-day basis. When the solar hot water capacity is exceeded, the backup system seamlessly takes over production of hot water without interruption or feedback on the switch to backup. This aspect seems to work well, giving no indication on how to favor solar over natural gas heated water. A few of the more environmentally-minded respondents monitored the temperature in the solar tank and adjusted their practices accordingly. Some households turned off their backup systems altogether during periods of ample sunlight, even in the winter, but this was probably quite rare—again underscoring an expectation of passive use, where the technology itself was enough.

To get an idea of whether and how much energy or money they were saving, households seemed to review their monthly natural gas bills or even total energy bills. Most survey respondents said they noticed a decrease in natural gas costs, equally divided between "a lot" and "a little;" 12 percent said there had been no change. The more analytic or interested households monitored (at least for a while) the contribution of solar to their hot water by contrasting summer gas bills with winter usage when backup systems were more frequently engaged. They would point out, for example, that their summer natural gas bills were only a few dollars a month, even when they used natural gas for cooking, meaning that water heating was virtually free in the summer months. These low summer bills were a point of real enthusiasm for some households. They signal substantial contribution of renewables and substantial savings (e.g., $30-$40 per month over four or more months), much more than most efficiency measures can do. Still, the high end for estimated bill savings, even for high water users and a well-operating system, is about $200 per year, as discussed in the next chapter.

There was no automatic way for households to know how much they were saving. One of the experts consulted argued that one of the difficulties faced by solar water heating was that there was no clear accounting of solar contribution for solar water heating. The meter does not "spin backward" for solar hot water nor do utility bills give an accounting, while anecdotally these can be real high points for rooftop PV users. It is possible that a well-designed feedback system would enable users to measure savings or environmental advantages and provide guidance for interested but "non-techy" households to manage their system operation and hot water usage timing. However, this would add cost, provide more opportunities for things to go wrong, and possibly demotivate some households too, whether because the savings are too low or because of the complication.

Figure 10. Survey Responses to "On average since the summer/winter, have your natural gas bills decreased since getting your solar water heater?"



Differences in hot water practices are related to the different backgrounds and interests of solar hot water users. Those with strong technical backgrounds, especially those motivated by the environment or energy savings, tend to monitor systems more closely and adjust their practices to improve the efficiency of hot water delivery. They may have had extended conversations with solar water heating experts or were technically savvy enough to have a very good idea of how the system was working and how to interact with it for positive effect.

In summary, though, most users say that their hot water use practices do not change after installing the system. It is possible that installers are reluctant to give much non-essential advice to most households; instructions can make people doubtful about system quality, cause confusion, and increase workload of both the installer and the household. So for many households, the expectation is that it is the purchase of the technology, rather than any details of how it is used, that provides environmental or financial benefits.

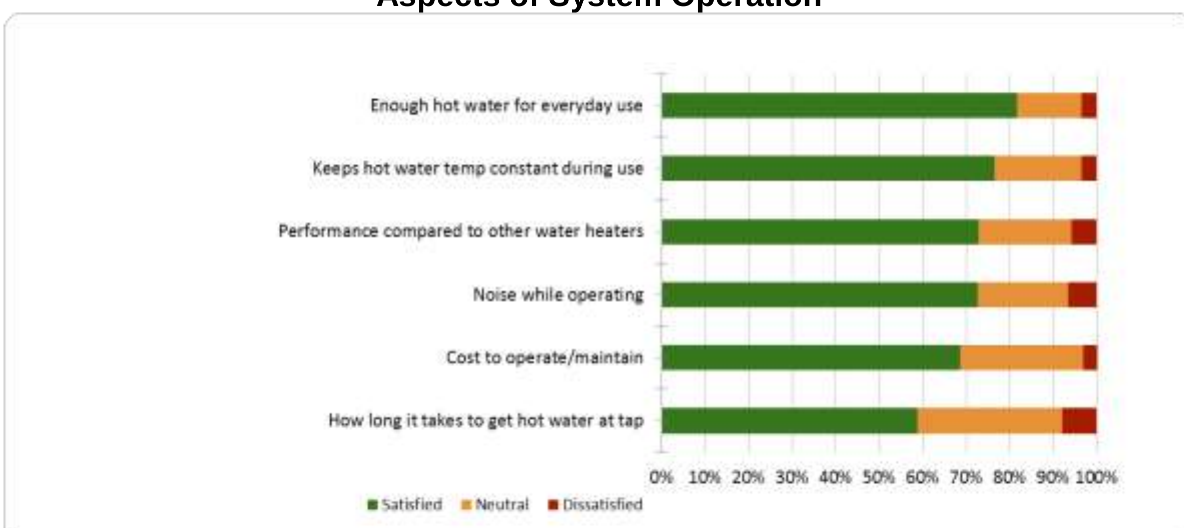
As to how this compares to results from other cases, first, as we mentioned above, there are few studies of solar water heating system use. Most studies instead report on modeling results or (in older studies) consumer interest in the technology. Two studies (Giglio & Lamberts 2016; Gill et al. 2015) that do look at system use both point to the importance of how households use the system in determining the advantages of the system. For example, Giglio and Lamberts studied five households where the shower was the only end use supported by the solar water heating system, supplemented by electric backup operated through a manual switch. Over a monitoring period of one year, the percentage of shower time using the electric energy, even when solar-heated water was available, ranged from 20 to 80 percent.

Householders' Assessments of Performance

A majority of householders who acquired a solar hot water system were pleased with their system, whether they purchased it, had it installed through a low-income program, or moved into a house in which a solar hot water system was already in place. This was especially evident in talking to the interviewed households. The survey results showed high levels of satisfaction with the system as judged by their likelihood of recommending a solar water heater to others (84 percent of the single-family program households and 75 percent of the low-income program households), with respondents giving particular attention to the energy savings and positive environmental benefits.

As to specific performance aspects of the solar water heater, satisfaction was mixed (Figure 11) Most survey respondents were satisfied overall, relative to the performance of other water heaters. The crowd favorite was having enough hot water for everyday use. The most common dissatisfaction was how long it took hot water to get to the tap; here only 58 percent said that they were satisfied with how their solar water heater did, though whether they felt it was worse than the previous water heater is unknown. Seven percent were dissatisfied with noise from the system. A few interviewees mentioned that they enjoyed the noise as it reminded them of their solar system working.

Figure 11: Survey Respondents' Satisfaction and Dissatisfaction with Various Aspects of System Operation



Source: University of California, Davis, analysis of survey data.

Satisfaction is likely based on an assessment of economic, functional and environmental considerations. In terms of the economics of the installation, low-income households were happy because the installation costs were covered by the community. The middle income Aztec client interviewees, for example, all pointed to the importance of subsidies and rebates to bring down the up-front costs, making their purchase a "good deal." The survey results showed that the availability of a rebate was a motivating factor for almost half the sample.[28] Only 22 percent said they would have installed solar water heating if the rebate had not been available. Almost half of the survey respondents indicated that up-front costs were their greatest concern when deciding to install solar hot water. Households in all of the demographic categories were aware that the system was saving them money on their energy bill; two-thirds of the survey respondents reported saving energy on their summer natural gas bills and 61 percent reported they had saved on their winter bills. A few had done some more elaborate calculations, but for the most part it was the low summer bills that were proof that the system was delivering. For those who had thought through the amount of time it would take for energy savings to pay back their investment costs, the long "payback" times (which might be 30 or more years for many customers) were regarded as a disincentive. Nonetheless, the rebates coupled with a sense of satisfaction over having limitless hot water at low environmental impact made the capital costs worth it to them.

In terms of functional issues, all of the purchasers of newer systems interviewed were happy with the functioning of the system. Some with older systems expressed frustrations with system performance, but the researchers' impression is that problems were regarded as being well within tolerable limits and were more than compensated by the advantages of having solar hot water.

Conversations with Neighbors, Friends, and Family

There have been notable examples in solar water heating history where the community aspects of the technology have been important. These include the 1980s solar communities and the rural Austrian solar water heating development (Ornetzeder et al. 2010) that helped pave the way for more solar water heating in Austria. Many studies have pointed to peer effects in rooftop PV, arguing that households are more likely to install PV if their neighbors, friends, or family do. PV installers often highly value referrals from their customers, and households tend to trust the experience and judgement of neighbors and friends more than they do the promises of sales people (Moezzi et al. 2017).

At this point, with so few installations in California, the peer effects are limited. Still there are obviously hot spots in installations under CSI-T. These are generally closely

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28 In reality, it was probably a motivating factor for considerably more than half of the installations and almost all of the low-income installs; only 63 percent of the CSI-T incentivized survey respondents were aware that the CSI-T incentive had been applied, presumably because the rebate was handled by the installer or Community Action Agency, or because they did not recognize the name.

linked to installer location and strategy. As seen in Figure 1 in Chapter 1, there is tremendous dominance of installations in Los Angeles County, many by Titanium Power. In many other counties, there is just a handful of CSI-T supported installations.

In the period just after installation, some system buyers actively communicated the environmental and energy saving advantages of their system to family, friends and neighbors. Low-income households served by the Merced Community Action Agency, for example, seemed enthusiastic about telling their neighbors about the opportunity for obtaining solar hot water at no cost. However, almost half of all survey respondents said they never or rarely talked about their solar water heating system outside the household. Some interviewees remarked that it seemed tough to get others interested, theorizing that PV was so dominant in neighbors' minds that solar water heating hardly registered. For most households, the panels and other roof equipment were probably not very visible from the street, and only a few interviewees noted spontaneous questions or comments from neighbors about solar hot water.

Nearly half (45 percent) of the survey respondents also had solar PV, typically acquired before (48 percent) or around the same time (30 percent) as solar water heating. Interviewees with both solar PV and solar hot water gave the impression they were more likely to brag about their PV than solar hot water. Comparing the results of the household survey to that of similar surveys of PV adopters suggests that solar water heating owners seem less likely than PV owners to recommend their solar technologies to others. This could be related to the extensive marketing of PV relative to solar hot water, where owners are often identified as having made an environmentally friendly choice. Several interviewees with solar PV also owned electric vehicles and pointed to this double environmental benefit as an advantage of PV over solar hot water. One conclusion of these conversations was that solar hot water could be made more attractive to more people through stronger marketing of the positive environmental contribution of owners. This could appeal to households already owning PV as well as for households that are not interested in or not able to install PV.

Conclusions and Implications

Skills and Engagement

With the exception of the solar hot water pioneers who are willing to tinker with the performance of their older systems, most people would prefer to have a system that works without the necessity of active control, adjustment, and attention. Owners find pleasure in the solar hot water system's capacity to supply the house with environmentally friendly and near zero cost hot water without active management. There is room for both levels of engagement.

Installation

There was a high rate of reported problems during installation. This is likely due to the complexity of the technology, including normal missteps in innovations, inexperienced crews in some cases, and faulty technology. This can lead to dissatisfaction that affects the reputation of solar water heating in general, especially if there is damage to the home. Almost a fifth of survey respondents indicated they were very unlikely to recommend their installer.

Maintenance

One of the dissatisfactions people have with their solar water heating systems is no or few local firms in their area who are willing or able to maintain or repair the system. For those who had no problems or were not at the stage of calling in a company for maintenance, this is not yet an issue. However, over time and if there were a big increase in the diffusion of solar hot water systems, maintenance could become a serious concern, especially if firms tend to exit the market after only a few years. One of the stories about the 1980s installation boom was that after incentives were removed, households found themselves without the original installer and with few options for repair. At the same time, some of the remaining installers turned heavily to maintenance and repair of systems. In a more robust solar hot water market, it would be important for firms to build out their capacity to perform maintenance and repairs and at rates that do not deter possible buyers.

Costs and Benefits

It seemed clear from the interviews that many owners of solar water heaters bought their systems despite unfavorable economics, as measured by long payback times. Even if these households were willing to do this, some acknowledged that high upfront costs and long paybacks could be a non-starter in the wider market. In fact, high costs and less-than-expected savings were the top two "least favorite" things about solar water heaters among survey respondents, each mentioned by about 44 percent of respondents. But this also depends on expectations (how much they expected to save) and available alternatives. If a household is looking to save natural gas, alternatives include more efficient storage tank water heaters, heat pump water heaters, rooftop PV (abandoning their natural gas water heating), and on-demand water heaters which themselves can be paired with solar water heating and in fact often were in the most recent years of the CSI-T program. In terms of active choices, rooftop PV is probably the biggest competitor to solar water heating, even while many households with solar water heating have both.

Performance Feedback and Savings Estimates

Some owners interviewed had a preference for simple controls that need minimal monitoring. Still, in-depth interviews suggested that at least some owners would like to have better feedback and transparency on how much hot water and how much energy they are saving relative to a conventional hot water system. Such feedback would draw attention to the favorable running costs and environmental benefits of solar hot water, providing owners a basis for making adjustments to their hot water practices and fodder for discussing the advantages of their systems with peers. On the other hand, this could also call attention to cases where households were not saving as much as they expected. Also, while "the meter spins backward" in the case of rooftop PV, this would not be the case with solar water heating, which adds heat to water but does not contribute electricity to the grid.

Use of Demonstrations and of Trusted Resources to Increase Familiarity and Comfort

Prior research shows that providing interested households with the possibility to experience how their peers use new household energy systems help to defray concerns that they imply inconvenient changes in practices or demand high technical skills (Thomsen and Schultz 2005). In California, the use of demonstration homes could be harnessed to dispel such concerns and demonstrate how everyday life with a solar water heating system can be familiar and undemanding.

The next chapter addresses technical performance of the solar water heating systems studied, in contrast to the performance as evaluated by owners and users. Technical performance depends on a wide variety of factors which include not only the technical circumstances but also how households use and manage hot water use and their water heaters.

