Historical Case Studies of Energy Technology Innovation

CASE STUDY 3: SOLAR WATER HEATERS (US).

SOLAR WATER HEATER INNOVATION IN THE US

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AUTHOR'S SUMMARY

Solar water heaters provide an example of three decades of innovation in an end-use technology. In this case, the diffusion of the technology underwent an extremely rapid boom and bust that was centered in California in the early 1980s. The technology was largely abandoned in the US for two decades, although diffusion has been much more rapid and consistent in China, and to a lesser extent in Europe.

Solar water heaters use a working fluid to absorb sunlight and provide heating and hot water in residential and commercial settings. The biggest technical improvement was the advent in the 1970s of selective coatings, which could absorb more sunlight. Since then, the technology has been rather stable, with some improvements in lifetime and reliability. The technology is currently cost effective, especially in large installations with high demand for hot water. China is currently by far the world's largest market for solar water heaters.

The key period of R&D investment was in the 1970s at national laboratories and universities in the US. Market subsidies in the 1980s were not monitored and were rampantly abused, with many installations that leaked and caused extensive damage to structures far in excess of the cost of the solar water heater itself. In response, the technology was largely abandoned in the US for two decades; the industry went from sales of US$1billion/year in 1982 to US$30million/year in the late 2000s, and hundreds of firms went out of business. As a result, much of the learning gained in the period of rapid deployment was lost. And perceptions of poor reliability persist and have proven difficult to overcome – bad news lasts. An exception to this general policy failure has been a program in Hawaii that makes consumer rebates contingent on an inspection that occurs one year after installation.

In the US, therefore, the history of solar water heaters is one of policy inconsistency, stagnant costs, and the implications of bad outcomes in early stages that are not easily forgotten and can have substantial spillover effects on other technologies. This presents a challenge to the need to support experimentation and intelligent failures.

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1 TECHNOLOGY AND MARKET OVERVIEW

Solar water heaters ('SWH') expose a working fluid to solar radiation to raise the fluid's temperature. The fluid circulates and can be used indirectly for space heating or directly as hot water. In direct use, heated potable water is typically stored in a well-insulated tank. In most cases in developed countries, SWH systems work as hybrid systems, in which heat from the combustion of natural gas or electric resistance supplements the solar heated water. The configuration of the SWH and the integration with conventional forms of water heating is one of several design elements that distinguish SWH systems. For example, passive systems use temperature gradients to circulate the working fluid while active systems use electrically powered pumps. In direct systems, the working fluid is potable water and leaves the system once heated. In indirect systems, a heat exchanger is used so that the working fluid need not be potable water and can have anti-freeze characteristics. Further, the temperature of the working fluid affects use: above 50^{o}C for residential water and heating, and below 50^{o}C for pool heating, an important niche market in the US. Several configurations exist with different trade-offs between upfront costs, maintenance costs, reliability and efficiency.

The global installed capacity of solar water and space heating in 2009 was about 257 million square meters (m^2) which corresponds to about 180 GW of thermal power or GW_{th} (REN21, 2010). This is approximately a 21% increase from 2008. According to the International Energy Agency, the total global solar thermal collector capacity in 2008 was about 217 m^2, which corresponds to about 152 GW_{th} using the IEA's conversion factor of 0.7 kW_{th}/m^2 (Werner and Mauthner, 2010). Of this total, about 54% was accounted for by evacuated tube collectors, about 33% by flat-plate collectors, about 12% by unglazed plastic collectors, and the remainder by air collectors.

The major markets for solar water heater installations are in China (58% of global total), Europe (19%), US and Canada (10%). Other large markets include Australia, Israel, Jordan, Japan, and New Zealand. The application of solar heat and the type of collector used vary greatly by country. In China, Japan, and Europe, flat-plate and evacuated tube collectors are dominant and the solar heat is primarily used to prepare hot water and to provide space heating. In United States, Canada, and Australia, unglazed plastic absorbers are predominantly used for swimming pool heating.

2 SOLAR WATER HEATING IN THE US: CALIFORNIA BOOM AND BUST

The central episode of SWH experience in the US occurred as a boom and subsequent bust in California in the 1980s. The boom was driven by federal and state subsidies as well as expectations of high energy prices during the late 1970s and early 1980s (Hirst et al., 1979). The crash that occurred after 1984 was due directly to the expiration of tax credits for new installations, and was perhaps reinforced by the high-profile announcement that solar water heaters had been removed from the White House.

