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Reducing Fossil Fuel Use and Greenhouse Gas Emissions with Solar Water Heating

Instructor: Jeffrey Havelin, PE

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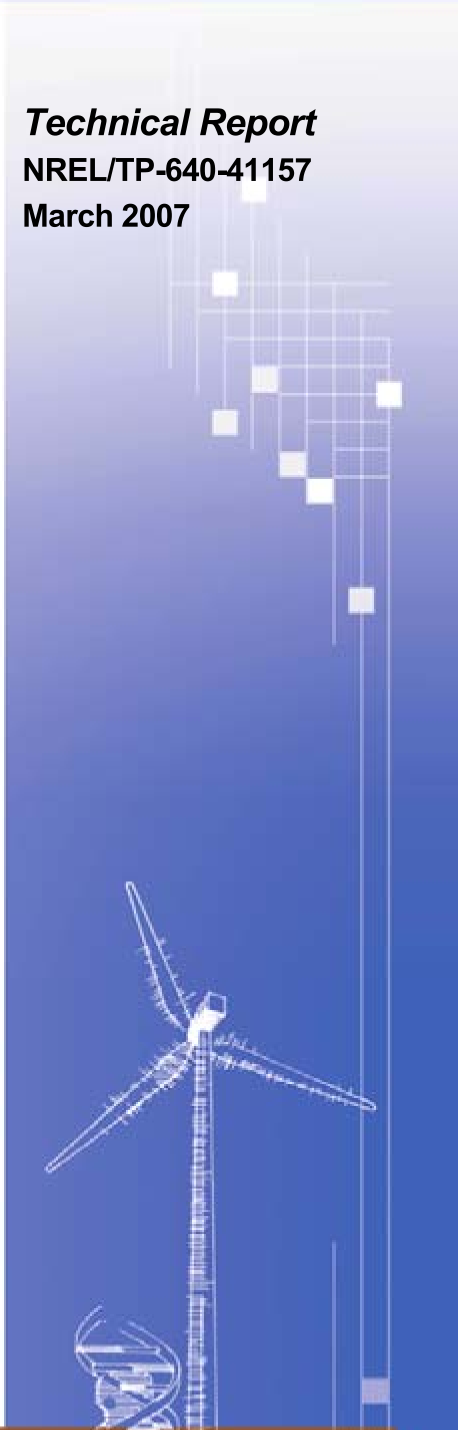
The Technical Potential of Solar Water Heating to Reduce Fossil Fuel Use and Greenhouse Gas Emissions in the United States

P. Denholm

Technical Report
NREL/TP-640-41157
March 2007



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National Renewable Energy Laboratory
1617 Cole Boulevard, Golden, Colorado 80401-3393
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Introduction

Use of solar water heating (SWH) in the United States grew significantly in the late 1970s and early 1980s, as a result of increasing energy prices and generous tax credits. Since 1985, however, expiration of federal tax credits and decreased energy prices have virtually eliminated the U.S. market for SWH.[1] More recently, increases in energy prices, concerns regarding emissions of greenhouse gases, and improvements in SWH systems have created new interest in the potential of this technology. SWH, which uses the sun to heat water directly or via a heat-transfer fluid in a collector, may be particularly important in its ability to reduce natural gas use. Dependence on natural gas as an energy resource in the United States has significantly increased in the past decade, along with increased prices, price volatility, and concerns about sustainability and security of supply. The U.S. Department of Energy (DOE) projects imports of liquefied natural gas (LNG) to increase by more than 500% from 2004 to 2020.[2] One of the readily deployable technologies available to decrease use of natural gas is solar water heating. This report provides an overview of the technical potential of solar water heating to reduce fossil fuel consumption and associated greenhouse gas emissions in U.S. residential and commercial buildings.

Water Heating Energy Use in the United States

Energy used for water heating is a significant fraction of the total energy demand in the commercial and residential sectors. In 2004, water heating in the residential sector consumed about 23% of all residential natural gas use, 8% of all residential electricity use, and about 12% of total residential energy expenditures.[3] Nationwide, about 8% of all end-use natural gas is used to heat water in commercial and residential buildings.

In 2004, the total delivered energy related to commercial and residential water heating in the United States was approximately 2.4 quadrillion BTU (quads). A large fraction of this energy (~0.5 quads) was delivered electricity. Considering primary energy,[4] water heating consumed about 3.5 quads or about 3.5% of total U.S. energy demand in 2004.

Major fuels used for water heating include natural gas, electricity, oil, and liquefied petroleum gas (LPG.) **Figure 1** provides an approximate distribution of fuels used for water heating.[5] Electricity is measured by its primary fuel content, which is assumed to be equal to 10,280 BTU/kWh.[6]

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[1] Much of the existing market for SWH is swimming pool heating and also domestic systems in Hawaii, which has state and utility incentives as well as the highest energy prices in the nation.

[2] U.S. Department of Energy (2006). *Annual Energy Outlook 2006*, DOE/EIA-0383(2006), Energy Information Administration, Washington, D.C.

[3] Ibid.

[4] Primary energy considers the energy content of fuels used to make electricity.

[5] U.S. Department of Energy (2006). *Annual Energy Outlook 2006*, DOE/EIA-0383(2006), Energy Information Administration, Washington, D.C.

[6] Ibid.

On a regional basis, there is considerable variation in the fuels used for water heating. Much of the data used to estimate the potential national benefits of SWH deployment were derived from the Energy Information Administration's *Residential Energy Consumption Survey* (RECS). [7] The data in this survey is aggregated to the "Census + 4" region level, consisting of U.S. census regions plus the four largest states. **Figure 2** provides a regional breakdown of the fuels used for residential water heating in 2001.[8]