CHAPTER 7: Greenhouse Gas Emissions Reductions and Other Performance Factors

This chapter assesses and interprets, within the limits of the data available, the extent to which solar water heating systems work well to reduce fuel use, natural gas bills, and greenhouse gas emissions. These are addressed both for current installations and for possible futures in the context of policy and environmental goals for transitioning California's systems of supply and demand to lower levels of GHG emissions along with reliability and resilience.

Benefits and Impacts

Solar water heating can in theory contribute in several ways to California policy goals (including Senate Bill 100 (De León, Chapter 312, Statutes of 2018) aimed at achieving carbon neutrality, Senate Bill 1477 (Stern, Chapter 378, Statutes of 2018) and Assembly Bill 3232 (Friedman, Chapter 373, Statutes of 2018), aimed at building decarbonization, and Assembly Bill 1470 (Huffman, Chapter 536, Statutes of 2007), which authorized the CSI-T program. AB32 (and others that support it) lays out a series of aggressive climate change mitigation goals; solar water heating can contribute to the achievement of these goals by using renewable solar energy to replace natural gas that would otherwise be combusted to heat water. This reduces GHG emissions and the production of NO_X, a byproduct of natural gas combustion that is a major smog precursor. Households using solar water heaters benefit privately from reduced natural gas bills. These lower bills are especially important for lower-income households and disadvantaged communities, which account for half of the CSI-T single-family solar water heating installations. Everybody benefits from reduced GHG and NO_X emissions, and installed systems represent progress made towards state goals. Other benefits of solar water heating are less quantifiable; it can often provide hot water (and even extra potable water) in the case of natural gas supply, electricity, or clean water shortages, adding community resilience.

There are possible negative effects, too. These include the possibility that lower costs for hot water—courtesy of solar water heating—could lead households to use more hot water or even more water overall. Using hot, rather than cold, water when solar-heated hot water is available is environmentally benign and can be a benefit of solar water heating. Using more water overall, however, would be a perverse outcome in a state with periodic water scarcity and substantial energy costs for transportation, pumping, and cleaning. There are also a variety of life-cycle costs, such as from manufacturing and transportation, which are generally modest (Hernandez & Kenny 2012); addressing these is the beyond the scope of this report.

For energy technologies, the standard criteria for whether a household should make a purchase is cost-effectiveness. Various metrics are routinely used here that see the purchase as an investment, comparing incremental technology cost and the future stream of energy expense savings relative to an assumed alternative without that technology. Given the often zero out-of-pocket cost of CSI-T supported systems and data limitations regarding actual bills, distributions of cost-effectiveness for the sampled households are not calculated.

Assessing Performance—Results from Literature and Definitional Difficulties

Literature on solar water heating performance focuses primarily on energy, engineering, and efficiency. For example: How much do solar water heating systems reduce water heating energy consumption compared to some chosen reference? Or: What portion of total water heating energy is provided by solar ("solar fraction")? The former depends on the assumed baseline and how that baseline is assumed to have functioned; even different legitimate choices can be highly consequential to the final answer. Neither necessarily reflects experience in the field.

Empirical evidence on solar water heating performance in California is scarce and somewhat contradictory. Two studies spanning the 10-year CSI-T program (Itron, 2011; Itron, 2018) came to quite different conclusions about the energy savings from California solar water heating systems, though in neither case did the performance estimates have statistically high confidence. Other studies in the United States have found quite variable performance. Some systems performed as expected, and others performed quite poorly due to a variety of problems (Rittleman 2004). Table 8 summarizes findings from four of these studies, the first two of which are from California. An important caveat in reviewing field monitoring results is that field-tested systems often receive extra scrutiny by virtual of monitoring, which may lead to performance improvements that would not have taken place in an ordinary installation.

A major challenge in assessing solar water heating performance is the choice of reference point or baseline. In saying a system is saving energy, the question is: "compared to what?" First, it is difficult to determine how much gas is being used for water heating, since it is entangled with space heating and possibly other end uses. Add to that the imaginary condition of the counterfactual (not having a solar water heating system) and the possibility that having the system affects how households use hot water. Some studies (e.g., Itron 2011 billing analysis), compare total gas billing data before and after installation of a solar water heating system, normalizing for weather differences. This approach seems viable, if other uncontrolled factors (such as an increasing or decreasing hot water demand trend independent of solar water heating, or backup water heater changeouts) are not present to interfere with the results. The Itron 2011 billing analysis had sample sizes that were fairly large for a field study (34 cases with natural gas backup) but still small relative to the variety observed, resulting in a wide confidence interval on the savings (41 percent to 140 percent of expected), higher than the other studies in Table 8.

Table 8: Relevant Previous Studies of Solar Water Heating Performance

	Itron 2018	Itron 2011	BEAM Engineering 2015	Rittleman 2004
Location	CA CSI-T	CA CSI-T pilot program	Massachusetts	Arizona
Relevant Sample	~18 single family and low-income	34 single family with gas backup, 28 with electric backup	35 installations in buildings with up to 4 units	18 homes in a single community
Method	Monitoring study	Billing analysis and monitoring study	Monitoring study of indirect forced systems	Monitoring study of ICS systems with gas or electric backup
Monitoring Study Findings	Mean of 50-60 Therms/yr saved, 47% of expected savings for single family; lower (22%) for low-income installations	Mean of 95 Therms/ year saved, 74% of expected savings (n=31), with a number of potential monitoring issues	After corrections and including 19 commercial/ multifamily systems, met 80% of expected savings	Properly operated systems with electric backup (6 of 18) achieved 88% of expected savings (equivalent to 66 Therms/yr); but most systems had much poorer performance
Billing Analysis Findings	n/a	Mean 108 Therms/year, 91% of expected savings for natural gas systems (n=34); 99% of expected savings from electric systems (n=28)	n/a	n/a

Source: University of California, Davis

An alternative is to measure or estimate the hot water produced by the solar water heating system, together with the hot water used overall. This approach was taken in all four studies listed in Table 8, but outside of laboratory conditions it is difficult to control for the many dimensions of system configurations, technology choices, and real-world challenges (such as connectivity issues and interactions with other systems). And without measuring water heating energy use prior to the installation of solar water heating, the question of what baseline to use remains.

A related problem is the difficulty in defining the boundary of the savings analysis. Most solar water heating systems can be added to an existing water heater. The OG-300 certifications[29] and CSI-T energy savings calculations for solar water heaters usually assume no change to the backup (natural gas) water heater. Of course, water heaters are sometimes, and maybe often, replaced when a solar water heating system is added, which affects (and possibly reduces) the energy savings that can be counted as a contribution of the solar water heating system, while also counterintuitively reducing the household total water heating energy use. Here the choice of system boundary inflates solar water heating savings estimates; a solar water heating system added to an old and inefficient tank water heater can potentially save more energy than the same system added to a typically new, higher-efficiency water heater. Certain solar water heating configurations are an exception, being certified with a tankless water heater backup. The OG-300 and CSI-T savings estimates for these systems appear to attribute gains from the tankless water heater efficiency as part of savings from the solar water heating system. Under the (modeled) energy savings metric used in OG-300 and for CSI-T incentive determinations, this may link to the popularity (about 30 percent of total CSI-T installations as of September 2018) of a relatively lower-cost and lower-rated-performance ICS-type solar water heating system installed with a tankless water heater. Most of the incentivized savings in this system may come from the tankless water heater rather than the solar water heater. This contrasts with the tendency to maximize the (modeled) efficiency of the solar water heating system when the incentive calculations assume an existing and relatively inefficient water heater.

Either technology should save water heating energy. But if the goal is minimizing GHG emissions or total water heating energy use, neither approach is necessarily optimal. GHG emissions are likely to end up somewhat higher than they might be if requirements and incentives were aligned. Focusing on this different metric leads back to questions about the boundary overall: should solar water heating instead be encouraged and incentivized within a bigger-picture approach also including (backup) water heater efficiency or tank size? Going further, could solar water heating and water heater efficiency be considered as part of a portfolio of actions that also includes hot water distribution systems and hot water demand including appliance efficiencies, fixtures, and people? This is closer to what is done in the California Energy Code for

29 The Solar Rating and Certification Corporation (ICC-SRCC) OG-300 Solar Water Heating System Certification Program provides proof of compliance for solar water heating systems to the current ICC 901/SRCC 300 standard (http://www.solar-rating.org/certification/system.html).

new construction (Title 24), and follows along the lines of the "whole house" or "deep" retrofit shift in focus of some efficiency programs in recent years.

Model-based savings estimates are necessary, but they can diverge wildly from field reality without the divergence being realized. Itron's CSI-T program evaluation (2018) noted several issues with the assumptions used in the Solar Rating and Certification Corporation (SRCC) simulation engine, which in turn has been the starting point for CSI-T savings estimates. The overall suggestion is that energy savings generated by a "corrected" model are about 40 percent lower than CSI-T reported estimates. This difference could explain the low performance of systems in the Itron evaluation (2018; see Table 8), though incorrect assumptions in the other direction could also be present in these models so this is not necessarily a final answer. More importantly, if these modeling corrections are applicable to solar water heating in California in general, the result would be a substantial reduction in the total estimated energy savings potential for California from solar water heating.

This raises the question of what is possible with well-functioning solar water heating systems. In terms of solar fraction (or equivalently: what portion of the natural gas used for water heating can be displaced by solar), common upper-end estimates range from 70 percent to 85 percent. This would be a tremendous proportion of residential energy use if the potential were scaled to all California single-family homes. But to achieve this, customer interest and costs aside, higher-performance systems (e.g., not ICS) and properly performing systems (many of which seem not to be) would be necessary. Also, achieving these performance levels averaged across all systems means adequately addressing the variability of hot water use and of system performance, as discussed next.

Performance Variability and Why it Matters

Researchers in this study paid particular attention to making sense of the variability of solar water heating performance by examining the sensitivity of energy savings and related impacts (energy cost savings, GHG reductions, NO_x reduction) to particular household, technical, and environmental factors. In what cases should solar water heating be expected to perform well, and in what cases poorly? A simulation was conducted, exploring the sensitivity of solar water heating system performance under a wide range of configurations and conditions.

Figure 12 shows the sensitivity of natural gas savings to a series of important performance factors in terms of the expected variability of those factors. For example, energy savings from solar water heating are dependent on hot water demand—no hot water use, no savings. House-to-house variability in the volume of hot water use is quite large, which is why this factor tops the list. Simulated savings are also sensitive to patterns of hot water use, controlling for the total level of hot water demand, especially when systems are closer to capacity. This effect is probably even larger for ICS systems (which were not simulated) because of higher rates of heat loss, especially on cool nights, resulting in larger swings in hot water availability and performance that is particularly sensitive to the timing of hot water use during the day and night.

Figure 12: Sensitivity of Natural Gas Savings to Performance Factors, Relative to Expected Variability in the Factor

Relative Sensitivity	Performance Factor
More sensitive	Household hot water use level by gallons per day (GPD) • Collector / storage tank configuration (however, only different indirect forced system configurations were considered) • Climate zone (solar resource and weather) • Solar water heating system inefficiencies • Backup water heater type / efficiency • Household hot water use pattern (for indirect forced systems; ICS system performance is likely to be much more sensitive); more when solar water heating systems are near capacity • Sizing of system relative to hot water demand • Year to year weather/solar variability
Less sensitive	Inlet temperatures

Source: University of California, Davis

Solar water heating performance is sensitive to system inefficiencies. In actual installations these tend to be diverse in cause, and sometimes include complete failures. These complete failures were not assessed here but, disappointingly, seem not uncommon in solar water heating installations. Most studies of solar water heating performance seem to have encountered some problems with systems related to installation, equipment malfunction, design flaws, and user interactions (for example BEAM Engineering 2015, Rittleman 2004, Itron 2018).

The median age of the solar water heaters in households surveyed in our study was three years. Even at this fairly new stage, 40 percent of respondents to the household survey completed for this project reported issues with their CSI-T installations, though many of these problems likely did not directly affect system performance (see Chapter 6). The data collected are not sufficient to quantify the overall effect of inefficiencies on solar water heating performance; however, they do suggest that performance problems are too common and significant to be ignored.

Benefits in the Face of Variability

For households, the implications of this variability are that some will save a lot on their bills while quite a few will save very little. This was roughly borne out by survey respondents, where 31 percent said they saved "a lot" on their natural gas bills in the summer, 38 percent said they saved "a little," 11 percent said there was no change, and 3 percent said bills had increased.[30] In most cases, from a household perspective the energy bill savings from solar water heating are modest in absolute terms. For nearly all households, they will be less than $200/year and for many or most, less than $100/year. These are modest amounts relative to potential electricity savings from PV for many households, but can represent a substantial proportion of natural gas bills for some households. Even at the high range of savings ($200/year) and the low range of system costs ($4,000), simple payback is twenty years, so for most households payback would be longer. As discussed in the previous chapter though, households are not necessarily looking for cost-effectiveness, but often instead steady savings and co-benefits at a reasonable cost.

In terms of emissions, solar water heating systems do reduce GHG and NO_x emissions, with the variability in energy savings translating fairly directly to variability in GHG emissions and with NO_x emissions additionally varying depending on whether the backup water heater is a low or ultra-low NO_x design.[31] Electricity for pumping (for the perhaps 50 percent of CSI-T systems that rely on grid electricity) takes only a small chunk out of the emissions reductions, at least for well-functioning systems. A system saving $100 in natural gas bills will save about 0.5 metric tons of CO_2 greenhouse gas emissions and about ¼ to 1 pound of NO_x emissions (depending on the make of the backup water heater) per year.

The availability of resilience benefits in emergencies and outages depends on the configuration of the solar water heating system and backup water heater. Similar to tank water heaters, the water in solar water heating system tank(s) is potentially drinkable in an emergency, if it can be safely accessed. Depending on whether they rely on grid electricity for circulation pumps and controllers, many but not all solar water heating systems will work and provide some hot or warm water in an electricity outage, weather and season permitting.

In terms of takeback or rebound from lower-cost hot water, evidence is scarce. Hot water use levels in the Itron evaluation (2018) did not suggest that those households

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30 An additional 16 percent said they were not sure of their savings.