2.1 US and California policies

A government report from the late 2000s made a retrospective analysis of the policies that led to the solar water heater boom and bust in the 1980s (Taylor et al., 2007). That study found over a dozen policy programs that had the potential to influence the rates of invention and diffusion of SWH. Ratings elicited from industry, government and academic experts on which policies had the most important effects are shown in Figure 1. A rating of 5 represents "most important". Four policies stand out. Most importantly, federal tax credits provided from 1978 - 1985 reduced the cost of installation by up to 25%, subject to the availability of tax liabilities against which to use the credits. In California, state tax credits effectively provided a 15% reduction in costs in addition to the federal credits. Another important policy was the requirement that installers be licensed, although deficiencies with stringency and enforcement of the licensing requirement became important later. Note that the US Department of Energy solar hot water R&D program was rated by experts as substantially less influential than these other policies.

Finally, one of the highest rated programs was Hawaii's program to provide incentives for SWH, though at much lower levels than in the 1970s. Among the most salient features of Hawaii's program was its requirement that all new installations receiving a subsidy be inspected a year after installation to ensure proper operation. Inspections cost on the order of $40/system and provide strong incentives to avoid the poor installations and subsequent non-operation that characterized perhaps half of the systems installed in the 1980s.

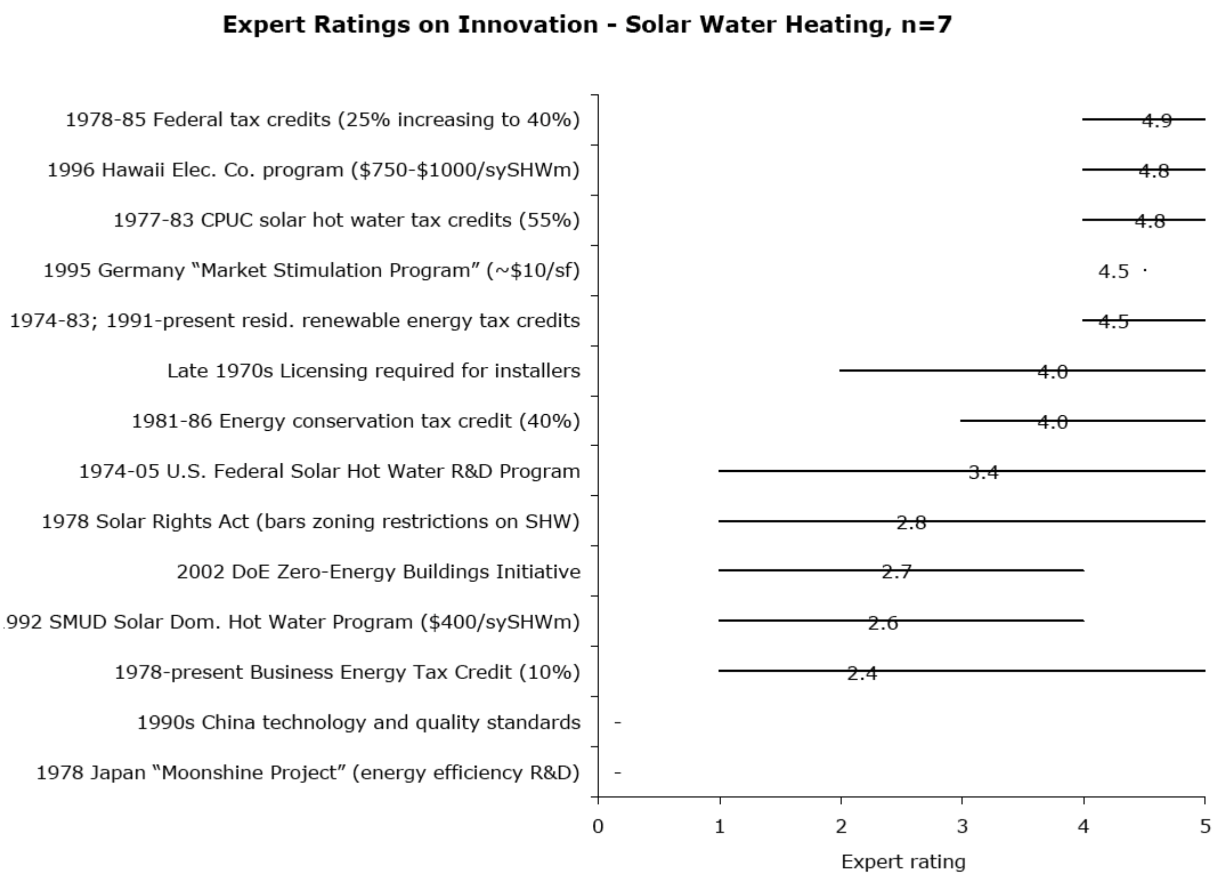

Figure 1. Elicited ratings of SWH policy influence on innovation (Taylor et al., 2007). Notes: CPUC = California Public Utilities Commission; 'resid' = residential; DoE = Department of Energy; SMUD = Sacramento Municipal Utility District.