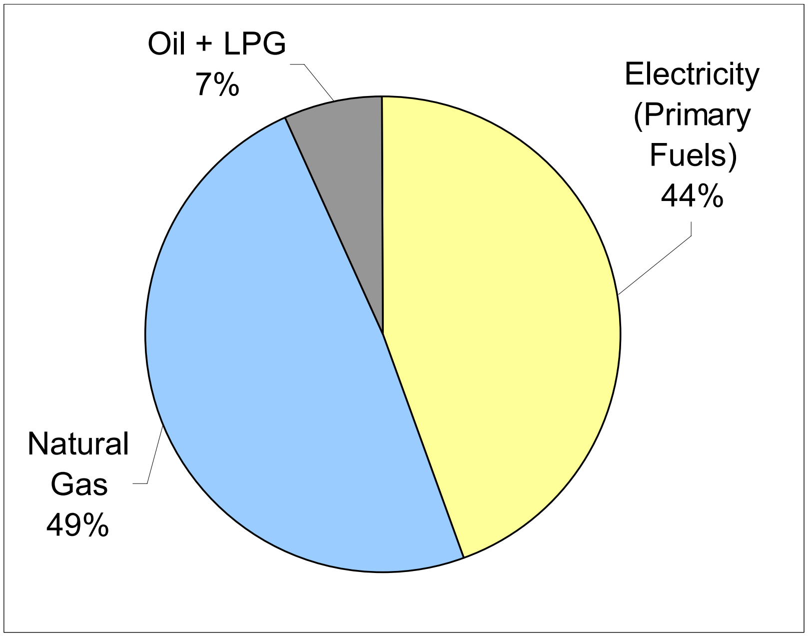

Figure 1: Approximate Distribution of Fuels Used for Water Heating in the United States

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[7] U.S. Department of Energy (2001). *Residential Energy Consumption Survey 2001*, Energy Information Administration, Washington, D.C. Via http://www.eia.doe.gov/emeu/recs/

[8] Ibid.

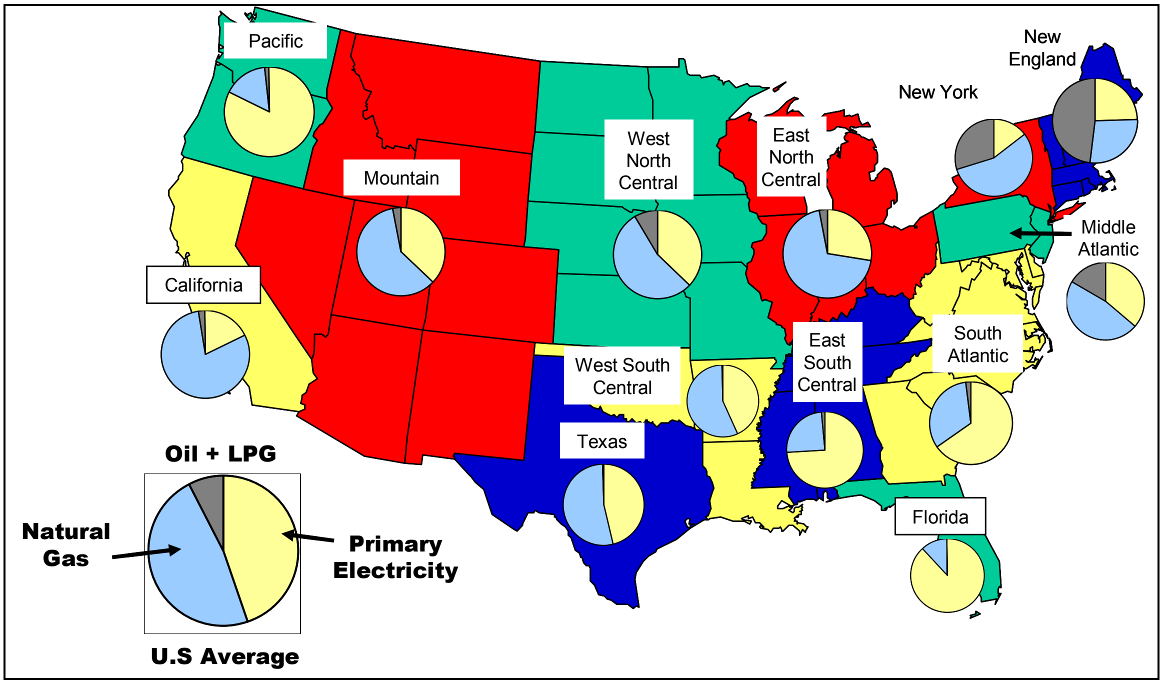

Figure 2: Regional Distribution of Residential Water Heating Fuels

In each region, the pie chart provides the fraction of primary fuel used for water heating. (It is not the fraction of homes that use a particular fuel.) There is significant regional variation, with heating performed largely by electricity in the warmer-climate areas, and with a significant contribution from oil in the New England region. It seems likely that the greater use of electric water heating in the South is partly due to the limited need for space heating, which results in a limited need for natural gas infrastructure. The use of oil in New England appears to be a historical artifact, because about 64% of homes using oil were constructed before 1960.

Using data from the EIA's *2006 Annual Energy Outlook*, 2001 RECS, and 2003 *Commercial Building Energy Consumption Survey* (CBECS),[9] we estimated the regional breakdown of delivered water heating energy use in the residential and commercial sectors. This data is provided in **Table 1**. End-use electricity is expressed in both thermal content (BTU) and more conventional units (kWh), where the energy content of electricity is 3,414 BTU/kWh.

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[9] U.S. Department of Energy (2001). *Commercial Building Energy Consumption Survey 2003*, Energy Information Administration, Washington, D.C. Via http://www.eia.doe.gov/emeu/cbecs/contents.html

Table 1: Estimated Regional End-Use Energy Consumption for Water Heating[10]

Region	Natural Gas (Trillion BTU)		Oil + LPG (Trillion BTU)		Electricity (Trillion BTU/Billion kWh)	
	Res.	**Com.**	**Res.**	**Com.**	**Res.**	**Com.**
New England	35	15	60	26	10 / 3	4 / 1
Mid-Atlantic	81	35	28	12	20 / 6	9 / 3
East No. Central	261	112	10	4	34 / 10	15 / 4
West No. Central	91	39	14	6	20 / 6	9 / 3
South Atlantic	113	49	7	3	75 / 22	32 / 9
East So. Central	43	19	3	1	44 / 13	19 / 6
West So. Central	54	23	0	0	14 / 4	6 / 2
Mountain	83	36	4	2	17 / 5	7 / 2
Pacific (w/o CA)	16	7	1	1	27 / 8	12 / 3
New York	78	34	42	18	7 / 2	3 / 1
California	180	78	6	2	14 / 4	6 / 2
Texas	95	41	1	0	27 / 8	12 / 3
Florida	18	8	0	0	44 / 13	19 / 6
U.S. Total	**1148**	**495**	**176**	**76**	**355 / 104**	**153 / 45**

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[10] There are two significant caveats in this data. There are likely large uncertainties in the data, because it is based on surveys and estimates, not systematic measurements of water heating energy consumption. In addition, the CBECS data does not provide a regional breakdown of water heating fuels used in the commercial sector. As a result, we assumed that the regional breakdown of fuel mixes in the commercial sector is equal to that in the residential sector.