31 Lower-NOx systems are standard smog-mitigation requirements of many air quality management districts in California.

were using exceptional quantities of hot water. Ten percent of respondents to the household survey completed for this project reported using more hot water because of their solar water heating system, and 4 percent reported using less (74 percent said it remained unchanged). Sixteen percent of households reported shifting when they use hot water to take better advantage of the solar resource.

Opportunities, Niches, Barriers and Paths Forward

Determining How Systems are Actually Performing

Even with the valuable findings from Itron's recent M&E study (2018), substantial uncertainty remains as to how well recently-installed solar water heating systems are performing in California. The Itron (2018) results suggest that systems are saving much less energy than expected, and though the study found performance problems with a few particular systems (in addition to the FAFCO® systems mentioned in Chapter 4), it did not conclude that systems were systematically inefficient or underperforming. Rather, it pointed to inflated model-based expectations being responsible for most of the problem. Does that mean that solar water heating, even if performing optimally, really can't save 75 percent or even 85 percent of a California home's water heating energy demand—and expectations should be reduced accordingly? The earlier pilot study results (Itron 2011) painted a different picture with savings estimates reasonably close to expectations (Table 8), though they showed somewhat lower monitoring-based performance estimates (with the monitoring study discounted as flawed).

There are many possible explanations for the discrepancy between the two studies. Due to small sample sizes and methodological limitations, confidence intervals on savings estimates from both studies are quite large and overlap considerably. Conditions also changed substantially between 2009 (around the time of the pilot study data collection) and 2016/2017 (the time of the final M&E data collection), from recession years to drought-affected years. Consistent with the changing conditions, average hot water draw volumes for monitored households in the pilot study appeared to be higher (mean approximately 55 to 60 gallons per day,[32] close to model-assumed levels of 64 gallons per day), while levels were substantially lower for most households in the final study (with a mean of 48.8 gallons per day and a median of 30 gallons per day[33]). Methodologically, it appears that the 2011 billing analysis does not account for energy savings from a backup water heater replacement completed along with the solar water heater, while the 2018 M&E does attempt to account for these differences. Similarly, the 2011 billing analysis methodology risks inadvertently attributing any incidental household changes affecting natural gas use around the time of the solar water heating

32 Estimates are calculated from data provided in Itron (2011).

33 Estimates are calculated from data provided for the study by Itron.

addition (for example a heating system retrofit) as savings from solar water heating. A new larger-scale billing analysis with an appropriate sample and using the hourly or daily interval natural gas metering data now regularly collected by California IOUs could help, but for now there remains a huge question around the potential scale of energy savings, GHG and NO_x reductions, and other benefits from solar water heating in California.

Finding High Gallon-per-Day Households

Hot water demand varies quite a bit, with few households using large amounts of hot water. From an optimization standpoint, these households could be targeted as potential solar water heater purchasers because the cost-effectiveness and emissions reductions would be high. Doing so would require intricate operations—for example, an analysis of natural gas usage from interval metered data (such as could be conducted by a utility)—and a good sales pitch. The system would have to be appropriately sized to take advantage of the potential savings from high hot water demand. In simulation results, this uncommon combination of high hot water demand and high solar water heating performance was generally what it took to get into the upper range of savings—say on the order of $150 to $200/year.

On the flip side, cost savings from households that use low amounts of hot water are low at normal, non-incented system costs because there is not much energy to be saved. These households may still want and enjoy solar water heating systems, including their environmental benefits, but they can also be misled into thinking they will be saving more money than is possible. Almost one-third of survey respondents said that their system did not save as much as they expected. While moderate- and low-use households can still benefit from these systems, substantial gas bill savings are less likely, and cost effectiveness is even more elusive with a lower-cost solar water heating system. Solar water heating systems sold to these households should probably be marketed on other grounds than cost-effectiveness—and this may be acceptable to many households.

Dealing with Problems and Inefficiencies

It is unclear quantitatively the degree to which performance problems, which have not been completely resolved, are degrading energy savings and other benefits from installed solar water heating systems in California. The FAFCO® problems experienced in CSI-T are a good example of the ongoing difficulties. There were other problems reported in the Itron M&E sample (Itron 2018) and in the household surveys completed for this project. These levels of difficulty are probably enough to reduce adopter satisfaction and cost-effectiveness, as well as affect the bottom line of solar water heating installers, though this cannot be empirically verified. Use of interval meter data would help to resolve questions about the discrepancies between performance-based monitoring and billing analysis, and clear up some of the uncertainty surrounding solar water heating performance.

Broadening Boundaries and Choosing Appropriate Metrics

As discussed above, solar water heating (in California, at least) is one possible element in a system of people, appliances, fixtures, distribution, and (backup) water heating equipment. The best solution for a particular home will depend on the chosen system boundaries and the goals (and metrics) chosen. Looking at energy savings from just the solar water heater (and sometimes from the backup water heater) will favor certain outcomes. While these may be generally good, a different combination of boundaries, metrics, and goals may lead to other (and possibly better) outcomes. The most holistic view would consider solar water heating among whole-house possibilities, given ongoing and projected transformations in California's energy and water systems.

CHAPTER 8: Technology Assessment Summary and Niche View

Solar water heating in the 20th century was characterized by fits and starts. In the early part of the century, solar water heating offered a superior way of heating water in the home but was derailed by unexpected technology failures and the discovery and embrace of cheap natural gas. In the 1970s and 1980s, solar water heating offered a welcome introduction to solar energy in line with environmental ideals and offered a response to international energy dependence and the energy crises of the era. Again, there were technical problems, generally attributed to inexperience with the technology and lack of government financial support.

Several companies continued installing solar water heating at a modest pace over the subsequent decades. Eventually, the CSI-T program was launched in 2010 at a time when natural gas prices had a major spike, although prices fell by half a year later. When locally defined CSI-T incentives increased in 2016 (related to managing a major leak in a natural gas storage field in the state), in less than two years a new player in the solar water heating market had installed 52 percent of the program year total. With this installation surge, the average price of installed systems dropped to a mode of $4,000-$5,000 per system—half the modal price of prior program years, in part because the simpler ICS technology was deployed and likely in part because customer acquisition became less expensive. In addition, these systems were paired almost exclusively with on-demand water heating systems rather than storage tanks. These innovations occurred in an environment of declining value of a solar water heater's savings. Californians use of hot water fell as a result of drought-induced conservation, energy-efficient appliances, and low natural gas prices. Thus, the impact of innovations in solar water heating technology were mostly offset by other conditions. Households that have installed solar water heating under CSI-T support include many for whom the system was installed at no cost, as well as many whose incomes were very high.

California's energy policy began focusing on zero net energy, widespread electrification, and decarbonization of electricity supply, leaving natural gas efficiency more associated with the past than with the future. The number of PV installations, a rare and largely utility-scale-only technology in the 1980s and rare even in 2005 when the Million Solar Roofs program started, is now close to one million in the state.[34] The attention to installing PV on rooftops left solar water heating in the shadows with less cachet, far

34 The California Solar Initiative (versus the related CSI-T addressing solar thermal technologies) estimates there have been 957,130 solar projects of all types as of March 31, 2019. (California Distributed Generation Statistics, https://www.californiadgstats.ca.gov/).

less sales pressure and industry interest, and otherwise lacking some of PV's selling points.

These are only some of the events and shifts affecting solar water heating in the past century in California. Any socially-grounded technology assessment toward the future has to take these into account. At the same time, getting a handle on the overall performance of solar water heating, in terms of the distribution of how well it works to reduce natural gas use, when it works well and when it does not, remains difficult. There are systematic barriers to large-scale evaluation of natural gas savings and pollution reduction, including the difficulty accessing natural gas billing data for solar water heater users, especially when the details of the home and the system can be linked to consumption data so that an analysis of factors affecting technical performance could be included.

Contrasts

A common characteristic of the experience with solar water heating is contrasts. Contrasts are not unique to solar water heating but may be especially important in understanding its prospects in California. The following are the most important of these contrasts:

Complexity versus Simplicity

In general, complex systems have the potential to be more efficient but are also more sensitive to installation and conditions.

Laboratory versus Field

There is no doubt that solar water heating can work well, but the field evidence shows that it often does not work as well as expected relative to efficiency ideals or user standards, and is sometimes quite disappointing. There are various explanations for this, including the fact that experience is still limited, and inexperience and experimental changes can lead to difficulties and failures. As yet there is no quick way to fix this.

Engaged versus Passive Users

One clear contrast is seen among users of solar water heaters. There are some households that enjoy the technology, and actively participate in its use by adjusting water use practices, monitoring the system, and experimenting. These households also tend to be especially aware and appreciative of technical, environmental, or social aspects of the technology. For others, the system is treated more like a typical household appliance–it garners attention when broken but otherwise is simply viewed as a technology that heats water efficiently.

Energy Efficiency versus Emissions Reductions

The energy efficiency view of solar water heating links the performance of solar water heaters to the costs under which it reduces fuel use relative to an alternative. The emissions reduction view focuses instead on the stream of reduced emissions going forward; costs matter, but are not the sole determining factor. This parallels how households think about the financial proposition. Most users focus on monthly reductions in energy use and costs, rather than viewing the technology as a financial investment, as an energy efficiency model would. The former is a relatively short term view stymied by uncertainty (Maiorano 2018).

Reducing Demand versus Increasing Supply

Similarly, solar water heating holds an ambiguous position between being an energy efficiency technology and an energy generating technology. The energy supply aspects may be more powerful and competitive going forward since there are few alternatives at the household level, and many that relate to energy efficiency.

Electrifying End Uses versus Lower-Carbon Natural Gas End Uses

In California there is a current emphasis on electrifying end uses as a way of moving away from fossil fuels (see Koehler 2018). In this context, using solar water heating in combination with natural gas water heating results in a technology cul de sac: all the emission reductions benefits are tied to the use of a fuel that is undesirable with respect to the overall goal. With respect to this electrification vision, the expected long lifetime of solar water heaters, as much as 30 years, becomes a conflict. Of course it is possible, and maybe even desirable, to develop a more moderate view of future electrification, where fossil fuels play a legitimate role for many decades to come. In that case, solar water heating as associated with natural gas-fired water heating is more suitable.

Finally, there is a contrast between seeing solar water heating as a technology almost universally suitable for households in the state, versus seeing it as a technology that is best suited to particular conditions and types of households. The remainder of this chapter summarizes findings on these niches.

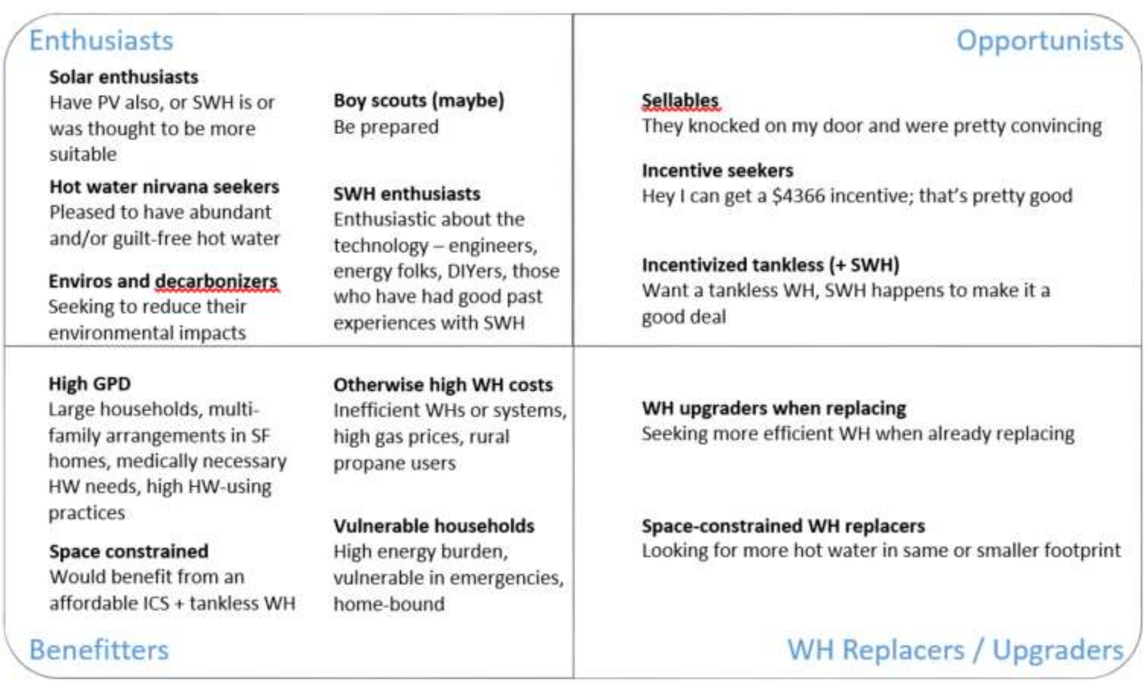
Niches

In technology transitions theory, a "technological niche" usually refers a technology that is highly isolated from the current sociotechnical regime and is unstable, a typical situation for innovations which are often supported by public subsidies (for example Schot & Geels 2007). While this is the case for solar water heating, the term as used here more specifically refers to situations in which solar water heating is, or could be, most appealing and most effective. A number of these niches were identified throughout the research. A few of these niches are outside the scope of this report (which is single-family homes using natural gas for water heating):

- Solar water heating for homes using electric water heating, which is appealing because it is much more cost-effective than for natural gas—though in these cases PV-based water heating is also a viable alternative.
- Homes using propane for water heating, since propane is expensive and homes with propane may be especially interested in resilience given their locations further from urban centers and services (depicted in Figure 13).
- Multi-family housing, since the costs for customer acquisition and installation can be centralized over multiple households, and diversity in hot water use across households can suit the efficiency characteristics of solar water heating well.