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2.2 The early SWH industry

This set of policies resulted in a dramatic scaling up of the industry from 1975-1985 and a subsequent crash that was even more rapid (Figure 2). Annual production was over 1 million square meters of panels from 1982-1985. In 1986, production fell by an order of magnitude and has stayed below even those levels since.

The industry structure followed a broadly similar pattern albeit with some key differences. The explosion of new firms producing solar water heaters increased from a couple of dozen in 1974 to over 300 three years later (Figure 3). Consolidation and exit kept the number of firms relatively constant during the years of increasing and large production. Once production declined in 1986, hundreds of firms left the industry and from the next two decades the industry was left with 10-20 firms, many of them sustained by building solar water heaters for the niche market of swimming pools.

One is left with a mixed impression of the firms in the industry. While many contributed to improvements in the quality of the equipment, such as designing systems that would not leak or freeze, many had a much shorter time horizon, such that performance and long-term reliability were less important than quantity installed. These so called "solar profiteers" likely had the dominant effect on how the industry was perceived (Taylor, 2008).

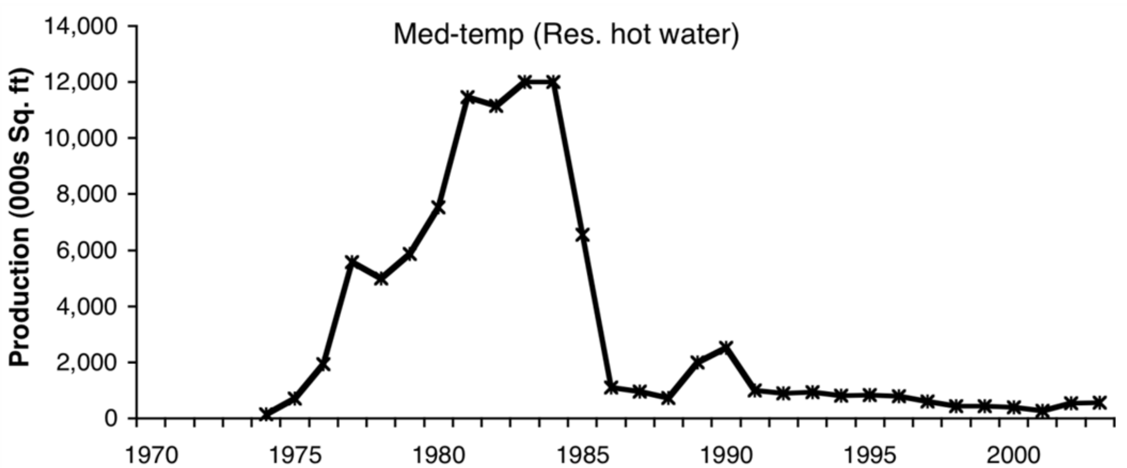

FIGURE 2. PRODUCTION OF SOLAR WATER HEATERS IN THE US (1974-2003).

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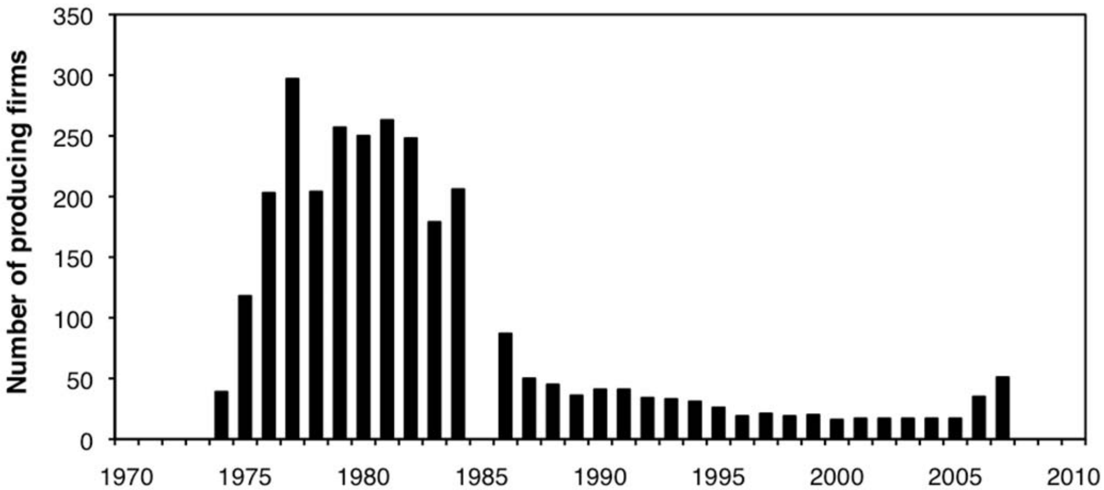

FIGURE 3. NUMBER OF FIRMS PRODUCING SOLAR WATER HEATERS IN THE US (1974-2007).