Solar Water Heating System Performance

Solar water heaters use the sun to heat water directly or via a heat-transfer fluid in a collector. Heated water is then held in the storage tank ready for use, with a conventional system providing additional heating as necessary.[11] **Figure 3** provides a simplified representation of an SWH system.[12]

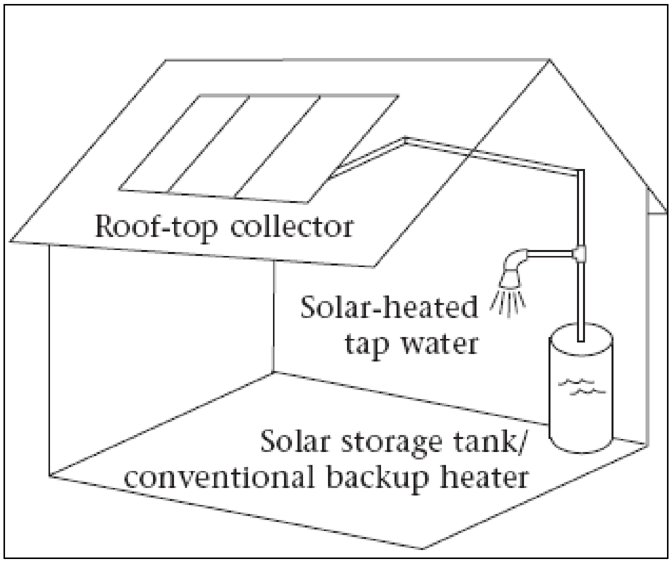

Figure 3: Simplified SWH System Schematic

An SWH system reduces, but does not eliminate, the need for electric or gas water heating. The performance of a SWH system may be defined by its *solar fraction* or the fraction of a building's water heating energy demand met by the SWH system. A system with a 60% solar fraction reduces the water heating demand (and also the water heating energy costs) by 60%. Typical solar fractions in the United States are in the range of 40-80%.

The actual solar fraction of a SWH system depends on the quality of the solar resource, the technical characteristics of the individual system, and water-use patterns. **Figure 4** provides the results of a simulation of a "base" residential SWH system in 215 locations in the United States.[13] This base system represents current technology, using a selective surface collector and glycol as the heat transfer fluid. The details of the SWH system, modeling methods, and results are described extensively in the referenced studies.[14,15]

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[11] U.S. Department of Energy (2007) Solar Water Heating for Buildings. Via http://www1.eere.energy.gov/solar/sh_basics_water.html

[12] U.S. Department of Energy (2003). *Heat Your Water with the Sun*, DOE/GO-102003-1824, Washington, D.C.

[13] While overall benefits of SWH could be estimated using a national average solar fraction, the use of regional performance data allows for incorporation of regional fuel use and variation in regional rooftop availability as discussed in the next section.

[14] Hillman, T., *Cost and Benefit Analysis of Cold Climate Solar Water Heating Systems,* M.S. Thesis, Architectural, Civil and Environmental Engineering Department, University of Colorado, Boulder, Colo.; 2005.

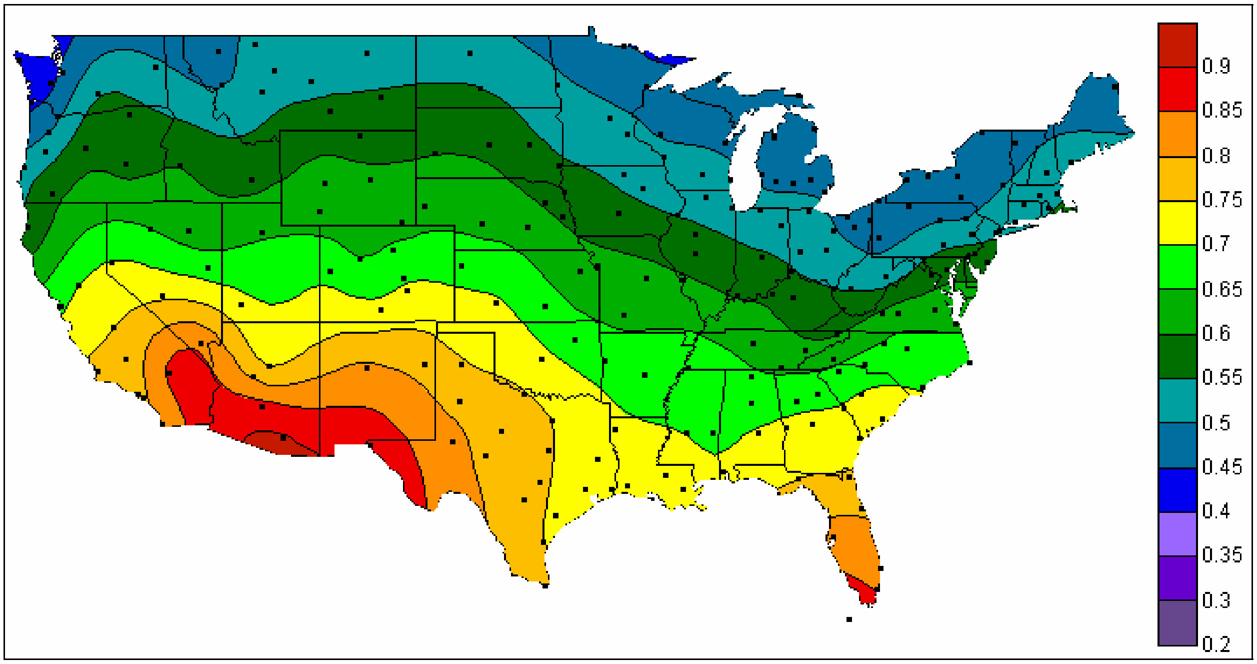

Figure 4: Simulated Solar Fraction Using a "Base" (Current Technology) Residential SWH System

A major goal of the U.S. DOE's Solar Heating and Lighting Subprogram is to decrease the installed cost of SWH systems.[16] This will be achieved with improved materials, design, and manufacturing techniques. **Figure 5** provides a solar fraction map of a simulated reduced-cost system. Relative to the base system, the simulated reduced-cost system incurs a modest penalty in solar fraction. However, the overall levelized cost of energy from the lower-cost system should be significantly less than current systems, while still providing solar fractions that exceed 50% in much of the United States.