Figure 13 lists the niches identified for households using gas for water heating (with a few exceptions). These echo the user segments discussed in the household analyses in Chapters 5 and 6. There are four quadrants. "Benefiters" (lower left quadrant) are households with high hot water use and expenses, or high energy burden relative to their means. In the latter case, under the CSI-T program there was usually no out-of-pocket cost to the household. Compared to other publicly-funded energy efficiency investments for these households, solar water heating can be a reliable and effective solution. Other households with high water use due to high occupancy or special needs are the best candidates for high cost-effectiveness.

Figure 13: Adopter Niches among Single-Family California Households



Source: University of California, Davis

“Enthusiasts” (top left quadrant) have probably been the most common type of solar water heater adopter outside of the CSI-T program. These households like the idea of solar water heating, often understand it, and may especially value the pleasures it brings (“Hot water nirvana seekers”) or the environmental, social, or political implications of the technology (“Enviros and decarbonizers”), as much or more so than the financial savings.

“Opportunists” (top right quadrant) might not have any special interest in solar water heating, but are persuaded by marketing outreach, the availability of incentives, or side-benefits such as tankless water heating. This opportunism is common in PV sales as well (Moezzi et al. 2017). Solar water heating’s opportunistic camp might be one of the most promising areas for future growth, spurred by active marketing techniques. It may be quite dependent on the availability of incentives and federal tax credits, neither of which have a clear long-term future.

Finally, the lower right quadrant contains households actively looking for improvements in their water heating. They could be at the point of needing to replace their existing water heating and want better or more service, such as more hot water, or to solve a specific problem such as relocation of their water heating tank. Currently, solar water heating may not often be presented to the “Water Heater Replacers/Upgraders” group as an option, but there may be effective ways of improving the connection: for example, making sure that solar water heating is on efficiency recommendation menus.

Identifying these types and their unique motivations and drivers may be useful in crafting a market segmentation approach to promoting solar water heating, at either the policy or installer level.

CHAPTER 9: Mid- and Long-Term Changes

Planners, policy makers, and households all speculate about potential changes in the mid- and long-term future of the state, but actual changes may not match up with these speculations. The official estimates and guideposts created through policy, planning, and sales tools (such as savings estimates) create expectations as well as benchmarks against which future performance can be judged. In the case of solar water heaters, the CSI-T program uses models together with a particular set of assumptions based on the house, its location, and the system description to estimate future savings and set incentive amounts. However, these future savings depend on many unknowns. This chapter lays out of a few of the dependencies in the future, illustrated by some of the changes observed in the past.

Natural Gas Prices

There are two main markets for natural gas in California: direct consumption by natural gas burning appliances, and sale of natural gas for electricity generation. About 90 percent of the natural gas used in California is imported from elsewhere in North America, including from Mexico and Canada (Braithwaite et al. 2018). Natural gas is traded in a market serving all of North America, with the exception of natural gas for power generation which is traded through a regional market. Natural gas contributes a high percentage of the electricity generated in California. It is also used especially for peak generation, playing an important role in fast-dispatch electricity and integrating renewables into the grid (Braithwaite et al. 2018).

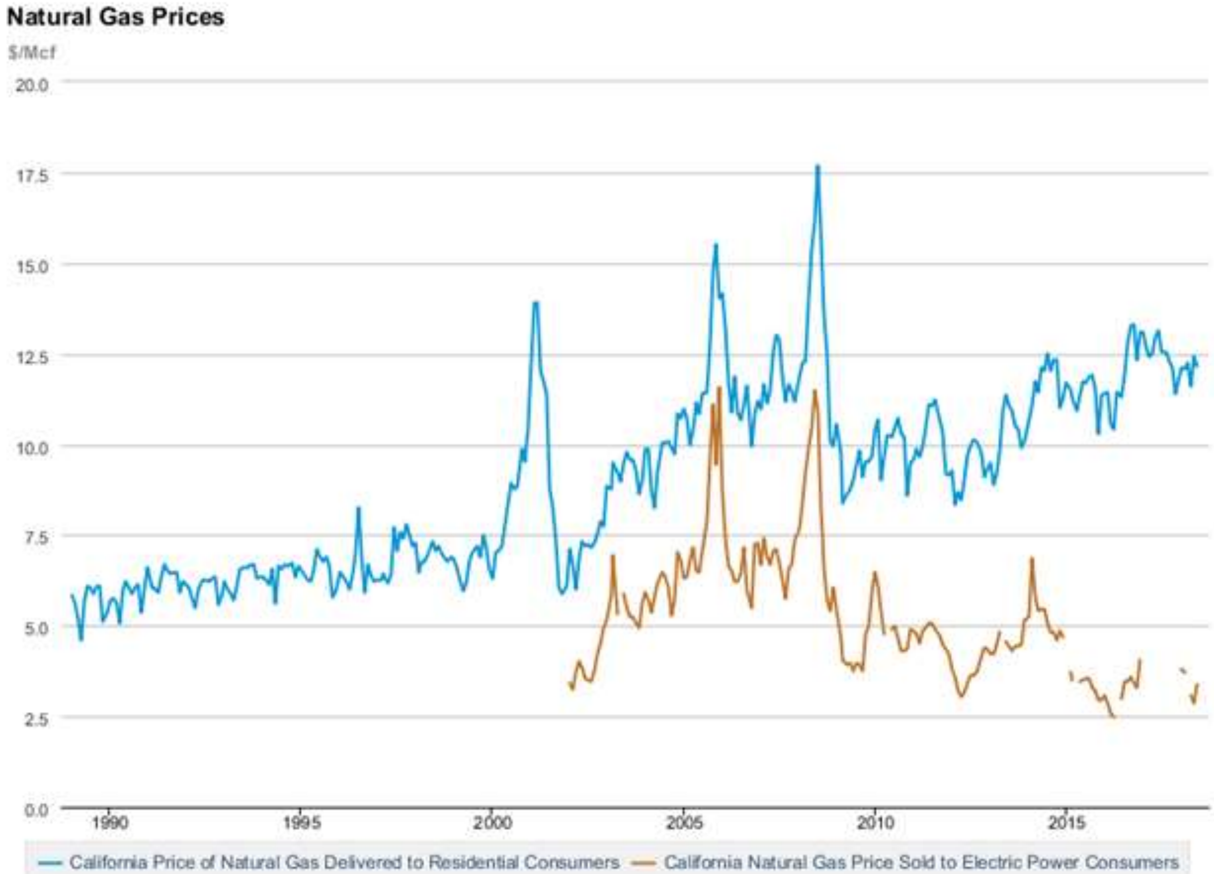
Figure 14 shows that the nominal price of natural gas is now more than twice the 1990 price in a steady but sometimes very spiky upward trend. Shortly after the $17.69 peak in 2008, the CSI-T program was developed; that price, nearly 50 percent higher than 2018 prices, results in a much more favorable cost-effectiveness estimate per dollar of solar water heating system cost than do current prices.[35]

In October 2015, a major leak was identified in the Aliso Canyon methane storage field near Porter Ranch, Los Angeles, one of the largest such storage fields in the United States. The leak released substantial GHGs into the atmosphere, reduced the availability of natural gas to power plants, displaced some local residents, and led to political and social questioning about the risks of natural gas use and storage. The incident also led to increased incentive levels for single-family and multi-family solar water heaters in the Southern California Gas Company territory, up to 59 percent of total project cost but in

35 See also the Energy Commission's *National Gas Market Trends and Outlook* series which outlines future expectations for natural gas in California.

fact enough to cover the whole cost of the lower-priced system types installed, as evidenced in CSI-T program reporting.

Figure 14: Residential Natural Gas Prices Compared to the Cost of Natural Gas for Electricity Generation (1990-2015), Dollars per Thousand Cubic Feet



Source: United States Energy Information Administration 2018

The future cost-effectiveness of solar water heating depends on future system costs, incentives and credits that reduce these costs, repair and maintenance costs that may increase the real price of the system, natural gas prices which are highly subject to at least short-term variability, and the amount of water heating used. California predicts that residential natural gas demand will fall flat in the near future, with a 3 percent increase in prices per year between 2018 and 2030 (USEIA). This price increase will not appreciably change the cost-effectiveness calculations for solar water heating. Rather, the critical cost apart from incentives is system prices, which can be strongly affected by international market as well as by the costs of customer acquisition. It is possible that system prices will be further reduced from their relatively low recent level ($4,800 mode). This may require building and selling a substantially simpler system.

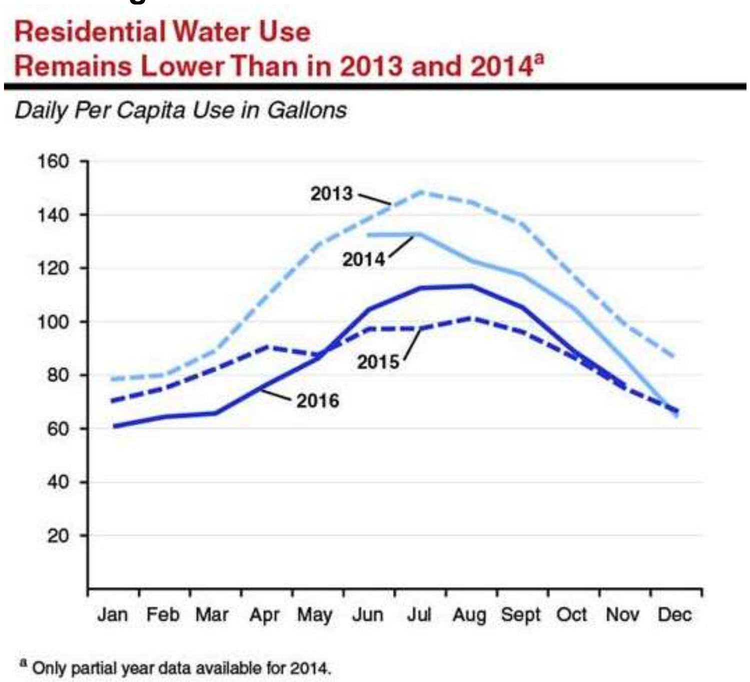
In short, cost-effectiveness of solar water heating may of course change, but there is nothing that promises major increases in current levels. Households with particularly high hot water use are the best candidates for solar water heating under cost-effectiveness criteria. And low-income households eligible for incentives covering all or the majority of project costs are good candidates for solar water heating in that they can achieve substantial energy cost savings and GHG emissions reductions, how program costs are accounted for aside. Capturing a fuller potential of emissions reductions available through solar water heating will depend, in part, on developing and highlighting other benefits of solar water heating, decreasing risks and vulnerabilities, and making solar water heating more visible in acquisition pathways, rather than simply focusing on current cost-effectiveness.

Water Use

Emissions and energy use reduction from solar water heating depend on how much hot water is used and on draw patterns relative to a counterfactual baseline. Households generally do not have a good idea of how much hot water they use, nor is there is a good set of data on actual usage or potential savings. This is a major uncertainty in savings estimates both in aggregate and in planning by individual households.

Most notably, achieving high levels of savings requires high levels of hot water use. Figure 15 shows that water use per capita in California has decreased substantially over the past few years. Much of this decrease is in summer use, likely for yards, gardens, and recreation, but winter use—and thus likely hot water use—has also declined.

Figure 15: Changes in Californian's Residential Water Use



Source: California Legislative Analyst's Office, 2017.

These declines may be due in large part to California's drought and related pressures to conserve water. Along with this, there has been a trend toward smaller average household size, which would reduce household hot water use on average, since hot water use levels are positively correlated with number of people in the home.

Solar Thermal Beyond Water

Household-level solar thermal water heating can be combined with other solar thermal-driven end uses. A few of the households consulted in this research used solar thermal hydronic radiant (underfloor) heating in addition to their solar thermal for water heating. In Europe these are known as combi-systems and are said to be "common" in Northern European countries, where the cost of upsizing is more suitable given higher heating loads (IRENA 2015). An IEA study estimates that combi-systems account for 2% of the worldwide installed solar thermal capacity (Weiss and Spörk-Dür 2018).[36] Thus, for now, combi-systems do not appear to be a natural bet for increasing the appeal of solar water heating in California, though there may be viable specialty markets in colder areas and for those who value maximizing levels of solar for their home.

Solar thermal cooling combined with solar thermal water heating could eventually be a relevant combination for California, especially given anticipated increases in cooling loads. In particular, many single-family households in California do not currently have central air conditioning but may be seeking it in the decade to come if hotter weather and heat waves continue. However, the solar thermal water heating and cooling combination is not very developed (IEA-ETSAP and IRENA 2015), and the current direction in the state points toward promoting electric heat pumps as a replacement for natural gas space heating. These heat pumps would probably often also provide air conditioning.

Neither a space heating nor space cooling add-on seem to currently offer a near-term boost to solar thermal water heating. This could change as (or if) experience increases or as technical innovations are developed.

Visions of the Future

The appeal of solar water heating also depends on visions of what the future might or should be like. Some of these visions are developed and promoted by government and research institutions, and then encoded into policies, standards, and regulations reflecting these visions. Other visions may be more sociocultural and are even harder to predict. One possibility, however, is a changing aesthetic of what technologies are appropriate for the home and why. This may be one of the most critical questions for

36 The 2% includes large domestic hot water systems as well as single-family domestic hot water systems and pool heating.

solar water heating going forward. Chapter 10 discusses a few of these possibilities in more detail.

Knowledge Transfer

Throughout the course of the project the researchers engaged with a wide variety of stakeholders (e.g., members of industry, policymakers, customers). Information about technical performance, market adoption, and the future potential for solar water heating in California was gathered and exchanged through interviews and a group discussion (i.e., Technical Advisory Committee meeting). The researchers facilitated dialogues across diverse stakeholder groups that do not typically overlap. Niche markets were identified and explored, as were opportunities for future markets. More such exchanges are needed to realize the potential for solar water heating to serve appropriate niche markets.