With this much churn of firms and personnel, it seems likely that there was a high level of knowledge depreciation in the solar hot water industry, particularly with respect to the technical improvements discussed below. Fewer than 300 people were employed in the industry from the late 1980s until the late 2000s (EIA, 2005). One compensating factor to this loss of tacit knowledge was the persistence of a annual conference devoted to solar energy which included large participation from the SWH community. The American Solar Energy Society held occasional conferences beginning in 1955 and then annually beginning in 1976. An analysis of the conference proceedings finds that 1100 papers on SWH were presented at the conference from 1955-2004, and that papers increased by a factor of 5 in 1975 and remained at that level until 1980 after which they declined steadily (Taylor et al., 2007). Academics and government laboratories authored three quarters of the papers—only a quarter were written by firms and electric utilities. Actor-networks appear to be dominated by researchers rather than installers. Notably, papers on SWH declined as the industry expanded to its highest levels of production; this negative correlation between expanding markets and creative efforts has also been observed in wind power (Nemet, 2009). Similarly, the solar hot water R&D program peaked before the market expanded and by 1982 had practically disappeared (Figure 4).

The composition of the authors as well as the timing of the decline in conference papers suggests that different types of knowledge depreciated at different rates. The knowledge that was codified and preserved was much more likely to consist of technical efforts to improve systems (described below), and less likely to capture learning-by-doing in installing and operating systems in real-world commercial environments. The tacit knowledge of installers was likely lost as many left the industry to pursue employment in other areas after what industry survivors referred to as the "tragedy of 1985" (Taylor, 2008). For SWH in the US, knowledge depreciation is much more of a concern for system integration and use, than for the components themselves.

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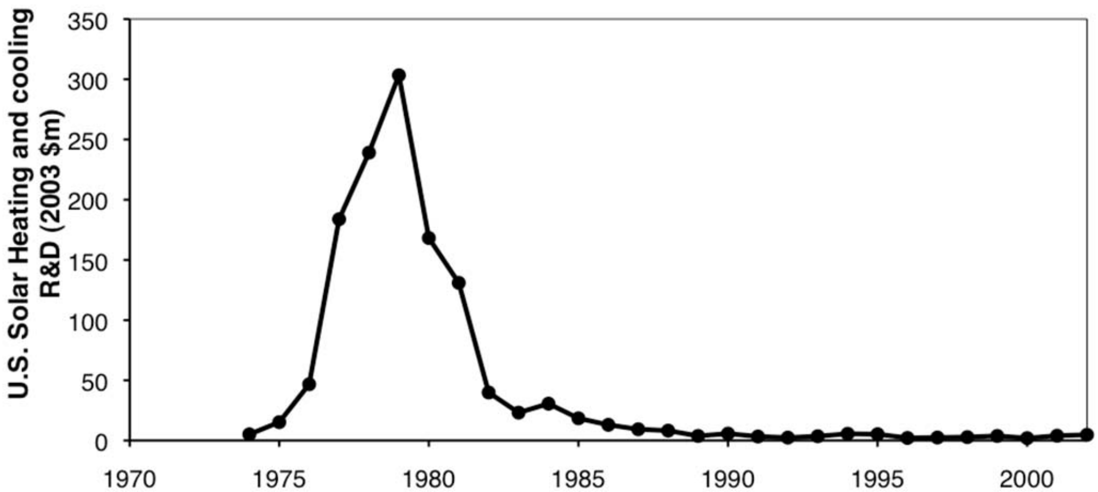

FIGURE 4. US FEDERAL R&D FOR SOLAR HEATING AND COOLING.

2.3 Technological change

There were four main sources of technical improvement in SWH in the 1980s and 1990s (Taylor et al., 2007):

- Selective coatings: This technology originated in Israel in the 1960s and was developed by the US Department of Energy in the 1970s. Coatings were applied to collector tubes that blocked the emission of infrared radiation that typically escaped from the system as the working fluid was heated. These coatings increased the amount of heat absorbed by 20%.
- Polymer-based systems: The switch from using glass and steel to plastic components has the potential to reduce system costs by a factor of 3. Polymer materials degrade after lengthy exposure to ultra-violet rays, so have only recently begun to be used commercially despite having been in development for several decades. The use of degradation resistant materials such as polybutelene and polysulfone have improved performance.
- External heat exchangers: designing heat exchangers so they are not integrated with the water tank allows the use of standard hot water tanks for storage. The use of these mature and mass produced systems reduces storage costs by half.
- Absorber plates: improvements in coatings and use of new materials in absorber plates have enabled the shift to thinner systems that require less material.