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[15] Burch, J.; Hillman, T.; Salasovich, J. 2005. *Cold-Climate Solar Domestic Hot Water Systems: Cost/Benefit Analysis and Opportunities for Improvement.* NREL Report No. CP-550-37105.
[16] U.S. Department of Energy (2006). *Solar Energy Technologies Multi-Year Program Plan, 2007-2011*. Washington, D.C.

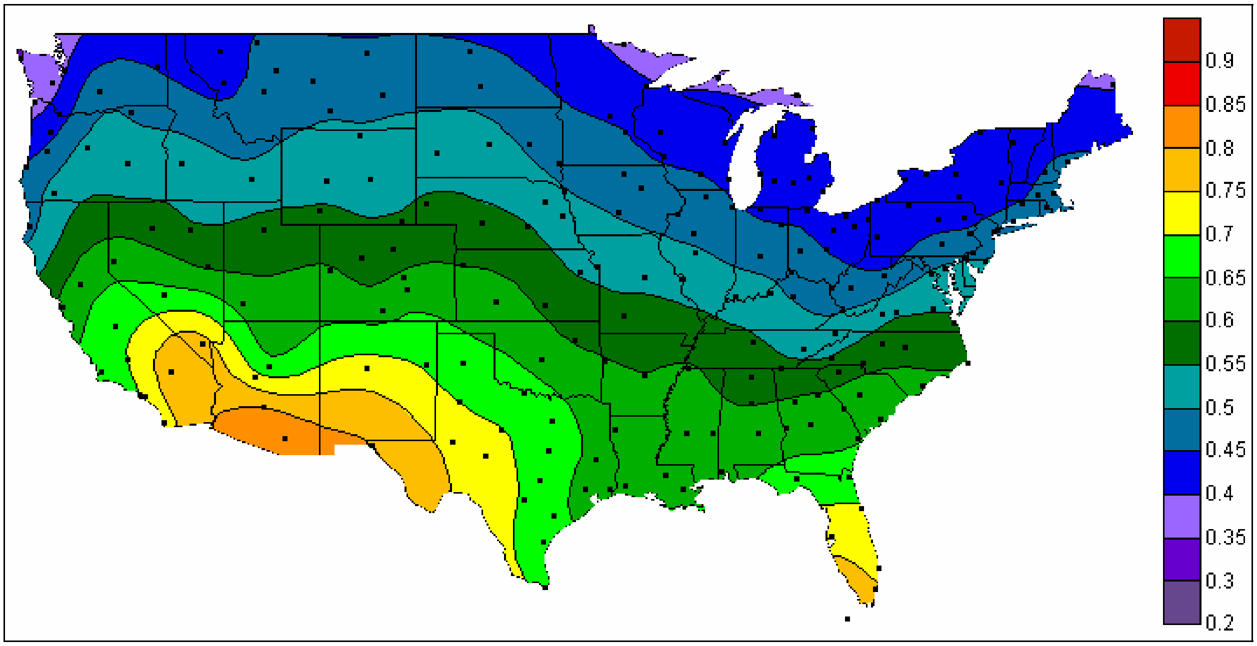

Figure 5: Simulated Solar Fraction Using a Lower-Cost SWH System

We picked a representative city in each of the 13 "Census +4" regions, and established the solar fraction for each city using the base and lower-cost SWH systems. This data is provided in **Table 2**. Unless otherwise stated, the results in this analysis use the solar fraction values from the lower-cost system.

Table 2: Assumed Solar Fractions for the Base and Lower-Cost System in Each Region[17]

Region	Representative City	Base System Solar Fraction (%)	Lower-Cost System Solar Fraction (%)
New England	Boston, MA	50	45
Mid-Atlantic	Harrisburg, PA	50	45
East No. Central	Chicago, IL	50	45
West No. Central	Des Moines, IA	55	45
South Atlantic	Raleigh, NC	65	55
East So. Central	Birmingham, AL	65	55
West So. Central	Little Rock, AR	65	60
Mountain	Denver, CO	65	60
Pacific (w/o CA)	Eugene, OR	50	45
New York	Albany	50	40
California	Sacramento	70	60
Texas	Fort Worth	75	65
Florida	Tampa	75	70
U.S. Weighted Avg.		**62**	**54**

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[17] The values in Table 2 are based on simulations of residential systems. We assume that the commercial systems would achieve the same solar fraction.

Regional Rooftop Availability

The regional or national energy savings potential from SWH is a product of the solar fraction and the number of buildings that can utilize SWH systems.

The number of homes that can use SWH systems is based on a combination of technical and nontechnical factors. Technical factors include roof orientation, minimum roof size, shading, and load-bearing capability. Nontechnical factors include economics, aesthetics, local building codes, and ordinances. Beyond standard economic metrics such as payback time or return on investment, there are a number of factors that may limit adoption of SWH. One significant factor is the fraction of buildings not occupied by the owners. For example, about 17% of residential water heating energy use occurs in apartment buildings. In addition, about 14% of all single-family homes are rented. In the commercial sector, about 45% of all buildings are leased. Buildings with low owner-occupied fractions include some building classes that can be expected to have significant demand for hot water, including food sales (58% leased), food service (73% leased), and lodging (61% leased). Deployment of SWH on rented or leased properties must address the limited incentive for the building owner to install equipment to reduce nonowner-related expenses.