CHAPTER 10: Implications of the Research

This study set out to explore California household solar water heating in an expansive way. It revisits some of the questions usually covered in energy technology evaluations as well as going further to consider the "why" and assessing solar water heating in terms of history, actors and actions, and plausible futures. Rather than a defense of a technology, this analysis, and especially this chapter, takes a broader perspective, viewing solar water heaters in light of technology trajectories seen in history, where attitudes, outlooks and conditions regularly evolve and sometimes sharply change. The first chapter presented a summary of common arguments about the viability of single-family solar water heating in California along with notes on how this research answers to or reorients them when necessary. This chapter recaps these arguments and highlights some possible next steps. Throughout, unless otherwise stated, "households" refers to California single-family households using natural gas for water heating.

Orientation

This report outlined two related research tenets. The first was seeing solar water heating distributionally rather than universally: households vary, as do the technological characteristics of installed solar water heating systems. This variability goes hand-in-hand with the fact that the prospects for the future of solar water heating are uncertain. There is a wide variety of ways that the performance of solar water heaters can be depicted: cases where solar water heaters are expensive, hard to get right, and do not work well; and cases where they are much-loved, work well, and operate for decades, whether or not cost-effectively in standard terms. Ideally, one could find the right combinations of households, technologies, and installers and adapt to achieve more of the latter and less of the former. But there are no good mechanisms to identify those situations and deliver the appropriate technologies. One simple example is the lack of a method for installers to identify and target high users of hot water for whom solar water heating would make a compelling economic argument. Detailed energy audits, perhaps especially through community energy agencies, might be able to identify households that would particularly benefit from solar water heating—but generally targeting energy efficiency is much less precise.

Second, solar water heating is neither purely an energy efficiency measure nor an energy supply source, and this ambiguity can cause some confusion. Seen in an energy efficiency framework, solar water heaters reduce the amount of natural gas needed to heat water, making the overall water heating system more fuel-efficient. The reductions in hot water demand from user conservation, low-flow showerheads, and water-efficient appliances have made solar water heating less cost-effective because the high first-cost must be spread over smaller energy savings. As an energy supplier, solar water heaters displace fossil fuel-based heating, serving the state's policy emphasis on emissions reductions. But solar water heating has been eclipsed by PV. PV, unlike solar water heating, can serve multiple different energy uses in the home. It also makes visible contributions to energy supply at the grid level, which solar water heating does not. The multiple dimensions to solar water heating – e.g., energy production, fuel-switching, energy efficiency – make it a more conceptually complex technology to characterize, and perhaps therefore to promote.

The Greenhouse Gas Emissions Reduction Argument

Water heating accounts for about as much natural gas use in California homes as space heating—each about 40 percent of aggregate residential use. This makes water heating a very attractive target for reducing natural gas use in the residential sector. Normal energy efficiency measures for natural gas water heating, such as higher-efficiency storage tank-based systems or flow regulation, can save energy, but only a small percentage (Itron 2017).

The climate change view is different than the energy efficiency view (Moezzi et al. 2018). Well-functioning solar water heaters, by displacing some fossil fuel-based heating with solar heating, can plausibly supply 70 percent or more of domestic hot water needs in many households, far beyond what efficiency measures can do. In addition, the prevalence of natural gas water heaters means there is a potentially large market for replacing them with solar water heaters.

Market adoption of solar water heating has been slow and erratic since their introduction in the early 20th century. More recently California's CSI-T program has heavily incentivized them (even to the point of total subsidization in some cases), but the penetration of solar water heaters remains low. This means that the aggregate contributions to statewide emissions reductions are still low, even if all systems worked perfectly. The discussions below essentially speak to pathways and options by which the potential of solar water heaters might be better captured, under what conditions, and address the feasibility given the obstacles and alternatives.

Household-Level Economics

- The cost-effectiveness of transitioning to solar water heating, in traditional energy efficiency terms, is not very favorable for most households using natural gas water heaters under current conditions. For most single-family California households, using solar water heating to displace natural gas use will not deliver a quick return on investment at non-incented system prices.[37] This result is

[37] Market prices are also sensitive to incentives, i.e. base pricing likely takes into account the availability of incentives in anticipating how purchasers will consider costs and adding administrative costs. As

consistent with most expectations and literature. A cost-effectiveness argument for solar water heating is much easier to make with propane and electricity backup, since both are expensive relative to natural gas. Therefore, these (especially propane) may be important (and readily observable), though small, niches for solar water heating in California.

- Installed costs show appreciable declines in recent years, but costs are not the only factor motivating adoption. One of the premises of this study was that a consideration of solar water heating and its cost-effectiveness should go beyond a simple evaluation, toward finding broader but still concrete pathways for energy systems transformations. First, typical system prices have decreased over the past decade. Half of the systems installed under CSI-T in 2017 and early 2018 cost less than $5,000, much lower than the median price of $9,000-10,000 in the first few years (2010-2013) of the program.[38,39] The more recent installations are dominated by a less expensive system type (ICS) and a single installer, one that focused in particular on installations in a few zip codes where incentives were elevated so that total system cost was nearly zero for many of these households. Thus a comparison over time may obscure key differences in payback rates, cost-effectiveness, commercial availability, and other important factors. CSI-T incentives – as a subsidy and a signal of technology quality – have also influenced adoption in recent years. Second, costs and savings are probably important for most buyers, but not necessarily in terms of a demand for short payback periods, and not to the exclusion of other properties valued, as discussed next. In fact, early adopters in California faced far longer payback periods than those estimated for some other countries (Hernandez & Kenney 2012).
- Households often used their own economic reasoning when adopting solar water heating and their arguments were legitimate and logical, though they did not always reflect a conventional cost-effectiveness calculation. Even at relatively low levels of cost-effectiveness some Californians have still bought solar water heaters, and sometimes with the goal of saving money. These households often focus on expected monthly savings and initial costs, balanced by other benefits

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estimated above, the best simple payback period households might expect is 20 years, short of major changes in natural gas prices.

38 These are the costs recorded in the non-public CSI-T database.

39 In addition to the differences in technical systems, the main types of households for which solar water heaters were installed were also different between these two time periods. The later installations were dominated by low-income installations (often with a near-zero cost to households), while the former installations were often to wealthier or more experimental households.

such as environmental benefits and ample, low-cost hot water.[40] When the environmental motive was especially strong investing in solar water heating merely had not to be financially imprudent. Purchasers with very high incomes (see more detail further below) reported this type of rationale, and different types of households displayed other ways of judging the merits, as the discussion of user/purchaser niches below describes.

With a small and select group of users, it is difficult to predict who the next set of purchasers might be. One thing is certain: the CSI-T incentive made a big difference in the installation rate for solar water heating, since few households (22 percent) surveyed were sure that they would have purchased solar water heating without it, and many even learned about the availability of the technology through the program and the incentives it offers. Also unknown is how many households have considered and then rejected the possibility of solar water heaters, perhaps choosing to purchase PV instead, or remaining with conventional storage tank. Like other household purchases (e.g., a new television or even a conventional water heater), solar water heater purchases are influenced by many factors beyond financial cost-effectiveness, such as expected benefits and costs, how the product is encountered and sold.

Technical Performance

From an environmental policy perspective, there are at least two important questions about solar water heating: How much does (or could) it reduce natural gas use and NO_x emissions? and, Does it provide adequate hot water to justify the costs? There are several ways to quantify the emissions and energy use reduction potential of solar water heating. One is relative to engineering ideals—how the technology performs relative to technical models or other expectations of its performance and efficiency. Another is how well it compares to competing technologies. These choices have an important impact on metricizing performance.

Performance in the field is uneven and sometimes poor. Field data are scant and varied. Some households surveyed were very satisfied with their solar water heaters, while others noted significant shortcomings. This has been shown by other studies in California (Itron 2018) and in some other countries (Giglio and Lamberts 2016 for Brazil, Gill et al. for Australia; Hernandez and Kenney 2012 for Ireland),[41] echoing some of the past problems in California. Itron's evaluation of California's CSI-T solar water

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40 To be more precise, cost-effectiveness is often used as a program metric, for example, in estimating which energy efficiency upgrades are "worth it" to consumers and in guiding households to those choices such as through home energy audit recommendations. This does necessarily mean that programs expect households to think this way.

41 Measured studies are often done in experimental contexts, such as evaluations, which can often mean that systems get more attention than run-of-the-mill installations, but also that there was something unusual about the technology or setting.

heaters revealed a case in point (Itron 2018). For any technology, small shortfalls relative to modeled technology performance are probably expected by or acceptable to most buyers. In fact, many household energy technologies, including refrigerators (Rees 2013) and compact fluorescent lamps (Sandahl et al. 2006), took decades to achieve consistent, high quality performance. In the meantime, "ideals" may constitute unrealistic performance targets that will inevitably not be met. In some cases, solar water heaters have failed to meet even very basic expectations, as in the malfunctioning of FAFCO® systems and the high percentage of households who said that there were problems during installation.

Both the technical analyses conducted in this study and the household survey found evidence of uneven technical performance of solar water heaters. More than half of households said they were likely to recommend solar water heaters to others (8 or higher on a 0-10 point scale). On the other hand, a notable minority (17 percent) rated satisfaction below the scale midpoint (4 or lower). Without detailed performance analysis or rigorous technical evaluation of natural gas savings, it is impossible to tell how much actual performance differs between the satisfied and dissatisfied households. Unpacking this would require fine-grained interval meter data for many households along with system details, information that was requested but not granted because the institutional hurdles could not be surmounted within the project time frame.

What difference does it make? Reducing technical problems improves actual GHG emissions reductions and savings. Technically, this would improve cost-effectiveness, most importantly for those where the systems work very poorly. This could have benefits throughout the supply-user chain, since it would reduce call-backs and customer dissatisfaction.

How would the risk of poor performance be reduced? First, it is important to consider what type of performance to aim for (e.g., perhaps overall efficiency is less important than minimizing failures) and how related improvements could be approached. The CSI-T program already provides many mechanisms to ensure product quality. The 10-year warranty required by the CSI-T program is virtually unprecedented and may provide some level of comfort, but warranties do not eliminate inconvenience and management costs.

Installation training is available, though few installers have long field experience, and the exact systems, configurations, and components used changes as installers, manufacturers, and other innovators respond to shifting market opportunities.

Simplifying solar water heating systems could help promote adoption. Solar water heaters can be complex; they involve interacting subsystems, elements exposed to the outdoors and to water, and sometimes various decisions that need to be made for the site that could affect performance. These sensitivities to deviations from ideal have led to arguments that systems that are less technically efficient but more robust

(Weingarten 2016) could reduce poor performance and lead to cheaper systems, though likely at the cost of system longevity and user convenience.

How might technical innovations change the landscape? The United States has made modest investments in solar water heating technical innovations, as have a variety of independent institutions and individuals (Moezzi et al. 2019). However, the "valley of death" between technical innovation to widespread (or at least profitable) dissemination is challenging. There is sponsored research in many other countries (IEA 2018), though the resulting innovations are not necessarily applicable to the conditions in the United States or California, where solar water heaters are not nearly as popular and economic and energy conditions are not as compelling. While solar water heating innovation continues on a small scale in the United States, some industry informants claimed there were few remaining opportunities for significant improvement apart from lower price points which would make the technology more economically competitive with respect to natural gas.

Understanding Users and Finding Buyers for Solar Water Heaters

There are a variety of different household types where solar water heating has been installed. There is no "average" solar water heater purchaser; instead, there are many types with different motivations (see Chapter 9 for a discussion of niches). These are partly linked to acquisition mechanisms. One main division in the sample used in this research was households that received their equipment free of charge or nearly so, versus those who paid moderate or high amounts. The no-cost households were mostly low-income households in contact with community-based organizations that help households with energy concerns or were sought out through on-the-ground sales and past participation in rebate programs. The others were usually households with moderate to very high incomes. Almost one third of those who applied for incentives for their solar water heater under the standard single-family CSI-T program had incomes of over $200,000 per year, compared to 10 percent of California households overall.[42] Still one-third had incomes lower than $75,000, compared to the California median household income of $82,000 in 2017.[43]

Beyond these economic divisions, almost half of the households surveyed also had rooftop PV panels. The presence of PV panels is probably one of the strongest indicators of favorability for installing solar water heating. It is an obvious signal of interest in solar, whether for reasons related to environmental values or energy costs. At the same time, it is certainly a competitor for some households who are set—or

42 These are American Community Survey 5-year estimates from 2013-2017, in 2017 dollars.

43 This is an American Community Survey 1-year estimate for 2017 (U.S. Bureau of the Census).

constrained—to choose one solar technology. Solar water heating is less popular as a modern solar technology than PV. One recommendation from this research is thus to highlight the renewable energy aspect of solar water heating, and even to clarify the solar thermal aspect as distinct from PV conversion. This can reframe solar hot water from being an efficiency technology to a solar technology. Nearly as many households said that using solar was one of their favorite things about their solar water heater as did those who said saving money was, though many said both.

Another type of household attracted to solar water heaters are those who like the technology itself, feel comfortable with it, and find pleasure in using it and sometimes even in experimenting with it, adjusting it, and monitoring it. While this might not at first seem like much of a niche for marketing purposes, it is an interesting group in other ways, including in signaling a type of social potential for valuing, encouraging, and developing environmental technologies and practices in a way that goes beyond what market channels can do (Moezzi and Janda 2014).

Most households were passive rather than active users. Older solar water heating systems have a reputation of having to be managed, whether by timing hot water use day-to-day to make the most of the solar contribution, or by pursuing preventative maintenance. This was not the expectation or practice for most of the users covered in this study. Rather, most households said they did not adapt usage patterns to their system and most did not adjust the timing of their hot water use to use more solar rather than natural gas-heated water (from the backup system). But some of the most engaged users did. Timing does make a difference, but how much difference, and the extent to which households whose usage already aligns with solar heating cycles are appreciably better candidates for solar water heating, are not clear. Hourly gas consumption data could help shed light on these questions.