While the quality of the technology has improved steadily, the cost of the technology has remained relatively stable over three decades. Figure 5 shows that the cost per watt of energy output in the mid-2000s was close to the level of the late-1970s. In this case, the quality improvements were focused on reliability, which is not captured in the energy produced at peak solar insolation. Rather, the cost per watt has been influenced by increases in the price of materials, especially steel and glass.

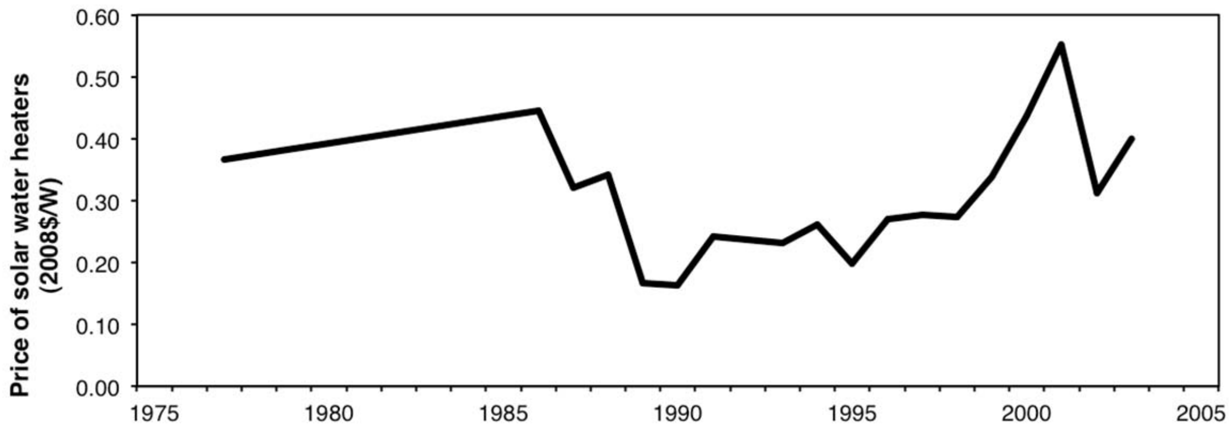

FIGURE 5. PRICE OF US SOLAR WATER HEATERS.

Frequency of filing applications for patents provides another perspective on the patterns of technological change in SWH. Figure 6 shows numbers of SWH patents by the year in which they were filed, again showing a boom and bust pattern (Taylor et al., 2007). The timing of the peak, 1977, precedes the peak market year by 5 years. The 1970s was a time of experimentation in solar water heaters during which many designs were tried. (This is similar to the case of wind power as described in another case study in this book). Relative to other energy technologies, SWH patent holders are more likely to be individuals (rather than firms) and from the US, rather than foreign. By the 1980s, when the market took off, many of the design questions were settled and patenting subsequently declined. The types of improvements that occurred during the period of market growth were subtle changes in avoiding leaks, and increasing reliability - many of these were not patentable, or perhaps were best protected as trade secrets.

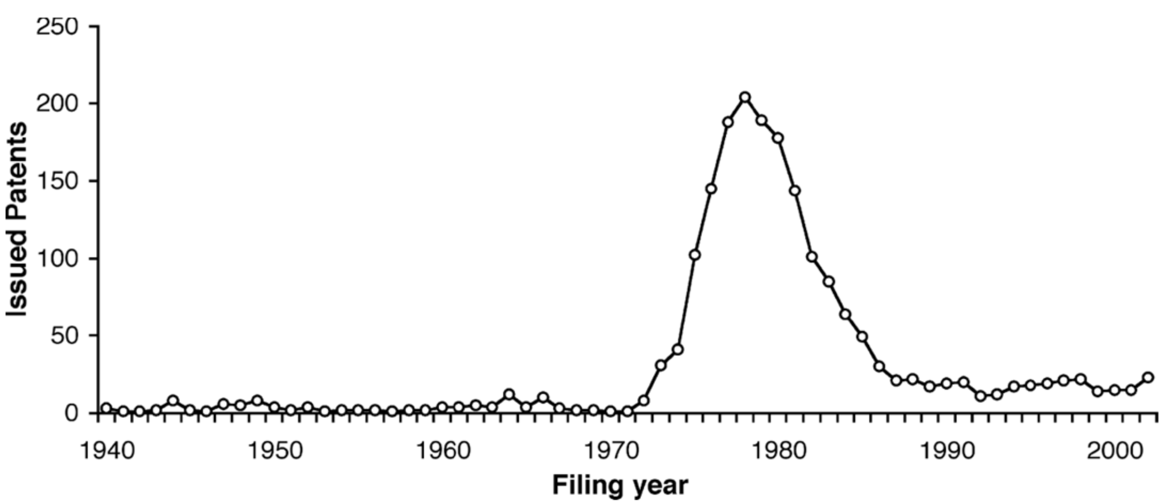

FIGURE 6. US SOLAR WATER HEATER PATENTS.