This study represents a purely technical analysis and assumes favorable economics for SWH for virtually all buildings in the residential and commercial sectors. The major limitation of SWH deployment under this assumption is rooftop availability. There are no well-documented studies of rooftop availability for SWH known to the author. A few published studies provide estimates for roof area available for photovoltaics (PV). One study estimates that 22% and 65% of total roof *area* is available on residential and commercial buildings respectively.[18] Other studies estimate between 30% and 45% of all residential buildings are suitable for PV deployment.[19] A major limitation of these studies is that they are national estimates only, and provide no regional breakdown. In addition, it is expected that the much smaller size of SWH systems would allow a greater fraction of buildings to deploy SWH as compared to PV. A typical residential SWH system occupies about 40-64 ft^2 of roof space, while a typical residential PV system occupies around 250-400 ft^2.[20]

To provide a baseline estimate for SWH potential, we used the assumptions in **Table 3**, the fraction of buildings in each census region that has sufficient roof area and orientation to deploy SWH. Also provided is a national average value, weighted by the number of buildings in each census region.

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[18] Chaudhari, M.; Frantzis, L.; Hoff, T.E. *PV Grid Connected Market Potential in 2010 under a Cost Breakthrough Scenario*, prepared by Navigant Consulting for The Energy Foundation, March 2005.

[19] Frantzis, L ; Friedman, D.; Hill, S.; Teagan, P.; Strong S.; Strong, M. *Building-Integrated Photovoltaics (BI-PV)—Analysis and U.S. Market Potential*, prepared by Arthur D. Little Inc. for the U.S. Department of Energy Office of Building Technologies, NREL/TP-472-7850, DE95004055, February 1995.

[20] Assuming a 2.5-4 kW PV system and PV rating of 10 watts peak/square foot.

Table 3: Assumed Building Rooftop Availability

Region	Fraction of Buildings with Roofs Available for SWH	
	Residential	Commercial
New England	35	50
Mid-Atlantic	40	60
East No. Central	40	60
West No. Central	50	70
South Atlantic	40	60
East So. Central	40	60
West So. Central	40	60
Mountain	55	65
Pacific (w/o CA)	55	65
New York	40	60
California	65	75
Texas	60	70
Florida	60	70
U.S. Weighted Avg.	**50**	**67**

Results: U.S. SWH Potential

The technical potential of SWH was evaluated in terms of end-use energy reduction, primary energy reduction, and CO_2 emissions reduction. End-use energy reduction describes the benefits to consumers, primarily through reduced fuel costs and reduced exposure to volatile fuel prices. Primary energy reduction reflects the overall benefit to the nation of reduced fossil fuel use, including reduced dependence on natural gas, which is increasingly derived from imported LNG. The reduction in fossil fuel use also provides environmental benefits, one of which is reduced emissions of greenhouse gases.

End-Use Energy Savings Potential

In each region, the potential energy reduction from SWH was calculated by multiplying the rooftop availability by the solar fraction. These factors were then multiplied by total water heating energy consumption to derive the technical potential. **Table 4** provides a regional estimate of the SWH savings potential by fuel type.

Table 4: Regional End-Use Energy Savings Potential of SWH

Region	Technical End-Use Energy Savings Potential		
	Natural Gas (Trillion BTU)	Oil + LPG (Trillion BTU)	Electricity (Trillion BTU/Billion kWh)
New England	9	15	3 / 0.8
Mid-Atlantic	24	8	6 / 1.8
East No. Central	77	3	10 / 3.0
West No. Central	31	5	7 / 2.0
South Atlantic	41	2.4	27 / 8.0
East So. Central	16	1	16 / 4.7
West So. Central	19	0	5 / 1.4
Mountain	42	2	9 / 2.5
Pacific (w/o CA)	6	1	10 / 3.0
New York	21	11	2 / 0.5
California	105	3	8 / 2.3
Texas	56	1	16 / 4.7
Florida	11	0	28 / 8.2
U.S. Total	**457**	**53**	**147 / 42.9**

The total end-use fuel savings potential exceeds 0.5 quads of delivered liquid and gaseous fuels plus electricity, which is roughly equal to the continuous output of five large (1 GW) power plants—about equal to the annual electric consumption of the state of Oregon.

These consumption values can be multiplied by the end-use energy prices for the various fuels. In 2004, the national average price of delivered natural gas was $8.3 per million BTU for commercial customers and $9.4 per million BTU for residential customers. The average price of electricity was $23.9 and $26.1 per million BTU for commercial customers and residential customers, respectively.[21] Using these values (plus values for oil and LPG), we derive an estimated potential annual SWH savings value of $8.4 billion per year. This value does not include any additional benefits of SWH to mitigate fuel price volatility or projected fuel price escalation.

Primary Energy Potential

To estimate the "real" (primary) energy savings, the results from **Table 4** must be adjusted, primarily to consider the amount of fuel required to deliver electricity for water heating. In addition, it is also useful to consider some of the upstream requirements for delivering natural gas and electricity, particularly when considering natural gas security issues as well as greenhouse gas emission impacts.

To convert delivered electricity to primary energy (the energy content in the fuel required to make one unit of electricity) we must know the power plant conversion efficiency. Previously, we used a value of 10,280 BTU/kWh to estimate the total primary energy

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[21] U.S. Department of Energy (2006). *Annual Energy Outlook 2006*, DOE/EIA-0383(2006), Energy Information Administration, Washington, D.C.

associated with electric water heating, based on the U.S. fleet average power plant efficiency.[22] This overall average value does not reflect the "marginal" units, or the units that would actually be used less if electricity were offset by SWH systems. In addition, this value does not provide any indication of what fuel type is actually used in the marginal unit—this is important if we want to understand the potential of SWH to reduce the use of natural gas (and associated reliance on foreign sources of LNG) or coal (and associated greenhouse gas and other emissions.)

Marginal analysis is difficult, partly because the marginal fuels vary on an hourly and seasonal basis, and by region. However, there are generalities that can be stated. First, with few exceptions, fossil fuels are "on the margin" at all times and in all locations. As a result, any reduction in consumption at nearly every hour in every location will result in reduced output of a fossil unit, whether it is a thermal steam plant or a gas turbine. Second, recent growth in electricity demand in much of the United States has been met with gas-fired generators. As a result, gas is now on the margin for many hours of the year in many locations. **Table 5** provides a number of estimates of the fraction of time natural gas is the marginal fuel source for various regions in the United States.