The availability of maintenance and repair services varied across households. Depending on where they were located and who installed their system, some households had little problem finding somebody to inspect, maintain, or repair their system. Others had difficulty, especially if the original installer went out of business or there was no specialist nearby. Given the geographic concentration of solar water heating systems, there may be many areas like this. Still other households had little awareness of their system's maintenance requirements. Not having, or expecting not to have, appropriate repair and maintenance services available could reduce the confidence of households to install solar water heating.

Changing Prospects for Solar Water Heating

The CSI-T incentives offered make solar water heating more cost-effective, but still, awareness of solar water hearting is very limited among California households. At the same time, low cost-effectiveness has made solar water heaters relatively unattractive in the energy efficiency arena. Solar water heaters were considered as a retrofit measure for natural gas water heating in California energy efficiency technical potential studies in 2008, for example, but were dropped in subsequent studies because of their low cost-effectiveness (Itron 2008, Itron 2017).[44] Home energy audits rarely consider solar water heaters for the same reason, especially since audit-based recommendations are often based on average use (versus the circumstances and patterns of particular households).

There are many obvious pathways by which the prospects for solar water heating could be improved: technically, economically, socially, reputationally, and through improved access, targeting households that would benefit the most. There are also less controllable changes that could lead to higher interest in solar water heating such as lower system prices and higher natural gas prices, and those that could lead to lower interest such as further moves toward electrification. The list below focuses on the more controllable prospects:

Economics

Incentivized prices could be much different than those offered on the non-incentivized market. Also, prices depend on system type (which is not climate-independent) and size, and in general, on how much effort has to be spend in acquiring customers. The CSI-T program has been highly instrumental in increasing the rate of installation of solar water heaters, workforce experience with solar water heater installation, and consumer exposure to solar water heaters. Without this program's financial benefits to households and installers, and its related support in improving system quality and promoting solar water heaters more generally, there is little reason to believe that solar water heater installation rates would have reached the levels they did in the past few years.

Performance

Solar water heater user perception of system performance varied greatly among those surveyed, ranging from excellent to total failure. Households may not have a precise idea of what their solar water heater is doing and how much natural gas it is displacing, and there is little field data available on system performance to fill that gap. That leads to very important questions for research and field observation. How can the probability of problems be reduced? How can system designers and installers learn from problems that arise? Can (or should) systems signal when there are problems, as some other energy technologies do? Would offering less complex, even if less efficient, solar water heaters garner more interest?

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44 The 2008 study used a feasibility estimate for solar water heaters of 50 percent of single-family homes.

Familiarity and Market Pathways

A handful of installers have done the majority of the CSI-T installations, though there have been more than 200 smaller installers who have installed at least one solar water heater. If markets were to be expanded, how could this be done in a way that leverages the innovations, understanding of local conditions and communities, and other entrepreneurial contributions of installers large and small?

Solar water heaters do not present themselves in most household's acquisition pathways, which limits how many households consider installing them. Solar water heaters are liminal in home upgrade and repair markets. Googling "solar water heating" leads to many relevant pages including blog posts and government pages that provide consumer guides (e.g., USDOE 2004). But most households do not seem to know much about solar water heating, have no close friends or neighbors who use it, and may not even recognize it as a viable option in California. Few households may be familiar enough to even consider installing solar water heating or to seek out additional information about it. In the meantime, likely candidates for rooftop PV say that they are inundated with sales pitches.

There are very limited natural entry points for solar water heating for most households, largely because it typically complements existing water heating systems. Solar water heaters have low visibility in the array of possible home repairs and upgrades. They are rarely promoted by plumbers (who reportedly avoid upselling their customers), PV specialists (who can instead promote a more familiar alternative), or energy auditors.

With strategic planning and development, the visibility, familiarity, and positioning of solar water heaters with water heater repair/replace processes, energy efficiency recommendations, and solar sales industry could be improved. For example, if solar water heating could be offered as a potential add-on when an existing non-solar water heater is being replaced, this could be cost-efficient for the household (and the installer trying to identify potential customers).

There are opportunities to raise public awareness of solar water heating. General public familiarity could be boosted through demonstration projects on public lands, demonstration homes or buildings, a revival of solar communities that include solar water heating, high school or college lessons, integrated solar water heating as an option in home energy audit recommendations, linking water heating replacement to solar water heating, or even traditional channels such as billboards or other forms of advertising. Few installers operate at a volume that would allow them to invest in much promotion on their own. It would require external (that is, government) support with the potential exception of organizations such as community action agencies that could leverage existing communication channels.

It is important to emphasize the value of solar water heating as actual users perceive it. Most of the households that paid thousands of dollars to install reported that they had not been looking for a good financial investment. Rather, they hoped for lower monthly natural gas bills and several other benefits, such as a pleasure in using solar, of having more hot water, of reducing reliance on natural gas, of taking advantage of the incentives, and of contributing to environmental benefits and energy transformations. Rather than being considered side-benefits, they could be considered to be the main benefits, at least for some households.

Final Words

There are many dimensions on which solar water heaters—and the experience of them—demonstrate notable contrasts. In principle, solar water heaters are simple, but some designs and installation requirements are actually quite complex. Some systems are performing well, while others are not. Perhaps few are living up to modeling estimates, but this is not necessarily unlike other energy efficiency or supply technologies. Some solar water heater users are satisfied with performance and others are not, and satisfaction does not necessarily correlate to the systems' actual technical performance. Solar water heater users also vary in their level of engagement with and behavioral adjustments to the technology.

Solar water heaters are part energy efficiency technology, part solar technology. They are a means to reduce both household energy consumption and emissions, and whether they are worth the investment (on the part of policymakers or households) depends on which one aims to reduce. Solar water heaters can be viewed as a step towards building decarbonization (by incrementally reducing the use of natural gas in California homes), or a hinderance to that goal by prolonging the state's reliance on natural gas (given the use of backup systems). How solar water heaters are viewed depends entirely on the lens through which one views it.

This research finds that solar water heaters *can be* effective technologies for meeting specific objectives – namely reductions in natural gas use and carbon emissions – to which policymakers have made commitments and some households find appealing. They should thus be compared to the aggregate and household costs, difficulties, and benefits of other methods that could reduce natural gas use and carbon emissions in homes, such as additional rooftop PV, or fuel switching from natural gas to electricity for water heating or space heating, all of which have been proposed by various policies and programs. It is clear that solar water heating is not a perfect technology, nor one that is currently highly cost-effective for most households in the absence of incentives. But a detailed comparative analysis may show that it competes favorably, or at least complements, these other technologies, along with the benefits that it directly relies on grid-independent renewable energy and can provide high levels of savings for certain households.

There are particular conditions and types of households (that is, niches) for which solar water heaters are well suited. But technical performance is variable and still not well documented, which needs to be addressed if the full potential of solar water heaters is to be realized (or even estimated).

No single solution can determine the future of solar water heating in California. This research has identified a series of roadblocks. If the state decides that solar water heating is to become a key element of California's efforts to achieve its energy and environmental targets, it will likely need to devise a combination of policies that would diffuse and circumvent the current roadblocks. This research provides a basis of understanding to inform such an effort.

LIST OF ACRONYMS

Term	Definition
CAA	Community action agency
CO_2	Carbon dioxide
CPUC	California Public Utilities Commission
CSI	California Solar Initiative
CSI-T	California Solar Initiative Thermal Program
DIY	Do-it-yourself
GHG	Greenhouse gas
GPD	Gallons per day
HVAC	Heating, ventilation, and air conditioning
ICS	Integrated collector storage
IEA	International Energy Agency
IOU	Investor Owned Utility
LADWP	Los Angeles Department of Water and Power
M&E	Measurement and evaluation
NDA	Non-disclosure agreement
NG	Natural gas
NO_x	Nitrogen oxide
PV	Photovoltaic panels especially residential rooftop systems
SHC	Solar Heating & Cooling Programme
SRCC	Solar Rating and Certification Corporation

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APPENDIX A: California Solar Initiative-Thermal Program Data

Data Collection

Description of Dataset

The research team used the California Solar Initiative - Thermal (CSI-T) program database to determine the number of installations, rebate values, project costs, characteristics of installers, and the range of technologies installed. This database likely includes most of the solar water heating systems installed in single-family residences in the three California natural gas investor-owned utility territories since the program began in May 2010.

How Data was Obtained

The publicly available database includes a variety of technical fields including contractor, site location and type, system ownership class, household characteristics, system description and characteristics, system certification, solar access, cost-to-savings estimate, and cost information. Through a non-disclosure agreement with the California Public Utilities Commission, the researchers obtained address information for the CSI-T installations, allowing the CSI-T technical and program data with survey responses and utility usage data to be linked.

Procedure to Isolate Relevant Cases

The CSI-T database contains data on all applications to the CSI-T program since 2010, but the analysis for this report was limited to a relevant subset based on the specific objectives of this project. Only cases that met the following criteria were included:

- Installation was intended for domestic hot water (rather than an alternative purpose).
- Applicant home is a single family residence.
- Solar water heating has a gas back-up.
- Incentive was paid, indicating the installation met all the program criteria.

There are 4,116 cases that meet these criteria, and the analysis relates to those.

Analysis

Method of Analysis

The CSI-T database provides a wealth of information on solar hot water adoption, installations, and industry members. Quantitative analysis of the data was conducted using STATA software to identify salient patterns and trends in, for example, technology adoption by customers and installers, responses to changes in the rebate amount, and market participation among installer.

APPENDIX B: Industry Interviews

Implementation and Analysis

The research team conducted interviews with a variety of stakeholders in the solar water heating industry (e.g., installers, manufacturers) and other experts to gather information about the industry, its challenges and opportunities. Nine interviews were conducted: 3 with manufacturers, 4 with installers, 2 with other industry experts. Participants were recruited from the professional network of the research team, and through referrals among interview subjects. Participants were targeted to cover a range of characteristics among industry participants as a whole, including diversity in size, geography, length of time in business, and business model (that is, community service versus for-profit).

The interviewers used a semi-structured interview protocol to enable systematic yet flexible data collection. Interviews were conducted over the telephone, and lasted 30 to 60 minutes. In most cases the interviews were recorded and transcribed. Interviews were analyzed using a grounded theory approach, allowing themes and findings to emerge from the data.

Interview Questions

Manufacturers

1. What type of SWH systems does your company make? Where are they best suited? (climate, building type, hot water load/end use) - SF residential only, or MF res, and commercial, too?
2. How did you get into SWH? What else does your company manufacture? What other kinds of solar systems do you manufacture?
3. How long have you been manufacturing SWH systems? What got you started? Who/where was the target market?
4. Can you tell me a bit more about the systems you make?
5. Do they have any kind of feedback, monitoring or app, etc.?
6. What do the SWH systems usually replace?
7. How many have been installed in CA? In what part of the state?
8. How do the CSI rules influence how and what you manufacture and how you distribute?
9. Can you talk a bit about the different pros and cons of various SF residential SWH systems you're familiar with?

10. In general, how well are the systems working? Do you get call-backs from installers?
11. If yes, what are the typical reasons you get called back?
12. How does your product get to market (for example, through a distributor, direct sale)? How did that relationship get established? Where are you looking to expand now (geographically or otherwise)?
13. Which companies install your product? Do they carry other SWH systems? What else do they sell/install? How did you get connected with them?
14. Do you provide training/education for contractors/installers? (If not, who does?)
15. Can you give me an overview of what the training involves/looks like?
16. Why provide training?
17. Do customers typically have other solar systems in their homes, like PV?
18. What are some of the reasons/motivations for contractors wanting to install/sell SWH system?
19. How feasible/sustainable do you feel SWH systems are as a business?
20. Do you have any idea how the new systems have affected your customers' utility bills?
21. How can SWH systems be made more attractive to households in California, do you think?
22. Anything else I didn't ask that you think I should think about or know to understand the SWH market better?

Installers

1. How did you come to installing SWH? How did you get into SWH? (What kind of installer they are: plumbing, general contractor, solar, etc)
    a. Do you install yourselves or outsource?
    b. How long have you been installing SWH systems?
    c. How do you find/recruit customers?
    d. Through the CSI program, do you install single family, and/or low-income single family?
    e. Do you install SWH systems outside the CSI program?
    f. How do the CSI rules influence how and what you install?
    g. Do you consider HH size, water consumption, housing/roof?
    h. Occupant owned? Renter owned?
2. What kinds of systems do you install?
    a. Do they have any kind of feedback, monitoring or app, etc.?
    b. What do the SHW systems usually replace?

3. What other kinds of solar systems do you install?
4. Can you talk a bit about the different pros and cons of various SWH systems you're familiar with?
5. How did you decide what kind of systems to carry/offer/install?
    a. What others have you tried or considered?
6. In general, how well are the systems working? Do you get call-backs from customers?
    a. If yes, what are the typical reasons you get called back?
7. How is installing SWH different from installing a more traditional water heating system?
8. What kinds of incentives do you offer to households who install SWH?
9. What are your conversations like with people (SWH non-owners, SWH owners) about it?
10. Do your customers typically have other solar systems in their homes, like PV?
11. What are some of the reasons customers usually give for wanting a SWH system?
12. Project costs
    a. What is the approximate price of your typical SWH installation (equipment, labor, permit, etc.)?
    b. How much subsidy does the customer receive? So the incentive covers about X percent of the installation, and the out-of-pocket cost is about $X?
    c. How do the customers pay upfront costs, generally?
13. How feasible/sustainable do you feel installing SHW systems are as a business?
    a. Is there a large market in your service area that is willing to pay $X for a solar water heating system?
14. Do you have any idea how the new systems have affected your customers' utility bills?
15. How can SHW systems be made more attractive to households in California, do you think?
16. (ASK IN SOCAL TERRITORY ONLY) Do you have any customers you might connect us with to help us get more perspective? Please remember, everything interview is anonymous, we don't share identifying info of our interview participants, including businesses and personal details.
17. Anything else I didn't ask that you think I should think about or know to understand the SWH market better?