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The factors that supported the emergence of the SWH industry in the US in the late 1970s—a shared perception of an energy crisis, expectation of high energy prices, technological promise, and strong government support—had all disappeared or diminished by the mid-1980s. In 1986 the SWH panels that had been installed on the White House in 1977 were removed. Interviews with experts in the industry suggest that rampant abuse of generous subsidies in the 1980s had led to poorly installed systems (Taylor et al., 2007). The fallout of the end of the boom led to a shrinking of the industry from $1b/year in 1982 to $30m/year in 2002. The number of companies involved in the industry diminished from a few hundred to a few dozen. A consequence has been the loss of people from the industry and of their experience of how to build and install systems, as well as how not to. Subsequently almost all growth in the industry has taken place in China, and to a lesser extent in Europe.

3 CHINA: FROM STEADY GROWTH TO DOMINANT MARKET

Currently, China is the world's largest market for solar water heaters. By the end of 2008, China had installed about 125 million m^2 of solar water heating capacity, about 60% of the global total (Werner and Mauthner, 2010). One study estimates that China accounted for more than 80% of global solar water and space heating capacity installed in 2009 (REN21, 2010). This study also estimates that the newly added capacity in 2009 increased by almost 34% compared with the new capacity addition in 2008. By the end of 2008, China had more than 1,300 SWH manufacturers operating in China (REN21, 2009). It is important to note that these growth rates are not just a recent phenomenon. The SWH market has grown steadily in China since the early 1990s, with an average increase of 49% per year for the period 2000 - 2009 (Figure 7). Urban areas accounted for almost 90% of the installations (Junfeng and Runqing, 2005). Around 30% of installations are concentrated in large cities and about 60% in suburban areas and small cities (Wallace and Wang, 2006).

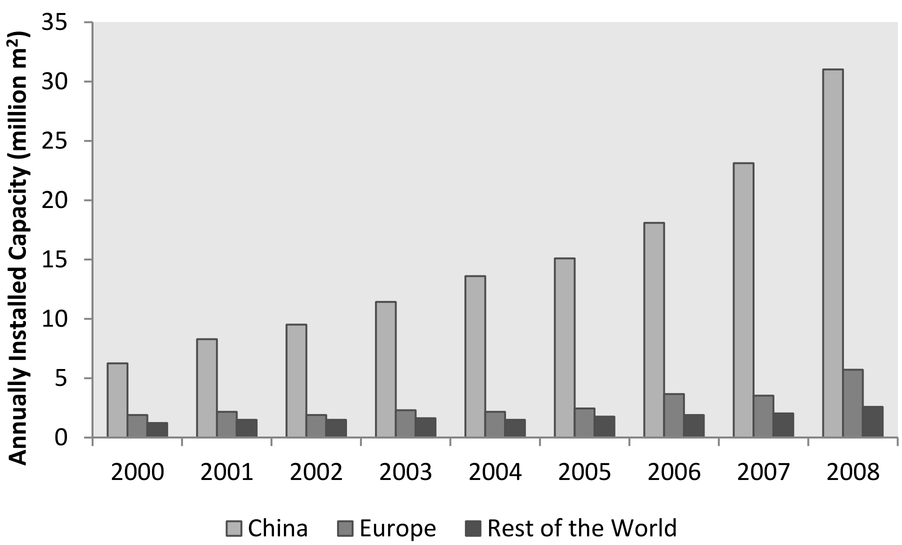

FIGURE 7. NEWLY INSTALLED CAPACITY OF FLAT-PLATE AND EVACUATED TUBE COLLECTORS FROM 2000 TO 2008 (WERNER AND MAUTHNER, 2010). NOTES: EUROPE INCLUDES EU 27, ALBANIA, MACEDONIA, NORWAY, SWITZERLAND, AND TURKEY.

Over half of the increase in the newly installed capacity in 2008 and 2009 was due to the central government's program called "home appliances going to the countryside" (REN21, 2010). In addition to domestic installations, China is positioning itself as a global leader in production as well as technology advancement of vacuum-tube solar heating systems. Chinese products dominate more than 90 percent of the global vacuum-tube systems market (REN21, 2009). This is an incredible feat considering that China only recently began exporting solar hot water systems to other developing countries in Asia, Africa, and South America. Chinese systems have also made their way to Europe through joint ventures with other European companies.