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[22] The EIA uses 10,280 BTU/kWh as its conversion from primary energy to electricity, representing an efficiency of 33.2%. U.S. Department of Energy (2006). *Annual Energy Outlook 2006*, DOE/EIA-0383(2006), Energy Information Administration, Washington, D.C.

Table 5: Estimates for Fraction of Hours Natural Gas Provides Marginal Electricity

	Estimated Fraction of Time Natural Gas Provides Marginal Electricity		
Region	**TXU 2006**[23]	**Global Energy 2005**[24]	**Energy and Environmental Analysis 2006**[25]
New England	80		
Mid-Atlantic	40 (PJM)	>20 (PJM)	"most of the time"
West No. Central	47 (SPP)		"most of the time" (parts)
South Atlantic	27 (VACAR)		
West So. Central	58 (Entergy)		
Mountain	80 (All of West)	~85 (Colorado)	
Pacific (w/o CA)	80 (All of West)		"most of the time" (NW)
California	80 (All of West)	>90	"most of the time"
Texas	>90	>95	"most of the time"
Florida	~92	~45 (fuel oil is ~ 30)	

If and when gas is on the margin, it may be used in thermal steam plants, simple-cycle combustion turbines, or combined-cycle gas turbines. The heat rate of these plants ranges from about 6,800 BTU/kWh to more than 10,000 BTU/kWh. The higher heat rates are for the simple-cycle and steam plants, used largely for peaking. Overall, gas-fired generators typically have lower heat rates than coal-fired plants.

Besides the need to estimate the primary energy content of delivered electricity, there is an additional consideration for end-use energy technologies such as SWH. Each unit of natural gas displaced by a SWH unit reduces the amount of required natural gas production by more than 1 unit. Depending on how far upstream natural gas processing is examined, the combined inherent loss rate and parasitic losses can be significant. In 2004, about 3% of natural gas actually produced was used as pipeline fuel, with another 5% used in well and field operations and natural gas processing plants.[26] When considering delivered electricity, about 7% of electricity actually generated is lost in transmission and

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[23] Wilder, C.J. TXU. *Merrill Lynch Power & Gas Leaders Conference*. September 26, 2006. Via www.txucorp.com/pdf/092606MerrillLynchDeck_TXUCorp_FINAL.pdf

[24] Global Energy. *Coal: America's Energy Security Insurance*. Global Energy Monthly Briefing, March 2005. Via http://www.globalenergy.com/BR05/BR05-coal-americas.pdf

[25] Bluesten, J. *Natural Gas, Electricity and CHP*. April 6, 2006. Energy and Environmental Analysis, Inc. April 6, 2006. Via http://www.chpcentermw.org/presentations/050518-IL/050518_Bluestein.pdf

[26] U.S. Department of Energy (2006). *Annual Energy Outlook 2006*, DOE/EIA-0383(2006), Energy Information Administration, Washington, D.C.

distribution. Accounting for these factors provides a more realistic consideration of the reduction in primary fuel production that could result from deployment of SWH.[27]

Considering these various factors, we can estimate the technical potential of SWH in terms of total primary energy displacement. **Figure 6** illustrates the total potential as a function of the marginal electricity fuel. The total SWH energy potential is the sum of the four primary energy sources of water heating: gas and oil used directly, and coal and gas used for electric water heating. The total primary energy savings associated with direct use is constant, based on our previous assumptions for the regional distribution of fuel use, solar fraction, rooftop potential, and upstream processing loss rates. However, the primary fuel savings associated with electric water heating depends on the power plant efficiency (heat rate), which varies as a function of the marginal fuel. In this figure, we consider scenarios where gas is at the margin from 0-100% of the time, and assume the average heat rate for a marginal gas plant is 8,000 BTU/kWh. All electricity not derived from gas is assumed to be derived from coal, with an assumed heat rate of 10,218 BTU/kWh. We also assumed a 7% electricity loss rate and a 5% parasitic loss rate for delivered natural gas.

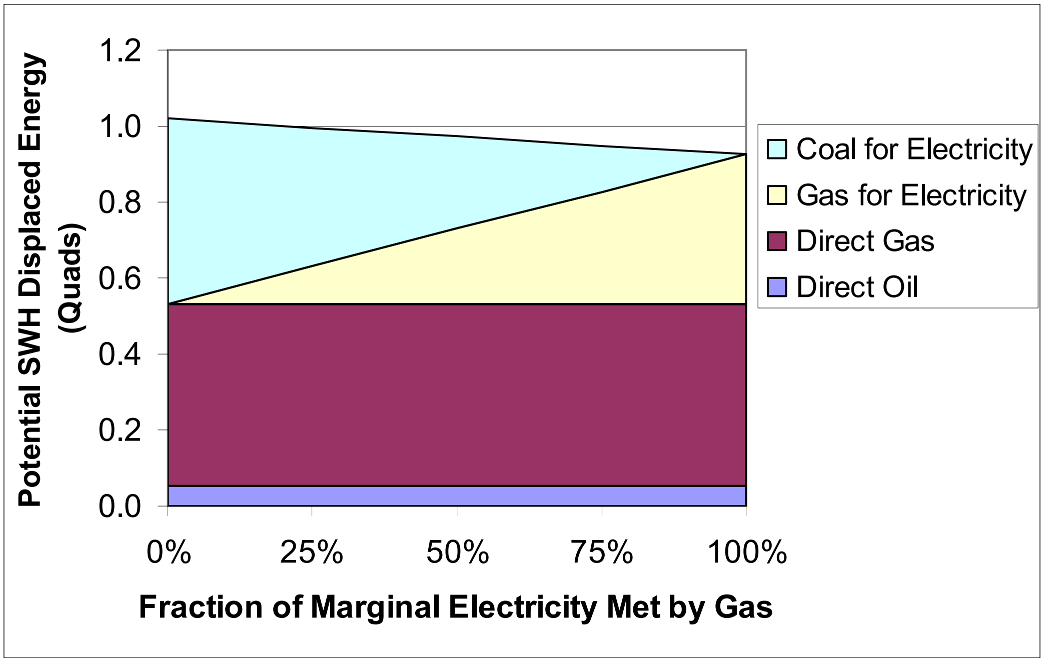

Figure 6: Technical Potential of SWH to Reduce Primary Energy Consumption Considering Sources of Electric Water Heating

In Figure 6, total natural gas displacement is the sum of the direct-use gas and gas used for electric water heating, and represents the majority of energy displaced by SWH, especially when considering the high probability that electric water heating is produced

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[27] There are many other "life-cycle" factors, including the energy and emissions related to extraction and transport of coal and oil. These factors were not considered in this analysis.

from gas-fired generators.[28] Table 6 provides two estimates for the reduced natural gas production that would result from full deployment of SWH. Two cases are provided, using two estimates for gas loss rates and the marginal fuel used for electricity.