Industry Experts

1. Tell us about your role in the solar water heating industry.
2. Give us a brief history of the solar water heating industry
3. What are the main types of solar WH systems currently being installed on single-family residential buildings in California?

For each main type of system:

4. A simple description of the system.
5. (For the project team, how does this match to the CPUC or CSI database?)
6. How common is this type of system? (Sales per year or fraction of installs per year)
7. What are the usual installation procedures?
8. How long does a typical installation take?
9. What is a typical range of price for this type of system?
10. What is the typical rated performance of this type of system?
11. What is the typical field performance of this type of system?
12. What are the benefits of this type of system for the consumer? Drawbacks?
13. What are the benefits of this type of system for the installers? Drawbacks?
14. Which installers prefer this system? Why?
15. Are there any financing options available just for this system?

-

From installers perspective:

16. What are the most successful marketing strategies for installers?
17. What are the best types of financing available?
18. Best type of incentives? Who should administer the incentives?
19. What are your thoughts on other types of systems, for example:
    - PV direct to electric resistance water heater
    - Grid-tied PV to electric heat pump water heater
    - Low-cost plastic collector
    - Other?
20. What other policies or research should the CEC be funding?

APPENDIX C: Household Interviews

Data Collection

Instrument/Protocol

The in-home interviews lasted between 45-60 minutes, while the phone interviews usually lasted about 30 minutes. The in-home interviews were especially valuable because of the in-person interaction and the opportunity to observe the house, equipment, and neighborhood first hand. Towards the end of the interview, the researchers asked for opinions and reflections on solar hot water, such as its relevance for a broader segment of the California population, how solar hot water systems could be made more attractive, and how diffusion could be enhanced. At some point during the visit for the in-home interviews, the householders were asked to show the solar system which provided an opportunity to ask questions about the placement and workings of the system. The script for the in-home and phone interviews follows.

Introductory Comments

Thank you for agreeing to participate. We are doing a study of solar thermal hot water systems*. (Interviewer describes funding and their affiliation with University of California Davis.)* Our part of the study is to get a better understanding of why people have installed them and how they have used them. In our analysis and reporting, your input will be anonymized. *(Interviewer asks permission to record in accordance with IRB rules. Recording begins after the interviewee agrees).*

About the House and Household

Who lives in the house?

How long have you lived here?

Employment

House size, age

What was the condition of the house when you moved in?

Did you do any major home improvements?

Installation Process

What got you interested in solar hot water?

Did you consider solar PV as an alternative?

How important were cost considerations?

How did you go about deciding on the type of technology and the installer?

Did you get a satisfactory explanation from the installer on the workings of the system?

Did you read the technical manual? Has it been useful?

Were you satisfied with the installation process?

Practices and Performance

Has it changed the way you use hot water? Water temperature settings changed? Showering practices changed? How many showers do you (and others in the household, if possible) take each day?

Has it worked the way you expected to? Do you ever run out of hot water?

Has it been reliable? Have you had to have the system repaired or modified? Who did you contact?

Have you noticed seasonal differences in performance?

Have there been structural problems (roof) or leaks?

Has it reduced your energy costs?

Do you have an idea of how much of your hot water use is provided by solar?

Reflections

To what extent was environment/energy saving an issue in choosing solar hot water?

Have neighbors or family commented on your solar heating installation?

Is your use of solar hot water a subject of family discussion?

If you could revisit your decision, would you choose solar hot water again?

Would you recommend solar hot water to others?

What would be needed to make solar hot water more attractive for California households?

Recruitment

Interviewees were identified in a variety of ways, including outreach through a solar water heater contractor customer list, households identified by the Merced Community Action Agency at our request, «Dear Resident» letters sent to Benicia Solar Village residents, visual inspection of homes on streets in Berkeley neighborhoods, and snowball/incidental referral. The Merced Community Action Agency directed us to three households, referred to below as the "low-income sample;" these households are sometimes exempted in the discussion of economic considerations as their systems were installed at no financial cost to the household—incidentally, along with a PV system. In general, in the low-income single-family home subprogram of CSI-T, low-income households may still pay something for their systems.

Most interviewees were in their 50s or older, usually with no children or only older children presently living at home. The biggest household had only four people, and a few had lodgers. Many were highly informed about solar water heating. Some could easily be described as solar water heating enthusiasts, presumably making them more willing to be interviewed. The results from the surveys, when available, will help the researchers judge the degree to which interviewees were representative of solar water heater owners. While this research project is dedicated to alternatives to natural gas water heating in single-family homes, two in the interview sample had a different backup water heating fuel: one electric, one propane.

Analysis

All interviews were recorded with consent from the interviewee(s). Recordings were transcribed using an automated service, manually cleaned, and shared with the interview analysis team. The transcripts were analyzed using a procedure typical for qualitative interviews: common themes that emerged from the interviews were identified and insightful or illustrative quotes from respondents noted (Seale 1999).

APPENDIX D: Household Survey Instrument

Data Collection

Instrument/Protocol

The research team conducted a survey of single-family households with solar water heating in California to extend the understanding of adopters and their motivations and experiences. The survey research builds on the interview research to more generally characterize the entire population of California single-family household solar water heater users. It also builds upon previous household surveys with a similar focus (Itron, 2011; NREL, 1999) by providing a more recent account and focusing on single-family solar water heating across the state of California.

The survey included questions targeting each of the five Innovation-decision Stages, though the primarily focus was on Implementation (e.g., installation, maintenance, and repairs) and Confirmation (e.g., satisfaction with performance, energy savings, and other outcomes). Questions were guided by insights from the interviews. Also included were questions about hot water use habits and household and participant characteristics. The survey was programmed in Qualtrics survey software.

Following are images of the survey distributed to households.

Intro Info

Thank you for logging in to this UC Davis survey on Solar Water Heating!

You are eligible to participate **if you have (or have had) a solar water heating system for general home water use in your current home** (not including solar heating for a pool).

This research is sponsored by the California Energy Commission. Your responses will help the State of California understand the experiences of solar water heater users. The State will use the results of the this study in planning the future of energy technologies in California. You are receiving this invitation because you may have participated in the CSI-Thermal Program.

The survey will take approximately **20 minutes** to complete.

Please complete only one survey per household, and if possible, by the person in the household who is most familiar with your solar water heating system.

As a token of our thanks, we will send you a **$20 e-gift card** after the study is completed (by August 31, 2018). At the end of the survey you will be asked to enter your email address in order to receive your $20 e-gift card and the mailing address where your solar water heater was installed in order to verify you are the original recipient of this invitation.

If you have any questions or comments please contact Angela Sanguinetti at asanguinetti@ucdavis.edu.

Please mark "Yes" if you have (or have had) a solar water heating system for indoor home water use **in your current home**, are at least 18 years old, and agree to participate in this survey.

- Yes
- No

Warm-up and Basic Information

How likely are you to recommend solar water heating to a friend or neighbor?

0 (Not at all likely)	1	2	3	4	5	6	7	8	9	10 (Extremely likely)
○	○	○	○	○	○	○	○	○	○	○

What are your <u>three</u> favorite things about your solar water heater? (Please select up to three)

- ☐ Plentiful hot water
- ☐ Setting a positive example for others in the community
- ☐ Feels good to use naturally-heated water
- ☐ Using renewable energy
- ☐ I like the technology
- ☐ Inexpensive to install
- ☐ Better for the environment / helps slow climate change
- ☐ Lower energy bills
- ☐ More independence from my energy utility / self-sufficiency
- ☐ Hot water when the power goes out
- ☐ Other (please specify)
- ☐ I don't like anything about it

What are your <u>three</u> LEAST favorite things about your solar water heater? (Please select up to three)

- ☐ High maintenance
- ☐ Causes conflict in home over managing hot water
- ☐ Caused damage to my house
- ☐ Poor water-heating performance
- ☐ Takes up too much space
- ☐ Problems such as leaks, component failures
- ☐ Installation difficulties
- ☐ Costs too much to install
- ☐ Doesn't save as much money / energy as we expected
- ☐ Don't like the way it looks
- ☐ Other (please specify)
- ☐ I don't dislike anything about it

When did you first become aware of solar water heaters?

- ○ When I moved into my current home
- ○ Used to live in a house with solar water heating
- ○ Saw or used while traveling/living in another country
- ○

- Friends, family, or neighbors had one
- Plumber/contractor told me about them
- Media (magazine, TV, radio, Internet)
- Retailer
- Manufacturer's advertisement
- Other (please specify)

What is the condition of your household solar water heating system?

- It is working
- It has been removed
- It is still there but has been disconnected/is broken
- Not sure if it is working
- Other (please specify)

How did you get your solar water heating system?

- We hired someone to install it
- It was already installed before we purchased the home / moved in
- Property owner installed it after we moved in
- Installed it ourselves

What year was your solar water heating system installed?

▼

About what month was your solar water heating system installed? (Please use your best estimate if unsure)

▼

In a few words, why did your household decide to install a solar water heater?

What type of water heating system was in your home prior to the solar water heater?

- Standard Tank
- Whole-house tankless (on-demand)
- High-efficiency condensing (with plastic vent pipe)
- Electric heat pump (hybrid) water heater
- Different solar water heater

Which of the following influenced you to install solar water heating? (Check all that apply)

- ☐ Contractor recommended
- ☐ Offered at a retail store, home show, or community event
- ☐ Planning/doing other work on our home
- ☐ Rebate available
- ☐ Dissatisfied with old system's performance/Possibility of more hot water
- ☐ Saw it on a home or being installed
- ☐ Previous water heater was failing/broken
- ☐ Heard about low-money-down options
- ☐ Someone we know talked to us about it
- ☐ Saw advertising or news article
- ☐ Wanted to save on energy bills
- ☐ We were building or buying a new home
- ☐ Approached by an installer/salesperson
- ☐ Attracted to idea of solar energy source
- ☐ Other (please specify) ______
- ☐ Planning/considering rooftop photovoltaic (PV)

What concerns, if any, did you have when deciding to install a solar water heater? (Check all that apply)

- ☐ High initial cost

- [ ] Having to perform regular maintenance on the system
- [ ] Risk of leaks or damaging house/roof
- [ ] Concerns about reliability over time
- [ ] That the system might detract from your home's "curb appeal"
- [ ] That it might be harder to sell your home with solar water heating
- [ ] Lack of information
- [ ] Concerns about performance (i.e., getting hot enough, or enough hot water)
- [ ] Not everyone in your household being convinced
- [ ] Unusual technology
- [ ] Whether it was a good financial decision (return-on-investment)
- [ ] Other (please specify)
- [ ] None

As far as financial incentives, rebates, or assistance for your solar water heater, did you (Check all that apply):

- [ ] Receive a rebate from your energy utility or California Solar Initiative (CSI) program
- [ ] Take, or plan to take, federal income tax credit (renewable energy)
- [ ] Take out a HERO loan or other PACE Financing (paid back on property taxes)
- [ ] Lease the system from a third party (e.g., City, installing company)
- [ ] Get another rebate, tax credit, financing, or loan (please specify):
- [ ] None of the above

What was your approximate final cost for your solar water heater (including all equipment and installation costs, after credits and rebates)?

Do you think you would have installed a solar water heater if the rebate had not been available?

- Yes
- No
- Maybe, depending on (please specify):

Were there any difficulties when going through the rebate process (e.g., delays, permitting, design approval, etc.)?

- Yes
- No

What were the difficulties?

On a scale of 0-10, how likely are you to recommend your solar water heater <u>installer</u> to a friend or neighbor?

0 (Not at all likely)	1	2	3	4	5	6	7	8	9	10 (Extremely likely)
○	○	○	○	○	○	○	○	○	○	○

What, if any, difficulties did you have during the installation of your solar water heater? (Check all that apply)

- Finding a trustworthy and competent installer
- Permitting, zoning, inspection, or neighborhood restrictions (please specify):
- Suitability of your home site (space, shading, orientation, roof structure or condition) (please specify):
- Damage to something else during installation (please specify):
- Other (please specify):
- None

Knowing what you do now, do you think you would have done something differently in installing your solar water heater? (Check all that apply)

- Yes, a different type or configuration of a solar water heater
- Yes, a different contractor / installer
- Yes, I would not have installed a solar water heater
- No
- Don't know

Other (please specify):

Maintenance and Repairs

You noted that your solar water heating system is no longer in use. In your answers to the following questions, please describe your experience with your solar water heater when it was in use.

Have you had any of the following problems with your solar water heater? (Check all that apply)

- ☐ Issues with freeze protection
- ☐ Issues with backup hot water system
- ☐ Solar collectors overheating
- ☐ Leaks in system or related to roof penetration
- ☐ Stopped heating water
- ☐ Not sure, but the installer had to come back one or more times to fix
- ☐ Other (please specify)
- ☐ None

How serious do you consider these problems?

- ○ Minor
- ○ Moderate
- ○ Serious
- ○ Don't know

When did the first problem occur?

- ○ Within six months after installation
- ○ Between 6 months and 2 years after installation
- ○ Between 2 and 5 years after installation
- ○ More than 5 years after installation
- ○ Don't know

About how much *in total* do you think you have paid for all repairs (not including regular maintenance)?

- ○ Less than $100

- $100-$499
- $500-$999
- More than $1,000
- Have not repaired

Were the repairs covered under warranty?

- Yes, all
- Yes, some but not all
- None

How satisfied are / were you with the warranty?

- Extremely satisfied
- Somewhat satisfied
- Neither satisfied nor dissatisfied
- Somewhat dissatisfied
- Extremely dissatisfied
- Did not have a warranty

Which of the following maintenance measures have you done, or had somebody else do, for your solar water heating system? (Check all that apply)

- Inspecting system
- Washing collectors
- Flushing and replacing antifreeze/glycol
- De-scaling (if you have hard water)
- Regular maintenance service by contractor
- Other (please specify):
- Not sure
- None of the above

Who has done the maintenance work? (Check all that apply)

- Installer
- Other contractor

- ☐ I/we do
- ☐ No maintenance work has been done yet

Are you satisfied with the availability of contractors to provide maintenance and repairs?