Sustained high growth in China's solar hot water market for over a decade has primarily been driven by government initiatives, and increasing living standards of the Chinese people resulting from rapid economic development (REN21, 2009). China was the first country with long-term national targets for solar hot water capacity: 150 million m^2 by 2010 and 300 million m^2 by 2020 (REN21, 2010). The Ministry of Construction issued specifications for building-integrated SWH systems in 2005 (REN21, 2009). As a result, building design and construction in many urban areas in China requires solar hot water integration. Some cities in China mandate solar hot water in all new residential buildings and in new construction and renovation of hotels and commercial buildings. The rapid expansion of SWH systems has reduced costs significantly and as a result, the price of solar heaters is competitive with electric and gas water heaters.

The main challenge facing the Chinese solar hot water industry is the lack of quality control and product standardization (REN21, 2010). Addressing these issues will help China to maintain its dominance in the global SWH market. Another major issue facing China is that the policies governing solar water heater installation are too vague and non-standardized (Han et al., 2010). Many provinces in China have economic subsidies on the installation of solar water heaters, but there is no uniform subsidy structure. Subsidies differ between different cities as well as provinces. National installers therefore face a complex regulatory and incentive environment, which makes it difficult to standardize business models and installation approaches. There are other technical issues that need to be addressed as well. As an example, the water tanks and pipes installed outdoors can crack during winter.

4 EUROPE: ACTIVE AND DIVERSE POLICIES

In Europe, the SWH market has been growing at an annual average of about 8% from 2000 to 2009 (Figure 7). The heat generated by these solar thermal technologies is primarily used for domestic hot water and space heating. Recently, small fraction of the solar heat is also being used for cooling purposes, industrial process heat, desalination, and swimming pools. The cumulative SWH capacity in Europe in 2009 was about 30 million m^2 (ESTIF, 2010; REN21, 2010). Figure 7 indicates that the newly installed capacity has increased consistently from 2000 to 2008, though decreasing from about 5 million m^2 in 2008 to about 4 million m^2 in 2009 as a result of the recent economic downturn. However, new capacity added in 2009 was more than any other previous years except for 2008.

According to the European Solar Thermal Industry Federation (ESTIF), the SWH market in Europe can broadly be divided into three zones based on cumulative installed capacity. The first zone comprises Germany, the second zone comprises Italy, Spain, Austria, France, and Greece, and the third zone comprises the remaining EU countries and Switzerland. The share of the SWH market in zone 1, 2, and 3 was 38%, 39%, and 23% respectively in 2009. Figure 8 shows the SWH capacity in operation per capita in major European markets. On a per capita basis, Cyprus is not only the leader in Europe, but also in the entire world. Austria and Germany are the other top two installers on a per capita basis in Europe after Cyprus. According to ESTIF, for many years almost 70% of SWH installations in Europe have occurred in Germany, Austria and Greece (ESTIF, 2007).