Table 6: Impact of SWH on Gas Production Requirements, Considering Losses and Electricity Generation from Gas

	Gas Production (Quads)	
	Low Case[1]	**High Case[2]**
Estimated Gas Produced for Gas Water Heating	1.7	1.8
Estimated Gas Produced for Electric Water Heating[3]	0.3	1.0
Estimated Total Gas Production for Water Heating	2.0	2.8
Potential Gas Production Met by SWH	0.6	0.9
Fraction of Total U.S. Gas Production Replaced by SWH (%)	2.6	4.1

1. Assumes 2.5% gas loss rate, gas provides 25% of marginal electric fuel. Previously stated assumptions for solar fraction and rooftop availability.
2. Assumes 8% gas loss rate, gas provides 75% marginal electric fuel. Previously stated assumptions for rooftop availability, but solar fraction equal to higher "base" technology
3. Average heat rate for gas generators is 8,000 BTU/kWh with a T&D loss rate of 7%.

If a major goal of SWH deployment is to maximize natural gas savings, it is useful to consider the relative use of primary fuels in an individual water heater. An electric water heater is more efficient when considering end-use energy, but much less efficient when considering primary energy (due to the relatively low efficiency of converting primary fuels to electricity). **Figure 7** illustrates the relationship between electric water heating and direct gas water heating in terms of total natural gas use. In this figure, the range of gas water heating efficiency (energy factor) is 55-85%, based on delivered energy, where an electric water heater is assumed to have an efficiency of 94%. The left y-axis determines the fraction of time gas must be at the margin for gas use in electric and water heaters to be equal, assuming an 8,000 BTU/kWh heat rate, a 5% gas loss rate and a 7% electricity loss rate. The right y-axis is similar, but expresses the equivalence in gas use in terms of the natural gas energy content of the average generated unit of electricity.

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[28] Water heating is a nearly ideal source of controllable load. If water heating were "dispatched" by the utility, it would substantially increase the probability of water heating electricity being derived from lower-cost coal-based generation. Current water heating load programs only curtail heating during peak hours to reduce capacity requirements, but not to make dispatch more economic.

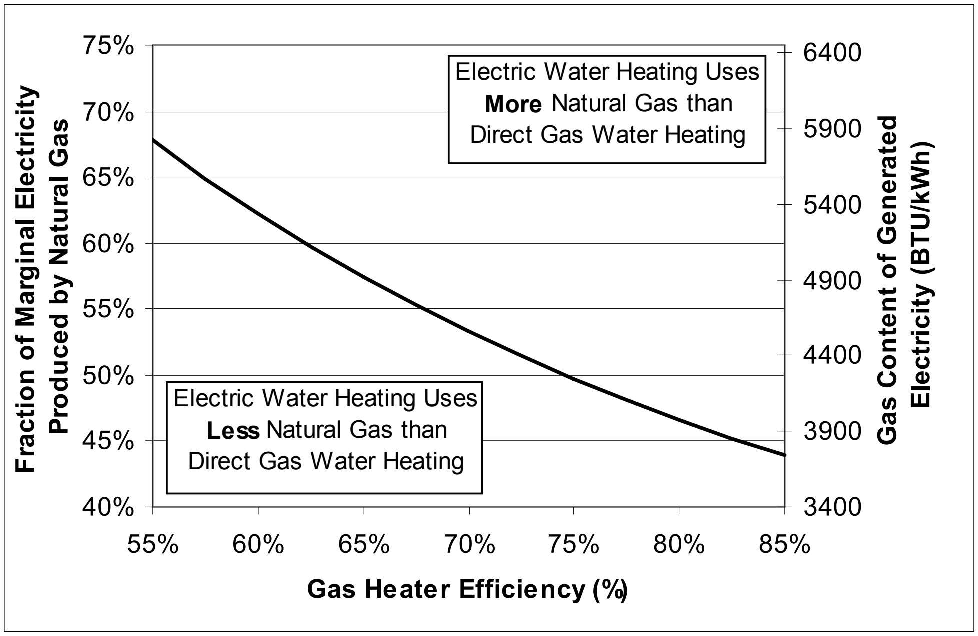

Figure 7: Natural Gas Use "Breakeven" for Electric and Direct Gas Water Heating

This graph can be compared to the estimates in Table 5 for regional fuel mixes—in places where gas is at the margin most of the time (western states, Texas, etc.), it is expected that electric water heating uses more natural gas than direct gas heating. In locations where gas is at the margin less often (potentially certain southern states) electric water heating may use less gas than direct water heating. This may provide additional insight when targeting SWH systems for maximum benefit in reducing natural gas use.