- ◯ Yes (optional comment)
- ◯ No (optional comment):
- ◯ Not applicable/ Not sure (optional comment):

How easy or difficult is it to maintain your solar water heating system?

- ◯ Extremely easy
- ◯ Somewhat easy
- ◯ Neither easy nor difficult
- ◯ Somewhat difficult
- ◯ Extremely difficult
- ◯ Too soon to tell

Hot Water Use

As a result of having a solar water heating system (instead of just a conventional water heater), would you say that your household:

- ◯ Uses MORE hot water
- ◯ Uses LESS hot water
- ◯ Uses about the SAME amount of hot water
- ◯ Don't know
- ◯ Not applicable

What are the main reasons for using LESS hot water as a result of your solar water heater? (Check all that apply)

- ☐ There is less hot water produced since we got the solar water heater
- ☐ We try to avoid using the back-up water heater
- ☐ We are more aware of how much hot water we use
- ☐ Other reasons (please specify):

What are the main reasons for using MORE hot water as a result of your solar water heater? (Check all that apply)

- ☐ Hot water costs less
- ☐ There is more hot water produced since we got the solar water heater
- ☐ It feels less wasteful knowing that the sun is providing the hot water
- ☐ Other reasons (please specify):

Have any of the following factors affected your household hot water usage in the past several years? (Check all that apply)

- ☐ We decreased water use because of concern for the drought
- ☐ Water use has increased because there are more people in the house
- ☐ Water use has decreased because there are fewer people in the house
- ☐ Water costs more now, so we use less
- ☐ Other changes to lifestyles, habits, appliances, or fixtures (please specify):
- ☐ None of the above

How, if at all, has solar water heating affected your household's showering/bathing routines? (Check all that apply)

- ☐ We take more baths
- ☐ We take fewer baths
- ☐ We take more showers
- ☐ We take fewer showers
- ☐ We take longer showers
- ☐ We take shorter showers
- ☐ No change
- ☐ Not sure
- ☐ Other (please specify):

How, if at all, has solar water heating affected your household's dish washing routines? (Check all that apply)

- ☐ We do more dishwashing loads
- ☐ We do fewer dishwashing loads
- ☐ We hand wash dishes more often
- ☐ We hand wash dishes less often
- ☐ No change
- ☐ Not sure
- ☐ Other (please specify):

Has your household changed **<u>when</u> you use hot water** (e.g., changing based on the season or time of day) to adjust to having your solar water heater?

- ○ Yes (please describe):
- ○ No
- ○ Not sure

During long periods when nobody is at home (e.g., a long vacation), do you adjust anything about your solar water heating system (e.g. to avoid overheating)?

- ○ Yes (please describe):
- ○ No
- ○ Not sure

What is the temperature setting on your **back-up** water heater? Please specify the exact temp if you know it; otherwise indicate a range (Medium is the standard factory setting)

- ○ Specific temperature (°F)
- ○

Low (below 130°F)

- Medium (130°F – 150°F)
- High (over 150°F)
- Don't have or use a back-up water heater
- Don't know

When, if ever, do you change the settings on your back-up water heater? (Check all that apply)

- Never change it
- Turn off when on vacation
- Turn down when on vacation
- Turn off in summer
- Turn down in summer
- Turn up when there are additional people in the home
- Other (please describe)

Has your household done anything else to adjust to having the solar hot water heater?

How did you learn how to use and manage your solar water heating system? (Check all that apply)

- The contractor told us
- Figured out how to use it by experimenting
- Information in the user's manual
- Looked for other published information (e.g., on the internet)
- Talked with other users
- Not applicable / Nothing to learn
- Other (please specify)

Outcomes and Satisfaction

Are you satisfied with the following aspects of your solar water heater?

	Satisfied	Neutral	Dissatisfied

	Satisfied	Neutral	Dissatisfied
Performance compared to other water heaters	◯	◯	◯
Enough hot water for everyday use	◯	◯	◯
How long it takes to get hot water at the tap	◯	◯	◯
Keeps hot water temperature constant during use	◯	◯	◯
Noise while operating	◯	◯	◯
Cost to operate/maintain	◯	◯	◯

On average **during the summer**, have your natural gas bills decreased since getting your solar water heater?

- ◯ Yes, a lot
- ◯ Yes, a little
- ◯ No, no change
- ◯ No, bills have increased
- ◯ Not applicable
- ◯ Not sure

On average **during the winter**, have your natural gas bills decreased since getting your solar water heater?

- ◯ Yes, a lot
- ◯ Yes, a little
- ◯ No, no change
- ◯ No, bills have increased
- ◯ Not applicable
- ◯ Not sure

How often have you talked about your solar water heater with your neighbors, friends, family, or colleagues?

- ◯ Never
- ◯ Rarely
- ◯ Sometimes
- ◯ Often

Do you think good information about the following aspects of solar water heaters is easy or difficult to find?

	Easy to find	Difficult to find	Not sure
Whether it is right for your home / lifestyle	○	○	○
Where to get one	○	○	○
Installation	○	○	○
Maintenance	○	○	○
How to use	○	○	○

Demographics and Household Characteristics

The following questions are about you, your household, and your home. We will use this information to better understand how solar water heating works for different types of households.

Do you rent or own your home?

- ○ Rent
- ○ Own
- ○ Other (please specify): ________

What year did you move into your house? (Please use your best estimate if unsure)

[▼]

How many full and half bathrooms are in your home?

Full bathrooms (has a sink with running water, a toilet, and a bath or shower)	[▼]
Half bathrooms (has a sink with running water and either a toilet, a bath, or a shower)	[▼]

What appliances in your home use natural gas (besides your backup water heater)? (Check all that apply)

- ☐ Furnace / space heating
- ☐ Cooktop / range
- ☐ Oven
- ☐ Clothes dryer
- ☐ Swimming pool heating
- ☐ Spa / hot tub heating

- ☐ Outdoor grill (piped, not propane)
- ☐ Other (please specify):
- ☐ None of the above

Which of the following do you have in your home? (Check all that apply)

- ☐ Solar thermal for space or floor heating or cooling
- ☐ Solar heater for swimming pool
- ☐ Monitor, meter, or app to track water heater / energy use
- ☐ Low-flow showerhead(s) or faucet aerators
- ☐ Solar PV for electricity
- ☐ Hot water recirculation pump
- ☐ Insulation around hot water pipes or tanks
- ☐ "Rain" showerhead
- ☐ Whirlpool / jetted or large-volume bathtub
- ☐ None of the above

Were the following installed before, around the same time, or after your solar water heater?

	Before	Same time	After	Not sure
» Solar thermal for space or floor heating or cooling	○	○	○	○
» Solar heater for swimming pool	○	○	○	○
» Monitor, meter, or app to track water heater / energy use	○	○	○	○
» Low-flow showerhead(s) or faucet aerators	○	○	○	○
» Solar PV for electricity	○	○	○	○
» Hot water recirculation pump	○	○	○	○
» Insulation around hot water pipes or tanks	○	○	○	○
» "Rain" showerhead	○	○	○	○
» Whirlpool / jetted or large-volume bathtub	○	○	○	○
» None of the above	○	○	○	○

Did you remove a solar water heater to make room to have PV installed?

- Yes (optional comment):
- No (optional comment):

Approximately what year was this residence built? (If you aren't sure, please provide your best estimate)

About how many square feet is your home? (please exclude garages, basements, and porches)

How many people live in your home, including yourself?

- 1
- 2
- 3
- 4
- 5
- 6
- 7
- 8
- 9
- 10 or more

Please list the ages of people in your home:

	Age (in years)
You	
Other occupant	
Other occupant	
Other occupant	

	Age (in years)
Other occupant	
Other occupant	
Other occupant	
Other occupant	
Other occupant	
Other occupant	

How many members of your household are retired or semi-retired?

- None
- 1
- 2 or more

About what is your annual combined household income, before taxes?

- Less than $34,999
- $35,000-$49,999
- $50,000-$74,999
- $75,000-$99,999
- $100,000-$149,999
- $150,000-$199,999
- $200,000 or more

Do you, or anyone in your household, have a background or job in the following fields? (Check all that apply)

- Engineering
- Construction, Housing, or Real Estate
- Machining, Mechanics, or Maintenance
- Biology, Chemistry, or Environmental Sciences
- Energy, Planning, or Policy
- Farming or Agriculture
- Do-It-Yourself Home Renovation

☐ None of the above

What is your gender?

○ Male
○ Female
○ Other

Final Questions

Is there anything else you would like to share with us about your solar water heater and your experience with it?

[ ]

Which is your natural gas energy utility company?

○ Pacific Gas & Electric (PG&E)
○ San Diego Gas & Electric (SDG&E)
○ Southern California Gas (SoCalGas) / Sempra
○ Other (please specify): [ ]

IMPORTANT: In order to receive your $20 gift certificate you must enter your email address AND the mailing address where your solar water heater was installed. The gift certificate will be sent to the email address you provide by August 31, 2018. The mailing address you provide will only be used to verify that you are the original recipient of a survey invitation.

Email Address (e.g., johnsmith@gmail.com)	
Street Number and Name (e.g., 10 Maple St.	
City, State, and Zip Code (e.g., Lodi, CA 95242)	

Additional $20 available for utility data shared with UC researchers!

You can receive an additional $20 gift certificate if you share your ${q://QID88/ChoiceGroup/SelectedChoices} utility data with with UC Davis researchers. Are you willing to share your data with us?

We will use the data to investigate whether your household natural gas usage has changed since the solar water heating system was installed. This will NOT give us access to your personal online utility account. Utility API, the company facilitating this access, is in compliance with the Department of Energy's DataGuard standard and has received two SunShot Award grants from the Department of Energy. You will have the ability to revoke access at any time.

If you complete this process, the $20 gift certificate will be sent to the email address you provide to UtilityAPI.

- Sure
- No thanks

Thank you! Please click here and follow the instructions to give us access to your data.

Note that the confirmation page will show you that your data are being processed; this will take several minutes, but you can navigate away from the page. You will also receive a confirmation email from UtilityAPI.

Thank you very much for completing our survey! You are done and your response has been recorded.

Recruitment/Sampling

To identify single-family households with solar water heaters, the research team acquired data from the CPUC CSI-Thermal (CSI-T) Rebate Program. The CPUC provided street addresses and some email addresses for installations associated with this program. The focus was on single family households with natural gas as the backup energy source for water heating, and 14 households were excluded that were the focus of the CSI-T performance evaluation in order to avoid introducing complexities or additional demand on participants in that study. The dataset contained 4,002 households that met these criteria. The research team recruited about half of these households (1,922) to participated in the survey, using a stratified sampling approach in order to increase representation of different utility territories, installing contractors, and the Low-income CSI-T Rebate Program.

Households with an associated personal email address (825) were invited to participate in the survey via email and also received an email reminder one week after the initial invitation. The remaining 1,097 households, including those with an associated email address that appeared to be for a third party, for example, contractor, were recruited via postal mail with no follow-up reminder.

Implementation and Response

The final cleaned survey dataset included 233 households, which is a 12 percent response rate overall (5.6 percent for the postal mail sub-sample; 20.8 percent for the email sub-sample). Responses were considered incomplete if questions on the last two pages of the survey were blank AND if there were no responses to open-ended survey questions; 22 responses met these criteria and were excluded from the final dataset and analysis.

Analysis

Method of Analysis

Solar water heating system, household, and participant characteristics are summarized in the following tables. Most of the households hired someone to install their system (94 percent) and it was currently still operating (91 percent). Seven percent had replaced a previous solar water heating with their current one. Homes varied widely in terms of vintage and size. A majority of respondents were male (61 percent), average age 55 years.

Table D-1: Solar Water Heating Characteristics

Characteristics	Responses
Current Condition of SWH	91% Working 3% Removed, disconnected or broken 3% Not sure 3% Other (waiting on a part, moved away)
Acquisition of SWH	94% Hired installer 4% DIY install 2% Moved in to home with SWH <1% Property owner installed
Type of System Replaced	80% Standard tank 7% Different SWH 5% Whole-house tankless 4% Electric heat pump 2% Electric heat pump 2% Not sure
Year of Install (self-report)	Min = 1975 25th percentile = 2012 Median = 2015 75th percentile = 2016 Max = 2018

Source: University of California, Davis

Table D-2: Participant Characteristics

Characteristics	Responses
Gender	61% Male 38% Female 1% Other
Age	Mean(SD) = 55(14)

Source: University of California, Davis

Table D-3: Building Characteristics

Characteristics	Responses
Year House Built	14% Before 1950 22% 1950s 11% 1960s 19% 1970-1982 10% 1983-1992 15% 1993-2004 9% After 2004
Square Footage	8% 1000 or less 22% 1001-1500 28% 1501-2000 17% 2001-2500 11% 2501-3000 9% 3001-4000 4% More than 4000
Housing Tenure	96% Own 4% Rent
Household Size	25th percentile = 2 Median = 3 75th percentile = 4
Natural Gas Utility	53% PG&E 35% SoCalGas 10% SDG&E 2% Other (survey invitation likely sent to a new address)
Household Income	25th percentile = $50,000-74,999 Median = $100,000-149,999 75th percentile = $150,000-199,999
Members with Relevant Profession (Count of Households Provided)	101 None of the above 51 Engineering 38 Construction, Housing, Real Estate 37 DIY Home Renovation 29 Biology, Chemistry, Environmental Science 22 Energy, Planning, Policy 22 Machining, Mechanics, Maintenance 13 Farming or Agriculture
Members who are Retired or Semi-retired	60% None 21% One 19% Two or more

Source: University of California, Davis