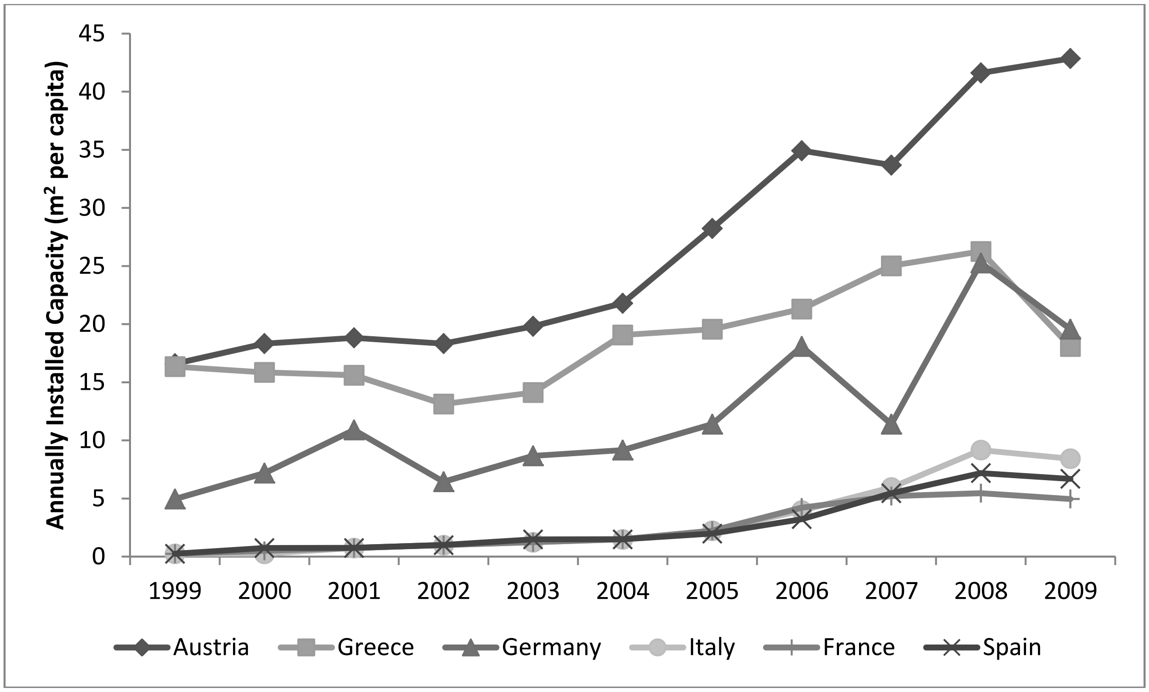

FIGURE 8. NEWLY INSTALLED CAPACITY PER CAPITA IN MAJOR EUROPEAN MARKETS FROM 1999 TO 2009 (WERNER AND MAUTHNER, 2010; ESTIF, 2010).

Public policies conducive to growth have played a critical role in the development and high growth rates of the SWH market in Europe. Other related drivers include increasing prices of conventional energy, and concern with supply security and climate change (ESTIF, 2007). Financial incentive schemes in the form of direct grants, tax reductions, and loans at reduced rates have been very important in various markets. For example, Germany implemented a program called "Market Rebate Programme for Renewable Energy (MAP)" that provided direct grants to eligible solar thermal installers based on the size of the system installed (Hack, 2006). In addition to this financial incentive scheme, Germany also benefitted from campaigns conducted at the federal and local levels to raise awareness of the benefits of solar power. Similarly, Greece implemented a program that offered investment cost deductions from personal income tax from the late 1970s till the early 1990s (Hack, 2006). This program helped the solar thermal market reach a critical mass in Greece and as a result the market is still flourishing even after the termination of the program (ESTIF, 2007). This stands in sharp contrast to the US experience. Austria has also benefited from public support programs in the form of financial incentives, professional building codes, R&D funding, and awareness campaigns.

Although Europe has seen a healthy growth rate in SWH markets, this growth is driven only by a handful of nations as noted above. France, Italy, and Spain have experienced healthy growth rates in the past few years, but their market size per capita is still relatively small (Figure 8). Europe can increase its solar capacity significantly by following the examples of Germany, Austria, Greece, and Cyprus, which have shown the promise of policy instruments including: implementing national as well as EU level solar thermal targets; implementing campaigns to raise public awareness; professional development and training; setting new standards for buildings and encouraging building-integrated SWH systems; implementing targeted financial incentives schemes; implementing best practices identified in member countries as well as other countries; and encouraging emerging technologies and applications.

5 CONCLUSION

The discussion presented in this case study indicates the important role government policy has played in shaping the solar water heater market in the US, China and Europe. The policy inconsistency in California led to stagnation in the US. Sustained and innovative policy support has contributed to a steadily growing solar market in Europe, and to an even greater extent in China. The lack of quality control and product standardization was an issue in California and continues to be in China. Implementation of mechanisms to enhance quality control has proven to be an effective way to improve reliability. A good example is Hawaii's program to inspect an installed system in order for purchasers to receive a tax credit. The discussion also indicated that the commercialization of SWH in the US might have been too rapid compared to China and Europe where growth has been steady over an extended period of time.

The ensuing two decades of stagnant demand in the US offer perhaps the most important insight from this case. The technology that was adopted very rapidly in the late 1970s was widely perceived to have been a failure. Stories abound of installations causing thousands of dollars of damage due to leaking roofs and fly-by-night installers. Perhaps 50% of systems were no longer functioning within 5 years. This large and prominent early failure of the technology has proven extremely difficult to overcome. The technology was no longer trusted, even though the quality of the technology improved steadily over the 1990s and 2000s (e.g. by avoiding freezing of the working fluid and so removing the issue of leaks). Moreover, policy innovations have found effective ways to improve reliability at a modest cost. The inspection program in Hawaii provides a way to create incentives for performance rather than just capital investment.

In many ways it is easier to learn from successes than from failures. The sustained support in both Europe and China are the central reasons for the success in growing those markets. Still, the failure of the California experience is important because of the shadow it cast over the US market for decades. The experience of the solar water heaters in the US raises the questions: did the incentive program in 1980s destroy the U.S. industry for 20 years? Was the technology commercialized too early? Too rapidly? Was this an example of relying too much on installers to learn by doing? The rapid removal of government and non-government incentives in the mid-1980s had adverse effects on the industry. But it is also possible that the combination of blunt policy instruments that were prone to abuse and the very rapid expansion of the industry in the late-1970s and early-1980s led to the proliferation of fraudulent installers, and low-quality installations that became the most lasting legacy of the US experience with solar water heating.

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6 FURTHER READING

For a comprehensive policy history of solar water heating see Taylor et al., 2007 for the US and Han et al., 2010 for China.

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