CO_2 Emissions Reduction Potential

The fossil energy savings produced by SWH can be directly translated into CO_2 emissions reductions. This is illustrated in **Figure 8**, which is similar to Figure 6, but with displaced energy replaced by CO_2 emissions, again as a function of marginal fuel for electric heat. We assumed a CO_2 emission rate of 93.0 kg/MMBTU for coal, 53.5 kg/MMBTU for natural gas, and 72.1 kg/MMBTU for fuel oil.[29]

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[29] U.S. EPA. 1996 "Compilation of Air Pollutant Emission Factors, AP-42," Fifth Edition, Volume I: Stationary Point and Area Sources. U.S. Environmental Protection, Agency. Via http://www.epa.gov/ttn/chief/ap42/

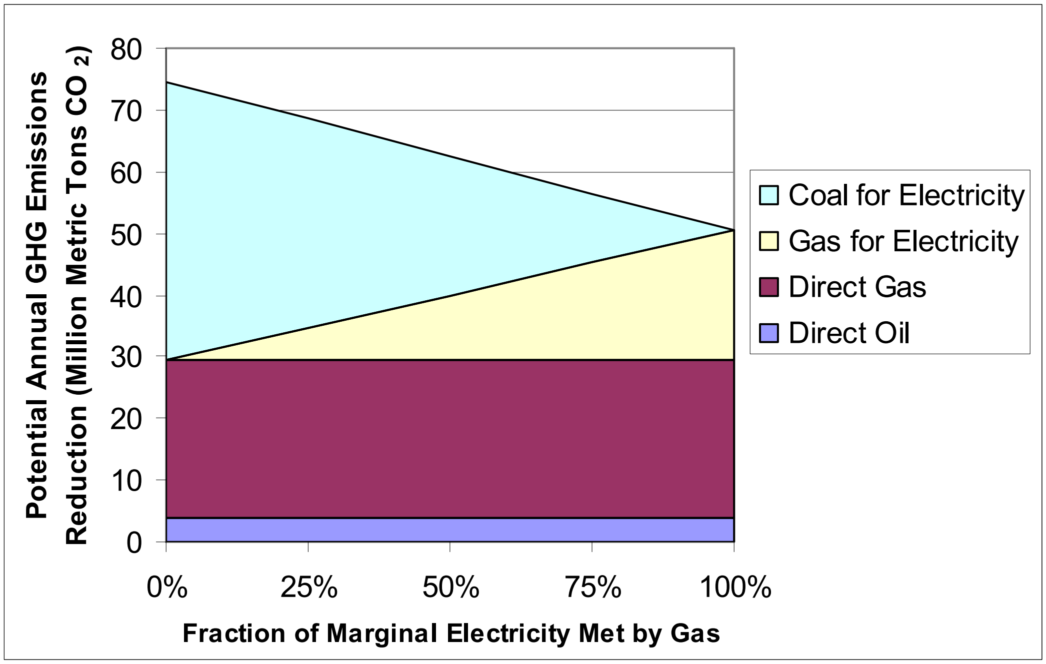

Figure 8: Technical Potential of SWH to Reduce CO_2 Emissions Considering Sources of Electric Water Heating

Table 7 provides a regional breakdown of potential emissions reductions by source. The assumptions used in Table 7 are identical to those used for Figure 8, where the “low” case assumes all electricity is derived from natural gas, and the “high” case assumes all electricity is derived from coal.

For comparison, the total U.S. CO_2 emissions in 2004 were about 5,900 million metric tons. As a result, SWH represents a total emissions reduction potential of about 1% of total annual emissions. Within the residential and commercial building sectors (about 2,230 MMT in 2004), SWH could reduce CO_2 emissions by 2-3%.

Table 7: Regional CO_2 Emissions Reduction Potential of SWH

Region	Technical CO_2 Emissions Reduction Potential (Million Metric Tons)			
	Natural Gas	Oil + LPG	Electricity (low / high)	Total (low / high)
New England	0.5	1.1	0.4 / 0.8	2.0 / 2.4
Mid-Atlantic	1.4	0.6	0.9 / 1.9	2.8 / 3.8
East No. Central	4.4	0.2	1.4 / 3.1	6.0 / 7.6
West No. Central	1.7	0.4	1.0 / 2.1	3.1 / 4.2
South Atlantic	2.3	0.2	3.9 / 8.4	6.4 / 10.8
East So. Central	0.9	0.1	2.3 / 4.9.	3.3 / 5.9
West So. Central	1.1	0.0	0.7 / 1.5	1.8 / 2.6
Mountain	2.3	0.2	1.2 / 2.6	3.7 / 5.1
Pacific (w/o CA)	0.3	0.0	1.5 / 3.1	1.8 / 3.5
New York	1.2	0.8	0.3 / 0.6	2.2 / 2.5
California	5.9	0.2	1.1 / 2.5	7.3 / 8.6
Texas	3.1	0.0	2.3 / 4.9	5.4 / 8.0
Florida	0.6	0.0	4.0 / 8.6	4.6 / 9.2
U.S. Total	25.8	3.8	20.9 / 45.0	50.4 / 74.6

Conclusions

The current technical potential of solar water heating in the United States is estimated at about 1 quad of primary energy savings per year, equivalent to an annual CO_2 emissions reduction potential of about 50-75 million metric tons. For consumers, this savings translates into more than $8 billion per year in retail energy costs, while protecting against fuel price escalation. A large fraction of water heating energy is derived from natural gas, either from direct use, or from electric water heating, where natural gas is the marginal fuel for much of the year. As a result, SWH represents a significant opportunity to reduce natural gas use in the building sector.

Greater understanding of the potential of SWH would result from further analysis of availability of roofs in the residential sector, as well as potentially significant opportunities in the industrial sector. Even applying conservative assumptions for rooftop availability, there are clearly significant opportunities for SWH in both new and retrofit markets. The relatively short life of conventional electric and gas water heaters (10-15 years) provides significant opportunities for ongoing end-of-life retrofits with SWH units. The actual potential of SWH depends largely on economic and market barriers to the deployment of current and future SWH systems.

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14. ABSTRACT *(Maximum 200 Words)*

Use of solar water heating (SWH) in the United States grew significantly in the late 1970s and early 1980s, as a result of increasing energy prices and generous tax credits. Since 1985, however, expiration of federal tax credits and decreased energy prices have virtually eliminated the U.S. market for SWH. More recently, increases in energy prices, concerns regarding emissions of greenhouse gases, and improvements in SWH systems have created new interest in the potential of this technology. SWH, which uses the sun to heat water directly or via a heat-transfer fluid in a collector, may be particularly important in its ability to reduce natural gas use. Dependence on natural gas as an energy resource in the United States has significantly increased in the past decade, along with increased prices, price volatility, and concerns about sustainability and security of supply. One of the readily deployable technologies available to decrease use of natural gas is solar water heating. This report provides an overview of the technical potential of solar water heating to reduce fossil fuel consumption and associated greenhouse gas emissions in U.S. residential and commercial buildings.

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